

Artificial Intelligence++

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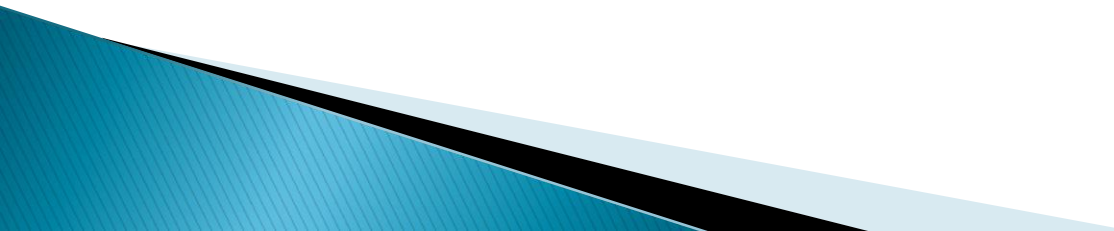
Computational Biomedicine (Combine) workgroup
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What is AI?

AI approaches can be grouped as follows:

Thinking humanly	Thinking rationally
Acting humanly	Acting rationally

These are individualist approaches, others:

- ▶ „Strong” AI: conscious, self-aware AI
 - ▶ Singularity: self-accelerating AI
 - ▶ Collective intelligence: multiagent AI approaches
 - ▶ Automated Science: beyond a singular cognition
 - ▶ Scientific paradigms in AI: towards data-driven AI
- 

What is AI? Strong AI

▶ About computation, cognition and art

- Interview with Douglas R. Hofstadter
 - <http://www.americanscientist.org/bookshelf/pub/douglas-r-hofstadter>
- D.R.Hofstadter: Gödel, Escher, Bach, 1979

▶ About computation and cognition

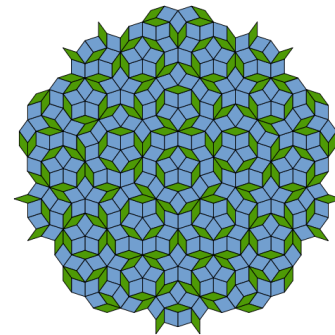
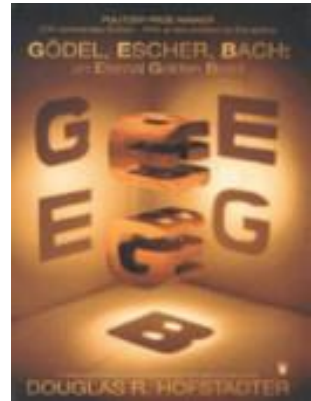
- R.Penrose: Emperor's new mind

▶ About cognition

- M.Boden: Artificial Intelligence and Natural Man, 1977
- M.B.: Computer Models of Mind, 1988
- M.B.: Mind As Machine: a History of Cognitive Science, 2006

▶ About consciousness

- K.R. Popper: The Self and Its Brain, 1977
- D.C. Dennett: Consciousness Explained, 1991
- http://www.ted.com/talks/dan_dennett_on_our_consciousness?language=en



What is AI? Singularity

- ▶ About singularity
 - R. Kurzweil: The singularity is near (when humans transcend biology), 2005
- ▶ „Optimal scientist”:
 - J. Schmidhuber: „his main scientific ambition has been to build an optimal scientist through self-improving AI, then retire.” „ build a scientist better than himself (his colleagues claim that should be easy) who will then do the remaining work” <http://people.idsia.ch/~juergen/>
- ▶ Self-improving AI
 - M. Hutter: AIXI
- ▶ Neuroprothesis
 - W.Gibson: Neuromancer, 1984
 - Artificial retina, Cochlear implants, Deep brain stimulation
- ▶ Simulating neurons
 - IBM's TrueNorth: neuromorph chip with a 10^6 neuron and 10^8 synapses
 - <http://www.research.ibm.com/articles/brain-chip.shtml>
- ▶ Connecting brains
 - Brainets: Building an organic computing device with multiple interconnected brains
- ▶ Synthetic biology
 - International Genetically Engineered Machine (iGEM)
 - http://igem.org/Main_Page

What is AI? Collective intelligence

- ▶ Game theory
 - Sequential decisions
 - Optimal policy
- ▶ Dashboard architecture
- ▶ „Democratic” voting schemes
- ▶ Protocols for agent communities
- ▶ Multiplayer games

What is AI? Automated science

- ▶ Classical flow/loop of science
 - Hypothesis/theory → design → experiment → data → ..
 - K.R.Popper: The Logic of Scientific Discovery, 1934
 - K.R.P: Objective Knowledge, 1972
 - T.S.Kuhn: The Structure of Scientific Revolutions, 1962
- ▶ Evolution/types of **scientific paradigms**.
 - Experimental
 - Theoretical
 - Computational
 - Data-driven
 - (AI: Brooks: Intelligence without representation)

Decision theory probability theory+utility theory

► Decision situation:

