Reductionism and complexity

Presentation at the research course
Numbers for policy

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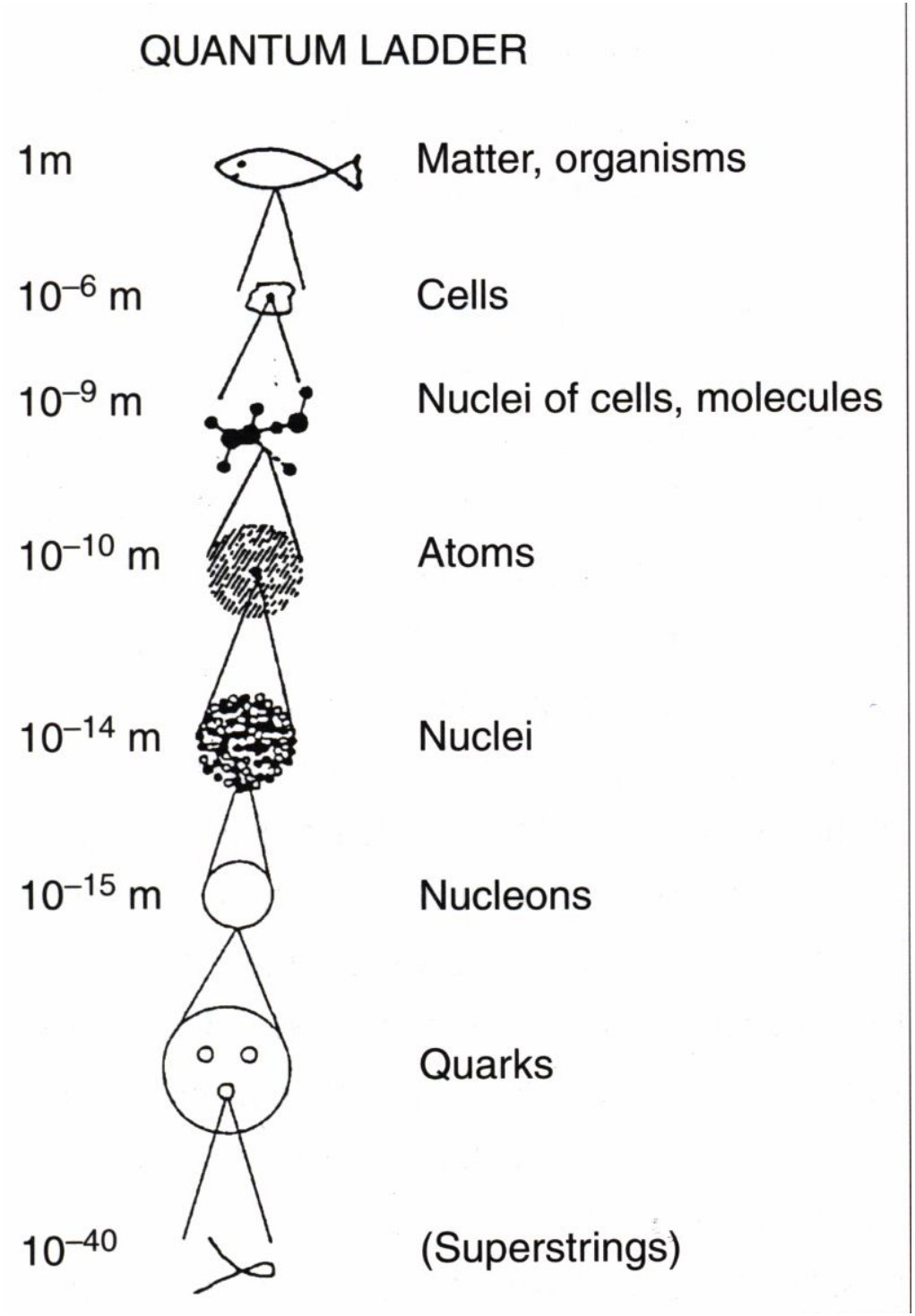

QUANTUM LADDER
1m
Matter, organisms
10^{-6} m
Cells
10^{-9} m
Nuclei of cells, molecules
10^{-10} m
Atoms
10^{-14} m
Nuclei
10^{-15} m
Nucleons
Quarks
10^{-40}
(Superstrings)

The problem of reductionism

- The structure of the hierarchy is from the whole to the parts.
- Can one level be completely reduced to a lower level? ("ontological reductionism")
- (For example, cells are “nothing but” molecules.)

