From bits to pieces – emergence

Complex Biology

Data integration?

Data driven
information cycle

Re-Engineering Philosophy for Limited Beings

William C. Wimsatt

piecewise approximations to reality

Complex Systems

To explain what we (don't) see: cognition and conscience

The more the better? About puzzles and mysteries

The history and theory of explanation (less than a richfull)

From health to disease

Science Principles for Biology
Causality & Complexity

M.M. Nalbant

Technische Universität München
Lehrstuhl für Bioinformatik

München, 16.02. 2017

TUM

Use CPC metadoxgies

Science Principles for Biology
Causality & Complexity

H.W. Mewes

Technische Universität München
Lehrstuhl f. Bioinformatik

München, 16.02. 2017

To start with the basics:
Why we are strongly biased and can be easily fooled?

The more details we know, the less we understand

This is the Discworld, which travels through space on the back of four elephants which themselves stand on the shell of Great A'Tuin, the sky turtle.

Once upon a time such a universe was considered unusual and, possibly, impossible.

But then... it used to be so simple, once upon a time.

Because the universe was full of ignorance all around and the scientist panned through it like a prospector crouched over a mountain stream, looking for the gold of knowledge among the gravel of unreason, the sand of uncertainty and the little whiskery eight-legged swimming things of superstition.

Occasionally he would straighten up and say things like 'Hurrah, I've discovered Boyle's Third Law.' And everyone knew where they stood. But the trouble was that ignorance became more interesting, especially big fascinating ignorance about huge and important things like matter and creation, and people stopped patiently building their little houses of rational sticks in the chaos of the universe and started getting interested in the chaos itself — partly because it was a lot easier to be an expert on chaos, but mostly because it made really good patterns that you could put on a t-shirt.

And instead of getting on with proper science scientists suddenly went around saying how impossible it was to know anything, and that there wasn't really anything you could call reality to know anything about, and how all this was tremendously exciting, and incidentally did you know there were possibly all these little universes all over the place but no-one can see them because they are all curved in on themselves? Incidentally, don't you think this is a rather good t-shirt?

Compared to all this, a large turtle with a world on its back is practically mundane. At least it doesn't pretend it doesn't exist, and no-one on the Discworld ever tried to prove it didn't exist in case they turned out to be right and found themselves suddenly floating in empty space. This is because the Discworld exists right on the edge of reality. The least little things can break through to the other side. So, on the Discworld, people take things seriously.

Like stories.

Because stories are important.

Occasionaly he would ...say things like "Hurrah, I've discovered Boyle's Law." And everyone knew where they stood. But the trouble was that ignorance became more interesting, especially big fascinating ignorance about huge and important things like matter and creation, and people stopped patiently building their little houses of rational sticks and started getting interested in the chaos itself - partly because it was a lot easier to be an expert on chaos, but mostly because it made really good patterns that you could pat on a t-shirt.

Terry Pratchart, Witches abroad

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Terry Pratchart, Witches abroad

- Data
- Data analysis
- Data interpretation
- Knowledge

Nothing wrong with it!

**What you have learned and what we
know about bioinformatics & systems biology?**

Ask a different question: how do we gain insight into biology?

Are there sound, computable underlying principles
   to construct a biological system?
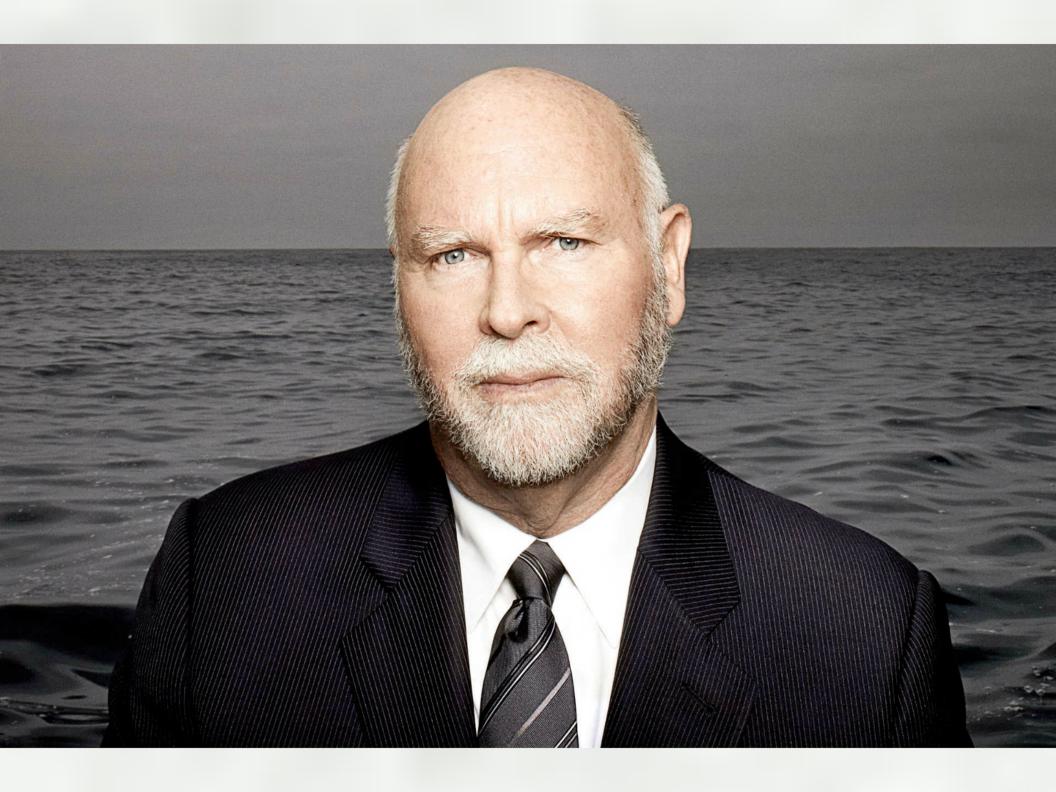
Do we follow defined principles investigating an organism?

What makes a good/successful biologist a good & successful biologist?

Your view:
- Sequence alignment
- Evolutionary principles
- Biochemistry
- Algorithms
- Data structures
- Gene prediction
- Protein structures
- DNA structure
- Genetic elements

So you view DNA as the software of life?

All the information needed to make a living, self-replicating cell is locked up within the spirals of DNA's double helix. As we read and interpret that software of life, we should be able to completely understand how cells work, then change and improve them by writing new cellular software.