- Actions
- Outcomes
- Probabilities of outcomes
- Utilities/losses of outcomes
- Maximum Expected Utility Principle (MEU)
- Best action is the one with maximum expected utility

$$a_i$$

$$o_j$$

$$p(o_j | a_i)$$

$$U(o_j | a_i)$$

$$EU(a_i) = \sum_j U(o_j | a_i) p(o_j | a_i)$$

$$a^* = \arg \max_i EU(a_i)$$

Actions a_i

Outcomes

Probabilities

Utilities, costs

Expected utilities

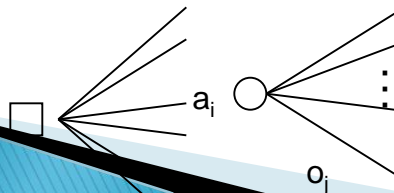
$$P(o_j | a_i)$$

\vdots

$$U(o_j), C(a_i)$$

\vdots

$$EU(a_i) = \sum P(o_j | a_i) U(o_j)$$



Milestones and phases in AI

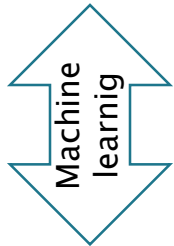


Computational complexity

Knowledge representation



Thresholds of knowledge



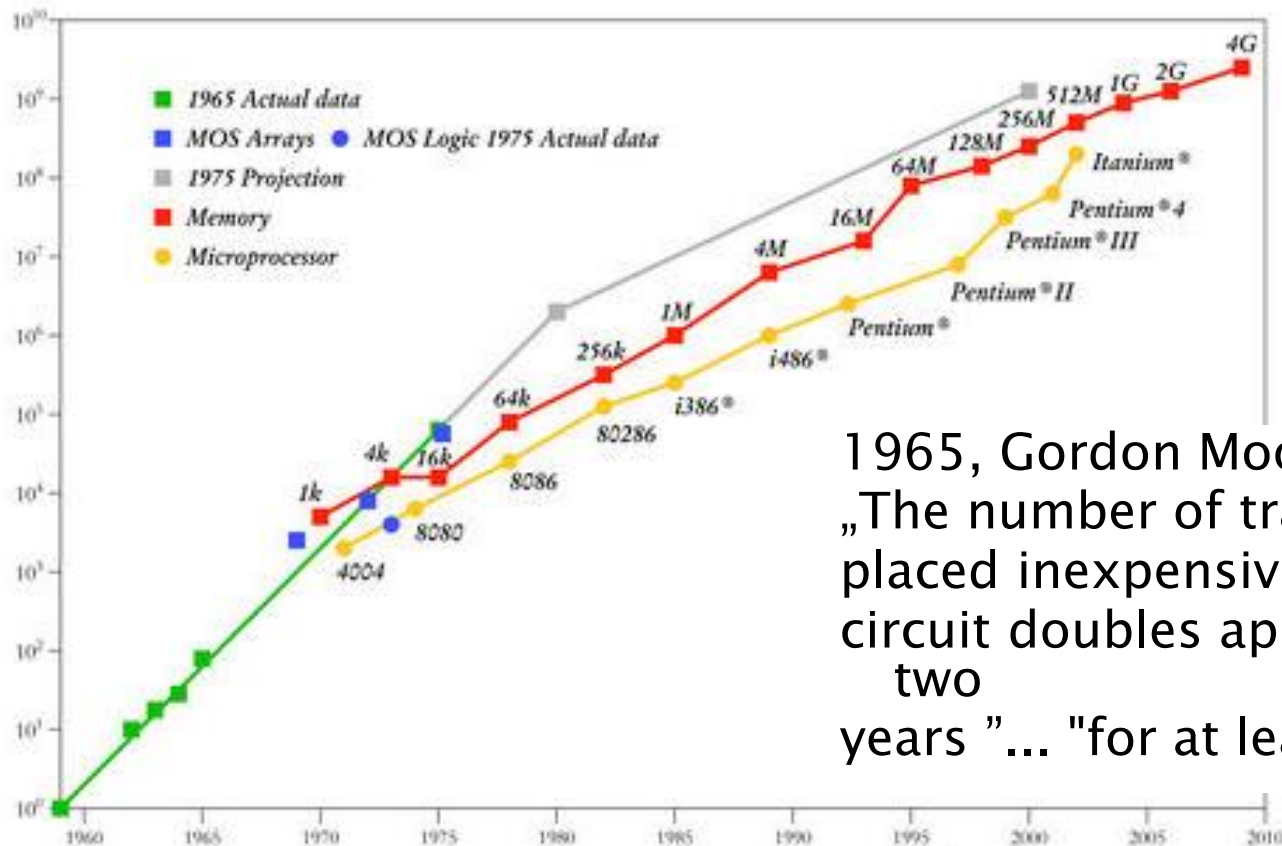
Statistical complexity

- ▶ 1943 McCulloch & Pitts: Boolean circuit model of brain
- ▶ 1950 Turing's "Computing Machinery and Intelligence"
- ▶ **1956** Dartmouth meeting: the term "Artificial Intelligence"
- ▶ 1950s Early AI programs, including Samuel's checkers program, Newell & Simon's Logic Theorist, Gelernter's Geometry Engine
- ▶ 1965 Robinson's complete algorithm for logical reasoning
- ▶ 1966—73 AI discovers computational complexity
Neural network research almost disappears
- ▶ 1969—79 Early development of knowledge-based systems
- ▶ 1986-- Neural networks return to popularity
- ▶ 1988-- Probabilistic expert systems
- ▶ 1995-- Emergence of machine learning

Today: heterogeneous AI, data-intensive science, data and knowledge fusion

Moore's Law (in computation)

Transistors
Per Die



Integration and parallelization won't bring us further. End of Moore's law?