“The reductionist hypothesis may still be a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted without question.The workings of our minds and bodies, and of all the animate or inanimate matter of which we have any detailed knowledge, are assumed to be controlled by the same set of fundamental laws, which except under certain extreme conditions we feel we know pretty well.” (P. W. Anderson: "More is Different", *Science*, 4. August 1972, Vol 177, No 4047)

“...if everything obeys the same fundamental laws, then the only scientists who are studying anything really fundamental are those who are working on those laws.” (Anderson: "More is Different")

- “There is only one science – physics. All the rest is social work.” (James Watson)

Gerard t' Hooft on a “Theory of Everything”

"The laws will determine with infinite accuracy the evolution of all physical dynamical variables at a local level, and should also include a description of the 'boundary' of the universe, as well as its initial state.

There exists no closely resembling alternative theory. This means that any slight change brought about in the rules would make the theory unlikely or inelegant. The theory will be a 'package deal': take it, or leave it. This should hold both for the local laws and for the boundary conditions."

"Evolution according to these laws will give rise to a nearly infinite complexity, a complexity sufficiently extensive to include the marvelously perplexing wonders abounding in our universe – the emergence of life and intelligence being only a few of these."

(Gerard 't Hooft: “Questioning the answers or Stumbling upon good and bad Theories of Everytning”, J. Hilgevoord (ed): *Physics and our View of the World,* 1994).

"However, if we do discover a complete theory [.....] it would be the ultimate triumph of human reason – for then we would know the mind of God."
(Stephen Hawking: *A Brief History of Time* (1988), Conclusion)

Francis Crick thought that he had solved the two fundamental problems of science:
1. What is life?
2. What is consciousness?

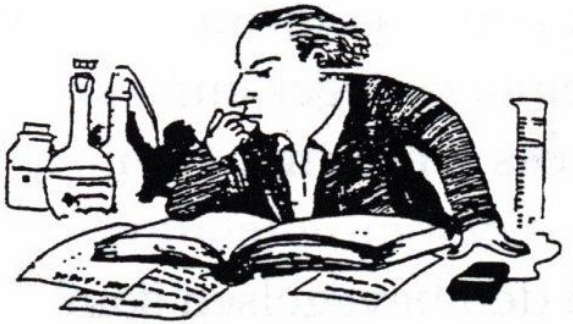
This is the second:

The Astonishing Hypothesis is that "You", your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules.

Francis Crick: The Astonishing Hypothesis. The Scientific Search for the Soul (1994)

All thinking is no doubt nothing but physiological processes

All physiological processes are in reality nothing but biochemistry



All biochemistry is in reality nothing but pure chemistry.

All chemistry is after all really nothing but atomic physics...

All atomic physics is in fact nothing but particle physics...

All particle physics is in fact nothing but mathematics...

All mathematics is in reality nothing but thinking...

"If my mental processes are determined wholly by the motions of atoms in my brain, I have no reason to suppose that my beliefs are true ... and hence I have no reason for supposing my brain to be composed of atoms." (J. B. S. Haldane, *Possible Worlds* 1927)

The principal candidate for a theory of everything was (and is?) string theory.

Lee Smolin has given substantial contributions to the theory. However .....

"There appears to be no precedent for a gap between theory and experiment lasting decades. It is something we theorists talk about often. Some see it as a temporary lull and look forward to new experiments now in preparation. Others speak of a new era in science in which mathematical consistency has replaced experiment as the final arbiter of a theory's correctness. A growing number of theoretical physicists, myself among them, see the present situation as a crisis that requires us to reexamine the assumptions behind our so-far unsuccessful theories."
(Lee Smolin: "A Crisis in Fundamental Physics", New York Academy of Science, January/February 2006)

"The great physicists of the beginning of the 20th century—Einstein, Bohr, Mach, Boltzmann, Poincare, Schrodinger, Heisenberg—thought of theoretical physics as a philosophical endeavor. They were motivated by philosophical problems, and they often discussed their scientific problems in the light of a philosophical tradition in which they were at home.

[...]

Thus, I suspect that the crisis is a result of having ignored foundational issues. If this is true, the problems of quantum gravity and unification can only be solved by returning to the older style of research."

