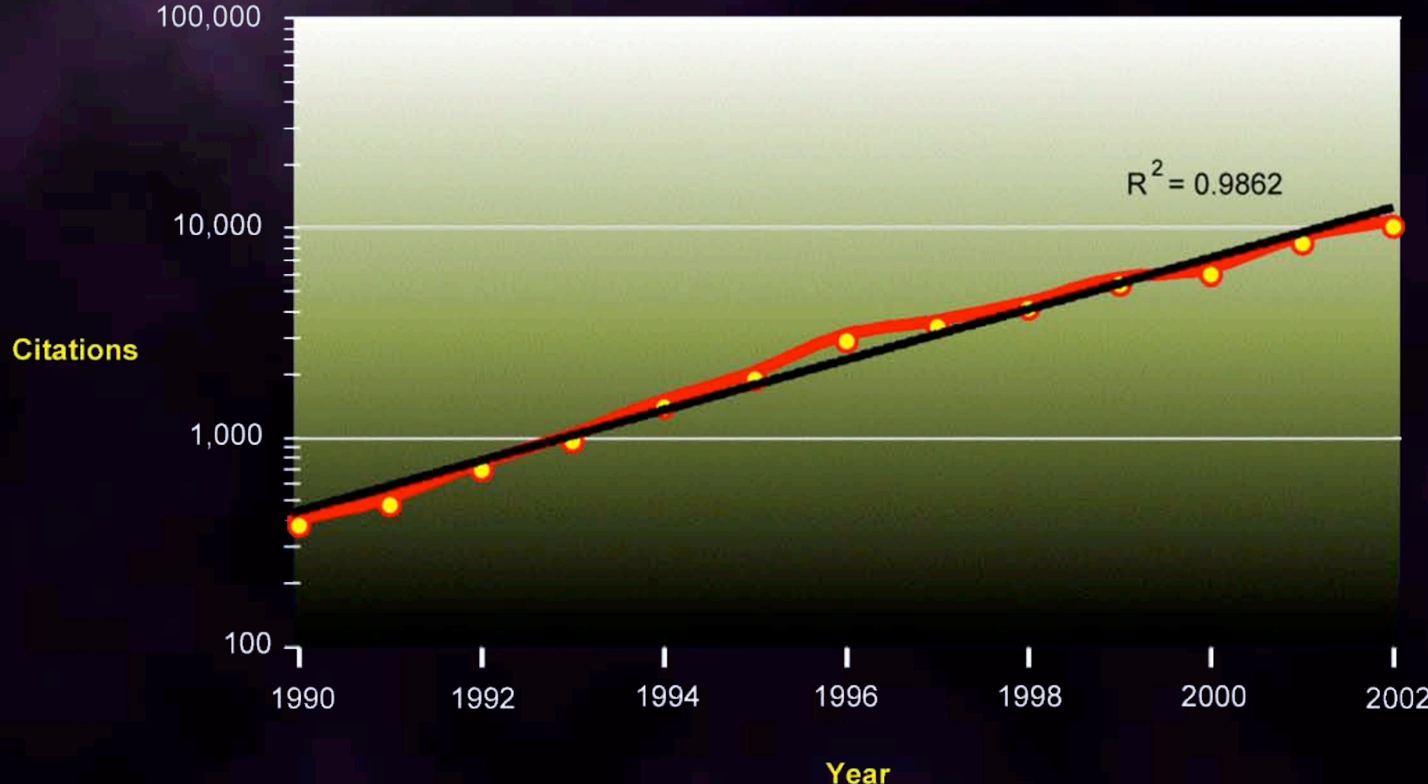
Nanotech Science Citations - 1990-2002

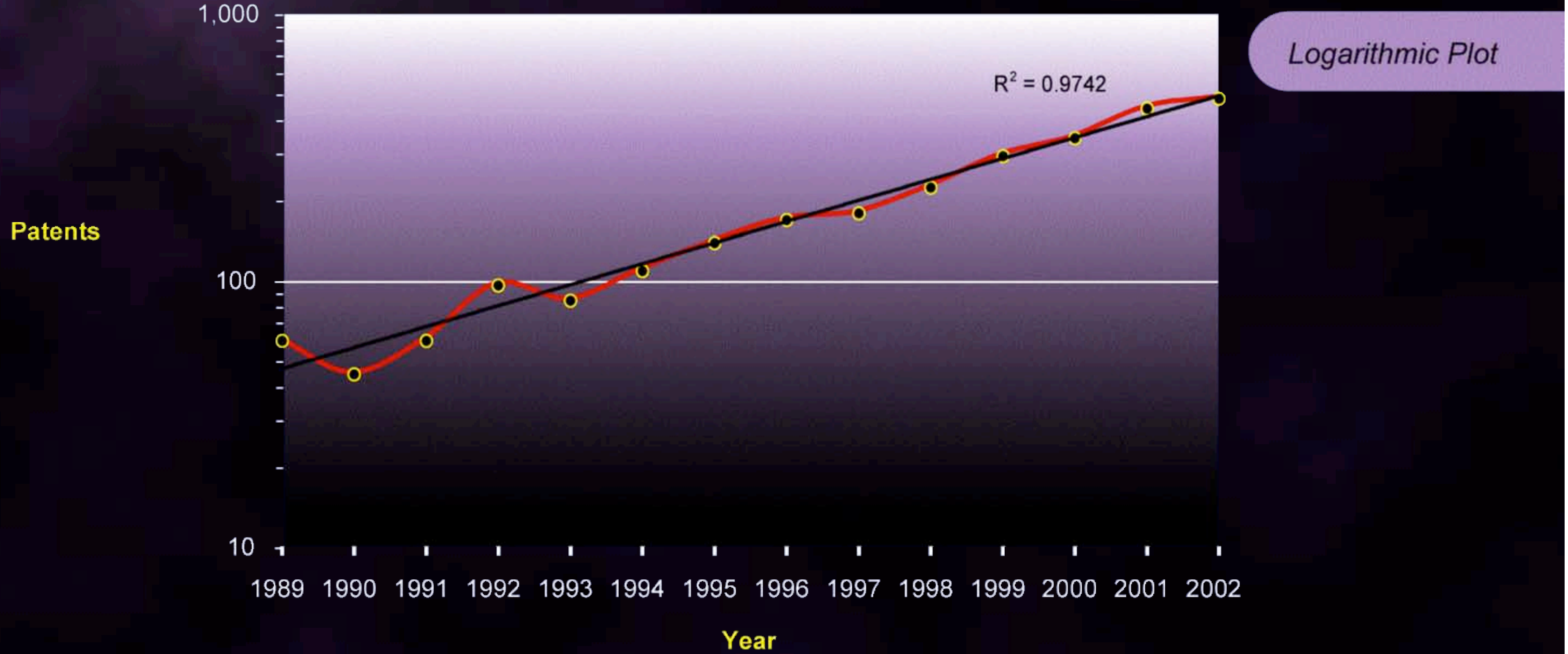