1965, Gordon Moore, founder of Intel:
„The number of transistors that can be placed inexpensively on an integrated circuit doubles approximately every two years “... “for at least ten years”

SCIENCEphotOLIBRARY

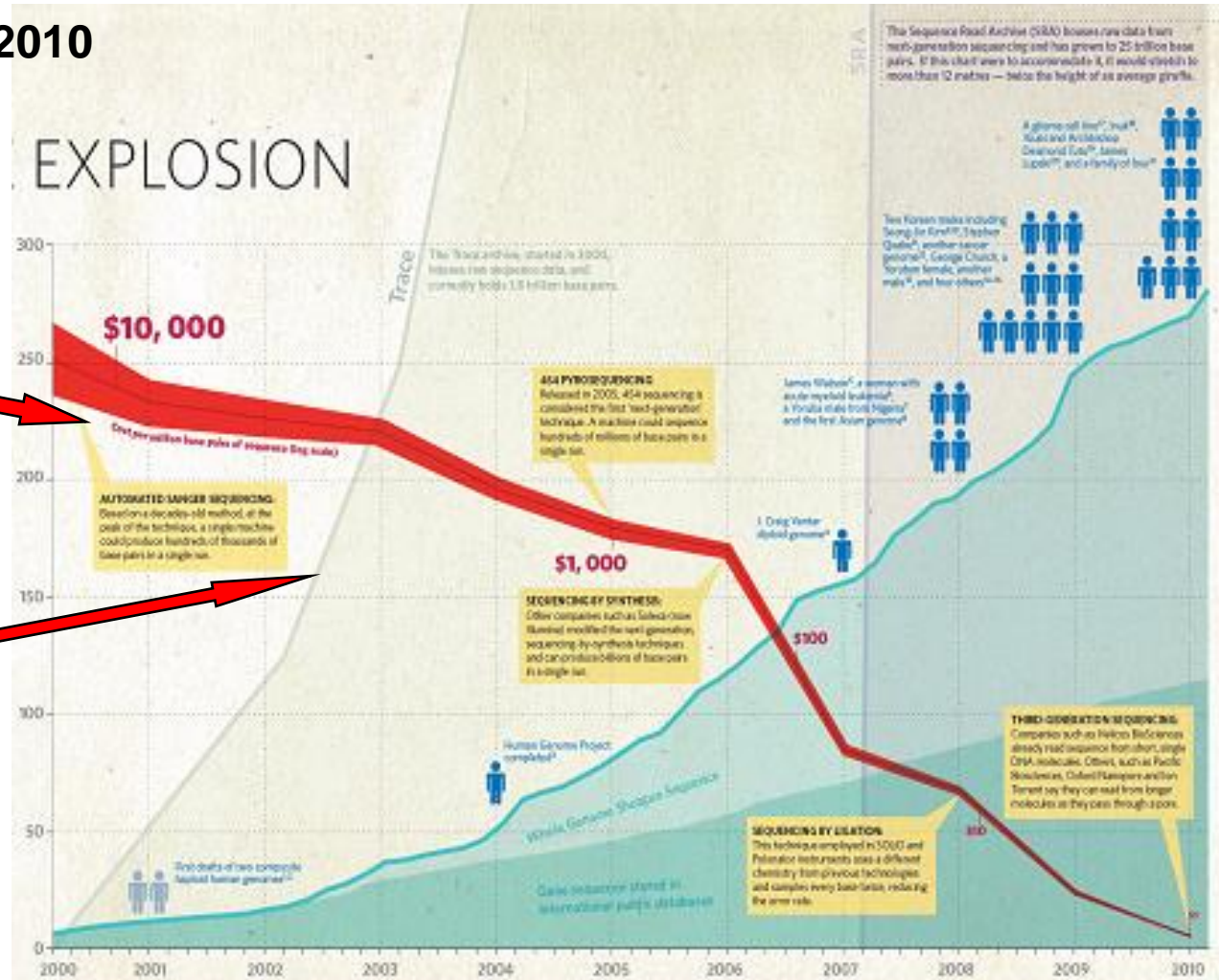
Carlson's Law for Biological Data

NATURE, Vol 464, April 2010

Sequencing costs per mill. base

Publicly available genetic data

- x10 every 2-3 years
- Data volumes and complexity that IT has never faced before...



Quantified self

Wearable electronics

With chips shrinking and sensors becoming cheaper, personal computing is moving from that smartphone in your pocket to your arm, your wrist, right out to your fingertips.



Graphic: Chuck Todd, Bay Area News Group

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The well-connected man

Wearable gadgets available now, or coming soon

Product: Google Glass

Price: \$1,500
Available by late 2013/early 2014

Link to the Internet through a wearable display screen
Overlays data into your field of vision

Camera-enabled for photos and video, controlled by voice and touch

Nike Fuelband

Price: \$149
For sale

Bracelet to track motion

Syns with smartphone to allow goal-setting and input for calorie intake to compare against activity

Fitbit One

\$99.95
For sale

Belt clip that tracks motion and sleep

Can record sleep quality, and number of times the wearer wakes
Wirelessly uploads data to a website to track progress and goals

Whistle

\$99.95
Available by September

Device to track dog's activity

Attaches to collar and records when the dog is at rest, walking, playing and sleeping

Jawbone Era

\$129.99
For sale

Wireless headset to connect with a phone

Allows wearer to answer calls by tapping the earpiece

Voice-activated dialing

Has motion detectors that senses when it is being worn and therefore responds to commands

Jawbone UP

\$129.99
For sale

Bracelet that tracks motion and sleep

Can record sleep quality, and number of times the wearer wakes
Movement tracker can record distance travelled and the amount of time active