Lee Smolin: "A Crisis in Fundamental Physics"

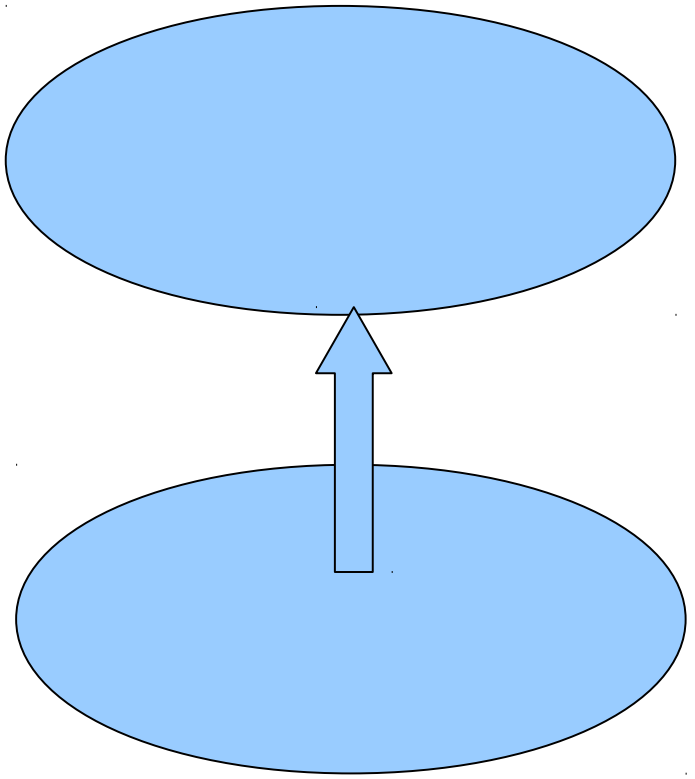
Almost twenty-five years after *A Brief History of Time* it looks as if Hawking has also given up the search for a final theory:

"Physicists have long sought to find one final theory that would unify all of physics. Instead they may have to settle for several."
(Stephen Hawking and Leonard Mlodinow: "The (Elusive) Theory of Everyting", *Scientific American*, Special issue on extreme physics, summer 2013.)

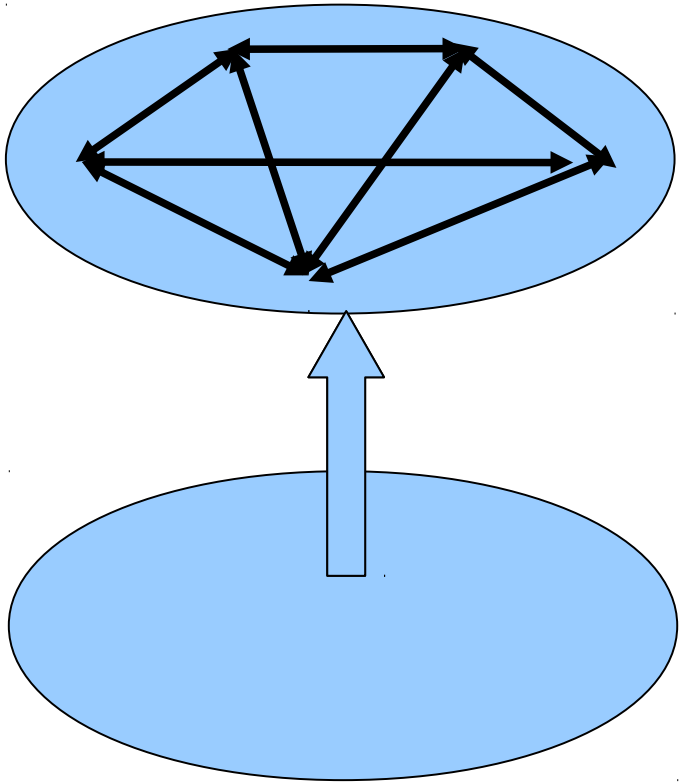
The real problem

The problem is that the world is in general not simple, but complex. The whole cannot in general be reduced to its parts. At each level of organization there are emergent properties that cannot be explained as just an interaction of the parts at the lower level.

