WHAT SCIENTIFIC CONCEPT WOULD IMPROVE EVERYBODY'S COGNITIVE TOOLKIT?

The term 'scientific"is to be understood in a broad sense as the most reliable way of gaining knowledge about anything, whether it be the human spirit, the role of great people in history, or the structure of DNA. A "scientific concept" may come from philosophy, logic, economics, jurisprudence, or other analytic enterprises, as long as it is a rigorous conceptual tool that may be summed up succinctly (or "in a phrase") but has broad application to understanding the world.

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HOWARD GARDNER
Psychologist, Harvard University; Author, Truth, Beauty, And Goodness Reframed: Educating For The Virtues In The 21St Century

"How Would You Disprove Your Viewpoint?!"

Thanks to Karl Popper, we have a simple and powerful tool: the phrase "How Would You Disprove Your Viewpoint?!"

In a democratic and demotic society like ours, the biggest challenge to scientific thinking is the tendency to embrace views on the basis of faith or of ideology. A majority of Americans doubt evolution because it goes against their religious teachings; and at least a sizeable minority are skeptical about global warming — or more precisely, the human contributions to global change — because efforts to counter climate change would tamper with the 'free market'.

Popper popularized the notion that a claim is scientific only to the extent that it can be disproved — and that science works through perpetual efforts to disprove claims.

If American citizens, or, for that matter, citizens anywhere were motivated to decribe the conditions under which they would relinquish their beliefs, they would begin to think scientifically. And if they admitted that empirical evidence would not change their minds, then at least they'd have indicated that their views have a religious or an ideological, rather than a scientific basis.

BRUCE HOOD
Director of the Bristol Cognitive Development Centre in the Experimental Psychology Department at the University of Bristol; Author, Supersense

Haecceity

Understanding the concept of haecceity would improve everybody's cognitive toolkit because it succinctly captures most people's intuitions about authenticity that are increasingly threatened by the development of new technologies. Cloning, genetic modification and even digital reproduction are some examples of new innovations that alarm many members of the public because they appear to violate a belief in the integrity of objects

Haecceity is originally a metaphysical concept that is both totally obscure and yet very familiar to all of us. It is the psychological attribution of an unobservable property to an object that makes it unique among identical copies. All objects may be categorized into groups on the basis of some shared property but an object within a category is unique by virtual of its haecceity. It is haecceity that makes your wedding ring authentic and your spouse irreplaceable, even though such things could be copied exactly in a futuristic science fiction world where matter duplication had been solved.

Haecceity also explains why you can gradually replace every atom in an object so that it not longer contains any of the original material and yet psychologically, we consider it to be the same object. That transformation can be total but so long as it has been gradual, we consider it to be the same thing. It is haecceity that enables us to accept restoration of valuable works of art and antiquities as a continuous process of rejuvenation. Even when we discover that we replace most of the cellular structures of our bodies every couple of decades, haecceity enables us to consider the continuity of our own unique self.

Haecceity is an intellectually challenging concept attributable to the medieval Scottish philosopher, John Duns Scotus, who ironically is also the origin of the term for the intellectually challenged, "dunces." Duns Scotus coined haecceity to address the confusion in Greek metaphysics between the invisible property that defines the individual, as opposed to "quiddity" which is the unique property that defines the group.

Today, both haecceity and quiddity have been subsumed under the more recognizable term, "essentialism." Richard Dawkins has recently called essentialism, "the dead hand of Plato," because, as he points out, a intuitive belief in distinct identities is a major impediment to accepting the reality that all diverse life forms have a common biological ancestry. However drawing the distinction within essentialism is important. For example, it is probably intuitive quiddity that makes some people unhappy about genetic modification because they see this as a violation of integrity of the species as a group. On the other hand it is intuitive haecceity that forms our barrier to cloning, where the authenticity of the individual is compromised.

By reintroducing haecceity as a scientific concept, albeit one that captures a psychological construct, we can avoid the confusion over using the less constrained term of essentialism that is applied to hidden properties that define both the group and the individual identity. It also provides a term for that gut feeling that many of us have when the identity and integrity of objects we value are threatened and we can't find the word for describing our concerns.

JOHN ALLEN PAULOS
Professor of Mathematics, Temple University, Philadelphia; Author, Irreligion: A Mathematician Explains Why the Arguments ofr God Just Don't Add Up

A Probability Distribution

The notion of a probability distribution would, I think, be a most useful addition to the intellectual toolkits of most people.

Most quantities of interest, most projections, most numerical assessments are not point estimates. Rather they are rough distributions — not always normal, sometimes bi-modal, sometimes exponential, sometimes something else.

Related ideas of mean, median, and variance are also important, of course, but the simple notion of a distribution implicitly suggests these and weans people from the illusion that certainty and precise numerical answers are always attainable.

W. DANIEL HILLIS

Physicist, Computer Scientist; Chairman, Applied Minds, Inc.; Author, The Pattern on the Stone

Possibility Spaces: Thinking Beyond Cause and Effect

One of the most widely-useful (but not widely-understood) scientific concepts is that of a possibility space. This is a way of thinking precisely about complex situations. Possibility spaces can be difficult to get your head around, but once you learn how to use them, they are a very powerful way to reason, because they allow you to sidestep thinking about causes and effects.

As an example of how a possibility space can help answer questions, I will use "the Monty Hall problem," which many people find confusing using our normal tools of thought. Here is the setup: A game-show host presents a guest with a choice of items hidden behind three curtains. Behind one is a valuable prize; behind the other two are disappointing duds. After the guest has made an initial choice, the host reveals what is behind one of the un-chosen curtains, showing that it would have been a dud. The guest is then offered the opportunity to change their mind. Should they change or stick with their original decision?

Plausible-sounding arguments can be made for different answers. For instance, one might argue that it does not matter whether the guest switches or not, since nothing has changed the probability that the original choice is correct. Such arguments can be very convincing, even when they are wrong. The possibility space approach, on the other hand, allows us skip reasoning about complex ideas like probabilities and what causes change. Instead, we use a kind of systematic bookkeeping that leads us directly to the answer. The trick is just to be careful to keep track of all of the possibilities.

One of the best ways to generate all the possibilities is to find a set of independent pieces of information that tell you everything you could possibly need to know about what could happen. For example, in the case of the Monty Hall problem, it would be sufficient to know what choice the guests is going to make, whether the host will reveal the leftmost or rightmost dud, and where the prize is located. Knowing these three pieces of information would allow you to predict exactly what is going to happen. It is also important that these three pieces of information are completely independent, in the sense that knowing one of them tells you nothing about any of the others. The possibility space is constructed by creating every possible combination of these three unknowns.

In this case, the possibility space is three-dimensional, because there are three unknowns. Since there are three possible initial choices for the guest, two dud options for the host, and three possible locations for the prize, there are initially 3x2x3=18 possibilities in the space. (One might reasonably ask why we don't just call this a possibility table. In this simple case, we could. But, scientists generally work with possibility spaces that contain an infinity of possibilities in a multidimensional continuum, more like a kind of physical space space.) This particular possibility space starts out as three-dimensional, but once the guest makes their initial choice, twelve of the possibilities become impossible and it collapses to two dimensions.

Let's assume that the guest already knows what initial choice they are going to make. In that case they could model the situation as a two-dimensional possibility space, one representing the location of the prize, the other representing whether the host will reveal the rightmost or leftmost dud. In this case, the first dimension indicates which curtain hides the prize (1, 2 or 3), and the second represents the arbitrary choice of the host (left dud or right dud), so there are six points in the space, representing the six possibilities of reality. Another way to say this is that the guest can deduce that they may be living in one of six equally-possible worlds. By listing them all, they will see that in four of these six, it is to their advantage to switch from their initial choice.

	Host reveals left dud	Host reveals right dud
Prize is behind 1	2 revealed, better to stick	3 revealed, better to stick
Prize is behind 2	3 revealed, better to switch	3 revealed, better to switch
Prize is Behind 3	2 revealed, better to switch	2 revealed, better to switch

Example of a two-dimensional possibility space, when guest's initial Choice is 1

After the host makes his revelation, half of these possibilities become impossible, and the space collapses to three possibilities. It will still be true that in two out of three of these possible worlds it is to the guest's advantage to switch. (In fact, this was even true of the original three-dimensional possibility space, before the guest made their initial choice.)

This is a particularly simple example of a possibility space where it is practical to list all the possibilities in a table, but the concept is far more general. In fact one way of looking at quantum mechanics is that reality actually consists of a possibility space, with Schrödinger's equation assigning a probability to each possibility. This allows quantum mechanics to explain phenomena that are impossible to account for in terms of causes and effects. Even in normal life, possibility spaces give us a reliable way the solve problems when our normal methods of reasoning seem to give contradictory or paradoxical answers. As Sherlock Holmes would say, "Once you eliminate the impossible, whatever remains, no matter how improbable, must be the truth."

HAIM HARARI
Physicist, former President, Weizmann Institute of Science; Author, A View from the Eye of the Storm

The Edge of the Circle

My concept is important, useful, scientific and very appropriate for *Edge*, but it does not exist. It is: The Edge of the Circle.

We know that a circle has no edge, and we also know that, when you travel on a circle far enough to the right or to the left, you reach the same place. Today's world is gradually moving towards extremism in almost every area: Politics, law, religion, economics, education, ethics, you name it. This is probably due to the brevity of messages, the huge amounts of information flooding us, the time pressure to respond before you think and the electronic means (Twitter, text messages) which impose superficiality. Only extremist messages can be fully conveyed in one sentence.

In this world, it often appears that there are two corners of extremism: Atheism and religious fanaticism; Far right and far left in politics; Suffocating bureaucratic detailed regulatory rules or a complete laissez faire; No ethical restrictions in Biology research and absolute restrictions imposed by religion; one can continue with dozens of examples.

But, in reality, the extremists in the two edges always end up in the same place. Hitler and Stalin both murdered millions, and signed a friendship pact. Far left secular atheist demonstrators in the western world, including gays and feminists, support Islamic religious fanatics who treat women and gays as low animals. It has always been known that no income tax and 100% income tax yield the same result: no tax collected at all, as shown by the famous Laffer curve. This is the ultimate meeting point of the extremist supporters of tax increase and tax reduction.

Societies, preaching for absolute equality among their citizens, always end up with the largest economic gaps. Fanatic extremist proponents of developing only renewable energy sources, with no nuclear power, delay or prevent acceptable interim solutions to global energy issues, just as much as the oil producers. Misuse of animals in biology research is as damaging as the objections of fanatic animal right groups. One can go on and on with illustrations, which are more visible now than they were a decade or two ago. We live on the verge of an age of extremism.

So, the edge of the circle is the place where all of these extremists meet, live and preach. The military doctor who refuses to obey orders "because Obama was born in Africa" and the army doctor, who murdered 12 people in Texas, are both at the edge of the circle.

If you are a sensible moderate thinking person, open any newspaper and see how many times you will read news items or editorials, which will lead you to say:

"Wow, these people are really at the edge of the circle" ...

CHRISTIAN KEYSERS

Neuroscientist; Scientific Director, Neuroimaging Center, University Medical Center Groningen

The Mirror Fallacy

With the discovery of mirror neurons and similar systems in humans, neuroscience has shown us that when we see the actions, sensations and emotions of others, we activate brain regions as if we were doing similar actions, were touched in similar ways or made similar facial expressions. In short, our brain mirrors the states of the people we observe. Intuitively, we have the impression that while we mirror, we feel what is going on in the person we observe. We empathize with him or her.

When the person we see has the exact same body and brain as we do, mirroring would tell us what the other feels. Whenever the other person is different in some relevant way, however, mirroring will mislead us. Imagine a masochist receiving a whiplash. Your mirror system might make you feel his pain — because you would feel pain in his stead. What he actually feels though is pleasure. You committed the mirror fallacy of incorrectly feeling that he would have felt what you would have felt — not what he actually felt.

The world is full of such fallacies: we feel dolphins are happy just because their face resembles ours while we smile or we attribute pain to robots in sci-fi movies. We feel an audience is Japan failed to like a presentation we gave because their poise would be our boredom. Labeling them, and realizing that the way we interpret the social world is through projection might help us reappraise these situations and beware.

NICHOLAS HUMPHREY

Psychologist, London School of Economics; Author, Soul Dust

The "Multiverse"

The scientific concept of the "multiverse" has already entered popular imagination. But the full implications of the idea that every possible universe has been and will be actualised have yet to sink in. One of these, which could do more to change our view of things than anything is that we are all destined to be immortal.

This welcome news (if indeed it is welcome) follows on two quite different grounds. First, death normally occurs to human bodies in due time either as the result of some kind of macro-accident — for example a car crash, or a homicide; or a micro-one — a heart attack, a stroke; or, if those don't get us, a nano-one — accidental errors in cell division, cancer, old age. Yet, in the multiverse, where every alternative is realised, the wonderful truth is that there has to be at least one particular universe in which by sheer luck each of us as individuals have escaped any and all of these blows.

Second, we live in a world where scientists are, in any case, actively searching for ways of combatting all such accidents: seat belts to protect us in the crash, aspirin to prevent stroke, red wine oxidants to counter heart attacks, antibiotics against disease. And in one or more of the possible universes to come these measures will surely have succeeded in making continuing life rather than death the natural thing.

Taking these possibilities — nay certainties — together, we can reasonably conclude that there will surely be at least one universe in which I — and you — will still find ourselves living in a thousand years, or a million years time.

Then, when we get there, should we, the ultimate survivors, the one in a trillion chancers, mourn our alter-egos who never made it? No, probably no more than we do now. We are already, as individuals, statistically so improbable as to be a seeming miracle. Having made it so far, shouldn't we look forward to more of the same?

GEORGE LAKOFF
Cognitive Scientist and Linguist; Richard and Rhoda Goldman Distinguished Professor of Cognitive Science and Linguistics, UC Berkeley; Author, The Political Mind

Conceptual Metaphor

Conceptual Metaphor is at the center of a complex theory of how the brain gives rise to thought and language, and how cognition is embodied. All concepts are physical brain circuits deriving their meaning via neural cascades that terminate in linkage to the body. That is how embodied cognition arises.

Primary metaphors are brain mappings linking disparate brain regions, each tied to the body in a different way. For example, More Is Up (as in "prices rose") links a region coordinating quantity to another coordinating verticality. The neural mappings are directional, linking frame structures in each region. The directionality is determined by first-spike synaptic strengthening. Primary metaphors are learned automatically and unconsciously by the hundreds prior to metaphoric language, just by living in the world and having disparate brain regions activated together when different experiences repeated co-occur.

Complex conceptual metaphors arise via neural bindings, both across metaphors and from a given metaphor to a conceptual frame circuit. Metaphorical reasoning arises when source domain inference structures are used for target domain reasoning via neural mappings. Linguistic metaphors occur when words for source domain concepts are used for target domain concepts via neural metaphoric mappings.

Because conceptual metaphors unconsciously structure the brain's conceptual system, much of normal everyday thought is metaphoric, with different conceptual metaphors used to think with on different occasions or by different people. A central consequence is the huge range of concepts that use metaphor cannot be defined relative to the outside world, but are instead embodied via interactions of the body and brain with the world.

There are consequences in virtually every area of life. Marriage, for example, is understood in many ways, as a journey, a partnership, a means for grown, a refuge, a bond, a joining together, and so on. What counts as a difficulty in the marriage is defined by the metaphor used. Since it is rare for spouses to have the same metaphors for their marriage, and since the metaphors are fixed in the brain but unconscious, it is not surprising that so many marriages encounter difficulties.

In politics, conservatives and progressives have ideologies defined by different metaphors. Various concepts of morality around the world are constituted by different metaphors. Even mathematical concepts are understood via metaphor, depending on the branch of mathematics. Emotions are conceptualized via metaphors that are tied to the physiology of emotion. In set theory, numbers are sets of a certain structure. On the number line, numbers are points on a line. "Real" numbers are defined via the metaphor that infinity is a thing; an infinite decimal like pi goes on forever, yet it is a single entity — an infinite thing.

Though conceptual metaphors have been researched extensively in the fields of cognitive linguistics and neural computation for decades, experimental psychologists have been experimentally confirming their existence by showing that, as circuitry physically in the brain they can influence behavior in the laboratory. The metaphors guide the experimenters, showing them what to look for. Confirming the conceptual metaphor that "The Future Is Ahead"; "The Past is Behind", experimenters found that subjects thinking about the future lean slightly forward, while those thinking about the past lean slightly backwards. Subjects asked to do immoral acts in experiments tended to wash or wipe their hands afterwards, confirming the conceptual metaphor "Morality Is Purity".

Subjects moving marbles upward tended to tell happy stories, while those moving marbles downward tended to tell sad stories, confirming "Happy Is Up;" "Sad is Down". Similar results are coming in by the dozens. The new experimental results on embodied cognition are mostly in the realm of conceptual metaphor.

Perhaps most remarkable, there appear to be brain structures that we are born with that provide pathways ready for metaphor circuitry. Edward Hubbard has observed that critical brain regions coordinating space and time measurement are adjacent in the brain, making it easy for the universal metaphors for understanding space in terms of time to develop (as in "Christmas is coming" or "We're coming up on Christmas.") Mirror neuron pathways linking brain regions coordinating vision and hand actions provide a natural pathway for the conceptual metaphor that "Seeing Is Touching" (as in "Their eyes met").

Though metaphor has been discussed in literature for over 2500 years, it is only within the last 30 years that conceptual metaphor has been found scientifically to be central to our mental life.

MILFORD H. WOLPOFF
Professor of Anthropology and Adjunct Associate Research Scientist, Museum of Anthropology at the University of Michigan; Author, Race and Human Evolution

GIGO

A shorthand abstraction I find to be particularly useful in my own cognitive toolkit comes from the world of computer science, and applies broadly in my experience to science and scientists. GIGO means "garbage in, garbage out." Its application in the computer world is straightforward and easy to understand, but I have found much broader applications throughout my career in paleoanthropology.

In computer work, garbage results can arise from bad data or from poorly conceived algorithms applied to analysis — I don't expect that the results from both of these combined are a different order of garbage because bad is bad enough. The science I am used to practicing has far too many examples of mistaken, occasionally fraudulent data and inappropriate, even illogical analysis, and it is all too often impossible to separate conclusions from assumptions.

I don't mean to denigrate paleoanthropology, which I expect is quite like other sciences in these respects, and wherein most work is superbly executed and cannot be described this way. The value of GIGO is to sharpen the skeptical sense and the critical facility because the truth behind GIGO is simple: science is a human activity.

GEORGE DYSON
Science Historian; Author, Darwin Among the Machines

Analog Computing

Imagine you need to find the midpoint of a stick. You can measure its length, using a ruler (or making a ruler, using any available increment) and digitally compute the midpoint. Or, you can use a piece of string as an analog computer, matching the length of the stick to the string, and then finding the middle of the string by doubling it back upon itself. This will correspond, without any loss of accuracy due to rounding off to the nearest increment, to the midpoint of the stick. If you are willing to assume that mass scales linearly with length, you can use the stick itself as an analog computer, finding its midpoint by balancing it against the Earth's gravitational field.

There is no precise distinction between analog and digital computing, but, in general, digital computing deals with integers, binary sequences, and time that is idealized into discrete increments, while analog computing deals with real numbers and continuous variables, including time as it appears to exist in the real world. The past sixty years have brought such advances in digital computing that it may seem anachronistic to view analog computing as an important scientific concept, but, more than ever, it is.

Analog computing, once believed to be as extinct as the differential analyzer, has returned. Not for performing arithmetic — a task at which even a pocket calculator outperforms an analog computer — but for problems at which analog computing can do a better job not only of computing the answer, but of asking the questions and communicating the results. Who is friends with whom? For a small high school, you could construct a database to keep track of this, and update it every night to keep track of changes to the lists. If you want to answer this question, updated in real time, for 500 million people, your only hope is to build an analog computer. Sure, you may use digital components, but at a certain point the analog computing being performed by the system far exceeds the complexity of the digital code with which it is built. That's the genius that powers Facebook and its ilk. Your model of the social graph becomes the social graph, and updates itself.

In the age of all things digital, "Web 2.0" is our code word for the analog increasingly supervening upon the digital — reversing how digital logic was embedded in analog components, sixty years ago. The fastest-growing computers of 2010 — search engines and social networks — are analog computers in a big, new, and important way. Instead of meaningful information being encoded as unambiguous (and fault-intolerant) digital sequences referenced by precise numerical addressing, meaningful information is increasingly being encoded (and operated upon) as continuous (and noise-tolerant) variables such as frequencies (of connection or occurrence) and the topology of what connects where, with location being increasingly defined by fault-tolerant template rather than by unforgiving numerical address.

Complex networks — of molecules, people, or ideas — constitute their own simplest behavioral descriptions. This behavior can be more easily and accurately approximated by continuous, analog networks than it can be defined by digital, algorithmic codes. These analog networks may be composed of digital processors, but it is in the analog domain that the interesting computation is being performed.

Analog is back, and here to stay.

ROGER SCHANK
Psychologist & Computer Scientist; Engines for Education Inc.; Author, Making Minds Less Well Educated Than Our Own

Experimentation

Some scientific concepts have been so ruined by our education system that it is necessary to explain about the ones that everyone thinks they know about when they really don't.

We learn about experimentation in school. What we learn is that scientists conduct experiments and if we copy exactly what they did in our high school labs we will get the results they got. We learn about the experiments that scientists do, usually about about the physical and chemical properties of things and we learn that they report their results in scientific journals. So, in effect we learn that experimentation is boring, is something done by scientists and has nothing to do with our daily lives.

And, this is a problem. Experimentation is something done by everyone all the time. Babies experiment with what might be good to put in their mouths. Toddlers experiment with various behaviors to see what they can get away with. Teenagers experiment with sex, drugs, and rock and roll. But because people don't really see these things as experiments nor as ways of collecting evidence in support or refutation of hypotheses, they don't learn to think about experimentation as something they constantly do and thus will need to learn to do better.

Every time we take a prescription drug we are conducting an experiment. But, we don't carefully record the results after each dose, and we don't run controls, and we mix up the variables by not changing only one behavior at a time, so that when we suffer from side effects we can't figure out what might have been the true cause. We do the same thing with personal relationships. When they go wrong, we can't figure out why because the conditions are different in each one.

Now, while it is difficult if not impossible to conduct controlled experiments in most aspects of our own lives, it is possible to come to understand that we are indeed conducting an experiment when we take a new job, or try a new tactic in a game we are playing, or when we pick a school to attend, or when we try and figure out how someone is feeling, or when we wonder why we ourselves feel the way we do.

Every aspect of life is an experiment that can be better understood if it is perceived in that way. But because we don't recognize this we fail to understand that we need to reason logically from evidence we gather, and that we need to carefully consider the conditions under which our experiments have been conducted, and that we need to decide when and how we might run the experiment again with better results.

In other words, the scientific activity that surrounds experimentation is about thinking clearly in the face of evidence obtained as the result of an experiment. But people who don't see their actions as experiments, and those who don't know how to reason carefully from data, will continue to learn less well from their own experiences than those who do.

Since most of us have learned the word "experiment" in the context of a boring ninth grade science class, most people have long since learned to discount science and experimentation as being relevant to their lives.

If school taught basic cognitive concepts such as experimentation in the context of everyday experience, and taught people how to carefully conduct experiments in their own lives instead of concentrating on using algebra as a way of teaching people how to reason, then people would be much more effective at thinking about politics, child raising, personal relationships, business, and every other aspect of daily life.

ROBERT R. PROVINE
Psychologist and Neuroscientist, University of Maryland; Author, Laughter

TANSTAAFL

TANSTAAFL is the acronym for "There ain't no such thing as a free lunch," a universal truth having broad and deep explanatory power in science and daily life.

The expression originated from the practice of saloons offering "free lunch" if you buy their overpriced drinks. Science fiction master Robert Heinlein introduced me to TANSTAAFL in *The Moon is a Harsh Mistress*, his 1966 classic, in which a character warns of the hidden cost of a free lunch.

The universality of the fact that you can't get something for nothing has found application in sciences as diverse as physics (Laws of Thermodynamics) and economics, where Milton Friedman used a grammatically upgraded variant as title of his 1975 book *There's No Such Thing as a Free Lunch*. Physicists are clearly on board with TANSTAAFL, less so many political economists in their smoke and mirrors world.

My students hear a lot about TANSTAAFL, from the biological costs of the peacock's tail, to our nervous system that distorts physical reality to emphasize changes in time and space. When the final tally is made, peahens cast their ballot for the sexually exquisite plumage of the peacock and its associated vigor, and it is more adaptive for humans to detect critical sensory events than to be high fidelity light and sound meters. In such cases, lunch is not free but comes at reasonable cost as determined by the grim but honest accounting of natural selection, a process without hand-waving and incantation.

GERALD HOLTON
Mallinckrodt Professor of Physics and Professor of the History of Science, Emeritus, at Harvard University; Coeditor, Einstein for the 21st Century: His Legacy in Science, Art, and Modern Culture

Skeptical Empiricism

In politics and society at large, important decision are all too often based on deeply held presuppositions,ideology or dogma — or, on the other hand, on headlong pragmatism without study of long-range consequences.

Therefore I suggest the adoption of *Skeptical Empiricism*, the kind that is exemplified by the carefully thought-out and tested research in science at its best. It differs from plain empiricism on the sort that characterized the writings of the scientist/philosopher Ernst Mach, who refused to believe in the existence of atoms because one could not "see" them.

To be sure, in politics and daily life, on some topics decisions have to be made very rapidly, on few or conflicting data. Yet, precisely for that reason it will be wise also to launch a more considerate program of skeptical empiricism on the same topic, if only to be better prepared for the consequences, intended or not, that followed from the quick decision.

MARTIN SELIGMAN
Zellerbach Family Professor of Psychology; Director of the Positive Psychology Center, University of Pennylvaniai; Author, Flourish

PERMA

Is global well being possible?

Scientists commonly predict dystopias: nuclear war, overpopulation, energy shortage, dysgenic selection, widespread soundbyte mentality, and the like. You don't get much attention predicting that the human future will work out. I am not, however, going to predict that a positive human future will in fact occur, but it becomes more likely if we think about it systematically. We can begin by laying out the measurable elements of well being and then asking how those elements might be achieved. I address only measurement.

Well being is about what individuals and societies choose for its own sake , that which is north of indifference. The elements of well being must be exclusive, measurable independently of each other, and ideally, exhaustive. I believe there are five such elements and they have a handy acronym, PERMA:

P Positive Emotion

E Engagement

R Positive Relationships

M Meaning and Purpose

A Accomplishment

There has been forward movement in the measurement of these over the last decade. Taken together PERMA forms a more comprehensive index of well being than "life satisfaction" and it allows for the combining of objective and subjective indicators. PERMA can index the well being of individuals, of corporations, and of cities. The United Kingdom has now undertaken the measurement of well being for the nation and as one criterion — in addition to Gross Domestic Product — of the success of its public policy.

PERMA is a shorthand abstraction for the enabling conditions of life.

How do the disabling conditions, such as poverty, disease, depression, aggression, and ignorance, relate to PERMA? The disabling conditions of life obstruct PERMA, but they do not obviate it. Importantly the correlation of depression to happiness is not minus 1.00, it is only about minus 0.35, and effect of income on life satisfaction is markedly curvilinear, with increased income producing less and less life satisfaction the further above the safety net you are.

Science and public policy have traditionally been focused solely on remediating the disabling conditions, but PERMA suggests that this is insufficient. If we want global well being, we should also measure and try to build PERMA. The very same principal seems to be true in your own life: if you wish to flourish personally, getting rid of depression, anxiety, and anger and getting rich is not enough, you also need to build PERMA directly.

What is known about how PERMA can be built?

Perhaps the *Edge* Question for 2012 will be "How Can Science Contribute To Building Global Well Being"?

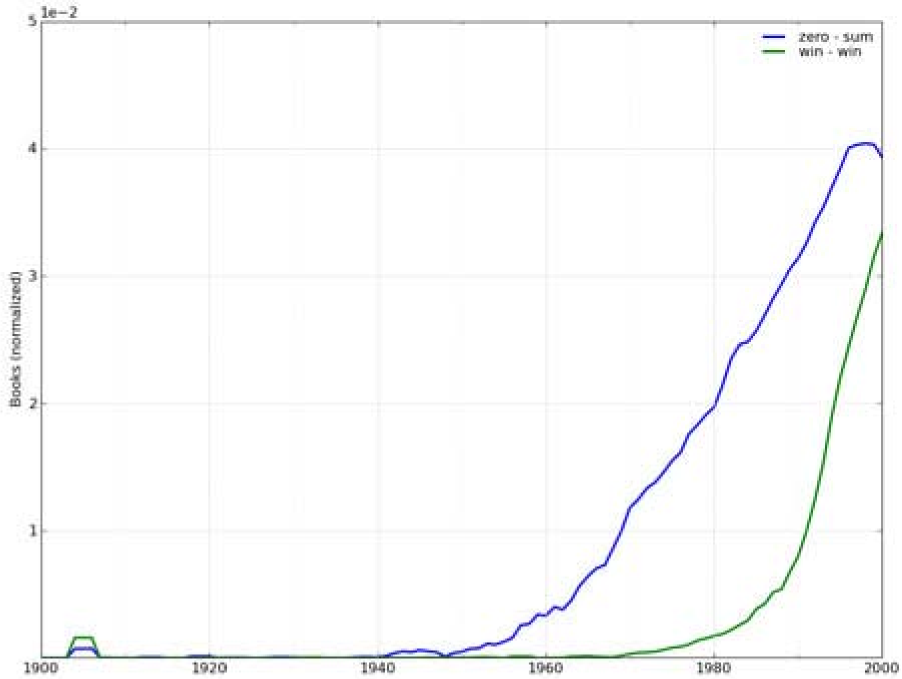
STEVEN PINKER
Johnstone Family Professor, Department of Psychology; Harvard University; Author, The Stuff of Thought

Positive-Sum Games

A zero-sum game is an interaction in which one party's gain equals the other party's loss — the sum of their gains and losses is zero. (More accurately, it is constant across all combinations of their courses of action.) Sports matches are quintessential examples of zero-sum games: winning isn't everything, it's the only thing, and nice guys finish last. A nonzero-sum game is an interaction in which some combinations of actions provide a net gain (positive-sum) or loss (negative sum) to the two of them. The trading of surpluses, as when herders and farmers exchange wool and milk for grain and fruit, is a quintessential example, as is the trading of favors, as when people take turns baby-sitting each others' children.

In a zero-sum game, a rational actor seeking the greatest gain for himself or herself will necessarily be seeking the maximum loss for the other actor. In a positive-sum game, a rational, self-interested actor may benefit the other guy with the same choice that benefits himself or herself. More colloquially, positive-sum games are called win-win situations, and are capture in the cliché "Everybody wins."

This family of concepts (zero-sum, nonzero-sum, positive-sum, negative-sum, constant-sum, and variable-sum games) was introduced by John von Neumann and Oskar Morgenstern when they invented the mathematical theory of games in 1944. The Google Books Ngram tool shows that the terms saw a steady increase in popularity beginning in the 1950s, and its colloquial relative "win-win" began a similar ascent in the 1970s.



[click to enlarge]

Once people are thrown together in an interaction, their choices don't determine whether they are in a zero- or nonzero-sum game; the game is a part of the world they live in. But people, by neglecting some of the options on the table, may perceive that they are in a zero-sum game when in fact they are in a nonzero-sum game. Moreover, they can change the world to make their interaction nonzero-sum. For these reasons, when people become consciously aware of the game-theoretic structure of their interaction (that is, whether it is positive-, negative-, or zero-sum), they can make choices that bring them valuable outcomes — like safety, harmony, and prosperity — without their having to become more virtuous, noble, or pure.

Some examples. Squabbling colleagues or relatives agree to swallow their pride, take their losses, or lump it to enjoy the resulting comity rather than absorbing the costs of continuous bickering in hopes of prevailing in a battle of wills. Two parties in a negotiation split the difference in their initial bargaining positions to "get to yes." A divorcing couple realizes that they can reframe their negotiations from each trying to get the better of the other while enriching their lawyers to trying to keep as much money for the two of them and out of the billable hours of Dewey, Cheatham, and Howe as possible. Populaces recognize that economic middlemen (particularly ethnic minorities who specialize in that niche such as Jews, Armenians, overseas Chinese, and expatriate Indians) are not social parasites whose prosperity comes at the expense of their hosts but positive-sum-game-creators who enrich everyone at once. Countries recognize that international trade doesn't benefit their trading partner to their own detriment but benefits them both, and turn away from beggar-thy-neighbor protectionism to open economies which (as classical economists noted) make everyone richer and which (as political scientists have recently shown) discourage war and genocide. Warring countries lay down their arms and split the peace dividend rather than pursuing Pyrrhic victories.

Granted, some human interactions really are zero-sum — competition for mates is a biologically salient example. And even in positive-sum games a party may pursue an individual advantage at the expense of joint welfare. But a full realization of the risks and costs of the game-theoretic structure of an interaction (particularly if it is repeated, so that the temptation to pursue an advantage in one round may be penalized when roles reverse in the next) can militate against various forms of short-sighted exploitation.

Has an increasing awareness of the zero- or nonzero-sumness of interactions in the decades since 1950 (whether referred to in those terms or not) actually led to increased peace and prosperity in the world? It's not implausible. International trade and membership in international organizations has soared in the decades that game-theoretic thinking has infiltrated popular discourse. And perhaps not coincidentally, the developed world has seen both spectacular economic growth and a historically unprecedented decline in several forms of institutionalized violence, such as war between great powers, war between wealthy states, genocides, and deadly ethnic riots. Since the 1990s these gifts have started to accrue to the developing world as well, in part because they have switched their foundational ideologies from ones that glorify zero-sum class and national struggle to ones that glorify positive-sum market cooperation. (All these claims can be documented from the literature in international studies.)

The enriching and pacifying effects of participation in positive-sum games long antedate the contemporary awareness of the concept. The biologists John Maynard Smith and Eörs Szathmáry have argued that an evolutionary dynamic which creates positive-sum games drove the major transitions in the history of life: the emergence of genes, chromosomes, bacteria, cells with nuclei, organisms, sexually reproducing organisms, and animal societies. In each transition, biological agents entered into larger wholes in which they specialized, exchanged benefits, and developed safeguards to prevent one from exploiting the rest to the detriment of the whole. The journalist Robert Wright sketched a similar arc in his book *Nonzero* and extended it to the deep history of human societies. An explicit recognition among literate people of the shorthand abstraction "positive-sum game" and its relatives may be extending a process in the world of human choices that has been operating in the natural world for billions of years.

DYLAN EVANS
Lecturer in Behavioral Science, University College Cork; Author, Introducing Evolutionary Psychology: A Graphic Guide

The Law of Comparative Advantage

It is not hard to identify the discipline in which to look for the scientific concept that would most improve everybody's cognitive toolkit; it *has* to be economics. No other field of study contains so many ideas ignored by so many people at such great cost to themselves and the world. The hard task is picking just one of the many such ideas that economists have developed.

On reflection, I plumped for the law of comparative advantage, which explains how trade can be beneficial for both parties even when one of them is more productive than the other in every way. At a time of growing protectionism, it is more important than ever to reassert the value of free trade. Since trade in labor is roughly the same as trade in goods, the law of comparative advantage also explains why immigration is almost always a good thing — a point which also needs emphasizing at a time when xenophobia is on the rise.

In the face of well-meaning but ultimately misguided opposition to globalization, we must celebrate the remarkable benefits which international trade has brought us, and fight for a more integrated world.

JASON ZWEIG
Journalist; Personal Finance Columnist, The Wall Street Journal; Author, Your Money and Your Brain

Structured Serendipity

Creativity is a fragile flower, but perhaps it can be fertilized with systematic doses of serendipity. Sarnoff Mednick showed decades ago that some people are better than others at detecting the associations that connect seemingly random concepts: Asked to name a fourth idea that links "wheel," "electric," and "high," people who score high on other measures of creativity will promptly answer "chair."

More recently, research in Mark Jung-Beeman's lab at Northwestern has found that sudden bursts of insight — the Aha! or Eureka! moment — comes when brain activity abruptly shifts its focus. The almost ecstatic sense that makes us cry "I see!" appears to come when the brain is able to shunt aside immediate or familiar visual inputs.

That may explain why so many of us close our eyes (often unwittingly) just before we exclaim "I see!" It also suggests, at least to me, that creativity can be enhanced deliberately through environmental variation. Two techniques seem promising: varying what you learn and varying where you learn it. I try each week to read a scientific paper in a field that is new to me — and to read it in a different place.

New associations often leap out of the air at me this way; more intriguingly, others seem to form covertly and then to lie in wait for the opportune moment when they can click into place. I do not try to force these associations out into the open; they are like shrinking mimosa plants that crumple if you touch them but bloom if you leave them alone.

Robert Merton argued that many of the greatest discoveries of science have sprung from serendipity. As a layman and an amateur, all I hope to accomplish by throwing myself in serendipity's path is to pick up new ideas, and combine old ones, in ways that haven't quite occurred to other people yet. So I let my curiosity lead me wherever it seems to want to go, like that heart-shaped piece of wood that floats across a Ouija board.

I do this remote-reading exercise on my own time, since it would be hard to justify to newspaper editors during the work day. But my happiest moments this autumn came as I reported an investigative article on how elderly investors are increasingly being scammed by elderly con artists. I later realized, to my secret delight, that the article had been enriched by a series of papers I had been reading on altruistic behavior among fish (Lambroides dimidiatus).

If I do my job right, my regular readers will never realize that I spend a fair amount of my leisure time reading *Current Biology*, the *Journal of Neuroscience*, and *Organizational Behavior and Human Decision Processes*. If that reading helps me find new ways to understand the financial world, as I suspect it does, my readers will indirectly be smarter for it. If not, the only harm done is my own spare time wasted.

In my view, we should each invest a few hours a week in reading research that ostensibly has nothing to do with our day jobs, in a setting that has nothing in common with our regular workspaces. This kind of structured serendipity just might help us become more creative, and I doubt that it can hurt.

GINO SEGRE
Professor of Physics and Astronomy at the University of Pennsylvania; *Author,* Ordinary Geniuses

Gedankenexperiment

The notion of *gedankenexperiment,* or thought experiment, has been integral to theoretical physics' toolkit ever since the discipline came into existence. It involves setting up an imagined piece of apparatus and then running a simple experiment with it in your mind for the purpose of proving or disproving a hypothesis. In many cases a *gedankenexperiment* is the only approach. An actual experiment to examine retrieval of information falling into a black hole cannot be carried out.

The notion was particularly important during the development of quantum mechanics when legendary gedankenexperiments were conducted by the likes of Bohr and Einstein to test such novel ideas as the Uncertainty Principle and wave-particle duality. Examples, like that of Schrodinger's Cat, have even come into the popular lexicon. Is the cat simultaneously dead and alive? Others, particularly the classic double slit through which a particle/wave passes, were part of the first attempt to understand quantum mechanics and have remained as tools for understanding its meaning.

However, the subject need not be an esoteric one for a *gedankenexperiment* to be fruitful. My own favorite is Galileo's proof that, contrary to Aristotle's view, more and less massive objects fall in a vacuum with the same acceleration. One might think that a real experiment needs to be conducted to test the hypothesis. But Galileo simply said: consider a large and a small stone tied together by a very light string. If Aristotle was right, he large stone should drag the smaller one and the smaller one retard the larger one if they fell at different rates. However, if you let the string length approach zero, you have a single object with a mass equal to the sum of their masses and hence it should fall at a higher rate than either. This is nonsensical. The conclusion is that all objects fall in vacuum at the same rate.

Consciously or unconsciously we carry out *gedankenexperiments* of one sort or another in our everyday life and are even trained to do perform them in a variety of disciplines, but I do think it would be useful to have a greater awareness of how they are conducted and how they could be positively applied. We could ask, when confronted with a puzzling situation, how can I set up a *gedankenexperiment* to resolve the issue? Perhaps our financial, political and military experts would benefit from following such a tactic and arrive at happier outcomes.

SEAN CARROLL
Theoretical Physicist, Caltech; Author, From Eternity to Here: The Quest for the Ultimate Theory of Time

The Pointless Universe

The world consists of things, which obey rules. If you keep asking "why" questions about what happens in the universe, you ultimately reach the answer "because of the state of the universe and the laws of nature."

This isn't an obvious way for people to think. Looking at the universe through our anthropocentric eyes, we can't help but view things in terms of causes, purposes, and natural ways of being. In ancient Greece, Plato and Aristotle saw the world teleologically — rain falls because water wants to be lower than air, animals (and slaves) are naturally subservient to human citizens.

From the start, there were skeptics. Democritus and Lucretius were early naturalists, who urged us to think in terms of matter obeying rules rather than chasing final causes and serving underlying purposes. But it wasn't until our understanding of physics was advanced by thinkers such as Avicenna, Galileo, and Newton that it became reasonable to conceive of the universe evolving under its own power, free of guidance and support from anything beyond itself.

Theologians sometimes invoke "sustaining the world" as a function of God. But we know better; the world doesn't need to be sustained, it can simply be. Pierre-

Simon Laplace articulated the very specific kind of rule that the world obeys: if we specify the complete state of the universe (or any isolated part of it) at some particular instant, the laws of physics tell us what its state will be at the very next moment. Applying those laws again, we can figure out what it will be a moment later. And so on, until (in principle, obviously) we can build up a complete history of the universe. This is not a universe that is advancing toward a goal; it is one that is caught in the iron grip of an unbreakable pattern.

This view of the processes at the heart of the physical world has important consequences for how we come to terms with the social world. Human beings like to insist that there are reasons why things happen. The death of a child, the crash of an airplane, or a random shooting must be explained in terms of the workings of a hidden plan. When Pat Robertson suggested that Hurricane Katrina was caused in part by God's anger at America's failing morals, he was attempting to provide an explanatory context for a seemingly inexplicable event.

Nature teaches us otherwise. Things happen because the laws of nature say they will — because they are the consequences of the state of the universe and the path of its evolution. Life on Earth doesn't arise in fulfillment of a grand scheme, but rather as a byproduct of the increase of entropy in an environment very far from equilibrium. Our impressive brains don't develop because life is guided toward greater levels of complexity and intelligence, but from the mechanical interactions between genes, organisms, and their surroundings.

None of which is to say that life is devoid of purpose and meaning. Only that these are things we create, not things we discover out there in the fundamental architecture of the world. The world keeps happening, in accordance with its rules; it's up to us to make sense of it and give it value.

RUDY RUCKER
Mathematician, Computer Scientist; CyberPunk Pioneer; Novelist; Author, Lifebox, the Seashell, and the Soul

The World is Unpredictable

The media cast about for the proximate causes of life's windfalls and disasters. The public demands blocks against the bad and pipelines to the good. Legislators propose new regulations, fruitlessly dousing last year's fires, forever betting on yesterday's winning horses.

A little-known truth: Every aspect of the world is fundamentally unpredictable. Computer scientists have long since proved this.

How so? To predict an event is to know a shortcut for foreseeing the outcome in advance. A simple counting argument shows there aren't enough shortcuts to go around. Therefore most processes aren't predictable. A deeper argument plays on the fact that, if you could predict your actions, you could deliberately violate your predictions which means the predictions were wrong after all.

We often suppose that unpredictability is caused by random inputs from higher spirits or from low-down quantum foam. But chaos theory and computer science tell us that non-random systems produce surprises on their own. The unexpected tornado, the cartoon safe that lands on Uncle George, the winning pull on a slot machine odd things pop out of a computation. The world can simultaneously be deterministic and unpredictable.

In the physical world, the only way to learn tomorrow's weather in detail is to wait twenty-four hours and see even if nothing is random at all. The universe is computing tomorrow's weather as rapidly and as efficiently as possible any smaller model is inaccurate, and the smallest error is amplified into large effects.

At a personal level, even if the world is as deterministic as a computer program, you still can't predict what you're going to do. This is because your prediction method would involve a mental simulation of you that produces its results slower than you. You can't think faster than you think. You can't stand on your own shoulders.

It's a waste to chase the pipedream of a magical tiny theory that allows us to make quick and detailed calculations about the future. We can't predict and we can't control. To accept this can be a source of liberation and inner peace. We're part of the unfolding world, surfing the chaotic waves.

CHARLES SEIFE
Professor of Journalism, New York University; formerly journalist, Science magazine; Author, Proofiness

Randomness

Our very brains revolt at the idea of randomness. We have evolved as a species to become exquisite pattern-finders — long before the advent of science, we figured out that a salmon-colored sky heralds a dangerous storm, or that a baby's flushed face likely means a difficult night ahead. Our minds automatically try to place data in a framework that allows us to make sense of our observations and use them to understand events and predict them.

Randomness is so difficult to grasp because it works against our pattern-finding instincts. It tells us that sometimes there is no pattern to be found. As a result, randomness is fundamental limit to our intuition; it says that there are processes that we can't predict fully. It's a concept that we have a hard time accepting even though it is an essential part of the way the cosmos works. Without an understanding of randomness, we are stuck in a perfectly predictable universe that simply doesn't exist outside of our own heads.

I would argue that only once we understand three dicta — three laws of randomness — can we break out of our primitive insistence on predictability and appreciate the universe for what it is rather than what we want it to be.

The First Law of Randomness: There is such a thing as randomness.

We use all kinds of mechanisms to avoid confronting randomness. We talk about karma, in a cosmic equalization that ties seemingly unconnected events together. We believe in runs of luck, both good and ill, and that bad things happen in threes. We argue that we are influenced by the stars, by the phases of the moon, and by the motion of the planets in the heavens. When we get cancer, we automatically assume that something — or someone — is to blame.

But many events are not fully predictable or explicable. Disasters happen randomly, to good people as well as to bad ones, to star-crossed individuals as well as those who have a favorable planetary alignment. Sometimes you can make a good guess about the future, but randomness can confound even the most solid predictions — don't be surprised when you're outlived by the overweight, cigar-smoking, speed-fiend motorcyclist down the block.

What's more, random events can mimic non-random ones. Even the most sophisticated scientists can have difficulty telling the difference between a real effect and a random fluke. Randomness can make placebos seem like miracle cures, harmless compounds appear to be deadly poisons, and can even create subatomic particles out of nothing.

The Second Law of Randomness: Some events are impossible to predict.

If you walk into a Las Vegas casino and observe the crowd gathered around the craps table, you'll probably see someone who thinks he's on a lucky streak. Because he's won several rolls in a row, his brain tells him that he's going to keep winning, so he keeps gambling. You'll probably also see someone who's been losing. The loser's brain, like the winner's, tells him to keep gambling. Since he's been losing for so long, he thinks he's due for a stroke of luck; he won't walk away from the table for fear of missing out.

Contrary to what our brains are telling us, there's no mystical force that imbues a winner with a streak of luck, nor is there a cosmic sense of justice that ensures that a loser's luck will turn around. The universe doesn't care one whit whether you've been winning or losing; each roll of the dice is just like every other.

No matter how much effort you put into observing how the dice have been behaving or how meticulously you have been watching for people who seem to have luck on their side, you get absolutely no information about what the next roll of a fair die will be. The outcome of a die roll is entirely independent of its history. And, as a result, any scheme to gain some sort of advantage by observing the table will be doomed to fail. Events like these — independent, purely random events — defy any attempts to find a pattern because there is none to be found.

Randomness provides an absolute block against human ingenuity; it means that our logic, our science, our capacity for reason can only penetrate so far in predicting the behavior of cosmos. Whatever methods you try, whatever theory you create, whatever logic you use to predict the next roll of a fair die, there's always a 5/6 chance you are wrong. Always.

The Third Law of Randomness: Random events behave predictably in aggregate even if they're not predictable individually

Randomness is daunting; it sets limits where even the most sophisticated theories can not go, shielding elements of nature from even our most determined inquiries. Nevertheless, to say that something is random is not equivalent to saying that we can't understand it. Far from it.

Randomness follows its own set of rules — rules that make the behavior of a random process understandable and predictable.

These rules state that even though a single random event might be completely unpredictable, a collection of independent random events is extremely predictable — and the larger the number of events, the more predictable they become. The law of large numbers is a mathematical theorem that dictates that repeated, independent random events converge with pinpoint accuracy upon a predictable average behavior. Another powerful mathematical tool, the central limit theorem, tells you exactly how far off that average a given collection of events is likely to be. With these tools, no matter how chaotic, how strange a random behavior might be in the short run, we can turn that behavior into stable, accurate predictions in the long run.

The rules of randomness are so powerful that they have given physics some of its most sacrosanct and immutable laws. Though the atoms in a box full of gas are moving at random, their collective behavior is described by a simple set of deterministic equations. Even the laws of thermodynamics derive their power from the predictability of large numbers of random events; they are indisputable only because the rules of randomness are so absolute.

Paradoxically, the unpredictable behavior of random events has given us the predictions that we are most confident in.

CLIFFORD PICKOVER
Author, The Math Book: From Pythagoras to the 57th Dimension; Jews in Hyperspace

Kaleidoscopic Discovery Engine

The famous Canadian physician William Osler once wrote, "In science the credit goes to the man who convinced the world, not to the man to whom the idea first occurs." When we examine discoveries in science and mathematics, in hindsight we often find that if one scientist did not make a particular discovery, some other individual would have done so within a few months or years of the discovery. Most scientists, as Newton said, stood on the shoulders of giants to see the world just a bit further along the horizon. Often, more than one individual creates essentially the same device or discovers the same scientific law at about the same time, but for various reasons, including sheer luck, history sometimes remembers only the more famous discoverer.

In 1858 the German mathematician August Möbius simultaneously and independently discovered the Möbius strip along with a contemporary scholar, the German mathematician Johann Benedict Listing. Isaac Newton and Gottfried Wilhelm Leibniz independently developed calculus at roughly the same time. British naturalists Charles Darwin and Alfred Wallace both developed the theory of evolution independently and simultaneously. Similarly, Hungarian mathematician János Bolyai and Russian mathematician Nikolai Lobachevsky seemed to have developed hyperbolic geometry independently and at the same time.

The history of materials science is replete with simultaneous discoveries. For example, in 1886, the electrolytic process for refining aluminum, using the mineral cryolite, was discovered simultaneously and independently by American Charles Martin Hall and Frenchman Paul Héroult. Their inexpensive method for isolating pure aluminum from compounds had an enormous effect on industry. The time was "ripe" for such discoveries, given humanity's accumulated knowledge at the time the discoveries were made. On the other hand, mystics have suggested that a deeper meaning exists to such coincidences. Austrian biologist Paul Kammerer wrote, "We thus arrive at the image of a world-mosaic or cosmic kaleidoscope, which, in spite of constant shufflings and rearrangements, also takes care of bringing like and like together." He compared events in our world to the tops of ocean waves that seem isolated and unrelated. According to his controversial theory, we notice the tops of the waves, but beneath the surface there may be some kind of synchronistic mechanism that mysteriously connects events in our world and causes them to cluster.

We are reluctant to believe that great discoveries are part of a discovery kaleidoscope and mirrored in numerous individuals at once. However, as further examples, there were several independent discoveries of sunspots in 1611, even though Galileo gets most of the credit today. Halley's Comet, named after English astronomer Edmond Halley, was not first discovered by Halley because it had actually seen by countless observers even before the time of Jesus. However, Halley's useful calculations enabled earlier references to the comet's appearance to be found in the historical record. Alexander Graham Bell and Elisha Gray filed their own patents on telephone technologies on the same day. As sociologist of science Robert Merton remarked, "The genius is not a unique source of insight; he is merely an efficient source of insight."

Robert Merton suggested that "all scientific discoveries are in principle 'multiples'." In other words, when a scientific discovery is made, it is made by more than one person. Sometimes a discovery is named after the person who develops the discovery rather than the original discoverer.

The world is full of difficulties in assigning credit for discoveries. Some of us have personally seen this in the realm of patent law, in business ideas, and in our daily lives. Fully appreciating the concept of the kaleidoscope discovery engine adds to our cognitive toolkits because the kaleidoscope succinctly captures the nature of innovation and the future of ideas. If schools taught more about kaleidoscopic discovery, even in the context of everyday experience, then innovators might enjoy the fruits of their labor and still become "great" without a debilitating concern to be first or to crush rivals. The great anatomist William Hunter frequently quarreled with his brother about who was first in making a discovery. But even Hunter admitted, "If a man has not such a degree of enthusiasm and love of the art, as will make him impatient of unreasonable opposition, and of encroachment upon his discoveries and his reputation, he will hardly become considerable in anatomy, or in any other branch of natural knowledge."

When Mark Twain was asked to explain why so many inventions were invented independently, he said "When it's steamboat time, you steam."

REBECCA NEWBERGER GOLDSTEIN
Philosopher; Novelist; Author, Betraying Spinoza; 36 Arguments for the Existence of God: A Work of Fiction

Inference To The Best Explanation

I'm alone in my home, working in my study, when I hear the click of the front door, the sound of footsteps making their way toward me. Do I panic? That depends on what I — my attention instantaneously appropriated to the task and cogitating at high speed—infer as the best explanation for those sounds. My husband returning home, the house cleaners, a miscreant breaking and entering, the noises of our old building settling, a supernatural manifestation? Additional details could make any one of these explanations, excepting the last, the best explanation for the circumstances. Why not the last? As Charles Sanders Peirce, who first drew attention to this type of reasoning, pointed out: "Facts cannot be explained by a hypothesis more extraordinary than these facts themselves; and of various hypotheses the least extraordinary must be adopted."

"Inference to the best explanation" is ubiquitously pursued, which doesn't mean that it is ubiquitously pursued well. The phrase, coined by the Princeton philosopher Gilbert Harmon as a substitute for Peirce's term "abduction," should be in everybody's toolkit, if only because it forces one to think about what makes for a good explanation. There is that judgmental phrase, *the best*, sitting out in the open, shamelessly invoking standards. Not all explanations are created equal; some are objectively better than others. And the phrasealso highlights another important fact. *The best* means the one that wins out over the alternatives, of which there are always many. Evidence calling for an explanation summons a great plurality (in fact an infinity) of possible explanations, the great mass of which can be eliminated on the grounds of violating Peirce's maxim. We decide among the remainder using such criteria as: which is the simpler, which does less violence to established beliefs, which is less ad hoc, which explains the most, which is the loveliest. There are times when these criteria clash with one another. Inference to the best explanation is certainly not as rule-bound as logical deduction, nor even as enumerative induction, which takes us from observed cases of all *a's* being *b's* to the probability that unobserved cases of *a's* are also *b's*. But inference to the best explanation also gets us a great deal more than either deduction or enumerative induction does.

It's inference to the best explanation that gives science the power to expand our ontology, giving us reasons to believe in things that we can't directly observe, from sub-atomic particles — or maybe strings — to the dark matter and dark energy of cosmology. It's inference to the best explanation that allows us to know something of what it's like to be other people on the basis of their behavior. I see the hand drawing too near the fire and then quickly pull away, tears starting in the eyes while an impolite word is uttered, and I know something of what that person is feeling. It's on the basis of inference to the best explanation that I can learn things from what authorities say and write, my inferring that the best explanation for their doing so is that they believe what they say or write. (Sometimes that's not the best explanation.) In fact, I'd argue that my right to believe in a world outside of my own solipsistic universe, confined to the awful narrowness of my own immediate experience, is based on inference to the best explanation. What best explains the vivacity and predictability of some of my representations of material bodies, and not others, if not the hypothesis of actual material bodies? Inference to the best explanation defeats mental-sapping skepticism.

Many of our most rancorous scientific debates — say, over string theory or foundations of quantum mechanics — have been over which competing criteria for judging explanations *the best* ought to prevail. So, too, have debates that many of us have been having over scientific versus religious explanations. These debates could be sharpened by bringing to bear on them the rationality-steeped notion of inference to the best explanation, its invocation of the sorts of standards that make some explanations objectively better than others, beginning with Peirce's enjoiner that extraordinary hypotheses be ranked far away from the best.

NASSIM N. TALEB
Distinguished Professor of Risk Engineering, New York University; Author, The Black Swan; The Bed of Procrustes

Antifragility — or— The Property Of Disorder-Loving Systems

I

Antifragility

Just as a package sent by mail can bear a stamp "fragile", "breakable" or "handle with care", consider the exact opposite: a package that has stamped on it "please mishandle" or "please handle carelessly". The contents of such package are not just unbreakable, impervious to shocks, but have something more than that , as they tend to benefit from shocks. This is beyond robustness.

So let us coin the appellation "antifragile" for anything that, on average, (i.e., in expectation) benefits from variability. Alas, I found no simple, noncompound word in any of the main language families that expresses the point of such fragility in reverse. To see how alien the concept to our minds, ask around what's the antonym of fragile. The likely answer will be: robust, unbreakable, solid, well-built, resilient, strong, something-proof (say waterproof, windproof, rustproof), etc. Wrong — and it is not just individuals, but branches of knowledge that are confused by it; this is a mistake made in every dictionary. Ask the same person the opposite of *destruction*, they will answer *construction* or *creation*. And ask for the opposite of *concavity*, they will answer *convexity*.

A verbal definition of convexity is: *benefits more than it loses from variations*; concavity is its opposite. This is key: when I tried to give a mathematical expression of fragility (using sums of path-dependent payoffs), I found that "fragile" could be described in terms of *concavity to a source of variation* (random or nonrandom), over a certain range of variations. So the opposite of that is convexity — *tout simplement.*

A grandmother's health is fragile, hence concave, with respect to variations in temperature, if you find it preferable to make her spend two hours in 70? F instead of an hour at 0? F and another at 140? F for the exact 70? F on average. (A concave function of a combination f(½ x1+½ x2) is higher than the combination ½ f(x1)+ ½ f(x2).

Further, one could be fragile to certain events but not others: A portfolio can be slightly concave to a small fall in the market but not to extremely large deviations (Black Swans).

Evolution is convex (up to a point) with respect to variations since the DNA benefits from disparity among the offspring. Organisms benefit, up to a point, from a spate of stressors. Trial and error is convex since errors cost little, gains can be large.

Now consider the Triad in the Table. Its elements are those for which I was able to find general concavities and convexities and catalogue accordingly.

The Triad

	FRAGILE	**ROBUST**	**ANTI-FRAGILE**
Mythology — Greek	Sword of Damocles, Rock of	Phoenix	Hydra

Biological & Economic Systems	Efficiency	Redundancy	Degeneracy (functional redundancy, in the Edelman-Galy sense)
Science/Technology	Directed Research	Opportunistic research	Stochastic Tinkering (convex bricolage)
Human Body	Mollification, atrophy, "aging", sarcopenia	Recovery	Hypertrophy, Hormesis, Mithridatism
Political Systems	Nation-State; Centralized	Statelings, vassals under a large empire	City-State; Decentralized
Income	Companies		Income of Executives (bonuses)
Civilization	Post-agricultural Modern urban	Ancient settlements	Nomadic and hunter-gatherer tribes
Decision Making	Model-based probabilistic decision making	Heuristic-based decision making	Convex heuristics
Knowledge	Explicit	Tacit	Tacit with convexity
Epistemology	True-False		Sucker-Nonsucker
Ways of Thinking	Modernity	Medieval Europe	Ancient Mediterranean
Errors	Hates mistakes	Mistakes are just information	Loves mistakes
Learning	Classroom	Real life, pathemata mathemata	Real life and library

Medicine	Additive treatment (give medication)		Subtractive treatment (remove items from consumption, say carbs, etc.)
Finance	Short Optionality		Long Optionality
Decision Making	Acts of commission		Acts of omission ("missed opportunity")
Literature	E-Reader	Book	Oral Tradition
Business	Industry	Small Business	Artisan
Finance	Debt	Equity	Venture Capital
Finance	Public Debt	Private debt with no bailout	
General	Large	Small but specialized	Small but not specialized
General	Monomodal payoff		Barbell polarized payoff
Finance	Banks, Hedge funds managed by economists	Hedge Funds (some)	Hedge Funds (some)
Business	Agency Problem		Principal Operated
Reputation (profession)	Academic, Corporate executive, Pope, Bishop, Politician	Postal employee, Truck driver, train conductor	Artist, Writer
Reputation (class)	Middle Class	Minimum wage persons	Bohemian, aristocracy, old money

The larger the corporation, the more concave to some squeezes (although on the surface companies they claim to benefit from economies of scale, the record shows mortality from disproportionate fragility to Black Swan events). Same with government projects: big government induces fragilities. So does overspecialization (think of the Irish potato famine). In general most top-down systems become fragile (as can be shown with a simple test of concavity to variations).