The software defines the manufacture of proteins that can be viewed as its hardware, the robots and chemical machines that run a cell. The software is vital because the cell's hardware wears out. Cells will die in minutes to days if they lack their genetic-information system. They will not evolve, they will not replicate, and they will not live.

cited from: wired.co.uk 2007

Christopher Voigt, professor of biological engineering at MIT, explains: "It is literally a programming language for bacteria. You use a text-based language, just like you're programming a computer. Then you take that text and you compile it and it turns it into a DNA sequence that you put into the cell, and the circuit runs inside the cell."
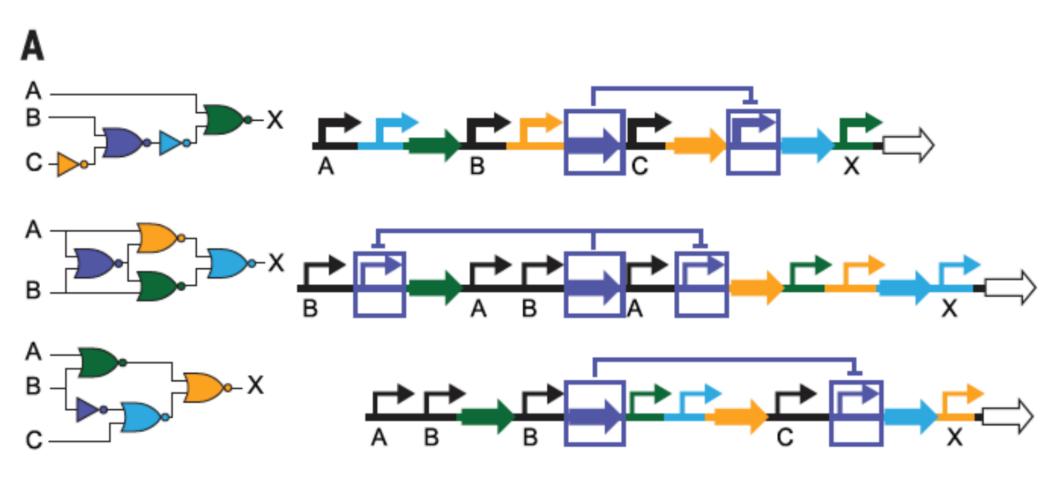
Essentially, you start with the ability you want to program into the bacterium—say, detecting the presence of certain harmful chemicals. You write up a program describing it, and a DNA sequence is created that will achieve the desired function.

And just like that, you've got a toxin-sniffing germ."

From:
We've Figured Out How to Program Living Cells

Janet Iwasa, 2016

A

A

Cello design specification

Sensors

name	low	high	promoter sequence
PTac	0.003	2.8	AACGATCGTTGGCTGTGTTGACAATTAATCATC
PTet	0.001	4.4	TACTCCACCGTTGGCTTTTTTCCCTATCAGTGA
PBAD	0.008	2.5	ACTTTTCATACTCCCGCCATTCAGAGAAGAAAC

Verilog

```
module 0x21(output out,input A,B,C);

always@(C,B,A)
  begin
    case({C,B,A})
      3'b000: {out} = 1'b0;
      3'b001: {out} = 1'b0;
      3'b010: {out} = 1'b1;
      3'b011: {out} = 1'b0;
      3'b100: {out} = 1'b0;
      3'b101: {out} = 1'b0;
      3'b110: {out} = 1'b0;
      3'b111: {out} = 1'b1;
    endcase
  end
endmodule
```

Run

Verilog parsing

CBA	w1	w2	w3	w4	X
000	0	1	0	1	0
001	0	0	1	1	0
010	0	1	0	0	1
011	0	0	1	0	0
100	0	0	1	1	0
101	1	0	1	0	0
110	0	0	1	0	0
111	1	0	0	0	1

Logic synthesis

AND-Inverter

NOR/NOT

Final circuit diagram

Assign gates

User Constraint File (UCF)

Gate library

- Gate technology
- Physical implementation
- Genetic and logic constraints
- Strain genotype
- Operating conditions

Combinatorial design

Genetic circuit DNA sequence

J. Craig Venter's Latest Venture Has Ambitions Across Human Lifespan

The goal is to integrate this mass of data for new discoveries that can wed individuals' own genetic variants, the composition of their bacteria, the molecules in their blood, and most importantly, their medical histories. Venter stressed that his aim is to enable predictive and preventative medicine for healthy aging, discovering early warning signs for susceptibility to chronic illnesses like cancer, Alzheimer's, and heart disease, as well as new interventions tailored to each individual's distinct profile. "We think this will have a huge impact on changing the cost of medicine," added Venter.

Table of Contents: March 2014

COVER
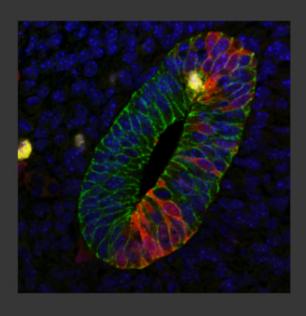
MAPK activity in pseudostratified renal epithelium, which exhibits different cell cycle phases in one layer of cells.

Image Credit: Anneliis Ihermann-Hella

Pseudostratified epithelium, characterized by cells in different cell cycle phases within one epithelial structure, exhibits mitotic nuclei (yellow) at the apical side, while S-phase nuclei are located on the basal surface and those in G1/2 occupy the middle epithelial zone. MAPK activity, as detected by phosphorylated ERK1/2 and depicted in red, is activated in some of the middle zone G1- and apical S-phase cells. As shown by Ihermann-Hella et al., MAPK activity is crucial for mediating the transition from G1- to S-phase and regulating epithelial cell adhesion. See Ihermann-Hella et al.

of developing kidney by genetically abrogating the pathway activity in mice lacking simultaneously dual-specificity protein kinases Mek1 and Mek2. Our data show that MAPK pathway is heterogeneously activated in the subset of G1- and S-phase epithelial cells, and its tissue-specific deletion results in severe renal hypodysplasia. Consequently to the deletion of Mek1/2, the activation of ERK1/2 in the epithelium is lost and normal branching pattern in mutant kidneys is substituted with elongation-only phenotype, in which the epithelium is largely unable to form novel branches and complex three-dimensional patterns, but able to grow without primary defects in mitosis. Cellular characterization of double mutant epithelium showed increased E-cadherin at the cell surfaces with its particular accumulation at baso-lateral locations. This indicates....

20.296 hits for MAPK pathway in Pubmed

COVER
Transcription factors control comb development in chickens.
Image Credit: Ben Dorshorst and colleagues
Issue Image

There are three comb types in chickens that are each inherited independently as single gene traits: Rose, Pea and Duplex comb. Here the Duplex V-Shaped phenotype is shown to be caused by ectopic expression of the transcription factor Eomesodermin (EOMES). Previous reports have shown Rose and Pea comb to be caused by ectopic expression of transcription factors MNR2 and SOX5, respectively. Remarkably, the causal mutations for all three comb types represent structural genomic variants (duplications and inversions) that disrupt normal expression of these transcription factors and result in vastly different developmental outcomes for the comb.
See Dorshorst et al. Plos Genetics 2015

Ectopic expression, expression of a gene in an abnormal place

To start with the basics:
Why we are strongly biased and can be easily fooled?

Are we fooled by bias?

The Art of Thinking Clearly

ROLF DOBELLI

Yes, but

we cannot always question every piece of the puzzle, we need to assume that most are ok.

Because we need to have an idea and a result

(c) 2010 Daniel J. Simons

Are we fooled by bias?