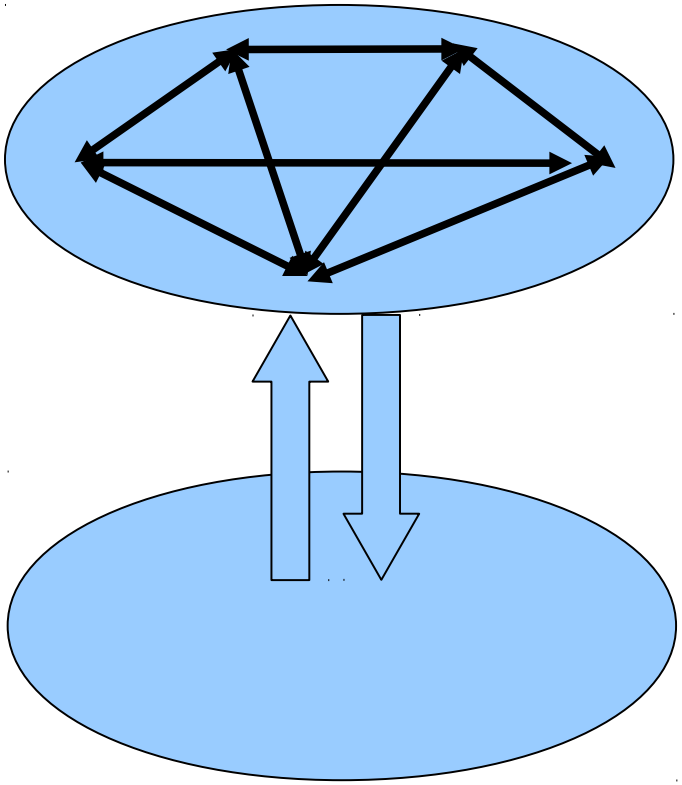
Not this



But this



Or even this



Emergence

“At each stage entirely new laws, concepts, and generalizations are necessary, requiring inspiration and creativity to just as great a degree as in the previous one. Psychology is not applied biology, nor is biology applied chemistry.” (Anderson: "More is Different",1972)

Emergence

"I heard the great evolutionist Ernst Mayr claiming 30 or 40 years ago, when he described emergence to Niels Bohr, Bohr said: "but we have that in physics as well! - physics is all emergent", but at the time, as usual, only Bohr knew what he meant.

In fact, the story of physics in the last half of the 20th century has been one of emergence – Bohr was also, as usual, basically right."

(Anderson: "What Is a Condensed Matter Theorist?", in *More and Different*, 2011)

Examples of emergent physical properties:

- A simple atom of gold cannot be yellow and shiny and conduct electricity. Properties of gold metal have only meaning at a macroscopic scale.
- A molecule of salt is not a cube. Only a salt crystal can have cubic symmetry.
- Anderson's key-word is "broken symmetry"

(Anderson: "Emergence vs Reductionism", in *More and Different*, 2011)

When a system has emergent properties, it is complex

A semi-formal definition of complexity:

"Loosely speaking, the complexity of a system is the amount of information needed in order to describe it."
Yaneer Bar-Yam: *Dynamics of Complex Systems* (1997)

A less formal (but perhaps more useful) characterization of complexity

"To investigate many-body systems, scientists construct simplified models that capture various important aspects of a larger picture from various perspectives. Consequently economics, evolutionary biology, and statistical physics all branch into a multitude of models, each of which addresses a particular process or a specific aspect of composition. Various models employ various approaches and approximations as befits their specific topics." (Sunny Y. Auyang: *Foundations of Complex-System Theories* (1998)

When reductionism works

"'Analytical procedure' means that an entity investigated be resolved into, and hence can be constituted or reconsituted from, the parts put together, these procedures being understood both in their material and conceptual sense. This is the basic principle of 'classical' science, which can be circumscribed in different ways: resolution into isolable causal trains, seeking for 'atomic' units in the various fields of science etc. The progress of science has shown that these principles of classical science – first enunciated by Galileo and Descartes – are highly successful in a wide realm of phenomena."