Worst of all, an optimized system becomes quickly concave to variations, by construction: think of the effect of absence of redundancies and spare parts. So about everything behind the mathematical economics revolution can be shown to fragilize.

Further we can look at the unknown, just like model error, in terms of antifragility (that is, payoff): is what you are missing from a model, or what you don't know in real life, going to help you more than hurt you? In other words are you antifragile to such uncertainty (physical or epistemic)? Is the utility of your payoff convex or concave? Pascal was first to express decisions in terms of these convex payoffs. And economics theories produce models that fragilize (except rare exceptions), which explains why using their models is vastly worse than doing nothing. For instance, financial models based on "risk measurements" of rare events are a joke. The smaller the probability, the more convex it becomes to computational error (and the more concave the payoff): an 25% error in the estimation of the standard deviation for a Gaussian can increase the expected shortfall from remote events by a billion (sic) times! (Missing this simple point has destroyed the banking system).

II

Jensen's Inequality as the Hidden Engine of History

Now the central point. By a simple mathematical property, one can show why, under a model of uncertainty, items on the right column will be likely to benefit in the long run, and thrive, more than shown on the surface, and items on the left are doomed to perish. Over the past decade managers of companies earned in, the aggregate, trillions while retirees lost trillions (the fact that executives get the upside not the downside gives them a convex payoff "free option"). And aggressive tinkering fares vastly better than directed research. How?

Jensen's inequality says the following: *for a convex payoff, the expectation of an average will be higher than the average of expectations*. For a concave one, the opposite (grandmother's health is worse if on average the temperature is 70 than in an average temperature of 70).

Squaring is a convex function. Take a die (six sides) and consider a payoff equal to the number it lands on. You expect 3½. The square of the expected payoff will be 12¼ (square 3½). Now assume we get the square of the numbers on the die, 15.1666, so, the average of a square payoff is higher than the square of the average payoff.

The implications can be striking as this second order effect explains so much of hidden things in history. In expectation, anything that loves Black Swans will be present in the future. Anything that fears it will be eventually gone — to the extent of its concavity.

AUBREY DE GREY
Gerontologist; Chief Science Officer. SENS Foundation; Author, Ending Aging

A Sense Of Proportion About Fear Of The Unknown

Einstein ranks extremely high not only among the all-time practitioners of science but also among the producers of aphorisms that place science in its real-world context. One of my favourites is "If we knew what we were doing, it wouldn't be called research." This disarming comment, like so many of the best quotes by experts in any field, embodies a subtle mix of sympathy and disdain for the difficulties that the great unwashed find in appreciating what those experts do.

One of the foremost challenges that face scientists today is to communicate the management of uncertainty. The public know that experts are, well, expert - that they know more than anyone else about the issue at hand. What is evidently far harder for most people to grasp is that "more than anyone else" does not mean "everything" - and especially that, given the possession of only partial knowledge, experts must also be expert at figuring out what is the best course of action. Moreover, those actions must be well judged whether in the lab, the newsroom or the policy-maker's office.

It must not, of course, be neglected that many experts are decidedly inexpert at communicating their work in lay terms. This remains a major issue largely because virtually all experts are called upon to engage in general-audience communication only very rarely, hence do not see it as a priority to gain such skills. Training and advice are available, often from university press offices, but even when experts take advantage of such opportunities it is generally too little and too late.

However, in my view that is a secondary issue. As a scientist with the luxury of communicating with the general public very frequently, I can report with confidence that experience only helps up to a point. A fundamental obstacle remains: that non-scientists harbour deep-seated instincts concerning the management of uncertainty in their everyday lives, which exist because they generally work, but which profoundly differ from the optimal strategy in science and technology. And of course it is technology that matters here, because technology is where the rubber hits the road - where science and the real world meet and must communicate effectively.

Examples of failure in this regard abound - so much so that they are hardly worthy of enumeration. Whether it be swine flu, bird flu, GM crops, stem cells:

the public debate departs so starkly from the scientist's comfort zone that it is hard not to sympathise with the errors that scientists make, such as letting nuclear transfer be called "cloning", which end up holding critical research fields back for years.

One particular aspect of this problem stands out in its potential for public self-harm, however: risk-aversion. When uncertainty revolves around such areas as ethics (as with nuclear transfer) or economic policy (as with flu vaccination), the issues are potentially avoidable by appropriate forward planning. This is not the case when it comes to the public attitude to risk. The immense fall in uptake of vaccinations for major childhood diseases following a single, contentious study lining them to autism is a prime example. Another is the suspension of essentially all clinical trials of gene therapy for at least a year in response to the death of one person in a trial: a decision taken by regulatory bodies, yes, but one that was in line with public opinion.

These responses to the risk benefit ratio of cutting-edge technologies are examples of fear of the unknown - of an irrationally conservative prioritisation of the risks of change over the benefits, with unequivocally deleterious consequences in terms of quality and quantity of life in the future. Fear of the unknown is not remotely irrational in principle, when "fear of" is understood as a synonym for "caution about" - but it can be, and generally is, overdone. If the public could be brought to a greater understanding of how to evaluate the risks inherent in exploring future technology, and the merits of accepting some short-term risk in the interests of overwhelmingly greater expected long-term benefit, progress in all areas of technology — especially biomedial technology - would be greatly accelerated.

EMANUEL DERMAN
Professor, Financial Engineering, Columbia University; Principal, Prisma Capital Partners; Former Head, Quantitative Strategies Group, Equities Division, Goldman Sachs & Co.; Author, My Life as a Quant

Pragmamorphism

Anthropomorphism means attributing the characteristics of human beings to inanimate things or animals.

I have invented the word pragmamorphism as a short-hand extension for the attribution of the properties of inanimate things to human beings.

One of the meanings of the Greek word pragma is a material object.

Being pragmamorphic sounds as though it would be equivalent to taking a scientific attitude to the world, but it easily evolves into dull scientism.

It's pragmamorphic to equate material correlates with human psychological states, to equate PET scans with emotion. It's also pragmamorphic to ignore human qualities you cannot measure.

We have discovered useful metrics for material objects -- length, temperature, pressure, volume, kinetic energy, etc. Pragmamorphism is a good word for the attempt to assign such one-dimensional thing-metrics to the mental qualities of humans.

IQ, a length scale for intelligence, is a result of pragmamorphism. Intelligence is more diffuse than linear.

The utility function in economics is similar. It's clear that people have preferences. But is it clear that there is a function that describes their preferences?

NICHOLAS CARR
Author, The Shallows: What the Internet Is Doing to Our Brains

Cognitive Load

You're sprawled on the couch in your living room, watching a new episode of Justified on the tube, when you think of something you need to do in the kitchen. You get up, take ten quick steps across the carpet, and then, just as you reach the kitchen door — poof! — you realize you've already forgotten what it was you got up to do. You stand befuddled for a moment, then shrug your shoulders and head back to the couch.

Such memory lapses happen so often that we don't pay them much heed. We write them off as "absentmindedness" or, if we're getting older, "senior moments." But the incidents reveal a fundamental limitation of our minds: the tiny capacity of our working memory. Working memory is what brain scientists call the short-term store of information where we hold the contents of our consciousness at any given moment — all the impressions and thoughts that flow into our mind as we go through a day. In the 1950s, Princeton psychologist George Miller famously argued that our brains can hold only about seven pieces of information simultaneously. Even that figure may be too high. Some brain researchers now believe that working memory has a maximum capacity of just three or four elements.

The amount of information entering our consciousness at any instant is referred to as our cognitive load. When our cognitive load exceeds the capacity of our working memory, our intellectual abilities take a hit. Information zips into and out of our mind so quickly that we never gain a good mental grip on it. (Which is why you can't remember what you went to the kitchen to do.) The information vanishes before we've had an opportunity to transfer it into our long-term memory and weave it into knowledge. We remember less, and our ability to think critically and conceptually weakens. An overloaded working memory also tends to increase our distractedness. After all, as the neuroscientist Torkel Klingberg has pointed out, "we have to remember what it is we are to concentrate on." Lose your hold on that, and you'll find "distractions more distracting."

Developmental psychologists and educational researchers have long used the concept of cognitive load in designing and evaluating pedagogical techniques. When you give a student too much information too quickly, they know, comprehension degrades and learning suffers. But now that all of us — thanks to the incredible speed and volume of modern digital communication networks and gadgets — are inundated with more bits and pieces of information than ever before, everyone would benefit from having an understanding of cognitive load and how it influences memory and thinking. The more aware we are of how small and fragile our working memory is, the more we'll be able to monitor and manage our cognitive load. We'll become more adept at controlling the flow of the information coming at us.

There are times when you want to be awash in messages and other info-bits. The resulting sense of connectedness and stimulation can be exciting and pleasurable. But it's important to remember that, when it comes to the way your brain works, information overload is not just a metaphor; it's a physical state. When you're engaged in a particularly important or complicated intellectual task, or when you simply want to savor an experience or a conversation, it's best to turn the information faucet down to a trickle.

HANS ULRICH OBRIST
Curator, Serpentine Gallery, London

To Curate

Lately, the word "curate" seems to be used in an greater variety of contexts than ever before, in reference to everything from a exhibitions of prints by Old Masters to the contents of a concept store. The risk, of course, is that the definition may expand beyond functional usability. But I believe "curate" finds ever-wider application because of a feature of modern life that is impossible to ignore: the incredible proliferation of ideas, information, images, disciplinary knowledge, and material products that we all witnessing today. Such proliferation makes the activities of filtering, enabling, synthesizing, framing, and remembering more and more important as basic navigational tools for 21st centurylife. These are the tasks of the curator, who is no longer understood as simply the person who fills a space with objects but as the person who brings different cultural spheres into contact, invents new display features, and makes junctions that allow unexpected encounters and results.

Michel Foucault once wrote that he hoped his writings would be used by others as a theoretical toolbox, a source of concepts and models for understanding the world. For me, the author, poet, and theoretician Eduard Glissant has become this kind of toolbox. Very early he noted that in our phase of globalization — which is not the first one — there is a danger of a homogenization, but at the same time there is a counter movement to globalization, the retreat into one's own culture. And against both dangers he proposes the idea of mondialité — a global dialogue that augments difference. This inspired me to handle exhibitions in a new way. There is a lot of pressure on curators to do shows not only in one place, but to send them around the world by simply packing them into boxes in one city and unpacking them in the next , this is a homogenizing sort of globalization. Using Glissant's idea as a tool means to develop exhibitions that always build a relation to their place, that change permanently with their different local conditions, that create a changing dynamic, complex system with feedback loops.

To curate, in this sense, is to refuse static arrangements and permanent alignments and instead to enable conversations and relations. Generating these kinds of links is an essential part of what it means to curate, as is disseminating new knowledge, new thinking, and new artworks in a way that can seed future cross-disciplinary inspirations. But there is another case for curating as a vanguard activity for the 21st century.

As the artist Tino Sehgal has pointed out, modern human societies find themselves today in an unprecedented situation: the problem of lack, or scarcity, which has been the primary factor motivating scientific and technological innovation, is now being joined and even superseded by the problem of the global effects of overproduction and resource use. Thus moving beyond the object as the locus of meaning has a further relevance. Selection, presentation, and conversation are ways for human beings to create and exchange real value, without dependence on older, unsustainable processes. Curating can take the lead in pointing us towards this crucial importance of choosing.

SAMUEL BARONDES
Director of the Center for Neurobiology and Psychiatry at the University of California, San Francisco; Author, Better than Prozac

Each Of Us Is Ordinary, And Yet One Of A Kind

Each of us is ordinary, and yet one of a kind.

Each of us is standard-issue, conceived by the union of two germ cells, nurtured in a womb, and equipped with a developmental program that guides our further maturation and eventual decline.

Each of us is also unique, the possessor of a particular selection of gene variants from the collective human genome, and immersed in a particular family, culture, era, and peer group. With inborn tools for adaptation to the circumstances of our personal world we keep building our own ways of being and the sense of who we are.

This dual view of each of us, as both run-of-the-mill and special, has been so well established by biologists and behavioral scientists that it may now seem self-evident. But it still deserves conscious attention as a specific cognitive chunk because it has such important implications. Recognizing how much we share with others promotes compassion, humility, respect, and brotherhood. Recognizing that we are each unique promotes pride, self-development, creativity, and achievement.

Embracing these two aspects of our personal reality can enrich our daily experience. It allows us to simultaneously enjoy the comfort of being ordinary and the excitement of being one of a kind.

RICHARD NISBETT
Social Psychologist, Co-Director, Culture and Cognition Program, University of Michigan; Author, Intelligence and How to Get It

"Graceful" SHA's

1. A university needs to replace its aging hospital. Cost estimates indicate that it would be equally expensive to remodel the old hospital vs. to demolish it and build a new one from scratch. The main argument offered by the proponents of the former is that the original hospital had been very expensive to build and it would be wasteful to simply demolish it. The main argument by the proponents of a new hospital is that a new hospital would inevitably be more modern than a remodeled one. Which seems wiser to you — remodel or build a new hospital?

2. David L., a high school senior, is choosing between two colleges, equal in prestige, cost and distance from home. David has friends at both colleges. Those at College A like it from both intellectual and personal standpoints. Those at College B are generally disappointed on both grounds. But David visits each college for a day and his impressions are quite different from those of his friends. He meets several students at College A who seem neither particularly interesting nor particularly pleasant, and a couple of professors give him the brushoff. He meets several bright and pleasant students at College B and two different professors take a personal interest in him. Which college do you think David should go to?

3. Which of the cards below should you turn over to answer to determine whether the following rule has been violated or not? "If there is a vowel on the front of the card then there is an odd number on the back."

"If there is a vowel on the front of the card then there is an odd number on the back."

U	**K**	**3**	**8**

Some considerations about each of these questions

Question 1: If you said that the university should remodel on the grounds that it had been expensive to build the old hospital you have fallen into the "sunk cost trap" SHA identified by economists. The money spent on the hospital is irrelevant — it's sunk — and has no bearing on the present choice. Amos Tversky and Daniel Kahneman pointed out that people's ability to avoid such traps might be helped by a couple of thought experiments like the following:

"Imagine that you have two tickets to tonight's NBA game in your city and that the arena is 40 miles away. But it's begun to snow and you've found out that your team's star has been injured and won't be playing. Should you go or just throw away the money and skip it?" To answer that question as an economist would, ask yourself the following question: Suppose you didn't have tickets to the game and a friend were to call you up and say that he has two tickets to tonight's game which he can't use and asks if you would like to have them. If the answer is "you've got to be kidding, it's snowing and the star isn't playing," then the answer is you shouldn't go. That answer shows you that the fact that you paid good money for the tickets you have is irrelevant — their cost is sunk and can't be retrieved by doing something you don't want to do anyway. Avoidance of sunk cost traps is a religion for economists, but I find that a single college course in economics actually does little to make people aware of the sunk cost trap. It turns out that exposure to a few basketball-type anecdotes does a lot.

Question 2: If you said that "David is not his friends; he should go to the place he likes," then the SHA of "the law of large numbers" has not been sufficiently salient to you. David has one day's worth of experiences at each; his friends have hundreds. Unless David thinks his friends have kinky tastes he should ignore his own impressions and go to College A. A single college course in statistics increases the likelihood of invoking LLN. Several courses in statistics make LLN considerations almost inevitable.

Question 3: If you said anything other than "turn over the U and turn over the 8," psychologists Wason and Johnson-Laird have shown that you would be in the company of 90% of Oxford students. Unfortunately, you — and they — are wrong. The SHA of the logic of the conditional has not guided your answer. "If P then Q is satisfied by showing that the P is associated with a Q and the not-Q is not associated with a P. A course in logic actually does nothing to make people better able to answer questions such as number 3. Indeed, a Ph.D. in philosophy does nothing to make people better able to apply the logic of the conditional to simple problems like Question 3 or meatier problems of the kind one encounters in everyday life.

Some SHAs apparently are "graceful" in that they are easily inserted into the cognitive toolbox. Others appear to be clunky and don't readily fit. If educators want to improve people's ability to think, they need to know which SHAs are graceful and teachable and which are clunky and hard to teach. An assumption of educators for centuries has been that formal logic improves thinking skills —

meaning that it makes people more intelligent in their everyday lives. But this belief may be mistaken. (Bertrand Russell said, almost surely correctly, that the syllogisms studied by the monks of medieval Europe were as sterile as they were.) But it seems likely that many crucially important SHAs, undoubtedly including some which have been proposed by this year's Edge contributors, are readily taught. Few questions are more important for educators to study than to find out which SHAs are teachable and how they can be taught most easily.

ROB KURZBAN
Psychologist, UPenn; Director, Penn Laboratory for Experimental Evolutionary Psychology (PLEEP); Author, Why Everyone (Else) is a Hypocrite

Externalities

When I go about doing what I do, frequently I affect you as an incidental side effect. In many such cases, I don't have to pay you to compensate for any inadvertent harm done; symmetrically, you frequently don't have to pay me for any inadvertent benefits I've bestowed upon you. The term — externalities — refers to these cases, and they are pervasive and important because, especially in the modern, interconnected world, when I go about pursuing my own goals, I wind up affecting you in any number of different ways.

Externalities can be small or large, negative and positive. When I lived in Santa Barbara, many people with no goal other than working on their tans generated (small, true) positive externalities for passersby, who benefitted from the enhanced scenery. These onlookers didn't have to pay for this improvement to the landscape but, on the same beach, rollerbladers, traveling at high speed and distracted by this particular positive externality, occasionally produced a negative one in the form of a risk of collision for pedestrians trying to enjoy the footpath.

Externalities loom large in the present era, when actions in one place can potentially affect others half a world away. When I manufacture widgets for you to buy, to make them I might, as a side effect of the process, produce waste that makes the people around my factory — and maybe around the world — worse off. As long as I don't have to compensate anyone for polluting their water and air, it's unlikely I'll make much of an effort to stop doing it.

At a smaller, more personal scale, we all impose externalities on one another as we go through our daily lives. I drive to work, increasing the amount of traffic you face. You feel the strange compulsion that infects people in theaters these days to check your text messages on your cell phone during the film, and the bright glow peeking over your shoulder reduces my enjoyment of the movie.

The concept of externalities is useful because it directs our attention to unintended side effects. If you weren't focused on externalities, you might think that the way to reduce traffic congestion was to build more roads. That might work, but another way, and a potentially more efficient way, is to implement policies that force drivers to pay the cost of their negative externalities by charging a price to use roads, particularly at peak times. Congestion charges, such as those implemented in London and Singapore, are designed to do exactly this.

If I have to pay to go into town during rush hour, I might stay home unless my need is pressing.

Keeping externalities firmly in mind also reminds us to be vigilant about the fact that in complex, integrated systems, simple interventions designed to bring about a particular desirable effect will potentially have many more consequences, both positive and negative. Consider, as an example, the history of DDT. When first used, it had its intended effect, which was to reduce the spread of malaria through the control of mosquito populations. However, its use also had two unintended consequences. First, it poisoned a number of animals (including humans) and, second, it selected for resistance among mosquitoes. Subsequently, policies to reduce the use of DDT probably were effective in their goals of preventing these two negative consequences. However, while there is some debate about the details, these policies might themselves have had an important side effect, increasing rates of malaria, carried by the mosquitoes no longer suppressed by DDT.

The key point is that the notion of externalities forces us to think about unintended (positive and negative) effects of actions, an issue that looms larger as the world gets smaller. It highlights the need to balance not only the intended costs and benefits of a given candidate policy, but also the unintended effects of the policy. Further, it helps focus attention on one type of solution to the problems of unintended harms, which is to think about using prices to provide incentives for people and firms to produce more positive externalities and fewer negative ones.

Considering externalities in our daily lives directs our attention to ways in which we harm, albeit inadvertently, the other people around us, and can be used to guide our own decision making, including waiting until after the credits have rolled to check our messages.

DAVID G. MYERS
Social psychologist, Hope College; Author, A Friendly Letter to Skeptics and Atheists

Self-Serving Bias

Most of us have a good reputation with ourselves. That's the gist of a sometimes amusing and frequently perilous phenomenon that social psychologists call self-serving bias.

Accepting more responsibility for success than failure, for good deeds than bad.

In experiments, people readily accept credit when told they have succeeded (attributing such to their ability and effort). Yet they attribute failure to external factors such as bad luck or the problem's "impossibility." When we win at Scrabble it's because of our verbal dexterity. When we lose it's because "I was stuck with a Q but no U."

Self-serving attributions have been observed with athletes (after victory or defeat), students (after high or low exam grades), drivers (after accidents), and managers (after profits and losses). The question, "What have I done to deserve this?" is one we ask of our troubles, not our successes.

The better-than-average phenomenon: How do I love me? Let me count the ways.

It's not just in Lake Wobegon that all the children are above average. In one College Board survey of 829,000 high school seniors, zero percent rated themselves below average in "ability to get along with others," 60 percent rated themselves in the top 10 percent, and 25 percent rated themselves in the top 1 percent. Compared to our average peer, most of us fancy ourselves as more intelligent, better looking, less prejudiced, more ethical, healthier, and likely to live longer — a phenomenon recognized in Freud's joke about the man who told his wife, "If one of us should die, I shall move to Paris."

In everyday life, more than 9 in 10 drivers are above average drivers, or so they presume. In surveys of college faculty, 90 percent or more have rated themselves as superior to their average colleague (which naturally leads to some envy and disgruntlement when one's talents are underappreciated). When husbands and wives estimate what percent of the housework they contribute, or when work team members estimate their contributions, their self-estimates routinely sum to more than 100 percent.

Studies of self-serving bias and its cousins — illusory optimism, self-justification, and ingroup bias — remind us of what literature and religion have taught: pride often goes before a fall. Perceiving ourselves and our groups favorably protects us against depression, buffers stress, and sustains our hopes. But it does so at the cost of marital discord, bargaining impasses, condescending prejudice, national hubris, and war. Being mindful of self-serving bias beckons us not to false modesty, but to a humility that affirms our genuine talents and virtues, and likewise those of others.

JAMES O'DONNELL
Classicist; Provost, Georgetown University; Author, The Ruin of the Roman Empire

Everything Is In Motion

Nothing is more wonderful about human beings than their ability to abstract, infer, calculate, and produce rules, algorithms, and tables that enable them to work marvels. We are the only species that could even imagine taking on mother nature in a fight for control of the world. We may well lose that fight, but it's an amazing spectacle nonetheless.

But nothing is less wonderful about human beings than their ability to refuse to learn from their own discoveries. The edge to the Edge question this year is the implication that we are brilliant and stupid at the same time, capable of inventing wonders and still capable of forgetting what we've done and blundering stupidly on. Our poor cognitive toolkits are always missing a screwdriver when we need it and we're always trying to get a bolt off that wheel with our teeth when a perfectly serviceable wrench is in the kit over there unused.

So as classicist, I'll make my pitch for what is arguably the oldest of our "SHA" concepts, the one that goes back to the senior pre-Socratic philosopher, Heraclitus."You can't step in the same river twice," he said; putting it another way his mantra was "Everything flows." Remembering that everything is in motion — feverish, ceaseless, unbelievably rapid motion — is always hard for us. Vast galaxies dash apart at speeds that seem faster than is physically possible, while the subatomic particles of which we are composed beggar our ability to comprehend large numbers when we try to understand their motion — and at the same time, I lie here, sluglike, inert, trying to muster the energy to change channels, convinced that one day is just like another, reflecting on the deep truth that my idiot cousin will never change, and wondering why my favorite cupcake store has lost its magic touch.

Because we think and move at human scale in time and space, we can deceive ourselves. Pre-Copernican astronomies depended on the self-evident fact that the "fixed stars" orbited around the other in a slow annual dance; and it was an advance in science to declare that "atoms" (in Greek, literally "indivisibles") were the changeless building blocks of matter — until we split them. Edward Gibbon could be puzzled by the fall of the Roman Empire without realizing that its most amazing feature was that it lasted so long. Scientists discover magic disease-fighting compounds only to find that the disease changes faster than they can keep up.

Take it from Heraclitus and put it in your toolkit: change is the law, stability and consistency are illusions, temporary in any case, a heroic achievement of human will and persistence at best. When we want things to stay the same, we'll always wind up playing catch-up. Better to go with the flow.

DOUGLAS T. KENRICK
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Subselves and the Modular Mind

Although it seems obvious that there is a single "you" inside your head, research from several subdisciplines of psychology suggests that this is an illusion. The "you" who makes a seemingly rational and "self-interested" decision to discontinue a relationship with a friend who fails to return your phone calls, borrows thousands of dollars he doesn't pay back, and lets you pick up the tab in the restaurant is not the same "you" who makes very different calculations about a son, about a lover, or about a business partner.

Three decades ago cognitive scientist Colin Martindale advanced the idea that each of us has several subselves, and he connected his idea to emerging ideas in cognitive science. Central to Martindale's thesis were a few fairly simple ideas, such as selective attention, lateral inhibition, state-dependent memory, and cognitive dissociation. Although all the neurons in our brains are firing all the time, we'd never be able to put one foot in front of the other if we were unable to consciously ignore almost all of that hyperabundant parallel processing going on in the background. When you walk down the street there are thousands of stimuli to stimulate your already overtaxed brain — hundreds of different people of different ages with different accents, different hair colors, different clothes, different ways of walking and gesturing, not to mention all the flashing advertisements, curbs to avoid tripping over, and automobiles running yellow lights as you try to cross at the intersection. Hence, attention is highly selective. The nervous system accomplishes some of that selectiveness by relying on the powerful principle of lateral inhibition — in which one group of neurons suppresses the activity of other neurons that might interfere with an important message getting up to the next level of processing. In the eye, lateral inhibition helps us notice potentially dangerous holes in the ground, as the retinal cells stimulated by light areas send messages suppressing the activity of neighboring neurons, producing a perceived bump in brightness and valley of darkness near any edge. Several of these local "edge detector" style mechanisms combine at a higher level to produce "shape detectors" — allowing us to discriminate a "b" from a "d" and a "p." Higher up in the nervous system, several shape detectors combine to allow us to discriminate words, and at a higher level, to discriminate sentences, and at a still higher level, place those sentences in context (thereby discriminating whether the statement "Hi, how are you today?" is a romantic pass or a prelude to a sales pitch).

State dependent memory helps sort out all that incoming information for later use, by categorizing new info according to context — if you learn a stranger's name after drinking a doppio espresso at the local java house, it will be easier to remember that name if you meet again at Starbucks than if the next encounter is at a local pub after a martini. For several months after I returned from Italy, I would start speaking Italian and making expansive hand gestures every time I drank a glass of wine.

At the highest level, Martindale argued that all of those processes of inhibition and dissociation lead us to suffer from an everyday version of dissociative disorder. In other words, we all have a number of executive subselves, and the only way we manage to accomplish anything in life is to allow only one subself to take the conscious driver's seat at any given time.

Martindale developed his notion of executive subselves before modern evolutionary approaches to psychology had become prominent, but the idea becomes especially powerful if you combine Martindale's cognitive model with the idea of *functional modularity*. Building on findings that animals and humans use multiple — and very different — mental processes to learn different things, evolutionarily informed psychologists have suggested that there is not a single information-processing organ inside our heads, but instead multiple systems dedicated to solving different adaptive problems. Thus, instead of having a random and idiosyncratic assortment of subselves inside my head, different from the assortment inside your head, each of us has a set of functional subselves — one dedicated to getting along with our friends, one dedicated to self-protection (protecting us from the bad guys), one dedicated to winning status, another to finding mates, a distinct one for keeping mates (which is a very different set of problems, as some of us have learned), and yet another to caring for our offspring.

Thinking of the mind as composed of several functionally independent adaptive subselves helps us understand many seeming inconsistencies and irrationalities in human behavior, such as why a decision that seems "rational" when it involves one's son seems eminently irrational when it involves a friend or a lover, for example.

SAMUEL ARBESMAN
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The Copernican Principle

The scientist Nicolaus Copernicus recognized that Earth is not in any particularly privileged position in the solar system. This elegant fact can be extended to encompass a powerful idea, known as the Copernican Principle, that we are not in a special or favorable place of any sort. By looking at the world through the eyes of this principle, we can remove certain blinders and preconceptions about ourselves and re-examine our relationship with the universe.

The Copernican Principle can be used in the traditional spatial sense, providing awareness of our mediocre place in the galaxy, and our galaxy's place in the universe. We now recognize that our solar system, once thought to be the center of the galaxy, is actually in the suburban portions of the Milky Way. And the Copernican Principle helps guide our understanding of the expanding universe, allowing us to see that anywhere in the cosmos one would also view other galaxies moving away at rapid speeds, just as we see here on Earth. We are not anywhere special.

The Copernican Principle has also been extended to our temporal position by astrophysicist J. Richard Gott to help provide estimates for lifetimes of events, independent of additional information. As Gott elaborated, other than the fact that we are intelligent observers, there is no reason to believe we are in any way specially located in time. It allows us to quantify our uncertainty and recognize that we are often neither at the beginning of things, nor at the end. This allowed Gott to estimate correctly when the Berlin Wall would fall, and has even provided meaningful numbers on the lifetime of humanity.

This principle can even anchor our location within the many orders of magnitude of our world: we are far smaller than most of the cosmos, far larger than most chemistry, far slower than much that occurs at subatomic scales, and far faster than geological and evolutionary processes. Through this principle, we are compelled to study successively larger and smaller orders of magnitude of our world, because we need not assume that everything interesting is at the same scale as ourselves.

And yet, despite this regimented approach to our mediocrity, we need not have cause for despair: as far as we know, we're the only species that can actually recognize its place in the universe. The paradox of the Copernican Principle is that, by properly understanding our place, even if it be rather humbling, we can only then truly understand our surroundings. And by being able to do that, we don't seem so small or insignificant after all.

MICHAEL SHERMER
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Think Bottom Up, Not Top Down

One of the most general shorthand abstractions that if adopted would improve the cognitive toolkit of humanity is to *think bottom up, not top down*. Almost everything important that happens in both nature and in society happens from the bottom up, not the top down. Water is a bottom up, self-organized emergent property of hydrogen and oxygen. Life is a bottom up, self-organized emergent property of organic molecules that coalesced into protein chains through nothing more than the input of energy into the system of Earth's early environment. The complex eukaryotic cells of which we are made are themselves the product of much simpler prokaryotic cells that merged together from the bottom up in a process of symbiosis that happens naturally when genomes are merged between two organisms. Evolution itself is a bottom up process of organisms just trying to make a living and get their genes into the next generation; out of that simple process emerges the diverse array of complex life we see today.

Analogously, an economy is a self-organized bottom up emergent process of people just trying to make a living and get their genes into the next generation, and out of that simple process emerges the diverse array of products and services available to us today. Likewise, democracy is a bottom up emergent political system specifically designed to displace top down kingdoms, theocracies, and dictatorships. Economic and political systems are the result of human action, not human design.

Most people, however, see the world from the top down instead of the bottom up. The reason is that our brains evolved to find design in the world, and our experience with designed objects is that they have a designer (us) who we consider to be intelligent. So most people intuitively sense that anything in nature that looks designed must be so from the top down, not the bottom up. Bottom up reasoning is counter intuitive. This is why so many people believe that life was designed from the top down, and why so many think that economies must be designed and that countries should be ruled from the top down.

One way to get people to adopt the bottom up shorthand abstraction as a cognitive tool is to find examples that we know evolved from the bottom up and were not designed from the top down. Language is an example. No one designed English to look and sound like it does today (in which teenagers use the word "like" every sentence). From Chaucer's time forward our language has evolved from the bottom up by native speakers adopting their own nuanced styles to fit their unique lives and cultures. Likewise, the history of knowledge production has been one long trajectory from top down to bottom up. From ancient priests and medieval scholars to academic professors and university publishers, the democratization of knowledge has struggled alongside the democratization of societies to free itself from the bondage of top down control. Compare the magisterial multi-volume encyclopedias of centuries past that held sway as the final authority for reliable knowledge, now displaced by individual encyclopedists employing wiki tools and making everyone their own expert.

Which is why the Internet is the ultimate bottom up self-organized emergent property of millions of computer users exchanging data across servers, and although there are some top-down controls involved—just as there are some in mostly bottom-up economic and political systems—the strength of digital freedom derives from the fact that no one is in charge. For the past 500 years humanity has gradually but ineluctably transitioned from top down to bottom up systems, for the simple reason that both information and people want to be free.

IRENE PEPPERBERG
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Fixed-Action Patterns: Using The Study Of Animal Instinct As A Metaphor For Human Behavior

The concept comes from early ethologists, scientists such as Oskar Heinroth and Konrad Lorenz, who defined it as an instinctive response — usually a series of predictable behavior patterns — that would occur reliably in the presence of a specific bit of input, often called a "releaser". FAPs, as they were known, were thought to be devoid of cognitive processing. As it turned out, FAPs were not nearly as fixed as the ethologists believed, but the concept has remained as part of the historical literature, as a way of scientifically describing what in the vernacular might be called "knee-jerk responses". The concept of a FAP, despite its simplicity, might prove quite valuable as a metaphorical means to study and change human behavior.

If we look into the literature on FAPs, we see that many such instinctive responses were actually learned, based on the most elementary of signals. For example, the newly-hatched herring gull chicks' supposed FAP of hitting the red spot on its parents' beak for food was far more complex: Hailman demonstrated that what was innate was only a tendency to peck at an oscillating object in the field of view. The ability to target the beak, and the red spot on the beak, though a pattern that developed steadily and fairly quickly, was acquired experientially. Clearly, certain sensitivities must be innate, but the specifics of their development into various behavioral acts likely depend on how the organism interacts with its surroundings and what feedback it receives. The system need not, especially for humans, be simply a matter of conditioning Response R to Stimulus S, but rather of evaluating as much input as possible.

The relevance is that, if we wish to understand why as humans we often act in certain predictable ways, and particularly if there is a desire or need to change these behavioral responses, we can remember our animal heritage and look for the possible releasers that appear to stimulate our FAPs. Might the FAP actually be a response learned over time, initially with respect to something even more basic than we expect? The consequences could affect aspects of our lives from our social interactions to what we see as our quick decision-making processes in our professional lives. Given an understanding of our FAPs, and those of the other individuals with whom we interact, we — as humans with cognitive processing powers — could begin to re-think our behavior patterns.

TERRENCE SEJNOWSKI
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Powers of 10

An important part of my scientific toolkit is how to think about things in the world over a wide range of magnitudes and time scales. This involves first understanding powers of ten; second, visualizing data over a wide range of magnitudes on graphs using logarithmic scales; and third, appreciating the meaning of magnitude scales such as the decibel (dB) scale for the loudness of sounds and the Richter scale for the strengths of earthquakes.

This toolkit ought to be a part of everyone thinking, but sadly I have found that even well educated nonscientists are flummoxed by log scales and can only vaguely grasp the difference between an earthquake on a Richter scale of 6 and 8 (a thousand times more energy released). Thinking in powers of 10 is such a basic skill that it ought to be taught along with integers in elementary school.

Scaling laws are found throughout nature. Galileo in 1638 pointed out that large animals have disproportionately thicker leg bones than small animals to support the weight of the animal. The heavier the animal, the more stout their legs need to be. This leads to a prediction that the thickness of the leg bone should scale with the 3/2 power of the length of the bone.

Another interesting scaling law is that between the volume of the cortical white matter, corresponding to the long-distance wires between cortical areas, and the gray matter, where the computing takes place. For mammals ranging over 5 orders of magnitude in weight from a pygmy shrew to an elephant, the white matter scales as the 5/4 power of the gray matter. This means that the bigger the brain, the disproportionately larger the fraction of the volume taken up by cortical wiring used for communication compared to the computing machinery.

I am concerned that students I teach have lost the art of estimating with powers of 10. When I was a student I used a slide rule to compute, but students now use calculators. A slide rule lets you carry out a long series of multiplications and divisions by adding and subtracting the logs of numbers; but at the end you need to figure out the powers of 10 by making a rough estimate. A calculator keeps track of this for you, but if you make a mistake in keying in a number you can be off by 10 orders of magnitude, which happens to students who don't have a feeling for orders of magnitude.

A final reason why familiarity with powers of 10 would improve everyone's cognitive toolkit is that it helps us comprehend our life and the world in which we live:

How many seconds are there in a lifetime? **10^9 sec**

A second is an arbitrary time unit, but one that is based on our experience. Our visual system is bombarded by snapshots at a rate of around 3 per second caused by rapid eye movements called saccades. Athletes often win or lose a race by a fraction of a second. If you earned a dollar for every second in your life you would be a billionaire. However, a second can feel like a minute in front of an audience and a quiet weekend can disappear in a flash. As a child, a summer seemed to last forever, but as an adult, summer is over almost before it begins. William James speculated that subjective time was measured in novel experiences, which become rarer as you get older. Perhaps life is lived on a logarithmic time scale, compressed toward the end.

What is the GDP of the world? **$\$10^{14}$**

A billion dollars was once worth a lot, but there is now a long list of multibillionaires. The US government recently stimulated the world economy by loaning several trillion dollars to banks. It is difficult to grasp how much a trillion dollars ($10[12]) represents, but several clever videos on YouTube (key words: trillion dollars) illustrate this with physical comparisons (a giant pile of $100 bills) and what you can buy with it (10 years of US response to 9/11). When you start thinking about the world economy, the trillions of dollars add up. A trillion here, a trillion there, pretty soon your talking about real money. But so far there aren't any trillionaires.

How many synapses are there in the brain? **10^{15}**

Two neurons can communicate with each other at a synapse, which is the computational unit in the brain. The typical cortical synapse is less than a micron in diameter (10[-6] meter), near the resolution limit of the light microscope. If the economy of the world is a stretch for us to contemplate, thinking about all the synapses in your head is mind boggling. If I had a dollar for every synapse in your brain I could support the current economy of the world for 10 years. Cortical neurons on average fire once a second, which implies a bandwidth of around 10[15] bits per second, greater than the total bandwidth of the internet backbone.

How many seconds will the sun shine? **10^{17} sec**

Our sun has shined for billions of years and will continue to shine for billions more. The universe seems to be standing still during our lifetime, but on longer time scales the universe is filled with events of enormous violence. The spatial scales are also immense. Our space-time trajectory is a very tiny part of the universe, but we can at least attach powers of 10 to it and put it into perspective.

JUAN ENRIQUEZ
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Life Code

Everyone is familiar with Digital Code, or the shorthand IT. Soon all may be discoursing about Life Code…

It took a while to learn how to read life code; Mendel's initial cookbook was largely ignored. Darwin knew but refused, for decades, to publish such controversial material. Even a term that now lies within every cheesy PR description of a firm, on jeans, and pop psych books…DNA… was largely ignored after its 1953 discovery. For close to a decade very few cited Watson and Crick. They were not even nominated, by anyone, for a Nobel till after 1960, despite the discovery of how life code is written.

First ignorance then controversy continued dogging life code as humanity moved from reading it to copying it. Tadpoles were cloned in 1952, but few focused until Dolly the sheep begat wonder, consternation, and fear. Much the same occurred with in vitro fertilization and Louise Brown, a breakthrough that got the Nobel in 2010, a mere 37 years after the first birth. Copying genes and dozens of species, leading to hundreds of thousands of almost identical animals is now commonplace. The latest controversy is no longer how do we deal with rare clones but should we eat them.

Much has occurred as we learned to read and copy life code, but there is still little understanding for what has occurred recently. But it is this third stage of life code, writing and re-writing, is by far the most important and profound change.

Few realize, so far, that life code is spreading across industries, economies, countries, and cultures. As we begin to rewrite existing life, strange things evolve. Bacteria can be programmed to solve Sudoku puzzles. Viruses begin to create electronic circuits. As we write life from scratch, Venter, Smith et al. partner with Exxon to try to change the world's energy markets. Designer genes introduced by retroviruses, organs built from scratch, the first synthetic cells further examples of massive change.

We see more and more products, derived from life code, changing fields as diverse as energy, textiles, chemicals, IT, vaccines, medicines, space exploration, agriculture, fashion, finance, and real estate. And gradually, "life code" a concept that only got 559 Goggle hits in 2000, and fewer than 50,000 in 2009, becomes a part of the everyday public discourse.

Many of the Fortune 500 within the next decade will be companies based on the understanding and application of life code, much as has occurred over the past decades with digital code leading to the likes of Digital, Lotus, HP, IBM, Microsoft, Amazon, Google, and Facebook.

But this is just the beginning. The real change will become apparent as we re-write life code to morph the human species. We are already transitioning from a humanoid that is shaped by and shapes its own environment into a Homo evolutis, a species that directly and deliberately designs and shapes its own evolution and that of other species…

CARLO ROVELLI
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The Uselessness of Certainty

There is a widely used notion that does plenty of damage: the notion of "scientifically proven". Nearly an oxymoron. The very foundation of science is to keep the door open to doubt. Precisely because we keep questioning everything, especially our own premises, we are always ready to improve our knowledge. Therefore a good scientist is never 'certain'. Lack of certainty is precisely what makes conclusions more reliable than the conclusions of those who are certain: because the good scientist will be ready to shift to a different point of view if better elements of evidence, or novel arguments emerge. Therefore certainty is not only something of no use, but is in fact damaging, if we value reliability.

Failure to appreciate the value of the lack of certainty is at the origin of much silliness in our society. Are we sure that the Earth is going to keep heating up, if we do not do anything? Are we sure of the details of the current theory of evolution? Are we sure that modern medicine is always a better strategy than traditional ones? No we are not, in none of these cases. But if from this lack of certainty we jump to the conviction that we better not care about global heating, that there is no evolution and the world was created six thousand years ago, or that traditional medicine must be more effective that the modern medicine, well, we are simply stupid. Still, many people do these silly inferences. Because the lack of certainty is perceived as a sign of weakness, instead of being what it is: the first source of our knowledge.

Every knowledge, even the most solid, carries a margin of uncertainty. (I am very sure about my own name ... but what if I just hit my head and got momentarily confused?) Knowledge itself is probabilistic in nature, a notion emphasized by some currents of philosophical pragmatism. Better understanding of the meaning of probability, and especially realizing that we never have, nor need, 'scientifically proven' facts, but only a sufficiently high degree of probability, in order to take decisions and act, would improve everybody' conceptual toolkit.

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Constraint Satisfaction

The concept of constraint satisfaction is crucial for understanding and improving human reasoning and decision making. A "constraint" is a condition that must be taken into account when solving a problem or making a decision, and "constraint satisfaction" is the process of meeting the relevant constraints. The key idea is that often there are only a few ways to satisfy a full set of constraints simultaneously.

For example, when moving into a new house, my wife and I had to decide how to arrange the furniture in the bedroom. We had an old headboard, which was so rickety that it had to be leaned against a wall. This requirement was a constraint on the positioning of the headboard. The other pieces of furniture also had requirements (constraints) on where they could be placed. Specifically, we had two small end tables that had to be next to either side of the headboard; a chair that needed to be somewhere in the room; a reading lamp that needed to be next to the chair; and an old sofa that was missing one of its rear legs, and hence rested on a couple of books — and we wanted to position it so that people couldn't see the books. Here was the remarkable fact about our exercises in interior design: Virtually always, as soon as we selected the wall for the headboard, bang! The entire configuration of the room was determined. There was only one other wall large enough for the sofa, which in turn left only one space for the chair and lamp.

In general, the more constraints, the fewer the possible ways of satisfying them simultaneously. And this is especially the case when there are many "strong" constraints. A strong constraint is like the locations of the end tables: there are very few ways to satisfy them. In contrast, a "weak" constraint, such as the location of the headboard, can be satisfied in many ways (many positions along different walls would work).

What happens when some constraints are incompatible with others? For instance, say that you live far from a gas station and so you want to buy an electric automobile — but you don't have enough money to buy one. Not all constraints are equal in importance, and as long as the most important ones are satisfied "well enough," you may have reached a satisfactory solution. For example, although an optimal solution to your transportation needs might have been an electric car, a hybrid that gets excellent gas mileage might be good enough.

In addition, once you begin the constraint satisfaction process, you can make it more effective by seeking out additional constraints. For example, when you are deciding what car to buy, you might start with the constraints of (a) your budget and (b) your desire to avoid going to a filling station. You then might consider the size of car needed for your purposes, length of the warrantee, and styling. You may be willing to make tradeoffs, for example, by satisfying some constraints very well (such as mileage) but just barely satisfying others (e.g., styling). Even so, the mere fact of including additional constraints at all could be the deciding factor.

Constraint satisfaction is pervasive. For example:

• This is how detectives — from Sherlock Holmes to the Mentalist — crack their cases, treating each clue as a constraint and looking for a solution that satisfies them all.

• This is what dating services strive to do — find the clients' constraints, identify which constraints are most important to him or her, and then see which of the available candidates best satisfies the constraints.

• This is what you go through when finding a new place to live, weighing the relative importance of constraints such as the size, price, location, and type of neighborhood.

• And this is what you are do when you get dressed in the morning: you choose clothes that "go with each other" (both in color and style).

Constraint satisfaction is pervasive in part because it does not require "perfect" solutions. It's up to you to decide what the most important constraints are, and just how many of the constraints in general must be satisfied (and how well they must be satisfied). Moreover, constraint satisfaction need not be linear: You can appreciate the entire set of constraints at the same time, throwing them into your "mental stewpot" and letting them simmer. And this process need not be conscious. "Mulling it over" seems to consist of engaging in unconscious constraint satisfaction.

Finally, much creativity emerges from constraint satisfaction. Many new recipes were created when chefs discovered that only specific ingredients were available — and they thus were either forced to substitute different ingredients or to come up with a new "solution" (dish) to be satisfied. Creativity can also emerge when you decide to change, exclude, or add a constraint. For example, Einstein had one of his major breakthroughs when he realized that time need not pass at a constant rate. Perhaps paradoxically, adding constraints can actually enhance creativity — if a task is too open or unstructured, it may be so unconstrained that it is difficult to devise any solution.

DANIEL C. DENNETT
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Cycles

Everybody knows about the familiar large-scale cycles of nature: day follows night follows day summer-fall-winter-spring-summer-fall-winter-spring, the water cycle of evaporation and precipitation that refills our lakes, scours our rivers and restores the water supply of every living thing on the planet. But not everybody appreciates how cycles — every spatial and temporal scale from the atomic to the astronomic — are quite literally the hidden spinning motors that power all the wonderful phenomena of nature.

Nikolaus Otto built and sold the first internal combustion gasoline engine in 1861, and Rudolf Diesel built his engine in 1897, two brilliant inventions that changed the world. Each exploits a cycle, the four-stroke Otto cycle or the two-stroke Diesel cycle, that accomplishes some work and then restores the system to the original position so that it is ready to accomplish some more work. The details of these cycles are ingenious, and they have been discovered and optimized by an R & D cycle of invention that is several centuries old. An even more elegant, micro-miniaturized engine is the Krebs cycle, discovered in 1937 by Hans Krebs, but invented over millions of years of evolution at the dawn of life. It is the eight-stroke chemical reaction that turns fuel — into energy in the process of metabolism that is essential to all life, from bacteria to redwood trees.

Biochemical cycles like the Krebs cycle are responsible for all the motion, growth, self-repair, and reproduction in the living world, wheels within wheels within wheels, a clockwork with trillions of moving parts, and each clock has to be rewound, restored to step one so that it can do its duty again. All of these have been optimized by the grand Darwinian cycle of reproduction, generation after generation, picking up fortuitous improvements over the eons.

At a completely different scale, our ancestors discovered the efficacy of cycles in one of the great advances of human prehistory: the role of repetition in manufacture. Take a stick and rub it with a stone and almost nothing happens — few scratches are the only visible sign of change. Rub it a hundred times and there is still nothing much to see. But rub it just so, for a few thousand times, and you can turn it into an uncannily straight arrow shaft. By the accumulation of imperceptible increments, the cyclical process creates something altogether new. The foresight and self-control required for such projects was itself a novelty, a vast improvement over the repetitive but largely instinctual and mindless building and shaping processes of other animals. And that novelty was, of course, itself a product of the Darwinian cycle, enhanced eventually by the swifter cycle of cultural evolution, in which the reproduction of the technique wasn't passed on to offspring through the genes but transmitted among non-kin conspecifics who picked up the trick of imitation.

The first ancestor who polished a stone into a handsomely symmetrical hand axe must have looked pretty stupid in the process. There he sat, rubbing away for hours on end, to no apparent effect. But hidden in the interstices of all the mindless repetition was a process of gradual refinement that was well nigh invisible to the naked eye designed by evolution to detect changes occurring at a much faster tempo. The same appearance of futility has occasionally misled sophisticated biologists. In his elegant book, *Wetware*, the molecular and cell biologist Dennis Bray describes cycles in the nervous system:

In a typical signaling pathway, proteins are continually being modified and demodified. Kinases and phosphates work ceaselessly like ants in a nest, adding phosphate groups to proteins and removing them again. It seems a pointless exercise, especially when you consider that each cycle of addition and removal costs the cell one molecule of — one unit of precious energy. Indeed, cyclic reactions of this kind were initially labeled "futile." But the adjective is misleading. The addition of phosphate groups to proteins is the single most common reaction in cells and underpins a large proportion of the computations they perform. Far from being futile, this cyclic reaction provides the cell with an essential resource: a flexible and rapidly tunable device.

The word "computations" is aptly chosen, for it turns out that all the "magic" of cognition depends, just as life itself does, on cycles within cycles of recurrent, re-entrant, reflexive information-transformation processes from the biochemical scale within the neuron to the whole brain sleep cycle, waves of cerebral activity and recovery revealed by EEGs. Computer programmers have been exploring the space of possible computations for less than a century, but their harvest of invention and discovery so far includes millions of loops within loops within loops. The secret ingredient of improvement is always the same: practice, practice, practice.

It is useful to remember that *Darwinian* evolution is just one kind of accumulative, refining cycle. There are plenty of others. The problem of the origin of life can be made to look insoluble ("irreducibly complex") if one argues, as Intelligent Design advocates have done, that "since evolution by natural selection depends on reproduction," there cannot be a Darwinian solution to the problem of how the first living, reproducing thing came to exist. It was surely breathtakingly complicated, beautifully designed — must have been a miracle.

If we lapse into thinking of the pre-biotic, pre-reproductive world as a sort of featureless chaos of chemicals (like the scattered parts of the notorious jetliner assembled by a windstorm), the problem does look daunting and worse, but if we remind ourselves that the key process in evolution is cyclical repetition (of which genetic replication is just one highly refined and optimized instance), we can begin to see our way to turning the mystery into a puzzle: How did all those seasonal cycles, water cycles, geological cycles, and chemical cycles, spinning for millions of years, gradually accumulate the preconditions for giving birth to the biological cycles? Probably the first thousand "tries" were futile, near misses. But as Cole Porter says in his most sensual song, see what happens if you "do it again, and again, and again."

A good rule of thumb, then, when confronting the apparent magic of the world of life and mind is: look for the cycles that are doing all the hard work.

JENNIFER JACQUET
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Keystone Consumer

When it comes to common resources, a failure to cooperate is a failure to control consumption. In Hardin's classic tragedy, everyone overconsumes and equally contributes to the detriment of the commons. But a relative few can also ruin a resource for the rest of us.

Biologists are familiar with the term 'keystone species', coined in 1969 after Bob Paine's intertidal exclusion experiments. Paine found that by removing the few five-limbed carnivores, Pisaster ochraceus, from the seashore, he could cause an overabundance of its prey, mussels, and a sharp decline in diversity. Without seastars, mussels outcompeted sponges. No sponges, no nudibranchs. Anenomes were also starved out because they eat what the seastars dislodge. Pisaster was the keystone that kept the intertidal community together. Without it, there were only mussels, mussels, mussels. The term keystone species, inspired by the purple seastar, refers to a species that has a disproportionate effect relative to its abundance.

In human ecology, I imagine diseases and parasites play a similar role to Pisaster in Paine's experiment. Remove disease (and increase food) and Homo sapiens takeover. Humans inevitably restructure their environment. But not all human beings consume equally. While a keystone species refers to a specific species that structures an ecosystem, I consider keystone consumers to be a specific group of humans that structures a market for a particular resource. Intense demand by a few individuals can bring flora and fauna to the brink.

There are keystone consumers in the markets for caviar, slipper orchids, tiger penises, plutonium, pet primates, diamonds, antibiotics, Hummers, and seahorses. Niche markets for frog legs in pockets of the U.S., Europe, and Asia are depleting frog populations in Indonesia, Ecuador, and Brazil. Seafood lovers in high-end restaurants are causing stocks of long-lived fish species like Orange roughy or toothfish in Antarctica to crash. The desire for shark fin soup by wealthy Chinese consumers has led to the collapse of several shark species.

One in every four mammals (1,141 of the 5,487 mammals on Earth) is threatened with extinction. At least 76 mammals have become extinct since the 16th century, many, like the Tasmanian tiger, the great auk, and the Steller sea cow, due to hunting by a relatively small group. It is possible for a small minority of humans to precipitate the disappearance of an entire species.

The consumption of non-living resources is also imbalanced. The 15% of the world's population that lives in North America, Western Europe, Japan and Australia consumes 32 times more resources, like fossil fuels and metals, and produces 32 times more pollution than the developing world, where the remaining 85% of humans live. City-dwellers consume more than people living in the countryside. A recent study determined the ecological footprint for an average resident of Vancouver, British Columbia was 13 times higher than his suburban/rural counterpart.

Developed nations, urbanites, ivory collectors: the keystone consumer depends on the resource in question. In the case of water, agriculture accounts for 80% of use in the U.S., i.e. large-scale farms are the keystone consumers. So why do many conservation efforts focus on households rather than water efficiency on farms? The keystone consumer concept helps focus conservation efforts where returns on investments are highest.

Like keystone species, keystone consumers also have a disproportionate impact relative to their abundance. Biologists identify keystone species as conservation priorities because their disappearance could cause the loss of many other species. In the marketplace, keystone consumers should be priorities because their disappearance could lead to the recovery of the resource. Humans should protect keystone species and curb keystone consumption. The lives of others depend on it.

JARON LANIER
Musician, Computer Scientist; Pioneer of Virtural Reality; Author, You Are Not A Gadget: A Manifesto

Cumulative Error

It is the stuff of children's games. In the game of "telephone," a secret message is whispered from child to child until it is announced out loud by the final recipient. To the delight of all, the message is typically transformed into something new and bizarre, no matter the sincerity and care given to each retelling.

Humor seems to be the brain's way of motivating itself — through pleasure — to notice disparities and cleavages in its sense of the world. In the telephone game we find glee in the violation of expectation; what we think should be fixed turns out to be fluid.

When brains get something wrong commonly enough that noticing the failure becomes the fulcrum of a simple child's game, then you know there's a hitch in human cognition worth worrying about. Somehow, we expect information to be Platonic and faithful to its origin, no matter what history might have corrupted it.

The illusion of Platonic information is confounding because it can easily defeat our natural skeptical impulses. If a child in the sequence sniffs that the message seems too weird to be authentic, she can compare notes most easily with the children closest to her, who received the message just before she did. She might discover some small variation, but mostly the information will appear to be confirmed, and she will find an apparent verification of a falsity.

Another delightful pastime is over-transforming an information artifact through digital algorithms that are useful if used sparingly, until it turns into something quite strange. For instance, you can use one of the online machine translation services to translate a phrase through a ring of languages back to the original and see what you get.

The phrase, "The edge of knowledge motivates intriguing online discussions" transforms into "Online discussions in order to stimulate an attractive national knowledge" in four steps on Google's current translator. (English->German->Hebrew->Simplified Chinese->English)

We find this sort of thing funny, just like children playing "telephone," as well we should, because it sparks our recollection that our brains have unrealistic expectations of information transformation.

While information technology can reveal truths, it can also create stronger illusions than we are used to. For instance, sensors all over the world, connected through cloud computing, can reveal urgent patterns of change in climate data. But endless chains of online retelling also create an illusion for masses of people that the original data is a hoax.

The illusion of Platonic information plagues finance. Financial instruments are becoming multilevel derivatives of the real actions on the ground that finance is ultimately supposed to motivate and optimize. The reason to finance the purchasing of a house ought to be at least in part to get the house purchased. But an empire of specialists and giant growths of cloud computers showed, in the run up to the Great Recession, that it is possible for sufficiently complex financial instruments to become completely disconnected from their ultimate purpose.

In the case of complex financial instruments, the role of each child in the telephone game does not correspond to a horizontal series of stations that relay a message, but a vertical series of transformations that are no more reliable. Transactions are stacked on top of each other. Each transaction is based on a formula that transforms the data of the transactions beneath it on the stack. A transaction might be based on the possibility that a prediction of a prediction will have been improperly predicted.

The illusion of Platonic information reappears as a belief that a higher-level representation must always be better. Each time a transaction is gauged to an assessment of the risk of another transaction, however, even if it is in a vertical structure, at least a little bit of error and artifact is injected. By the time a few layers have been compounded, the information becomes bizarre.

Unfortunately, the feedback loop that determines whether a transaction is a success or not is based only on its interactions with its immediate neighbors in the phantasmagorical abstract playground of finance. So a transaction can make money based on how it interacted with the other transactions it referenced directly, while having no relationship to the real events on the ground that all the transactions are ultimately rooted in. This is just like the child trying to figure out if a message has been corrupted only by talking to her neighbors.

In principle, the Internet can make it possible to connect people directly to information sources, to avoid the illusions of the game of telephone. Indeed this happens. Millions of people had a remarkable direct experience of the Mars rovers.

The economy of the Internet as it has evolved incentivizes aggregators, however. Thus we all take seats in a new game of telephone, in which you tell the blogger who tells the aggregator of blogs, who tells the social network, who tells the advertiser, who tells the political action committee, and so on. Each station along the way finds that it is making sense, because it has the limited scope of the skeptical girl in the circle, and yet the whole systems becomes infused with a degree of nonsense.

A joke isn't funny anymore if it's repeated too much. It is urgent for the cognitive fallacy of Platonic information to be universally acknowledged, and for information systems to be designed to reduce cumulative error.