Pebble

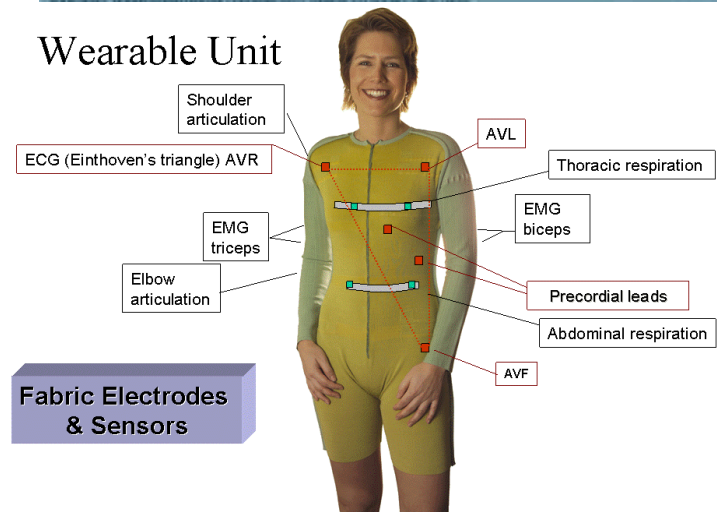
\$150
For sale

A watch that connects with a smartphone

Displays notifications for calls, emails and messages

Sources: Google/Jawbone/Kickstarter/Pebble/Whistle/Fitbit/Nike

Wearable Unit

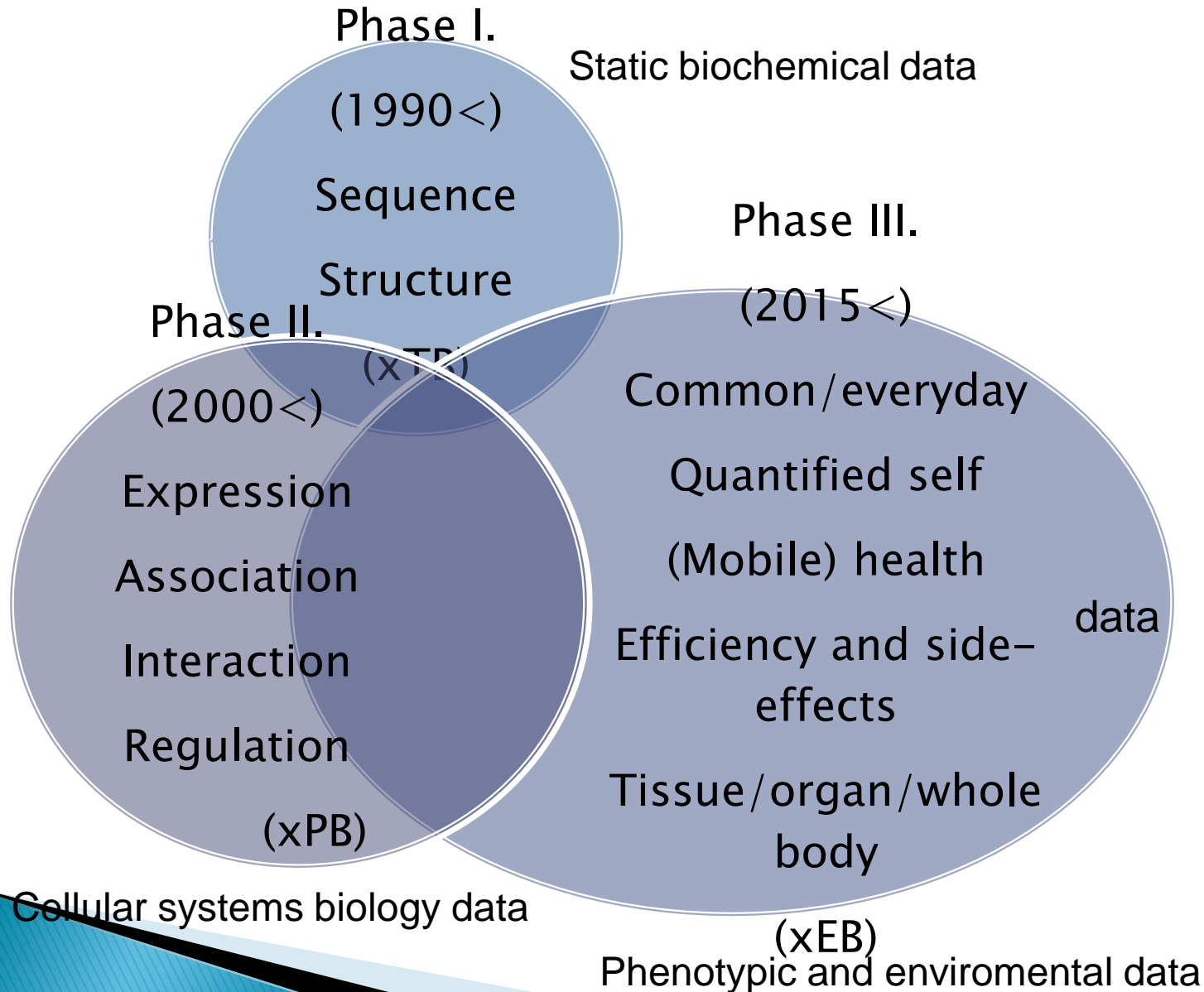


Big health data streams

New "Omics" Data Streams	Traditional Data Streams	Quantified Self Data Streams
Genome -SNP mutations ✓ -Structural variation -Epigenetics	Personal and Family Health History ✓	Self-reported data: health, exercise, food, mood journals, etc. ✓
Microbiome ✓	Prescription History ✓	Mobile Application Data ✓
Transcriptome	Lab Tests: History and Current ✓	Quantified Self Device Data ✓
Metabolome	Demographic Data ✓	Biosensor Data Objective Metrics
Proteome	Standardized Instrument Response ✓	
Diseasome ✓		
Environmentome ✓		
Legend: Consumer-available ✓		