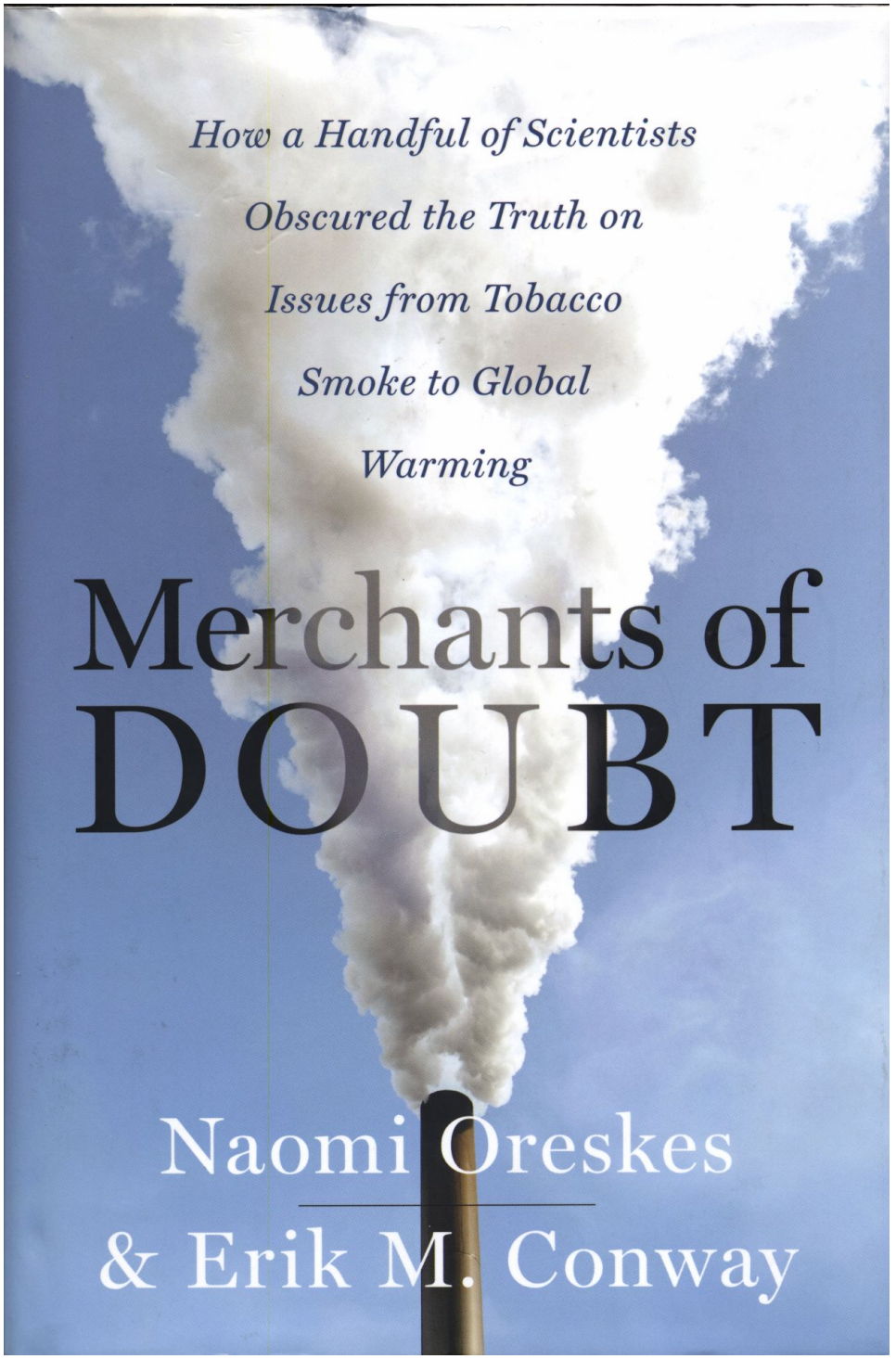
Ludwig von Bertalanffy: General System Theory (1968)

"Application of the analytical procedure depends on two conditions. The first is that interactions between 'parts' be non-existent or weak anough to be neglected for certain research purposes. Only under this condition, can the parts be 'worked out', actually, logically, and mathematically, and then be 'put together'. The second condition is that the relations describing behavior of the parts be linear; only then is the condition of summativity given, i.e. an equation describing the behaviour of the total is of the same form as the equations describing the behaviour of the parts; partial processes can be superimposed to obtain the total process, etc."

When reductionism does not work

- In a complex system an analytic approach does not increas certainty.

- On the contrary, it increases uncertainty.


How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming
Merchants of DOUBT
Naomi Oreskes
& Erik M. Conway

2010

Frederick Seitz: Physicist who participated in the Manhattan project to construct the atomic bomb, and had later been president of US National Academy of Sciences