FRANK WILCZEK
Physicist, MIT; Recipient, 2004 Nobel Prize in Physics; Author, The Lightness of Being

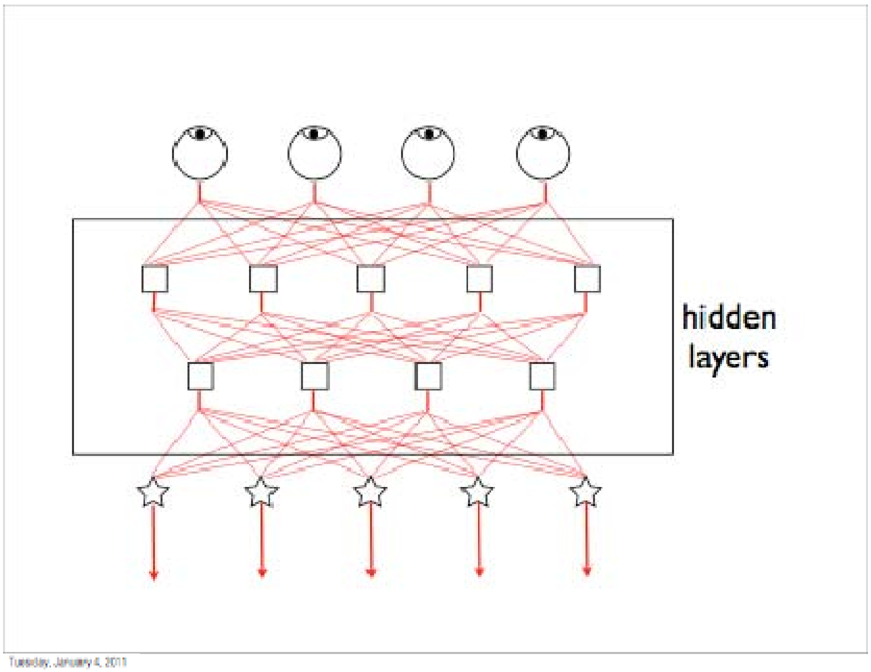
Hidden Layers

When I first took up the piano, merely hitting each note required my concentrated attention. With practice, however, I began to work in phrases and chords. Eventually I was able to produce much better music with much less conscious effort.

Evidently, something powerful had happened in my brain.

That sort of experience is very common, of course. Something similar occurs whenever we learn a new language, master a new game, or get comfortable in a new environment. It seems very likely that a common mechanism is involvedf. I think it's possible to identify, in broad terms, what that mechanism is: We create *hidden layers.*

The scientific concept of a hidden layer arose from the study of neural networks. Here a little picture is worth a thousand words:



In this picture, the flow of information runs from top to bottom. Sensory neurons — the eyeballs at the top — take input from the external world and encode it into a convenient form (which is typically electrical pulse trains for biological neurons, and numerical data for the computer "neurons" of artificial neural networks). They distribute this encoded information to other neurons, in the next layer below. Effector neurons — the stars at the bottom — send their signals to output devices (which are typically muscles for biological neurons, and computer terminals for artificial neurons). In between are neurons that neither see nor act upon the outside world directly. These inter-neurons communicate only with other neurons. They are the hidden layers.

The earliest artificial neural networks lacked hidden layers. Their output was, therefore, a relatively simple function of their input. Those two-layer, input-output "perceptrons" had crippling limitations. For example, there is no way to design a perceptron that, faced with pictures of a few black circles on a white background, counts the number of circles. It took until the 1980s, decades after the pioneering work, for people to realize that including even one or two hidden layers could vastly enhance the capabilities of their neural networks. Nowadays such multilayer networks are used, for example, to distill patterns from the explosions of particles that emerge from high-energy collisions at the Large Hadron Collider. They do it much faster and more reliably than humans possibly could.

David Hubel and Torstein Wiesel were awarded the 1981 Nobel Prize in physiology or medicine for figuring out what neurons in the visual cortex are doing. They showed that successive hidden layers first extract features of visual scenes that are likely to be meaningful (for example, sharp changes in brightness or color, indicating the boundaries of objects), and then assemble them into meaningful wholes (the underlying objects).

In every moment of our adult waking life, we translate raw patterns of photons impacting our retinas — photons arriving every which way from a jumble of unsorted sources, and projected onto a two-dimensional surface — into the orderly, three-dimensional visual world we experience. Because it involves no conscious effort, we tend to take that everyday miracle for granted. But when engineers tried to duplicate it, in robotic vision, they got a hard lesson in humility. Robotic vision remains today, by human standards, primitive. Hubel and Wiesel exhibited the architecture of Nature's solution. It is the architecture of hidden layers.

Hidden layers embody, in a concrete physical form, the fashionable but rather vague and abstract idea of *emergence*. Each hidden layer neuron has a template. It becomes activated, and sends signals of its own to the next layer, precisely when the pattern of information it's receiving from the preceding layer matches (within some tolerance) that template. But this is just to say, in precision-enabling jargon, that the neuron defines, and thus creates, a new *emergent* concept.

In thinking about hidden layers, it's important to distinguish between the routine efficiency and power of a good network, once that network has been set up, and the difficult issue of how to set it up in the first place. That difference is reflected in the difference between playing the piano, say, or riding a bicycle, or swimming, once you've learned (easy), and learning to do those things in the first place (hard). Understanding exactly how new hidden layers get laid down in neural circuitry is a great unsolved problem of science. I'm tempted to say it's the greatest.

Liberated from its origin in neural networks, the concept of hidden layers becomes a versatile metaphor, with genuine explanatory power. For example, in my own work in physics I've noticed many times the impact of inventing names for things. When Murray Gell-Mann invented "quarks", he was giving a name to a paradoxical pattern of facts. Once that pattern was recognized, physicists faced the challenge of refining it into something mathematically precise and consistent; but identifying the problem was the crucial step toward solving it! Similar, when I invented "anyons" I knew I had put my finger on a coherent set of ideas, but I hardly anticipated how wonderfully those ideas would evolve and be embodied in reality. In cases like this, names create new nodes in hidden layers of thought.

I'm convinced that the general concept of hidden layers captures deep aspects of the way minds — whether human, animal, or alien; past, present, or future — do their work. Minds mobilize useful concepts by embodying them in a specific way, namely as features recognized by hidden layers. And isn't it pretty that "hidden layers" is itself a most useful concept, worthy to be included in hidden layers everywhere?

LISA RANDALL
Physicist, Harvard University; Author, Warped Passages

"Science"

The word "science" itself might be the best answer to this year's Edge question. The idea that we can systematically understand certain aspects of the world and make predictions based on what we've learned — while appreciating and categorizing the extent and limitations of what we know — plays a big role in how we think. Many words that summarize the nature of science such as "cause and effect," "predictions," and " experiments," as well as words that describe probabilistic results such as "mean," "median," "standard deviation," and the notion of "probability" itself help us understand more specifically what this means and how to interpret the world and behavior within it.

"Effective theory" is one of the more important notions within and outside of science. The idea is to determine what you can actually measure and decide — given the precision and accuracy of your measuring tools — and to find a theory appropriate to those measurable quantities. The theory that works might not be the ultimate truth—but it's as close an approximation to the truth as you need and is also the limit to what you can test at any given time. People can reasonably disagree on what lies beyond the effective theory, but in a domain where we have tested and confirmed it, we understand the theory to the degree that it's been tested.

An example is Newton's Laws, which work as well as we will ever need when they describe what happens to a ball when we throw it. Even though we now know quantum mechanics is ultimately at play, it has no visible consequences on the trajectory of the ball. Newton's Laws are part of an effective theory that is ultimately subsumed into quantum mechanics. Yet Newton's Laws remain practical and true in their domain of validity. It's similar to the logic you apply when you look at a map. You decide the scale appropriate to your journey — are you traveling across the country, going upstate, or looking for the nearest grocery store — and use the map scale appropriate to your question.

Terms that refer to specific scientific results can be efficient at times but they can also be misleading when taken out of context and not supported by true scientific investigation. But the scientific methods for seeking, testing, and identifying answers and understanding the limitations of what we have investigated will always be reliable ways of acquiring knowledge. A better understanding of the robustness and limitations of what science establishes, as well as probabilistic results and predictions, could make the world a better place.

DOUGLAS RUSHKOFF
Media theorist, Author of Life Inc *and* Program or Be Programmed

Technologies Have Biases

People like to think of technologies and media as neutral and that only their use or content determines their impact. Guns don't kill people, after all, people kill people. But guns are much more biased toward killing people than, say, pillows

— even though many a pillow has been utilized to smother an aging relative or adulterous spouse.

Our widespread inability to recognize or even acknowledge the biases of the technologies we use renders us incapable of gaining any real agency through them. We accept our iPads, Facebook accounts and automobiles at face value — as pre-existing conditions — rather than tools with embedded biases.

Marshall McLuhan exhorted us to recognize that our media have impacts on us beyond whatever content is being transmitted through them. And while his message was itself garbled by the media through which he expressed it (the medium is the what?) it is true enough to be generalized to all technology. We are free to use any car we like to get to work — gasoline, diesel, electric, or hydrogen — and this sense of choice blinds us to the fundamental bias of the automobile towards distance, commuting, suburbs, and energy consumption.

Likewise, soft technologies from central currency to psychotherapy are biased in their construction as much as their implementation. No matter how we spend US dollars, we are nonetheless fortifying banking and the centralization of capital. Put a psychotherapist on his own couch and a patient in the chair, and the therapist will begin to exhibit treatable pathologies. It's set up that way, just as Facebook is set up to make us think of ourselves in terms of our "likes" and an iPad is set up to make us start paying for media and stop producing it ourselves.

If the concept that technologies have biases were to become common knowledge, we would put ourselves in a position to implement them consciously and purposefully. If we don't bring this concept into general awareness, our technologies and their effects will continue to threaten and confound us.

MARCEL KINSBOURNE
Neurologist & Cognitive Neuroscientist, The New School; Coauthor, Children's Learning and Attention Problems

The Expanding In-Group

The ever-cumulating dispersion, not only of information, but also of population, across the globe, is the great social phenomenon of this age. Regrettably, cultures are being homogenized, but cultural differences are also being demystified, and intermarriage is escalating, across ethnic groups within states and between ethnicities across the world. The effects are potentially beneficial for the improvement of cognitive skills, from two perspectives. We can call these "the expanding in-group" and the "hybrid vigor" effects.

The in-group versus out-group double standard, which had and has such catastrophic consequences, could in theory be eliminated if everyone alive were to be considered to be in everyone else's in-group. This Utopian prospect is remote, but an expansion of the conceptual in-group would expand the range of friendly, supportive and altruistic behavior. This effect may already be in evidence in the increase in charitable activities in support of foreign populations that are confronted by natural disasters. Donors identifying to a greater extent with recipients make this possible. The rise in frequency of international adoptions also indicates that the barriers set up by discriminatory and nationalistic prejudice are becoming porous.

The other potential benefit is genetic. The phenomenon of hybrid vigor in offspring, which is also called heterozygote advantage, derives from a cross between dissimilar parents. It is well established experimentally, and the benefits of mingling disparate gene pools are seen not only in improved physical but also in improved mental development. Intermarriage therefore promises cognitive benefits. Indeed, it may already have contributed to the Flynn effect, the well known worldwide rise in average measured intelligence, by as much as three I.Q. points per decade, over successive decades since the early twentieth century.

Every major change is liable to unintended consequences. These can be beneficial, detrimental or both. The social and cognitive benefits of the intermingling of people and populations are no exception, and there is no knowing whether the benefits are counterweighed or even outweighed by as yet unknown drawbacks. Nonetheless, unintended though they might be, the social benefits of the overall greater probability of in-group status, and the cognitive benefits of increasing frequency of intermarriage entailed by globalization may already be making themselves felt.

JONATHAN HAIDT
Psychologist, University of Virginia; Author, The Happiness Hypothesis

Contingent Superorganism

Humans are the giraffes of altruism. We're freaks of nature, able (at our best) to achieve ant-like levels of service to the group. We readily join together to create superorganisms, but unlike the eusocial insects, we do it with blatant disregard for kinship, and we do it temporarily, and contingent upon special circumstances (particularly intergroup conflict, as is found in war, sports, and business).

Ever since the publication of G. C. Williams' 1966 classic *Adaptation and Natural Selection*, biologists have joined with social scientists to form an altruism debunkery society. Any human or animal act that appears altruistic has been explained away as selfishness in disguise, linked ultimately to kin selection (genes help copies of themselves), or reciprocal altruism (agents help only to the extent that they can expect a positive return, including to their reputations).

But in the last few years there's been a growing acceptance of the fact that "Life is a self-replicating hierarchy of levels," and natural selection operates on multiple levels simultaneously, as Bert Hölldobler and E. O. Wilson put it in their recent book, *The Superorganism*. Whenever the free-rider problem is solved at one level of the hierarchy, such that individual agents can link their fortunes and live or die as a group, a superorganism is formed. Such "major transitions" are rare in the history of life, but when they have happened, the resulting superorganisms have been wildly successful. (Eukaryotic cells, multicelled organisms, and ant colonies are all examples of such transitions).

Building on Hölldobler and Wilson's work on insect societies, we can define a "contingent superorganism" as a group of people that form a functional unit in which each is willing to sacrifice for the good of the group in order to surmount a challenge or threat, usually from another contingent superorganism. It is the most noble and the most terrifying human ability. It is the secret of successful hive-like organizations, from the hierarchical corporations of the 1950s to the more fluid dot-coms of today. It is the purpose of basic training in the military. It is the reward that makes people want to join fraternities, fire departments, and rock bands. It is the dream of fascism.

Having the term "contingent superorganism" in our cognitive toolkit may help people to overcome 40 years of biological reductionism and gain a more accurate view of human nature, human altruism, and human potential. It can explain our otherwise freakish love of melding ourselves (temporarily, contingently) into something larger than ourselves.

NEIL GERSHENFELD
Director, MIT Center for Bits and Atoms; Author, FAB

Truth is a Model

The most common misunderstanding about science is that scientists seek and find truth. They don't — they make and test models.

Kepler packing Platonic solids to explain the observed motion of planets made pretty good predictions, which were improved by his laws of planetary motion, which were improved by Newton's laws of motion, which were improved by Einstein's general relativity. Kepler didn't become wrong because of Newton being right, just as Newton didn't then become wrong because of Einstein being right; this succession of models differed in their assumptions, accuracy, and applicability, not their truth.

This is entirely unlike the polarizing battles that define so many areas of life: either my political party, or religion, or lifestyle is right, or yours is, and I believe in mine. The only thing that's shared is the certainty of infallibility.

Building models is very different from proclaiming truths. It's a never-ending process of discovery and refinement, not a war to win or destination to reach. Uncertainty is intrinsic to the process of finding out what you don't know, not a weakness to avoid. Bugs are features — violations of expectations are opportunities to refine them. And decisions are made by evaluating what works better, not by invoking received wisdom.

These are familiar aspects of the work of any scientist, or baby: it's not possible to learn to talk or walk without babbling or toddling to experiment with language and balance. Babies who keep babbling turn into scientists who formulate and test theories for a living. But it doesn't require professional training to make mental models — we're born with those skills. What's needed is not displacing them with the certainty of absolute truths that inhibit the exploration of ideas. Making sense of anything means making models that can predict outcomes and accommodate observations. Truth is a model.

ANDY CLARK
Philosopher and Cognitive Scientist, University of Edinburgh. Author: Supersizing the Mind: Embodiment, Action, and Cognitive Extension

Predictive Coding

The idea that the brain is basically an engine of prediction is one that will, I believe, turn out to be very valuable not just within its current home (computational cognitive neuroscience) but across the board: for the arts, for the humanities, and for our own personal understanding of what it is to be a human being in contact with the world.

The term 'predictive coding' is currently used in many ways, across a variety of disciplines. The usage I recommend for the Everyday Cognitive Toolkit is, however, more restricted in scope. It concerns the way the brain exploits prediction and anticipation in making sense of incoming signals and using them to guide perception, thought, and action. Used in this way 'predictive coding' names a technically rich body of computational and neuroscientific research (key theorists include Dana Ballard, Tobias Egner, Paul Fletcher, Karl Friston, David Mumford, and Rajesh Rao) . This corpus of research uses mathematical principles and models that explore in detail the ways that this form of coding might underlie perception, and inform belief, choice, and reasoning.

The basic idea is simple. It is that to perceive the world is to successfully predict our own sensory states. The brain uses stored knowledge about the structure of the world and the probabilities of one state or event following another to generate a prediction of what the current state is likely to be, given the previous one and this body of knowledge. Mismatches between the prediction and the received signal generate error signals that nuance the prediction or (in more extreme cases) drive learning and plasticity.

We may contrast this with older models in which perception is a 'bottom-up' process, in which incoming information is progressively built (via some kind of evidence accumulation process, starting with simple features and working up) into a high-level model of the world. According to the predictive coding alternative, the reverse is the case. For the most part, we determine the low-level features by applying a cascade of predictions that begin at the very top; with our most general expectations about the nature and state of the world providing constraints on our successively more detailed (fine grain) predictions.

This inversion has some quite profound implications.

First, the notion of good ('veridical') sensory contact with the world becomes a matter of applying the right expectations to the incoming signal. Subtract such expectations and the best we can hope for are prediction errors that elicit plasticity and learning. This means, in effect, that all perception is some form of 'expert perception', and that the idea of accessing some kind of unvarnished sensory truth is untenable (unless that merely names another kind of trained, expert perception!).

Second, the time course of perception becomes critical. Predictive coding models suggest that what emerges first is the general gist (including the general affective feel) of the scene, with the details becoming progressively filled in as the brain uses that larger context — time and task allowing — to generate finer and finer predictions of detail. There is a very real sense in which we properly perceive the forest before the trees.

Third, the line between perception and cognition becomes blurred. What we perceive (or think we perceive) is heavily determined by what we know, and what we know (or think we know) is constantly conditioned on what we perceive (or think we perceive). This turns out to offer a powerful window on various pathologies of thought and action, explaining the way hallucinations and false beliefs go hand-in-hand in schizophrenia, as well as other more familiar states such as 'confirmation bias' (our tendency to 'spot' confirming evidence more readily than disconfirming evidence).

Fourth, if we now consider that prediction errors can be suppressed not just by changing predictions but by changing the things predicted, we have a simple and powerful explanation for behavior and the way we manipulate and sample our environment. In this view, action is there to make predictions come true and provides a nice account of phenomena that range from homeostasis to the maintenance of our emotional and interpersonal status quo.

Understanding perception as prediction thus offers, it seems to me, a powerful tool for appreciating both the power and the potential pitfalls of our primary way of being in contact with the world. Our primary contact with the world, all this suggests, is via our expectations about what we are about to see or experience. The notion of predictive coding, by offering a concise and technically rich way of gesturing at this fact, provides a cognitive tool that will more than earn its keep in science, law, ethics, and the understanding of our own daily experience.

CLAY SHIRKY
Social & Technology Network Topology Researcher; Adjunct Professor, NYU Graduate School of Interactive Telecommunications Program (ITP); Author, Cognitive Surplus

Pareto Principle

You see the pattern everywhere: the top 1% of the population control 35% of the wealth. On Twitter, the top 2% of users send 60% of the messages. In the health care system, the treatment for the most expensive fifth of patients create fourfifths of the overall cost. These figures are always reported as shocking, as if the normal order of things has been disrupted, as if the appearance of anything other than a completely linear distribution of money, or messages, or effort, is a surprise of the highest order.

It's not. Or rather, it shouldn't be.

The Italian economist Vilfredo Pareto undertook a study of market economies a century ago, and discovered that no matter what the country, the richest quintile of the population controlled most of the wealth. The effects of this *Pareto Distribution* go by many names — the *80/20 Rule, Zipfs Law,* the *Power Law* distribution, *Winner-Take-All* — but the basic shape of the underlying distribution is always the same: the richest or busiest or most connected participants in a system will account for much *much* more wealth, or activity, or connectedness than average.

Furthermore, this pattern is recursive. Within the top 20% of a system that exhibits a Pareto distribution, the top 20% of *that* slice will also account for disproportionately more of whatever is being measured, and so on. The most highly ranked element of such a system will be much more highly weighted than even the #2 item in the same chart. (The word "the" is not only the commonest word in English, it appears twice as often the second most common, "of".)

This pattern was so common, Pareto called it a "predictable imbalance"; despite this bit of century-old optimism, however, we are still failing to predict it, even though it is everywhere.

Part of our failure to expect the expected is that we have been taught that the paradigmatic distribution of large systems is the Gaussian distribution, commonly known as the bell curve. In a bell curve distribution like height, say, the average and the median (the middle point in the system) are the same — the average height of a hundred American women selected at random will be about 5'4", and the height of the 50th woman, ranked in height order, will also be 5'4".

Pareto distributions are nothing like that — the recursive 80/20 weighting means that the average is far from the middle. This in turn means that in such systems most people (or whatever is being measured) are below average, a pattern encapsulated in the old economics joke: "Bill Gates walks into a bar and makes everybody a millionaire, on average."

The Pareto distribution shows up in a remarkably wide array of complex systems. Together, "the" and "of" account for 10% of all words used in English. The most volatile day in the history of a stock market will typically be twice that of the second-most volatile, and ten times the tenth-most. Tag frequency on Flickr photos obeys a Pareto distribution, as does the magnitude of earthquakes, the popularity of books, the size of asteroids, and the social connectedness of your friends. The Pareto Principle is so basic to the sciences that special graph paper that shows Pareto distributions as straight lines rather than as steep curves is manufactured by the ream.

And yet, despite a century of scientific familiarity, samples drawn from Pareto distributions are routinely presented to the public as anomalies, which prevents us from thinking clearly about the world. We should stop thinking that average family income and the income of the median family have anything to do with one another, or that enthusiastic and normal users of communications tools are doing similar things, or that extroverts should be only moderately more connected than normal people. We should stop thinking that the largest future earthquake or market panic will be as large as the largest historical one; the longer a system persists, the likelier it is that an event twice as large as all previous ones is coming.

This doesn't mean that such distributions are beyond our ability to affect them. A Pareto curve's decline from head to tail can be more or less dramatic, and in some cases, political or social intervention can affect that slope — tax policy can raise or lower the share of income of the top 1% of a population, just as there are ways to constrain the overall volatility of markets, or to reduce the band in which health care costs can fluctuate.

However, until we assume such systems *are* Pareto distributions, and will remain so even after any such intervention, we haven't even started thinking about them in the right way; in all likelihood, we're trying to put a Pareto peg in a Gaussian hole. A hundred years after the discovery of this predictable imbalance, we should finish the job and actually start expecting it.

KEVIN KELLY
Editor-At-Large, Wired; Author, What Technology Wants

The Virtues of Negative Results

We can learn nearly as much from an experiment that does not work as from one that does. Failure is not something to be avoided but rather something to be cultivated. That's a lesson from science that benefits not only laboratory research, but design, sport, engineering, art, entrepreneurship, and even daily life itself. All creative avenues yield the maximum when failures are embraced. A great graphic designer will generate lots of ideas knowing that most will be aborted. A great dancer realizes most new moves will not succeed. Ditto for any architect, electrical engineer, sculptor, marathoner, startup maven, or microbiologist. What is science, after all, but a way to learn from things that don't work rather than just those that do? What this tool suggests is that you should aim for success while being prepared to learn from a series of failures. More so, you should carefully but deliberately press your successful investigations or accomplishments to the point that they break, flop, stall, crash, or fail.

Failure was not always so noble. In fact much of the world today failure is still not embraced as a virtue. It is a sign of weakness, and often a stigmata that prohibits second chances. Children in many parts of the world are taught that failure brings disgrace, and that one should do everything in one's power to succeed without failure. The rise of the West is in many respects due to the rise in tolerating failure. Indeed many immigrants trained in a failure-intolerant culture may blossom out of stagnancy once moved into a failure-tolerant culture. Failure liberates success.

The chief innovation that science brought to the state of defeat is a way to manage mishaps. Blunders are kept small, manageable, constant, and trackable. Flops are not quite deliberate, but they are channeled so that something is learned each time things fell. It becomes a matter of failing forward.

Science itself is learning how to better exploit negative results. Due to the problems of costly distribution most negative results have not been shared, thus limiting their potential to speed learning for others. But increasingly published negative results (which include experiments that succeed in showing no effects) are becoming another essential tool in the scientific method.

Wrapped up in the idea of embracing failure is the related notion of breaking things to make them better, particularly complex things. Often the only way to improve a complex system is to probe its limits by forcing it to fail in various ways. Software, among the most complex things we make, is usually tested for quality by employing engineers to systematically find ways to crash it. Similarly, one way to troubleshoot a complicated device that is broken is to deliberately force negative results (temporary breaks) in its multiple functions in order to locate the actual disfunction. Great engineers have a respect for breaking things that sometimes surprises non-engineers, just as scientists have a patience with failures that often perplexes outsiders. But the habit of embracing negative results is one of the most essential tricks to gaining success.

ALISON GOPNIK
Psychologist, UC, Berkeley; Author, The Philosophical Baby

The Rational Unconscious

One of the greatest scientific insights of the twentieth century was that most psychological processes are not conscious. But the "unconscious" that made it into the popular imagination was Freud's irrational unconscious — the unconscious as a roiling, passionate id, barely held in check by conscious reason and reflection. This picture is still widespread even though Freud has been largely discredited scientifically.

The "unconscious" that has actually led to the greatest scientific and technological advances might be called Turing's rational unconscious .If the vision of the "unconscious" you see in movies like *Inception* was scientifically accurate, it would include phalanxes of nerds with slide rules, instead of women in negligees wielding revolvers amid Daliesque landscapes.. At least that might lead the audience to develop a more useful view of the mind if not, admittedly, to buy more tickets.

Earlier thinkers like Locke and Hume anticipated many of the discoveries of psychological science but thought that the fundamental building blocks of the mind were conscious "ideas". Alan Turing, the father of the modern computer, began by thinking about the highly conscious and deliberate step-by-step calculations performed by human "computers" like the women decoding German ciphers at Bletchley Park. His first great insight was that the same processes could be instantiated in an entirely unconscious machine with the same results. A machine could rationally decode the German ciphers using the same steps that the conscious "computers" went through. And the unconscious relay and vacuum tube computers could get to the right answers in the same way that the flesh and blood ones could.

Turing's second great insight was that we could understand much of the human mind and brain as an unconscious computer too. The women at Bletchley Park brilliantly performed conscious computations in their day jobs, but they were unconsciously performing equally powerful and accurate computations every time they spoke a word or looked across the room. Discovering the hidden messages about three- dimensional objects in the confusing mess of retinal images is just as difficult and important as discovering the hidden messages about submarines in the incomprehensible Nazi telegrams, and the mind turns out to solve both mysteries in a similar way.

More recently, cognitive scientists have added the idea of probability into the mix, so that we can describe an unconscious mind, and design a computer, that can perform feats of inductive as well as deductive inference. Using this sort of probabilistic logic a system can accurately learn about the world in a gradual, probabilistic way, raising the probability of some hypotheses and lowering that of others, and revising hypotheses in the light of new evidence. This work relies on a kind of reverse engineering. First work out how any rational system could best infer the truth from the evidence it has. Often enough, it will turn out that the unconscious human mind does just that.

Some of the greatest advances in cognitive science have been the result of this strategy. But they've been largely invisible in popular culture, which has been understandably preoccupied with the sex and violence of much evolutionary psychology (like Freud, it makes for a better movie). Vision science studies how we are able to transform the chaos of stimulation at our retinas into a coherent and accurate perception of the outside world. It is, arguably, the most scientifically successful branch of both cognitive science and neuroscience. It takes off from the idea that our visual system is, entirely unconsciously, making rational inferences from retinal data to figure out what objects are like. Vision scientists began by figuring out the best way to solve the problem of vision, and then discovered, in detail, just how the brain performs those computations.

The idea of the rational unconscious has also transformed our scientific understanding of creatures who have traditionally been denied rationality, such as young children and animals. It should transform our everyday understanding too.

The Freudian picture identifies infants with that fantasizing, irrational unconscious, and even on the classic Piagetian view young children are profoundly illogical. But contemporary research shows the enormous gap between what young children say, and presumably what they experience, and their spectacularly accurate if unconscious feats of learning, induction and reasoning. The rational unconscious gives us a way of understanding how babies can learn so much when they consciously seem to understand so little.

Another way the rational unconscious could inform everyday thinking is by acting as a bridge between conscious experience and the few pounds of grey goo in our skulls. The gap between our experience and our brains is so great that people ping-pong between amazement and incredulity at every study that shows that knowledge or love or goodness is "really in the brain" (though where else would it be?). There is important work linking the rational unconscious to both conscious experience and neurology.

Intuitively, we feel that we know our own minds — that our conscious experience is a direct reflection of what goes on underneath. But much of the most interesting work in social and cognitive psychology demonstrates the gulf between our rationally unconscious minds and our conscious experience. Our conscious understanding of probability, for example, is truly awful, in spite of the fact that we unconsciously make subtle probabilistic judgments all the time. The scientific study of consciousness has made us realize just how complex, unpredictable and subtle the relation is between our minds and our experience.

At the same time, to be genuinely explanatory neuroscience has to go beyond "the new phrenology" of simply locating psychological functions in particular brain regions. The rational unconscious lets us understand the how and why of the brain and not just the where. Again, vision science has led the way, with elegant empirical studies showing just how specific networks of neurons can act as computers rationally solving the problem of vision.

Of course, the rational unconscious has its limits. Visual illusions demonstrate that our brilliantly accurate visual system does sometimes get it wrong. Conscious reflection may be misleading sometimes, but it can also provide cognitive prostheses, the intellectual equivalent of glasses with corrective lenses, to help compensate for the limitations of the rational unconscious. The institutions of science do just that.

The greatest advantage of understanding the rational unconscious would be to demonstrate that rational discovery isn't a specialized abstruse privilege of the few we call "scientists", but is instead the evolutionary birthright of us all. Really tapping into our inner vision and inner child might not make us happier or more well-adjusted, but it might make us appreciate just how smart we really are.

NICHOLAS A. CHRISTAKIS
Physician and Social Scientist, Harvard University; Coauthor, Connected: The Surprising Power of Our Social Networks and How They Shape Our Lives

Holism

Some people like to build sand castles, and some like to tear them apart. There can be much joy in the latter. But it is the former that interests me. You can take a bunch of minute silica crystals, pounded for thousands of years by the waves, use your hands, and make an ornate tower. Tiny physical forces govern how each particle interacts with its neighbors, keeping the castle together, at least until the *force majeu*r of a foot appears.

But, having built the castle, this is the part that I like the most: you step back and look at it. Across the expanse of beach, here is something new, something not present before among the endless sand grains, something risen from the ground, something that reflects the scientific principle of holism.

Holism is colloquially summarized as "the whole is greater than the sum of its parts." What is interesting to me, however, are not the artificial instantiations of this principle — when we deliberately form sand into ornate castles or metal into airborne planes or ourselves into corporations — but rather the natural instantiations. The examples are widespread and stunning. Perhaps the most impressive one is that carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, iron, and a few other elements, when mixed in just the right way, yield life. And life has emergent properties not present in — nor predictable from — these constituent parts. There is a kind of awesome synergy between the parts.

Hence, I think that the scientific concept that would improve everyone's cognitive toolkit is holism: the abiding recognition that wholes have properties not present in the parts and not reducible to the study of the parts.

For example, carbon atoms have particular, knowable physical and chemical properties. But the atoms can be combined in different ways to make, say, graphite or diamond. The properties of those substances — properties such as darkness and softness and clearness and hardness — are not properties of the carbon atoms, but rather properties of the collection of carbon atoms. Moreover, which particular properties the collection of atoms has depends entirely on how they are assembled — into sheets or pyramids. The properties arise because of the connections between the parts. I think grasping this insight is crucial for a proper scientific perspective on the world. You could know everything about isolated neurons and not be able to say how memory works, or where desire originates.

It is also the case that the whole has a complexity that rises faster than the number of its parts. Consider social networks as a simple illustration. If we have ten people in a group, there are a maximum of 10x9/2=45 possible connections between them. If we increase the number of people to 1,000, the number of possible ties increases to 1,000x999/2=499,500. So, while the number of people has increased by 100-fold (from 10 to 1,000), the number of possible ties (and hence, this one measure of the complexity of the system), has increased by over 10,000-fold.

Holism does not come naturally. It is an appreciation not of the simple, but of the complex, or at least of the simplicity and coherence in complex things. Moreover, unlike curiosity or empiricism, say, holism takes a while to acquire and to appreciate. It is a very grown-up disposition. Indeed, for the last few centuries, the Cartesian project in science has been to break matter down into ever smaller bits, in the pursuit of understanding. And this works, to some extent. We can understand matter by breaking it down to atoms, then protons and electrons and neutrons, then quarks, then gluons, and so on. We can understand organisms by breaking them down into organs, then tissues, then cells, then organelles, then proteins, then DNA, and so on.

But putting things back together in order to understand them is harder, and typically comes later in the development of a scientist or in the development of science. Think of the difficulties in understanding how all the cells in our bodies work together, as compared with the study of the cells themselves. Whole new fields of neuroscience and systems biology and network science are arising to accomplish just this. And these fields are arising just now, after centuries of stomping on castles in order to figure them out.

WILLIAM CALVIN
Neuroscientist, Professor Emeritus, University of Washington in Seattle. Author, Global Fever: How to Treat Climate Change

Find That Frame

An automatic stage of "Compare and contrast" would improve most cognitive functions, not just the grade on an essay. You set up a comparison — say, that the interwoven melodies of Rock 'n' Roll are like how you must twist when dancing on a boat when the bow is rocking up and down in a different rhythm than the deck is rolling from side to side.

Comparison is an important part of trying ideas on for size, for finding related memories, and exercising constructive skepticism. Without it, you can become trapped in someone else's framing of a problem. You often need to know where someone is coming from — and while Compare 'n' Contrast is your best friend, you may also need to search for the cognitive framing. What has been cropped out of the frame can lead the unwary to an incorrect inference, as when they assume that what is left out is unimportant. For example, "We should reach a 2°C (3.6°F) fever in the year 2049" always makes me want to interject "Unless another abrupt climate shift gets us there next year."

Global warming's ramp up in temperature is the aspect of climate change that climate scientists can currently calculate — that's where they are coming from. And while this can produce really important insights — even big emission reductions only delay the 2°C fever for 19 years — it leaves out all of those abrupt climate shifts observed since 1976, as when the world's drought acreage doubled in 1982 and jumped from double to triple in 1997, then back to double in

2005. That's like stairs, not a ramp.

Even if we thoroughly understood the mechanism for an abrupt climate shift — likely a rearrangement of the winds that produce Deluge 'n' Drought by delivering ocean moisture elsewhere, though burning down the Amazon rain forest should also trigger a big one — chaos theory's "butterfly effect" says we still could not predict when a big shift will occur or what size it would be. That makes a climate surprise like a heart attack. You can't predict when. You can't say whether it will be minor or catastrophic. But you can often prevent it — in the case of climate, by cleaning up the excess CO2.

Drawing down the CO2 is also typically excluded from the current climate framing. Mere emissions reduction now resembles locking the barn door after the horse is gone — worthwhile, but not exactly recovery either. Politicians usually love locking barn doors as it gives the appearance of taking action cheaply. Emissions reduction only slows the rate at which things get worse, as the CO2 accumulation still keeps growing. (People confuse annual emissions with the accumulation that causes the trouble.) On the other hand, cleaning up the CO2 actually cools things, reverses ocean acidification, and even reverses the thermal expansion portion of rising sea level.

Recently I heard a biologist complaining about models for insect social behavior: "All of the difficult stuff is not mentioned. Only the easy stuff is calculated." Scientists first do what they already know how to do. But their quantitative results are no substitute for a full qualitative account. When something is left out because it is computationally intractable (sudden shifts) or would just be a guess (cleanup), they often don't bother to mention it at all. "Everybody [in our field] knows that" just won't do when people outside the field are hanging on your every word.

So find that frame and ask about what was left out. Like abrupt climate shifts or a CO2 cleanup, it may be the most important consideration of all.

LAWRENCE KRAUSS
Physicist, Foundation Professor & Director, Origins Project, Arizona State University; Author, A Universe from Nothing; Quantum Man: Richard Feynman's Life in Science

Uncertainty

The notion of uncertainty is perhaps the least well understood concept in science. In the public parlance, uncertainty is a bad thing, implying a lack of rigor and predictability. The fact that global warming estimates are uncertain, for example, has been used by many to argue against any action at the present time.

In fact, however, uncertainty is a central component of what makes science successful. Being able to quantify uncertainty, and incorporate it into models, is what makes science quantitative, rather than qualitative. Indeed, no number, to measurement, no observable in science is exact. Quoting numbers without attaching an uncertainty to them implies they have, in essence, no meaning.

One of the things that makes uncertainty difficult for members of the public to appreciate is that the significance of uncertainty is relative. Take, for example, the distance between the earth and sun, 1.49597 x 108 km. This seems relatively precise, after all using six significant digits means I know the distance to an accuracy of one part in a million or so. However, if the next digit is uncertain, that means the uncertainty in knowing the precise earth-sun distance is larger than the distance between New York and Chicago!

Whether or not the quoted number is 'precise' therefore depends upon what I am intending to do with it. If I only care about what minute the Sun will rise tomorrow then the number quoted above is fine. If I want to send a satellite to orbit just above the Sun, however, then I would need to know distances more accurately.

This is why uncertainty is so important. Until we can quantify the uncertainty in our statements and our predictions, we have little idea of their power or significance. So too in the public sphere. Public policy performed in the absence of understanding quantitative uncertainties, or even understanding the difficulty of obtaining reliable estimates of uncertainties usually means bad public policy.

THOMAS METZINGER
Philosopher, Johannes Gutenberg-Universität Mainz and Frankfurt Institute for Advanced Studies; Author, The Ego Tunnel

Phenomenally Transparent Self-Model

A self-model is the inner representation some information-processing systems have of themselves as a whole. A representation is phenomenally transparent, if it a) is conscious and b) cannot be experienced *as* a representation. Therefore, transparent representations create the phenomenology of naïve realism, the robust and irrevocable sense that you are directly and immediately perceiving something which must be real. Now apply the second concept to the first: A "transparent self-model", necessarily, creates the realistic conscious experience of selfhood, of being directly and immediately in touch with oneself as a whole.

This concept is important, because it shows how, in a certain class of information-processing systems, the robust phenomenology of *being a self* would inevitably appear — although they never were, or had, anything like a self. It is empirically plausible that we might just be such systems.

LEE SMOLIN
Physicist, Perimeter Institute; Author, The Trouble With Physics

Thinking In Time Versus Thinking Outside Of Time

One very old and pervasive habit of thought is to imagine that the true answer to whatever question we are wondering about lies out there in some eternal domain of "timeless truths." The aim of re-search is then to "discover" the answer or solution in that already existing timeless domain. For example, physicists often speak as if the final theory of everything already exists in a vast timeless Platonic space of mathematical objects. This is thinking outside of time.

Scientists are thinking in time when we conceive of our task as the invention of genuinely novel ideas to describe newly discovered phenomena, and novel mathematical structures to express them. If we think outside of time, we believe these ideas somehow "existed" before we invented them. If we think in time we see no reason to presume that.

The contrast between thinking in time and thinking outside of time can be seen in many domains of human thought and action. We are thinking outside of time when, faced with a technological or social problem to solve, we assume the possible approaches are already determined by a set of absolute pre-existing categories. We are thinking in time when we understand that progress in technology, society and science happens by the invention of genuinely novel ideas, strategies, and novel forms of social organization.

The idea that truth is timeless and resides outside the universe was the essence of Plato's philosophy, exemplified in the parable of the slave boy that was meant to argue that discovery is merely remembering. This is reflected in the philosophy of mathematics called Platonism, which is the belief that there are two ways of existing. Regular physical things exist in the universe and are subject to time and change, while mathematical objects exist in a timeless realm. The division of the world into a time-drenched Earthly realm of life, death, change and decay, surrounded by a heavenly sphere of perfect eternal truth, framed both ancient science and Christian religion.

If we imagine that the task of physics is the discovery of a timeless mathematical object that is isomorphic to the history of the world, then we imagine that the truth to the universe lies outside the universe. This is such a familiar habit of thought that we fail to see its absurdity: if the universe is all that exists then how can something exist outside of it for it to be isomorphic to?

On the other hand, if we take the reality of time as evident, then there can be no mathematical object that is perfectly isomorphic to the world, because one property of the real world that is not shared by any mathematical object is that it is always some moment. Indeed, as Charles Sanders Pierce first observed, the hypothesis that the laws of physics evolved through the history of the world is necessary if we are to have a rational understanding of why one particular set of laws hold, rather than others.

Thinking outside of time often implies the existence of an imagined realm outside the universe where the truth lies. This is a religious idea, because it means that explanations and justifications ultimately refer to something outside of the world we experience ourselves to be a part of. If we insist there is nothing outside the universe, not even abstract ideas or mathematical objects, we are forced to find the causes of phenomena entirely within our universe. So thinking in time is also thinking within the one universe of phenomena our observations show us to inhabit.

Among contemporary cosmologists and physicists, proponents of eternal inflation and timeless quantum cosmology are thinking outside of time. Proponents of evolutionary and cyclic cosmological scenarios are thinking in time. If you think in time you worry about time ending at space-time singularities. If you think outside of time this is an ignorable problem because you believe reality is the whole history of the world at once.

Darwinian evolutionary biology is the prototype for thinking in time because at its heart is the realization that natural processes developing in time can lead to the creation of genuinely novel structures. Even novel laws can emerge when the structures to which they apply come to exist. Evolutionary dynamics has no need of abstract and vast spaces like all the possible viable animals, DNA sequences, sets of proteins, or biological laws. Exaptations are too unpredictable and too dependent on the whole suite of living creatures to be analyzed and coded into properties of DNA sequences. Better, as Stuart Kauffman proposes, to think of evolutionary dynamics as the exploration, in time, by the biosphere, of *the adjacent possible.*

The same goes for the evolution of technologies, economies and societies. The poverty of the conception that economic markets tend to unique equilibria, independent of their histories, shows the danger of thinking outside of time. Meanwhile the path dependence that Brian Arthur and others show is necessary to understand real markets illustrates the kind of insights that are gotten by thinking in time.

Thinking in time is not relativism, it is a form of relationalism. Truth can be both time bound and objective, when it is about objects that only exist once they are invented, by evolution or human thought.

When we think in time we recognize the human capacity to invent genuinely novel constructions and solutions to problems. When we think about the organizations and societies we live and work in outside of time we unquestioningly accept their strictures, and seek to manipulate the levers of bureaucracy as if they had an absolute reason to be there. When we think about organizations in time we recognize that every feature of them is a result of their history and everything about them is negotiable and subject to improvement by the invention of novel ways of doing things.

RICHARD FOREMAN
Playwright & Director; Founder, The Ontological-Hysteric Theater

Negative Capability Is A Profound Therapy

Mistakes, errors, false starts — accept them all. The basis of creativity.

My reference point (as a playwright, not a scientist) was Keat's notion of negative capability (from his letters). Being able to exist with lucidity and calm amidst uncertainty, mystery and doubt, without "irritable (and always premature) reaching out" after fact and reason.

This toolkit notion of negative capability is a profound *therapy* for all manner of ills — intellectual, psychological, spiritual and political. I reflect it (amplify it) with Emerson's notion that "Art (any intellectual activity?) is (best thought of as but) the *path* of the creator *to his work*."

Bumpy, twisting roads. (New York City is about to repave my cobblestone street with smooth asphalt. Evil bureaucrats and tunnel-visioned 'scientists" — fast cars and more tacky up-scale stores in Soho.)

Wow! I'll bet my contribution is shorter than anyone else's. Is this my inadequacy *or an important toolkit item heretofore overlooked*?

DONALD HOFFMAN
Cognitive Scientist, UC, Irvine; Author, Visual Intelligence

Sensory Desktop

Our perceptions are neither true nor false. Instead, our perceptions of space and time and objects, the fragrance of a rose, the tartness of a lemon, are all a part of our "sensory desktop," which functions much like a computer desktop.

Graphical desktops for personal computers have existed for about three decades. Yet they are now such an integral part of daily life that we might easily overlook a useful concept that they embody. A graphical desktop is *a guide to adaptive behavior*. Computers are notoriously complex devices, more complex than most of us care to learn. The colors, shapes and locations of icons on a desktop shield us from the computer's complexity, and yet they allow us to harness its power by appropriately informing our behaviors, such as mouse movements and button clicks, that open, delete and otherwise manipulate files. In this way, a graphical desktop is a guide to adaptive behavior.

Graphical desktops make it easier to grasp the idea that guiding adaptive behavior is different than reporting truth. A red icon on a desktop does not report the true color of the file it represents. Indeed, a file has no color. Instead, the red color guides adaptive behavior, perhaps by signaling the relative importance or recent updating of the file. The graphical desktop guides useful behavior, and hides what is true but not useful. The complex truth about the computer's logic gates and magnetic fields is, for the purposes of most users, of no use.

Graphical desktops thus make it easier to grasp the nontrivial difference between utility and truth. Utility drives evolution by natural selection. Grasping the distinction between utility and truth is therefore critical to understanding a major force that shapes our bodies, minds and sensory experiences.

Consider, for instance, facial attractiveness. When we glance at a face we get an immediate feeling of its attractiveness, a feeling that usually falls somewhere between hot and not. That feeling can inspire poetry, evoke disgust, or launch a thousand ships. It certainly influences dating and mating. Research in evolutionary psychology suggests that this feeling of attractiveness is a guide to adaptive behavior. The behavior is mating, and the initial feeling of attractiveness towards a person is an adaptive guide because it correlates with the likelihood that mating with that person will lead to successful offspring.

Just as red does not report the true color of a file, so hotness does not report the true feeling of attractiveness of a face: Files have no intrinsic color, faces have no intrinsic feeling of attractiveness. The color of an icon is an artificial convention to represent aspects of the utility of a colorless file. The initial feeling of attractiveness is an artificial convention to represent mate utility.

The phenomenon of synesthesia can help to understand the conventional nature of our sensory experiences. In many cases of synesthesia, a stimulus that is normally experienced in one way, say as a sound, is also automatically experienced in another way, say as a color. Someone with sound-color synesthesia sees colors and simple shapes whenever they hear a sound. The same sound always occurs with the same colors and shapes. Someone with taste-touch synesthesia feels touch sensations in their hands every time they taste something with their mouth. The same taste always occurs with the same feeling of touch in their hands. The particular connections between sound and color that one sound-color synesthete experiences typically differ from the connections experienced by another such synesthete. In this sense, the connections are an arbitrary convention. Now imagine a sound-color synesthete who no longer has sound experiences to acoustic stimuli, and instead has only their synesthetic color experiences. Then this synesthete would only experience as colors what the rest of us experience as sounds. In principle they could get all the acoustic information the rest of us get, only in a color format rather than a sound format.

This leads to the concept of a sensory desktop. Our sensory experiences, such as vision, sound, taste and touch, can all be thought of as sensory desktops that have evolved to guide adaptive behavior, not to report objective truths. As a result, we should take our sensory experiences seriously. If something tastes putrid, we probably shouldn't eat it. If it sounds like a rattlesnake, we probably should avoid it. Our sensory experiences have been shaped by natural selection to guide such adaptive behaviors.

We must take our sensory experiences seriously, but not literally. This is one place where the concept of a sensory desktop is helpful. We take the icons on a graphical desktop seriously; we won't, for instance, carelessly drag an icon to the trash, for fear of losing a valuable file. But we don't take the colors, shapes or locations of the icons literally. They are not there to resemble the truth. They are there to facilitate useful behaviors.

Sensory desktops differ across species. A face that could launch a thousand ships probably has no attraction to a macaque monkey. The rotting carrion that tastes putrid to me might taste like a delicacy to a vulture. My taste experience guides behaviors appropriate for me: Eating rotten carrion could kill me. The vulture's taste experience guides behaviors appropriate to it: Carrion is its primary food source.

Much of evolution by natural selection can be understood as an arms race between competing sensory desktops. Mimicry and camouflage exploit limitations in the sensory desktops of predators and prey. A mutation that alters a sensory desktop to reduce such exploitation conveys a selective advantage. This cycle of exploiting and revising sensory desktops is a creative engine of evolution.

On a personal level, the concept of a sensory desktop can enhance our cognitive toolkit by refining our attitude towards our own perceptions. It is common to assume that the way I see the world is, at least in part, the way it really is. Because, for instance, I experience a world of space and time and objects, it is common to assume that these experiences are, or at least resemble, objective truths. The concept of a sensory desktop reframes all this. It loosens the grip of sensory experiences on the imagination. Space, time and objects might just be aspects of a sensory desktop that is specific to *Homo sapiens*. They might not be deep insights into objective truths, just convenient conventions that have evolved to allow us to survive in our niche. Our desktop is just a desktop.

DANIEL GOLEMAN
Psychologist; Author, Ecological Intelligence

Anthropocene Thinking

Do you know the PDF of your shampoo? A 'PDF' refers to a "partially diminished fraction of an ecosystem," and if your shampoo contains palm oil cultivated on clearcut jungle in Borneo, say, that value will be high. How about your shampoo's DALY? This measure comes from public health: "disability adjusted life years," the amount of one's life that will be lost to a disabling disease because of, say, a liftetime's cumulative exposure to a given industrial chemical. So if your favorite shampoo contains two common ingredients, the carcinogen 1,4 dioxane, or BHA , an endocrine disrupter, its DALY will be higher.

PDFs and DALYs are among myriad metrics for Anthropocene thinking, which views how human systems impact the global systems that sustain life. This way of perceiving interactions between the built and the natural worlds comes from the geological sciences. If adopted more widely this lens might usefully inform how we find solutions to the singular peril our species faces: the extinction of our ecological niche.

Beginning with cultivation and accelerating with the Industrial Revolution, our planet left the Holocene Age and entered what geologists call the Anthropocene Age, in which human systems erode the natural systems that support life. Through the Anthropocene lens, the daily workings of the energy grid, transportation, industry and commerce inexorably deteriorate global biogeochemical systems like the carbon, phosphorous and water cycles. The most troubling data suggests that since the 1950s, the human enterprise has led to an explosive acceleration that will reach criticality within the next few decades as different systems reach a point-of-no-return tipping point. For instance, about half the total rise in atmospheric CO_2 concentration has occurred in just the last 30 years — and of all the global life-support systems, the carbon cycle is closest to no-return. While such "inconvenient truths" about the carbon cycle have been the poster child for our species' slow motion suicide, that's just part of a much larger picture, with all the eight global life-support systems under attack by our daily habits.

Anthropocene thinking tells us the problem is not necessarily inherent in the systems like commerce and energy that degrade nature; hopefully these can be modified to become self-sustaining with innovative advances and entrepreneurial energy. The real root of the Anthropocene dilemma lies in our neural architecture.

We approach the Anthropocene threat with brains shaped in evolution to survive the previous geological epoch, the Holocene, when dangers were signaled by growls and rustles in the bushes, and it served one well to reflexively abhor spiders and snakes. Our neural alarm systems still attune to this largely antiquated range of danger.

Add to that misattunement to threats our built-in perceptual blindspot: we have no direct neural register for the dangers of the Anthropocene age, which are too macro or micro for our sensory apparatus. We are oblivious to, say, our body burden, the lifetime build-up of damaging industrial chemicals in our tissues.

To be sure, we have methods for assessing CO_2 buildups or blood levels of BHA. But for the vast majority of people those numbers have little to no emotional impact. Our amygdala shrugs.

Finding ways to counter the forces that feed the Anthropocene effect should count high in prioritizing scientific efforts. The earth sciences of course embrace the issue — but do not deal with the root of the problem, human behavior. The sciences that have most to offer have done the least Anthropocene thinking.

The fields that hold keys to solutions include economics, neuroscience, social psychology and cognitive science — and their various hybrids. With a focus on Anthropocene theory and practice they might well contribute species-saving insights. But first they have to engage this challenge, which for the most part has remained off their agenda.

When, for example, will neuroeconomics tackle the brain's perplexing indifference to the news about planetary meltdown, let alone how that neural blindspot might be patched? Might cognitive neuroscience one day offer some insight that might change our collective decision-making away from a lemmings' march to oblivion? Could any of the computer, behavioral or brain sciences come up with an information prosthetic that might reverse our course?

Paul Crutzen, the Dutch atmospheric chemist who won a Nobel for his work on ozone depletion, coined the term 'Anthropocene' ten years ago. As a meme, 'Anthropocene' has as yet little traction in scientific circles beyond geology and environmental science, let alone the wider culture: A Google check on 'anthropocene' shows 78,700 references (mainly in geoscience), while by contrast 'placebo', a once-esoteric medical term now well-established as a meme, has more than 18 million (and even the freshly coined 'vuvuzela' has 3,650,000).

GIULIO BOCCALETTI
Physicist, Atmospheric and Oceanic scientist, and Associate Principal with McKinsey & Company

Scale Analysis

There is a well-known saying: dividing the universe into things that are linear and those that are non-linear is very much like dividing the universe into things that are bananas and things that are not. Many things are not bananas.

Non-linearity is a hallmark of the real world. It occurs anytime outputs of a system cannot be expressed in terms of a sum of inputs, each multiplied by a simple constant — a rare occurrence in the grand scheme of things. Non-linearity does not necessarily imply complexity, just as linearity does not exclude it, but most real systems do exhibit some non-linear feature that results in complex behaviour. Some, like the turbulent stream from a water tap, hide deep non-linearity under domestic simplicity, while others, weather for example, are evidently non-linear to the most distracted of observers. Non-linear complex dynamics are around us: unpredictable variability, tipping points, sudden changes in behaviour, hysteresis are frequent symptoms of a non-linear world.

Non-linear complexity has also the unfortunate characteristic of being difficult to manage, high-speed computing not withstanding, because it tends to lack the generality of linear solutions. As a result we have a tendency to try and view the world in terms of linear models — much for the same reason that looking for lost keys under a lamppost might make sense: because that is where the light is. Understanding — of the kind that "rests in the mind" — seems to require simplification, one in which complexity is reduced where possible and only the most material parts of the problem are preserved.

One of the most robust bridges between the linear and the non-linear, the simple and the complex, is scale analysis, the dimensional analysis of physical systems. It is through scale analysis that we can often make sense of complex non-linear phenomena in terms of simpler models. At its core reside two questions. The first asks what quantities matter most to the problem at hand (which tends to be less obvious than one would like). The second asks what the expected magnitude and — importantly — dimensions of such quantities are. This second question is particularly important, as it captures the simple yet fundamental point that physical behaviour should be invariant to the units we use to measure quantities in. It may sound like an abstraction but, without jargon, you could really call scale analysis "focusing systematically only on what matters most at a given time and place".

There are some subtle facts about scale analysis that make it more powerful than simply comparing orders of magnitude. A most remarkable example is that scale analysis can be applied, through a systematic use of dimensions, even when the precise equations governing the dynamics of a system are not known. The great physicist G.I. Taylor, a character whose prolific legacy haunts any aspiring scientist, gave a famous demonstration of this deceptively simple approach. In the 1950's, back when the detonating power of the nuclear bomb was a carefully guarded secret, the US Government incautiously released some unclassified photographs of a nuclear explosion. Taylor realized that, while its details would be complex, the fundamentals of the problem would be governed by few parameters. From dimensional arguments, he posited that there ought to be a scale-invariant number linking the radius of the blast, the time from detonation, energy released in the explosion and the density of the surrounding air. From the photographs, he was able to estimate the radius and timing of the blast, inferring a remarkably accurate — and embarrassingly public — estimate of the energy of the explosion.

Taylor's capacity for insight was no doubt uncommon: scale analysis seldom generates such elegant results. Nevertheless, it has a surprisingly wide range of applications and an illustrious history of guiding research in applied sciences, from structural engineering to turbulence theory.

But what of its broader application? The analysis of scales and dimensions can help understand many complex problems, and should be part of everybody's toolkit. In business planning and financial analysis for example, the use of ratios and benchmarks is a first step towards scale analysis. It is certainly not a coincidence that they became common management tools at the height of Taylorism — a different Taylor, F.W. Taylor the father of modern management theory — when "scientific management" and its derivatives made their first mark. The analogy is not without problems and would require further detailing than we have time here — for example, on the use of dimensions to infer relations between quantities. But inventory turnover, profit margin, debt and equity ratios, labour and capital productivity are dimensional parameters that could tell us a great deal about the basic dynamics of business economics, even without detailed market knowledge and day to day dynamics of individual transactions.

In fact, scale analysis in its simplest form can be applied to almost every quantitative aspect of daily life, from the fundamental timescales governing our expectations on returns on investments, to the energy intensity of our lives. Ultimately, scale analysis is a particular form of numeracy — one where the relative magnitude, as well as the dimensions of things that surround us, guide our understanding of their meaning and evolution. It almost has the universality and coherence of Warburg's Mnemosyne Atlas: a unifying system of classification, where distant relations between seemingly disparate objects can continuously generate new ways of looking at problems and, through simile and dimension, can often reveal unexpected avenues of investigation.

Of course, anytime a complicated system is translated into a simpler one, information is lost. Scale analysis is a tool that will only be as insightful as the person using it. By itself, it does not provide answers and is no substitute for deeper analysis. But it offers a powerful lens through which to view reality and to understand "the order of things".

HELEN FISHER
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Temperament Dimensions

"I am large, I contain multitudes" wrote Walt Whitman. I have never met two people who were alike. I am an identical twin, and even we are not alike. Every individual has a distinct personality, a different cluster of thoughts and feelings that color all their actions. But there are patterns to personality: people express different styles of thinking and behaving — what psychologists call "temperament dimensions." I offer this concept of temperament dimensions as a useful new member of our cognitive tool kit.

Personality is composed of two fundamentally different types of traits: those of "character;" and those of "temperament." Your character traits stem from your experiences. Your childhood games; your family's interests and values; how people in your community express love and hate; what relatives and friends regard as courteous or perilous; how those around you worship; what they sing; when they laugh; how they make a living and relax: innumerable cultural forces build your unique set of character traits. The balance of your personality is your temperament, all the biologically based tendencies that contribute to your consistent patterns of feeling, thinking and behaving. As Spanish philosopher, Jose Ortega y Gasset, put it, "I am, plus my circumstances." Temperament is the "I am," the foundation of who you are.

Some 40% to 60% of the observed variance in personality is due to traits of temperament. They are heritable, relatively stable across the life course, and linked to specific gene pathways and/or hormone or neurotransmitter systems. Moreover, our temperament traits congregate in constellations, each aggregation associated with one of four broad, interrelated yet distinct brain systems: those associated with dopamine, serotonin, testosterone and estrogen/oxytocin. Each constellation of temperament traits constitutes a distinct temperament dimension.

For example, specific alleles in the dopamine system have been linked with exploratory behavior, thrill, experience and adventure seeking, susceptibility to boredom and lack of inhibition. Enthusiasm has been coupled with variations in the dopamine system, as have lack of introspection, increased energy and motivation, physical and intellectual exploration, cognitive flexibility, curiosity, idea generation and verbal and non-linguistic creativity.

The suite of traits associated with the serotonin system includes sociability, lower levels of anxiety, higher scores on scales of extroversion, and lower scores on a scale of "No Close Friends," as well as positive mood, religiosity, conformity, orderliness, conscientiousness, concrete thinking, self-control, sustained attention, low novelty seeking, and figural and numeric creativity.

Heightened attention to detail, intensified focus, and narrow interests are some of the traits linked with prenatal testosterone expression. But testosterone activity is also associated with emotional containment, emotional flooding (particularly rage), social dominance and aggressiveness, less social sensitivity, and heightened spatial and mathematical acuity.