The Art of ~~Thinking~~ Clearly

ROLF DOBELLI

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Because we need to have an idea and a result

- Overestimate the chances of success
- Havard makes you smarter?
- Professional swimmers have perfect bodies
- Patterns of recognition:
  we map what we have ready in our mind
- The social bias "most popular": if fifty million people say/do
  something foolish, it is still foolish"
- **The confirmation bias**: everything we see, we map to the
  principles we know and avoid contradiction -
  counterarguments are dismisses as exceptions
- Groups stick together in **harmony**: parties, clubs, religious
  groups
- **Authority bias** (e.g. Steven Milgram)
- Contrast effect (was 100€, only 60 € now)
- Availability bias:
  we prefer what is there (to love the girl next to you)
- It gets worse before it gets better:
  belief in confirmation (doctors bias, consultant bias)
- Shaping consistent stories, the media make every story
  consistent (explain the Lehman Brothers): example: the
  king died and the queen died vs. the king died and the
  queen died of grief
- We are bad predictors - as everybody else - but, we
  remember the true predictions

It helps

It helps m...
of bias and
In science
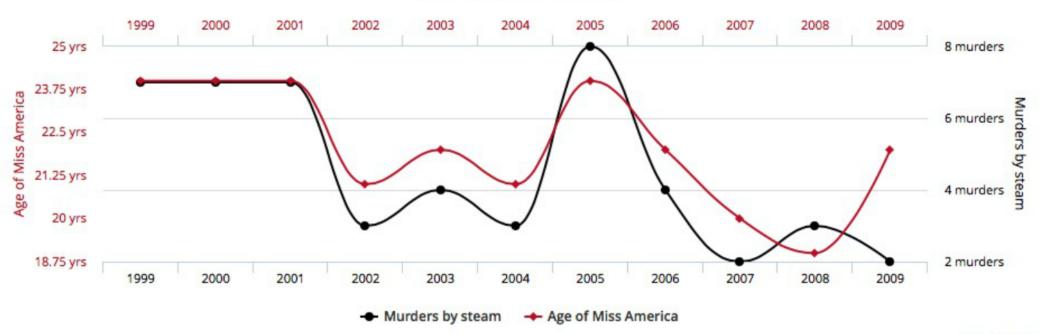
- The overconfidence effect (80% believe they are better drivers than average)
- Chauffeur knowledge / circle of confidence
- Illusion of control - much visible in irrational correlations
- False incentives (bonus system, number of publications)
- Outcome bias: the case of the most successful monkey
- The case of "unlikely events": why are unlikely events frequent?
- The problem of choice/decision leads to secondary options (e.g. "likes", the secret of selling)
- Team spirit creates common illusions of success (politics)
- Neglect probability (Lotto!, being afraid of non-bio food but taking the car everyday; smoking!)
- Rare things attract us - although we should know better
- Base rate neglection (what is your chance to become...)
- Anchor bias (you associate to unrelated anchors)
- The bias of inductive thinking (stock market)
- Loss aversion: we fear more losses than wins (less good to imagine than bad to fear)
- Underestimating non-linear growth
- Paying highest price in an auction (Phyrrus victory)
- Reduction of group performance to individuals
- The **correlation bias** (in the press!): in families with more books, kids are more successful; more kids from wealthy families have better education, because the education system is unfair (see also confounding factors)
- .... and more!

Age of Miss America
correlates with
Murders by steam, hot vapours and hot objects

Correlation: 87.01% (r=0.870127)

Legend: Murders by steam — Age of Miss America

Per capita cheese consumption
correlates with
Number of people who died by becoming tangled in their bedsheets

Correlation: 94.71% (r=0.947091)
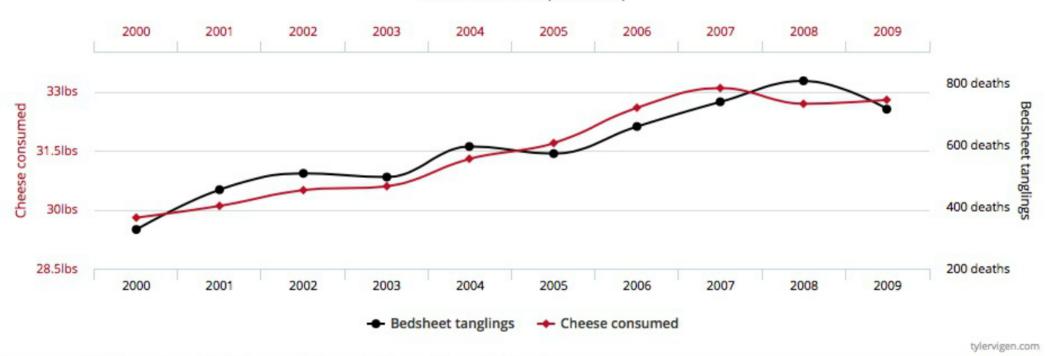
Data sources: U.S. Department of Agriculture and Centers for Disease Control & Prevention

tylervigen.com

Scientists fool themselves: "This is a great time for research on research," he says. "The massive growth of science allows for a massive number of results, and a massive number of errors and biases to study. So there's good reason to hope we can find better ways to deal with these problems.

_____

"Science is an ongoing race between our inventing ways to fool ourselves, and our inventing ways to avoid fooling ourselves." So researchers are trying a variety of creative ways to debias data analysis — strategies that involve collaborating with academic rivals, getting papers accepted before the study has even been started and working with strategically faked data.

Nuzzo, Nature 2015

It helps much to be aware
of bias and to avoid it !
In science & everyday life!

)?

f biology
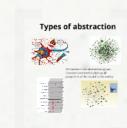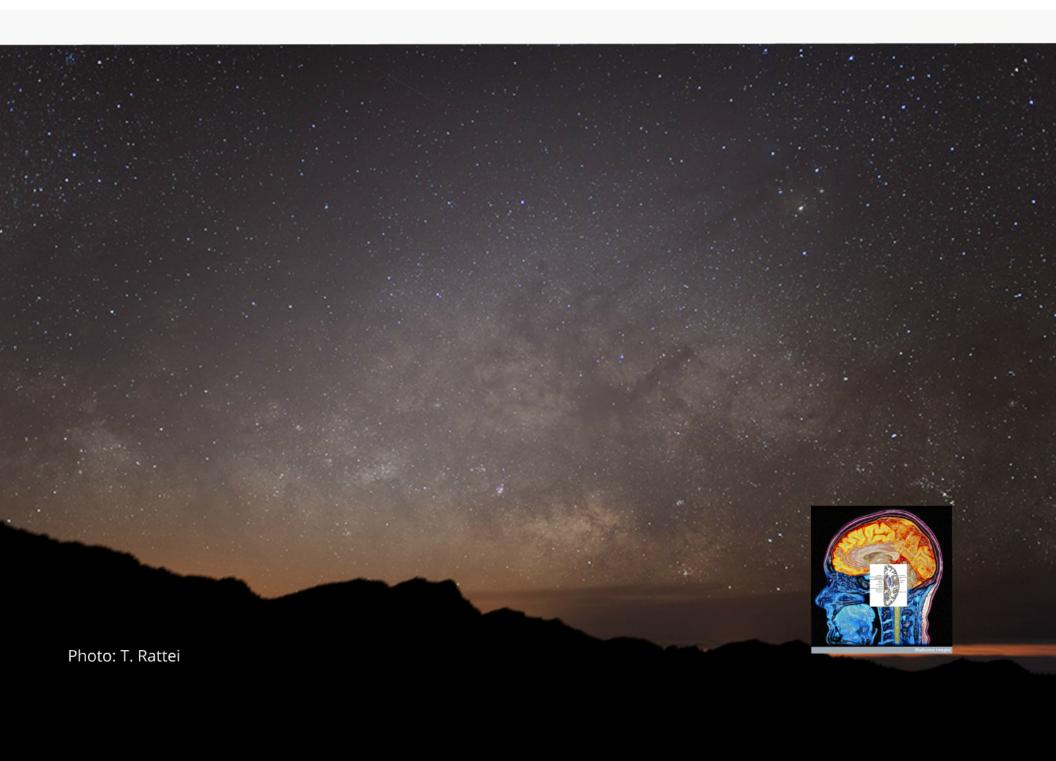
To explain what we (don't) see: cognition and conscience

Neuroplasticity, Cognition, and Conscience

Ageing

Learning
Environment
Communication

Social control

Training

Experience

Mechanical metaphores

Metaphores are everywhere. We uses them as symbols to transfer properties from evident, "easily understandable" to the "not so evident".