*M.Swan: THE QUANTIFIED SELF: Fundamental Disruption in
Big Data Science and Biological Discovery, Big data, Vol
1., No. 2., 2013*

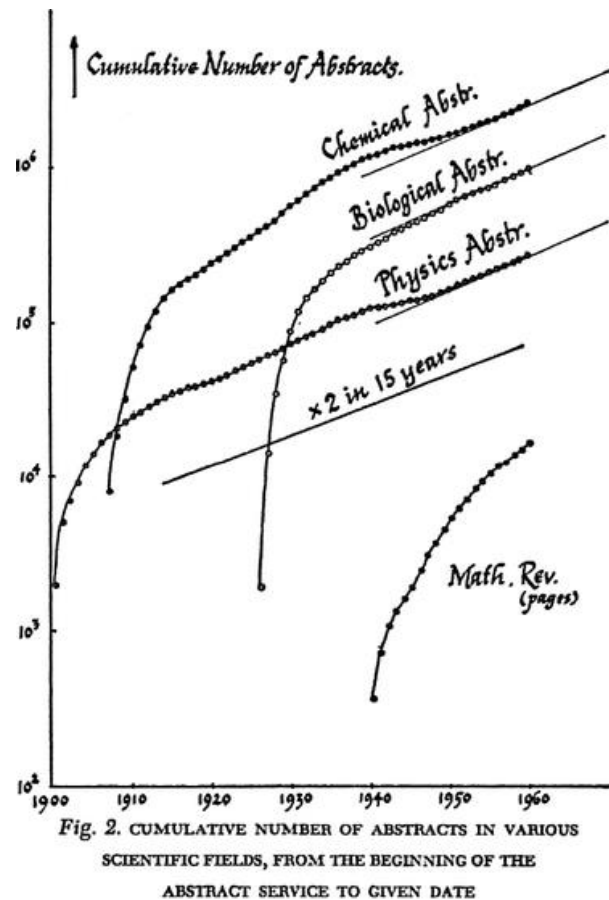
(Big) Data floods in biomedicine



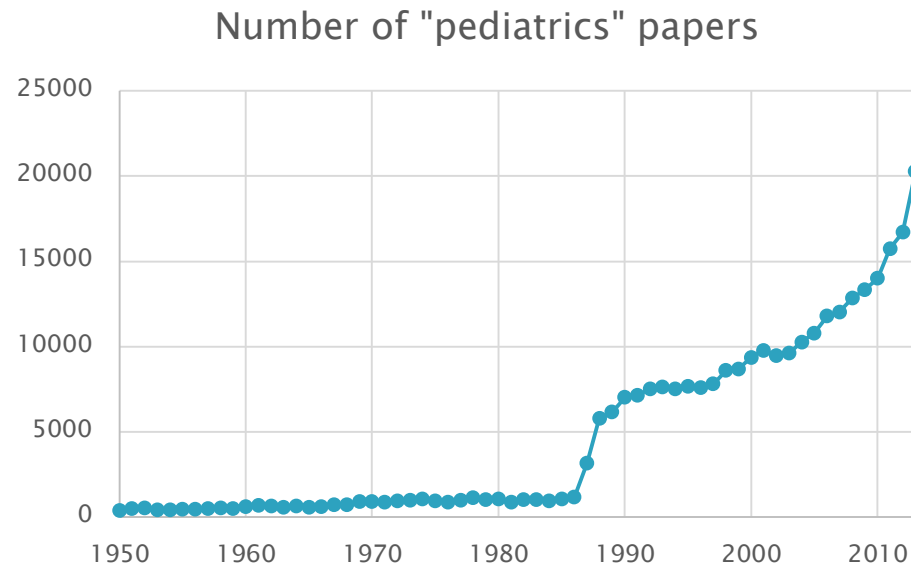
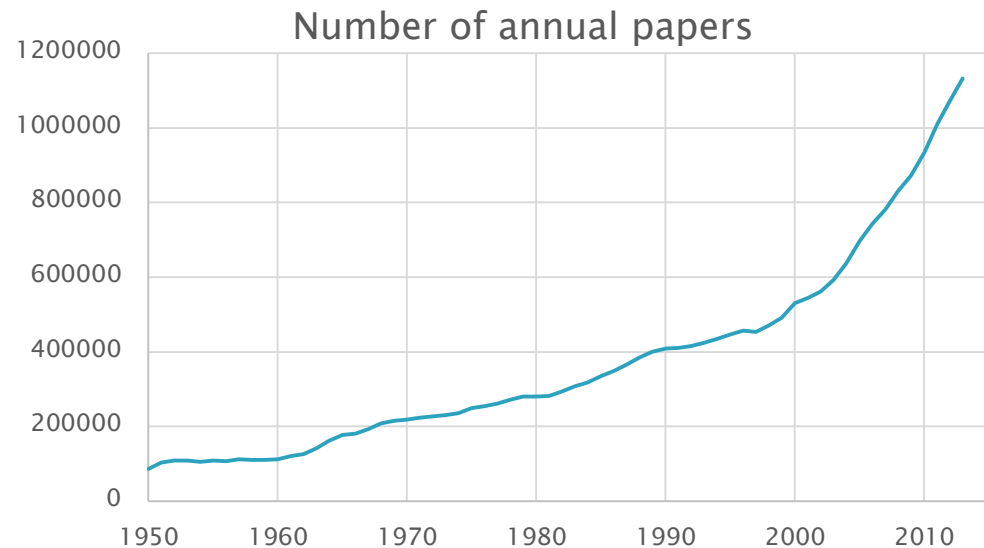
The data-intensive science, data science, data engineering