Last, the constellation of traits associated with the estrogen and related oxytocin system include verbal fluency and other language skills, empathy, nurturing, the drive to make social attachments and other prosocial aptitudes, contextual thinking, imagination, and mental flexibility.

We are each a different mix of these four broad temperament dimensions. But we do have distinct personalities People are malleable, of course; but we are not blank slates upon which the environment inscribes personality. A curious child tends to remain curious, although what he or she is curious about changes with maturity. Stubborn people remain obstinate; orderly people remain punctilious; and agreeable men and women tend to remain amenable.

We are capable of acting "out of character," but doing so is tiring. People are biologically inclined to think and act in specific patterns — temperament dimensions. But why would this concept of temperament dimensions be useful in our human cognitive tool kit? Because we are social creatures, and a deeper understanding of who we (and others) are can provide a valuable tool for understanding, pleasing, cajoling, reprimanding, rewarding and loving others — from friends and relatives to world leaders. It's also practical.

Take hiring. Those expressive of the novelty-seeking temperament dimension are unlikely to do their best in a job requiring rigid routines and schedules. Biologically cautious individuals are not likely to be comfortable in high-risk posts. Decisive, tough minded high testosterone types are not well suited to work with those who can't get to the point and decide quickly. And those predominantly of the compassionate, nurturing high estrogen temperament dimension are not likely to excel at occupations that require them to be ruthless.

Managers might form corporate boards containing all four broad types. Colleges might place freshman with roommates of a similar temperament, rather than similarity of background. Perhaps business teams, sports teams, political teams and teacher-student teams would operate more effectively if they were either more "like-minded" or more varied in their cognitive skills. And certainly we could communicate with our children, lovers, colleagues and friends more effectively. We are not puppets on a string of DNA. Those biologically susceptible to alcoholism, for example, often give up drinking. The more we come to understand our biology, the more we will appreciate how culture molds our biology.

JOEL GOLD, M.D.
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ARISE

ARISE, or *Adaptive Regression In the Service of the Ego*, is a psychoanalytic concept recognized for decades, but little appreciated today. It is one of the ego functions which, depending on who you ask, may number anywhere from a handful to several dozen. They include reality testing, stimulus regulation, defensive function and synthetic integration. For simplicity, we can equate the ego with the self (though ARISS doesn't quite roll off the tongue).

In most fields, including psychiatry, regression is not considered a good thing. Regression implies a return to an earlier and inferior state of being and functioning. But the key here is not the regression, but rather whether the regression is maladaptive or adaptive.

There are numerous vital experiences that cannot be achieved without adaptive regression: The creation and appreciation of art, music, literature and food; the ability to sleep; sexual fulfillment; falling in love; and, yes, the ability to free associate and tolerate psychoanalysis or psychodynamic therapy without getting worse. Perhaps the most important element in adaptive regression is the ability to fantasize, to daydream. The person who has access to their unconscious processes and can mine them, without getting mired in them, can try new approaches, can begin to see things in new ways and, perhaps, can achieve mastery of their pursuits.

In a word: Relax.

It was ARISE that allowed Friedrich August Kekulé to use a daydream about a snake eating its tail as inspiration for his formulation of the structure of the benzene ring. It's what allowed Richard Feynman to simply drop an O-ring into a glass of ice water, show that when cold the ring is subject to distortion, and thereby explain the cause of the Space Shuttle Challenger disaster. Sometimes it takes a genius to see that a fifth grade science experiment is all that is needed to solve a problem.

In another word: Play.

Sometimes in order to progress you need to regress. Sometimes you just have to let go and ARISE.

MATTHEW RITCHIE
Artist

Systemic Equilibrium

The second law of thermodynamics, the so-called "arrow of time", popularly associated with entropy (and by association death), is the most widely misunderstood shorthand abstraction in human society today. We need to fix this.

The second law states that over time, closed systems will become more similar, eventually reaching systemic equilibrium. It is not a question of if a system will reach equilibrium; it is only a question of whena system will reach equilibrium.

Living on a single planet, we are all participants in a single physical system which has only one direction — towards systemic equilibrium. The logical consequences are obvious; our environmental, industrial and political systems (even our intellectual and theological systems) will become more homogenous over time. It's already started. The physical resources available to every person on earth, including air, food and water, have already been significantly degraded by the high burn rate of industrialization, just as the intellectual resources available to every person on earth have already been significantly increased by the high distribution rate of globalization.

Human societies are already far more similar than ever before (does anyone really miss dynastic worship?) and it would be very tempting to imagine that a modern democracy based on equal rights and opportunities is the system in equilibrium. That seems unlikely, given our current energy footprint. More likely, if the total system energy is depleted too fast, is that modern democracies will be compromised if the system crashes to its lowest equilibrium too quickly for socially equitable evolution.

Our one real opportunity is to use the certain knowledge of ever increasing systemic equilibrium to build a model for an equitable and sustainable future. The mass distribution of knowledge and access to information through the world wide web is our civilization's signal achievement. Societies that adopt innovative, predictive and adaptive models designed around a significant, on-going redistribution of global resources will be most likely to survive in the future.

But since we are biologically and socially programmed to avoid discussing entropy (death), we reflexively avoid the subject of systemic changes to our way of life, both as a society and individuals. We think it's a bummer. Instead of examining the real problems, we consume apocalyptic fantasies as "entertainment" and deride our leaders for their impotence. We really need to fix this.

Unfortunately, even facing this basic concept faces an uphill battle today. In earlier, expansionist phases of society, various metaphorical engines such as "progress" and "destiny" allowed the metaphorical "arrow" to supplant the previously (admittedly spirit-crushing) "wheel" of time. Intellectual positions that supported scientific experimentation and causality were tolerated, even endorsed, as long as they contributed to the arrow's cultural momentum. But in a more crowded and contested world, the limits of projected national power and consumption control have become more obvious. Resurgent strands of populism, radicalism and magical thinking have found mass appeal in their rejection of many rational concepts. But perhaps most significant is the rejection of undisputed physical laws.

The practical effect of this denial on the relationship between the global economy and the climate change debate (for example) is obvious. Advocates propose continuous "good" (green) growth, while denialists propose continuous "bad" (brown) growth. Both sides are more interested in backing winners and losers in a future economic environment predicated on the continuation of today's systems, than accepting the physical inevitability of increasing systemic equilibrium in any scenario.

Of course, any system can temporarily cheat entropy. Hotter particles (or societies) can "steal" the stored energy of colder (or weaker) ones, for a while. But in the end, the rate at which the total energy is burned and redistributed will still determine the speed at which the planetary system will reach its true systemic equilibrium. Whether we extend the lifetime of our local "heat" through war, or improved window insulation, is the stuff of politics. But even if in reality we can't beat the house, its worth a try, isn't it?

LINDA STONE
Hi-Tech Industry Consultant; Former Executive at Apple Computer and Microsoft Corporation

Suspending Disbelief

Barbara McClintock was ignored and ridiculed, by the scientific community, for thirty-two years before winning a Nobel Prize in 1984, for discovering "jumping genes." During the years of hostile treatment by her peers, McClintock didn't publish, preferring to avoid the rejection of the scientific community. Stanley Prusiner faced significant criticism from his colleagues until his prion theory was confirmed. He, too, went on to win a Nobel Prize in 1982.

Barry Marshall challenged the medical "fact" that stomach ulcers were caused by acid and stress; and presented evidence that H. Pylori bacteria is the cause. Marshall is quoted as saying, "Everyone was against me."

Progress in medicine was delayed while these "projective thinkers" persisted, albeit on a slower and lonelier course.

Projective thinking is a term coined by Edward de Bono to describe generative rather than reactive thinking. McClintock, Prusiner, and Marshall offered projective thinking; suspending their disbelief regarding accepted scientific views at the time.

Articulate, intelligent individuals can skillfully construct a convincing case to argue almost any point of view. This critical, reactive use of intelligence narrows our vision. In contrast, projective thinking is expansive, "open-ended" and speculative, requiring the thinker to create the context, concepts, and the objectives.

Twenty years of studying maize created a context within which McClintock could speculate. With her extensive knowledge and keen powers of observation, she deduced the significance of the changing color patterns of maize seed. This led her to propose the concept of gene regulation, which challenged the theory of the genome as a static set of instructions passed from one generation to the next.

The work McClintock first reported in 1950, the result of projective thinking, extensive research, persistence, and a willingness to suspend disbelief, wasn't understood or accepted until many years later.

Everything we know, our strongly held beliefs, and, in some cases, even what we consider to be "factual," creates the lens through which we see and experience the world, and can contribute to a critical, reactive orientation. This can serve us well: Fire is hot; it can burn if touched. It can also compromise our ability to observe and to think in an expansive, generative way.

When we cling rigidly to our constructs, as McClintock's peers did, we can be blinded to what's right in front of us. Can we support a scientific rigor that embraces generative thinking and suspension of disbelief? Sometimes science fiction does become scientific discovery.

DAVID GELERNTER
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Recursive Structure

Recursive structure is a simple idea (or shorthand abstraction) with surprising applications beyond science.

A structure is recursive if the shape of the whole recurs in the shape of the parts: for example, a circle formed of welded links that are circles themselves. Each circular link might itself be made of smaller circles, and in principle you could have an unbounded nest of circles made of circles made of circles.

The idea of recursive structure came into its own with the advent of computer science (that is, software science) in the 1950s. The hardest problem in software is controlling the tendency of software systems to grow incomprehensibly complex. Recursive structure helps convert impenetrable software rainforests into French gardens — still (potentially) vast and complicated, but much easier to traverse and understand than a jungle.

Benoit Mandelbrot famously recognized that some parts of nature show recursive structure of a sort: a typical coastline shows the same shape or pattern whether you look from six inches or sixty feet or six miles away.

But it also happens that recursive structure is fundamental to the history of architecture, especially to the gothic, renaissance and baroque architecture of Europe — covering roughly the 500 years between the 13th and 18th centuries. The strange case of "recursive architecture" shows us the damage one missing idea can create. It suggests also how hard it is to talk across the cultural Berlin Wall that separates science and art. And the recurrence of this phenomenon in art and nature underlines an important aspect of the human sense of beauty.

The re-use of one basic shape on several scales is fundamental to medieval architecture. But, lacking the idea (and the term) "recursive structure," art historians are forced to improvise ad hoc descriptions each time they need one. This hodgepodge of improvised descriptions makes it hard, in turn, to grasp how widespread recursive structure really is. And naturally, historians of post-medieval art invent their own descriptions—thus obfuscating a fascinating connection between two mutually alien aesthetic worlds.

For example: One of the most important aspects of mature gothic design is tracery — the thin, curvy, carved stone partitions that divide one window into many smaller panes. Recursion is basic to the art of tracery.

Tracery was invented at the cathedral of Reims circa 1220, and used soon after at the cathedral of Amiens. (Along with Chartres, these two spectacular and profound buildings define the High Gothic style.) To move from the characteristic tracery design of Reims to that of Amiens, just add recursion. At Reims, the basic design is a pointed arch with a circle inside; the circle is supported on two smaller arches. At Amiens, the basic design is the same — except that now, the window recurs in miniature inside each smaller arch. (Inside each smaller arch is a still-smaller circle supported on still-smaller arches.)

In the great east window at Lincoln Cathedral, the recursive nest goes one step deeper. This window is a pointed arch with a circle inside; the circle is supported on two smaller arches — much like Amiens. Within each smaller arch is a circle supported on two still-smaller arches. Within each still-smaller arch, a circle is supported on even-smaller arches.

There are other recursive structures throughout medieval art.

Jean Bony and Erwin Panofsky were two eminent 20th century art historians. Naturally they both noticed recursive structure. But neither man understood *the idea in itself*. And so, instead of writing that the windows of Saint-Denis show recursive structure, Bony said that they are "composed of a series of similar forms progressively subdivided in increasing numbers and decreasing sizes." Describing the same phenomenon in a different building, Panofsky writes of the "principle of progressive divisibility (or, to look at it the other way, multiplicability)." Panofsky's "principle of progressive divisiblity" is a fuzzy, roundabout way of saying "recursive structure."

Louis Grodecki noticed the same phenomenon—a chapel containing a display-platform shaped like the chapel in miniature, holding a shrine shaped like the chapel in extra-miniature. And he wrote that "This is a common principle of Gothic art." But he doesn't say *what* the principle is; he doesn't describe it *in general* or give it a name. William Worringer, too, had noticed recursive structure. He described gothic design as "a world which repeats in miniature, but with the same means, the expression of the whole."

So each historian makes up his own name and description for the same basic idea—which makes it hard to notice that all four descriptions actually describe the same thing. *Recursive structure is a basic principle of medieval design*; but this simple statement is hard to say or even think if we don't know what "recursive structure" is.

If the literature makes it hard to grasp the importance of recursive structure in medieval art, it's even harder to notice that exactly the same principle recurs in the radically different world of Italian Renaissance design.

George Hersey wrote astutely of Bramante's design (ca 1500) for St Peter's in the Vatican that it consists of "a single macrochapel…, four sets of what I will call maxichapels, sixteen minichapels, and thirty-two microchapels." "The principle [he explains] is that of Chinese boxes — or, for that matter, fractals."

If he had only been able to say that "recursive structure is fundamental to Bramante's thought," the whole discussion would have been simpler and clearer — and an intriguing connection between medieval and renaissance design would have been obvious.

Using instead of ignoring the idea of recursive structure would have had other advantages too.

It helps us understand the connections between art and technology; helps us see the aesthetic principles that guide the best engineers and technologists, and the ideas of clarity and elegance that underlie every kind of successful design. These ideas have practical implications. For one, technologists must study and understand elegance and beauty as design goals; any serious technology education must include art history. And we reflect, also, on the connection between great art and great technology on the one hand and natural science on the other.

But without the right intellectual tool for the job, new instances of recursive structure make the world more complicated instead of simpler and more beautiful.

DON TAPSCOTT
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Designing Your Mind

Given recent research about brain plasticity and the dangers of cognitive load, the most powerful tool in our cognitive arsenal may well be design.
Specifically, we can use design principles and discipline to shape our minds. This is different than learning and acquiring knowledge. It's about designing how each of us thinks, remembers and communicates — appropriately and effectively for the digital age.

Today's popular handwringing about its effects on cognition has some merit. But rather than predicting a dire future, perhaps we should be trying to achieve a new one.

New neuroscience discoveries give hope. We know that brains are malleable and can change depending on how they are used. The well-known study of London taxi drivers showed that a certain region in the brain involved in memory formation was physically larger than in non-taxi-driving individuals of a similar age. This effect did not extend to London bus drivers, supporting the conclusion that the requirement of London's taxi drivers to memorize the multitude of London streets drove structural brain changes in the hippocampus.

Results from studies like these support the notion that even among adults the persistent, concentrated use of one neighborhood of the brain real can increase its size, and presumably also its capacity. Not only does intense use change adult brain regional structure and function, but temporary training and perhaps even mere mental rehearsal seem to have an effect as well. A series of studies showed that one can improve tactile (Braille character) discrimination among seeing people who are temporarily blindfolded. Brain scans revealed that participants' visual cortex responsiveness was heightened to auditory and tactile sensory input after only five days of blindfolding for over an hour each time.

The existence of lifelong neuroplasticity is no longer in doubt. The brain runs on a "use it or lose it" motto. So could we "use it to build it right?" Why don't we use the demands of our information-rich, multi-stimuli, fast-paced, multi-tasking, digital existence to expand our cognitive capability? Psychiatrist Dr. Stan Kutcher, an expert on adolescent mental health who has studied the effect of digital technology on brain development, says we probably can: "There is emerging evidence suggesting that exposure to new technologies may push the Net Generation [teenagers and young adults] brain past conventional capacity limitations."

When the straight A student is doing her homework at the same time as five other things online, she is not actually multi-tasking. Instead, she has developed better active working memory and better switching abilities. I can't read my email and listen to iTunes at the same time, but she can. Her brain has been wired to handle the demands of the digital age.

How could we use design thinking to change the way we think? Good design typically begins with some principles and functional objectives. You might aspire to have a strong capacity to perceive and absorb information effectively, concentrate, remember, infer meaning, be creative, write, speak and communicate well, and to enjoy important collaborations and human relationships. How could you design your use (or abstinence) of media to achieve these goals?

Something as old-school as a speed-reading course could increase your input capacity without undermining comprehension. If it made sense in Evelyn Woods' day it is doubly important now and we've learned a lot since her day about how to read effectively.

Feeling distracted? The simple discipline of reading a few full articles per day rather than just the headlines and summaries could strengthen attention.

Want to be a surgeon? Become a gamer or rehearse while on the subway. Rehearsal can produce changes in the motor cortex as big as those induced by physical movement. One study a group of participants were asked to play a simple five-finger exercise on the piano while another group of participants were asked to think about playing the same "song" in their heads using the same finger movements, one note at a time. Both groups showed a change in their motor cortex, with differences among the group who mentally rehearsed the song as great as those who physically played the piano.

Losing retention? Decide how far you want to adopt Alfred Einstein's law of memory. When asked why he went to the phone book to get his number he replied that he only memorizes things he can't look up. There is a lot to remember these days. Between the dawn of civilization and 2003 there were 5 exabytes of data collected (an exabyte equals 1 quintillion bytes). Today 5 exabytes of data gets collected every two days! Soon there will be 5 exabytes every few minutes. Humans have a finite memory capacity. Can you develop criteria for which will be inboard and outboard?

Or want to strengthen your working memory and capability to multitask? Try reverse mentoring — learning with your teenager. This is the first time in history when children are authorities about something important, and the successful ones are pioneers of a new paradigm in thinking. Extensive research shows that people can improve cognitive function and brain efficiency through simple lifestyle changes, such as incorporating memory exercises into their daily routine.

Why don't schools and universities teach design thinking for thinking? We teach physical fitness. But rather than brain fitness we emphasize cramming young heads with information and testing their recall. Why not courses that emphasize designing a great brain?

Does this modest proposal raise the specter of "designer minds?" I don't think so. The design industry is something done to us. I'm proposing we each become designers. But I suppose "I love the way she thinks" could take on new meaning.

ANDRIAN KREYE
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Free Jazz

It's always worth to take a few cues from mid-20th-century avant-garde. So when it comes to improving your cognitive toolkit Free Jazz is perfect. It is a highly evolved new take on an art that has (at least in the West) been framed by a strict set of twelve notes played in accurate factions of bars. It is also the pinnacle of a genre that had begun with the Blues just a half century before Ornette Coleman assembled his infamous double quartet in the A&R Studio in New York City one December day in 1960. In science terms that would mean an evolutionary leap from elementary school math to game theory and fuzzy logic in a mere fifty years.

If you really want to appreciate the mental prowess of Free Jazz players and composers you should start just one step behind. A half a year before Ornette Coleman's Free Jazz session let loose the improvisational genius of eight of the best musicians of their times, John Coltrane recorded what is still considered the most sophisticated Jazz solo ever — his tour de force through the rapid chord progressions of his composition "Giant Steps".

The film student Daniel Cohen has recently animated the notation for Coltrane's solo in a YouTube video. You don't have to be able to read music to grasp the intellectual firepower of Coltrane. After the deceivingly simple main theme the notes start to race up and down the five lines of the stave in dizzying speeds and patterns. If you also take into consideration that Coltrane used to record unrehearsed music to keep it fresh, you know that he was endowed with a cognitive toolkit way beyond normal.

Now take these almost 4:43 minutes, multiply Coltrane's firepower by eight, stretch it into 37 minutes and deduct all traditional musical structures like chord progressions or time. The session that gave the genre it's name in the first place foreshadowed not just the radical freedom the album's title implied. It was a precursor to a form of communication that has left linear conventions and entered the realm of multiple parallel interactions.

It is admittedly still hard to listen to the album "Free Jazz: A Collective Improvisation by the Ornette Coleman Double Quartet". It is equally taxing to listen to recordings of Cecil Taylor, Pharoah Sanders, Sun Ra, Anthony Braxton or Gunter Hampel. It has always been easier to understand the communication processes of this music in a live setting. One thing is a given — it is never anarchy, never was meant to be.

If you're able to play music and you manage to get yourself invited to a Free Jazz session, there is an incredible moment, when all musicians find what is considered "The Pulse". It is a collective climax of creativity and communication that can leap to the audience and create an electrifying experience. It's hard to describe, but might be comparable to the moment when a surfer finds the point when the catalyst of a surfboard bring together the motor skills of his body and the forces of the swell of an ocean start in these few seconds of synergy on top of a wave. It is a fusion of musical elements though that defies common musical theory.

Of course there is a lot of Free Jazz that merely confirms prejudice. Or as the vibraphonist and composer Gunter Hampel phrased it: "At one point it was just about being the loudest on stage." But all the musicians mentioned above have found new forms and structures, Ornette Coleman's music theory called Harmolodics being just one of them. In the perceived cacophony of their music there is a multilayered clarity to discover that can serve as a model for a cognitive toolkit for the 21st century. The ability to find cognitive, intellectual and communication skills that work in parallel contexts rather than linear forms will be crucial. Just as Free Jazz abandoned harmonic structures to find new forms in polyrhythmic settings, one might just have to enable himself to work beyond proven cognitive patterns.

MATT RIDLEY
*Science Writer; Founding chairman of the International Centre for Life; Author, F*rancis Crick: Discoverer of the Genetic Code

Collective intelligence

Brilliant people, be they anthropologists, psychologists or economists, assume that brilliance is the key to human achievement. They vote for the cleverest people to run governments, they ask the cleverest experts to devise plans for the economy, they credit the cleverest scientists with discoveries, and they speculate on how human intelligence evolved in the first place.

They are all barking up the wrong tree. The key to human achievement is not individual intelligence at all. The reason human beings dominate the planet is not because they have big brains: Neanderthals had big brains but were just another kind of predatory ape. Evolving a 1200-cc brain and a lot of fancy software like language was necessary but not sufficient for civilization. The reason some economies work better than others is certainly not because they have cleverer people in charge, and the reason some places make great discoveries is not because they have smarter people.

Human achievement is entirely a networking phenomenon. It is by putting brains together through the division of labor — through trade and specialisation — that human society stumbled upon a way to raise the living standards, carrying capacity, technological virtuosity and knowledge base of the species. We can see this in all sorts of phenomena: the correlation between technology and connected population size in Pacific islands; the collapse of technology in people who became isolated, like native Tasmanians; the success of trading city states in Greece, Italy, Holland and south-east Asia; the creative consequences of trade.

Human achievement is based on collective intelligence — the nodes in the human neural network are people themselves. By each doing one thing and getting good at it, then sharing and combining the results through exchange, people become capable of doing things *they do not even understand*. As the economist Leonard Read observed in his essay "I, Pencil' (which I'd like everybody to read), no single person knows how to make even a pencil — the knowledge is distributed in society among many thousands of graphite miners, lumberjacks, designers and factory workers.

That's why, as Friedrich Hayek observed, central planning never worked: the cleverest person is no match for the collective brain at working out how to distribute consumer goods. The idea of bottom-up collective intelligence, which Adam Smith understood and Charles Darwin echoed, and which Hayek expounded in his remarkable essay "The use of knowledge in society", is one idea I wish everybody had in their cognitive toolkit.

GERD GIGERENZER
Psychologist; Director of the Center for Adaptive Behavior and Cognition at the Max Planck Institute for Human Development in Berlin; Author, Gut Feelings

Risk Literacy

Literacy — the ability to read and write — is the precondition for an informed citizenship in a participatory democracy. But knowing how to read and write is no longer enough. The breakneck speed of technological innovation has made risk literacy as indispensable in the 21st century as reading and writing were in the 20th century. Risk literacy is the ability to deal with uncertainties in an informed way.

Without it, people jeopardize their health and money and can be manipulated into experiencing unwarranted, even damaging hopes and fears. Yet when considering how to deal with modern threats, policy makers rarely ever invoke the concept of risk literacy in the general public. To reduce the chances of another financial crisis, proposals called for stricter laws, smaller banks, reduced bonuses, lower leverage ratios, less short-termism, and other measures.

But one crucial idea was missing: helping the public better understand financial risk. For instance, many of the "NINJAs" (no income, no job, no assets) who lost everything but the shirts on their backs in the subprime crisis didn't realize that their mortgages were variable, not fixed-rate. Another serious problem that risk literacy can help solve are the exploding costs of health care.. Tax hikes or rationed care are often presented as the only viable alternatives. Yet by promoting health literacy in patients, better care can be had for less money.

For instance, many parents are unaware that one million U.S. children have unnecessary CT scans annually and that a full body scan can deliver one thousand times the radiation dose of a mammogram, resulting in an estimated 29,000 cancers per year.

I believe that the answer to modern crises is not simply more laws, more bureaucracy, or more money, but, first and foremost, more citizens who are risk literate. This can be achieved by cultivating statistical thinking.

Simply stated, statistical thinking is the ability to understand and critically evaluate uncertainties and risks. Yet 76 percent of U.S. adults and 54 percent of Germans do not know how to express a 1 in 1,000 chance as a percentage (0.1%). Schools spend most of their time teaching children the mathematics of certainty — geometry, trigonometry — and spend little if any time on the mathematics of uncertainty. If taught at all, it is mostly in the form of coin and dice problems that tend to bore young students to death. But statistical thinking could be taught as the art of real-world problem solving, i.e. the risks of drinking, AIDS, pregnancy, horseback riding, and other dangerous things. Out of all mathematical disciplines, statistical thinking connects most directly to a teenager's world.

Even at the university level, law and medical students are rarely taught statistical thinking — even though they are pursuing professions whose very nature it is to deal with matters of uncertainty. U.S. judges and lawyers have been confused by DNA statistics and fallen prey to the prosecutor's fallacy; their British colleagues drew incorrect conclusions about the probability of recurring sudden infant death. Many doctors worldwide misunderstand the likelihood that a patient has cancer after a positive screening test and can't critically evaluate new evidence presented in medical journals. Experts without risk literacy skills are part of the problem rather than the solution.

Unlike basic literacy, risk literacy requires emotional re-wiring: rejecting comforting paternalism and illusions of certainty, and learning to take responsibility and to live with uncertainty. Daring to know. But there is still a long way to go. Studies indicate that most patients want to believe in their doctors' omniscience and don't dare to ask for backing evidence, yet nevertheless feel well-informed after consultations. Similarly, even after the banking crisis, many customers still blindly trust their financial advisors, jeopardizing their fortune in a consultation that takes less time than they'd spend watching a football game. Many people cling to the belief that others can predict the future and pay fortune sellers for illusory certainty. Every fall, renowned financial institutions forecast next year's Dow and dollar exchange rate, even though their track record is hardly better than chance. We pay $200 billion yearly to a forecasting industry that delivers mostly erroneous future predictions.

Educators and politicians alike should realize that risk literacy is a vital topic for the 21st century. Rather than being nudged into doing what experts believe is right, people should be encouraged and equipped to make informed decisions for themselves. Risk literacy should be taught beginning in elementary school. Let's dare to know — risks and responsibilities are chances to be taken, not avoided.

KEITH DEVLIN
Executive Director, H-STAR Institute, Stanford University; Author, The Unfinished Game: Pascal, Fermat, and the Seventeenth-Century Letter that Made the World Modern

Base rate

The recent controversy about the potential dangers to health of the back-scatter radiation devices being introduced at the nation's airports and the intrusive pat-downs offered as the only alternative by the TSA might well have been avoided had citizens been aware of, and understood, the probabilistic notion of base rate.

Whenever a statistician wants to predict the likelihood of some event based on the available evidence, there are two main sources of information that have to be taken into account:

1. The evidence itself, for which a reliability figure has to be calculated;

2. The likelihood of the event calculated purely in terms of relative incidence.

The second figure here is the base rate. Since it is just a number, obtained by the seemingly dull process of counting, it frequently gets overlooked when there is new information, particularly if that new information is obtained by "clever experts" using expensive equipment. In cases where the event is dramatic and scary, like a terrorist attack on an airplane, failure to take account of the base rate can result in wasting massive amounts of effort on money trying to prevent something that is very unlikely.

For example, suppose that you undergo a medical test for a relatively rare cancer. The cancer has an incidence of 1% among the general population. (That is the base rate.) Extensive trials have shown that the reliability of the test is 79%. More precisely, although the test does not fail to detect the cancer when it is present, it gives a positive result in 21% of the cases where no cancer is present — what is known as a "false positive." When you are tested, the test produces a positive diagnosis. The question is: What is the probability that you have the cancer?

If you are like most people, you will assume that if the test has a reliability rate of nearly 80%, and you test positive, then the likelihood that you do indeed have the cancer is about 80% (i.e., the probability is approximately 0.8). Are you right?

The answer is no. You have focused on the test and its reliability, and overlooked the base rate, Given the scenario just described, the likelihood that you have the cancer is a mere 4.6% (i.e., the probability is 0.046). That's right, there is a less than 5% chance that you have the cancer. Still a worrying possibility, of course. But hardly the scary 80% you thought at first.

In the case of the back-scatter radiation devices at the airports, the base rate for dying in a terrorist attack is lower than many other things we do every day without hesitation. In fact, according to some reports, it is about the same as the likelihood of getting cancer as a result of going through the device.

MARTI HEARST

Professor of Computer Science, UC Berkeley, School of Information; Author, Search User Interfaces

Findex

Findex (n): The degree to which a desired piece of information can be found online.

We are the first humans in history to be able to form just about any question in our minds and know that very likely the answer can be before us in minutes, if not seconds. This omnipresent information abundance is a cognitive toolkit entirely in itself. The actuality of this continues to astonish me.

Although some have written about information overload, data smog, and the like, my view has always been the more information online, the better, so long as good search tools are available. Sometimes this information is found by directed search using a web search engine, sometimes by serendipty by following links, and sometimes by asking hundreds of people in our social network or hundreds of thousands of people on a question answering website such as Answers.com, Quora, or Yahoo Answers.

I do not actually know of a real findability index, but tools in the field of information retrieval could be applied to develop one. One of the unsolved problems in the field is how to help the searcher to determine if the information simply is not available.

SUSAN FISKE

Eugene Higgins Professor, Department of Psychology, Princeton University

An Assertion Is Often An Empirical Question, Settled By Collecting Evidence

The most important scientific concept is that an assertion is often an empirical question, settled by collecting evidence. The plural of anecdote is not data, and the plural of opinion is not facts. Quality, peer-reviewed scientific evidence accumulates into knowledge. People's stories are stories, and fiction keeps us going. But science should settle policy.

GREGORY PAUL

Independent Researcher; Author, Dinosaurs of the Air

Scientists Should Be Scientists

The archenemy of scientific thinking is conversation. As in typical human conversational discourse, much of which is BS. Personally I have become rather fed up with talking to people. Seriously, it is something a problem. Fact is, folks are prone to getting pet opinions into their heads and then actually thinking they are true to the point of obstinacy, even when they have little or no idea of what they are talking about in the first place. We all do it. It is part of how the sloppy mind generating piece of meat between our ears we call the human brain is prone to work. Humans may be the most rational beings on the planet these days — but that's not saying much considering that the next most rational are chimpanzees.

Take creationism. Along with the global climate issue and parental fear of vaccination, the fact that a big chunk of the American body politic deny evolutionary and paleontological science and actually think a god created humans in near historical times is causing scientists to wonder just what is wrong with the thinking of so many people — mass creationism has been used as a classic example of mass anti-scientific thinking by others responding to this question. But I am not going to focus so much on the usual problem of why creationism is popular, but more on what many who promote science over creationism think they know about those who deny the reality of Darwin's theory.

A few years back an anti-creationist documentary came out, *A Flock of Dodos*. Nicely done in many regards, it scored some points against the anti-evolution crowd, and when it came to trying to explain why many Americans are repelled by evolution was way off base. The reason it was so wrong was because the creator of the film, Randy Olson, went to the wrong people to find out where the problem lies. A (seeming) highlight of the picture featured a bunch of poker playing Harvard evolutionary scientists gathered around a table to converse and opine on why the yahoos don't like the results of their research. This was a very bad mistake for the simple reason that evolutionary scientists are truly knowledgeable only about their area of expertise, evolutionary science.

If you really want to know why regular folk think the way they do then you go to the experts on that subject, sociologists. Because *A Flock of Dodos* never does that, its viewers never find out why creationism thrives in the age of science, and what needs to be done to tame the pseudoscientific beast.

This is not an idle problem. In the last decade big strides have been made in understanding the psychosociology of popular creationism — basically, it flourishes only in seriously dysfunctional societies, and the one sure why to suppress the errant belief is to run countries well enough that the religion creationism depends upon withers to minority status, dragging creationism down with it.

In other words better societies result in mass acceptance of evolution. Yet getting the word out is proving disturbingly difficult. So the chatty pet theories abut why creationism is a problem and what to do about it continue to dominant the national conversation, and pro-creationist opinion remains rock steady (although those who favor evolution without a God is rising along with the general increase of nonbelievers).

It's not just evolution. A classic example of conversational thinking by a scientist causing trouble was Linus Pauling's obsession with vitamin C. Many ordinary citizens are skeptical of scientists in general. When researchers offer up poorly sustained opinions on matters outside their firm knowledge base it does not help the general situation.

So what can be done? In principle it is simple enough. Scientists should be scientists. We should know better than to cough up committed but dubious opinion on subjects outside our expertise. This does not mean a given scientist has to limit their observations solely to their official field of research. Say a scientist is also a self-taught authority on baseball. By all means ardently discuss that subject the way Stephen Gould used to.

I have long had an intense interest in the myths of World War II, and can offer an excellent discourse on why the atom bombing of Hiroshima and Nagasaki had pretty much nothing to do with ending the war in case you are interested (it was the Soviet attack on Japan that forced Hirohito to surrender to save his war criminal's neck and keep Japan from being split into occupation zones like Germany and Korea). But if a scientist finds him or herself being asked about something they do not know a lot about either decline to opine, or qualify the observations by stating that the opinion is tentative and nonexpert.

In practical terms the problem is, of course, that scientists are human beings like everyone else. So I am not holding my breath waiting for us to achieve a level of factual discourse that will spread enlightenment to the masses. It's too bad but very human. I have tried to cut down on throwing out idle commentary without qualifying its questionable reality, while being ardent about my statements only when I know I can back them up. Me thinks I am fairly successful in this endeavor, and it does seem to keep me out of trouble.

JAMES CROAK
Artist

Bricoleur

French for handyman or do-it-yourselfer, this word has migrated into art and philosophy recently and savants would do well tossing it into their cognitive toolbox. A Bricoleur is a talented tinkerer, the sort who can build anything out of anything: whack off a left-over drain pipe, fasten a loop of tin roofing, dab some paint, and presto a mailbox. If one peers closely all the parts are still there, still a piece of roofing, a piece of pipe, but now the assembly exceeds the sum of the parts and is useful in a different way. In letters a Bricoleur is viewed as an intellectual MacGyver tacking bits of his heritage to sub-cultures about him for a new meaning-producing pastiche.

A Bricoleur is not a new thing, but it has become a new way of understanding old things: Epistemology, the Counter-Enlightenment, and the endless parade of "isms" of the 19th and 20th Centuries: Marxism, Modernism, Socialism, Surrealism, Abstract Expressionism, Minimalism — the list is endless, and often exclusive, each insisting that the other cannot be. The exegesis of these grand theories by deconstruction — substituting trace for presence — and similar activities during the past century shows these worldviews not as discoveries, instead but assemblies, by creative Bricoleurs who had been working in the background, stapling together meaning producing scenarios from textual bric-a-brac lying about.

Presently, encompassing worldviews in philosophy have been shelved, and master art movements of style and conclusion folded along side it, no more "isms" are being run up the flagpole, because no one is saluting. Pluralism and modest descriptions of the world have become the activity of fine arts and letters, personalization and private worlds the Zeitgeist. The common prediction was that the loss of grand narrative would result in a descent into end-of-history purposelessness, instead everywhere the Bricoleurs are busy manufacturing meaning-eliciting metaphor.

Motion Graphics, Bio-art, Information Art, Net Art, Systems Art, Glitch Art, Hacktivism, Robotic Art, Relational Esthetics and others, all current art movements tossed up by contemporary Bricoleurs in an endless salad. Revisit 19th Century Hudson River landscape painting? Why not. Neo-Rodin, Post-New Media? A Mormon dabbling with the Frankfurt School. Next month. With the quest for universal validity suspended there is a pronounced freedom to assemble lives filled with meaning from the nearby and at-hand, one just needs a Bricoleur.

GERALD SMALLBERG, MD
Practicing Neurologist, New York City; Playwright, Off-Off Broadway Productions, Charter Members; The Gold Ring

Bias Is The Nose For The Story

The exponential explosion of information and our ability to access it make our ability to validate its truthfulness not only more important but also more difficult. Information has importance in proportion to its relevance and meaning. Its ultimate value is how we use it to make decisions and put it in a framework of knowledge

Our perceptions are crucial in appreciating truth. However, we do not apprehend objective reality. Perception is based on recognition and interpretation of sensory stimuli derived from patterns of electrical impulses. From this data, the brain creates analogues and models that simulate tangible, concrete objects in the real world. Experience, though, colors and influences all of our perceptions by anticipating and predicting everything we encounter and meet. It is the reason Goethe advised that "one must ask children and birds how cherries and strawberries taste." This preferential set of intuitions, feelings, and ideas, less poetically characterized by the term bias, poses a challenge to the ability to weigh evidence accurately to arrive at truth. Bias is the non-dispassionate thumb which experience puts on the scale.

Our brains evolved having to make the right bet with limited information. Fortune, it has been said, favors the prepared mind. Bias in the form of expectation, inclination and anticipatory hunches helped load the dice in our favor and for that reason is hardwired into our thinking.

Bias is an intuition, sensitivity, receptiveness which acts as a lens or filter on all our perceptions. "If the doors of perception were cleansed," Blake said, "everything would appear to man as it is, infinite." But without our biases to focus our attention, we would be lost in that endless and limitless expanse. We have at our disposal an immeasurable assortment of biases and their combination in each of us is as unique as a fingerprint. These biases mediate between our intellect and emotions to help congeal perception into opinion, judgment, category, metaphor, analogy, theory, and ideology which frame how we see the world.

Bias is tentative. Bias adjusts as the facts change. Bias is a provisional hypothesis. Bias is normal.

Although bias is normal in the sense that it is a product of how we select and perceive information, its influence on our thinking cannot be ignored. Medical science has long been aware of the inherent bias, which occurs in collecting and analyzing clinical data. The double blind, randomized controlled study, the gold standard of clinical design, was developed in an attempt to nullify its influence.

We live in the world, however, not in a laboratory and bias cannot be eliminated. Bias critically utilized sharpens the collection of data by knowing when to look, where to look, and how to look. It is fundamental to both inductive and deductive reasoning. Darwin didn't collect his data to formulate the theory of evolution randomly or disinterestedly. Bias is the nose for the story.

Truth needs continually to be validated against all evidence, which challenges it fairly and honestly. Science with its formal methodology of experimentation and reproducibility of its findings is available to anyone who plays by its rules. No ideology, religion, culture or civilization is awarded special privileges or rights. The truth, which survives this ordeal, has another burden to bear. Like the words in a multi-dimensional crossword puzzle, it has to fit together with all the other pieces already in place. The better and more elaborate the fit, the more certain the truth. Science permits no exceptions. It is inexorably revisionary, learning from its mistakes, erasing and rewriting, even their most sacred texts, until the puzzle is complete.

THOMAS A. BASS
Professor of English at the University at Albany; Author, The Spy Who Loved Us

Open Systems

This year, *Edge* is asking us to identify a scientific concept that "would improve everybody's cognitive toolkit." Not clever enough to invent a concept of my own, I am voting for a winning candidate. It might be called the Swiss Army knife of scientific concepts, a term containing a remarkable number of useful tools for exploring cognitive conundrums. I am thinking of open systems, an idea that passes through thermodynamics and physics, before heading into anthropology, linguistics, history, philosophy, and sociology, until arriving, finally, into the world of computers, where it branches into other ideas such as open source and open standards.

Open standards allow knowledgeable outsiders access to the design of computer systems, to improve, interact with, or otherwise extend them. These standards are public, transparent, widely accessible, and royalty-free for developers and users. Open standards have driven innovation on the Web and allowed it to flourish as both a creative and commercial space.

Unfortunately, the ideal of an open web is not embraced by companies that prefer walled gardens, silos, proprietary systems, aps, tiered levels of access, and other metered methods for turning citizens into consumers. Their happy-face web contains tracking systems useful for making money, but these systems are also appreciated by the police states of the world, for they, too, have a vested interest in surveillance and closed systems.

Now that the Web has frothed through twenty years of chaotic inventiveness, we have to push back against the forces that would close it down. A similar push should be applied to other systems veering toward closure. "Citoyens, citoyennes, arm yourselves with the concept of openness."

MARK HENDERSON
Science Editor, The Times; Author, 50 Genetics Ideas You Really Need to Know

Science's Methods Aren't Just For Science

Most people tend to think of science in one of two ways. It is a body of knowledge and understanding about the world: gravity, photosynthesis and evolution. Or it is the technology that has emerged from the fruits of that knowledge: vaccines, computers and cars. Science is both of these things, yet as Carl Sagan so memorably explained in The Demon-Haunted World, it is something else besides. It is a way of thinking, the best approach yet devised (if still an imperfect one) to discovering progressively better approximations of how things really are.

Science is provisional, always open to revision in light of new evidence. It is anti-authoritarian: anybody can contribute, and anybody can be wrong. It seeks actively to test its propositions. And it is comfortable with uncertainty. These qualities give the scientific method unparalleled strength as a way of finding things out. Its power, however, is too often confined to an intellectual ghetto:

those disciplines that have historically been considered "scientific".

Science as a method has great things to contribute to all sorts of pursuits beyond the laboratory. Yet it remains missing in action from far too much of public life. Politicians and civil servants too seldom appreciate how tools drawn from both the natural and social sciences can be used to design more effective policies, and even to win votes.
In education and criminal justice, for example, interventions are regularly undertaken without being subjected to proper evaluation. Both fields can be perfectly amenable to one of science's most potent techniques — the randomised controlled trial — yet these are seldom required before new initiatives are put into place. Pilots are often derisory in nature, failing even to collect useful evidence that could be used to evaluate a policy's success.

Sheila Bird of the Medical Research Council, for instance, has criticised the UK's introduction of a new community sentence called the Drug Treatment and Testing Order, following pilots designed so poorly as to be worthless. They included too few subjects; they were not randomised; they did not properly compare the orders with alternatives; and judges were not even asked to record how they would otherwise have sentenced offenders.

The culture of public service could also learn from the self-critical culture of science. As Jonathan Shepherd, of the University of Cardiff, has pointed out, policing, social care and education lack the cadre of practitioner-academics that has served medicine so well. There are those who do, and there are those who research: too rarely are they the same people. Police officers, teachers and social workers are simply not encouraged to examine their own methods in the same way as doctors, engineers and bench scientists. How many police stations run the equivalent of a journal club?

The scientific method and the approach to critical thinking it promotes are too useful to be kept back for "science" alone. If it can help us to understand the first microseconds of creation and the structure of the ribosome, it can surely improve understanding of how best to tackle the pressing social questions of our time.

PAUL KEDROSKY
Editor, Infectious Greed; *Senior Fellow, Kauffman Foundation*

Shifting Baseline Syndrome

When John Cabot came to the Grand Banks off Newfoundland in 1497 he was astonished at what he saw. Fish, so many fish — fish in numbers he could hardly comprehend. According to Farley Mowat, Cabot wrote that the waters were so "swarming with fish [that they] could be taken not only with a net but in baskets let down and [weighted] with a stone."

The fisheries boomed for five hundred years, but by 1992 it was all over. The Grand Banks cod fishery was destroyed, and the Canadian government was forced to close it entirely, putting 30,000 fishers out of work. It has never recovered.

What went wrong? Many things, from factory fishing to inadequate oversight, but much of it was aided and abetted by treating each step toward disaster as normal. The entire path, from plenitude to collapse, was taken as the status quo, right up until the fishery was essentially wiped out.

In 1995 fisheries scientist Daniel Pauly coined a phrase for this troubling ecological obliviousness — he called it "shifting baseline syndrome". Here is how Pauly first described the syndrome: "Each generation of fisheries scientist accepts as baseline the stock situation that occurred at the beginning of their careers, and uses this to evaluate changes. When the next generation starts its career, the stocks have further declined, but it is the stocks at that time that serve as a new baseline. The result obviously is a gradual shift of the baseline, a gradual accommodation of the creeping disappearance of resource species…"

It is blindness, stupidity, intergeneration data obliviousness. Most scientific disciplines have long timelines of data, but many ecological disciplines don't. We are forced to rely on second-hand and anecdotal information — we don't have enough data to know what is normal, so we convince ourselves that this is normal.

But it often isn't normal. Instead, it is a steadily and insidiously shifting baseline, no different than convincing ourselves that winters have always been this warm, or this snowy. Or convincing ourselves that there have always been this many deer in the forests of eastern North America. Or that current levels of energy consumption per capita in the developed world are normal. All of these are shifting baselines, where our data inadequacy, whether personal or scientific, provides dangerous cover for missing important longer-term changes in the world around us.

When you understand shifting baseline syndrome it forces you to continually ask what is normal. Is this? Was that? And, at least as importantly, it asks how we "know" that it's normal. Because, if it isn't, we need to stop shifting the baselines and do something about it before it's too late.

ROSS ANDERSON
FRS; Professor, Security Engineering, Cambridge Computer Laboratory; Researcher in Security Psychology

Science Versus Theatre

Modern societies waste billions on protective measures whose real aim is to reassure rather than to reduce risk. Those of us who work in security engineering refer to this as "security theatre", and there are examples all around us. We're searched going into buildings that no terrorist would attack. Social network operators create the pretence of a small intimate group of "friends" in order to inveigle users into disclosing personal information that can be sold to advertisers; the users don't get privacy but privacy theatre. Environmental policy is a third example: cutting carbon emissions would cost lots of money and votes, so governments go for gesture policies that are highly visible even if their effect is negligible. Specialists know that most of the actions that governments claim will protect the security of the planet are just theatre.

Theatre thrives on uncertainty. Wherever risks are hard to measure, or their consequences hard to predict, appearance can be easier to manage than reality. Reducing uncertainty and exposing gaps between appearance and reality are among the main missions of science.

Our traditional approach was the painstaking accumulation of knowledge that enables people to understand risks, options and consequences. But theatre is a deliberate construct rather than just an accidental side-effect of ignorance, so perhaps we need to become more sophisticated about theatrical mechanisms too. Science communicators need to become adept at disrupting the show, illuminating the dark corners of the stage and making the masks visible for what they are.

ADAM ALTER
Psychologist; Assistant Professor, Stern School of Business, NYU

The "Cognitive Iceberg:" Humans Are Blind To Many Of The Processes That Shape Their Mental Lives

The human brain is an inconceivably complex tool, and while we're focusing on the business of daily life, our brains are processing multitudes of information below the surface of conscious awareness. Meanwhile, this peripheral information subtly shapes our thoughts, feelings and actions, and crafts some of our most critical life outcomes. This information takes many forms, but I'll illustrate the principle with three brief examples:

1. Color

Color is a ubiquitous feature of the environment, though we rarely notice colors unless they're particularly bright or deviate dramatically from our expectations. Nonetheless, colors have the capacity to shape a range of outcomes: men are ever so slightly more attractive to women when they wear red colored shirts (rather than shirts of another color); the same effect applies to women, who seem more attractive to men when their pictures are bounded by a red colored border. Red signals both romantic intent and dominance amongst lower-order species, and this same signal applies to men and women. This same relationship between red and dominance explains why sporting teams that wear red are more aggressive and tend to dominate sporting teams that wear other colors; meanwhile, sports referees and umpires assign more points to teams wearing red uniforms, which may explain in part why those teams tend to outperform teams wearing other colors. But, red isn't always beneficial: we've come to associate red with errors and caution, which makes people avoidant and in turn limits their creativity (though it also improves their attention to detail). These effects have sound bases in biology and human psychology, but that doesn't make them any less remarkable or surprising to the lay population.

2. Weather and Ambient Temperature

No one's surprised that the sunny warmth of summer makes people happy, but weather conditions and ambient temperature have other more surprising effects on our mental lives. Rainy weather makes us more introspective and thoughtful, which in turn improves our memory — in one study, people remembered the features of a store with greater accuracy on rainy days than on sunny days. On a grander scale, the stock market tends to rise on fine, sunny days, while cooler, rainy days prompt sluggishness and brief downturns. More surprising, still, is the relationship between changes in weather and various accidents, suicide, depression and irritability, all of which are claimed to respond to changes in the electrical state of the atmosphere. The metaphor between warmth and human kindness is also more than a metaphor, as recent studies have shown that people find strangers more likable when they form their first impressions while holding a cup of warm coffee. The warmth-kindness metaphor extends to social exclusion, as people literally feel colder when they've been socially excluded. The simple relationship between fine weather and happiness is joined by a series of more surprising and complicated relationships between weather and warmth on the one hand, and a range of important life outcomes on the other.

3. Symbols and Images

Urban landscapes are populated by thousands of symbols and images that unwittingly influence how we think and behave. Self-identified Christians tend to behave more honestly when they're exposed to an image of the crucifix, even when they have no conscious memory of seeing the crucifix in the first place. Honesty is a virtue, but another experiment showed that Christians held lower opinions of themselves after they were subliminally exposed to an image of then Pope John Paul II. On a brighter note, people think more creatively when they're exposed to the Apple Computers logo, or when they witness the illumination of an incandescent light bulb; both the Apple logo and the illuminated light bulb are popularly associated with creativity, and deeply ingrained metaphors once activated have the capacity to shape actual behavior. Similar associative logic suggests that national flags should prompt unity, and indeed a sample of left-wing and right-wing Israelis were more accommodating of opposing political views when they were subliminally exposed to an image of the Israeli flag. Likewise, a sample of Americans responded more favorably to Muslims when seated in front of a large U.S. flag.

These three cues — colors, weather conditions, and symbols and images — are joined by dozens of others that have a surprising capacity to influence how we think, feel, behave, and decide. Once we understand what those cues are and how they shape our mental lives, we're better equipped to harness them to our advantage.

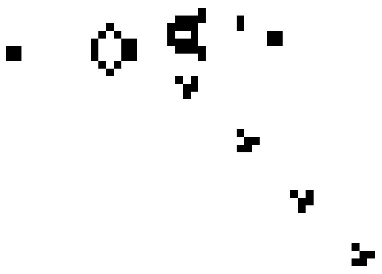
NICK BOSTROM
Professor; Director, Future of Humanity Institute, Faculty of Philosophy & Oxford Martin School, University of Oxford

Game of Life — And Looking For Generators

The Game of Life is a cellular automaton, invented by the British mathematician John Horton Conway in 1970.

Many will already be acquainted with Conway's invention. For those aren't, the best way to familiarize oneself with it is to experiment with one of the many free implementations that can be found on the Internet (or better yet, if you have at least rudimentary programming skills, make one yourself).

Basically, there is a grid and each cell can be in either of two states: dead or alive. One starts by seeding the grid with some initial distribution of live cells. Then one lets the system evolve according to three simple rules.

(Birth) A dead cell with exactly three live neighbours becomes a live cell. (Survival) A live cell with two or three neighbours stays alive. (Death) Any other cell dies or remains dead.	 "Gosper's Glider Gun"

Why is this interesting? Certainly, the Game of Life is not biologically realistic. It doesn't do anything useful. It isn't even really game in the ordinary sense of the word.

But it's a brilliant demonstration platform for several important concepts — a virtual 'philosophy of science laboratory'. (The philosopher Daniel Dennett has expressed the view that it should be incumbent on every philosophy student to be acquainted with it.) It gives us the microcosm, simple enough that we can easily understand how things are happening, yet with sufficient generative power to produce interesting phenomena.

By playing with the Game of Life for an hour, one can develop an intuitive understanding of the following concepts and ideas:

• *Emergent complexity* — How complex patterns can arise from very simple rules.

• *Basic dynamics concepts* — such as the distinction between laws of nature and initial conditions.

• *Levels of explanation* — One quickly notices patterns arising that can be efficiently described in higher-level terms (such as "gliders", a specific kind of pattern that crawls across the screen) but that are quite cumbersome to describe in the language of the basic physics upon which the patterns supervene (i.e., in terms of individual pixels being alive or dead)

• *Supervenience* — This leads one to think about the relation between different sciences in the real world… Does chemistry, likewise, supervene on physics? Biology on chemistry? The mind on the brain?

• *Concept formation, and carving nature at its joints* — how and why we recognize certain types of pattern and give them names. For instance, in the Game of Life one distinguishes "still lives", small local patterns that are stable and unchanging; "oscillators", local patterns that perpetually cycle through a fixed sequence of states; "spaceships", patterns that move across the grid (such as gliders); "guns", stationary patterns that send out an incessant stream of spaceships; and "puffer trains", patterns that move themselves across the grid leaving debris behind. As one begins to form these and other concepts, the chaos on the screen gradually becomes more comprehensible. Developing concepts that carve nature at its joints is the first crucial step towards understanding, not only in the Game of Life but in science and in ordinary life as well.

At a more advanced level, one discovers that the Game of Life is Turing complete. That is, it's possible to build a pattern that acts like a universal Turing machine. Thus, any computable function could be implemented in the Game of Life — including perhaps a function that describes a universe like the one we inhabit. It's also possible to build a universal constructor in the Game of Life, a pattern which can build many types of complex objects, including copies of itself. Nonetheless, it seems that the structures that evolve into Game of Life are different from the ones who find in the real world: Game of Life structures tend to be very fragile in the sense that changing a single cell will often cause them to dissolve. It is interesting to try to figure out exactly what it is about the rules of the Game of Life and the laws of physics that govern our own universe that accounts for these differences.

Conway's Life is perhaps best viewed not as a single shorthand abstraction, but rather as a generator of such abstractions. We get a whole bunch of useful abstractions — or at least a recipe for how to generate them — all for the price of one.

And this, in fact, points us to one especially useful shorthand abstraction: the strategy of Looking for Generators. We confront many problems. We can try to solve them one by one. But alternatively, we can try to create a generator that produces solutions to multiple problems.

Consider, for example, the challenge of advancing scientific understanding. We might make progress by directly tackling some random scientific problem. But perhaps we can make more progress by Looking for Generators and focusing our efforts on certain subsets of scientific problems, namely those whose solutions would do most to facilitate the discovery of many other solutions. On this approach, we would pay most attention to innovations in methodology that can be widely applied; and to the development of scientific instruments that can enable many new experiments; and to improvements in institutional processes, such as peer review, that can make many decisions about whom to hire, fund, and promote more closely reflecting true merit.

In the same vein, we would be extremely interested in developing effective biomedical cognitive enhancers and other ways of improving the human thinker — the brain being, after all, the generator par excellence.

ROBERT SAPOLSKY
Neuroscientist, Stanford University; Author, Monkeyluv

The Lure Of A Good Story

Various concepts come to mind for inclusion in that cognitive toolkit. "Emergence," or related to that, "the failure of reductionism" — mistrust the idea that if you want to understand a complex phenomenon, the only tool of science to use is to break it into its component parts, study them individually in isolation, and then glue the itty-bitty little pieces back together. This often doesn't work and, increasingly, it seems like it doesn't work for the most interesting and important phenomena out there. To wit — you have a watch that doesn't run correctly and often, indeed, you can fix it by breaking it down to its component parts and finding the gear that has had a tooth break (actually, I haven't a clue if there is any clock on earth that still works this way). But if you have a cloud that doesn't rain, you don't break it down to its component parts. Ditto for a person whose mind doesn't work right. Or for going about understanding the problems of a society or ecosystem. So that was a scientific concept that was tempting to cite.

Related to that are terms like "synergy" and "interdisciplinary," but heaven save us from having to hear more about those words. There are now whole areas of science where you can't get a faculty position unless you work one of those words into the title of your job talk and have it tattooed on the small of your back.

Another useful scientific concept is "genetic vulnerability." This would be great if it found its way into everyone's cognitive toolkit because its evil cousins of genetic inevitability and genetic determinism are already deeply entrenched there, and with long long legacies of bad consequences. Everyone should be taught about work like that of Avshalom Caspi and colleagues, who looked at genetic polymorphisms related to various neurotransmitter systems that are associated with psychiatric disorders and anti-social behaviors. Ah ha, far too many people will say, drawing on that nearly useless, misshapen tool of genetic determinism, have one of those polymorphisms and you're hosed by inevitability. And instead, what those studies beautifully demonstrate is how these polymorphisms carry essentially zero increased risk of those disorders…..unless you grow up in particularly malign environments. Genetic determinism, my tuches.

But the scientific concept that I've chosen is one that is useful simply because it isn't a scientific concept, can be the antithesis of — "anecdotalism." Every good journalist knows its power — start an article with statistics about foreclosure rates or feature a family victimized by some bank? No brainer. Display maps showing the magnitudes of refugees flowing out of Darfur or the face of one starving orphan in a camp? Obvious choice. Galvanize the readership.

But anecdotalism is potentially a domain of distortion as well. Absorb the lessons of science and cut saturated fats from your diet, or cite the uncle of the spouse of a friend who eats nothing but pork rinds and is still pumping iron at age 110? Depend on one of the foundations of the 20th century's extension of life span and vaccinate your child, or obsess over a National Enquirer-esque horror story of one vaccination disaster and don't immunize? I shudder at the current potential for another case of anecdotalism — I write four days after the Arizona shooting of Gabby Giffords and 19 other people by Jared Loughner. As of this writing, experts such as the esteemed psychiatrist Fuller Torrey are guessing that Loughner is a paranoid schizophrenic. And if this is true, this anecdotalism will give new legs to the tragic misconception that the mentally ill are more dangerous than the rest of us.

So maybe when I say argue for "anecdotalism" going into everyone's cognitive toolkit, I am really arguing for two things to be incorporated — a) appreciation of how distortive it can be, and b) recognition, in a salute to the work of people like Tversky and Kahnemann, of its magnetic pull, its cognitive satisfaction. As a social primate complete with a region of the cortex specialized for face recognition, the individual face — whether literal or metaphorical — has a special power. But unappealing, unintuitive patterns of statistics and variation generally teach us much more.

CHRISTINE FINN
Archaeologist, Journalist; Author, Artifacts

Absence and Evidence

I first heard the words "absence of evidence is not evidence of absence" as a first-year archaeology undergraduate. I now know it was part of Carl Sagan's retort against evidence from ignorance, but at the time the non-ascribed quote was part of the intellectual toolkit offered by my professor to help us make sense of the process of excavation.

Philosophically this is a challenging concept, but at an archaeological site all became clear in the painstaking tasks of digging, brushing and trowelling. The concept was useful to remind us, as we scrutinised what was there, to take note of the possibility of what was not there. What we were finding, observing, and lifting, were the material remains, the artifacts which had survived, usually as a result of their material or the good fortune of their deposition. There were barely recordable traces of what was there — the charcoal layer of a prehistoric hearth for example — and others recovered in the washing, or the lab, but this was still tangible evidence. What the concept brought home to us was the invisible traces, the material which had gone from our reference point in time, but which still had a bearing in the context.