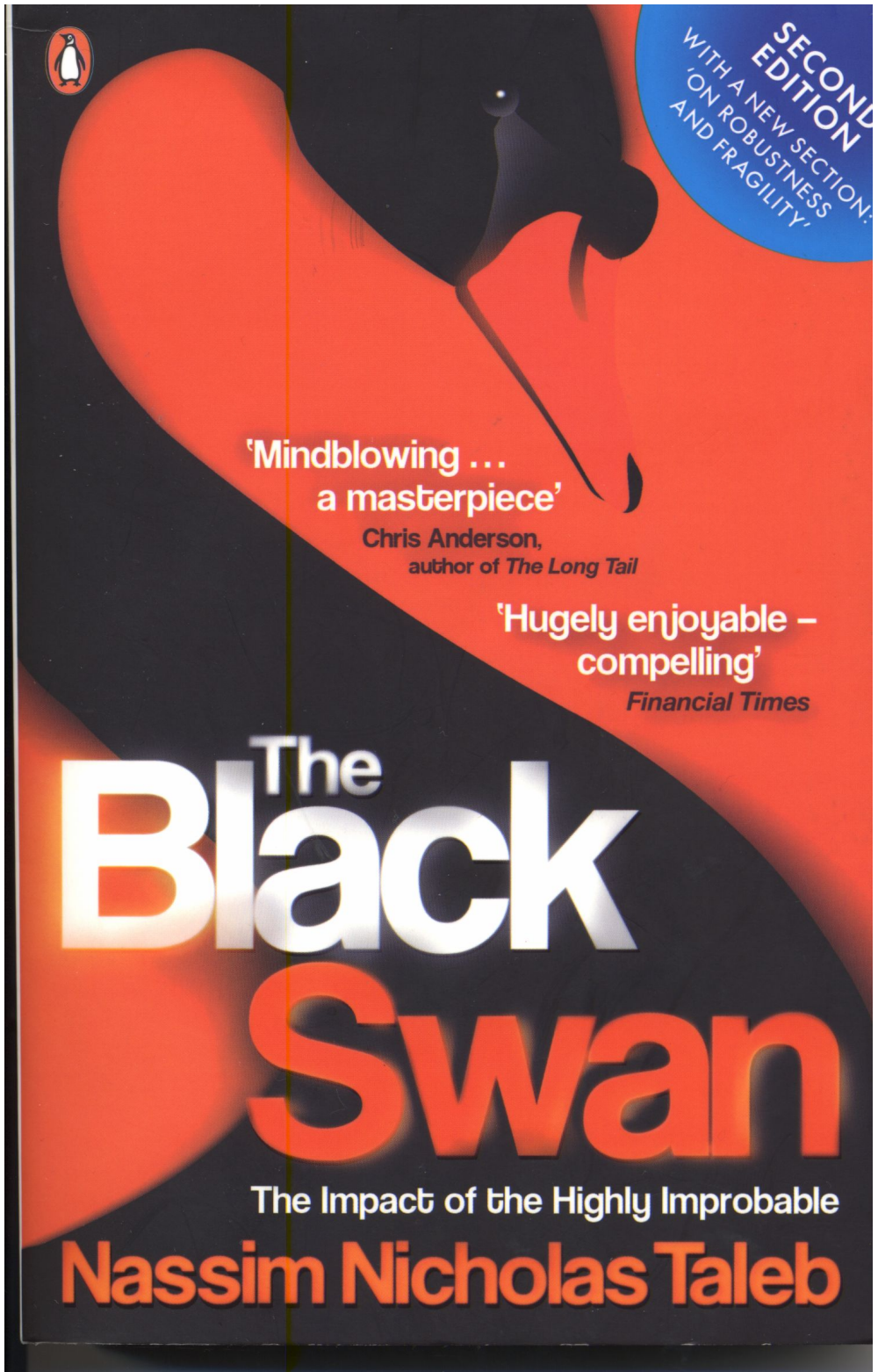
Fred Singer: Physicist who had pioneered the development of observation satellites, and had been director of National Weather Satellite Service, and had worked for the Reagan administration

From Fred Singer's and Fred Seitz's “list of merits”

- Causal connection between cigarette smoking and cancer not proven.
- Scientists erroneously critisised SDI (Reagan's “Star Wars project”).
- Acid rain and the ozon hole caused by volcano eruption.
- They first denied global warming, then they argued that it represented natural variation, and finally, even if it is the case, we may adapt.
- The general strategy was to emphasize uncertainty.

However, uncertainty may go both ways:

- It can be a justification for acting
- It can be a justification for not acting



Which way in the case of the environment?

2007

"Learning from Mother Nature, the oldest and wisest" (Postscript added 2010)

"We do not understand enough about Mother Nature to mess with her – and I do not trust the models used to forecast climate change."

"But the skepticism about models that I propose does not lead to the conclusions endorset by anti-environmentalists and pro-market fundamentalists. Quite the contrary: we need to be hypter-conservationists ecologically, since we do not know what we are harming *with* now. That's the sound policy under conditions of ignorance and epistemic opacity."

"To those who say "We have no proof that we are harming nature", a sound response is "We have no proof that we are not harming nature, either"; the burden of proof is not on the ecological conservationist, but on someone disrupting an old system."

What kind of knowledge?