- ▶ Data analysis and knowledge fusion is more important than simulation of „simple” laws.
- 20th century: Physics vs. 21st century: Biology.
 - Tony Hey, Stewart Tansley, and Kristin Tolle: **The fourth paradigm (Data-Intensive Scientific Discovery)**, <http://research.microsoft.com/en-us/collaboration/fourthparadigm/>, 2009
 - Gordon Bell, Tony Hey, Alex Szalay: **Beyond the Data Deluge**, Science, 323, pp 1297–1298, 2009

Besides data: expert knowledge

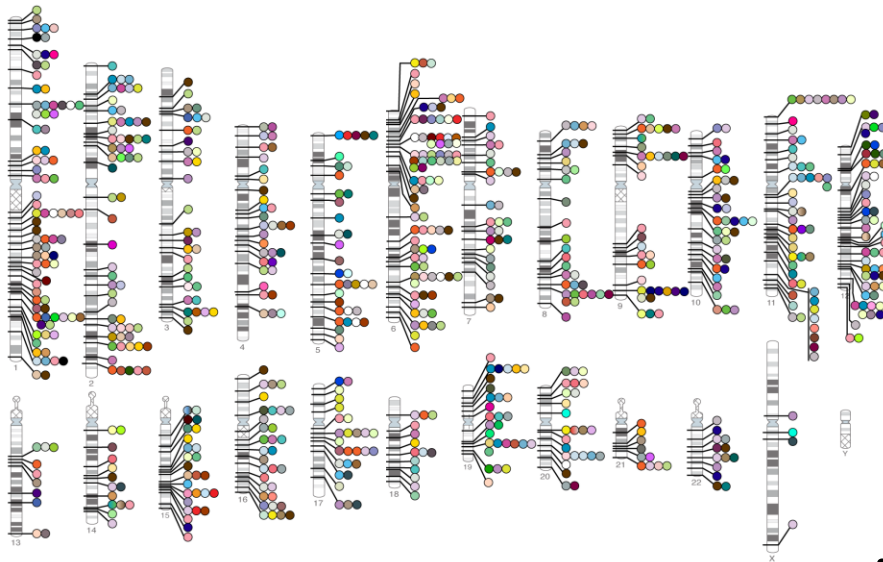


It will be noted that after an initial period of rapid expansion to a stable growth rate, the number of abstracts increases exponentially, doubling in approximately 15 years.

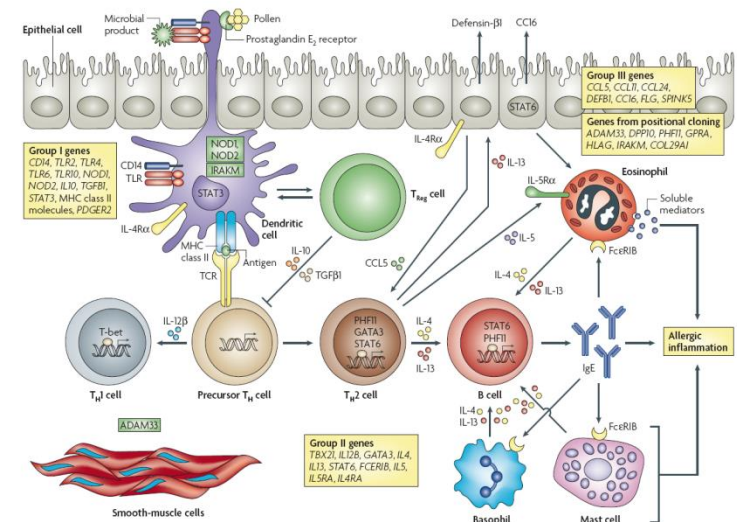
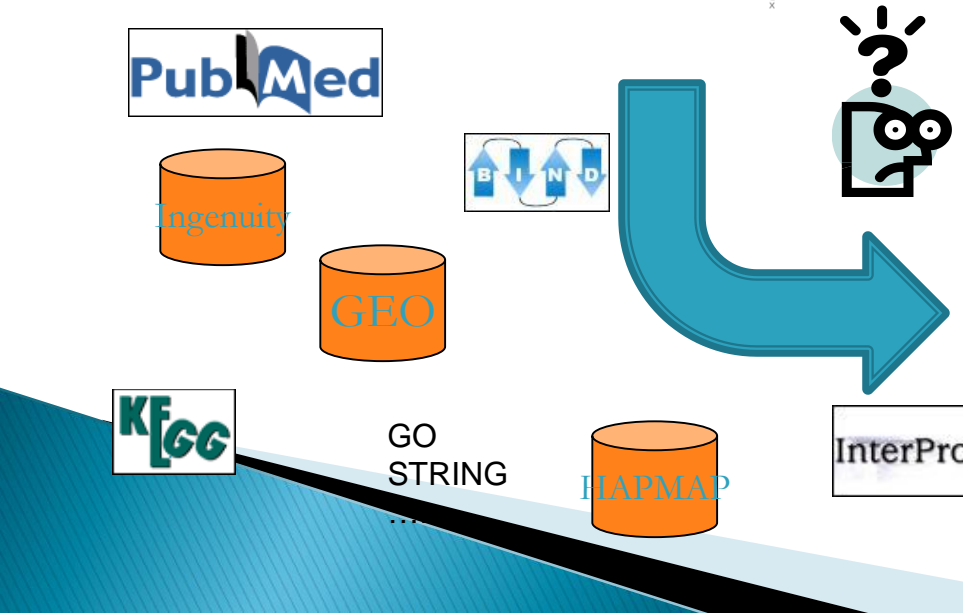