F. Kahn

From health to disease

Environment, nutrition & life-style

Genetics

Ageing

Types of abstraction

Photo: T. Rattei

Ventriculus I	Crus anterius
Nucleus caudatus (Caput)	Capsula externa
Capsula interna	
Genu capsulae internae	Claustrum
Putamen	Insula
Pallidum	
Crus posterius	
Thalamus	
Nucleus caudatus (Cauda)	
Hippocampus	
Ventriculus I	Radiatio optica

Neuroplasticity, Cognition, and Conscience

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Experience

We have a system I and a system II for thinking.

D. Kahnemann

We have a system I and a system II for thinking.

D. Kahnemann

The principle of iteration:

- As long as humans were reflecting nature, they believed that the sun will rise next morning.
- If the earth surrounds the sun spinning with constant frequency, there is a regular period of light and shadow (deduction on premises).
- Since the rule holds, for an observer on earth the sun will rise tomorrow (induction).
- The success of Galileo & Newton (Principia) to reduce observations to rules has driven modern science since.
- A law is a compressed description of the regularities of a phenomenon (M. Gell-Mann, cited by S. Kauffman).

The Principle of Induction:

due to the uniformity of principles we expect that a regular event (or observation) reoccurs under (some) given conditions.

We conclude from the properties of the observed objects that other objects of the same class must have the same properties.
However, often we do not have explanations for exceptions and cannot deduce rules or laws by induction.

"The philosophical definition of inductive reasoning is much more nuanced than simple progression from particular / individual instances to wider generalizations. Rather, the premises of an inductive logical argument indicate some degree of support (inductive probability) for the conclusion but do not entail it; that is, they suggest truth but do not ensure it." (Wikipedia "Inductive reasoning")

What about deduction?
Deductive reasoning is a logical
step to draw conclusions.
Be aware: it is tricky!
What you observe may depend
on condition and perspective.

An example of a deductive argument:
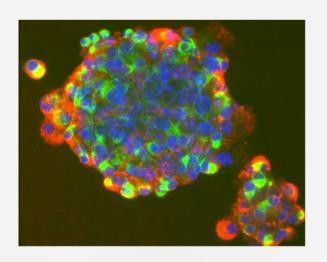
An example of a deductive argument:

All men are mortal.
Socrates is a man.
Therefore, Socrates is mortal.

What determines our fate?
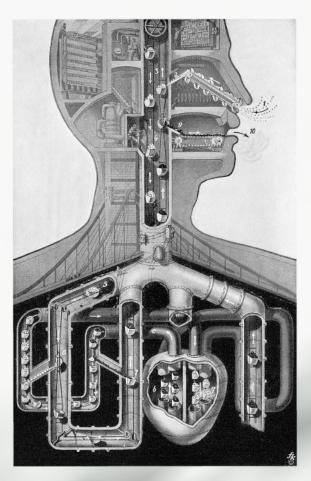
The modern view to the invisible world is driven by logical empiricism using symbolic logic.
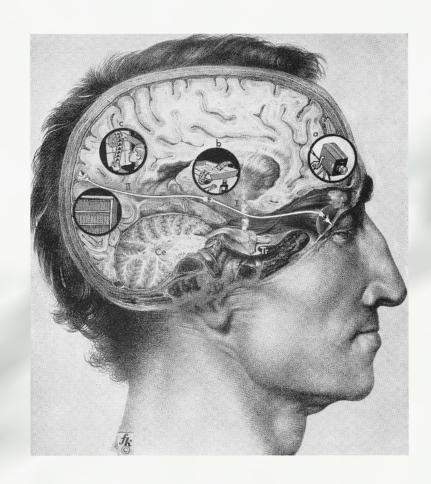
"Our computational view builds on algorithms. Using routines and modules reflects the hierarchical nature of biology - but tries to construct a well defined structure to the problem space"
(from Wimsatt, Re-engineering Philosophy).

Biology does not separate soft- and hardware, it is hard to be caught in well defined structures. The biology of mind is the most prominent example!

Mechanical metaphores
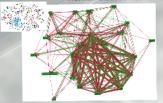
F. Kahn

Metaphores are everywhere. We uses them as symbols to transfer properties from evident, "easily understandable" to the "not so evident".

How we can understand the complex world (of PM)?
About science, medicine, cats, and the language of biology

Human disease networks

Degree of complexity?

Science

- *Understanding*
- *Prediction*
- *Control*

Biology

- *Molecular and cellular principles*
- *Understanding interactions and processing*
- *Intervention (knock-out)*
- *Therapy*

Networks/Systems Medicine

A tradition of narrative description and speculation

"The language used by biologists for verbal communications is not better and is not unlike that used by stock market analysts. Both are vague (e.g., a balance between pro- and anti-apoptotic bcl-2 proteins appears to control the cell viability, and seems to correlate in long-term with the ability to form tumors,) and avoid clear predictions."

Y. Lazebnik

The hardest thing is to find a black cat in a dark room - especially if there is no cat.

But we can make one!

Human disease networks

Degree of complexity?

activation
inhibition
regulation

Networks are presented static, but:
· the action is the function of the network
· edges are dynamic in space and time
· action is conditional
· nodes feed back (e.g. epigenetics)
Action Network Theory: B. Latour

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Complex Systems

Scientists and others tend to be quite found of neat, clear-cut patterns. Nature is not.

Nature is inherently messy... Natural selection is a long, haphazard process.

The fundamental drivers of this process have been random – gene mutations and genetic drift, weather, and meteoric and geological events.

Why, then, should the outcome correspond to our logical ideas about how to build a living system that succeeds? (D. Noble)

There are no simple answers in complex systems
S. Mitchell

Possibilities and realization

Biological Possibilities
Chemical Possibilities
Physical Possibilities
Logical Possibilities

Mysteries, though, are a lot murkier: sometimes the information we've been given is inadequate, and sometimes we aren't very smart about making sense of what we've been given, and sometimes the question itself cannot be answered. Puzzles come to satisfying conclusions. Mysteries often don't.

Mysteries require judgments and the assessment of uncertainty, and the hard part is not that we have too little information but that we have too much.

(don't) see: cognition and conscience

Mechanical metaphores

Science P...
Causalit...
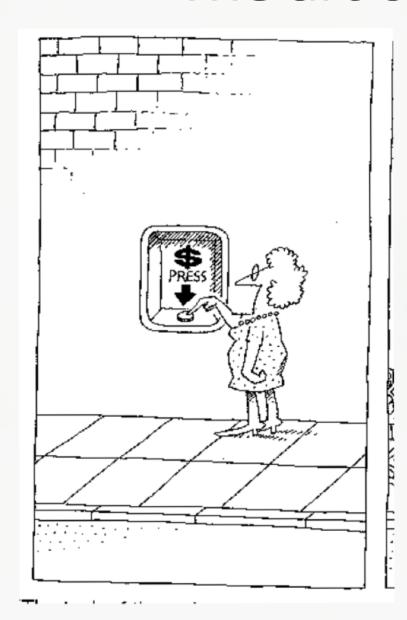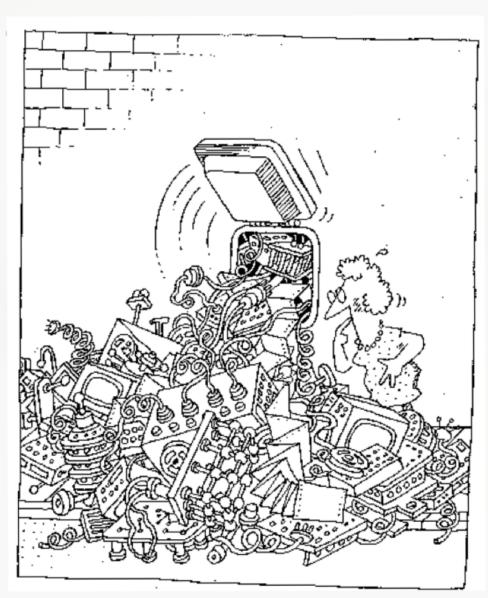
The art of reduction

Cartoon G. Brooch

LIFE IS COMPLICATED

The more biologists look, the more complexity there seems to be.
**Erika Check Hayden** asks if there's a way to make life simpler.