Daniel Sarewitz: "Science and Environmental Policy: An Excess of objectivity", in Robert Frodeman & Victor R. Baker (eds.), Earth Matters: The Earth Sciences, Philosophy, and the Claims of Community. Prentice-Hall. pp. 79 - 98 (2000)

"The atmospheric science view has a fundamentally reductionist and deterministic component. It is rooted in the search for causation; it seeks to combine theoretical "first principles" that govern the climate system (mathematical representations of basic physical principles) with quantified observational data to yeld predictive and "retrodictive" models of system evolution." (p. 87)

"...the details of a complex system behavior are much more difficult to characterize than are general attributes." (p. 85)

"To be blunt: Despite the insistence of many scientists and philosophers that all is reducible to physics, there is no empirical basis for such an assertion-the weight of evidence is thus far firmly on the other side." (p. 87)

Reductionism is based on the application of an analytic/synthetic method. We go from the whole to the part, we devide and put together again (Galileo called it metodo resolutivo and metodo compositivo)

The method is nicely described by von Bertalanffy:

" This is the basic principle of 'classical' science, which can be circumscribed in different ways: resolution into isolable causal trains, seeking for 'atomic' units in the various fields of science, etc. "

"The Spandrels of San Marco and the Panglossian Paradigm: A Critique of the Adaptationist Programme"

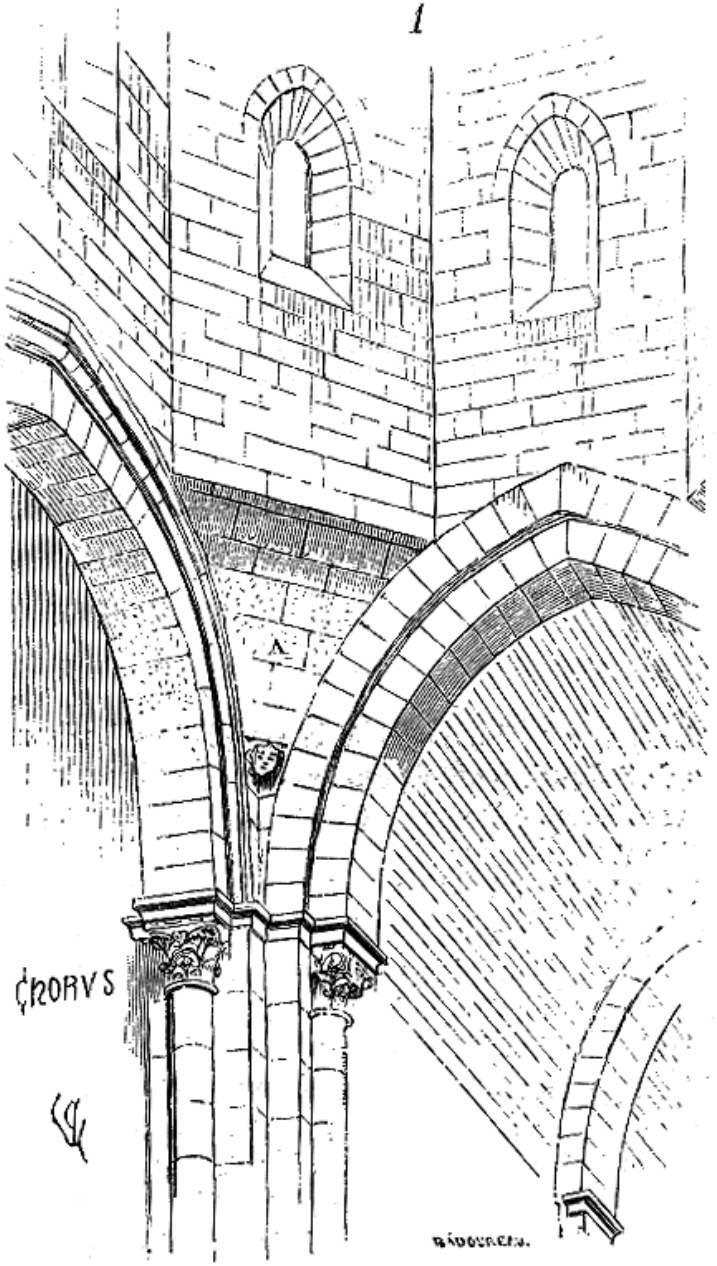
Stephen Jay Gould og Richard C. Lewontin

Republished from the original with the kind permission of The Royal Society of London: Gould, S. J. And Lewontin, R. C., "The Spandrels of San Marco and the Panglossian Paradigm: A Critique Of The Adaptationist Programme," Proceedings Of The Royal Society of London, Series B, Vol. 205, No. 1161 (1979), Pp. 581-598.

"An adaptationist programme has dominated evolutionary thought in England and the United States during the past forty years. It is based on faith in the power of natural selection as an optimizing agent. It proceeds by breaking an organism into unitary "traits" and proposing an adaptive story for each considered separately. Trade-offs among competing selective demands exert the only brake upon perfection; non-optimality is thereby rendered as a result of adaptation as well. We criticize this approach and attempt to reassert a competing notion (long popular in continental Europe) that organisms must be analyzed as integrated wholes....."