It was powerful stuff which stirred my imagination. I looked for more examples outside philosophy. I learned about the great near-Eastern archaeologist, Sir Leonard Woolley who, when excavating the 3rd millennium BC Mesopotamian palace at Ur, modern day Iraq. There, he conjured up musical instruments from their absence. The evidence was the holes left in the excavation layers, the ghosts of wooden objects which had long since disappeared into time. He used this absence to advantage by making casts of the holes and realising the instruments as reproductions. It struck me at the time that he was creating works of art. The absent lyres were installations which he rendered as interventions, and transformed into artifacts. More recently the British artist Rachel Whiteread has made her name through an understanding of the absent form, from the cast of a house to the undersides and spaces of domestic interiors.

Recognising the evidence of absence is not about forcing a shape on the intangible, but acknowledging a potency in the not-thereness. Taking the absence concept to be a positive idea, I suggest interesting things happen. For years middle-eastern archaeologists puzzled over the numerous, isolated bath-houses and other structures in the deserts of North Africa. Where was the evidence of habitation? The clue was in the absence: the buildings were used by nomads who left only camel prints in the sand. Their habitations were ephemeral, tents which, if not taken away with them, were of such material that they would too disappear into the sand. Observed again in this light, the ariel photos of desert ruins are hauntingly repopulated.

The absent evidence of ourselves is all around us, beyond the range of digital traces.

When my parents died and I inherited their house, the task of clearing their rooms was both emotional, and archaeological. The last mantelpiece in the sitting room had accreted over 35 years of married life, a midden of photos, ephemera, beach-combing trove and containers of odd buttons and old coins. I wondered what a stranger — maybe a forensic scientist, or traditional archaeologist — would make of this array if the narrative was woven simply from the tangible evidence. But as I took the assemblage apart in a charged moment, I felt there was a whole lot of no-thing which was coming away with it. Something invisible, and unquantifiable, which had been holding these objects in that context.

I recognised the feeling, and cast my memory back to my first archaeological excavation. It was of a long-limbed hound, one of those 'fine, hunting dogs' the classical writer, Strabo, described as being traded from ancient Britain into the Roman world. As I knelt in the 2000 year old grave, carefully removing each tiny bone, as if engaged with a sculptural process, I felt the presence of something absent. I could not quantify it, but it was that unseen 'evidence' which, it seemed, had given the dog its dog-ness.

JON KLEINBERG
Professor, Computer Science, Cornell University

E Pluribus Unum

If you used a personal computer 25 years ago, everything you needed to worry about was taking place in the box in front of you. Today, the applications you use over the course of an hour are scattered across computers all over the world; for the most part, we've lost the ability to tell where our data sits at all. We invent terms to express this lost sense of direction: our messages, photos, and on-line profiles are all somewhere in "The Cloud".

The Cloud is not a single thing; what you think of as your Gmail account or Facebook profile is in fact made possible by the teamwork of a huge number of physically dispersed components — a distributed system, in the language of computer science. But we can think of it as a single thing, and this is the broader point: The ideas of distributed systems apply whenever we see many small things working independently but cooperatively to produce the illusion of a single unified experience. This effect takes place not just on the Internet, but in many other domains as well. Consider for example a large corporation that is able to release new products and make public announcements as though it were a single actor, when we know that at a more detailed level it consists of tens of thousands of employees. Or a massive ant colony engaged in coordinated exploration, or the neurons of your brain creating your experience of the present moment.

The challenge for a distributed system is to achieve this illusion of a single unified behavior in the face of so much underlying complexity. And this broad challenge, appropriately, is in fact composed of many smaller challenges in tension with each other.

One basic piece of the puzzle is the problem of consistency. Each component of a distributed system sees different things and has a limited ability to communicate with everyone else, so different parts of the system can develop views of the world that are mutually inconsistent. There are numerous examples of how this can lead to trouble, both in technological domains and beyond. Your handheld device doesn't sync with your e-mail, so you act without realizing that there's already been a reply to your message. Two people across the country both reserve seat 5F on the same flight at the same time. An executive in an organization "didn't get the memo" and so strays off-message. A platoon attacks too soon and alerts the enemy.

It is natural to try "fixing" these kinds of problems by enforcing a single global view of the world, and requiring all parts of the system to constantly refer to this global view before acting. But this undercuts many of the reasons why one uses a distributed system in the first place. It makes the component that provides the global view a massive bottleneck, and a highly dangerous single point of potential failure. The corporation doesn't function if the CEO has to sign off on every decision.

To get a more concrete sense for some of the underlying design issues, it helps to walk through an example in a little detail, a basic kind of situation in which we try to achieve a desired outcome with information and actions that are divided over multiple participants. The example is the problem of sharing information securely: imagine trying to back up a sensitive database on multiple computers, while protecting the data so that it can only be reconstructed if a majority of the backup computers cooperate. But since the question of secure information sharing ultimately has nothing specifically to do with computers or the Internet, let's formulate it instead using a story about a band of pirates and a buried treasure.

Suppose that an aging Pirate King knows the location of a secret treasure, and before retiring he intends to share the secret among his five shiftless sons. He wants them to be able to recover the treasure if three or more of them work together, but he also wants to prevent a "splinter group" of one or two from being able to get the treasure on their own. To do this, he plans to split the secret of the location into five "shares," giving one to each son, in such a way that he ensures the following condition. If at any point in the future, at least three of the sons pool their shares of the secret, then they will know enough to recover the treasure. But if only one or two pool their shares, they will not have enough information.

How to do this? It's not hard to invent ways of creating five clues so that all of them are necessary for finding the treasure. But this would require unanimity among the five sons before the treasure could be found. How can we do it so that cooperation among any three is enough, and cooperation among any two is insufficient?

Like many deep insights, the answer is easy to understand in retrospect. The Pirate King draws a secret circle on the globe (known only to himself) and tells his sons that he's buried the treasure at the exact southernmost point on this circle. He then tells each son a different point on this circle. Three points are enough to uniquely reconstruct a circle, so any three pirates can pool their information, identify the circle, and find the treasure. But for any two pirates, an infinity of circles pass through their two points, and they cannot know which is the one they need for recovering the secret. It's a powerful trick, and broadly applicable; in fact, versions of this secret-sharing scheme form a basic principle of modern data security, discovered by the cryptographer Adi Shamir, where arbitrary data can be encoded using points on a curve, and reconstructed from knowledge of other points on the same curve.

The literature on distributed systems is rich with ideas in this spirit. More generally, the principles of distributed systems give us a way to reason about the difficulties inherent in complex systems built from many interacting parts. And so to the extent that we sometimes are fortunate enough to get the impression of a unified Web, a unified global banking system, or a unified sensory experience, we should think about the myriad challenges involved in keeping these experiences whole.

JOHN MCWHORTER
Linguist; Cultural Commentator; William Simon Fellow, Colmbia; Author, That Being Said

Path Dependence

In an ideal world all people would spontaneously understand that what political scientists *call path dependence* explains much more of how the world works than is apparent. Path dependence refers to the fact that often, something that seems normal or inevitable today began with a choice that made sense at a particular time in the past, but survived despite the eclipse of the justification for that choice, because once established, external factors discouraged going into reverse to try other alternatives.

The paradigm example is the seemingly illogical arrangement of letters on typewriter keyboards. Why not just have the letters in alphabetical order, or arrange them so that the most frequently occurring ones are under the strongest fingers? In fact, the first typewriter tended to jam when typed on too quickly, so its inventor deliberately concocted an arrangement that put A under the ungainly little finger. In addition, the first row was provided with all of the letters in the word *typewriter* so that salesmen, new to typing, could wangle typing the word using just one row.

Quickly, however, mechanical improvements made faster typing possible, and new keyboards placing letters according to frequency were presented. But it was too late: there was no going back. By the 1890s typists across America were used to QWERTY keyboards, having learned to zip away on new versions of them that did not stick so easily, and retraining them would have been expensive and, ultimately, unnecessary. So QWERTY was passed down the generations, and even today we use the queer QWERTY configuration on computer keyboards where jamming is a mechanical impossibility.

The basic concept is simple, but in general estimation tends to be processed as the province of "cute" stories like the QWERTY one, rather than explaining a massive weight of scientific and historical processes. Instead, the natural tendency is to seek explanations for modern phenomena in present-day conditions.

One may assume that cats cover their waste out of fastidiousness, when the same creature will happily consume its own vomit and then jump on your lap. Cats do the burying as an instinct from their wild days when the burial helped avoid attracting predators, and there is no reason for them to evolve out of the trait now (to pet owners' relief). I have often wished there were a spontaneous impulse among more people to assume that path dependence-style explanations are as likely as jerry-rigged present-oriented ones.

For one, that the present is based on a dynamic mixture of extant and ancient conditions is simply more interesting than assuming that the present (mostly) all there is, with history as merely "the past," interesting only for seeing whether something that happened then could now happen again, which is different from path dependence.

For example, path dependence explains a great deal about language which is otherwise attributed to assorted just-so explanations. Much of the public embrace of the idea that one's language channels how one thinks is based on this kind of thing. Robert McCrum celebrates English as "efficient" in its paucity of suffixes of the kind that complexify most European languages. The idea is that this is rooted in something in its speakers' spirit, which would have propelled them to lead the world via exploration and the Industrial Revolution.

But English lost its suffixes starting in the eighth century, A.D. when Vikings invaded Britain and so many of them learned the language incompletely that children started speaking it that way. After that, you can't create gender and conjugation out of thin air — there's no going back until gradual morphing recreates such things over eons of time. That is, English's current streamlined syntax has nothing to do with any present-day condition of the spirit, nor with any even four centuries ago. The culprit is path dependence, as are most things about how a language is structured.

Or, we hear much lately about a crisis in general writing skills, suposedly due to email and texting. But there is a circularity here — why, precisely, could people not write emails and texts with the same "writerly" style that people used to couch letters in? Or, we hear of a vaguely defined effect of television, despite that kids were curled up endlessly in front of the tube starting in the fifties, long before the eighties when outcries of this kind first took on their current level of alarm in the report *A Nation at Risk*.

Once again, the presentist explanation does not cohere, whereas one based on an earlier historical development that there is no turning back from does. Public American English began a rapid shift from cosseted to less formal "spoken" style in the sixties, in the wake of cultural changes amidst the counterculture. This sentiment directly affected how language arts textbooks were composed, the extent to which any young person was exposed to an old-fashioned formal "speech," and attitudes towards the English language heritage in general. The result: a linguistic culture stressing the terse, demotic, and spontaneous. After just one generation minted in this context, there was no way to go back. Anyone who decided to communicate in the grandiloquent phraseology of yore would sound absurd and be denied influence or exposure. Path dependence, then, identifies this cultural shift as the cause of what dismays, delights, or just interests us in how English is currently used, and reveals television, email and other technologies as merely epiphenomenal.

Most of life looks path dependent to me. If I could create a national educational curriculum from scratch, I would include the concept as one taught to young people as early as possible.

SCOTT D. SAMPSON
Paleontologist and science communicator; Author: Dinosaur Odyssey: Fossil Threads in the Web of Life

INTERBEING

Humanity's cognitive toolkit would greatly benefit from adoption of "interbeing," a concept that comes from Vietnamese Buddhist monk Thich Nhat Hanh. In his words:

"If you are a poet, you will see clearly that there is a cloud floating in [a] sheet of paper. Without a cloud, there will be no rain; without rain, the trees cannot grow; and without trees, we cannot make paper. The cloud is essential for the paper to exist. If the cloud is not here, the sheet of paper cannot be here either . . . "Interbeing" is a word that is not in the dictionary yet, but if we combine the prefix "inter-" with the verb to be," we have a new verb, inter-be. Without a cloud, we cannot have a paper, so we can say that the cloud and the sheet of paper *inter-are*. . . . "To be" is to inter-be. You cannot just be by yourself alone. You have to inter-be with every other thing. This sheet of paper is, because everything else is."

Depending on your perspective, the above passage may sound like profound wisdom or New Age mumbo-jumbo. I would like to propose that interbeing is a robust scientific fact — at least insomuch as such things exist — and, further, that this concept is exceptionally critical and timely.

Arguably the most cherished and deeply ingrained notion in the Western mindset is the separateness of our skin-encapsulated selves — the belief that we can be likened to isolated, static machines. Having externalized the world beyond our bodies, we are consumed with thoughts of furthering our own ends and protecting ourselves. Yet this deeply rooted notion of isolation is illusory, as evidenced by our constant exchange of matter and energy with the "outside" world. At what point did your last breath of air, sip of water, or bite of food cease to be part of the outside world and become you? Precisely when did your exhalations and wastes cease being you? Our skin is as much permeable membrane as barrier, so much so that, like a whirlpool, it is difficult to discern where "you" end and the remainder of the world begins. Energized by sunlight, life converts inanimate rock into nutrients, which then pass through plants, herbivores, and carnivores before being decomposed and returned to the inanimate Earth, beginning the cycle anew. Our internal metabolisms are intimately interwoven with this Earthly metabolism; one result is the replacement of every atom in our bodies every seven years or so.

You might counter with something like, "Ok, sure, everything changes over time. So what? *At any given moment*, you can still readily separate self from other."

Not quite. It turns out that "you" are not one life form — that is, one self — but many. Your mouth alone contains more than 700 distinct *kinds* of bacteria. Your skin and eyelashes are equally laden with microbes and your gut houses a similar bevy of bacterial sidekicks. Although this still leaves several bacteria-free regions in a healthy body — for example, brain, spinal cord, and blood stream — current estimates indicate that your physical self possesses about a trillion human cells and about 10 trillion bacterial cells. In other words, *at any given moment*, your body is about 90% nonhuman, home to many more life forms than the number of people presently living on Earth; more even than the number of stars in the Milky Way Galaxy! To make things more interesting still, microbiological research demonstrates that we are utterly dependent on this ever-changing bacterial parade for all kinds of "services," from keeping intruders at bay to converting food into useable nutrients.

So, if we continually exchange matter with the outside world, if our bodies are completely renewed every few years, and if each of us is a walking colony of *trillions* of largely symbiotic life forms, exactly what is this self that we view as separate? You are not an isolated being. Metaphorically, to follow current bias and think of your body as a machine is not only inaccurate but destructive. Each of us is far more akin to a whirlpool, a brief, ever-shifting concentration of energy in a vast river that's been flowing for billions of years. The dividing line between self and other is, in many respects, arbitrary; the "cut" can be made at many places, depending on the metaphor of self one adopts. We must learn to see ourselves not as isolated but as permeable and interwoven — selves within larger selves, including the species self (humanity) and the biospheric self (life). The interbeing perspective encourages us to view other life forms not as objects but subjects, fellow travelers in the current of this ancient river. On a still more profound level, it enables us to envision ourselves and other organisms not as static "things" at all, but as *processes* deeply and inextricably embedded in the background flow.

One of the greatest obstacles confronting science education is the fact that the bulk of the universe exists either at extremely large scales (e.g., planets, stars, and galaxies) or extremely small scales (e.g., atoms, genes, cells) well beyond the comprehension of our (unaided) senses. We evolved to sense only the middle ground, or "mesoworld," of animals, plants, and landscapes. Yet, just as we have learned to accept the non-intuitive, scientific insight that the Earth is not the center of the universe, so too must we now embrace the fact that we are not outside or above nature, but fully enmeshed within it. Interbeing, an expression of ancient wisdom backed by science, can help us comprehend this radical ecology, fostering a much-needed transformation in mindset.

AMANDA GEFTER
Books & Arts editor, New Scientist; founder and editor, CultureLab

Duality

It is one of the stranger ideas to emerge from recent physics. Take two theories that describe utterly dissimilar worlds — worlds with different numbers of dimensions, different geometries of spacetime, different building blocks of matter. Twenty years ago, we'd say those are indisputably disparate and mutually exclusive worlds. Today, there's another option: two radically different theories might be *dual* to one another — that is, they might be two very different manifestations of the same underlying reality.

Dualities are as counterintuitive a notion as they come, but physics is riddled with them. When physicists looking to unite quantum theory with gravity found themselves with five very different but equally plausible string theories, it was an embarrassment of riches — everyone was hoping for one "theory of everything", not five. But duality proved to be the key ingredient. Remarkably, all five string theories turned out to be dual to one another, different expressions of a single underlying theory.

Perhaps the most radical incarnation of duality was discovered in 1997 by Juan Maldacena. Maldacena found that a version of string theory in a bizarrely shaped universe with five large dimensions is mathematically dual to an ordinary quantum theory of particles living on that universe's four-dimensional boundary. Previously, one could argue that the world was made up of particles *or* that the world was made up of strings. Duality transformed *or* into *and* — mutually exclusive hypotheses, both equally true.

In everyday language, duality means something very different. It is used to connote a stark dichotomy: male and female, east and west, light and darkness. Embracing the physicist's meaning of duality, however, can provide us with a powerful new metaphor, a one-stop shorthand for the idea that two very different things might be equally true. As our cultural discourse is becoming increasingly polarized, the notion of duality is both more foreign and more necessary than ever. If accessible in our daily cognitive toolkit, it could serve as a potent antidote to our typically Boolean, two-valued, zero-sum thinking — where statements are either true or false, answers are yes or no, and if I'm right, then you are wrong. With duality, there's a third option. Perhaps my argument is right and yours is wrong; perhaps your argument is right and mine is wrong; or, just maybe, our opposing arguments are dual to one another.

That's not to say that we ought to descend into some kind of relativism, or that there are no singular truths. It is to say, though, that truth is far more subtle than we once believed, and that it shows up in many guises. It is up to us to recognize it in all its varied forms.

ERIC TOPOL
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Hunting for Root Cause: The Human "Black Box"

Root cause analysis is an attractive concept for certain matters in industry, engineering and quality control. A classic application is to determine why a plane crashed by finding the proverbial "black box" — the tamper-proof event data recorder. Even though this box is usually bright orange, the term symbolizes the sense of dark matter, a container with critical information to help illuminate what happened. Getting the black box audio recording is just one component of a root cause analysis for why a plane goes down.

Man is gradually being morphed into an event data recorder by virtue of each person's digital identity and presence on the web. Not only do we post our own data, sometimes unwittingly, but also others post information about us, and all of this is permanently archived. In that way it is close to tamper-proof. With increasing use of biosensors, high-resolution imaging (just think of our current cameras and video recording, no less digital medical imaging), and DNA sequencing, the human data event recorder will be progressively enriched with data and information.

In our busy, networked lives with constant communication, streaming and distraction, the general trend has moved away from acquiring deep knowledge for why something happened. This is best exemplified in health and medicine. Physicians rarely seek root cause. If a patient has a common condition such as high blood pressure, diabetes, or asthma, he or she is put on some prescription drugs without any attempt at ascertaining why the individual crashed — certainly a new, chronic medical condition can be likened to such an event. There are usually specific reasons for these disorders but they are not hunted down. Taken to an extreme, when an individual dies and the cause is not known it is now exceedingly rare that an autopsy is ever performed. Doctors have generally caved in their quest to define root cause, and they are fairly representative of most of us. Ironically, this is happening at a time when there is unprecedented capability for finding the explanation. But we're just too busy.

So to tweak our cognitive performance in the digital world where there is certainly no shortage of data, it's time to use it and understand, as fully as possible, why unexpected or unfavorable things happen. Or even why something great transpired. It's a prototypic scientific concept that has all too often been left untapped. Each person is emerging as an extraordinary event recorder and part of the Internet of all things. Let's go deep. Nothing unexplained these days should go without a hunt.

ALUN ANDERSON
Senior Consultant (and former Editor-in-Chief and Publishing Director of New Scientist)*; Author,* After the Ice: Life, Death, and Geopolitics in the New Arctic

Homo Dilatus

Our species might well be renamed *Homo Dilatus*, the procrastinating ape. Somewhere in our evolution we acquired the brain circuitry to deal with sudden crises and respond with urgent action. Steady declines and slowly developing threats are quite different. "Why act now when the future is far off," is the maxim for a species designed to deal with near-term problems and not long term uncertainties. It's a handy view of humankind which everyone who uses science to change policy should keep in their mental took kit, and one that that is greatly reinforced by the endless procrastination in tacking climate change. Cancun follows Copenhagen follows Kyoto but the more we dither and no extraordinary disaster follows, the more dithering seems just fine.

Such behaviour is not unique to climate change. It took the sinking of the Titanic to put sufficient life boats on passenger ships, the huge spill from the Amoco Cadiz to set international marine pollution rules and the Exxon Valdez disaster to drive the switch to double-hulled tankers. The same pattern is seen in the oil industry, with the Gulf spill the latest chapter in the disaster first-regulations later mindset of Homo dilatus.

There are a million similar stories from human history. So many great powers and once dominant corporations slipped away as their fortunes declined without the crisis they needed to force change. Slow and steady change simply leads to habituation not action: you could walk in the British countryside now and hear only a fraction of the birdsong that would have delighted a Victorian poet but we simply cannot feel insidious loss. Only a present crisis wakes us.

So puzzling is our behaviour that the "psychology of climate change" has become a significant area of research, with efforts to find those vital messages that will turn our thinking towards the longer term and away from the concrete now. Sadly, the skull of Homo dilatus seems too thick for the tricks that are currently on offer. In the case of climate change, we might better focus on adaptation until a big crisis comes along to rivet our minds. The complete loss of the summer Arctic ice might be the first. A huge dome of shining ice, about half the size of the United States covers the top of the world in summer now. In a couple of decades it will likely be gone. Will millions of square kilometers of white ice turning to dark water feel like a crisis? If that doesn't do it then following soon after will likely be painful and persistent droughts across the United States, much of Africa, Southeast Asia and Australia.

Then the good side of Homo dilatus may finally surface. A crisis will hopefully bring out the Bruce Willis in all of us and with luck we'll find an unexpected way to right the world before the end of the reel. Then we'll no doubt put our feet up again.

SATYAJIT DAS
Expert, Financial Derivatives and Risk; Author, Traders, Guns & Money: Knowns and Unknowns in the Dazzling World of Derivatives

Parallel Errors

Confluence of factors is highly influential in setting off changes in complex systems. A common example is in risk — the "*Swiss cheese theory*". Losses only occur if all controls fail — the holes in the Swiss cheese align.

Confluence, coincidence of events in a single setting, is well understood. Parallel developments, often in different settings or disciplines, can be influential in shaping events. A coincidence of similar logic and processes in seemingly unrelated activities provide indications of likely future developments and risks. The ability to better recognize *"parallelism"* would improve cognitive processes.

Economic forecasting is dismal, prompting John Kenneth Galbraith to remark that economists were only put on earth to make astrologers look good. Few economists anticipated the current financial problems, at least before they happened.

However, the art market proved remarkably accurate in anticipating developments, especially the market in the work of Damien Hirst — the best known of a group of artists dubbed *yBAs* (young British Artists).

Hirst's most iconic work — *The Physical Impossibility of Death in the Mind of Someone Living* — is a 14-foot (4.3 meter) tiger shark immersed in formaldehyde in a vitrine weighing over two tons. Charles Saatchi (the advertising guru) bought it for £50,000. In December 2004, Saatchi sold the work to Steve Cohen, founder and principal of the uber hedge fund — SAC Capital Advisers, which manages $20 billion. Cohen paid $12 million for *The Physical Impossibility of Death in the Mind of Someone Living*, although there are allegation that it was *only* $8 million.

In June 2007, Damien Hirst tried to sell a life size platinum cast of a human skull, encrusted with £15 million worth of 8,601 pave-set industrial diamonds, weighing 1,100 carats including a 52.4 carat pink diamond in the center of the forehead valued at £4 million. *For the Love of God* was a *memento mori,* in Latin *remember you must die*. The work was offered for sale at £50 million as part of Hirst's *Beyond Belief* show. In September 2007, *For the Love of God* was sold to Hirst and some investors for full price, for later resale.

The sale of *The Physical Impossibility of Death in the Mind of Someone Living* marked the final phase of the irresistible rise of markets. The failure of For the Love of God to sell marked its zenith as clearly as any economic marker.

Parallelism exposes common thought processes and similar valuation approaches to unrelated objects.

Hirst was the artist of choice for conspicuously consuming hedge fund managers, who were getting very rich managing money. Inflated prices suggested the presence of *"irrational excess"*. The nature of sought after Hirst pieces and even their titles provided an insight into the hubristic self-image of financiers. With its jaws gaping, poised to swallow its prey, *The Physical Impossibility of Death in the Mind of Someone Living* mirrored the killer instincts of hedge funds, feared predators in financial markets. Cohen "*… liked the whole fear factor*."

The work of Japanese artist Takeshi Murakami provides confirmation. Inspired by Hokusai's famous 19th century woodblock print *The Great Wave of Kanagawa*, Murakami's 727 paintings showed Mr. DOB, a post nuclear Mickey Mouse character, as a god riding on a cloud or a shark surfing on a wave. The first 727 is owned by New York's Museum of Modern Art, the second by Steve

Cohen.

Parallelism is also evident in the causes underlying several crises facing humanity. It is generally acknowledged that high levels of debt were a major factor in the ongoing global financial crisis. What is missed is that the logic of debt is similar to one underlying other problematic issues.

There is a striking similarity between the problems of the financial system, irreversible climate change and shortages of vital resources like oil, food and water. Economic growth and wealth was based on borrowed money. Debt allowed society to borrow from the future. It accelerated consumption, as debt is used to purchase something today against the uncertain promise of paying back the borrowing in the future. Society polluted the planet, creating changes in the environment which are difficult to reserve. Under-priced, natural finite resources were wantonly utilized, without proper concern about conservation.

In each area, society borrowed from and pushed problems into the future. Current growth and short-term profits were pursued at the expense of risks which were not evident immediately and that would emerge later.

To dismiss this as short-term thinking and greed is disingenuous. A crucial cognitive factor underlying the approach was a similar process of problem solving — borrowing from or pushing problems further into the future. This was consistently applied across different problems, without consideration of either it relevance, applicability or desirability. Where such parallelism exists, it feeds on itself, potentially leading to total systemic collapse.

Recognition and understanding of parallelism is one way to improve cognitive thinking. It may provide a better mechanism for predicting specific trends. It may also enable people to increase the dialectic richness, drawing on different disciplines. It requires overcoming highly segmented and narrow educational disciplines, rigid institutional structures and restricted approaches to analysis or problem solving.

GEOFFREY MILLER
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Personality traits are continuous with mental illnesses

We like to draw clear lines between normal and abnormal behavior. It's reassuring, for those who think they're normal. But it's not accurate. Psychology, psychiatry, and behavior genetics are converging to show that there's no clear line between "normal variation" in human personality traits and "abnormal" mental illnesses. Our instinctive way of thinking about insanity — our intuitive psychiatry — is dead wrong.

To understand insanity, we have to understand personality. There's a scientific consensus that personality traits can be well-described by five main dimensions of variation. These "Big Five" personality traits are called openness, conscientiousness, extraversion, agreeableness, and emotional stability. The Big Five are all normally distributed in a bell curve, statistically independent of each other, genetically heritable, stable across the life-course, unconsciously judged when choosing mates or friends, and found in other species such as chimpanzees. They predict a wide range of behavior in school, work, marriage, parenting, crime, economics, and politics.

Mental disorders are often associated with maladaptive extremes of the Big Five traits. Over-conscientiousness predicts obsessive-compulsive disorder, whereas low conscientiousness predicts drug addiction and other "impulse control disorders". Low emotional stability predicts depression, anxiety, bipolar, borderline, and histrionic disorders. Low extraversion predicts avoidant and schizoid personality disorders. Low agreeableness predicts psychopathy and paranoid personality disorder. High openness is on a continuum with schizotypy and schizophrenia. Twin studies show that these links between personality traits and mental illnesses exist not just at the behavioral level, but at the genetic level. And parents who are somewhat extreme on a personality trait are much more likely to have a child with the associated mental illness.

One implication is that the "insane" are often just a bit more extreme in their personalities than whatever promotes success or contentment in modern societies — or more extreme than we're comfortable with. A less palatable implication is that we're all insane to some degree. All living humans have many mental disorders, mostly minor but some major, and these include not just classic psychiatric disorders like depression and schizophrenia, but diverse forms of stupidity, irrationality, immorality, impulsiveness, and alienation. As the new field of positive psychology acknowledges, we are all very far from optimal mental health, and we are all more or less crazy in many ways. Yet traditional psychiatry, like human intuition, resists calling anything a disorder if its prevalence is higher than about 10%.

The personality/insanity continuum is important in mental health policy and care. There are angry and unresolved debates over how to revise the 5th edition of psychiatry's core reference work, the *Diagnostic and Statistic Manual of Mental Disorders* (DSM-5), to be published in 2013. One problem is that American psychiatrists dominate the DSM-5 debates, and the American health insurance system demands discrete diagnoses of mental illnesses before patients are covered for psychiatric medications and therapies. Also, the U.S. Food and Drug Administration approves psychiatric medications only for discrete mental illnesses. These insurance and drug-approval issues push for definitions of mental illnesses to be artificially extreme, mutually exclusive, and based on simplistic checklists of symptoms. Insurers also want to save money, so they push for common personality variants — shyness, laziness, irritability, conservatism — not to be classed as illnesses worthy of care. But the science doesn't fit the insurance system's imperatives. It remains to be seen whether DSM-5 is written for the convenience of American insurers and FDA officials, or for international scientific accuracy.

Psychologists have shown that in many domains, our instinctive intuitions are fallible (though often adaptive). Our intuitive physics — ordinary concepts of time, space, gravity, and impetus — can't be reconciled with relativity, quantum mechanics, or cosmology. Our intuitive biology — ideas of species essences and teleological functions — can't be reconciled with evolution, population genetics, or adaptationism. Our intuitive morality — self-deceptive, nepotistic, clannish, anthropocentric, and punitive — can't be reconciled with any consistent set of moral values, whether Aristotelean, Kantian, or utilitarian. Apparently, our intuitive psychiatry has similar limits. The sooner we learn those limits, the better we'll be able to help people with serious mental illnesses, and the more humble we'll be about our own mental health.

DAN SPERBER
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Cultural Attractors

In 1967, Richard Dawkins introduced the idea of a meme: a unit of cultural transmission capable of replicating itself and of undergoing Darwinian selection. "Meme" has become a remarkably successful addition to everybody's cognitive toolkit. I want to suggest that the concept of a meme should be, if not replaced, at least supplemented with that of a *cultural attractor*.

The very success of the word "meme" is, or so it seems, an illustration of the idea of a meme: the word has now been used billions of time. But is the idea of a meme being replicated whenever the word is being used? Well, no. Not only do "memeticists" have many quite different definition of a meme, but also and more importantly most users of the term have no clear idea of what a meme might be. Each time, the term is being used with a vague meaning relevant in the circumstances. All these meanings overlap but they are not replications of one another. The idea of a meme, as opposed to the word "meme", may not be such a good example of a meme after all!

The case of the meme idea illustrates a general puzzle. Cultures do contain items — ideas, norms, tales, recipes, dances, rituals, tools, practices, and so on — that are produced again and again. These items remain self-similar over social space and time: in spite of variations, an Irish stew is an Irish stew, Little Red Riding Hood is Little Red Riding Hood and a samba is a samba. The obvious way to explain this stability at the macro level of the culture is, or so it seems, to assume fidelity at the micro level of interindividual transmission. Little Red Riding Hood must have been replicated faithfully enough most of the time for the tale to have remained self-similar over centuries of oral transmission or else the story would have drifted in all kinds of ways and the tale itself would have vanished like water in the sand. Macro stability implies micro fidelity. Right? Well, no. When we study micro processes of transmission — leaving aside those that use techniques of strict replication such as printing or internet forwarding — what we observe is a mix of *preservation* of the model and of *construction* of a version that suits the capacities and interests of the transmitter. From one version to the next, the changes may be small, but when they occur at the population scale, their cumulative effect should compromise the stability of cultural items. But — and here lies the puzzle — they don't. What, if not fidelity, explains stability?

Well, bits of culture — memes if you want to dilute the notion and call them that — remain self-similar not because they are replicated again and again but because variations that occur at almost every turn in their repeated transmission, rather than resulting in "random walks" drifting away in all directions from an initial model, tend to gravitate around cultural attractors. Ending Little Red Riding Hood when the wolf eats the child would make for a simpler story to remember, but a Happy Ending is too powerful a cultural attractor. If a person had only heard the story ending with the wolf's meal, my guess is that either she would not have retold it at all — and that is selection — , or she would have modified by reconstructing a happy ending — and this is attraction. Little Red Riding Hood has remained culturally stable not because it has been faithfully replicated all along, but because the variations present in all its versions have tended to cancel one another out.

Why should there be cultural attractors at all? Because there are in our minds, our bodies, and our environment biasing factors that affect the way we interpret and re-produce ideas and behaviors. (I write "re-produce" with a hyphen because, more often than not, we produce a new token of the same type without reproducing in the usual sense of copying some previous tokens.) When these biasing factors are shared in a population, cultural attractors emerge.

Here are a few rudimentary examples.

Rounded numbers are cultural attractors: they are easier to remember and provide better symbols for magnitudes. So, we celebrate twentieth wedding anniversaries, hundredth issue of journals, millionth copy sold of a record, and so on. This, in turn, creates a special cultural attractor for prices, just below rounded numbers — \$9.99 or \$9,990 are likely price tags — , so as to avoid the evocation of a higher magnitude.

In the diffusion of techniques and artifacts, efficiency is a powerful cultural attractor. Paleolithic hunters learning from their elders how to manufacture and use bows and arrows were aiming not so much at copying the elders than at becoming themselves as good as possible at shooting arrows. Much more than faithful replication, this attraction of efficiency when there aren't that many ways of being efficient, explains the cultural stability (and also the historical transformations) of various technical traditions.

In principle there should be no limit to the diversity of supernatural beings humans can imagine. However, as Pascal Boyer has argued, only a limited repertoire of such beings is exploited in human religions. Its members — ghosts, gods, ancestor spirits, dragons, and so on — have all in common two features. On the one hand, they each violate some major intuitive expectations about living beings: expectation of mortality, of belonging to one and only one species, of being limited in one's access to information, and so on. On the other hand, they satisfy all other intuitive expectations and are therefore, in spite of their supernaturalness, rather predictable. Why should this be so? Because being "minimally counterintuitive" (Boyer's phrase) makes for "relevant mysteries" (my phrase) and is a cultural attractor. Imaginary beings that are either less or more counterintuitive than that are forgotten or are transformed in the direction of this attractor.

And what is the attractor around which the "meme" meme gravitate? The meme idea — or rather a constellation of trivialized versions of it — has become an extraordinarily successful bit of contemporary culture not because it has been faithfully replicated again and again, but because our conversation often does revolve — and here is the cultural attractor — around remarkably successful bits of culture that, in the time of mass media and the internet, pop up more and more frequently and are indeed quite relevant to our understanding of the world we live in. They attract our attention even when — or, possibly, especially when — we don't understand that well what they are and how they come about. The meaning of "meme" has drifted from Dawkins precise scientific idea to a means to refer to these striking and puzzling objects.

This was my answer. Let me end by sharing a question (which time will answer): is the idea of a cultural attractor itself close enough to a cultural attractor for a version of it to become in turn a "meme"?

VINOD KHOSLA
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The Black Swan Technology

Think back to the world 10 years ago. Google had just gotten started; Facebook and Twitter didn't exist. There were no smart phones, no one remotely conceived of the possibility of the 100,000 iPhone apps that exist today. The few large impact technologies (versus slightly incremental advances in technologies) that occurred in the past 10 years were black swan technologies. In his book, Nassim Taleb defines a Black Swan as an event of low probability, extreme impact, and with only retrospective predictability. Black swans can be positive or negative in their impact and are found in every sector. Still, the most pressing reason I believe "black swan technology" is a conceptual tool that should be added to everyone's cognitive toolkit today is simply because the challenges of climate change and energy production we face today are too big to be tackled by known solutions and safe bets.

I recall fifteen years ago when we were starting Juniper networks, there was absolutely no interest in replacing traditional telecommunications infrastructure

(ATM was the mantra) with Internet protocols. After all, there were hundreds of billions of dollars invested in the legacy infrastructure, and it looked as immovable as today's energy infrastructure. Conventional wisdom would say to make incremental improvement to maximize the potential of the existing infrastructure. The fundamental flaw in the conventional wisdom is the failure to acknowledge the possibility of a black swan. Improbable is not unimportant. I believe the likely future is not a traditional econometric forecast but rather one of today's improbable becoming tomorrow's conventional wisdom! Who would be crazy enough t forecast in 2000 that by 2010 almost twice as many people in India would have access to cell phones than latrines? Wireless phones were once only for the very rich. With a black swan technology shot you need not be constrained with the limits of the current infrastructure, projections or market. You simply change the assumptions.

Many argue that since we already have some alternative energy technology today, we should quickly deploy it. They fail to see the potential of the Black Swan technology possibilities; they discount them because they mistake improbable for unimportant and cannot imagine the art of the possible which technology enables. I believe doing this alone runs the risk of spending vast amounts of money on outdated conventional wisdom. Even more importantly, it won't solve the problems we face. Any time focused on short-term, incremental solutions will only distract from working on the homeruns that could change the assumptions around energy and society's resources. While there is no shortage of existing technology providing incremental improvements today — whether today's thin film solar cells, wind turbines, or lithium ion batteries — even summed, they are simply irrelevant to the scale of our problems. They may even make interesting and sometimes large businesses, but will not impact the prevailing energy and resource issues at scale. For that we must look for and invest in quantum jumps in technology with low probability of success; we must create in Black Swan technologies. We must enable the multiplication of resources that only technology can do.

So what are these next generation technologies, these black swan technologies of energy? These are risky investments that stand a high chance of failure, but enable larger technological leaps that promise earthshaking impact if successful: making solar power cheaper than coal or viable without subsidies, economically making lighting and air conditioning 80 percent more efficient. Consider 100 percent more efficient vehicle engines, ultra-cheap energy storage, and countless other technological leaps that we can't yet imagine. It's unlikely that any single shot works, of course. But even 10 Google-like disruptions out of 10,000 shots will completely upend conventional wisdom, econometric forecasts, and, most importantly, our energy future.

To do so we must reinvent the infrastructure of society by harnessing and motivating bright minds with a whole new set of future assumptions, asking "what could possibly be?" rather than "what is." We need to create a dynamic environment of creative contention and collective brilliance that will yield innovative ideas from across disciplines to allow innovation to triumph. We must encourage a social ecosystem that encourages taking risks on innovation.

Popularization of the concept of the "Black Swan Technology," is essential to incorporate the right mindset into the minds of entrepreneurs, policymakers, investors and the public: that anything (maybe even everything) is possible. If we harness and motivate these bright new minds with the right market signals and encouragement, a whole new set of future assumptions, unimaginable today, will be tomorrow's conventional wisdom.

TOM STANDAGE
Digital Editor, The Economist*; Author*, The Edible History of the Humanity

You can show something is definitely dangerous, but not definitely safe

A wider understanding of the fact that you can't prove a negative would, in my view, do a great deal to upgrade the public debate around science and technology.

As a journalist I have lost count of the number of times that people have demanded that a particular technology be "proven to do no harm". This is, of course, impossible, in just the same way that proving that there are no black swans is impossible. You can look for a black swan (harm) in various ways, but if you fail to find one that does not mean that none exists: absence of evidence is not evidence of absence.

All you can do is look again for harm, in a different way. If you still fail to find it after looking in all the ways you can possibly think of, the question is still open: "lack of evidence of harm" means both "safe as far as we can tell" and "we still can't be sure if it's safe or not".

Scientists are often accused of logic-chopping when they point this out. But it would be immensely helpful to public discourse if there was a wider understanding that you can show something is definitely dangerous, but you cannot show it is definitely safe.

GLORIA ORIGGI
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***Kakonomics*, or the strange preference for Low-quality outcomes**

I think that an important concept to understand why does life suck so often is *Kakonomics*, or the weird preference for *Low-quality* payoffs.

Standard game-theoretical approaches posit that, whatever people are trading (ideas, services, or goods), each one wants to *receive High-quality* work from others. Let's stylize the situation so that goods can be exchanged only at two quality-levels: *High* and *Low*. *Kakonomics* describes cases where people not only have standard preferences to receive a *High-quality* good and deliver a *Low-quality* one (the standard sucker's payoff) but they actually *prefer* to deliver a *Low-quality* good and receive a *Low-quality* one, that is, they connive on a *Low-*

Low exchange.

How can it ever be possible? And how can it be rational? Even when we are lazy, and prefer to deliver a Low-quality outcome (like prefer to write a piece for a mediocre journal provided that they do not ask one to do too much work), we still would have preferred to work less and receive more, that is deliver Low-quality and receive High-quality. *Kakonomics* is different: Here, we not only prefer to deliver a Low-quality good, but also, prefer to receive a Low-quality good in exchange!

Kakonomics is the strange — yet widespread — preference for mediocre exchanges insofar as nobody complains about. Kakonomic worlds are worlds in which people not only live with each other's laxness, but expect it: I trust you not to keep your promises in full because I want to be free not to keep mine *and* not to feel bad about it. What makes it an interesting and weird case is that, in all kakonomic exchanges, the two parties seem to have a double deal: an official pact in which both declare their intention to exchange at a High-quality level, and a tacit accord whereby discounts are not only allowed but expected. It becomes a form of tacit mutual connivance. Thus, nobody is free-riding: *Kakonomics* is regulated by a tacit social norm of discount on quality, a mutual acceptance for a mediocre outcome that satisfies both parties, as long as they go on saying publicly that the exchange is in fact at a High-quality level.

Take an example: A well-established best-seller author has to deliver his long overdue manuscript to his publisher. He has a large audience, and knows very well that people will buy his book just because of his name and anyway, the average reader doesn't read more than the first chapter. His publisher knows it as well…Thus, the author decides to deliver to the publisher the new manuscript with a stunning incipit and a mediocre plot (the Low-quality outcome): she is happy with it, congratulates him as she had received a masterpiece (the High-quality rhetoric) and they are both satisfied. The author's preference is not only to deliver a Low-quality work, but also that the publisher gives back the same, for example by avoiding to provide a too serious editing and going on publishing. They trust each other's untrustworthiness, and connive on a mutual advantageous Low outcome. Whenever there is a tacit deal to converge to Low-quality with mutual advantages, we are dealing with a case of *Kakonomics*.

Paradoxically, if one of the two parties delivers a High-quality outcome instead of the expected Low-quality one, the other party resents it as a breach of trust, even if he may not acknowledge it openly. In the example, the author may resent the publisher if she decides to deliver a High-quality editing. Her being trustworthy in this relation means to deliver Low-quality too. Contrary to the standard Prisoner Dilemma game, the willingness to repeat an interaction with someone is ensured if he or she delivers Low-quality too rather than High-quality.

Kakonomics is not always bad. Sometimes it allows a certain tacitly negotiated discount that makes life more relaxing for everybody. As one friend who was renovating a country house in Tuscany told me once: "Italian builders never deliver when they promise, but the good thing is they do not expect you to pay them when you promise either."

But the major problem of *Kakonomics* — that in ancient Greek means the economics of the worst — and the reason why it is a form of collective insanity so difficult to eradicate, is that each Low-quality exchange is a local equilibrium in which both parties are satisfied, but each of these exchanges erodes the overall system in the long run. So, the threat to good collective outcomes doesn't come only from free riders and predators, as mainstream social sciences teach us, but also from well-organized norms of *Kakonomics* that regulate exchanges for the worse. The cement of society is not just cooperation for the good: in order to understand why life sucks, we should look also at norms of cooperation for a local optimum and a common worse.

KAI KRAUSE
Software Pioneer, Interface Designer, Author, I Think, There 4 am?

Einstein's Blade in Ockham's Razor

In 1971, when I was a teenager, my father died in a big airplane crash. Somehow I began to turn 'serious', trying to understand the world around me and my place in it, looking for meaning and sense, beginning to realize: everything was very different than I had previously assumed in the innocence of childhood.

It was the beginning of my own "building a cognitive toolset" and I remember the pure joy of discovery, reading voraciously and — quite out of sync with friends and school — I devoured encyclopedias, philosophy, biographies and... science fiction.

One such story stayed with me and one paragraph within it especially:
"*We need to make use of Thargola's Sword! The principle of Parsimony.*
First put forth by the medieval philosopher Thargola14, who said,
'We must drive a sword through any hypothesis that is not strictly necessary"

That really made me think — and rethink again...
Finding out who this man might have been took quite a while, but it was also another beginning: a love affair with libraries, large tomes, dusty bindings... surfing *knowledge*, as it were.

And I did discover: there had been a monk named *Guillelmi*, from a hamlet surrounded by oaks, apocryphally called 'William of Ockham'. He crossed my path again years later when lecturing in Munich near Occam Street, realizing he had spent the last 20 years of his life there, under King Ludwig IV in the mid 1300s.

Isaac Asimov had pilfered, or let's say homaged, good old Guillelmi for what is now known in many variants as "Ockham's razor", such as
"*Plurality should not be posited without necessity.*"

"*Entities are not to be multiplied beyond necessity*"
or more general and colloquial and a bit less transliterated from Latin:
A simpler explanation invoking fewer hypothetical constructs is preferrable.

And there it was, the dancing interplay between *Simplex and Complex,* which has fascinated me in so many forms ever since. For me, it is very near the center of "understanding the world", as our question posited.

Could it really be true, that the innocent sounding 'keep it simple' is really such an optimal strategy for dealing with questions large and small, scientific as well as personal? Surely, trying to *eliminate superflous assumptions* can be a useful tenet, and can be found from Sagan to Hawking as part of their approach to thinking in science. But something never quite felt right to me — intuitively it was clear that sometimes *things are just not simple* — and that merely "the simplest" of all explanations cannot be taken as truth or proof.

Any detective story would pride itself in not using the most obvious explanation who did it or how it happened.
Designing a car to 'have the optimal feel going into a curve at high speed' will require hugely complex systems to finally arrive at "simply good".
Water running downhill will *take a meandering path instead of the straight line.*

Both are examples for a domain shift: the non-simple solution is still "the easiest" seen from another viewpoint: for the water the *least energy used going down the shallowest slope* is more important than *taking the straightest line from A to B.*

And that is one of the issues with Ockham:
The definition of what "*simple*" is — can already be anything but simple.
And what "*simpler*" is — well, it just doesn't get any simpler there.

There is that big difference between *simple* and *simplistic.*
And seen more abstractly, the principle of *simple things leading to complexity* dances in parallel and involved me deeply throughout my life.

In the early seventies I also began tinkering with the first large scale modular synthesizers, finding quickly how hard it is to recreate seemingly 'simple sounds'. There was unexpected complexity in a single note struck on a piano that eluded even dozens of oscillators and filters, by magnitudes.

Lately one of many projects has been to revisit the aesthetic space of scientific visualizations, and another, which is the epitomy of mathematics made tangible: *Fractal*s — which I had done almost 20 years ago with virtuoso coder Ben Weiss, now enjoying them via *realtime flythroughs* on a handheld little smartphone.
Here was the most extreme example: a tiny formula, barely one line on paper, used recursively iterated it yields *worlds* of complex images of amazing beauty.
(Ben had the distinct pleasure of showing Benoit Mandelbrot an alpha version at the last TED just months before his death)

My hesitation towards overuse of parsimony was expressed perfectly in the quote by Albert Einstein, arguably the counterpart "blade" to Ockham's razor: "*Things should be made as simple as possible — but not simpler*"

And there we have the perfect application of its truth, used recursively on itself: *Neither Einstein nor Ockham actually used the exact words as quoted!*

After I sifted through dozens of books, his collected works and letters in German, the Einstein archives: nowhere there, nor in Britannica, Wikipedia or Wikiquote was anyone able to substantiate exact sources, and the same applies to Ockham. If anything *can* be found, it is earlier precedences...;)

Surely one can amass retweeted, reblogged and regurgitated instances for both very quickly — they have become memes, of course. One could also take the standpoint that in each case they certainly 'might' have said it 'just like that', since each used several expressions quite similar in form and spirit.
But just to attribute the exact words *because they are kind of close* would be, well..another case of: *it is not that simple*!

And there is a huge difference between *additional* and *redundant* information. (Or else one could lose the second redundant "*ein*" in "Einstein" ?)

Linguistic jesting aside: Nonetheless, the Razor and the Blade constitute a very useful combination of approaching analytical thinking.
Shaving away *non-essential conjectures* is a good thing, a worthy inclusion in "everybody's toolkit" — and so is the corollary: *not to overdo it!*

And my own bottom line: *There is nothing more complex than simplicity*.

GEORGE CHURCH
Professor, Harvard University, Director, Personal Genome Project

Non-Inherent Inheritance

The names Lysenko and Lamarck are nearly synonymous with bad science — worse than merely mediocre science because of the huge political and economical consequences.

From 1927 to 1964 Lysenkov managed to keep the "theory of the inheritance of acquired characteristics" dogmatically directing Soviet agriculture and science. Andrei Sakharov and other Soviet physicists finally provoked the fall of this cabal in the 1960s, blaming it for the "shameful backwardness of Soviet biology and of genetics in particular … defamation, firing, arrest, even death, of many genuine scientists".

At the opposite (yet equally discredited) end of the genetic theory spectrum was the Galtonian eugenic movement, which from 1883 onward grew in popularity in many countries until the 1948 Universal Declaration of Human Rights, ("the most translated document in the world") stated that "Men and women of full age, without any limitation due to race, nationality or religion, have the right to marry and to found a family." Nevertheless, forced sterilizations persisted into the 1970s. The "shorthand abstraction" is that Lysenkoism overestimated the impact of environment and eugenics overestimated the role of genetics.

One form of scientific blindness occurs, as above, when a theory displays exceptional political or religious appeal. But another source of blindness arises when we rebound from catastrophic failures of pseudoscience (or science).

We might conclude from the two aforementioned genetic disasters that we only need to police abuses of our human germ-line inheritance. Combining the above with the ever-simmering debate on Darwin, we might develop a bias that human evolution has stopped or that "design" has no role.

But we are well into an unprecedented new phase of evolution in which we must generalize beyond our DNA-centric world-view. We now inherit acquired characteristics. We always have, but now this feature is dominant and exponential. We apply eugenics at the individual family level (where it is a right) not the governmental level (where it is a wrong). Moreover, we might aim for the same misguided targets that eugenics chose (i.e. uniformity around "ideal" traits), via training and medications.

Evolution has accelerated from geologic speed to internet speed — still employing random mutation and selection, but also using non-random intelligent design — which makes it even faster. We are losing species — not just by extinction, but by merger. There are no longer species barriers between humans, bacteria and plants — or even between humans and machines.

Short-hand abstractions are only one device that we employ to construct the "Flynn Effect". How many of us noticed the minor milestone when the SAT tests first permitted calculators? How many of us have participated in conversations semi-discreetly augmented by Google or text messaging? Even without invoking artificial intelligence, how far are we from commonplace augmentation of our decision-making the way we have augmented our math, memory, and muscles?

DAVE WINER
Visiting Scholar in Journalism, NYU; Pioneer Software Developer (Blogging, Podcasting, RSS, Outliners, Web Content Management)

While We Are Social Creatures, It's Often Best Not To Admit It

New York City, my new home, teaches you, that while we are social creatures, it's often best not to admit it.

As you weave among the obstacles on the sidewalks of Manhattan, it's easy to get distracted from your thoughts and pay attention to the people you're encountering. It's okay to do that if you're at a stop, but if you're in motion, if your eyes engage with another, that signals that you would like to negotiate.

Not good. A sign of weakness. Whether the oncoming traffic is aware or not, he or she will take advantage of this weakness and charge right into your path, all the while not making eye contact. There is no appeal. All you can do is shift out of their path, but even this won't avoid a collision because your adversary will unconsciously shift closer to you. Your weakness is attractive. Your space is up for grabs. At this point you have no choice but to collide, and in the etiquette of New York street walking you're responsible.

That's why the people who check their smartphones for text messages or emails while walking so totally command the sidewalks. They are heat-seeking missiles, and it's your heat they seek.

I don't think this is just New York, it's a feature of the human species. We seek companionship.

For a while in 2005 I lived on the beach in northeast Florida outside St Augustine. The beach is so long and relatively empty, they let you drive on the beach to find the perfect spot to bathe, and if you're willing to drive a bit you can be alone. So I would drive to a secluded spot, park my car and go out into the surf. When I came back, more often than not, there was a car parked right next to mine. They could have parked anywhere in a mile in either direction and had it all to themselves.

Add that to your cognitive toolkit!

MARCO IACOBONI
Neuroscientist, UCLA Brain Mapping Center; Author, Mirroring People

Entanglement

Entanglement is "spooky action at a distance", as Einstein liked to say (he actually did not like it at all, but at some point he had to admit that it exists.) In quantum physics, two particles are entangled when a change in one particle is immediately associated with a change in the other particle. Here comes the spooky part: we can separate our "entangled buddies" as far as we can, they will still remain entangled. A change in one of them is instantly reflected in the other one, even though they are physically far apart (and I mean different countries!)

Entanglement feels like magic. It is really difficult to wrap our heads around it. And yet, entanglement is a real phenomenon, measurable and reproducible in the lab. And there is more. While for many years entanglement was thought to be a very delicate phenomenon, only observable in the infinitesimally small world of quantum physics ("oh good, our world is immune from that weird stuff") and quite volatile, recent evidence suggests that entanglement may be much more robust and even much more widespread than we initially thought. Photosynthesis may happen through entanglement, and recent brain data suggest that entanglement may play a role in coherent electrical activity of distant groups of neurons in the brain.

Entanglement is a good cognitive chunk because it challenges our cognitive intuitions. Our minds seem built to prefer relatively mechanic cause-and-effect stories as explanations of natural phenomena. And when we can't come up with one of those stories, then we tend to resort to irrational thinking, the kind of magic we feel when we think about entanglement. Entangled particles teach us that our beliefs of how the world works can seriously interfere with our understanding of it. But they also teach us that if we stick with the principles of good scientific practice, of observing, measuring, and then reproducing phenomena that we can frame in a theory (or that are predicted by a scientific theory), we can make sense of things. Even very weird things like entanglement.

Entanglement is also a good cognitive chunk because with its existence it implicitly whispers to us that seemingly self-evident cause-and-effect phenomena may not be cause-and-effect at all. The timetable of modern vaccination, probably the biggest accomplishment in modern medicine, coincides with the onset of symptoms of autism in children. This temporal correspondence may mislead us to think that the vaccination may have produced the symptoms, hence the condition of autism. At the same time, that temporal correspondence should make us suspicious of straightforward cause-and-effect associations, inviting us to have a second look, and to make controlled experiments to find out whether or not there is really a link between vaccines and autism. We now know there is no such link. Unfortunately though, this belief is very hard to eradicate and is producing in some parents the potentially disastrous decision of not vaccinating their children.

The story of entanglement is a great example of the capacity of the human mind of reaching out almost beyond itself. The key word here is "almost." Because we "got there", it is self-evident that we could "get there." But it didn't feel like it, did it? Until we managed to observe, measure, and reproduce that phenomenon predicted by quantum theory, it just felt a little "spooky." (It still feels a bit spooky, doesn't it?) Humans are naturally inclined to reject facts that do not fit their beliefs, and indeed when confronted with those facts, they tend to automatically reinforce their beliefs and brush those facts under the carpet. The beautiful story of entanglement reminds us that we can go "beyond ourselves," that we don't have to desperately cling to our beliefs, and that we can make sense of things. Even spooky ones.

JONAH LEHRER
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Control Your Spotlight

In the late 1960s, the psychologist Walter Mischel began a simple experiment with four-year old children. He invited the kids into a tiny room, containing a desk and a chair, and asked them to pick a treat from a tray of marshmallows, cookies, and pretzel sticks. Mischel then made the four-year olds an offer: they could either eat one treat right away or, if they were willing to wait while he stepped out for a few minutes, they could have two treats when he returned. Not surprisingly, nearly every kid chose to wait.

At the time, psychologists assumed that the ability to delay gratification — to get that second marshmallow or cookie — depended on willpower. Some people simply had more willpower than others, which allowed them to resist tempting sweets and save money for retirement.

However, after watching hundreds of kids participate in the marshmallow experiment, Mischel concluded that this standard model was wrong. He came to realize that willpower was inherently weak, and that children that tried to outlast the treat — gritting their teeth in the face of temptation — soon lost the battle, often within thirty seconds.

Instead, Mischel discovered something interesting when he studied the tiny percentage of kids who could successfully wait for the second treat. Without exception, these "high delayers" all relied on the same mental strategy: they found a way to keep themselves from thinking about the treat, directing their gaze away from the yummy marshmallow. Some covered their eyes or played hide-and-seek underneath the desk. Others sang songs from "Sesame Street," or repeatedly tied their shoelaces, or pretended to take a nap. Their desire wasn't defeated — it was merely forgotten.

Mischel refers to this skill as the "strategic allocation of attention," and he argues that it's the skill underlying self-control. Too often, we assume that willpower is about having strong moral fiber. But that's wrong — willpower is really about properly directing the spotlight of attention, learning how to control that short list of thoughts in working memory. It's about realizing that if we're thinking about the marshmallow we're going to eat it, which is why we need to look away.

What's interesting is that this cognitive skill isn't just a useful skill for dieters. Instead, it seems to be a core part of success in the real world. For instance, when Mischel followed up with the initial subjects 13 years later — they were now high school seniors — he realized that performance on the marshmallow task was highly predictive on a vast range of metrics. Those kids who struggled to wait at the age of four were also more likely to have behavioral problems, both in school and at home. They struggled in stressful situations, often had trouble paying attention, and found it difficult to maintain friendships. Most impressive, perhaps, were the academic numbers: The little kid who could wait fifteen minutes for their marshmallow had an S.A.T. score that was, on average, two hundred and ten points higher than that of the kid who could wait only thirty seconds.

These correlations demonstrate the importance of learning to strategically allocate our attention. When we properly control the spotlight, we can resist negative thoughts and dangerous temptations. We can walk away from fights and improve our odds against addiction. Our decisions are driven by the facts and feelings bouncing around the brain — the allocation of attention allows us to direct this haphazard process, as we consciously select the thoughts we want to think about.

Furthermore, this mental skill is only getting more valuable. We live, after all, in the age of information, which makes the ability to focus on the important information incredibly important. (Herbert Simon said it best: "A wealth of information creates a poverty of attention.") The brain is a bounded machine and the world is a confusing place, full of data and distractions — intelligence is the ability to parse the data so that it makes just a little bit more sense. Like willpower, this ability requires the strategic allocation of attention.

One final thought: In recent decades, psychology and neuroscience have severely eroded classical notions of free will. The unconscious mind, it turns out, is most of the mind. And yet, we can still control the spotlight of attention, focusing on those ideas that will help us succeed. In the end, this may be the only thing we can control. We don't have to look at the marshmallow.

TIMOTHY TAYLOR
Archaeologist, University of Bradford; Author, The Artificial Ape

Technology Came Before Humanity And, Evolutionarily, Paved The Way For It

The very idea of a "cognitive toolkit" is one of the most important items in our cognitive toolkit. It is far more than just a metaphor, for the relationship between actual physical tools and the way we think is profound and of immense antiquity.

Ideas such as evolution and a deep prehistory for humanity are as factually well-established as the idea of a round earth, or gravity as a force pulling apples from trees. Only bigots and the misled can doubt them. But the idea that the first chipped stone tool pre-dates, by at least half a million years, the expansion of mind that is so characteristic of humans, should also be knowable by all.

The idea that technology came before humanity and, evolutionarily, paved the way for it, is the scientific concept that I believe should be part of everybody's cognitive toolkit. We could then see that thinking through things and with things, and manipulating virtual things in our minds, is an essential part of critical self-consciousness. The ability to internalize our own creations, by abstracting them, and converting "out-there" tools into mental mechanisms, is what allows the entire scientific project.