This gulf between simplifiers and dividers isn't just a matter of curiosity for armchair philosophers. It plays out every day as study sections and peer reviewers decide which approach to science is worth funding and publishing.

"It's people who complicate things. Some people are simplifiers and others are dividers."
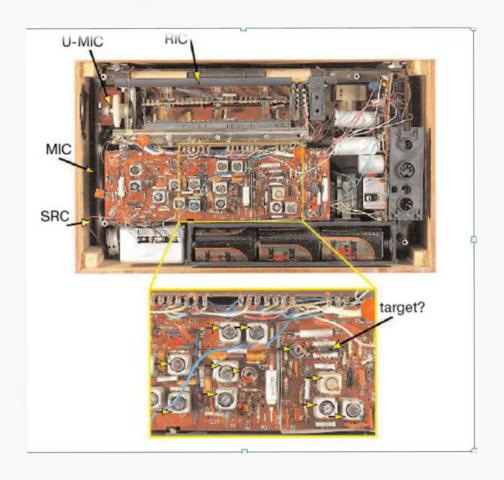
E.C. Hayden, The Genome at 10, Nature 2010
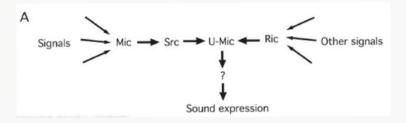
Can a biologist fix a radio?
Y. Lazebnik

A

Signals ⟶ Mic ⟶ Src ⟶ U-Mic ⟵ Ric ⟵ Other signals

?

Sound expression

Even if a diagram makes overall sense (Fig. 3a), it is usually useless for a quantitative analysis, which limits its predictive or investigative value to a very narrow range.
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U-Mic → ? → Sound expression

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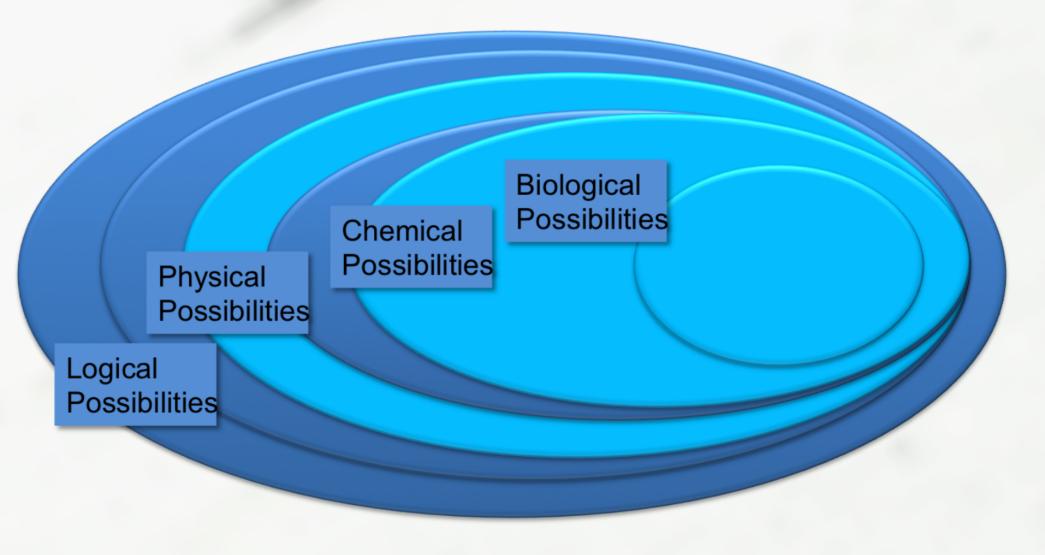
Adopted from S. Mitchell

The more the better? About puzzles and mysteries

Improved study designs — which take into account technological advances in revealing the transcriptome, its history and states, population of origin and diverse mitochondrial pool are providing insights into the architecture of disease and the landscape of gene regulation in humans.

Cited from a recent Nature publication.

Multidimensional data space – unlimited number of possible observations.
The information available is always smaller than the data space of the system.

If things go wrong with a puzzle, identifying the culprit is easy: it's the person who withheld information.
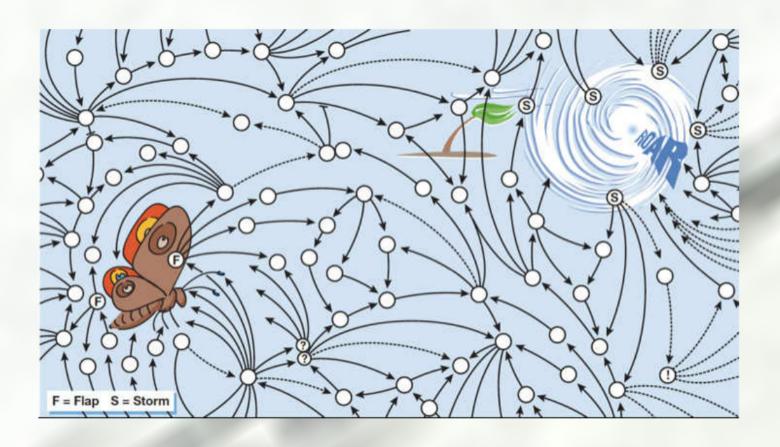

M. Gladwell, New Yorker 2007

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Wikipedia - Complexity
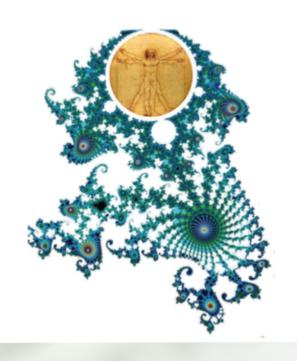
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SIMPLICITY
the art of complexity

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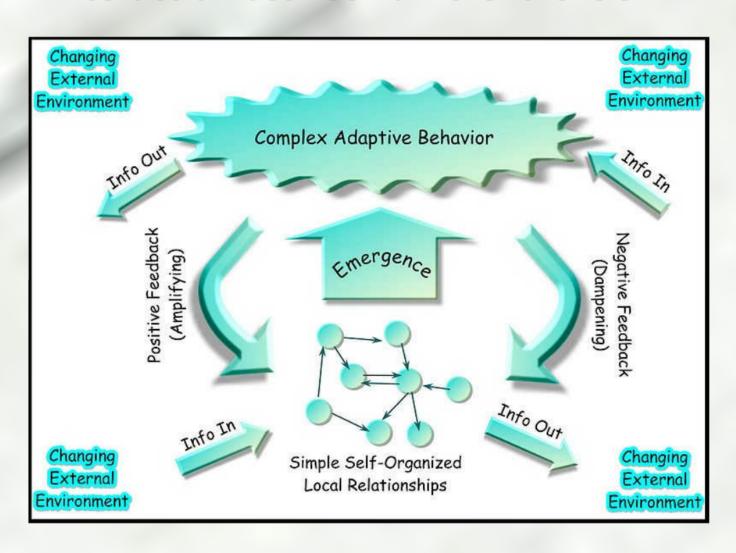
Association is the fast way to integrate and compress complex information. We are very good to catch so many bits and translate it to a simple decision. And we are very good the other way round: to justify an intuitive decision with a thousand words of arguments.