The hypothesis-free research

2010 1st quarter



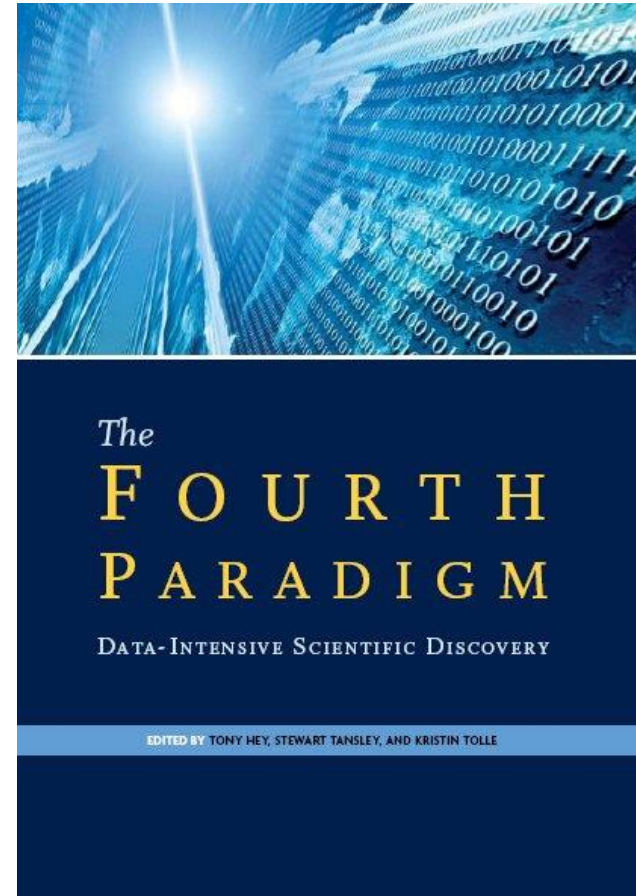
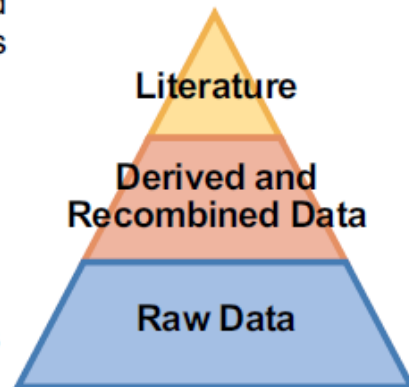
- Hypothesis-free measurement
- Hypothesis-free data analysis
- Interpretational/translational bottleneck
- Dissemination and reuse of significantly weak results?



E-science, data-intensive science, the fourth paradigm

All Scientific Data Online

- Many disciplines overlap and use data from other sciences
- Internet can unify all literature and data
- Go from literature to computation to data back to literature
- Information at your fingertips for everyone-everywhere
- Increase Scientific Information Velocity
- Huge increase in Science Productivity