JAY ROSEN
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Wicked Problems

There is a problem that anyone who has lived in New York City must wonder about: you can't get a cab from 4 to 5 pm. The reason for this is not a mystery: at a moment of peak demand, taxi drivers tend to change shifts. Too many cabs are headed to garages in Queens because when a taxi is operated by two drivers 24 hours a day, a fair division of shifts is to switch over at 5 pm. Now this is a problem for the city's Taxi and Limousine Commission, it may even be a hard one to solve, but it is not a wicked problem. For one thing, it's easy to describe, as I just showed you. That right there boots it from the category.

Among some social scientists, there is this term of art: *wicked problems*. We would be vastly better off if we understood what wicked problems are, and learned to distinguish between them and regular (or "tame") problems.

Wicked problems have these features: It is hard to say what the problem is, to define it clearly or to tell where it stops and starts. There is no "right" way to view the problem, no definitive formulation. The way it's framed will change what the solution appears to be. Someone can always say that the problem is just a symptom of another problem and that someone will not be wrong. There are many stakeholders, all with their own frames, which they tend to see as exclusively correct. Ask what the problem is and you will get a different answer from each. The problem is inter-connected to a lot of other problems; pulling them apart is almost impossible.

It gets worse. Every wicked problem is unique, so in a sense there is no prior art and solving one won't help you with the others. No one has "the right to be wrong," meaning enough legitimacy and stakeholder support to try stuff that will almost certainly fail, at first. Instead failure is savaged, and the trier is deemed unsuitable for another try. The problem keeps changing on us. It is never definitely resolved. Instead, we just run out of patience, or time, or money. It's not possible to understand the problem first, then solve it. Rather, attempts to solve it reveal further dimensions of the problem. (Which is the secret of success for people who are "good" at wicked problems.)

Know any problems like that? Sure you do. Probably the best example in our time is climate change. What could be more inter-connected than it? Someone can always say that climate change is just a symptom of another problem--our entire way of life, perhaps — and he or she would not be wrong. We've certainly never solved anything like it before. Stakeholders: everyone on the planet, every nation, every company.

When General Motors was about go bankrupt and throw tends of thousands of people out of work that was a big, honking problem, which rightly landed on the president's desk, but it was not a wicked one. Barack Obama's advisors could present him with a limited range of options; if he decided to take the political risk and save General Motors from collapse he could be reasonably certain that the recommended actions would work. If they didn't, he could try more drastic measures.

But health care reform wasn't like that at all. In the United States, rising health care costs are a classic case of a wicked problem. No "right" way to view it. Every solution comes with its own contestable frame. Multiple stakeholders who don't define the problem the same way. If the uninsured go down but costs go up, is that progress? We don't even know.

Wicked!

Still, we would be better off if we knew when we were dealing with a wicked problem, as opposed to the regular kind. If we could designate some problems as wicked we might realize that "normal" approaches to problem-solving don't work. We can't define the problem, evaluate possible solutions, pick the best one, hire the experts and implement. No matter how much we may want to follow a routine like that, it won't succeed. Institutions may require it, habit may favor it, the boss may order it, but wicked problems don't care.

Presidential debates that divided wicked from tame problems would be very different debates. Better, I think. Journalists who covered wicked problems differently than they covered normal problems would be smarter journalists. Institutions that knew when how to distinguish wicked problems from the other kind would eventually learn the limits of command and control.

Wicked problems demand people who are creative, pragmatic, flexible and collaborative. They never invest too much in their ideas because they know they are going to have to alter them. They know there's no right place to start so they simply start somewhere and see what happens. They accept the fact that they're more likely to understand the problem after its "solved" than before. They don't expect to get a good solution; they keep working until they've found something that's good enough. They're never convinced that they know enough to solve the problem, so they are constantly testing their ideas on different stakeholders.

Know any people like that? Maybe we can get them interested in health care...

PAUL SAFFO
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Time Span of Discretion

Half a century ago, while advising a UK Metals company, Elliott Jaques had a deep and controversial insight. He noticed that workers at different levels of the company had very different time horizons. Line workers focused on tasks that could be completed in a single shift, while managers devoted their energies to tasks requiring six months or more to complete. Meanwhile, their CEO was pursuing goals realizable only over the span of several years.

After several decades of empirical study, Jaques concluded that just as humans differ in intelligence, we differ in our ability to handle time-dependent complexity. We all have a natural time horizon we are comfortable with, what Jaques called "Time span of discretion," or the length of the longest task an individual can successfully undertake. Jaques observed that organizations implicitly recognize this fact in everything from titles to salary: line workers are paid hourly, managers annually, and senior executives compensated with longer-term incentives such as stock options.

Jaques also noted that effective organizations were comprised of workers of differing time spans of discretion, each working at a level of natural comfort. If a worker's job was beyond their natural time span of discretion, they would fail. If it was less, they would be insufficiently challenged, and thus unhappy.

Time span of discretion is about achieving intents that have explicit time frames. And in Jaques model, one can rank discretionary capacity in a tiered system. Level 1 encompasses jobs such as sales associates or line workers handling routine tasks with a time horizon of up to three months. Levels 2 to 4 encompass various managerial positions with time horizons between one to five years. Level 5 crosses over to five to 10 years and is the domain of small company CEOs and large company executive vice presidents. Beyond Level 5, one enters the realm of statesmen and legendary business leaders comfortable with innate time horizons of 20 years (Level 6), 50 years (Level 7) or beyond. Level 8 is the realm of 100 year thinkers like Henry Ford, while Level 9 is the domain of the Einsteins, Gandhis, and Galileos, individuals capable of setting grand tasks into motion that continue centuries into the future.

Jaques' ideas enjoyed currency into the 1970s and then fell into eclipse, assailed as unfair stereotyping or worse, a totalitarian stratification evocative of Huxley's *Brave New World*. It is now time to reexamine Jaques theories and revive time span of discretion as a tool for understanding our social structures and matching them to the overwhelming challenges facing global society. Perhaps problems like climate change are intractable because we have a political system that elects Level 2 thinkers to Congress when we really need Level 5s in office. As such, Jaques ideas might help us realize that the old saying, "he who thinks longest wins" is only half the story, and that the society in which everyone explicitly thinks about tasks in the context of time will be the most effective.

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Defeasibility

On its face, defeasibility is a modest concept with roots in logic and epistemology. An inference is defeasible if it can potentially be "defeated" in light of additional information. Unlike deductively sound conclusions, the products of defeasible reasoning remain subject to revision, held tentatively no matter how firmly.

All scientific claims — whether textbook pronouncements or haphazard speculations — are held defeasibly. It is a hallmark of the scientific process that claims are forever vulnerable to refinement and rejection, hostage to what the future could bring. Far from being a weakness, this is a source of science's greatness. Because scientific inferences are defeasible, they remain responsive to a world that can reveal itself gradually, change over time, and deviate from our dearest assumptions.

The concept of defeasibilility has proven valuable in characterizing artificial and natural intelligence. Everyday inferences, no less than scientific inferences, are vetted by the harsh judge of novel data: additional information that can potentially defeat current beliefs. On further inspection, the antique may turn out to be a fake and the alleged culprit an innocent victim. Dealing with an uncertain world forces cognitive systems to abandon the comforts of deduction and engage in defeasible reasoning.

Defeasibility is a powerful concept when we recognize it not as a modest term of art, but as the proper attitude towards all belief. Between blind faith and radical skepticism is a vast but sparsely populated space where defeasibility finds its home. Irreversible commitments would be foolish; boundless doubt paralyzing. Defeasible beliefs provide the provisional certainty necessary to navigate an uncertain world.

Recognizing the potential revisability of our beliefs is a prerequisite to rational discourse and progress, be it in science, politics, religion, or the mundane negotiations of daily life. Consider the world we could live in if all of our local and global leaders, if all of our personal and professional friends and foes, recognized the defeasibility of their beliefs and acted accordingly. That sure sounds like progress to me. But of course, I could be wrong.

ERNST PÖPPEL
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A cognitive toolkit full of garbage

To get rid of garbage is essential, also of mental garbage. Cognitive toolkits are filled with such garbage, simply because we are victims of ourselves. We should regularly empty this garbage can, or in case we enjoy to sit in garbage, we better check how "shorthand abstractions" (SHA's) limit our creativity (certainly an SHA). Why is the cognitive toolkit filled with garbage?

Let us look back in history (SHA): Modern science (SHA) can be said to have started in 1620 with "Novum Organum" ("New Instrument") by Francis Bacon. It should impress us today that his analysis (SHA) begins with a description (SHA) of four mistakes we run into when we do science. Unfortunately, we usually forget these warnings. Francis Bacon argued that we are — first — victims of evolution (SHA), i.e. that our genes (SHA), define constraints that necessarily limit insight (SHA). Second — we suffer from the constraints of imprinting (SHA); the culture (SHA) we live in provides a frame for epigenetic programs (SHA) that ultimately define the structure (SHA) of neuronal processing (SHA). Third — we are corrupted by language (SHA) as thoughts (SHA) cannot be easily transformed into verbal expressions . Fourth — we are guided or even controlled by theories (SHA), may they be explicit or implicit.

What are the implications for a cognitive toolkit? We are caught for instance in a language trap. On the basis of our evolutionary heritage we have the power of abstraction (SHA), but this has inspite of some advantages we brag about (to make us superior to other creatures) a disastrous consequence: Abstractions are usually represented in words; apparently we cannot do otherwise; we have to "ontologize"; we invent nouns to extract knowledge (SHA) from processes (SHA). (I do not refer to the powerful pictorial shorthand abstractions). Abstraction is obviously complexity reduction (SHA). We make it simple. Why do we do this? Evolutionary heritage dictates to be fast. However, speed may give an advantage for a "survival toolkit", but not for a "cognitive toolkit". It is a categorical error (SHA) to confuse speed in action with speed in thinking. The selection pressure for speed invites to neglect the richness of facts. This pressure allows the invention (SHA) of a simple, clear, easy to understand, easy to refer to, easy to communicate shorthand abstraction. Thus, because we are a victim of our biological past and as a consequence a victim of ourselves we end up with shabby SHA's having left behind reality. If there is one disease all humans share, it is "monocausalitis", i.e. the motivation (SHA) to explain everything on the basis of just one cause. This may be a nice intellectual exercise but it is simply misleading.

Of course we depend on communication (SHA), and this requires verbal references usually tagged with language. But if we do not understand within the communicative frame or reference system (SHA) that we are a victim of ourselves by "ontologizing" and continuously creating "practical" SHA's, we simply use a cognitive toolkit of mental garbage. Is there a pragmatic way out other than to radically get rid of mental garbage? Yes, perhaps: Simply not using the the key SHA's explicitly in one's toolkit. Working on "consciousness", don't use (at least for one year) the SHA consciousness; if you work on the "self", never refer explicitly to self. Going through the own garbage one discovers many misleading SHA's, like just a few in my focus of attention (SHA): the brain as a net, localization of function, representation, inhibition, threshold, decision, the present, ... An easy way out is of course to refer to some of these SHA's as metaphors (SHA), but this again is evaiding the problem (SHA). I am aware of the fact (SHA) that I am also a victim of evolution, and to suggest "garbage" as a SHA also suffers from the same problem; even the concept of garbage required a discovery (SHA). But we cannot do otherwise than simply being aware of this challenge (SHA) that the content of the cognitive toolkit is characterized by self–referentiality (SHA), i.e. by the fact that the SHA's define themselves by their unreflected use.

KATHRYN SCHULZ

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The Pessimistic Meta-Induction from the History of Science

Okay, okay: it's a terrible phrase. (In my defense, I didn't coin it. Philosophers of science have been kicking it around for a while.) But if "The Pessimistic Meta-Induction from the History of Science" is cumbersome to say and difficult to remember, it is also a great idea. In fact, as the "meta" part suggests, it's the kind of idea that puts all other ideas into perspective.

Here's the gist: because so many scientific theories from bygone eras have turned out to be wrong, we must assume that most of today's theories will eventually prove incorrect as well. And what goes for science goes in general. Politics, economics, technology, law, religion, medicine, child-rearing, education: no matter the domain of life, one generation's verities so often become the next generation's falsehoods that we might as well have a Pessimistic Meta-Induction from the History of Everything.

Good scientists understand this. They recognize that they are part of a long process of approximation. They know that they are constructing models rather than revealing reality. They are comfortable working under conditions of uncertainty — not just the local uncertainty of "Will this data bear out my hypothesis?", but the sweeping uncertainty of simultaneously pursuing and being cut off from absolute truth.

The rest of us, by contrast, often engage in a kind of tacit chronological exceptionalism. Unlike all those suckers who fell for the flat earth or the geocentric universe or cold fusion or the cosmological constant, we ourselves have the great good luck to be alive during the very apex of accurate human thought. The literary critic Harry Levin put this nicely: "The habit of equating one's age with the apogee of civilization, one's town with the hub of the universe, one's horizons with the limits of human awareness, is paradoxically widespread." At best, we nurture the fantasy that knowledge is always cumulative, and therefore concede that future eras will know more than we do. But we ignore or resist the fact that knowledge collapses as often as it accretes, that our own most cherished beliefs might appear patently false to posterity.

That fact is the essence of the meta-induction — and yet, despite its name, this idea is not pessimistic. Or rather, it is only pessimistic if you hate being wrong. If, by contrast, you think that uncovering your mistakes is one of the best ways to revise and improve your understanding of the world, then this is actually a highly *optimistic* insight.

The idea behind the meta-induction is that all of our theories are fundamentally provisional and quite possibly wrong. If we can add that idea to our cognitive toolkit, we will be better able to listen with curiosity and empathy to those whose theories contradict our own. We will be better able to pay attention to counterevidencethose anomalous bits of data that make our picture of the world a little weirder, more mysterious, less clean, less done. And we will be able to hold our own beliefs a bit more humbly, in the happy knowledge that better ideas are almost certainly on the way.

MARK PAGEL
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Knowledge

The Oracle of Delphi famously pronounced Socrates to be "the most intelligent man in the world because he knew that he knew nothing". Over 2000 years later the physicist-turned-historian Jacob Bronowski would emphasize — in the last episode of his landmark 1970s television series the "Ascent of Man" — the danger of our all-too-human conceit of thinking we know something. What Socrates knew and what Bronowski had come to appreciate is that knowledge — true knowledge — is difficult, maybe even impossible, to come buy, it is prone to misunderstanding and counterfactuals, and most importantly it can never be acquired with exact precision, there will always be some element of doubt about anything we come to "know"' from our observations of the world.

What is it that adds doubt to our knowledge? It is not just the complexity of life: uncertainty is built in to anything we measure. No matter how well you can measure something, you might be wrong by up to ½ of the smallest unit you can discern.

If you tell me I am 6 feet tall, and you can measure to the nearest inch, I might actually be 5' 11 and ½" or 6' and ½" and you (and I) won't know the difference. If something is really small you won't even be able to measure it, and if it is really really small a light microscope (and thus your eye, both of which can only see objects larger than the shortest wavelength of visible light) won't even know it is there. What if you measure something repeatedly?

This helps, but consider the plight of those charged with international standards of weights and measures. There is a lump of metal stored under a glass case in Sèvres, France. It is, by the decree of *Le Système International d'Unités*, the definition a kilogram. How much does it weigh? Well, by definition whatever it weighs is a kilogram. But the fascinating thing is that it has never *weighed* exactly the same twice. On those days it weighs less than a kilogram you are not getting such a good deal at the grocery store. On other days you are.

The often blithe way in which scientific "findings" are reported by the popular press can mask just how difficult it is to acquire reliable knowledge. Height and weight are — as far as we know — single dimensions. Consider then how much more difficult it is to measure something like intelligence, the risk of getting cancer from eating too much meat, whether cannibas should be legalized, whether the climate is warming and why, what a "shorthand abstraction" or even "science" is, the risk of developing psychosis from drug abuse, the best way to lose weight, whether it is better to force people receiving state benefits to work, whether prisons work, how to quit smoking, whether a glass of wine every day is good for you, whether it will hurt your children's eyes to use 3D glasses, or even just the best way to brush your teeth. In each case, what was actually measured, or who was measured, who were they compared to, for how long, are they like you and me, were there other factors that could explain the outcome?

The elusive nature of knowledge should remind us to be humble when interpreting it and acting on it, and this should grant us both a tolerance and skepticism towards others and their interpretations: *knowledge* should always be treated as a hypothesis.

It has only just recently emerged that Bronowski himself was involved in the Second World War project to design nuclear weapons — vicious projectiles of death that don't discriminate between good guys and bad guys. Maybe Bronowski's later humility was borne of this realization — that our views can be wrong and they can have consequences for others' lives.

Eager detractors of science as a way of understanding the world will jump on these ideas with glee, waving them about as proof that "nothing is real" and that science and its outputs are as much a human construct as art or religion. This is facile, ignorant and naïve.

Measurement and the "science" or theories it spawns must be treated with humility precisely because they are powerful ways of understanding and manipulating the world. Their observations can be replicated — even if imperfectly — and others can agree on how to make the measurements on which they depend, be they of intelligence, the mass of the Higgs boson, poverty, the speed at which proteins can fold into their three dimensional structures, or how big gorillas are.

No other system for acquiring knowledge even comes close to science, but this is precisely why we must treat its conclusions with humility. Einstein knew this when he said "all our science measured against reality is primitive and childlike" and yet he added "it is the most precious thing we have".

EVGENY MOROZOV

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Einstellung Effect

Constant awareness of the Eintstellung Effect would make a useful addition to our cognitive toolkit.

The Einstellung Effect is more ubiquitous than its name suggests. We constantly experience it when trying to solve a problem by pursuing solutions that have worked for us in the past - instead of evaluating and addressing it on its own terms. Thus, while we may eventually solve the problem, we may also be wasting an opportunity to so in a more rapid, effective, and resourceful manner.

Think of a chess match. If you are a chess master with a deep familarity with chess history, you are likely to spot game developments that look similar to other matches that you know by heart. Knowing how those previous matches unfolded, you may automatically pursue similar solutions.

This may be the right thing to do in matches that are exactly alike - but in all other situations, you've got to watch out! Familar solutions may not be optima. Some recent research into the occurences of the Einstellung Effect in chess players suggests that it tends to be less prominent once players reach a certain level of mastery, getting a better grasp of the risks associated with pursuing solutions that look familiar and trying to avoid acting on "autopilot".

The irony here is that the more expansive our cognitive toolkit, the more likely we are to fall back on solutions and approaches that have worked in the past instead of asking whether the problem in front of us is fundamentally different from anything else we have dealt with in the past. A cognitive toolkit that has no built-in awareness of the Einstellung Effect seems somewhat defective to me.

PAUL BLOOM

Psychologist, Yale University; Author, How Pleasure Works

Reason

We are powerfully influenced by irrational processes such as unconscious priming, conformity, groupthink, and self-serving biases. These affect the most trivial aspects of our lives, such as how quickly we walk down a city street, and the most important, such as who we choose to marry. The political and moral realms are particularly vulnerable to such influences. While many of us would like to think that our views on climate change or torture or foreign policy are the result of rational deliberation, we are more affected than we would like to admit by considerations that have nothing to do with reason.

But this is not inevitable. Consider science. Plainly, scientists are human and possess the standard slate of biases and prejudices and mindbugs. This is what skeptics emphasize when they say that science is "just another means of knowing" or "just like religion". But science also includes procedures — such as replicable experiments and open debate — that cultivate the capacity for human reason. Scientists can reject common wisdom, they can be persuaded by data and argument to change their minds. It is through these procedures that we have discovered extraordinary facts about the world, such as the structure of matter and the evolutionary relationship between monkey and man.

The cultivation of reason isn't unique to science; other disciplines such as mathematics and philosophy possess it as well. But it is absent in much of the rest of life. So I admit to twisting the question a bit: The concept that people need to add to their toolkit isn't a scientific discovery; it is science itself. Wouldn't the world be better off if, as we struggle with moral and political and social problems, we adopted those procedures that make science so successful?

EDUARDO SALCEDO-ALBARÁN
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Homo Sensus-Sapiens: The animal that feels and rationalizes

For the last three years, Mexican narcotraffickers have decapitated hundreds of people to gain control of routes for transporting cocaine. In the last two decades Colombian narco-paramilitaries tortured and incinerated thousands of people, in part, because they needed more land for their crops and for transporting cocaine. In both cases, they were not satisfied with 10 or 100 million dollars; even the richest narcotraffickers, kill or die for more.

In Guatemala and Honduras, cruel mortal battles between gangs known as "maras", happen for gaining control of a street in a poor neighborhood. In Rwanda's genocide, in 1994, people who had been friends for their entire life suddenly became mortal enemies, because of their ethnic appearance.

Is this the enlightened man?

These cases may sound like rarities. However, in any city, in any random street, it is easy to find a thief who is willing to kill or die for 10 bucks to satisfy the need for heroin, a fanatic who is willing to kill or die for defending a "merciful God", or a regular guy next-door willing to kill or die in a fight after a car crash.

Is this rationality?

It is easy to find examples in which automatic responses of emotions and feelings, like ambition, anger or anxiety overcome rationality. Those responses keep assaulting us like uncontrollable forces of nature; like earthquakes or storms.

We modern humans, taxonomically define ourselves as Homo Sapiens Sapiens, that is, wise-wise beings. Apparently, we can dominate the influence of natural forces, no matter if they are instincts, viruses or storms. Homo Sapiens Sapiens represents the overconfidence of the enlightened man who understands and manipulates nature, while making the best decisions. However, we cannot avoid destroying natural resources while consuming more than we need. We cannot control excessive ambition. We cannot avoid surrendering to the power of sex or money. Despite our evolved brain, despite our capacity to argue and think in abstract ways, despite the amazing power of the neocortex, inner feelings are still at the base of our behavior.

The WisdomX2 characteristic typically does not coincide exactly with our neuropsychological reality. To discover it, you can pay attention to your everyday actions, you can trust neurological observations showing how instinctive areas of the brain are active most of the time or you can trust evidence showing how our nervous system is constantly at the mercy of neurotransmitters and hormones determining levels of emotional responses.

Observations from experimental psychology and behavioral economics also show that people do not always try to maximize present or future profits. Rational expectations, once thought as the main characteristic of Homo Economicus are not neurologically sustainable anymore. Sometimes people care nothing about future or profit; sometimes, we only want to satisfy a desire, right here, right now, no matter what.

Human beings have unique rational capacities indeed. No other animal can evaluate, simulate and decide for the best, like humans do. However, "having" the capacity doesn't imply "executing" it.

The inner and oldest areas of human's brain, the reptilian brain, generate and regulate instinctive and automatic responses, which have a role in preserving the organism. Because of these areas, we move without analyzing the consequence of each action; we move like a machine of automatic and unconscious induction. We walk without determining if the floor's structure will remain after each step and we run faster than normal when we feel a threat, not because of rational planning, but because of automatic responses.

Only a strict training allows us to dominate instincts. However, for most of us, the "don't panic" advice only works when we are not in panic. Most of us should be defined as beings firstly moved by instincts, social empathy and automatic responses resulting from perceptions, instead of sophisticated plans and arguments.

Homo economicus and Homo Politicus are, therefore, normative entelechies, behavioral benchmarks instead of descriptive models. Always calculating utility and always resolving social disputes through civilized debates are behavioral utopias instead of adjusted descriptions of what we are. However, for decades we've been constructing policies, models and sciences based on these assumptions not coinciding with reality.

Homo Sensus Sapiens is a more accurate image of the human being.

The concepts of the liberal hyper-rationalist man and the conservative hyper-communitarian man are hypertrophies of a single human facet. The first one is the hypertrophy of the neocortex: the idea that rationality dominates instincts. The second one is the hypertrophy of the inner reptilian brain: the idea that social empathy and cohesive institutions define humanity. However we are both at the same time. We are the tension of the sensus and the sapiens.

The concept of Homo Sensus Sapiens allows us to realize that we are at a point somewhere between overconfidence on rational capacities, and resignation to instincts. Homo Sensus Sapiens reminds us that we cannot surrender or escape from rationality or instincts. But this concept is not only about criticizing overconfidence or resignation. It is about improving explanations of social phenomena. Social Scientists should not always choose between rationality/irrationality. They should get out of the comfort zone of positivist fragmentation, and integrate scientific areas to explain an analogue human being, not a digital one, defined by the continuum between sensitivity and rationality. Better inputs for public policy would be proposed with this adjusted image.

The first character of this Homo, the Sensus, allows movement, reproduction, atomization of his biology, and preservation of the species. The second part, the Sapiens, allows this Homo to psychologically oscillate between the ontological world of matter and energy, and the epistemological world of socio-cultural codification, imagination, arts, technology and symbolic construction. This combination allows understanding of the nature of a hominid characterized by the constant tension between emotions and reason, and the search of a middle point of biological and cultural evolution. We are not only fears, not only plans. We are Homo Sensus Sapiens, the animal that feels and rationalizes.

JOHN TOOBY
Founder of field of Evolutionary Psychology; Co-Director, UC Santa Barbara's Center for Evolutionary Psychology

Nexus causality, moral warfare and misattribution arbitrage.

We could become far more intelligent than we are by adding to our stock of concepts, and by forcing ourselves to use them even when we don't like what they are telling us. This will be nearly always, because they generally tell us that our self-evidently superior selves and ingroups are error-besotted. We all start from radical ignorance in a world that is endlessly strange, vast, complex, intricate, and surprising. Deliverance from ignorance lies in good concepts — inference fountains that geyser out insights that organize and increase the scope of our understanding. We are drawn to them by the fascination of the discoveries they afford, but resist using them well and freely because they would reveal too many of our apparent achievements to be embarrassing or tragic failures. Those of us who are non-mythical lack the spine that Oedipus had — the obsidian resolve that drove him to piece together shattering realizations despite portents warning him off. Because of our weakness, "to see what is in front of one's nose needs a constant struggle" as Orwell says. So why struggle? Better instead to have one's nose and what lies beyond shift out of focus — to make oneself hysterically blind as convenience dictates, rather than to risk ending up like Oedipus, literally blinding oneself in horror at the harvest of an exhausting, successful struggle to discover what is true.

Alternatively, even modest individual-level improvements in our conceptual toolkit can have transformative effects on our collective intelligence, promoting incandescent intellectual chain reactions among multitudes of interacting individuals. If this promise of intelligence-amplification through conceptual tools seems like hyperbole, consider that the least inspired modern engineer, equipped with the conceptual tools of calculus, can understand, plan and build things far beyond what da Vinci or the mathematics-revering Plato could have achieved without it. We owe a lot to the infinitesimal, Newton's counterintuitive conceptual hack — something greater than zero but less than any finite magnitude. Far simpler conceptual innovations than calculus have had even more far reaching effects — the experiment (a danger to authority), zero, entropy, Boyle's atom, mathematical proof, natural selection, randomness, particulate inheritance, Dalton's element, distribution, formal logic, culture, Shannon's definition of information, the quantum…

Here are three simple conceptual tools that might help us see in front of our noses: *nexus causality, moral warfare,* and *misattribution arbitrage*. Causality itself is an evolved conceptual tool that simplifies, schematizes, and focuses our representation of situations. This cognitive machinery guides us to think in terms of *the* cause — of an outcome having a single cause. Yet for enlarged understanding, it is more accurate to represent outcomes as caused by an intersection or nexus of factors (including the absence of precluding conditions). In *War and Peace,* Tolstoy asks "When an apple ripens and falls, why does it fall? Because of its attraction to the earth, because its stem withers, because it is dried by the sun, because it grows heavier, because the wind shakes it….?" — with little effort any modern scientist could extend Tolstoy's list endlessly. We evolved, however, as cognitively improvisational tool-users, dependent on identifying actions we could take that lead to immediate payoffs. So, our minds evolved to represent situations in a way that highlighted the element in the nexus that we could manipulate to bring about a favored outcome. Elements in the situation that remained stable and that we could not change (like gravity or human nature) were left out of our representation of causes. Similarly, variable factors in the nexus (like the wind blowing) that we could not control, but that predicted an outcome (the apple falling), were also useful to represent as causes, in order to prepare ourselves to exploit opportunities or avoid dangers. So the reality of the causal nexus is cognitively ignored in favor of the cartoon of single causes. While useful for a forager, this machinery impoverishes our scientific understanding, rendering discussions (whether elite, scientific, or public) of the "causes" — of cancer, war, violence, mental disorders, infidelity, unemployment, climate, poverty, and so on — ridiculous.

Similarly, as players of evolved social games, we are designed to represent others' behavior and associated outcomes as caused by free will (by *intentions*). That is, we evolved to view "man" as Aristotle put it, as "the originator of his own actions." Given an outcome we dislike, we ignore the nexus, and trace "the" causal chain back to a person. We typically represent the backward chain as ending in — and the outcome as originating in — the person. Locating the "cause" (blame) in one or more persons allows us to punitively motivate others to avoid causing outcomes we don't like (or to incentivize outcomes we do like). More despicably, if something happens that many regard as a bad outcome, this gives us the opportunity to sift through the causal nexus for the one thread that colorably leads back to our rivals (where the blame obviously lies). Lamentably, much of our species' moral psychology evolved for moral warfare, a ruthless zero-sum game. Offensive play typically involves recruiting others to disadvantage or eliminate our rivals by publically sourcing them as the cause of bad outcomes. Defensive play involves giving our rivals no ammunition to mobilize others against us.

The moral game of blame attribution is only one subtype of misattribution arbitrage. For example, epidemiologists estimate that it was not until 1905 that you were better off going to a physician. (Semelweiss noticed that doctors doubled the mortality rate of mothers at delivery). For thousands of years, the role of the physician pre-existed its rational function, so why were there physicians? Economists, forecasters, and professional portfolio managers typically do no better than chance, yet command immense salaries for their services. Food prices are driven up to starvation levels in underdeveloped countries, based on climate models that cannot successfully retrodict known climate history. Liability lawyers win huge sums for plaintiffs who get diseases at no higher rates than others not exposed to "the" supposed cause. What is going on? The complexity and noise permeating any real causal nexus generates a fog of uncertainty. Slight biases in causal attribution, or in blameworthiness (e.g., sins of commission are worse than sins of omission) allow a stable niche for extracting undeserved credit or targeting undeserved blame. If the patient recovers, it was due to my heroic efforts; if not, the underlying disease was too severe. If it weren't for my macroeconomic policy, the economy would be even worse. The abandonment of moral warfare, and a wider appreciation of nexus causality and misattribution arbitrage would help us all shed at least some of the destructive delusions that cost humanity so much.

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Sexual Selection

When most people think about evolution by selection, they conjure up phrases such as "survival of the fittest" or "nature red in tooth and claw." These focus attention on the Darwinian struggle for survival. Many scientists, but few others, know that evolution by selection occurs through the process of differential *reproductive* success by virtue of heritable differences in design, not by differential survival success. And differential reproductive success often boils down to differential mating success, the focus of Darwin's 1871 theory of sexual selection.

Darwin identified two separate (but potentially related) causal processes by which sexual selection occurs. The first, intrasexual or same-sex competition, involves members of one sex competing with each other in various contests, physical or otherwise, the winners of which gain preferential sexual access to mates. Qualities that lead to success evolve. Those linked to failure bite the evolutionary dust. Evolution, change over time, occurs as a consequence of the process of intrasexual competition. The second, intersexual selection, deals with preferential mate choice. If members of one sex exhibit a consensus about qualities desired in mates, and those qualities are partially heritable, then those of the opposite sex possessing the desired qualities have a mating advantage. They get preferentially chosen. Those lacking desired mating qualities get shunned, banished, and remain mateless (or must settle for low quality mates). Evolutionary change over time occurs as a consequence of an increase in frequency of desired traits and a decrease in frequency of disfavored traits.

Darwin's theory of sexual selection, controversial in his day and relatively neglected for nearly a century after its publication, has mushroomed today into a tremendously important theory in evolutionary biology and evolutionary psychology. Research on human mating strategies has exploded over the past decade, as the profound implications of sexual selection become more deeply understood. Adding sexual selection to everyone's cognitive toolkit will provide profound insights into many human phenomena that otherwise remain baffling. In its modern formulations, sexual selection theory provides answers to weighty and troubling questions that elude many scientists and most non-scientists living today:

• Why do male and female minds differ?
• What explains the rich menu of human mating strategies?
• Why is conflict between the sexes so pervasive?
• Why does conflict between women and men focus so heavily on sex?
• What explains sexual harassment and sexual coercion?
• Why do men die earlier than women, on average, in every culture around the world?
• Why are most murderers men?
• Why are men so much keener than women on forming coalitions for warfare?
• Why are men so much more prone to becoming suicide terrorists?
• Why is suicide terrorism so much more prevalent in polygynous cultures that create a greater pool of mateless males?

Adding sexual selection theory to everyone's cognitive toolkit, in short, provides deep insight into the nature of human nature, people's obsession with sex and mating, the origins of sex differences, and many of the profound social conflicts that beset us all.

BART KOSKO
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Q. E. D. Moments

Everyone should know what proof feels like. It reduces all other species of belief to a distant second-class status. Proof is the far end on a cognitive scale of confidence that varies through levels of doubt. And most people never experience it.

Feeling proof comes from finishing a proof. It does not come from pointing at a proof in a book or in the brain of an instructor. It comes when the prover himself takes the last logical step on the deductive staircase. Then he gets to celebrate that logical feat by declaring "Q. E. D." or "Quod Erat Demonstrandum" or just "Quite Easily Done." Q. E. D. states that he has proven or demonstrated the claim that he wanted to prove. The proof need not be original or surprising. It just needs to be logically correct to produce a Q. E. D. moment. A proof of the Pythagorean Theorem has always sufficed.

The only such proofs that warrant the name are those in mathematics and formal logic. Each logical step has to come with a logically sufficient justification. That way each logical step comes with binary certainty. Then the final result itself follows with binary certainty. It is as if the prover multiplied the number 1 by itself for each step in the proof. The result is still the number 1. That is why the final result warrants a declaration of Q. E. D. That is also why the process comes to an unequivocal halt if the prover cannot justify a step. Any act of faith or guesswork or cutting corners will destroy the proof and its demand for binary certainty.

The catch is that we can really only prove tautologies.

The great binary truths of mathematics are still logically equivalent to the tautology "1 = 1" or "green is green." This differs from the factual statements we make about the real world — statements such as "Pine needles are green" or "Chlorophyll molecules reflect green light."

These factual statements are approximations. They are technically vague or fuzzy. And they often come juxtaposed with probabilistic uncertainty: "Pine needles are green with high probability." Note that this last statement involves triple uncertainty. There is first the vagueness of green pine needles because there is no bright line between greenness and non-greenness. It is a matter of degree. There is second only a probability whether pine needles have the vague property of greenness. And there is last the magnitude of the probability itself. The magnitude is the vague or fuzzy descriptor "high" because here too there is no bright line between high probability and not-high probability.

No one has ever produced a statement of fact that has the same 100% binary truth status as a mathematical theorem. Even the most accurate energy predictions of quantum mechanics hold only out to a few decimal places. Binary truth would require getting it right out to infinitely many decimal places.

Most scientists know this and rightly sweat it. The logical premises of a math model only approximately match the world that the model purports to model. It is not at all clear how such grounding mismatches propagate through to the model's predictions. Each infected inferential step tends to degrade the confidence of the conclusion as if multiplying fractions less than one. Modern statistics can appeal to confidence bounds if there are enough samples and if the samples sufficiently approximate the binary assumptions of the model. That at least makes us pay in the coin of data for an increase in certainty.

It is a big step down from such imperfect scientific inference to the approximate syllogistic reasoning of the law. There the disputant insists that similar premises must lead to similar conclusions. But this similarity involves its own approximate pattern matching of inherently vague patterns of causal conduct or hidden mental states such as intent or foreseeability. The judge's final ruling of "granted" or "denied" resolves the issue in practice. But it is technically a non sequitir. The product of any numbers between zero and one is again always less than one. So the confidence of the conclusion can only fall as the steps in the deductive chain increase. The clang of the gavel is no substitute for proof.

Such approximate reasoning may be as close as we can come to a Q. E. D. moment when using natural language. The everyday arguments that buzz in our brains hit far humbler logical highs. That is precisely why we all need to prove something at least once — to experience at least one true Q. E. D. moment. Those rare but god-like tastes of ideal certainty can help keep us from mistaking it for anything else.

SUE BLACKMORE
Psychologist; Author, Consciousness: An Introduction

Correlation is not a cause

The phrase "correlation is not a cause" (CINAC) may be familiar to every scientist but has not found its way into everyday language, even though critical thinking and scientific understanding would improve if more people had this simple reminder in their mental toolkit.

One reason for this lack is that CINAC can be surprisingly difficult to grasp. I learned just how difficult when teaching experimental design to nurses, physiotherapists and other assorted groups. They usually understood my favourite example: imagine you are watching at a railway station. More and more people arrive until the platform is crowded, and then — hey presto — along comes a train. Did the people cause the train to arrive (A causes B)? Did the train cause the people to arrive (B causes A)? No, they both depended on a railway timetable (C caused both A and B).

I soon discovered that this understanding tended to slip away again and again, until I began a new regime, and started every lecture with an invented example to get them thinking.

"Right", I might say "Suppose it's been discovered (I don't mean it's true) that children who eat more tomato ketchup do worse in their exams. Why could this be?" They would argue that it wasn't true (I'd explain the point of thought experiments again). "But there'd be health warnings on ketchup if it's poisonous" (Just pretend it's true for now please) and then they'd start using their imaginations.

"There's something in the ketchup that slows down nerves", "Eating ketchup makes you watch more telly instead of doing your homework", "Eating more ketchup means eating more chips and that makes you fat and lazy". Yes, yes, probably wrong but great examples of A causes B — go on. And so to "Stupid people have different taste buds and don't like ketchup", "Maybe if you don't pass your exams your Mum gives you ketchup". And finally " "Poorer people eat more junk food and do less well at school".

Next week: "Suppose we find that the more often people consult astrologers or psychics the longer they live." "But it can't be true — astrology's bunkum" (Sigh … just pretend it's true for now please.) OK. "Astrologers have a special psychic energy that they radiate to their clients", "Knowing the future means you can avoid dying", "Understanding your horoscope makes you happier and healthier" Yes, yes, excellent ideas, go on. "The older people get the more often they go to psychics", "Being healthy makes you more spiritual and so you seek out spiritual guidance". Yes, yes, keep going, all testable ideas, and finally "Women go to psychics more often and also live longer than men."

The point is that once you greet any new correlation with "CINAC" your imagination is let loose. Once you listen to every new science story Cinacally (which conveniently sounds like "cynically") you find yourself thinking: OK, if A doesn't cause B, could B cause A? Could something else cause them both or could they both be the same thing even though they don't appear to be? What's going on? Can I imagine other possibilities? Could I test them? Could I find out which is true? Then you can be critical of the science stories you hear. Then you are thinking like a scientist.

Stories of health scares and psychic claims may get people's attention but understanding that a correlation is not a cause could raise levels of debate over some of today's most pressing scientific issues. For example, we know that global temperature rise correlates with increasing levels of atmospheric carbon dioxide but why? Thinking Cinacally means asking which variable causes which or whether something else causes both, with important consequences for social action and the future of life on earth.

Some say that the greatest mystery facing science is the nature of consciousness. We *seem* to be independent selves having consciousness and free will, and yet the more we understand how the brain works, the less room there seems to be for consciousness to do anything. A popular way of trying to solve the mystery is the hunt for the "neural correlates of consciousness". For example, we know that brain activity in parts of the motor cortex and frontal lobes correlates with conscious decisions to act. But do our conscious decisions cause the brain activity, does the brain activity cause our decisions, or are both caused by something else?

The fourth possibility is that brain activity and conscious experiences are really the same thing, just as light turned out not to be *caused* by electromagnetic radiation but to *be* electromagnetic radiation, or heat turned out to be the movement of molecules in a fluid. At the moment we have no inkling of how consciousness could *be* brain activity but my guess is that it will turn out that way. Once we clear away some of our delusions about the nature of our own minds, we may finally see why there is no deep mystery and our conscious experiences simply *are* what is going on inside our brains. If this is right then there are no neural correlates of consciousness. But whether it is or not, remembering CINAC and working slowly from correlations to causes is likely to be how this mystery is finally solved.

P.Z. MYERS
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The Mediocrity Principle

As someone who just spent a term teaching freshman introductory biology, and will be doing it again in the coming months, I have to say that the first thing that leapt to my mind as an essential skill everyone should have was algebra. And elementary probability and statistics. That sure would make my life easier, anyway — there's something terribly depressing about seeing bright students tripped up by a basic math skill that they should have mastered in grade school.

But that isn't enough. Elementary math skills are an essential tool that we ought to be able to take for granted in a scientific and technological society. What *idea* should people grasp to better understand their place in the universe?

I'm going to recommend the mediocrity principle. It's fundamental to science, and it's also one of the most contentious, difficult concepts for many people to grasp — and opposition to the mediocrity principle is one of the major linchpins of religion and creationism and jingoism and failed social policies. There are a lot of cognitive ills that would be neatly wrapped up and easily disposed of if only everyone understood this one simple idea.

The mediocrity principle simply states that you aren't special. The universe does not revolve around you, this planet isn't privileged in any unique way, your country is not the perfect product of divine destiny, your existence isn't the product of directed, intentional fate, and that tuna sandwich you had for lunch was not plotting to give you indigestion. Most of what happens in the world is just a consequence of natural, universal laws — laws that apply everywhere and to everything, with no special exemptions or amplifications for your benefit — given variety by the input of chance. Everything that you as a human being consider cosmically important is an accident. The rules of inheritance and the nature of biology meant that when your parents had a baby, it was anatomically human and mostly fully functional physiologically, but the unique combination of traits that make you male or female, tall or short, brown-eyed or blue-eyed were the result of a chance shuffle of genetic attributes during meiosis, a few random mutations, and the luck of the draw in the grand sperm race at fertilization.

Don't feel bad about that, though, it's not just you. The stars themselves form as a result of the properties of atoms, the specific features of each star set by the chance distribution of ripples of condensation through clouds of dust and gas. Our sun wasn't required to be where it is, with the luminosity it has — it just happens to be there, and our existence follows from this opportunity. Our species itself is partly shaped by the force of our environment through selection, and partly by fluctuations of chance. If humans had gone extinct 100,000 years ago, the world would go on turning, life would go on thriving, and some other species would be prospering in our place — and most likely not by following the same intelligence-driven technological path we did.

And if you understand the mediocrity principle, that's OK.

The reason this is so essential to science is that it's the beginning of understanding how we came to be here and how everything works. We look for general principles that apply to the universe as a whole first, and those explain much of the story; and then we look for the quirks and exceptions that led to the details. It's a strategy that succeeds and is useful in gaining a deeper knowledge. Starting with a presumption that a subject of interest represents a violation of the properties of the universe, that it was poofed uniquely into existence with a specific purpose, and that the conditions of its existence can no longer apply, means that you have leapt to an unfounded and unusual explanation with no legitimate reason. What the mediocrity principle tells us is that our state is not the product of intent, that the universe lacks both malice and benevolence, but that everything does follow rules — and that grasping those rules should be the goal of science.

SAM HARRIS
Neuroscientist; Chairman, Project Reason; Author, The Moral Landscape

We are Lost in Thought

I invite you to pay attention to anything — the sight of this text, the sensation of breathing, the feeling of your body resting against your chair — for a mere sixty seconds without getting distracted by discursive thought. It sounds simple enough: Just pay attention. The truth, however, is that you will find the task impossible. If the lives of your children depended on it, you could not focus on anything — even the feeling of a knife at your throat — for more than a few seconds, before your awareness would be submerged again by the flow of thought. This forced plunge into unreality is a problem. In fact, it is the problem from which every other problem in human life appears to be made.

I am by no means denying the importance of thinking. Linguistic thought is indispensable to us. It is the basis for planning, explicit learning, moral reasoning, and many other capacities that make us human. Thinking is the substance of every social relationship and cultural institution we have. It is also the foundation of science. But our habitual identification with the flow of thought — that is, our failure to recognize thoughts *as thoughts*, as transient appearances in consciousness — is a primary source of human suffering and confusion.

Our relationship to our own thinking is strange to the point of paradox, in fact. When we see a person walking down the street talking to himself, we generally assume that he is mentally ill. But we all talk to ourselves *continuously* — we just have the good sense to keep our mouths shut. Our lives in the present can scarcely be glimpsed through the veil of our discursivity: We tell ourselves what just happened, what almost happened, what should have happened, and what might yet happen. We ceaselessly reiterate our hopes and fears about the future. Rather than simply exist as ourselves, we seem to presume a relationship with ourselves. It's as though we are having a conversation with an imaginary friend possessed of infinite patience. Who are we talking to?

While most of us go through life feeling that we are the thinker of our thoughts and the experiencer of our experience, from the perspective of science we know that this is a distorted view. There is no discrete self or ego lurking like a minotaur in the labyrinth of the brain. There is no region of cortex or pathway of neural processing that occupies a privileged position with respect to our personhood. There is no unchanging "center of narrative gravity" (to use Daniel Dennett's phrase). In subjective terms, however, there *seems* to be one — to most of us, most of the time.

Our contemplative traditions (Hindu, Buddhist, Christian, Muslim, Jewish, etc.) also suggest, to varying degrees and with greater or lesser precision, that we live in the grip of a cognitive illusion. But the alternative to our captivity is almost always viewed through the lens of religious dogma. A Christian will recite the Lord's Prayer continuously over a weekend, experience a profound sense of clarity and peace, and judge this mental state to be fully corroborative of the doctrine of Christianity; A Hindu will spend an evening singing devotional songs to Krishna, feel suddenly free of his conventional sense of self, and conclude that his chosen deity has showered him with grace; a Sufi will spend hours whirling in circles, pierce the veil of thought for a time, and believe that he has established a direct connection to Allah.

The universality of these phenomena refutes the sectarian claims of any one religion. And, given that contemplatives generally present their experiences of self-transcendence as inseparable from their associated theology, mythology, and metaphysics, it is no surprise that scientists and nonbelievers tend to view their reports as the product of disordered minds, or as exaggerated accounts of far more common mental states — like scientific awe, aesthetic enjoyment, artistic inspiration, etc.

Our religions are clearly false, even if certain classically religious experiences are worth having. If we want to actually understand the mind, and overcome some of the most dangerous and enduring sources of conflict in our world, we must begin thinking about the full spectrum of human experience in the context of science.

But we must first realize that we are lost in thought.

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The Paradox

Paradoxes arise when one or more convincing truths contradiction either each other, clash with other convincing truths, or violate unshakeable intuitions. They are frustrating, yet beguiling. Many see virtue in avoiding, glossing over, or dismissing them. Instead we should seek them out, if we find one sharpen it, push it to the extreme, and hope that the resolution will reveal itself, for with that resolution will invariably come a dose of Truth.

History is replete with examples, and with failed opportunities. One of my favorites is Olber's paradox. Suppose the universe were filled with an eternal roughly uniform distribution of shining stars. Faraway stars would look dim because they take up a tiny angle on the sky; but within that angle they are as bright as the Sun's surface. Yet in an eternal and infinite (or finite but unbounded) space, every direction would lie within the angle taken up by some star. The sky would be alight like the surface of the sun. Thus, a simple glance at the dark night sky reveals that the universe must be dynamic: expanding, or evolving. Astronomers grappled with this paradox for several centuries, devising unworkable schemes for its resolution. Despite at least one correct view (by Edgar Allen Poe!), the implications never really permeated even the small community of people thinking about the fundamental structure of the universe. And so it was that Einstein, when he went to apply his new theory to the universe, sought an eternal and static model that could never make sense, introduced a term into his equations which he called his greatest blunder, and failed to invent the big-bang theory of cosmology.

Nature appears to contradict itself with the utmost rarity, and so a paradox can be opportunity for us to lay bare our cherished assumptions, and discover which of them we must let go. But a good paradox can take us farther, to reveal that the not just the assumptions but the very modes of thinking we employed in creating the paradox must be replaced. Particles and waves? Not truth, just convenient models. The same number of integers as perfect squares of integers? Not crazy, though you might be if you invent cardinality. This sentence is false. And so, says Godel, might be the foundations of any formal system that can refer to itself. The list goes on.

What next? I've got a few big ones I'm wrestling with. How can thermodynamics' second law arise unless cosmological initial conditions are fine-tuned in a way we would never accept in any other theory or explanation of anything? How do we do science if the universe is infinite, and every outcome of every experiment occurs infinitely many times?

What impossibility is nagging at you?

RICHARD SAUL WURMAN

Architect, Cartographer; Founder, TED Conference; Author, 33: Understanding Change & the Change in Understanding

OBJECTS OF UNDERSTANDING AND COMMUNICATION

THE WAKING DREAM I HAVE FOR MY TOOLKIT IS ONE FILLED WITH OBJECTS OF UNDERSTANDING AND COMMUNICATION.

THE TOOLS IN MY TOOLBOX RESPOND TO ME. THEY NOD WHEN I TALK, GIVE ME EVIDENCE OF ME, AND SUGGEST SECONDARY AND TERTIARY JOURNEYS THAT EXTEND MY CURIOSITIES.

THIS TOOLKIT IS WOVEN OF THREADS OF IGNORANCE AND STITCHES OF QUESTIONS THAT INVITE KNOWLEDGE IN.

IN THIS WEAVE ARE MAPS AND PATTERNS WITH ENOUGH STITCHES TO ALLOW ME TO MAKE THE CHOICE, AS I WISH, TO ADD A TINY DROP OF SUPERGLUE.

I WANT AN iPHONE / iPAD / iMAC THAT NODS.

THE FIRST MOVIES ARCHIVED STAGE SHOWS.

THE iPAD AND KINDLE ARCHIVE MAGAZINES, NEWSPAPERS AND BOOKS.

I WANT A NEW MODALITY WITH WHICH I CAN CONVERSE AT DIFFERING LEVELS OF COMPLEXITY, IN DIFFERENT LANGUAGES, AND WHICH UNDERSTANDS THE NUANCE OF MY QUESTIONS.

I WANT HELP FLYING THROUGH MY WAKING DREAMS CONNECTING

THE THREADS OF THESE EPIPHANIES.

I BELIEVE WE ARE AT THIS CUSP.

A FIRST TOE IN THE WARM BATH OF THIS NEW MODALITY.

MARCELO GLEISER
Physicist; Appleton Professor of Natural Philosophy, Dartmouth College; Author, The Prophet and the Astronomer*:* Apocalyptic Science and the End of the World

We Are Unique

To improve everybody's cognitive toolkit, the required scientific concept has to be applicable to all humans. It needs to make a difference to us as a species, or, more to the point I am going to make, as a key factor in defining our collective role. This concept must impact the way we perceive who we are and why we are here. Hopefully, it will redefine the way we live our lives and plan for our collective future. This concept must make it clear that we matter.

A concept that might grow into this life-redefining powerhouse is the notion that we, humans in a rare planet, are unique and uniquely important. But what of Copernicanism — the notion that the more we learn about the universe the less important we become? I will argue that modern science, traditionally considered guilty of reducing our existence to a pointless accident in an indifferent universe, is actually saying the opposite. While it does say that we are an accident in an indifferent universe, it also says that we are a rare accident and thus not pointless.

But wait! Isn't it the opposite? Shouldn't we expect life to be common in the cosmos and us to be just one of many creatures out there? After all, as we discover more and more worlds circling other suns, the so-called exoplanets, we find an amazing array of possibilities. Also, given that the laws of physics and chemistry are the same across the universe, we should expect life to be ubiquitous: if it happened here, it must've happened in many other places. So why am I claiming that we are unique?

There is an *enormous* difference between life and intelligent life. By intelligent life I don't mean clever crows or dolphins, but minds capable of self-awareness and the ability to develop advanced technologies, that is, not just use what is at hand but transform materials into new devices that can perform a multitude of tasks. Keeping this definition in mind, I agree that single-celled life, although dependent on a multitude of physical and biochemical factors, shouldn't be an exclusive property of our planet. First, because life on Earth appeared almost as quickly as it could, no more than a few hundred million years after things quieted down enough; second, due to the existence of extremophiles, life forms capable of surviving in extreme conditions (very hot or cold, very acidic or/and radioactive, no oxygen, etc.), showing that life is very resilient and spreads into every niche that it can.

However, the existence of single-celled organisms doesn't necessarily lead to that of multicellular ones, much less to that of *intelligent* multicellular ones. Life is in the business of surviving the best way it can in a given environment. If the environment changes, those creatures that can survive under the new conditions will. Nothing in this dynamics supports the notion that once there is life all you have to do is wait long enough and puff, there pops a clever creature. (This smells of biological teleology, the concept that life's purpose is to create intelligent life, a notion that seduces many people for obvious reasons: it makes us the special outcome of some grand plan.) The history of life on Earth doesn't support this evolution toward intelligence: there have been many transitions toward greater complexity, none of them obvious: prokaryotic to eukaryotic unicellular creatures (and nothing more for 3 billion years!), unicellular to multicellular, sexual reproduction, mammals, intelligent mammals, edge.org...Play the movie differently, and we wouldn't be here.

As we look at planet Earth and the factors that came into play for us to be here, we quickly realize that our planet is very special. Here is a short list: the long-term existence of a protective and oxygen-rich atmosphere; Earth's axial tilt, stabilized by a single large moon; the ozone layer and the magnetic field that jointly protect surface creatures from lethal cosmic radiation; plate tectonics that regulate the levels of carbon dioxide and keep the global temperature stable; the fact that our sun is a smallish, fairly stable star not too prone to releasing huge plasma burps. Consequently, it's rather naive to expect life — at the complexity level that exists here — to be ubiquitous across the universe.

A further point: even if there is intelligent life elsewhere and, of course, we can't rule that out (science is much better at finding things that exist than at ruling out things that don't), it will be so remote that for all practical purposes we are alone. Even if SETI finds evidence of other cosmic intelligences, we are not going to initiate a very intense collaboration. And if we are alone, and alone have the awareness of what it means to be alive and of the importance of remaining alive, we gain a new kind of cosmic centrality, very different — and much more meaningful — from the religiously-inspired one of pre-Copernican days, when Earth was the center of Creation: we matter because we are rare and we know it.

The joint realization that we live in a remarkable cosmic cocoon and that we are able to create languages and rocket ships in an otherwise apparently dumb universe ought to be transformative. Until we find other self-aware intelligences, we are how the universe thinks. We might as well start enjoying each other's company.

ROGER HIGHFIELD
Editor, New Scientist; *Coauthor,* After Dolly

The Snuggle For Existence

Everyone is familiar with the struggle for existence. In the wake of the revolutionary work by Charles Darwin we realized that competition is at the very heart of evolution. The fittest win this endless "struggle for life most severe", as he put it, and all others perish. In consequence, every creature that crawls, swims, and flies today has ancestors that once successfully reproduced more often than their unfortunate competitors.

This is echoed in the way that people see life as competitive. Winners take all. Nice guys finish last. We look after number one. We are motivated by self-interest. Indeed, even our genes are said to be selfish.

Yet competition does not tell the whole story of biology.

I doubt many realise that, paradoxically, one way to win the struggle for existence is to pursue the snuggle for existence: to cooperate.

We already do this to a remarkable extent. Even the simplest activities of everyday life involve much more cooperation than you might think. Consider, for example, stopping at a coffee shop one morning to have a cappuccino and croissant for breakfast. To enjoy that simple pleasure could draw on the labors of a small army of people from at least half a dozen countries. Delivering that snack also relied on a vast number of ideas, which have been widely disseminated around the world down the generations by the medium of language.

Now we have remarkable new insights into what makes us all work together. Building on the work of many others, Martin Nowak of Harvard University has identified at least five basic mechanisms of cooperation. What I find stunning is that he shows the way that we human beings collaborate is as clearly described by mathematics as the descent of the apple that once fell in Newton's garden. The implications of this new understanding are profound.

Global human cooperation now teeters on a threshold. The accelerating wealth and industry of Earth's increasing inhabitants — itself a triumph of cooperation-is exhausting the ability of our home planet to support us all. Many problems that challenge us today can be traced back to a profound tension between what is good and desirable for society as a whole and what is good and desirable for an individual. That conflict can be found in global problems such as climate change, pollution, resource depletion, poverty, hunger, and overpopulation.

As once argued by the American ecologist Garrett Hardin, the biggest issues of all — saving the planet and maximizing the collective lifetime of the species Homo sapiens — cannot be solved by technology alone. If we are to win the struggle for existence, and avoid a precipitous fall, there's no choice but to harness this extraordinary creative force. It is down to all of us to refine and to extend our ability to cooperate.

Nowak's work contains a deeper message. Previously, there were only two basic principles of evolution — mutation and selection — where the former generates genetic diversity and the latter picks the individuals that are best suited to a given environment. We must now accept that cooperation is the third principle. From cooperation can emerge the constructive side of evolution, from genes to organisms to language and the extraordinarily complex social behaviors that underpin modern society.

CARL ZIMMER
Journalist; Author, The Tangled Bank: An Introduction to Evolution; *Blogger,* The Loom

Life As A Side Effect

It's been over 150 years since Charles Darwin published the *Origin of Species*, but we still have trouble appreciating the simple, brilliant insight at its core. That is, life's diversity does not exist because it is necessary for living things. Birds did not get wings so that they could fly. We do not have eyes so that we can read. Instead, eyes, wings, and the rest of life's wonder has come about as a side effect of life itself. Living things struggle to survive, they reproduce, and they don't do a perfect job of replicating themselves. Evolution spins off of that loop, like heat coming off an engine. We're so used to seeing agents behind everything that we struggle to recognize life as a side effect. I think everyone would do well do overcome that urge to see agents where there are none. It would even help us to understand why we are so eager to see agents in the first place.

LAURENCE C. SMITH
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Innovation

As scientists, we're sympathetic to this question. We've asked it of ourselves before, many times, after fruitless days lost at the lab bench or computer seat. If only our brains could find a new way to process the delivered information faster, to interpret it better, to align the world's
noisy torrents of data in an crystalline moment of clarity. In a word, for our brains to forgo their familiar thought sequences, and innovate.

To be sure, the word "innovate" has become something of a badly overused cliche. Tenacious CEO's, clever engineers, and restless artists come to mind before the methodical, data-obsessed scientist. But how often do we consider the cognitive role of innovation in the supposedly bone-dry world of hypothesis-testing, mathematical constraints and data-dependent empiricism?

In the world of science, innovation stretches the mind to find an explanation when the universe wants to hold on to its secrets just a little longer. This can-do attitude is made all the more valuable, not less, in a world constrained by ultimate barriers like continuity of mass and energy, Absolute zero, or the Clausius-Clapeyron relation. Innovation is a critical enabler of discovery around and of these bounds. It is the occasional architect of that rare, wonderful breakthrough even when the tide of scientific opinion is against you.

A reexamination of this word from the scientific perspective reminds us of the extreme power of this cognitive tool, one that most people possess already. Through innovation, we all can transcend social, professional, political, scientific, and most importantly, personal limits. Perhaps we might all put it to better and more frequent use.

TOR NØRRETRANDERS
Science Writer; Consultant; Lecturer, Copenhagen; Author, The Generous Man *and* The User Illusion

Depth

Depth is what you do not see immediately at the surface of things. Depth is what is below that surface: a body of water below the surface of a lake, the rich life of a soil below the dirt or the spectacular line of reasoning behind a simple statement.