The problem (of determinism), simply stated, is as follows: If nothing is determined, how can lawful chains of cause and effect occur, but if everything is determined, what then of free will and creativity? (S. Kauffman)

Biologica
as much

Biological systems are active, not passive: as much as in social sciences, perfect prediction appears to be impossible as much as simple reduction

Interaction between different levels

How to deal with complexity?

- Split the system into subsystems
- "Reductionism"
- Is there a way back to reassemble the system?
- Do we need to understand the system in every possible detail?

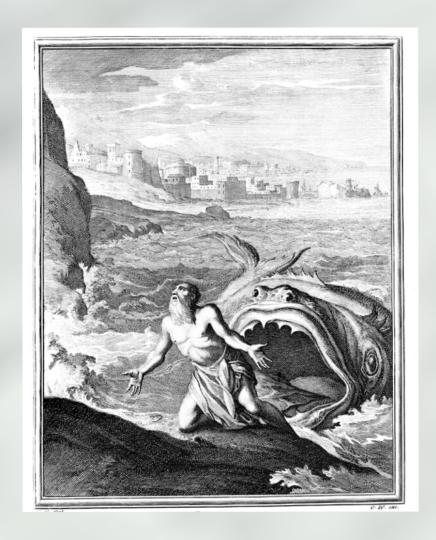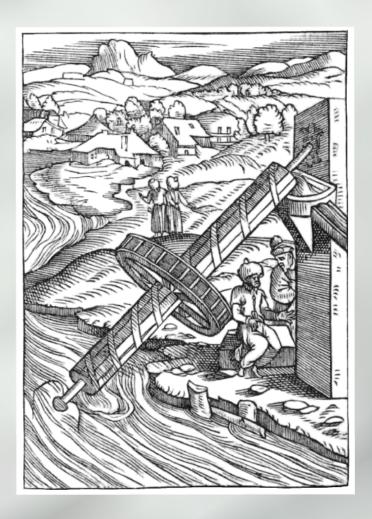# The history and theory of explanation (less than a nutshell)

J. Pearl, Lecture Art and Science of Cause and Effect

Explanation by divine action

Made by humans, not devine!

FIGURE 3

Frontispice du De Humanis corpore fabrica *de Vésale,* © *CESR, Tours.*
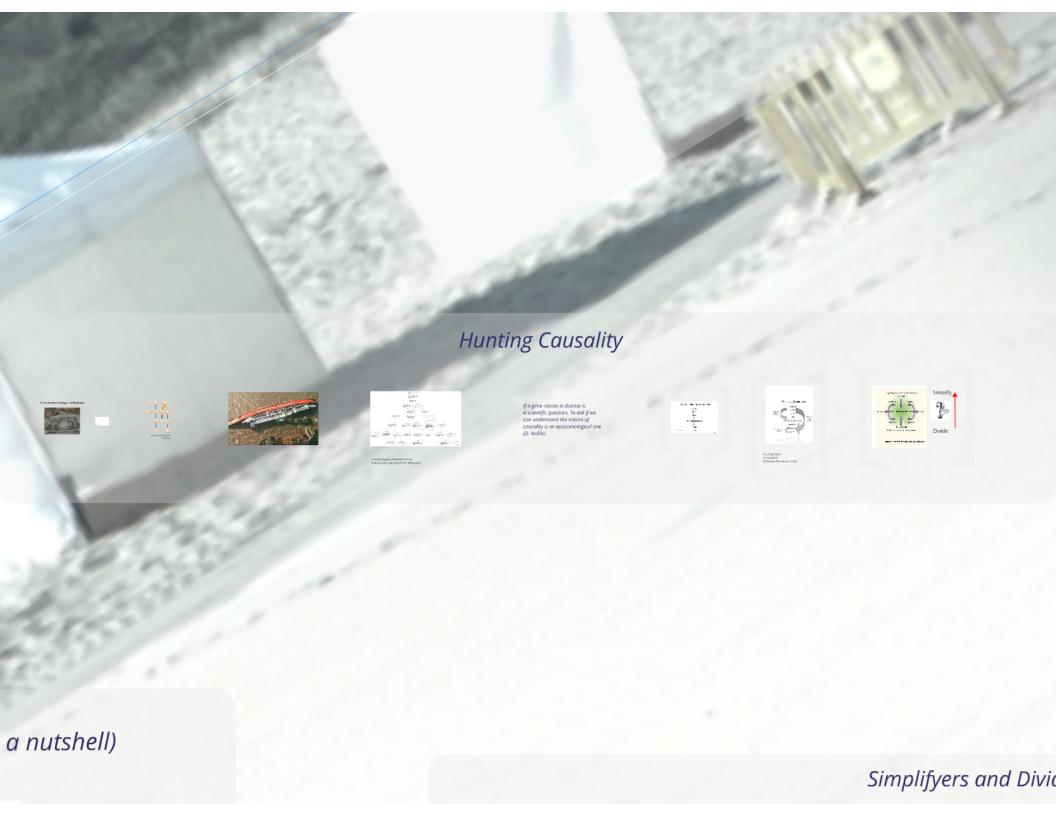
Observation
and Knowledge

How do we reason in science?
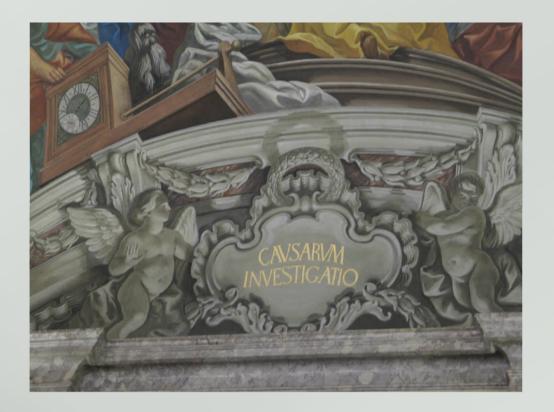
Arguments in science:

- are often used to confirm our intuitive judgements
- are based on logic, but logic is sometimes replaced by authority or metaphors
- are accepted because we want to accept them - or we reject them intuitively
- often we have a higher order principle that guides or intuition

Some axioms in science:

- The rules of the game don't change.

- The logic is fixed (Aristotle)

- Natural processes are repetitive: if the conditions causing an effect are the same, the outcome will be the same

- A statement based on a true proposition is true until it is shown to be false (paradigm of contradiction free science)

Hunting Causality

If a gene causes a disease is a scientific question. To ask if we can understand the nature of causality is an epistomological one (D. Noble).