From the San Marco cathedral in Venice

Copied from http://en.wikipedia.org/wiki/Pendentive


CHORVS

Barry Commoner 1917 – 2012

Barry Commoner: The Closing Circle: Nature, Man, and Technology (1971)

"Understanding the ecosphere comes hard because, to the modern mind it is a curiously foreign place. We have become accustomed to think about separate, singular events, each dependent on a unique, singular cause. But in the ecosphere every effect is also a cause: an animal's waste becomes food for soil bacteria; what bacteria excrete nourishes plants; animals eat the plants. Such ecological cycles are hard to fit into human experience in the age of technology, where machine A always yields product B, and product B, once used, is cast away, having no further meaning for the machine, the product, or the user."

Barry Commoner's four laws of ecology:

1) Everything is connected to everything else

2) Everything must go somewhere

3) Nature knows best

4) There is no such thing as a free lunch

Commoner later added:

“Since they inhabit both worlds, people are caught in the clash between the ecosphere and the technosphere. What we call the “environmental crisis” - the array of critical unsolved problems ranging from local toxic dumps to the disruption of global climate – is a product of the drastic mismatch between the cyclical, conservative, and self-consistent processes of the ecosphere and the linear, innovative, but ecologically disharmonious processes of the technosphere.”

Commoner: Man inhabits two different spheres

- the ecosphere: cyclical

The secons law of ecology: “Everything has to go somewhere”

- the technosphere: linear

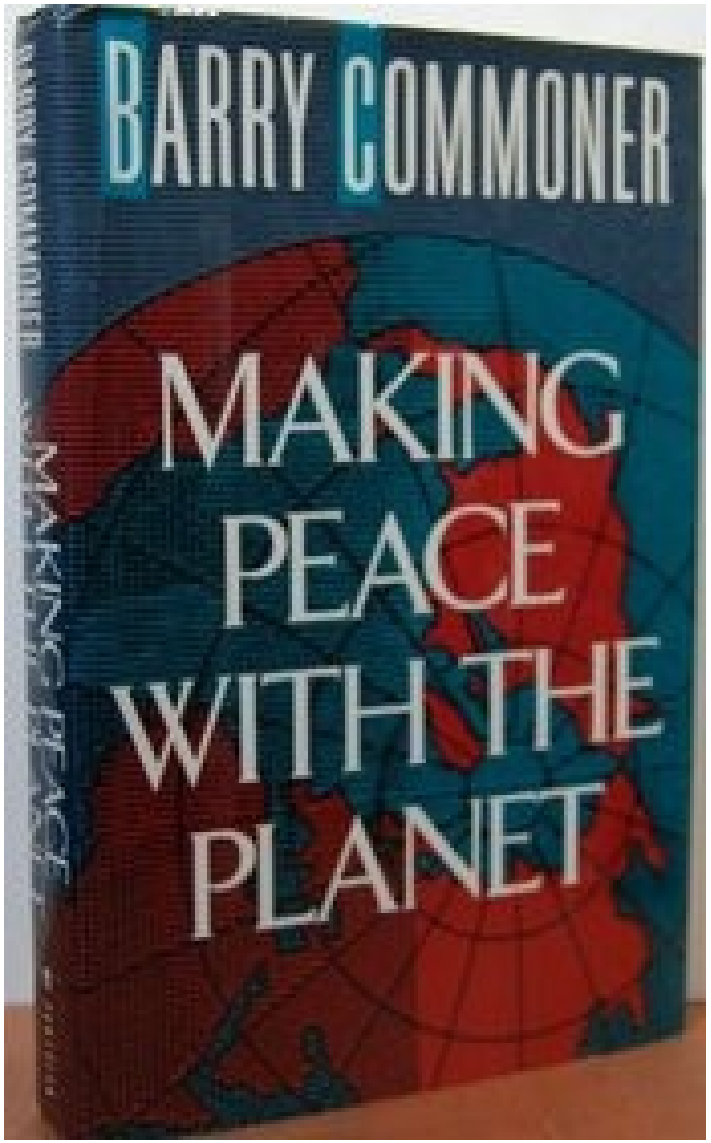
production – use – disposal

“The human attack on the ecosphere has instigated an ecological counterattack. The two worlds are at war.”

I will add a quotation from Ernst Schumacher: *Small is Beautiful*:

"Modern man does not experience himself as a part of nature but as an outside force destined to dominate and conquer it. He even talks of a battle with nature, forgetting that, if he won the battle, he would find himself on the losing side."

There is only one real solution:



1975, 1990