Depth is a straightforward aspect of the physical world. Gravity stacks stuff and not everything can be at the top. Below there is more and you can dig for it.

Depth acquired a particular meaning with the rise of complexity science a quarter of a century ago: What is characteristic of something complex? Very orderly things like crystals are not complex. They are simple. Very messy things like a pile of litter are very difficult to describe: They hold a lot of information. Information is a measure of how difficult something is to describe. Disorder has a high information content and order has a low one. All the interesting stuff in life is in-between: Living creatures, thoughts and conversations. Not a lot of information, but neither a little. So information content does not lead us to what is interesting or complex. The marker is rather the information that is not there, but was somehow involved in creating the object of interest. The history of the object is more relevant than the object itself, if we want to pin-point what is interesting to us.

It is not the informational surface of the thing, but its informational depth that attracts our curiosity. It took a lot to bring it here, before our eyes. It is not what is there, but what used to be there, that matters. Depth is about that.

The concept of depth in complexity science was expressed in different ways: You could talk about the actual amount of physical information that was involved in bringing about something — the thermodynamic depth — or the amount of computation it took to arrive at a result— the logical depth. Both express the notion that the process behind is more important than the eventual product.

This idea can also be applied to human communication.

When you say "yes" at a wedding it (hopefully) re-presents a huge amount of conversation, coexistence and fun that you have had with that other person present. And a lot of reflection upon it. There is not a lot of information in the "yes" (one bit, actually), but the statement has depth. Most conversational statements have some kind of depth: There is more than meets the ear, something that happened between the ears of the person talking — before a statement was made. When you understand the statement, the meaning of what is being said, you "dig it", you get the depth, what is below and behind. What is not said, but meant — the exformation content, information processed and thrown away before the actual production of explicit information.

2 + 2 = 4. This is a simple computation. The result, 4, hold less information than the problem, 2 + 2 (essentially because the problem could also have been 3 + 1 and yet the result would still be 4). Computation is wonderful as a method for throwing away information, getting rid of it. You do computations to ignore all the details, to get an overview, an abstraction, a result.

What you want is a way to distinguish between a very deep "yes" and a very shallow one: Did the guy actually think about what he said? Was the result 4 actually the result of a meaningful calculation? Is there in fact water below that surface? Does it have depth?

Most human interaction is about that question: Is this bluff or for real? Is there sincere depth in the affection? Does the result stem from intense analysis or is it just an estimate? Is there anything between the lines?

Signaling is all about this question: fake or depth? In biology the past few decades have seen the rise of studies of how animals prove to each other that there is depth behind the signal. The handicap principle of sexual selection is about a way to prove that you signal has depth: If a peacock has long, spectacular feathers it proves that it can survive its predators even though the fancy plumage represents a disadvantage, a handicap. Hence, the peahen can know that the individual displaying the huge tail is a strong one, or else it could not survive with that extreme tail.

Amongst humans you have what economists call costly signals: Ways to show that you have something of value. The phenomenon conspicuous consumption was observed by sociologist Thorstein Veblen already in 1899: If you want to prove that you have a lot of money, you have to waste them. That is: Use them in a way that is absurd and idiotic, because only the rich guy can do so. But do it conspicuously, so that other people will know. Waste is a costly signal of the depth of pile of money. Poor people have to use their money in functional way.

Handicaps, costly signals, intense eye contact and rhetorical gestures are all about proving that what seems so simple really has a lot of depth.

That is also the point with abstractions: We want them to be shorthand for a lot of information that was digested in the process leading to the use of the abstraction, but is not present when we use it. Such abstractions have depth. We love them.

Other abstraction have no depth. They are shallow and just used to impress the other guy. They do not help us. We hate them.

Intellectual life is very much about the ability to distinguish between the shallow and the deep abstractions. You need to know if there is any depth before you make that headlong dive and jump into it.

GREGORY COCHRAN
Consultant, Adaptive Optics; Adjunct Professor of Anthropology, University of Utah; Coauthor, The 10,000 Year Explosion

The Veeck Effect

There's an invidious rhetorical strategy that we've all seen — and I'm afraid that most of us have inflicted it on others as well. I call it the Veeck effect (of the first kind) — it occurs whenever someone adjusts the standards of evidence in order to favor a preferred outcome.

Why Veeck? Bill Veeck was a flamboyant baseball owner and promoter.
In his autobiography — (Veeck — As in Wreck) he described installing a flexible fence in the right field of the Milwaukee Brewers. At first he only put the fence up when facing a team full of power hitters, but eventually he took it to the limit, moving the fence up when the visitors were at bat and down when his team was.

The history of science is littered with flexible fences. The phlogiston theory predicted that phlogiston would be released when magnesium burned. It looked bad for that theory when experiments showed that burning magnesium became heavier — but its supporters happily explained that phlogiston had negative weight.

Consider Kepler. He came up with the idea that the distances of the six (known) planets could be explained by nesting the five Platonic solids. It almost worked for Earth, Mars, and Venus, but clearly failed for Jupiter. He dismissed the trouble with Jupiter, saying "nobody will wonder at it, considering the great distance". The theory certainly wouldn't have worked with any extra planets, but fortunately for Kepler's peace of mind, Uranus was discovered well after his death.

The Veeckian urge is strong in every field, but it truly flourishes in the human and historical sciences, where the definitive experiments that would quash such nonsense are often impossible, impractical, or illegal. Nowhere is this tendency stronger than among cultural anthropologists, who at times seem to have no reason for being other than refurbishing the reputations of cannibals.

Sometimes this has meant denying a particular case of cannibalism, for example among the Anasazi in the American Southwest. Evidence there has piled up and up -archaeologists have found piles of human bones with muscles scraped off, split open for marrow, polished by stirring in pots. They have even found human feces with traces of digested human tissue. But that's not good enough. For one thing, this implication of ancient cannibalism among the Anasazi is offensive to their Pueblo descendants, and that somehow trumps mounds of bloody evidence. You would think that the same principle would cause cultural anthropologists to embrace the face-saving falsehoods of other ethnic groups - didn't the South really secede over the tariff? But that doesn't seem to happen.

Some anthropologists have carried the effort further, denying that any culture was ever cannibalistic. They don't just deny Anasazi archaeology — they deny every kind of evidence, from archaeology to historical accounts, even reports from people alive today. When Álvaro de Mendaña discovered the Solomon Islands, he reported that a friendly chieftain threw a feast and offered him a quarter of a boy. Made up, surely. The conquistadors described the Aztecs as a cannibal kingdom — can't be right, even if the archeology supports it. When Papuans in Port Moresby volunteered to have a picnic in the morgue — to attract tourists, of course — they were just showing public spirit.

The Quaternary mass extinction, which wiped out much of the world's megafauna, offers paleontologists a chance to crank up their own fences. The large marsupials, flightless birds and reptiles of Australia disappeared shortly after humans arrived, about 50,000 years ago. The large mammals of North and South America disappeared about 10,000 years ago — again, just after humans showed up. Moas disappear within two centuries after Polynesian colonization in New Zealand, while giant flightless birds and lemurs disappeared from Madagascar shortly after humans arrived. What does this pattern suggest as the cause? Why, climate change, of course. Couldn't be human hunters — that's unpossible!

The Veeck effect is even more common in everyday life than it is in science. It's just that we expect more from scientists. But scientific examples are clear-cut, easy to see, and understanding the strategy helps you avoid succumbing to it.

Whenever some Administration official says that absence of evidence is not evidence of absence — whenever a psychiatrist argues that Freudian psychotherapy works for some people, even if proven useless on average — Bill Veeck's spirit goes marching on.

*If you're wondering about the second Veeck effect, it's the intellectual equivalent of putting a midget up to bat. And that's another essay.

STEPHON H. ALEXANDER
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Duality and World Piece

In the northeast Bronx, I walk through a neighborhood that I once feared going into, this time with a big smile on my face. This is because I can quell the bullies with a new slang word in our dictionary "dual". As I approach the 2-train stop on

East 225st , the bullies await me. I say, "Yo, whats the dual?" The bullies embrace me with a pound followed by a high five. I make my train.

In physics one of the most beautiful yet underappreciated ideas is that of duality. A duality allows us to describe a physical phenomenon from two different perspectives; often a flash of creative insight is needed to find both. However the power of the duality goes beyond the apparent redundancy of description. After all, why do I need more than one way to describe the same thing? There are examples in physics where either description of the phenomena fails to capture its entirety. Properties of the system 'beyond' the individual descriptions 'emerge'. I will provide two beautiful examples of how dualities manage to yield 'emergent' properties and, end with a speculation.

Most of us know about the famous wave-particle duality in quantum mechanics, which allowes the photon (and the electron) to attain their magical properties to explain all of the wonders of atomic physics and chemical bonding. The duality states that matter (such as the electron) has both wave-like and particle like properties depending on the context. What's weird is *how* quantum mechanics manifests the wave-particle duality. According to the traditional Copenhagen interpretation, the wave is a travelling oscillation of possibility that the electron can be realized omewhere as a particle.

Life gets strange in the example of quantum tunneling where the electron can penetrate a barrier only because of its 'wave-like' property. Classical physics tells us that an object will not surmount a barrier (like a hill) if its total kinetic energy is less than the potential energy of the barrier. However quantum mechanics predicts that particles can penetrate (or tunnel) through a barrier even when the kinetic energy is less than the potential energy of the barrier. This effect is used every time you use a flash drive or a CD player!

Most people assume that the conduction of electrons in a metal, is a well understood property of classical physics. But when we look deeper we realize that conduction happens because of the wave-like nature of the electrons. We call the collective electron waves that move through the periodic lattice of a metal a Bloch-wave. Qualitatively, when the electron's Bloch waves constructively interfere we get conduction. Moreover, the wave-particle duality takes us further to predict superconductivity, how it is that electrons (and other spin ½ particles like quarks) can conduct without resistance.

Nowadays in my field of quantum gravity and relativistic cosmology, theorists are exploiting another type of duality to address unresolved questions. This holographic duality was pioneered by Leonard Susskind and Gerhard 't Hooft, and later it found a home in the form of the AdS/CFT duality by Juan Maldacena.

This posits that the phenomenon of quantum gravity is described on one hand by a ordinary gravitational theory (a beefed up version of Einstein's general relativity). On the other hand a dual description of quantum gravity is described by a non-gravitational physics with a space-time of one lower dimension. We are left to wonder in the spirit of the wave-particle duality, what new physics we would glean from this type of duality.

The holographic duality also seems to persist in other approaches of quantum gravity, such as Loop Quantum Gravity, and researchers are still in exploring the true meaning behind holography and potential predictions for experiments.

Dualities seem to allow us to understand and make use of properties in physics that go beyond a singular lense of analysis. Might we wonder if duality can transcend its role in physics and into other fields? The dual of time will tell.

JOSHUA GREENE
Cognitive Neuroscientist and Philosopher, Harvard University

Supervenience!

There's a lot of stuff in the world: trees, cars, galaxies, benzene, the Baths of Caracalla, your pancreas, Ottawa, *ennui*, Walter Mondale. How does it all fit together? In a word… Supervenience. (Pronounced soo-per-VEEN-yence. The verb form is to *supervene*.)

Supervenience is a shorthand abstraction, native to Anglo-American philosophy, that provides a general framework for thinking about how everything relates to everything else. The technical definition of supervenience is somewhat awkward:

Supervenience is a relationship between two sets of properties. Call them Set A and Set B. The Set A properties supervene on the Set B properties if and only if no two things can differ in their A properties without also differing in their B properties.

This definition, while admirably precise, makes it hard to see what supervenience is really about, which is the relationships among different levels of reality. Take, for example, a computer screen displaying a picture. At a high level, at the level of images, a screen may depict an image of a dog sitting in a rowboat, curled up next to a life vest. The screen's content can also be described as an arrangement of pixels, a set of locations and corresponding colors. The image *supervenes* on the pixels. This is because a screen's image-level properties (its dogginess, its rowboatness) cannot differ from another screen's image-level properties unless the two screens also differ in their pixel-level properties.

The pixels and the image are, in a very real sense, the same thing. But — and this is key — their relationship is asymmetrical. The image supervenes on the pixels, but the pixels *do not* supervene on the image. This is because screens can differ in their pixel-level properties without differing in their image-level properties. For example, the same image may be displayed at two different sizes or resolutions. And if you knock out a few pixels, it's still the same image. (Changing a few pixels will not protect you from charges of copyright infringement.) Perhaps the easiest way to think about the asymmetry of supervenience is in terms of what determines what. Determining the pixels completely determines the image, but determining the image does not completely determine the pixels.

The concept of supervenience deserves wider currency because it allows us to think clearly about many things, not just about images and pixels. Supervenience explains, for example, why physics is the most fundamental science and why the things that physicists study are the most fundamental things. To many people, this sounds like a value judgment, but it's not, or need not be. Physics is fundamental because everything in the universe, from your pancreas to Ottawa, supervenes on physical stuff. (Or so "physicalists" like me claim.) If there were a universe physically identical to ours, then it would also include a pancreas just like yours and an Ottawa just like Canada's.

Supervenience is especially helpful when grappling with three contentious and closely related issues: (1) the relationship between science and the humanities, (2) the relationship between the mind and brain, and (3) the relationship between facts and values.

Humanists sometimes perceive science as imperialistic, as aspiring to take over the humanities, to "reduce" everything to electrons, genes, numbers, and neurons, and thus to "explain away" all of the things that make life worth living. Such thoughts are accompanied by disdain or fear, depending on how credible such ambitions are taken to be. Scientists, for their part, sometimes are imperious, dismissing humanists and their pursuits as childish and unworthy of respect. Supervenience can help us think about how science and the humanities fit together, why science is sometimes perceived as encroaching on the humanist's territory, and the extent to which such perceptions are and are not valid.

It would seem that humanists and scientists study different things. Humanists are concerned with things like love, revenge, beauty, cruelty, and our evolving conceptions of such things. Scientists study things like electrons and nucleotides. But sometimes it sounds like scientists are getting greedy. Physicists aspire to construct a complete physical theory, which is sometimes called a "Theory of Everything" (TOE). If humanists and scientists study different things, and if physics covers everything, then what is left for the humanists? (Or, for that matter, non-physicists?)

There is a sense in which a TOE really is a TOE, and there is a sense in which it's not. A TOE is a complete theory of everything upon which everything else *supervenes*. If two worlds are physically identical, then they are also humanistically identical, containing exactly the same love, revenge, beauty, cruelty, and conceptions thereof. But that does not mean that a TOE puts all other theorizing out of business, not by a long shot. A TOE won't tell you anything interesting about *Macbeth* or the Boxer Rebellion.

Perhaps the threat from physics was never all that serious. Today, the real threat, if there is one, is from the behavioral sciences, especially the sciences that connect the kind of "hard" science we all studied in high school to humanistic concerns. In my opinion, three sciences stand out in this regard: behavioral genetics, evolutionary psychology, and cognitive neuroscience. I study moral judgment, a classically humanistic topic. I do this in part by scanning people's brains while they make moral judgments. More recently I've started looking at genes, and my work is guided by evolutionary thinking. My work assumes that the mind supervenes on the brain, and I attempt to explain human values — for example the tension between individual rights and the greater good — in terms of competing neural systems.

I can tell you from personal experience that this kind of work makes some humanists uncomfortable. During the discussion following a talk I gave at Harvard's Humanities Center, a prominent professor declared that my talk — not any particular conclusion I'd drawn, but the whole approach — made him physically ill. (Of course, this could just be me!)

The subject matter of the humanities has always supervened on the subject matter of the physical sciences, but in the past a humanist could comfortably ignore the subvening physical details, much as an admirer of a picture can ignore the pixel-level details. Is that still true? Perhaps it is. Perhaps it depends on one's interests. In any case, it's nothing to be worried sick about.

NB: Andrea Heberlein points out that "supervenience" may also refer to exceptional levels of convenience, as in, "New Chinese take-out right around the corner — *Supervenient!*"

W. TECUMSEH FITCH
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An Instinct to Learn

One of the most pernicious misconceptions in cognitive science is the belief in a dichotomy between nature and nurture. Many psychologists, linguists and social scientists, along with the popular press, continue to treat nature and nurture as combatting ideologies, rather than complementary perspectives. For such people, the idea that something is *both* "innate" and "learned", or *both* "biological" and "cultural", is an absurdity. Yet most biologists today recognize that understanding behavior requires that we understand the interaction between inborn cognitive processes (e.g. learning and memory) and individual experience. This is particularly true in human behaviour, since the capacities for language and culture are some of the key adaptations of our species, and involve irreducible elements of both biology and environment, of both nature and nurture.

The antidote to "nature versus nurture" thinking is to recognize the existence, and importance, of "instincts to learn". This phrase was introduced by Peter Marler, one of the fathers of birdsong research. A young songbird, while still in the nest, eagerly listens to adults of its own species sing. Months later, having fledged, it begins singing itself, and shapes its own initial sonic gropings to the template provided by those stored memories. During this period of "subsong" the bird gradually refines and perfects its own song, until by adulthood it is ready to defend a territory and attract mates with its own, perhaps unique, species-typical song.

Songbird vocal learning is the classic example of an instinct to learn. The songbird's drive to listen, and to sing, and to shape its song to that which it heard, is all instinctive. The bird needs no tutelage, nor feedback from its parents, to go through these stages. Nonetheless, the actual song that it sings is learned, passed *culturally* from generation to generation. Birds have local dialects, varying randomly from region to region. If the young bird hears no song, it will produce only an impoverished squawking, not a typical song.

Importantly, this capacity for vocal learning is only true of some birds, like songbirds and parrots. Other bird species, like seagulls, chickens or owls, do not learn their vocalizations: rather, their calls develop reliably in the absence of any acoustic input. The calls of such birds are truly instinctive, rather than learned. But for those birds capable of vocal learning, the song that an adult bird sings is the result of a complex interplay between instinct (to listen, to rehearse, and to perfect) and learning (matching the songs of adults of its species).

It is interesting, and perhaps surprising, to realize that most mammals do not have a capacity for complex vocal learning of this sort. Current research suggests that, aside from humans, only marine mammals (whales, dolphins, seals…), bats, and elephants have this ability. Among primates, humans appear to be the *only* species that can hear new sounds in the environment, and then reproduce them. Our ability to do this seems to depend on a babbling stage during infancy, a period of vocal playfulness that is as instinctual as the young bird's subsong. During this stage, we appear to fine tune our vocal control so that, as children, we can hear and reproduce the words and phrases of our adult caregivers.

So is human language an instinct, or learned? The question, presupposing a dichotomy, is intrinsically misleading. Every word that any human speaks, in any of our species' 6000 languages, has been learned. And yet the *capacity* to learn that language is a human instinct, something that every normal human child is born with, and that no chimpanzee or gorilla possesses.

The instinct to learn language is, indeed, innate (meaning simply that it reliably develops in our species), even though every language is learned. As Darwin put it in *Descent of Man*, "language is an art, like brewing or baking; but … certainly is not a true instinct, for every language has to be learnt. It differs, however, widely from all ordinary arts, for man has an instinctive tendency to speak, as we see in the babble of our young children; whilst no child has an instinctive tendency to brew, bake, or write."

And what of culture? For many, human culture seems the very antithesis of "instinct". And yet it must be true that language plays a key role in every human culture. Language is the primary medium for the passing on of historically-accumulated knowledge, tastes, biases and styles that makes each of our human tribes and nations its own unique and precious entity. And if human language is best conceived of as an instinct to learn, why not culture itself?

The past decade has seen a remarkable unveiling of our human genetic and neural makeup, and the coming decade promises even more remarkable breakthroughs. Each of us six billion humans is genetically unique (with the fascinating exception of identical twins). For each of us, our unique genetic makeup influences, but does not determine, what we are.

If we are to grapple earnestly and effectively with the reality of human biology and genetics, we will need to jettison outmoded dichotomies like the traditional distinction between nature and nurture. In their place, we will need to embrace the reality of the many instincts to learn (language, music, dance, culture…) that make us human.

I conclude that the dichotomy-denying phrase "instinct to learn" deserves a place in the cognitive toolkit of everyone who hopes, in the coming age of individual genomes, to understand human culture and human nature in the context of human biology. Human language, and human culture, are not instincts — but they *are* instincts to learn.

MAX TEGMARK
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Scientific Concept

I think the scientific concept that would improve everybody's cognitive toolkit the most is "*scientific concept*".

Despite spectacular success in research, I feel that our global scientific community has been nothing short of a spectacular failure when it comes to educating the public. Haitians burned 12 "witches" in 2010. In the US, recent polls show that 39% consider astrology scientific, and 40% believe that our human species is less than 10,000 years old. If everyone understood the concept of "scientific concept", these percentages would be zero.

Moreover, the world would be a better place, since people with a scientific lifestyle, basing their decisions on correct information, maximize their chances of success. By making rational buying and voting decisions, they also strengthen the scientific approach to decision-making in companies, organizations and governments.

Why have we scientists failed so miserably? I think the answers lie mainly in psychology, sociology and economics.

A scientific lifestyle requires a scientific approach to both *gatherin* information and *using* information, and both have their pitfalls.

You're clearly more likely to make the right choice if you're aware of the full spectrum of arguments before making your mind up, yet there are many reasons why people don't get such complete information. Many lack access to it (3% of Afghans have internet, and in a 2010 poll, 92% didn't know about the 9/11 attacks).

Many are too swamped with obligations and distractions to seek it. Many seek information only from sources that confirm their preconceptions. The most valuable information can be hard to find even for those who are online and uncensored, buried in an unscientific media avalanche.

Then there's what we do with the information we have. The core of a scientific lifestyle is to change your mind when faced with information that disagrees with your views, avoiding intellectual inertia, yet many laud leaders stubbornly sticking to their views as "strong". The great physicist Richard Feynman hailed "distrust of experts" as a cornerstone of science, yet herd mentality and blind faith in authority figures is widespread. Logic forms the basis of scientific reasoning, yet wishful thinking, irrational fears and other cognitive biases often dominate decisions.

So what can we do to promote a scientific lifestyle?

The obvious answer is improving education. In some countries, having even the most rudimentary education would be a major improvement (less than half of all Pakistanis can read). By undercutting fundamentalism and intolerance, it would curtail violence and war.

By empowering women, it would curb poverty and the population explosion. However, even countries that offer everybody education can make major improvements.

All too often, schools resemble museums, reflecting the past rather than shaping the future. The curriculum should shift from one watered down by consensus and lobbying to skills our century needs, for relationships, health, contraception, time management, critical thinking and recognizing propaganda. For youngsters, learning a global language and typing should trump long division and writing cursive. In the internet age, my own role as a classroom teacher has changed. I'm no longer needed as a conduit of information, which my students can simply download on their own. Rather, my key role is inspiring a scientific lifestyle, curiosity and desire to learn more.

Now let's get to the most interesting question: how can we *really* make a scientific lifestyle take root and flourish?

Reasonable people have been making similar arguments for better education since long before I was in diapers, yet rather than improving, education and adherence to a scientific lifestyle is arguably deteriorating further in many countries, including the US. Why? Clearly because there are powerful forces pushing back in the opposite direction, and they are pushing more effectively. Corporations concerned that a better understanding of certain scientific issues would harm their profits have an incentive to muddy the waters, as do fringe religious groups concerned that questioning their pseudoscientific claims would erode their power.

So what can we do? The first thing we scientists need to do is get off our high horses, admit that our persuasive strategies have failed, and develop a better strategy. We have the advantage of having the better arguments, but the anti-scientific coalition has the advantage of better funding.

However, and this is painfully ironic, it is also more scientifically organized! If a company wants to change public opinion to increase their profits, it deploys scientific and highly effective marketing tools. What do people believe today? What do we want them to believe tomorrow? Which of their fears, insecurities, hopes and other emotions can we take advantage of? What's the most cost-effective way of changing their mind? Plan a campaign. Launch. Done.

Is the message oversimplified or misleading? Does it unfairly discredit the competition? That's par for the course when marketing the latest smartphone or cigarette, so it would be naive to think that the code of conduct should be any different when this coalition fights science.

Yet we scientists are often painfully naive, deluding ourselves that just because we think we have the moral high ground, we can somehow defeat this corporate-fundamentalist coalition by using obsolete unscientific strategies. Based of what scientific argument wil it make a hoot of a difference if we grumble "we won't stoop that low" and "people need to change" in faculty lunch rooms and recite statistics to journalists?

We scientists have basically been saying "tanks are unethical, so let's fight tanks with swords".

To teach people what a scientific concept is and how a scientific lifestyle will improve their lives, we need to go about it scientifically:

We need new science advocacy organizations which use all the same scientific marketing and fundraising tools as the anti-scientific coalition.
We'll need to use many of the tools that make scientists cringe, from ads and lobbying to focus groups that identify the most effective sound bites.
We won't need to stoop all the way down to intellectual dishonesty, however. Because in this battle, we have the most powerful weapon of all on our side: the facts.

JOAN CHIAO
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Diversity is Universal

At every level in the vast and dynamic world of living things lies diversity. From biomes to biomarkers, the complex array of solutions to the most basic problems regarding survival in a given environment afforded to us by nature is riveting. In the world of humans alone, diversity is apparent in the genome, in the brain and in our behavior.

The mark of multiple populations lies in the fabric of our DNA. The signature of selfhood in the brain holds dual frames, one for thinking about one's self as absolute, the other in context of others. From this biological diversity in humans arises cultural diversity directly observable in nearly every aspect of how people think, feel and behavior. From classrooms to conventions across continents, the range and scope of human activities is stunning.

Recent centuries have seen the scientific debate regarding the nature of human nature cast as a dichotomy between diversity on the one hand and universalism on the other. Yet a seemingly paradoxical, but tractable, scientific concept that may enhance our cognitive toolkit over time is the simple notion that diversity is universal.

DAVID EAGLEMAN
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The Umwelt

In 1909, the biologist Jakob von Uexküll introduced the concept of the *umwelt*. He wanted a word to express a simple (but often overlooked) observation: different animals in the same ecosystem pick up on different environmental signals. In the blind and deaf world of the tick, the important signals are temperature and the odor of butyric acid. For the black ghost knifefish, it's electrical fields. For the echolocating bat, it's air-compression waves. The small subset of the world that an animal is able to detect is its *umwelt*. The bigger reality, whatever that might mean, is called the *umgebung.*

The interesting part is that each organism presumably assumes its umwelt to be the entire objective reality "out there." Why would any of us stop to think that there is more beyond what we can sense? In the movie *The Truman Show*, the eponymous Truman lives in a world completely constructed around him by an intrepid television producer. At one point an interviewer asks the producer, "Why do you think Truman has never come close to discovering the true nature of his world?" The producer replies, "We accept the reality of the world with which we're presented." We accept our umwelt and stop there.

To appreciate the amount that goes undetected in our lives, imagine you're a bloodhound dog. Your long nose houses two hundred million scent receptors. On the outside, your wet nostrils attract and trap scent molecules. The slits at the corners of each nostril flare out to allow more air flow as you sniff. Even your floppy ears drag along the ground and kick up scent molecules. Your world is all about olfaction. One afternoon, as you're following your master, you stop in your tracks with a revelation. What is it like to have the pitiful, impoverished nose of a human being? What can humans possibly detect when they take in a feeble little noseful of air? Do they suffer a hole where smell is supposed to be?

Obviously, we suffer no absence of smell because we accept reality as it's presented to us. Without the olfactory capabilities of a bloodhound, it rarely strikes us that things could be different. Similarly, until a child learns in school that honeybees enjoy ultraviolet signals and rattlesnakes employ infrared, it does not strike her that plenty of information is riding on channels to which we have no natural access. From my informal surveys, it is very *un*common knowledge that the part of the electromagnetic spectrum that is visible to us is less than a ten-trillionth of it.

Our unawareness of the limits of our umwelt can be seen with color blind people: until they learn that others can see hues they cannot, the thought of extra colors does not hit their radar screen. And the same goes for the congenitally blind: being sightless is not like experiencing "blackness" or "a dark hole" where vision should be. As a human is to a bloodhound dog, a blind person does not miss vision. They do not conceive of it. Electromagnetic radiation is simply not part of their umwelt.

The more science taps into these hidden channels, the more it becomes clear that our brains are tuned to detect a shockingly small fraction of the surrounding reality. Our sensorium is enough to get by in our ecosystem, but is does not approximate the larger picture.

I think it would be useful if the concept of the umwelt were embedded in the public lexicon. It neatly captures the idea of limited knowledge, of unobtainable information, and of unimagined possibilities. Consider the criticisms of policy, the assertions of dogma, the declarations of fact that you hear every day — and just imagine if all of these could be infused with the proper intellectual humility that comes from appreciating the amount unseen.

FIERY CUSHMAN
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Confabulation

We are shockingly ignorant of the causes of our own behavior. The explanations that we provide are sometimes wholly fabricated, and certainly never complete. Yet, that is not how it feels. Instead it feels like we know exactly what we're doing and why. This is confabulation: Guessing at plausible explanations for our behavior, and then regarding those guesses as introspective certainties. Every year psychologists use dramatic examples to entertain their undergraduate audiences. Confabulation is funny, but there is a serious side, too. Understanding it can help us act better and think better in everyday life.

Some of the most famous examples of confabulation come "split-brain" patients, whose left and right brain hemispheres have been surgically disconnected for medical treatment. Neuroscientists have devised clever experiments in which information is provided to the right hemisphere (for instance, pictures of naked people), causing a change in behavior (embarrassed giggling). Split-brain individuals are then asked to explain their behavior verbally, which relies on the left hemisphere. Realizing that their body is laughing, but unaware of the nude images, the left hemisphere will confabulate an excuse for the body's behavior ("I keep laughing because you ask such funny questions, Doc!").

Wholesale confabulations in neurological patients can be jaw-dropping, but in part that is because they do not reflect ordinary experience. Most of the behaviors that you or I perform are not induced by crafty neuroscientists planting subliminal suggestions in our right hemisphere. When we are outside the laboratory — and when our brains have all the usual connections — most behaviors that we perform are the product of some combination of deliberate thinking and automatic action.

Ironically, that is exactly what makes confabulation so dangerous. If we routinely got the explanation for our behavior totally wrong — as completely wrong as split-brain patients sometimes do — we would probably be much more aware that there are pervasive, unseen influences on our behavior. The problem is that we get all of our explanations partly right, correctly identifying the conscious and deliberate causes of our behavior. Unfortunately, we mistake "party right" for "completely right", and thereby fail to recognize the equal influence of the unconscious, or to guard against it.

A choice of job, for instance, depends partly on careful deliberation about career interests, location, income, and hours. At the same time, research reveals that choice to be influenced by a host of factors of which we are unaware. People named Dennis or Denise are more likely to be dentists, while people named Virginia are more likely to locate to (you guessed it) Virginia. Less endearingly, research suggests that on average people will take a job with fewer benefits, a longer commute and a smaller income if it allows them to avoid having a female boss. Surely most people do not want to choose a job based on the sound of their name, nor do they want to sacrifice job quality in order to perpetuate old gender norms. Indeed, most people have no awareness that these factors influence their own choices. When you ask them why they took the job, they are likely to reference their conscious thought processes: "I've always loved making ravioli, the Lira is on the rebound and Rome is for lovers…" That answer is partly right, but it is also partly wrong, because it misses the deep reach of automatic processes on human behavior.

People make harsher moral judgments in foul-smelling rooms, reflecting the role of disgust as a moral emotion. Women are less likely to call their fathers (but equally likely to call their mothers) during the fertile phase of their menstrual cycle, reflecting a means of incest avoidance. Students indicate greater political conservatism when polled near a hand-sanitizing station during a flu epidemic, reflecting the influence of a threatening environment on ideology. They also indicate a closer bond to their mother when holding hot coffee versus iced coffee, reflecting the metaphor of a "warm" relationship.

Automatic behaviors can be remarkably organized, and even goal-driven. For example, research shows that people tend to cheat just as much as they can without realizing that they are cheating. This is a remarkable phenomenon: Part of you is deciding how much to cheat, calibrated at just the level that keeps another part of you from realizing it.

One of the ways that people pull off this trick is with innocent confabulations: When self-grading an exam, students think, "Oh, I was going to circle e, I really knew that answer!" This isn't a lie, any more than it's a lie to say you have always loved your mother (latte in hand), but don't have time to call your dad during this busy time of the month. These are just incomplete explanations, confabulations that reflect our conscious thoughts while ignoring the unconscious ones.

This brings me to the central point, the part that makes confabulation an important concept in ordinary life and not just a trick pony for college lectures. Perhaps you have noticed that people have an easier time sniffing out unseemly motivations for other's behavior than recognizing the same motivations for their own behavior. Others avoided female bosses (sexist) and inflated their grades (cheaters), while we chose Rome and really meant to say that Anne was the third Brontë. There is a double tragedy in this double standard.

First, we jump to the conclusion that others' behaviors reflect their bad motives and poor judgment, attributing conscious choice to behaviors that may have been influenced unconsciously. Second, we assume that our own choices were guided solely by the conscious explanations that we conjure, and reject or ignore the possibility of our own unconscious biases.

By understanding confabulation we can begin to remedy both faults. We can hold others responsible for their behavior without necessarily impugning their conscious motivations. And, we can hold ourselves more responsible by inspecting our own behavior for its unconscious influences, as unseen as they are unwanted.

HAZEL ROSE MARKUS & **ALANA CONNER**
Hazel Rose Markus is the Davis-Brack Professor of Behavioral Sciences at Stanford University. Co-author of Doing Race: 21 essays for the 21st century - *Alana Carter is a science writer, cultural psychologist, and museum curator, The Tech Museum, San Jose, Calif.*

The Culture Cycle

Pundits now invoke culture to explain all manner of tragedies and triumphs, from why a disturbed young man opens fire on a politician, to why African-American children struggle in school, to why the United States can't establish democracy in Iraq, to why Asian factories build better cars. A quick click through a single morning's media, for example, yields the following catch: gun culture, Twitter culture, ethical culture, Arizona culture, always-on culture, winner-take-all culture, culture of violence, culture of fear, culture of sustainability, culture of corporate greed.

Yet no one explains what, exactly, culture is, how it works, or how to change it for the better.

A cognitive tool that fills this gap is *the culture cycle*, a tool that not only simply describes how culture works, but also clearly prescribes how to make lasting change. *The culture cycle* is the iterative, recursive process by which 1) people create the cultures to which they later adapt, and 2) cultures shape people so that they act in ways that perpetuate their cultures. In other words, cultures and people (and some other primates) make each other up. This process involves four nested planes: individual selves (their thoughts, feelings, and actions); the everyday practices and artifacts that reflect and shape those selves; the institutions (such as education, law, and media) that afford or discourage certain everyday practices and artifacts; and pervasive ideas about what is good, right, and human that both influence and are influenced by all these levels. (See figure below). The culture cycle rolls for all types of social distinctions, from the macro (nation, race, ethnicity, region, religion, gender, social class, generation, etc.) to the micro (occupation, organization, neighborhood, hobby, genre preference, family, etc.)

One consequence of the culture cycle is that no action is caused by *either* individual psychological features *or* external influences. Both are always at work. Just as there is no such thing as a culture without agents, there are no agents without culture. Humans are culturally-shaped shapers. And so, for example, in the case of a school shooting it is overly simplistic to ask whether the perpetrator shot because of either a mental illness or because of his interactions with a hostile and bullying school climate, or with a particularly deadly cultural artifact (i.e., a gun), or with institutions that encourage that climate and allow access to that artifact, or with pervasive ideas and images that glorify resistance and violence. The better question, and the one that the culture cycle requires, is how do these four levels of forces interact? Indeed, researchers at the vanguard of public health contend that neither social stressors nor individual vulnerabilities are enough to produce most mental illnesses. Instead, the interplay of biology and culture, of genes and environments, of nature and nurture is responsible for most psychiatric disorders.

Social scientists succumb to another form of this oppositional thinking. For example, in the face of Hurricane Katrina, thousands of poor African-American residents "chose" not to evacuate the Gulf Coast, to quote most news accounts. More charitable social scientists had their explanations ready, and struggled to get their variables into the limelight. Of course they didn't leave, said the psychologists, because poor people have an external locus of control, low intrinsic motivation, or low self-efficacy. Of course they didn't leave, said the sociologists and political scientists, because their cumulative lack of access to adequate income, banking, education, transportation, healthcare, police protection, and basic civil rights makes staying put is their only option. Of course they didn't leave, said the anthropologists, because their kin networks, religious faith, and historical ties held them there. Of course they didn't leave, said the economists, because they didn't have the material resources, knowledge, or financial incentives to get out.

The irony in the interdisciplinary bickering is that everyone is mostly right. But they are right in the same way that the blind men touching the elephant in the Indian proverb are right: the failure to integrate each field's contributions makes everyone wrong and, worse, not very useful.

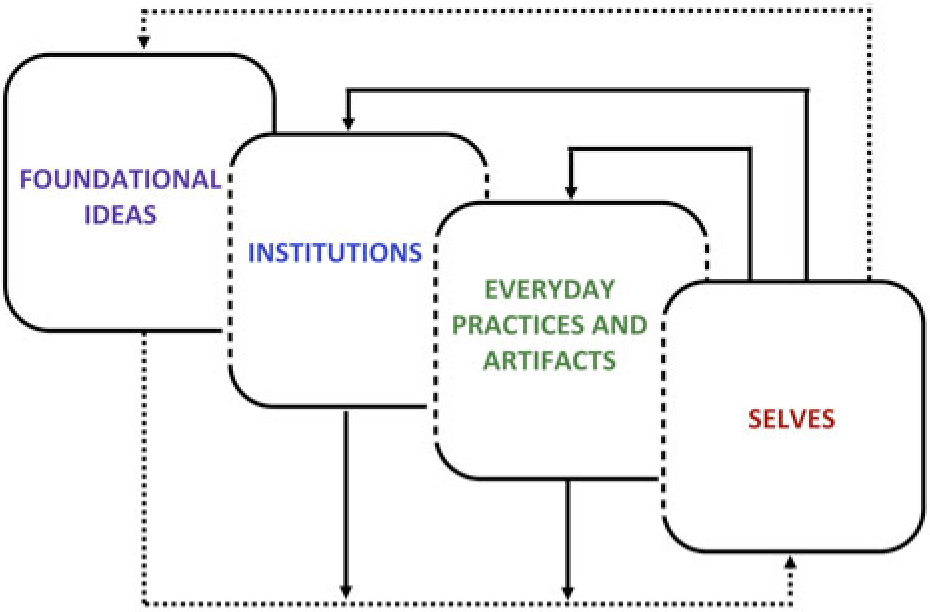
The culture cycle captures how these different levels of analyses relate to each other. Granted, our four-level process explanation is not as zippy as the single-variable accounts that currently dominate most public discourse. But it's far simpler and accurate than the standard "it's complicated" and "it depends" answers that more thoughtful experts often supply.

Moreover, built into the culture cycle are the instructions for how to reverse engineer it: a sustainable change at one level usually requires change at all four levels. There are no silver bullets. The ongoing U.S. Civil Rights Movement, for example, requires the opening of individual hearts and mind; and the mixing of people as equals in daily life, along with media representations thereof; and the reform of laws and policies; and fundamental revision of our nation's idea of what a good human being is.

Just because people can change their cultures, however, does not mean that they can do so easily. A major obstacle is that most people don't even realize that they have cultures. Instead, they think that they are standard-issue humans—they are normal; it's all those *other* people who are deviating from the natural, obvious and *right* way to be.

Yet we are all part of multiple culture cycles. And we should be proud of that fact, for the culture cycle is our smart human trick. Because of it, we don't have to wait for mutation or natural selection to allow us to range farther over the face of the earth, to extract nutrition from a new food source, or to cope with a change in climate. And as modern life becomes more complex, and social and environmental problems become more widespread and entrenched, people will need to understand and use the culture cycle more skillfully.

The Culture Cycle



DAVID ROWAN
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Personal data mining

From the dawn of civilisation until 2003, Eric Schmidt is fond of saying, humankind generated five exabytes of data. Now we produce five exabytes every two days — and the pace is accelerating. In our post-privacy world of pervasive social-media sharing, GPS tracking, cellphone-tower triangulation, wireless sensor monitoring, browser-cookie targeting, face-recognition detecting, consumer-intention profiling, and endless other means by which our personal presence is logged in databases far beyond our reach, citizens are largely failing to benefit from the power of all this data to help them make smarter decisions. It's time to reclaim the concept of data mining from the marketing industry's microtargeting of consumers, the credit-card companies' anti-fraud profiling, the intrusive surveillance of state-sponsored Total Information Awareness. We need to think more about mining our own output to extract patterns that turn our raw personal datastream into predictive, actionable information. All of us would benefit if the idea of personal data mining were to enter popular discourse.

Microsoft saw the potential back in September 2006, when it filed United States Patent application number 20,080,082,393 for a system of "personal data mining". Having been fed personal data provided by users themselves or gathered by third parties, the technology would then analyse it to "enable identification of opportunities and/or provisioning of recommendations to increase user productivity and/or improve quality of life". You can decide for yourself whether you trust Redmond with your lifelog, but it's hard to fault the premise: the personal data mine, the patent states, would be a way "to identify relevant information that otherwise would likely remain undiscovered".

Both I as a citizen and society as a whole would gain if individuals' personal datastreams could be mined to extract patterns upon which we could act. Such mining would turn my raw data into predictive information that can anticipate my mood and improve my efficiency, make me healthier and more emotionally intuitive, reveal my scholastic weaknesses and my creative strengths. I want to find the hidden meanings, the unexpected correlations that reveal trends and risk factors of which I had been unaware. In an era of oversharing, we need to think more about data-driven self-discovery.

A small but fast-growing self-tracking movement is already showing the potential of such thinking, inspired by Kevin Kelly's quantified self and Gary Wolf's data-driven life. With its mobile sensors and apps and visualisations, this movement is tracking and measuring exercise, sleep, alertness, productivity, pharmaceutical responses, DNA, heartbeat, diet, financial expenditure — and then sharing and displaying its findings for greater collective understanding. It is using its tools for clustering, classifying and discovering rules in raw data, but mostly is simply quantifying that data to extract signals — information — from the noise.

The cumulative rewards of such thinking will be altruistic rather than narcissistic, whether in pooling personal data for greater scientific understanding (23andMe) or in propagating user-submitted data to motivate behaviour change in others (Traineo). Indeed, as the work of Daniel Kahneman, Daniel Gilbert, and Christakis and Fowler demonstrate so powerfully, accurate individual-level data-tracking is key to understanding how human happiness can be quantified, how our social networks affect our behaviour, how diseases spread through groups.

The data is already out there. We just need to encourage people to tap it, share it, and corral it into knowledge.

VICTORIA STODDEN
Computational Legal Scholar; Assistant Professor of Statistics, Columbia University

Phase Transitions And "Scale Transitions:" Conceptualizing Unexpected Changes Due To Scale

Physicists created the term "phase transition" to describe a change of state in a physical system, such as liquid to gas. The concept has since been applied in a variety of academic circles to describe other types of systems, from social transformations (think hunter-gatherer to farmer) to statistics (think abrupt changes in algorithm performance as parameters change), but has not yet emerged as part of the common lexicon.

One interesting aspect of the concept of the phrase transition is that it describes a shift to a state seemingly unrelated to the previous one, and hence provides a model for phenomena that challenge our intuition. With only knowledge of water as a liquid, who would have imagined a conversion to gas with the application of heat? The mathematical definition of a phase transition in the physical context is well-defined, but even without this precision I argue this idea can be usefully extrapolated to describe a much broader class of phenomena today, particularly those that change abruptly and unexpectedly with an increase in scale.

Imagine points in 2 dimensions — a spray of dots on a sheet of paper. Now imagine a point cloud in three dimensions, say, dots hovering in the interior of a cube. Even if we could imagine points in four dimensions would we have guessed that all these points lie on the convex hull of this point cloud? In dimensions greater than three they always do. There hasn't been a phase transition in the mathematical sense, but as dimension is scaled up the system shifts in a way we don't intuitively expect.

I call these types of changes "scale transitions:" unexpected outcomes resulting from increases in scale. For example, increases in the number of people interacting in a system can produce unforeseen outcomes: the operation of markets at large scales is often counterintuitive, think of the restrictive effect rent control laws can have on the supply of affordable rental housing or how minimum wage laws can reduce the availability of low wage jobs (James Flynn gives "markets" as an example of a "shorthand abstraction," here I am interested in the often counterintuitive operation of a market system at large scale); the serendipitous effects of enhanced communication, for example collaboration and interpersonal connection generating unexpected new ideas and innovation; or the counterintuitive effect of massive computation in science reducing experimental reproducibility as data and code have proved harder to share than their descriptions. The concept of the scale transition is purposefully loose, designed as a framework for understanding when our natural intuition leads us astray in large scale situations.

This contrasts from Merton's concept of "unanticipated consequences" in that a scale transition refers both to a system, rather than individual purposeful behavior, and is directly tied to the notion of changes due to scale increases. Our intuition regularly seems to break down with scale and we need a way of conceptualizing the resulting counterintuitive shifts in the world around us. Perhaps the most salient feature of the digital age is its facilitation of massive increases in scale, in data storage, processing power, connectivity, thus permitting us to address an unparalleled number of problems on an unparalleled scale. As technology becomes increasingly pervasive I believe scale transitions will become commonplace.

CARL PAGE
Serial Entrepreneur; Co-founder, eGroups, Inc; Investor

The Power of 10

Any citizen who wants to vote responsibly needs to have a sense of proportion and be able to weigh the choices our democratic government is making quickly and easily.

You can practice thinking on your feet with large numbers, a different skill from what we were taught in primary school, so that you can calculate informed, fact-based opinions on which policies are winning and which may be bankrupt.

You need the ability to make approximate estimates involving large numbers, quickly in your head. The best news I ever heard was: you can multiply numbers by adding their exponents. Or divide them by subtracting their exponents. And the exponent is nothing more than the length of the number in digits. If the first digit is over 3, you can add a half. A painless way to get approximate answers to large-number problems in your head allows you to be more inventive and creative in considering all kinds of business and policy questions.

How can we reason with powers of 10 in real life? Let's use the California High Speed Rail proposal as an example. Most folks either support it because "I Like Trains", or oppose it because "I hate socialism". But a smart person should make a decision using a sense of proportion.

I always start by calculating the cost per person.

The total cost of CA high speed rail is projected to be $45 billion. Using exponents to estimate, remember that a billion is 9 digits. 45 billion adds another digit. Since 4 is larger than 3, you can add another half a digit, and about 1.6 digits. So that is about 10 to the 10.6 .

The California Population is 37 million, so that is about 10 to the 7.5.

To get cost/Californian simply subtract the exponents. 10.6 – 7.5 = 3.1.

Now 10 to the 4.1 is a bit more than $1,000 so we say $1,200 to be in the ballpark of cost of the High Speed Rail project per Californian. Now you have grounds for an informed decision in terms of cost. Some people would save money and carbon emissions if they invested $1,200 in a train. Many Californians will never travel between SF and LA and would be forced to make the same investment, instead of something that would help them with their daily commute. If you could save 10 million Californians 30 minutes a work day, and their free time is worth $8/hour then you have saved each $1000 per year in commuting costs, not counting fuel. That's worth (10^3 * 10&7 = 10&10) 10 billion dollars per year. So modest improvements in traffic and gridlock alleviation through commute traffic improvements can provide benefits to pay for themselves quickly.

For your next exercise, you may want to calculate the cost of the Iraq war in dollars per Iraqi. (Maybe 3 trillion dollars, 30 million Iraqis. 10^12.5 / 10^7.5 = 10^5 = 100,000 $/Iraqi.)

Or the cost per American of the 3 million dollar investment the DOE made in the very promising area of Airborne Wind Turbines. (10^6.5 / 10^8.5 = 10^(-2)). So we each spent about a penny on one of the most promising forms of renewable energy. These numbers are thought-provoking, and now they are comparable: do we want to spend:

• $1,200 per Californian on High Speed Rail?
• $100,000 per Iraqi on the Iraq war?
• $.01 per American on renewable energy?

Practice one of these back-of-the-envelope calculations every day and you will have the sense of proportion you need to know which policies to support and keep politicians accountable. It will serve you very well in business and personal finance. It is so easy once you get started!

BRIAN KNUTSON
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Replicability

Since different visiting teachers had promoted contradictory philosophies, the villagers asked the Buddha whom they should believe. The Buddha advised: "When you know for yourselves ... these things, when performed and undertaken, conduce to well-being and happiness — then live and act accordingly." Such empirical advice might sound surprising coming from a religious leader, but not from a scientist.

"See for yourself" is an unspoken credo of science. It is not enough to run an experiment and report the findings. Others who repeat that experiment must find the same thing. Repeatable experiments are called "replicable." Although scientists implicitly respect replicability, they do not typically explicitly reward it.

To some extent, ignoring replicability comes naturally. Human nervous systems are designed to respond to rapid changes, ranging from subtle visual flickers to pounding rushes of ecstasy. Fixating on fast change makes adaptive sense — why spend limited energy on opportunities or threats that have already passed? But in the face of slowly growing problems, "change fixation" can prove disastrous (think of lobsters in the cooking pot or people under greenhouse gases).

Cultures can also promote change fixation. In science, some high profile journals and even entire fields emphasize novelty, consigning replications to the dustbin of the unremarkable and unpublishable. More formally, scientists are often judged based on their work's novelty rather than replicability. The increasingly popular "h-index" quantifies impact by assigning a number (h) which indicates that an investigator has published h papers that have been cited h or more times (so, Joe Blow has an h-index of 5 if he has published 5 papers, each of which others have cited 5 or more times). While impact factors correlate with eminence in some fields (e.g., physics), problems can arise. For instance, Doctor Blow might boost his impact factor by publishing controversial (thus, cited) but unreplicable findings.

Why not construct a replicability (or "r") index to complement impact factors? As with h, r could indicate that a scientist has originally documented r separate effects that independently replicate r or more times (so, Susie Sharp has an r-index of 5 if she has published 5 independent effects, each of which others have replicated 5 or more times). Replication indices would necessarily be lower than citation indices, since effects have to first be published before they can be replicated, but might provide distinct information about research quality. As with citation indices, replication indices might even apply to journals and fields, providing a measure that can combat biases against publishing and publicizing replications.

A replicability index might prove even more useful to nonscientists. Most investigators who have spent significant time in the salt mines of the laboratory already intuit that most ideas don't pan out, and those that do sometimes result from chance or charitable interpretations. Conversely, they also recognize that replicability means they're really on to something. Not so for the general public, who instead encounter scientific advances one cataclysmic media-filtered study at a time. As a result, laypeople and journalists are repeatedly surprised to find the latest counterintuitive finding overturned by new results. Measures of replicability could help channel attention towards cumulative contributions. Along these lines, it is interesting to consider applying replicability criteria to public policy interventions designed to improve health, enhance education, or curb violence. Individuals might even benefit from using replicability criteria to optimize their personal habits (e.g., more effectively dieting, exercising, working, etc.).

Replication should be celebrated rather than denigrated. Often taken for granted, replicability may be the exception rather than the rule. As running water resolves rock from mud, so can replicability highlight the most reliable findings, investigators, journals, and even fields. More broadly, replicability may provide an indispensable tool for evaluating both personal and public policies. As suggested in the Kalama Sutta, replicability might even help us decide whom to believe.

SETH LLOYD
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Living is fatal

The ability to reason clearly in the face of uncertainty.

If everybody could learn to deal better with the unknown, then it would improve not only their individual cognitive toolkit (to be placed in a slot right next to the ability to operate a remote control, perhaps), but the chances for humanity as a whole.

A well-developed scientific method for dealing with the unknown has existed for many years — the mathematical theory of probability. Probabilities are numbers whose values reflect how likely different events are to take place. People are bad at assessing probabilities. They are bad at it not just because they are bad at addition and multiplication. Rather, people are bad at probability in a deep, intuitive level: they overestimate the probability of rare but shocking events -- a burglar breaking into your bedroom while you're asleep, say. Conversely, they underestimate the probability of common, but quiet and insidious events — the slow accretion of globules of fat on the walls of an artery, or another ton of carbon dioxide pumped into the atmosphere.

I can't say that I'm very optimistic about the odds that people will learn to understand the science of odds. When it comes to understanding probability, people basically suck. Consider the following example, based on a true story, and reported by Joel Cohen of Rockefeller University. A group of graduate students note that women have an significantly lower chance of admission than men to the graduate programs at a major university. The data are unambiguous: women applicants are only two thirds as likely as male applicants to be admitted. The graduate students file suit against the university, alleging discrimination on the basis of gender. When admissions data are examined on a department by department basis, however, a strange fact emerges: within each department, women are MORE likely to be admitted than men. How can this possibly be?

The answer turns out to be simple, if counterintuitive. More women are applying to departments that have few positions. These departments admit only a small percentage of applicants, men or women. Men, by contrast, are applying to departments that have more positions and that admit a higher percentage of applicants. Within each department, women have a better chance of admission than men — it's just that few women apply to the departments that are easy to get into.

This counterintuitive result indicates that the admissions committees in the different departments are not discriminating against women. That doesn't mean that bias is absent. The number of graduate fellowships available in a particular field is determined largely by the federal government, which chooses how to allocate reserach funds to different fields. It is not university that is guilty of sexual discrimination, but the society as a whole, which chose to devote more resources — and so more graduate fellowships — to the fields preferred by men.

Of course, some people are good at probability. A car insurance company that can't accurately determine the probabilities of accidents will go broke. In effect, when we pay out premiums to insure ourselves against a rare event, we are buying into the insurance company's estimate of just how likely that event is. Driving a car is one of those common but dangerous processes where human beings habitually understimate the odds of something bad happening, however. Accordingly, some are disinclined to obtain car insurance (perhaps not suprising when the considerable majority of people rate themselves as better than average drivers). When a state government requires its citizens to buy car insurance, it does so because it figures, rightly, that people are underestimating the odds of an accident.

Let's consider the debate over whether health insurance should be required by law. Living, like driving, is a common but dangerous process where people habitually underestimate risk, despite that fact that, with probability equal to one, living is fatal.

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AMBIENT MEMORY AND THE MYTH OF NEUTRAL OBSERVATION

Like others whose early life experiences were punctuated with trauma, my memory has holes. Some of those holes are as wide as years. Others, just big enough to swallow painful incidents that lasted moments, but reverberated for decades.

The brain-record of those experiences sometimes submerges, then resurfaces, sometimes submerging again over time. As I grow older, stronger, and more capable of contending with memory, I become more aware of how different my own internal record may be from others who lived the identical moment.

Each of us commit our experiences to memory and permanence differently. Time and human experience are not linear, nor is there one and only one neutral record of each lived moment. Human beings are impossibly complex tarballs of muscle, blood, bone, breath, and electrical pulses that travel through nerves and neurons; we are bundles of electrical pulses carrying payloads, pings hitting servers. And our identities are inextricably connected to our environments: no story can be told without a setting.

My generation is the last generation of human beings who were born into a pre-internet world, but who matured in tandem with that great, networked hive-mind. In the course of my work online, committing new memories to network mind each day, I have come to understand that our shared memory of events, of truths, of biography, and of fact-- all of this shifts and ebbs and flows, just as our most personal memories do.

Ever-edited Wikipedia replaces paper encyclopedias. The chatter of Twitter eclipses fixed-form and hierarchical communication. The news flow we remember from our childhoods, a single voice of authority on one of three channels, is replaced by something hyper-evolving, chaotic, and less easily defined. Even the formal histories of State may be rewritten by the likes of Wikileaks, and its yet-unlaunched children.

Facts are more fluid than in the days of our grandfathers. In our networked mind, the very act of observation--reporting or tweeting or amplifying some piece of experience--changes the story. The trajectory of information, the velocity of this knowledge on the network, changes the very nature of what is remembered, who remembers it, and for how long it remains part of our shared archive. There are no fixed states.

So must our notion of memory and record evolve.

The history we are creating now is alive. Let us find new ways of recording memory, new ways of telling the story, that reflect life. Let us embrace this infinite complexity as we commit new history to record.

Let us redefine what it means to remember.

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INFORMATION FLOW

The concept of cause and effect is better understood as the flow of information between two connected events, from the earlier event to the later one. Saying "A causes B" sounds precise, but is actually very vague. I would specify much more by saying "with the information that A has happened, I can compute with almost total confidence* that B will happen." The latter rules out the possibility that other factors could prevent B even if A does happen, but allows the possibility that other factors could cause B even if A doesn't happen.

As shorthand, we can say that one set of information "specifies" another if the latter can be deduced or computed from the former. Note that this doesn't only apply to one-bit sets of information, like the occurrence of a specific event. It can also apply to symbolic variables (given the state of the Web, the results you get from a search engine are specified by your query), numeric variables (the number read off a precise thermometer is specified by the temperature of the sensor), or even behavioral variables (the behavior of a computer is specified by the bits loaded in its memory).

But let's take a closer look at the assumptions we're making. Astute readers may have noticed that in one of my examples, I assumed that the entire state of the Web was a constant. How ridiculous! In mathematical parlance, assumptions are known as "priors," and in a certain widespread school of statistical thought, they are considered the most important aspect of any process involving information. What we really want to know is if, given a set of existing priors, adding one piece of information (A) would allow us to update our estimate of the likelihood of another piece of information (B). Of course, this depends on the priors — for instance, if our priors include absolute knowledge of B, then an update will not be possible.

If, for most reasonable sets of priors, information about A would allow us to update our estimate of B, then it would seem there is some sort of causal connection between the two. But the form of the causal connection is unspecified — a principle often called "correlation does not imply causation." The reason for this is that the essence of causation as a concept rests on our tendency to have information about earlier events before we have information about later events. (The full implications of this concept on human consciousness, the second law of thermodynamics, and the nature of time are interesting, but sadly outside the scope of this essay.)

If information about all events always came in the order they occurred, then correlation would indeed imply causation. But, in the real world, not only are we limited to observing events in the past, but we may also discover information about those events out of order. Thus, the correlations we observe could be reverse causes (information about A allows us to update our estimate of B, although B happened first and thus was the cause of A) or even more complex situations (e.g. information about A allows us to update our estimate of B, but is also giving us information about C, which happened before either A or B and caused both).

Information flow is symmetric: if information about A were to allow us to update our estimate of B, then information about B would allow us to update our estimate of A. But since we cannot change the past or know the future, these constraints are only useful to us when contextualized temporally and arranged in order of occurrence. Information flow is always from the past to the future, but in our minds, some of the arrows may be reversed. Resolving this ambiguity is essentially the problem that science was designed to solve. If you can master the technique of visualizing all information flow and keeping track of your priors, then the full power of the scientific method — and more — is yours to wield from your personal cognitive toolkit.

* In our universe, too many things are interconnected for absolute statements of any kind, so we usually relax our criteria; for instance, "total confidence" might be relaxed from a 0% chance of being wrong to, say, a 1 in 3 quadrillion chance of being wrong — about the chance that, as you finish this sentence, all of humanity will be wiped out by a meteor.

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The Controlled Experiment

The scientific concept that most people would do well to understand and exploit is the one that almost defines science itself: the controlled experiment.

When required to make a decision, the instinctive response of most non-scientists is to introspect, or perhaps call a meeting. The scientific method dictates that wherever possible we should instead conduct a suitable controlled experiment. The superiority of the latter approach is demonstrated not only by the fact that science has uncovered so much about the world in which we live, but also, and even more powerfully, by the fact that such a lot of it — from the Copernican principle and evolution by natural selection to general relativity and quantum mechanics — is so mind-bendingly counter-intuitive.