Simplify

Divide

a nutshell)

Simplifyers and Divid

A very known challenge, a difficult one

General

- Cosmological argument
- Domino effect
- Effectuation
- Sequence of events

Mathematics:

- Causal filter
- Causal system
- Causality conditions
- Chaos theory

Physics:

- Anthropic principle
- Arrow of time
- Butterfly effect
- Chain reaction
- Feedback
- Grandfather paradox
- Quantum Zeno effect
- Retrocausality
- Schrödinger's cat
- Wheeler–Feynman absorber theory

Philosophy:

- Aetiology
- Arche (ἀρχή)
- Chance (philosophy)
- Chicken or the egg
- Condition of possibility
- Determinism
- Mill's Methods
- Newcomb's paradox
- Non sequitur (logic)
- Ontological paradox
- Post hoc ergo propter hoc
- Predestination paradox
- Proximate and ultimate causation
- Subject–object problem
- Supervenience

Philosophy of mind:

- Synchronicity

Statistics:

- Causal loop diagram
- Causal Markov condition
- Correlation does not imply causation
- Experimental design
- Granger causality
- Linear regression
- Randomness
- Rubin causal model
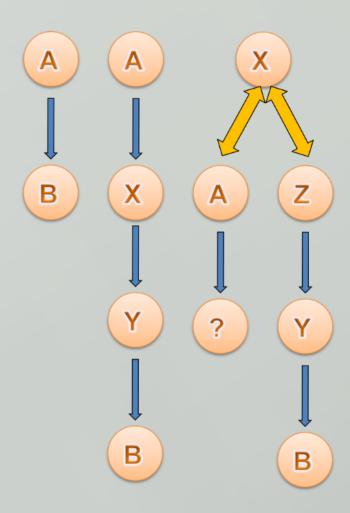- Validity (statistics)

Psychology & Medicine:

- Adverse effect
- Clinical trial
- Force dynamics
- Iatrogenesis
- Nocebo
- Placebo
- Scientific control
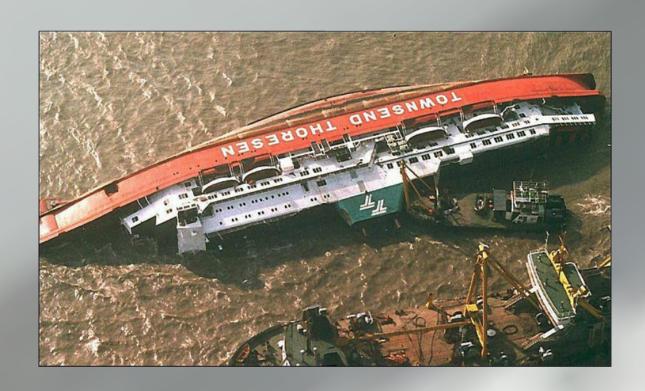- Suggestibility
- Suggestion

Pathology & Epidemiology

- Causal inference
- Epidemiology
- Etiology
- Molecular pathology
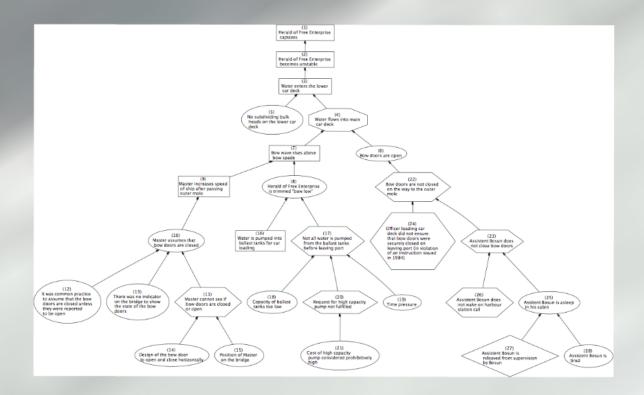- Molecular pathological epidemiology
- Pathogenesis
- Pathology

Sociology & Economics:

- Instrumental variable
- Root cause analysis
- Self-fulfilling prophecy
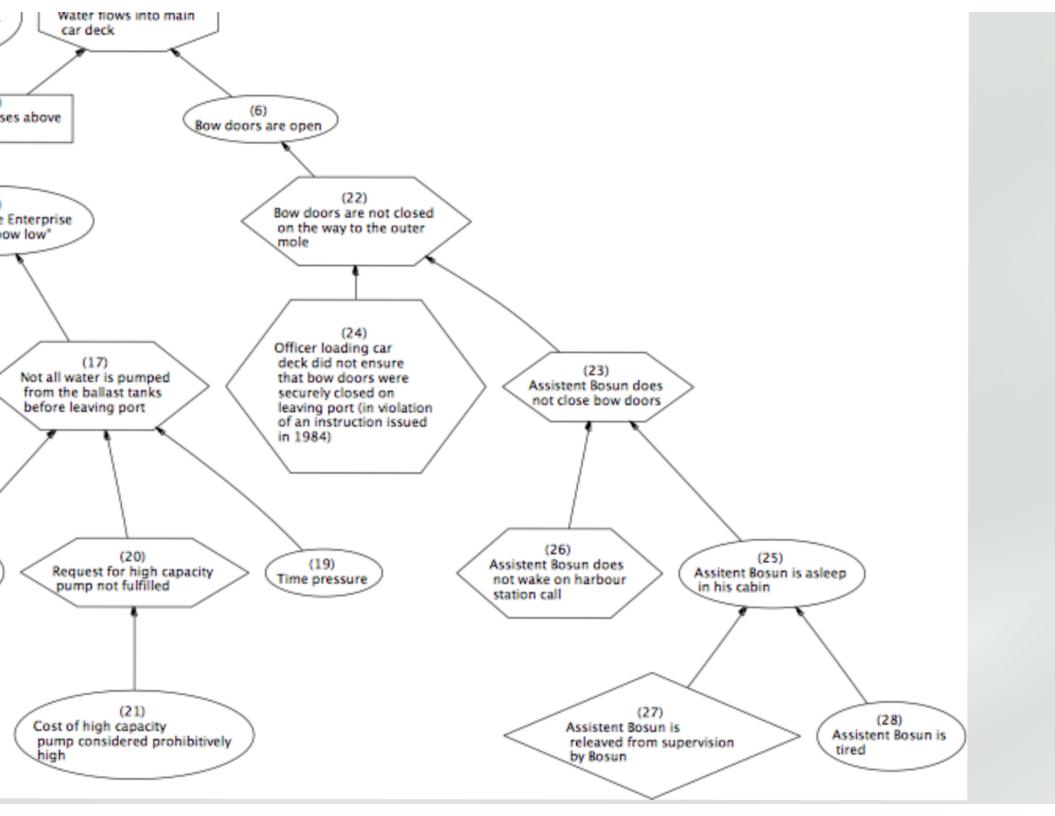- Unintended consequence
- Virtuous circle and vicious circle

Given A why then B?

Always?
Sometimes?
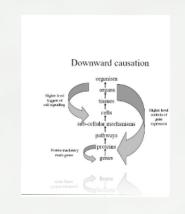Conditional?