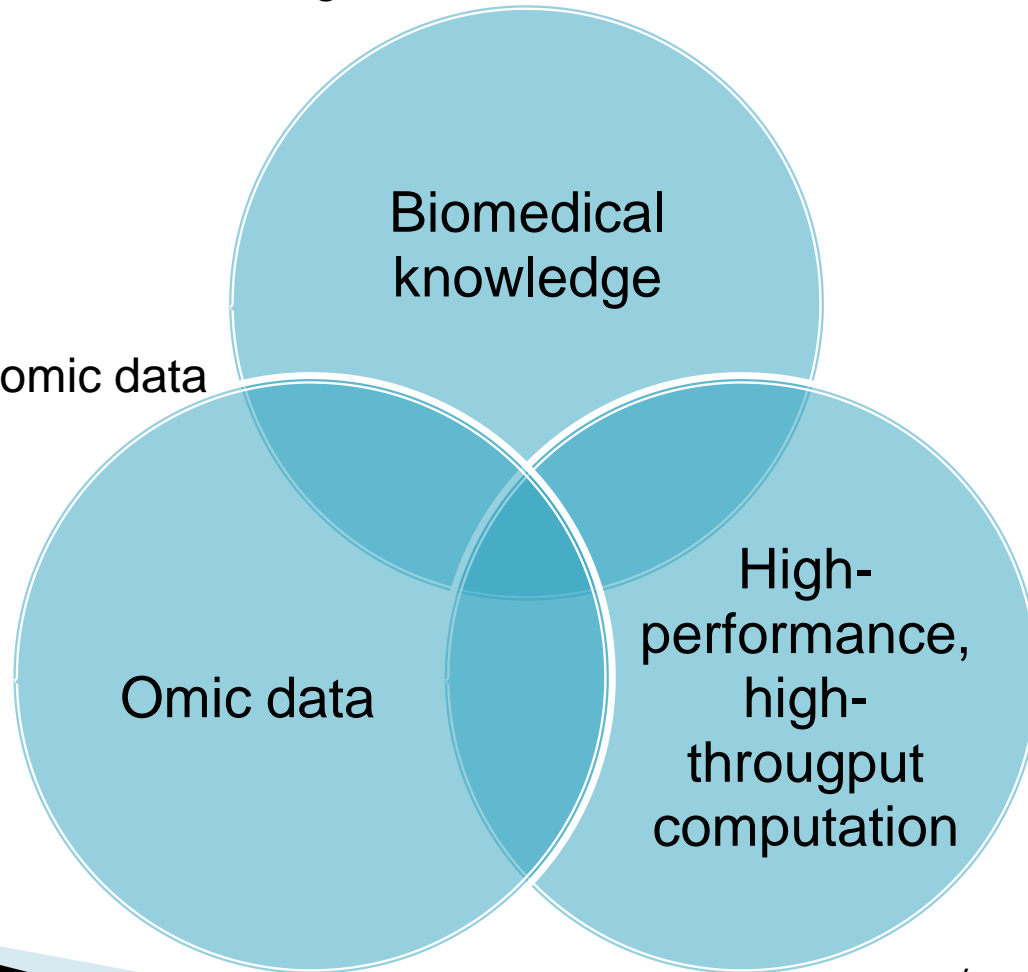


<http://research.microsoft.com/en-us/collaboration/fourthparadigm/>

Vision: the fusion dream

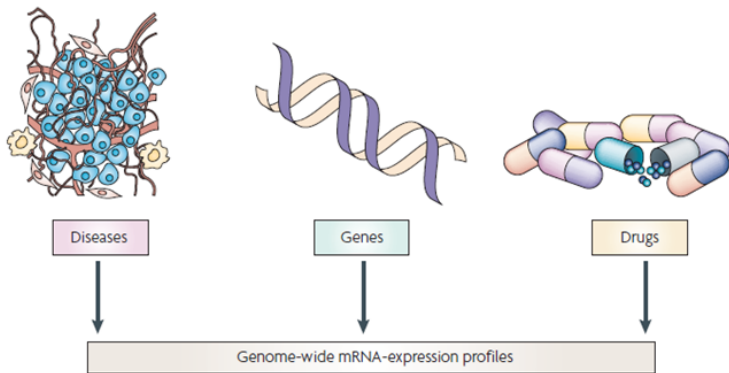
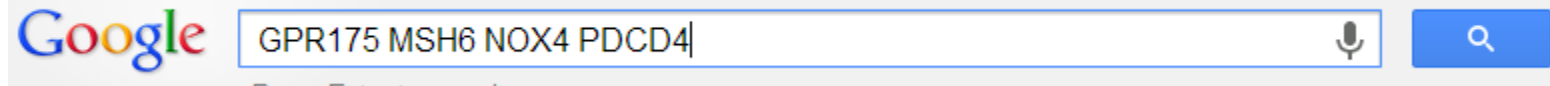
mega-scale memes

giga/tera-scale omic data



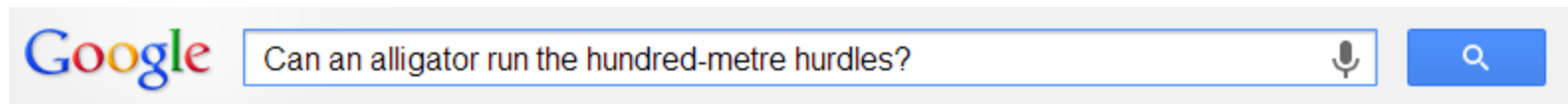
tera/peta-scale computing

“Real” artificial intelligence?



“Molecular google”

J.Lamb: The Connectivity Map, Nature, 2007

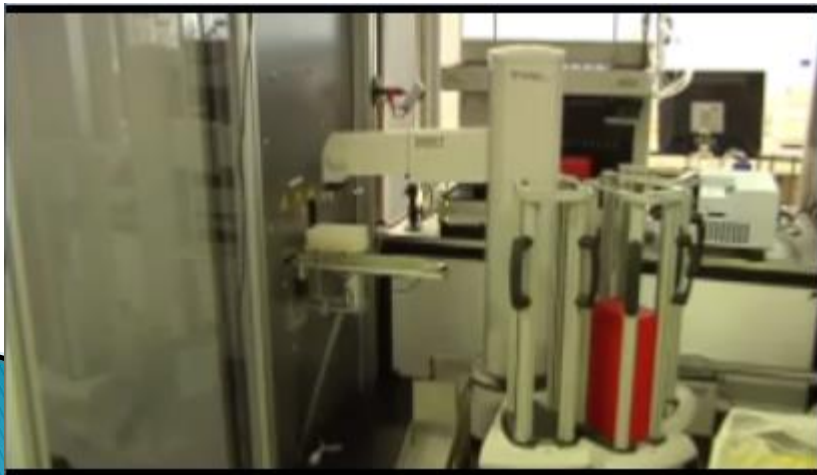


“The Science Behind an Answer”

Turing test and prediction, Computing Machinery and
Intelligence, 1950

Automated discovery systems

- Langley, P. (1978). Bacon: A general discovery system. Proceedings of the Second Biennial Conference of the Canadian Society for Computational Studies of Intelligence (pp. 173-180). Toronto, Ontario.
- ...
- Chrisman, L., Langley, P., & Bay, S. (2003). Incorporating biological knowledge into evaluation of causal regulatory hypotheses. Proceedings of the Pacific Symposium on Biocomputing (pp. 128-139). Lihue, Hawaii.
- (Gene prioritization...)
- R.D.King et al.: The Automation of Science, Science, 2009



Summary

- ▶ Besides individualist approaches to AI others:
 - Self-aware AI
 - Self-accelerating AI
 - Cooperative/collective AI
 - Data-driven AI
 - Automated Science
- ▶ Suggested reading:
 - Boden: Computer models of creativity, 2009
 - King: The Automation of Science, Science, 2009