Our embrace of truth as defined by experiment (rather than by common sense, or consensus, or seniority, or revelation or any other means) has in effect released us from the constraints of our innate preconceptions, prejudices and lack of imagination. Instead it has freed us to appreciate the universe in terms that are well beyond our abilities to derive by intuition alone.

What a shame then that experiments are, by and large, used only by scientists. What if businesspeople and policy-makers were to spend less time relying on instinct or partially informed debate, and more time devising objectives ways to identify the best answers? I think that would often lead to better decisions.

In some domains this is already starting to happen. Online companies like Amazon and Google don't anguish over how to design their websites. Instead they conduct controlled experiments by showing different versions to different groups of users until they have iterated to an optimal solution. (And with the amount of traffic those sites receive, individual tests can be completed in seconds.) They are helped, of course, by the fact that the web is particularly conducive to rapid data acquisition and product iteration. But they are helped even more by the fact that their leaders often have backgrounds in engineering or science and therefore adopt a scientific — which is to say, experimental — mindset.

Government policies — from teaching methods in schools to prison sentencing to taxation — would also benefit from more use of controlled experiments. This is where many people start to get squeamish. To become the subject of an experiment in something as critical or controversial as our children's education or the incarceration of criminals feels like an affront to our sense of fairness, and our strongly held belief in the right to be treated exactly the same as everybody else.

After all, if there are separate experimental and control groups then surely one of them must be losing out. Well, no, because we do not know in advance which group will be better off, which is precisely why we are conducting the experiment. Only when a potentially informative experiment is not conducted do true losers arise: all those future generations who stood to benefit from the results. The real reason people are uncomfortable is simply that we're not used to seeing experiments conducted in these domains. After all, we willingly accept them in the much more serious context of clinical trials, which are literally matters of life and death.

Of course, experiments are not a panacea. They will not tell us, for example, whether an accused person is innocent or guilty. Moreover, experimental results are often inconclusive. In such circumstances a scientist can shrug his shoulders say that he is still unsure, but a businessperson or lawmaker will often have no such luxury and may be forced to make a decision anyway. Yet none of this takes away from the fact that the controlled experiment is the best method yet devised to reveal truths about the world, and we should use them wherever they can be sensibly applied.

GARRETT LISI
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Uncalculated Risk

We humans are terrible at dealing with probability. We are not merely bad at it, but seem hardwired to be incompetent, in spite of the fact that we encounter innumerable circumstances every day which depend on accurate probabilistic calculations for our wellbeing. This incompetence is reflected in our language, in which the common words used to convey likelihood are "probably" and "usually" — vaguely implying a 50% to 100% chance. Going beyond crude expression requires awkwardly geeky phrasing, such as "with 70% certainty," likely only to raise the eyebrow of a casual listener bemused by the unexpected precision. This blind spot in our collective consciousness — the inability to deal with probability — may seem insignificant, but it has dire practical consequences. We are afraid of the wrong things, and we are making bad decisions.

Imagine the typical emotional reaction to seeing a spider: fear, ranging from minor trepidation to terror. But what is the likelihood of dying from a spider bite? Fewer than four people a year (on average) die from spider bites, establishing the expected risk of death-by-spider at lower than one in a hundred million. This risk is so minuscule that it is actually counterproductive to worry about it! Millions of people die each year from stress-related illnesses.

The startling implication is that the risk of being bitten and killed by a spider is less than the risk that being afraid of spiders will kill you from increased stress. Our irrational fears and inclinations are costly. The typical reaction to seeing a sugary donut is the desire to consume it. But, given the potential negative impact of that donut, including the increased risk of heart disease and reduction in overall health, our reaction should rationally be one of fear and revulsion. It may seem absurd to fear a donut — or, even more dangerous, a cigarette — but this reaction rationally reflects the potential negative impact on our lives.

We are especially ill-equipped to manage risk when dealing with small likelihoods of major events. This is evidenced by the success of lotteries and casinos at taking peoples' money, but there are many other examples. The likelihood of being killed by terrorism is extremely low, yet we have instituted actions to counter terrorism that significantly reduce our quality of life. As a recent example, x-ray body scanners could increase the risk of cancer to a degree greater than the risk from terrorism — the same sort of counterproductive overreaction as the one to spiders. This does not imply we should let spiders, or terrorists, crawl all over us — but the risks need to be managed rationally.

Socially, the act of expressing uncertainty is a display of weakness. But our lives are awash in uncertainty, and rational consideration of contingencies and likelihoods is the only sound basis for good decisions. As another example, a federal judge recently issued an injunction blocking stem cell research funding. The shallowly viewed implication is that some scientists won't be getting money; but what is really at stake is much more important. The probability that stem cell research will quickly lead to life saving medicine is low, but, if successful, the positive impact could be huge. If one considers outcomes and approximates the probabilities, the conclusion is that the judge's decision destroyed the lives of thousands of people, based on probabilistic expectation.

How do we make rational decisions based on contingencies? That judge didn't actually cause thousands of people to die... or did he? If we follow the "many worlds" interpretation of quantum physics — the most direct interpretation of its mathematical description — then our universe is continually branching into all possible contingencies, and there is a world in which stem cell research saves millions of lives, and another world in which people die because of the judge's decision. Using the "frequentist" method of calculating probability, we have to add the probabilities of the worlds in which an event occurs to obtain the probability of that event.

Quantum mechanics dictates that the world we experience will happen according to this probability — the likelihood of the event. In this bizarre way, quantum mechanics reconciles the frequentist and "Bayesian" points of view, equating the frequency of an event over many possible worlds with its likelihood. An "expectation value," such as the expected number of people killed by the judge's decision, is the number of people killed in the various contingencies, weighted by their probabilities. This expected value is not necessarily likely to happen, but is the weighted average of the expected outcomes — useful information when making decisions. In order to make good decisions about risk we need to become better at these mental gymnastics, improve our language, and retrain our intuition.

Perhaps the best arena for honing our skills and making precise probabilistic assessments would be a betting market — an open site for betting on the outcomes of many quantifiable and socially significant events. In making good bets, all the tools and shorthand abstractions of Bayesian inference come into play — translating directly to the ability to make good decisions. With these skills, the risks we face in everyday life would become clearer, and we would develop more rational intuitive responses to uncalculated risks, based on collective rational assessment and social conditioning.

We might get over our excessive fear of spiders, and develop a healthy aversion to donuts, cigarettes, television, and stressful full-time employment. We would become more aware of the low cost compared to probable rewards of research, including research into improving the quality and duration of human life. And, more subtly, as we became more aware and apprehensive of ubiquitous vague language, such as "probably" and "usually," our standards of probabilistic description would improve.

Making good decisions requires concentrated mental effort; and if we overdo it we run the risk of being counterproductive through increased stress and wasted time. So it's best to balance, and play, and take healthy risks — as the greatest risk is that we'll get to the end of our lives having never risked them on anything.

KEVIN HAND
Planetary Scientist

The Gibbs Landscape

Biology is rarely wasteful. Sure, on the individual organism level there is plenty of waste involved with reproduction and other activities (think of all the fruit on a tree or the millions of sperm that loose out in the race to the egg). But on the ecosystem level one bug's trash is another bug's treasure - provided that some useful energy can still be extracted by reacting that trash with something else in the environment. The food chain is not a simple linear staircase of predator-prey relationships; it is a complex fabric of organisms large, small, and microscopic interacting with each other and with the environment to tap every possible energetic niche.

Geobiologists and astrobiologists can measure and map this energy - referred to as the Gibbs free energy. Doing so is useful for assessing the energetic limits of life on Earth and for assessing potentially habitable regions on other worlds. In an ecosystem Gibbs free energy - named for it's discoverer, the late 19th century scientist J. Willard Gibbs - is the energy in a biochemical reaction that is available to do work. It's the energy left over after producing some requisite waste heat and a dollop or two of entropy. This energy to do work is harnessed by biological systems for activities like making repairs, growing, and reproducing. For a given metabolic pathway used by life, e.g. reacting carbohydrates with oxygen, we can measure how many Joules are available to do work per mole of reactants. Humans and essentially all the animals you know and love typically harness a couple thousand kiloJoules per mole by burning food with oxygen. Microbes have figured out all sorts of ways to harness the Gibbs free energy by combining various gases, liquids, and rocks. Measurements by Tori Hoehler and colleagues at NASA Ames Research Center on methane-generating and sulfate-eating microbes indicate that the limit for life may be about 10 kiloJoules per mole. Within a given environment there may be many chemical pathways in operation and if there is an open energetic niche, chances are life will find a way to fill it. Biological ecosystems can be mapped as a landscape of reactions and pathways for harnessing energy; this is the Gibbs landscape.

Civilizations and the rise of industrial and technological ecosystems bring a new challenge to our understanding of the dynamic between energy needs and energy resources. The Gibbs landscape provides a short-hand abstraction for conceptualizing this dynamic. We can imagine any given city, country, or continent overlain with a map of energy available to do work. This includes, but extends beyond the chemical energy framework used in the context of biological ecosystems. For instance, automobiles with internal combustion engines metabolize gasoline with air. Buildings eat the electricity supplied by power plants or rooftop solar panels. Every component in modern industrial society occupies some niche in the landscape.

But importantly, many of the Gibbs landscapes in place today are ripe with unoccupied niches. The systems we have designed and built are inefficient and incomplete in the utilization of energy to do the work of civilization's ecosystems. Much of what we have designed excels at producing waste heat with little concern for optimizing work output. From lights that remain on all night to landfills that contain discarded resources, the Gibbs landscapes of today offer much room for technological innovation and evolution. The Gibbs landscape also provides a way for visualizing untapped capacity to do work — wind, solar, hydroelectric, tides and geothermal, these are just a few of the layers. Taken together, all of these layers show us where and how we can work to close the loops and connect the dangling threads of our nascent technological civilization.

When you start to view the world around you with Gibbsian eyes you see the untapped potential in so many of our modern technological and industrial ecosystems. It's disturbing at first because we've done such a poor job, but the marriage between civilization and technology is young. The landscape provides much reason for hope as we continue to innovate and strive to reach the balance and continuity that has served complex biological ecosystems so well for billions of years on Earth.

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The Senses and the Multi-Sensory

For far too long we have laboured under a faulty conception of the senses. Ask anyone you know how many senses we have and they will probably say five; unless they start talking to you about a sixth sense. But why pick five? What of the sense of balance provided by the vestibular system, telling you whether you are going up or down in a lift, forwards or backwards on a train, or side to side on a boat? What about proprioception that gives you a firm sense of where your limbs are when you close your eyes? What about feeling pain, hot and cold? Are these just part of touch, like feeling velvet or silk? And why think of sensory experiences like seeing, hearing, tasting, touching and smelling as being produced by a single sense?

Contemporary neuroscientists have postulated two visual systems — one responsible for how things look to us, the other for controlling action — that operate independently of one another. The eye may fall for visual illusions but the hand does not, reaching smoothly for a shape that looks larger than it is to the observer.

And it doesn't stop here. There is good reason to think that we have two senses of smell: an external sense of smell, orthonasal olfaction, produced by inhaling, that enables us to detect things in the environment such food, predators or smoke; and internal sense, retronasal olfaction, produced by exhaling, that enables us to detect the quality of what we have just eaten, allowing us to decide whether we want any more or should expel it.

Associated with each sense of smell is a distinct hedonic response. Orthonasal olfaction gives rise to the pleasure of anticipation. Retronasal olfaction gives rise to the pleasure of reward. Anticipation is not always matched by reward. Have you ever noticed how the enticing aromas of freshly brewed coffee are never quite matched by the taste? There is always a little disappointment. Interestingly, the one food where the intensity of orthonsally and retronasally judged aromas match perfectly is chocolate. We get just what we expected, which may explain why chocolate is such a powerful stimulus.

Besides the proliferation of the senses in contemporary neuroscience, another major change is taking place. We used to study the senses in isolation, with the greatest majority of researchers focusing on vision. Things are rapidly changing. We now know that the senses do not operate in isolation, but combine at both early and late stages of processing to produce our rich perceptual experiences of our surroundings. It is almost never the case that our experience presents us with just sights or sounds. We are always enjoying conscious experiences made up of sights and sounds, smells, the feel of our body, the taste in our mouths; and yet these are not presented as separate sensory parcels. We simply take in the rich and complex scene without giving much thought to how the different contributors produce the whole experience.

We give little thought to how smell provides a background to every conscious waking moment. People who lose their sense of smell can be plunged into depression and show less sign of recovery a year later than people who lose their sight. This is because familiar places no longer smell the same, and people no longer have their reassuring olfactory signature. Also, patients who lose their smell believe they have lost their sense of taste. When tested, they acknowledge that that can taste sweet, sour, salt, bitter savoury, and metallic. But everything else, missing from the taste of what they are eating, is due to retronasal smell.

What we call taste is one of the most fascinating case studies for how inaccurate our view of our senses is: it is not produced by the tongue alone but is always an amalgam of taste, touch and smell. Touch contributes to sauces tasting creamy, and other foods tasting chewy, crisp, or stale. The only difference between potato chips, which "taste" fresh or stale, is a difference in texture. The largest part of what we call "taste" is in fact smell in the form of retronasal olfaction, which is why people who lose their ability to smell say they can no longer taste anything. Taste, touch and smell are not merely combined to produce experiences of foods of liquids, rather the information from the separate sensory channels is fused into a unified experience of that we call taste and food scientists call *flavour*.

Flavour perception is the result of multi-sensory integration of gustatory, olfactory and oral somatosenory information into a single experience whose components we are unable to distinguish. It is one of the most multi-sensory experiences we have and can be influenced by both sight and sound. The colours of wines and the sounds food make when we bite or chew them can have large impacts on our resulting appreciation and assessment, and irritation of the trigeminal nerve in the face will make chillies feel "hot" and menthol feel "cool" in the mouth without any actual change in temperature.

In sensory perception, multi-sensory integration is the rule not the exception. In audition, we don't just hear with our ears, we use our eyes to locate the apparent sources of sounds in the cinema where we "hear" the voices coming from the actors' mouths on the screen although the sounds are coming from the sides of the theatre. This is known as the ventriloquism effect. Similarly, retronasal odours detected by olfactory receptors in the nose are experienced as tastes in the mouth. The sensations get re-located to the mouth because oral sensations of chewing or swallowing capture our attention, making us think these olfactory experiences are occurring in the same place.

Other surprising collaboration among the senses are due to cross-modal effects, where stimulation of one sense boosts activity in another. Looking at someone's lips across a crowded room can improve our ability to hear what they are saying, and the smell of vanilla can make a liquid we sip "taste" sweeter, and less sour. This is why we say vanilla is sweet smelling, although sweet is a taste, and pure vanilla is not sweet at all. Industrial manufacturers know about these effects and exploit them. Certain aromas in shampoos, for example, can make the hair "feel" softer; and red coloured drinks "taste" sweet, while drinks with a light green colour "taste" sour. In many of these interactions vision will dominate; but not in every case

. For anyone unlucky enough to have disturbance in their vestibular system they will feel the world is spinning although cues from the eyes and the body should be telling them everything is still. Instead, the brain goes with the combined picture and vision and proprioception fall in line. Luckily, our senses cooperate and we get us around the world, and the world we inhabit is not a sensory, but a multisensory world.

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A Statistically Significant Difference in Understanding the Scientific Process

Statistically significant difference — It is a simple phrase that is essential to science and that has become common parlance among educated adults. These three words convey a basic understanding of the scientific process, random events, and the laws of probability. The term appears almost everywhere that research is discussed — in newspaper articles, advertisements for "miracle" diets, research publications, and student laboratory reports, to name just a few of the many diverse contexts where the term is used. It is a short hand abstraction for a sequence of events that includes an experiment (or other research design), the specification of a null and alternative hypothesis, (numerical) data collection, statistical analysis, and the probability of an unlikely outcome. That is a lot of science conveyed in a few words.

It would be difficult to understand the outcome from any research without at least a rudimentary understanding of what is meant by the conclusion that the researchers found or did not find evidence of a "statistically significant difference." Unfortunately, the old saying that "a little knowledge is a dangerous thing" applies to the partial understanding of this term. One problem is that "significant" has a different meaning when used in everyday speech than when used to report research findings.

Most of the time, the word "significant" means that something important happened. For example, if a physician told you that you would feel significantly better following surgery, you would correctly infer that your pain would be reduced by a meaningful amount—you would feel less pain. But, when used in "statistically significant difference," the term "significant" means that the results are unlikely to be due to chance (if the null hypothesis were true); the results may or may not be important. In addition, sometimes, the conclusion will be wrong because researcher can only assert their conclusion at some level of probability. "Statistically significant difference" is a core concept in research and statistics, but as anyone who was taught undergraduate statistics or research methods can tell you, it is not an intuitive idea.

Despite the fact that "statistically significant difference" communicates a cluster of ideas that are essential to the scientific process, there are many pundits who would like to see it removed from our vocabulary because it is frequently misunderstood. Its use underscores the marriage of science and probability theory, and despite its popularity, or perhaps because of it, some experts have called for a divorce because the term implies something that it does not, and the public is often misled. In fact, experts are often misled as well. Consider this hypothetical example: In a well-done study that compares the effectiveness of two drugs relative to a placebo, it is possible that Drug X is statistically significantly different from a placebo and Drug Y is not, yet Drugs X and Y might not be statistically significant different from each other. This could result when Drug X is statistically different from placebo at a probability level of $p < .04$, but Drug Y is statistically significantly different from a placebo only at a probability level of $p < .06$, which is higher than most a priori levels used to test for statistical significance. If just reading about this makes your head hurt, you are among the masses who believe they understand this critical shorthand phrase which is at the heart of the scientific method, but actually may have a shallow-level of understanding.

There are many critically important ways that findings of "statistically significant difference" can be misleading. But, even though there are real problems with understanding this term, it is firmly entrenched in everyday discussions of research, and for the general public, it shows some knowledge of the process of science.

A better understanding of the pitfalls associated with this term would go a long way toward improving our "cognitive toolkits." If common knowledge of what this term means included the ideas that a) the findings may not be important and b) conclusions based on finding or failure to find statistically significant differences may be wrong, then we would have significantly advanced general knowledge. When people read or use the term "statistically significant difference," it is an affirmation of the scientific process, which, for all of its limitations and misunderstandings, is a significant advance over alternative ways of knowing about the world. If we could just add two more key concepts to the meaning of that phrase, we could improve how the general public thinks about science.

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The Dece(i)bo Effect

The Dece(i)bo Effect — think portmanteau of Deceive and Placebo — refers to the facile application of constructs, without unpackaging the concept and the assumptions on which it relies, in a fashion that, rather than benefiting thinking, leads reasoning astray.

Words and phrases enter common parlance, that capture a concept: Occam's razor, placebo, Hawthorne effect. Such phrases and code-words in principle facilitate discourse — and can indeed do so. Deploying the word or catchphrase adds efficiency to the interchange, by obviating the need for pesky review of the principles and assumptions encapsulated in the word.

Unfortunately, bypassing the need to articulate the conditions and assumptions on which validity of the construct rests, may lead to bypassing consideration of whether these conditions and assumptions legitimately apply. Use of the term can then, far from fostering sound discourse, serve to undermine it.

Take, for example, the "placebo," and "placebo effects." Unpackaging the terms, a "placebo" is in principle something that is physiologically "inert" — but believed by the recipient to be active, or possibly so. The term "placebo effect" refers to improvement of a condition when persons have been placed on a placebo, due to effects of expectation/suggestion.

With these terms well ensconced in the vernacular, Dece(i)bo Effects associated with them are much in evidence. Key presumptions regarding placebos and placebo effects are more typically wrong than not.

*1. When hearing the word "placebo," scientists often presume "inert" - without stopping to ask: what is that allegedly physiologically inert substance? Indeed, even in principle, what **could** it be??*

There isn't anything known to be physiologically inert. There are no regulations about what constitute placebos; and their composition — commonly determined by the manufacturer of the drug under study — is typically undisclosed. Among the uncommon cases where placebo composition has been noted, there are documented instances in which the placebo composition apparently produced spurious effects. Two studies used corn oil and olive oil placebos for cholesterol-lowering drugs: one noted that the "unexpectedly" low rate of heart attacks in the control group may have contributed to failure to see a benefit from the cholesterol drug. Another study noted "unexpected" benefit of a drug to gastrointestinal symptoms in cancer patients. But cancer patients bear increased likelihood of lactose intolerance — and the placebo was lactose, a "sugar pill." When the term "placebo" substitutes for actual ingredients, any thinking about how the composition of the control agent may have influenced the study is circumvented.

2. Because there are many settings in which persons with a problem, given placebo, report sizeable improvement on average when they are re-queried (see 3), many scientists have accepted that "placebo effects" — of suggestion — are both large in magnitude and widespread in the scope of what they benefit.

The Danish researcher Asbjørn Hróbjartsson conducted a systematic review of studies that compared a placebo to no treatment. He found that the placebo generally does: nothing. In most instances, there is no placebo effect. Mild "placebo effects" are seen, in the short term, for pain and anxiety. Placebo effects for pain are reported to be blocked by naloxone, an opiate antagonist — specifically implicating endogenous opiates in pain placebo effects, which would not be expected to benefit every possible outcome that might be measured.

3. When hearing that persons with a problem placed on a "placebo" report improvement, scientists commonly presume this must be due to the "placebo effect" - the effect of expectation/suggestion.

However, the effects are usually something else entirely. For instance: natural history of the disease, and regression to the mean. Consider a distribution, such as a bell-shape. Whether the outcome of interest is pain, blood pressure, cholesterol, or other, persons are classically selected for treatment if they are at one end of the distribution - say, the high end. But these outcomes are quantities that vary (for instance from physiological variation, natural history, measurement error...), and on average the high values will vary back down — a phenomenon termed "regression to the mean" that operates, placebo or no. (Hence, Hróbjartsson's findings.)

A different dece(i)bo problem beset Ted Kaptchuk's recent Harvard study in which researchers gave a "placebo," or nothing, to people afflicted with irritable bowel syndrome. They administered the placebo in a bottle boldly labeled "Placebo," and advised patients they were receiving placebos, which were known to be potent. The thesis was that one might harness the effects of expectation honestly, without deception, by telling subjects how powerful placebos in fact were - and by developing a close relationship with subjects. Researchers met repeatedly with subjects, gained subjects' appreciation for their concern and listening (as the researchers made clear), and repeatedly told subjects that placebos are powerful. Those placed on placebo obliged the researchers by telling them they had gotten better, moreso than those on nothing. The scientists attributed this to a placebo effect.

But what's to say patients weren't simply telling the scientists what they thought the scientists wished to hear? Such desire to please (a form, perhaps, of "social approval" reporting bias) had fertile grounds in which to operate and create what was interpreted as a placebo effect — which implies actual subjective benefit to symptoms. One wonders if so great an error of presumption would operate were there not an existing term, "placebo effect," to signify the interpretation the Harvard group chose.

Another explanation consistent with these results is specific physiological benefit. The study used a nonabsorbed fiber — microcrystalline cellulose — as the "Placebo" that subjects were told would be effective. The authors are applauded for disclosing its composition. But other nonabsorbed fibers benefit both constipation and diarrhea — symptoms of irritable bowel — and are prescribed for that purpose; psyllium is an example. Thus, specific physiological benefit of the "Placebo" to symptoms cannot be excluded.

Together these points illustrate that the term "placebo" cannot be presumed to imply "inert" (and generally does not); and that when studies see large benefit to symptoms in patients treated with "placebo" (expected from distribution considerations alone), one cannot infer these arose from large benefits of suggestion to symptoms (which evidence indicates may seldom operate).

Thus, rather than facilitating sound reasoning, evidence suggests that in many cases, including high stakes settings in which inferences may propagate to medical practice, substitution of a term — here, "placebo," "placebo effect" — for the concepts they are intended to convey, may actually thwart or bypass critical thinking about key issues, with implications to fundamental concerns for us all.

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The Name Game

Too often in science we operate under the principle that "to name it is to tame it", or so we think. One of the easiest mistakes, even among working scientists, is to believe that labeling something has somehow or another added to an explanation or understanding of it. Worse than that we use it all the time when we are teaching, leading students to believe that a phenomenon that is named is a phenomenon that is known, and that to know the name is to know the phenomenon. It's what I, and others, have called the nominal fallacy. In biology especially, we have labels for everything - from molecules to anatomical parts, to physiological functions, to organisms, to ideas or hypotheses. The nominal fallacy is the error of believing that the label carries explanatory information.

An instance of the nominal fallacy is most easily seen when the meaning or importance of a term or concept shrinks with knowledge. One example of this would be the word "instinct". Instinct refers to a set of behaviors whose actual cause we don't know or simply don't understand or have access to; and therefore we call them instinctual, inborn, innate. Often this is the end of the exploration of these behaviors, they are the nature part of the nature-nurture argument (a term that itself is likely a product of the nominal fallacy) and therefore can't be broken down or reduced any further. But experience has shown that this is rarely the truth. In one of the great examples of this, it was for quite some time thought that when chickens hatched and they immediately began pecking the ground for food, this behavior must have been instinctive. In the 1920s a Chinese researcher named Zing-Yang Kuo made a remarkable set of observations on the developing chick egg that overturned this idea — and many similar ones. Using a technique of elegant simplicity he found that rubbing heated Vaseline on a chicken egg caused it to become transparent enough to see the embryo inside without disturbing it. In this way he was able to make detailed observations of the development of the embryo from fertilization to hatching. One of his observations was that, in order for the growing embryo to fit properly in the egg, the neck is bent over the chest of the body in such a way that the head rests upon the chest just where the developing heart is encased. As the heart begins beating the head of the chicken is moved in an up-and-down manner that precisely mimics the movement that will be used later for pecking the ground. Thus the "innate" pecking behavior that the chicken appears to know miraculously upon birth has, in fact, been practiced for more than a week within the egg.

In medicine as well, physicians often find technical terms that lead patients to believe that more is known about pathology than may actually be the case. In Parkinson's patients we notice that they have an altered gait and in general that their movement's are slower. Physicians call this "bradykinesia", but it doesn't really tell you anymore than simply saying "they move slower".

Why do they move slower, what is the pathology and what is the mechanism for this slowed movement - these are the deeper questions hidden by the simple statement that "a cardinal symptom of Parkinson's is bradykinesia", satisfying though it might be to say the word to a patient's family.

In science the one critical issue is to be able to distinguish between what we know and what we don't know. This is often difficult enough as things that seem known, sometimes become unknown or at least more ambiguous. When is it time to quit doing an experiment because we now know something, when is it time to stop spending money and resources on a particular line of investigation because the facts are known? This line between the known and the unknown is already difficult enough to define, but the nominal fallacy often obscures it needlessly. Even words like gravity, which seems so well-settled, may lend more of an aura to the idea than it deserves. After all, the apparently very well settled ideas of Newtonian gravity were almost completely undone after 400 years by Einstein's General Relativity. And still today physicists do not have a clear understanding of what gravity is or where it comes from, even though it's effects can be described quite accurately.

Another facet of the nominal fallacy is the danger of using common words and giving them a scientific meaning. This has the often disastrous effect of leading an unwary public down a path of misunderstanding. Words like 'theory', 'law', 'force', do not mean in common discourse what they mean to a scientist. 'Success' in Darwinian evolution is not the same 'success' as taught by Dale Carnegie. Force to a physicist has a meaning quite different from that used in political discourse. The worst of these though may be "theory" and "law" which are almost polar opposites — theory being a strong idea in science while vague in common discourse, and law being a much more muscular social than scientific concept. These differences lead to sometimes serious misunderstandings between scientists and the public who supports their work.

Of course language is critical and we must have names for things to talk about them. But the power of language to direct thought should never be taken lightly and the dangers of the name game deserve our respect.

ANDREW REVKIN
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Anthropophilia

To sustain progress on a finite planet that is increasingly under human sway, but also full of surprises, what is needed is a strong dose of *anthropophilia*. I propose this word as shorthand for a rigorous and dispassionate kind of self regard, even self appreciation, to be employed when individuals or communities face consequential decisions attended by substantial uncertainty and polarizing disagreement.

The term is an intentional echo of Ed Wilson's valuable effort to nurture *biophilia*, the part of humanness that values and cares for the facets of the non-human world we call nature. What's been missing too long is an effort to fully consider, even embrace, the human role *within* nature and — perhaps more important still — to consider our own inner nature, as well.

Historically, many efforts to propel a durable human approach to advancement were shaped around two organizing ideas: "woe is me" and "shame on us," with a good dose of "shame on you" thrown in.

The problem?

Woe is paralytic, while blame is both divisive and often misses the real target. (Who's the bad guy, BP or those of us who drive and heat with oil?)

Discourse framed around those concepts too often produces policy debates that someone once described to me, in the context of climate, as "blah, blah, blah bang." The same phenomenon can as easily be seen in the unheeded warnings leading to the most recent financial implosion and the attack on the World Trade Center.

More fully considering our nature — both the "divine and felonious" sides, as Bill Bryson has summed us up — could help identify certain kinds of challenges that we *know* we'll tend to get wrong.

The simple act of recognizing such tendencies could help refine how choices are made — at least giving slightly better odds of getting things a little less wrong the next time. At the personal level, I know when I cruise into the kitchen tonight I'll tend to prefer to reach for a cookie instead of an apple. By pre-considering that trait, I might have a slightly better chance of avoiding a couple of hundred unnecessary calories.

Here are a few instances where this concept is relevant on larger scales.

There's a persistent human pattern of not taking broad lessons from localized disasters. When China's Sichuan province was rocked by a severe earthquake, tens of thousands of students (and their teachers) died in collapsed schools. Yet the American state of Oregon, where more than a thousand schools are already known to be similarly vulnerable when the great Cascadia fault off the Northwest Coast next heaves, still lags terribly in speeding investments in retrofitting.

Sociologists understand with quite a bit of empirical backing why this disconnect exists even though the example was horrifying and the risk in Oregon is about as clear as any scientific assessment can be. But does that knowledge of human biases toward the "near and now" get taken seriously in the realms where policies are shaped and the money to carry them out is authorized? Rarely, it seems.

Social scientists also know, with decent rigor, that the fight over human-driven global warming — both over the science and policy choices — is largely cultural. As in many other disputes (consider health care) the battle is between two quite fundamental subsets of human communities — communitarians (aka, liberals) and individualists (aka, libertarians). In such situations, a compelling body of research has emerged showing how information is fairly meaningless. Each group selects information to reinforce a position and there are scant instances where information ends up shifting a position.

That's why no one should expect the next review of climate science from the Intergovernmental Panel on Climate Change to suddenly create a harmonious path forward.

The more such realities are recognized, the more likely it is that innovative approaches to negotiation can build from the middle, instead of arguing endlessly from the edge. The same body of research on climate attitudes, for example, shows far less disagreement on the need for advancing the world's limited menu of affordable energy choices.

Murray Gell-Mann has spoken often of the need, when faced with multi-dimensional problems, to take a "crude look at the whole" — a process he has even given an acronym, CLAW. It's imperative, where possible, for that look to include an honest analysis of the species doing the looking, as well.

There will never be a way to invent a replacement for, say, the United Nations or the House of Representatives. But there is a ripe opportunity to try new approaches to constructive discourse and problem solving, with the first step being an acceptance of our humanness, for better and worse.

That's anthropophilia.

GARY MARCUS
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Cognitive Humility

Hamlet may have said that human beings are noble in reason and infinite in faculty, but in reality — as four decades of experiments in cognitive psychology have shown — our minds are very finite, and far from noble. Knowing the limits of our minds can help us to make better reasoners.

Almost all of those limits start with a peculiar fact about human memory: although we are pretty good at storing information in our brains, we are pretty poor at retrieving that information. We can recognize photos from our high school yearbooks decades later—yet still find it impossible to remember what we had for breakfast yesterday. Faulty memories have been known to lead to erroneous eyewitness testimony (and false imprisonment), to marital friction (in the form of overlooked anniversaries), and even death (skydivers, for example have been known to forget to pull their ripcords — accounting, by one estimate, for approximately 6% of skydiving fatalities).

Computer memory is much more better than human memory because early computer scientists discovered a trick that evolution never did: organizing information according by assigning every memory to a sort of master map, in which each bit of information that is to be stored is assigned a specific, uniquely identifiable location in the computer's memory vaults. Human beings, in contrast. appear to lack such master memory maps, and instead retrieve information in far more haphazard fashion, by using clues (or cues) to what it's looking for, rather than knowing in advance where in the brain a given memory lies.

In consequence, our memories cannot be searched as systematically or as reliably as those of us a computer (or internet database). Instead, human memories are deeply subject to context. Scuba divers, for example, are better at remembering the words they study underwater when they are tested underwater (relative to when they were a tested on land), even if the words have nothing to do with the sea.

Sometimes this sensitivity to context is useful. We are better able to remember what we know about cooking when we are in the kitchen than when we are skiing, and vice versa.

But it also comes at a cost: when we need to remember something in a situation other than the one in which it was stored, it's often hard to retrieve it. One of the biggest challenges in education, for example, is to get children to take what they learn in school and apply it to real world situations, in part because context-driven memory means that what is learned in school tends to stay in school.

Perhaps the most dire consequence is that human beings tend almost invariably to be better at remembering evidence that is consistent with their beliefs than evidence that might disconfirm them. When two people disagree, it is often because their prior beliefs lead them to remember (or focus on) different bits of evidence. To consider something well, of course, is to evaluate both sides of an argument, but unless we also go the extra mile of deliberately forcing ourselves to consider alternatives—not something that comes naturally—we are more prone to recalling evidence consistent with a proposition than inconsistent with it.

Overcoming this mental weakness, known as confirmation bias, is a lifelong struggle; recognizing that we all suffer from it is a important first step.To the extent that we can beware of this limitation in our brains, we can try to work around it, compensating for our in-born tendencies towards self-serving and biased recollections by disciplining ourselves to consider not just the data that might fit with our own beliefs, but also the data that might lead other people to have beliefs that differ from our own.

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Because

When you are facing in the wrong direction, progress means walking backwards. History suggests that our world view undergoes disruptive change not so much when science adds new concepts to our cognitive toolkit, but when it takes away old ones. The sets of intuitions that have been with us since birth define our scientific prejudices, and not only are poorly-suited to the realms of the very large and very small, but also fail to describe everyday phenomena. If we are to identify where the next transformation of our world view will come from, we need to take a fresh look at our deep intuitions. In the two minutes that it takes you to read this essay, I am going to try and rewire your basic thinking about causality.

Causality is usually understood as meaning that there is a single, preceding cause for an event. For example in classical physics, a ball may be flying through the air, because of having been hit by a tennis racket. My 16 year-old car always revs much too fast, because the temperature sensor wrongly indicates that the engine temperature is cold, as if the car was in start-up mode. We are so familiar with causality as an underlying feature of reality that we hard-wire it into the laws of physics. It might seem that this would be unnecessary, but it turns out that the laws of physics do not distinguish between time going backwards and time going forwards. And so we make a choice about which sort of physical law we would like to have.

However, complex systems, such as financial markets or the Earth's biosphere, do not seem to obey causality. For every event that occurs, there are a multitude of possible causes, and the extent to which each contributes to the event is not clear, not even after the fact! One might say that there is a web of causation. For example, on a typical day, the stock market might go up or down by some fraction of a percentage point. The Wall Street Journal might blithely report that the stock market move was due to "traders taking profits" or perhaps "bargain-hunting by investors". The following day, the move might be in the opposite direction, and a different, perhaps contradictory, cause will be invoked. However, for each transaction, there is both a buyer and a seller, and their world views must be opposite for the transaction to occur. Markets work only because there is a plurality of views. To assign single or dominant cause to most market moves is to ignore the multitude of market outlooks and to fail to recognize the nature and dynamics of the temporary imbalances between the numbers of traders who hold these differing views.

Similar misconceptions abound elsewhere in public debate and the sciences. For example, are there single causes for diseases? In some cases, such as Huntingdon's disease, the cause can be traced to a unique factor, in this case extra repetitions of a particular nucleotide sequence at a particular location in an individual's DNA, coding for the amino acid glutamine. However, even in this case, the age of onset and the severity of the condition are also known to be controlled by environmental factors and interactions with other genes. The web of causation has been for many decades a well-worked metaphor in epidemiology, but there is still little quantitative understanding of how the web functions or forms. As Krieger poignantly asked in a celebrated 1994 essay, "Has anyone seen the spider?"

The search for causal structure is nowhere more futile than in the debate over the origin of organismal complexity: intelligent design vs. evolution. Fueling the debate is a fundamental notion of causality, that there is a beginning to life, and that such a beginning must have had a single cause. On the other hand, if there is instead a web of causation driving the origin and evolution of life, a skeptic might ask: has anyone seen the spider?

It turns out that there is no spider. Webs of causation can form spontaneously through the concatenation of associations between the agents or active elements in the system. For example, consider the Internet. Although a unified protocol for communication (TCP/IP etc) exists, the topology and structure of the Internet emerged during a frenzied build-out, as Internet service providers staked out territory in a gold-rush of unprecedented scale. Remarkably, once the dust began to settle, it became apparent that the statistical properties of the resulting Internet were quite special: the time delays for packet transmission, the network topology, and even the information transmitted exhibit fractal properties.

However, you look at the Internet, locally or globally, on short time scales or long, it looks exactly the same. Although the discovery of this fractal structure around 1995 was an unwelcome surprise, because standard traffic control algorithms as used by routers were designed assuming that all properties of the network dynamics would be random, the fractality is also broadly characteristic of biological networks. Without a master blueprint, the evolution of an Internet is subject to the same underlying statistical laws that govern biological evolution, and structure emerges spontaneously without the need for a controlling entity. Moreover, the resultant network can come to life in strange and unpredictable ways, obeying new laws whose origin cannot be traced to any one part of the network. The network behaves as a collective, not just the sum of parts, and to talk about causality is meaningless because the behavior is distributed in space and in time.

Between 2.42pm and 2.50pm on May 6 2010, the Dow-Jones Industrial Average experienced a rapid decline and subsequent rebound of nearly 600 points, an event of unprecedented magnitude and brevity. This disruption occurred as part of a tumultuous event on that day now known as the Flash Crash, which affected numerous market indices and individual stocks, even causing some stocks to be priced at unbelievable levels (e.g. Accenture was at one point priced at 1 cent).

With tick-by-tick data available for every trade, we can watch the crash unfold in slow motion, a film of a financial calamity. But the cause of the crash itself remains a mystery. The US Securities and Exchange Commission report on the flash crash was able to identify the trigger event (a $4 billion sale by a mutual fund), but could provide no detailed understanding of why this event caused the crash. The conditions that precipitate the crash were already embedded in the market's web of causation, a self-organized rapidly evolving structure created by the interplay of high frequency trading algorithms. The Flash Crash was the birth cry of a network coming to life, eerily reminiscent of Arthur C. Clarke's science fiction story "Dial F for Frankenstein", which begins "At 0150 GMT on December 1, 1975, every telephone in the world started to ring." I'm excited by the scientific challenge of understanding all this in detail, because … well, never mind. I guess I don't really know.

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Proxemic of Urban Sexuality

In every room, in every house, in every street, in every city, movements, relations and spaces are also defined with regards to logics of attraction-repulsion between the sexuality of individuals.

Even the most insurmountable ethnic or religious barriers can suddenly disappear with the furor of an intercourse; even the warmest and cohesive community can rapidly dissolve in absence of erotic tension.

To understand how our cosmopolitan and multi-gendered cities work, today we need a Proxemic of Urban Sexuality.

MAHZARIN R. BANAJI
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A Solution for Collapsed Thinking: Signal Detection Theory

We perceive the world through our senses. The brain-mediated data we receive in this way form the basis of our understanding of the world. From this become possible the ordinary and exceptional mental activities of attending, perceiving, remembering, feeling, and reasoning. Via these mental processes we understand and act on the material and social world.

In the town of Pondicherry in South India, where I sit as I write this, many do not share this assessment. There are those, including some close to me, who believe there are extrasensory paths to knowing the world that transcend the five senses, that untested "natural" foods and methods of acquiring information are superior to those based in evidence. On this trip, for example, I learned that they believe that a man has been able to stay alive without and caloric intake for months (although his weight falls, but only when he is under scientific observation).

Pondicherry is an Indian Union Territory that was controlled by the French for

300 years (staving off the British in many a battle right outside my window) and held on to until a few years after Indian independence. It has, in addition to numerous other points of attraction, become a center for those who yearn for spiritual experience, attracting many (both whites and natives) to give up their worldly lives to pursue the advancement of the spirit, to undertake bodily healing, and to invest in good works on behalf of a larger community.

Yesterday, I met a brilliant young man who had worked as a lawyer for eight years who now lives in the ashram and works in their book sales division. Sure, you retort, the profession of the law would turn any good person toward spirituality but I assure you that that the folks here have given up wealth and professional life of a wide variety of sorts to pursue this manner of life. The point is that seemingly intelligent people seem to crave non-rational modes of thinking and the Edge question this years forced me to think not only about the toolkit of the scientist but every person.

I do not mean to pick on any one city, and certainly not this unusual one in which so much good effort is put towards the arts and culture and on social upliftment of the sort we would admire. But this is a town that also attracts a particular type of European, American, and Indian — those whose minds seem more naturally prepared to believe that unprocessed "natural" herbs do cure cancer and that standard medical care is to be avoided (until one desperately needs chemo), that Tuesdays are inauspicious for starting new projects, that particular points in the big toe control the digestive system, that the position of the stars at the time of their birth led them to Pondicherry through an inexplicable process emanating from a higher authority and through a vision from "the mother", a deceased French woman, who dominates the ashram and surrounding area in death more than many successful politicians ever do in their entire lives.

These types of beliefs may seem extreme but they are not considered as such in most of the world. Change the content and the underlying false manner of thinking is readily observed just about anywhere — the new 22 inches of snow that has fallen where I live in the United States while I'm away will no doubt bring forth beliefs of a god angered by crazy scientists toting global warming.

As I contemplate the single most powerful tool that could be put into the heads of every growing child and every adult seeking a rational path, scientists included, it is the simple and powerful concept of "signal detection". In fact, the Edge question this year happens to be one I've contemplated for a while — should anybody ever ask such a question, the answer I've known would be an easy one: I use Green & Swets Signal detection theory and Psychophysics as the prototype, although the idea has its origins in earlier work among scientists concerned with the fluctuations of photons and their influence on visual detection and sound waves and their influence on audition.

The idea underlying the power of signal detection theory is simple: The world gives noisy data, never pure. Auditory data, for instance, are degraded for a variety of reasons having to do with the physical properties of the communication of sound. The observing organism has properties that further affect how those data will be experienced and interpreted, such as ability (e.g., a person's auditory acuity), the circumstances under which the information is being processed (e.g., during a thunderstorm), and motivation (e.g., disinterest). Signal detection theory allows us to put both aspects of the stimulus and the respondent together to understand the quality of the decision that will result given the uncertain conditions under which data are transmitted, both physically and psychologically.

To understand the crux of signal detection theory, each event of any data impinging on the receiver (human or other) is coded into four categories, providing a language to describe the decision:

		Did the event occur?	
		Yes	***No***
Did the received detect it?	***Yes***	Hit	False Alarm
	No	Miss	Correct Rejection

Hit: A signal is present and the signal is detected (correct response)

False Alarm: No signal is presented but a signal is detected (incorrect response)

Miss: A signal is present but no signal is detected (incorrect response)

Correct Rejection: No signal is present and no signal is detected (correct response)

If the signal is clear, like a bright light against a dark background, the decision maker has good visual acuity and is motivated to watch for the signal, we should see a large number of Hits and Correct Rejections and very few False Alarms and Misses. As these properties change, so does the quality of the decision. Whether the stimulus is a physical one like a light or sound, or a piece of information requiring an assessment about its truth, information is almost always deviates from goodness.

It is under such ordinary conditions of uncertainty that signal detection theory yields a powerful way to assess the stimulus and respondent qualities including the respondent's idiosyncratic criterion (or cutting score, "c") for decision-making. The criterion is the place along the distribution at which point the respondent switches from the saying "no" to a "yes".

The applications of signal detection theory have been in areas as diverse as locating objects by sonar, the quality of remembering, the comprehension of language, visual perception, consumer marketing, jury decisions, price predictions in financial markets, and medical diagnoses.

The reason signal detection theory should be in the toolkit of every scientist is because it provides a mathematically rigorous framework to understand the nature of decision processes. The reason its logic should be in the toolkit of every thinking person is because it forces a completion of the four cells when analyzing the quality of any statement such as "Good management positions await Saggitarius this week".

MARTIN REES
President Emeritus, The Royal Society; Professor of Cosmology & Astrophysics; Master, Trinity College, University of Cambridge; Author, Our Final Century: The 50/50 Threat to Humanity's Survival

"Deep Time" And The Far Future

We need to extend our time-horizons. Especially, we need deeper and wider awareness that far more time lies ahead than has elapsed up till now.

Our present biosphere is the outcome of more than four billion years of evolution; and we can trace cosmic history right back to a "big bang" that happened about 13.7 billion years ago. The stupendous time-spans of the evolutionary past are now part of common culture and understanding — even though the concept may not yet have percolated all parts of Kansas, and Alaska.

But the immense time-horizons that stretch ahead — though familiar to every astronomer — haven't permeated our culture to the same extent. Our Sun is less than half way through its life. It formed 4.5 billion years ago, but it's got 6 billion more before the fuel runs out. It will then flare up, engulfing the inner planets and vaporising any life that might then remain on Earth. But even after the Sun's demise, the expanding universe will continue — perhaps for ever — destined to become ever colder, ever emptier. That, at least, is the best long range forecast that cosmologists can offer, though few would lay firm odds on what may happen beyond a few tens of billions of years.

Awareness of the "deep time" lying ahead is still not pervasive. Indeed, most people — and not only those for whom this view is enshrined in religious beliefs —envisage humans as in some sense the culmination of evolution. But no astronomer could believe this; on the contrary, it would be equally plausible to surmise that we are not even at the halfway stage. There is abundant time for posthuman evolution, here on Earth or far beyond, organic or inorganic, to give rise to far more diversity, and even greater qualitative changes, than those that have led from single-celled organisms to humans. Indeed this conclusion is strengthened when we realise that future evolution will proceed not on the million-year timescale characteristic of Darwinian selection, but at the much accelerated rate allowed by genetic modification and the advance of machine intelligence (and forced by the drastic environmental pressures that would confront any humans who were to construct habitats beyond the Earth.

Darwin himself realised that "No living species will preserve its unaltered likeness into a distant futurity". We now know that "futurity" extends far further, and alterations can occur far faster — than Darwin envisioned. And we know that the cosmos, through which life could spread, is far more extensive and varied than he envisaged. So humans are surely not the terminal branch of an evolutionary tree, but a species that emerged early in cosmic history, with special promise for diverse evolution. But this is not to diminish their status. We humans are entitled to feel uniquely important as the first known species with the power to mould its evolutionary legacy.

J. CRAIG VENTER
Genome Scientist; Sequenced first genome of a living species, the human genome, and created the first synthetic life; Author, A Life Decoded

We Are Not Alone In The Universe

I cannot imagine any single discovery that would have more impact on humanity than the discovery of life outside of our solar system. There is a human-centric, Earth-centric view of life that permeates most cultural and societal thinking. Finding that there are multiple, perhaps millions of origins of life and that life is ubiquitous throughout the universe will profoundly affect every human.

We live on a microbial planet. There are one million microbial cells per cubic centimeter of water in our oceans, lakes and rivers; deep within the Earth's crust and throughout our atmosphere. We have more than 100 trillion microbes on and in each of us. The Earth's diversity of life would have seemed like science fiction to our ancestors. We have microbes that can withstand millions of Rads of ionizing radiation; such strong acid or base that it would dissolve our skin; microbes that grow in ice and microbes that grow and thrive at temperatures exceeding 100 degrees C. We have life that lives on carbon dioxide, on methane, on sulfur, or on sugar. We have sent trillions of bacteria into space over the last few billion years and we have exchanged material with Mars on a constant basis, so it would be very surprising if we do not find evidence of microbial life in our solar system, particularly on Mars.

The recent discoveries by Dimitar Sasselov and colleagues of numerous Earth and super-Earth-like planets outside our solar system, including water worlds, greatly increases the probability of finding life. Sasselov estimates approximately 100,000 Earth and super-Earths within our own galaxy. The universe is young so wherever we find microbial life there will be intelligent life in the future.

Expanding our scientific reach further into the skies will change us forever.

BRIAN ENO
Artist; Composer; Recording Producer: U2, Cold Play, Talking Heads, Paul

Simon; Recording Artist; *Author,* A Year With Swollen Appendices

Ecology

That idea, or bundle of ideas, seems to me the most important revolution in general thinking in the last 150 years. It has given us a whole new sense of who we are, where we fit, and how things work. It has made commonplace and intuitive a type of perception that used to be the province of mystics — the sense of wholeness and interconnectedness.

Beginning with Copernicus, our picture of a semi-divine humankind perfectly located at the centre of The Universe began to falter: we discovered that we live on a small planet circling a medium sized star at the edge of an average galaxy. And then, following Darwin, we stopped being able to locate ourselves at the centre of life. Darwin gave us a matrix upon which we could locate life in all its forms: and the shocking news was that we weren't at the centre of that either — just another species in the innumerable panoply of species, inseparably woven into the whole fabric (and not an indispensable part of it either). We have been cut down to size, but at the same time we have discovered ourselves to be part of the most unimaginably vast and beautiful drama called Life.

Before "ecology" we understood the world in the metaphor of a pyramid — a heirarchy with God at the top, Man a close second and, sharply separated, a vast mass of life and matter beneath. In that model, information and intelligence flowed in one direction only — from the intelligent top to the "base" bottom — and, as masters of the universe, we felt no misgivings exploiting the lower reaches of the pyramid.

The ecological vision has changed that: we now increasingly view life as a profoundly complex weblike system, with information running in all directions, and instead of a single heirarchy we see an infinity of nested-together and co-dependent heirarchies — and the complexity of all this is such to be in and of itself creative. We no longer need the idea of a superior intelligence outside of the system — the dense field of intersecting intelligences is fertile enough to account for all the incredible beauty of "creation".

The "ecological" view isn't confined to the organic world. Along with it comes a new understanding of how intelligence itself comes into being. The classical picture saw Great Men with Great Ideas...but now we tend to think more in terms of fertile circumstances where uncountable numbers of minds contribute to a river of innovation. It doesn't mean we cease to admire the most conspicuous of these — but that we understand them as effects as much as causes. This has ramifications for the way we think about societal design, about crime and conflict, education, culture and science.

That in turn leads to a re-evaluation of the various actors in the human drama. When we realise that the cleaners and the bus drivers and the primary school teachers are as much a part of the story as the professors and the celebrities, we will start to accord them the respect they deserve.

RICHARD THALER

The Father of Behavioral Economics; Director, Center for Decision Research at the University of Chicago Graduate School of Business; Coauthor, Nudge: Improving Decisions About Health, Wealth, and Happiness

Aether

I recently posted a question in this space asking people to name their favorite example of a wrong scientific belief. One of my favorite answers came from Clay Shirky. Here is an excerpt:

The existence of ether, the medium through which light (was thought to) travel. It was believed to be true by analogy — waves propagate through water, and sound waves propagate through air, so light must propagate through X, and the name of this particular X was ether.

It's also my favorite because it illustrates how hard it is to accumulate evidence for deciding something doesn't exist. Ether was both required by 19th century theories and undetectable by 19th century apparatus, so it accumulated a raft of negative characteristics: it was odorless, colorless, inert, and so on.

Several other entries (such as the "force of gravity") shared the primary function of ether: they were convenient fictions that were able to "explain" some otherwise ornery facts. Consider this quote from Max Pettenkofer, the German chemist and physician, is disputing the role of bacteria as a cause of the cholera. "Germs are of no account in cholera! The important thing is the disposition of the individual."

So in answer to the current question I am proposing that we now change the usage of the word Aether, using the old spelling, since there is no need for a term that refers to something that does not exist. Instead, I suggest we use that term to describe the role of any free parameter used in a similar way: that is, Aether is the thing that makes my theory work. Replace the word disposition with Aether in Pettenkofer's sentence above to see how it works.

Often Aetherists (theorists who rely on an Aether variable) think that their use of the Aether concept renders the theory untestable. This belief is often justified during their lifetimes, but then along comes clever empiricists such as Michelson and Morley and last year's tautology become this year's example of a wrong theory.

Aether variables are extremely common in my own field of economics. Utility is the thing you must be maximizing in order to render your choice rational.

Both risk and risk aversion are concepts that were once well defined, but are now in danger of becoming Aetherized. Stocks that earn surprisingly high returns are labeled as risky, because in the theory, excess returns must be accompanied by higher risk. If, inconveniently, the traditional measures of risk such as variance or covariance with the market are not high, then the Aetherists tell us there must be some other risk; we just don't know what it is.

Similarly, traditionally the concept of risk aversion was taken to be a primitive; each person had a parameter, gamma, that measured her degree of risk aversion. Now risk aversion is allowed to be time varying, and Aetherists can say with a straight face that the market crashes of 2001 and 2008 were caused by sudden increases in risk aversion. (Note the direction of the causation. Stocks fell because risk aversion spiked, not vice versa.)

So, the next time you are confronted with such a theory, I suggest substituting the word Aether for the offending concept. Personally, I am planning to refer to the time-varying variety of risk aversion as Aether aversion.

V.S. RAMACHANDRAN
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Chunks With "Handles"

Do you need language — including words — for sophisticated thinking or do they merely facilitate thought? This question goes back to a debate between two Victorian scientists Max Mueller and Francis Galton.

A word that has made it into the common vocabulary of both science and pop culture is "paradigm" (and the converse "anomaly") having been introduced by the historian of science Thomas Kuhn. It is now widely used and misused both in Science and in other disciplines almost to the point where the original meaning is starting to be diluted. (This often happens to "memes" of human language and culture; which don't enjoy the lawful, particulate transmission of genes.) The word "paradigm" is now often used inappropriately — especially in the US — to mean any experimental procedure such as "The Stroop paradigm" or " A reaction time paradigm" or "fMR paradigm".

However, its appropriate use has shaped our culture in significant ways; even influencing the way scientists work and think. A more prevalent associated word is "skepticism", originating from the name of a Greek school of philosophy . This is used even more frequently and loosely than "anomaly" and "paradigm shift".

One can speak of reigning paradigms; what Kuhn calls normal science — What I cynically refer to as a "mutual admiration club trapped in a cul-de-sac of specialization". The club usually has its Pope(s), hierarchical priesthood, acolytes and a set of guiding assumptions and accepted norms that are zealously guarded almost with religious fervor. (They also fund each other and review each other's papers and grants and give each other awards.)

This isn't entirely useless; its called "normal science" that grows by progressive accretion, employing the bricklayers rather than architects of science. If a new experimental observation (e.g. bacterial transformation; Ulcers cured by antibiotics) threatens to topple the edifice, its called an anomaly and the typical reaction of those who practice normal science is to ignore it or brush it under the carpet — a form of psychological denial surprisingly common among my colleagues.

This is not an unhealthy reaction since most anomalies turn out to be false alarms; the baseline probability of their survival as real" anomalies is small and whole careers have been wasted pursuing them (think "poly water", cold fusion".) Yet even such false anomalies serve the useful purpose of jolting scientists from their slumber by calling into question the basic axioms that drive their particular area of science. Conformist science feels cozy given the gregarious nature of humans and anomalies force periodic reality checks even if the anomaly turns out to be flawed.

More important, though, are genuine anomalies that emerge every now and then, legitimately challenging the status quo, forcing paradigm shifts and leading to scientific revolutions. Conversely, premature skepticism toward anomalies can lead to stagnation of science. One needs to be skeptical of anomalies but equally skeptical of the status quo if science is to progress.

I see an analogy between the process of science and of evolution by natural selection. For evolution, too, is characterized by periods of stasis (= normal science) punctuated by brief periods of accelerated change (= paradigm shifts) based on mutations (= anomalies) most of which are lethal (false theories) but some lead to the budding off of new species and phylogenetic trends (=paradigm shifts).

Since most anomalies are false alarms (spoon bending, telepathy, homeopathy) one can waste a lifetime pursuing them. So how does one decide which anomalies to invest in? Obviously one can do so by trial and error but that can be tedious and time consuming.

Let's take four well-known examples: (1) Continental drift; (2) Bacterial transformation; (3) cold fusion; (4) telepathy. All of these were anomalies when first discovered because they didn't fit the big picture of normal science at that time. The evidence that all the continents broke off and drifted away from a giant super-continent was staring at peoples faces — as Wagener noted in the early 20th century. (The coastlines coincided almost perfectly; certain fossils found on the east coast of Brazil were exactly the same as the ones on the west coast of Africa etc.) Yet it took fifty years for he idea to be accepted by the skeptics.

The second anomaly (2) — observed a decade before DNA and the genetic code — was that if you incubate one species of bacterium (pneumococcus A) with another species in a test tube (Pneumococcus B) then bacterium A becomes *transformed* into B! (Even the DNA —rich *juice* from B will suffice — leading Avery to suspect that heredity might have a chemical basis) Others replicated this. It was almost like saying put a pig and donkey into a room and two pigs emerge — yet the discovery was largely ignored for a dozen years. Until Watson and Crick pointed out the *mechanism* of transformation. The third anomaly — telepathy — is almost certainly a false alarm.

You will see a general rule of thumb emerging here. Anomalies (1) and (2) were not ignored because of lack of empirical evidence. Even a school child can see the fit between continental coastlines or similarity of fossils. It was ignored solely because it didn't fit the big picture — the notion of terra firma or a solid, immovable earth — and there was no conceivable *mechanism* that would allow continents to drift (until plate tectonics was discovered). Likewise (2) was repeatedly confirmed but ignored because it challenged the fundamental doctrine of biology — the stability of species. But notice that the third (telepathy) was rejected for *two* reasons; first, it didn't fit the big picture and second because it was hard to replicate

This gives us the recipe we are looking for; focus on anomalies that have survived repeated attempts to disprove experimentally, but are ignored by the establishment *solely* because you cant think of a mechanism. But don't waste time ones that have not been empirically confirmed despite repeated attempts (or the effect becomes smaller with each attempt — a red flag!)

"Paradigm" and "paradigm shift" have now migrated from science into pop culture (not always with good results) and I suspect many other words and phrases will follow suit — thereby enriching our intellectual and conceptual vocabulary and day-to-day thinking.

Indeed, words themselves are paradigms or stable "species" of sorts that evolve gradually with progressively accumulating penumbras of meaning, or sometimes mutate into new words to denote new concepts. These can then consolidate into chunks with "handles" (names) for juggling ideas around generating novel combinations. As a behavioral neurologist I am tempted to suggest that such crystallization of words and juggling them is unique to humans and it occurs in brain areas in and near the left TPO (temporal-parietal-occipital junction). But that's pure speculation.

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James Flynn has defined "shorthand abstractions" (or "SHA's") as concepts drawn from science that have become part of the language and make people smarter by providing widely applicable templates ("market", "placebo", "random sample," "naturalistic fallacy," are a few of his examples). His idea is that the abstraction is available as a single cognitive chunk which can be used as an element in thinking and debate.

The *Edge* Question 2011