It ain't necessarily so.
(Lewontif)

Causal diagram of Harald of Free
EnterpriseCatastrophy (from Wikipedia)

Water flows into main
car deck

ses above

(6)
Bow doors are open

Enterprise
ow low"

(22)
Bow doors are not closed
on the way to the outer
mole

(17)
Not all water is pumped
from the ballast tanks
before leaving port

(24)
Officer loading car
deck did not ensure
that bow doors were
securely closed on
leaving port (in violation
of an instruction issued
in 1984)

(23)
Assistent Bosun does
not close bow doors

(20)
Request for high capacity
pump not fulfilled

(19)
Time pressure

(26)
Assistent Bosun does
not wake on harbour
station call

(25)
Assitent Bosun is asleep
in his cabin

(21)
Cost of high capacity
pump considered prohibitively
high

(27)
Assistent Bosun is
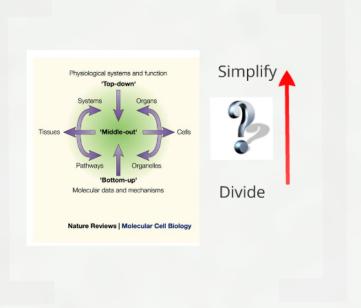releaved from supervision
by Bosun

(28)
Assistent Bosun is
tired

If a gene causes a disease is a scientific question. To ask if we can understand the nature of causality is an epistomological one (D. Noble).
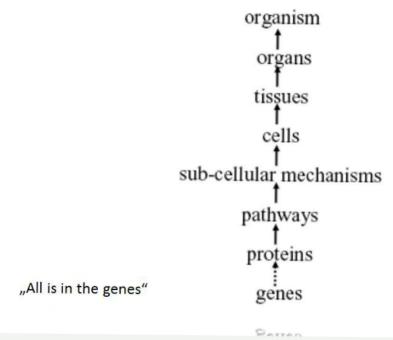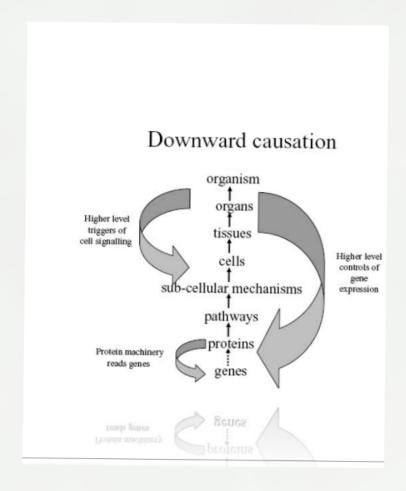
The reductionist causal chain

organism
↑
organs
↑
tissues
↑
cells
↑
sub-cellular mechanisms
↑
pathways
↑
proteins
↑
genes

Downward causation

organism
↑
organs
↑
tissues
↑
cells
↑
sub-cellular mechanisms
↑
pathways
↑
proteins
↑
genes

Higher level trigger of cell signalling

Higher level controls of *gene* expression

Protein machinery reads genes

No single layer
of causation
(D. Noble, The music of life)

Physiological systems and function
'Top-down'

Systems   Organs

Tissues   **'Middle-out'**   Cells

Pathways   Organelles

'Bottom-up'
Molecular data and mechanisms

Nature Reviews | Molecular Cell Biology

Simplify

Divide

The reductionist causal chain

organism

↑

organs

↑

tissues

↑

cells

↑

sub-cellular mechanisms

↑

pathways

↑

proteins

⋮

„All is in the genes"   genes

Downward causation

No single layer
of causation
(D. Noble, The music of life)

Physiological systems and function

'Top-down'

Systems   Organs

Tissues   'Middle-out'   Cells

Pathways   Organelles

'Bottom-up'

Molecular data and mechanisms

Nature Reviews | Molecular Cell Biology

Simplify

?

Divide

Simplifyers and Dividers

Cause →

Strong	Puzzle	simplify
Weak	Mystery	unpredictable, intuitive

Strong
Causality
Weak

What if, rules and laws

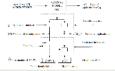Chaotic, stochastic

Many types of causation

N. Cartwrigth

…, and we should say that the phenomenon has been predicted, that it is goverened by laws. But it is not always so; it may happen that small differences in the initial conditios produce very great oes in the final phenomenon…Prediction becomes impossible…

Poincaré 1887

Correlation is not equivalent to causation!

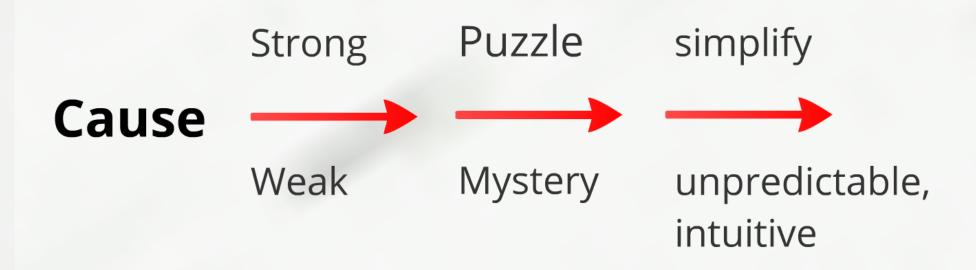It ain´t necessarily so!
(Lewontli)

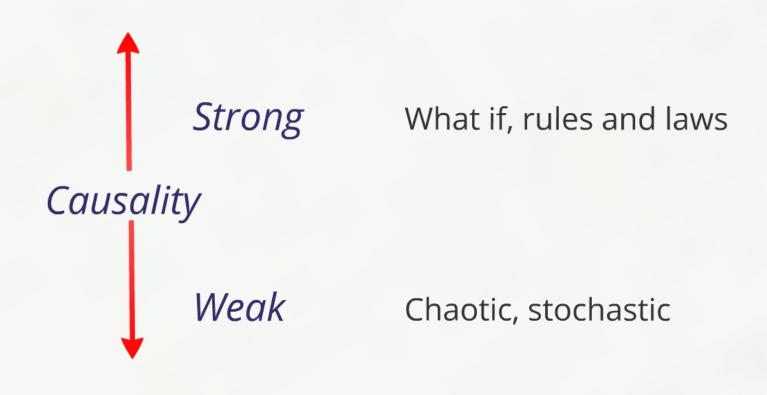Causality should be a hypothesis but not a pick from the causality space!

The Causal Foundations of Structural Equation Modeling; Judea Pearl, 2011

…lecules, as a house is with …es is no more a cell …s is a house.

Cause $\longrightarrow$ Strong / Weak $\longrightarrow$ Puzzle / Mystery $\longrightarrow$ simplify / unpredictable, intuitive

.., and we should say that the phenomenon has been predicted, that it is goverened by laws. But it is not always so; it may happen that small differences in the initial conditios produce very great oes in the final phenomenon...Prediction becomes impossible...
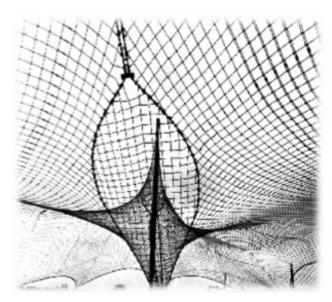
Poincaré 1887

Correlation is not equivalent to causation!

It ain´t necessarily so!
(Lewontif)

From building blocks to systems

➢ System properties cannot be explained by the properties of its components alone.

➢ Although systems are composed of matters, the essence of system lies in dynamics and it cannot be described merely by enumerating components of the system. ....

➢ The information encoded in the genes is highly relevant but not determining their biological function

A cell is built up of molecules, as a house is with stones.
But a soup of molecules is no more a cell
Than a heap of stones is a house.

(In Wolkenhauer et al., FEBS Lett., 2005)

Re-Engineering Philosophy for Limited Beings

piecewise approximations to reality

William C. Wimsatt