Logarithmic Plot

Data from: ETC Group

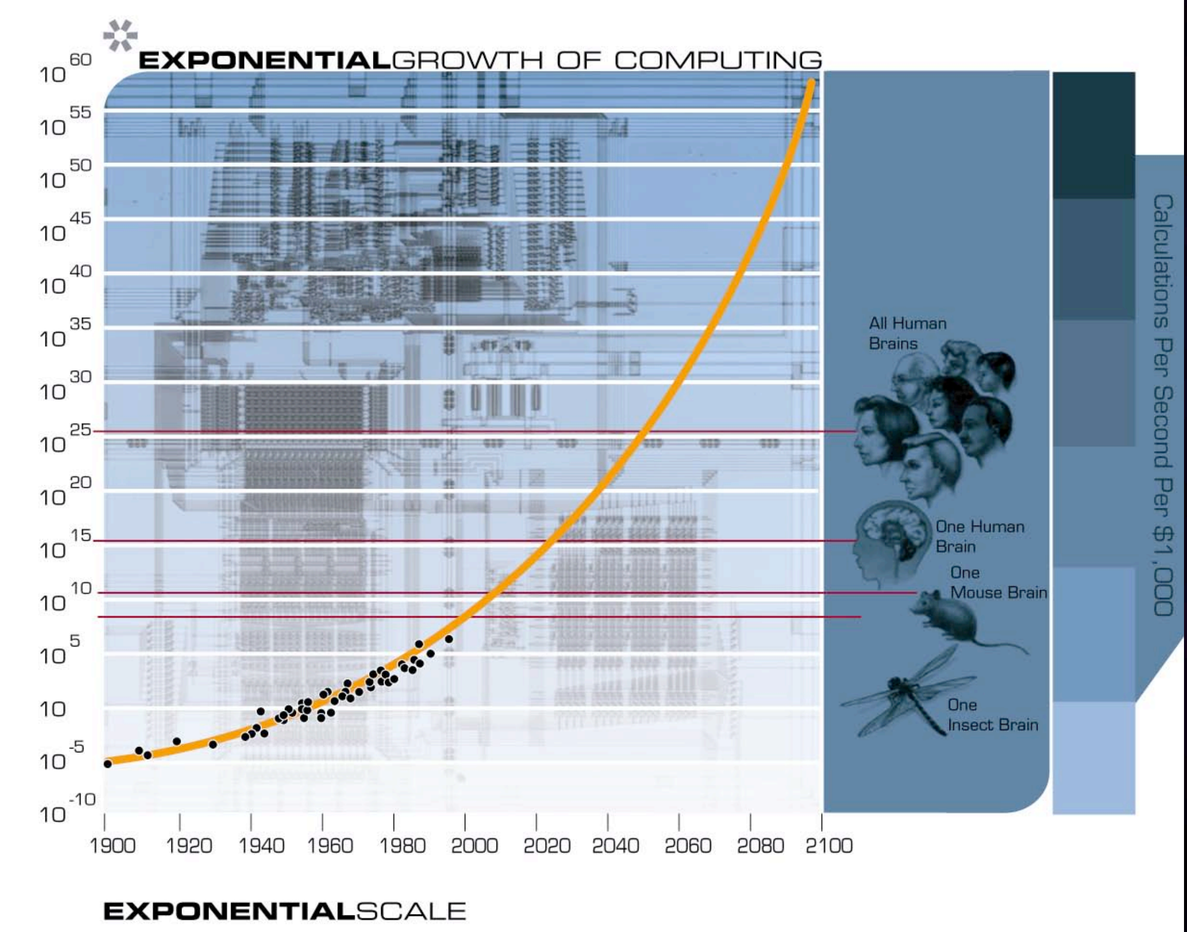
Doubling time: 2.4 years

U.S. Nano-Related Patents



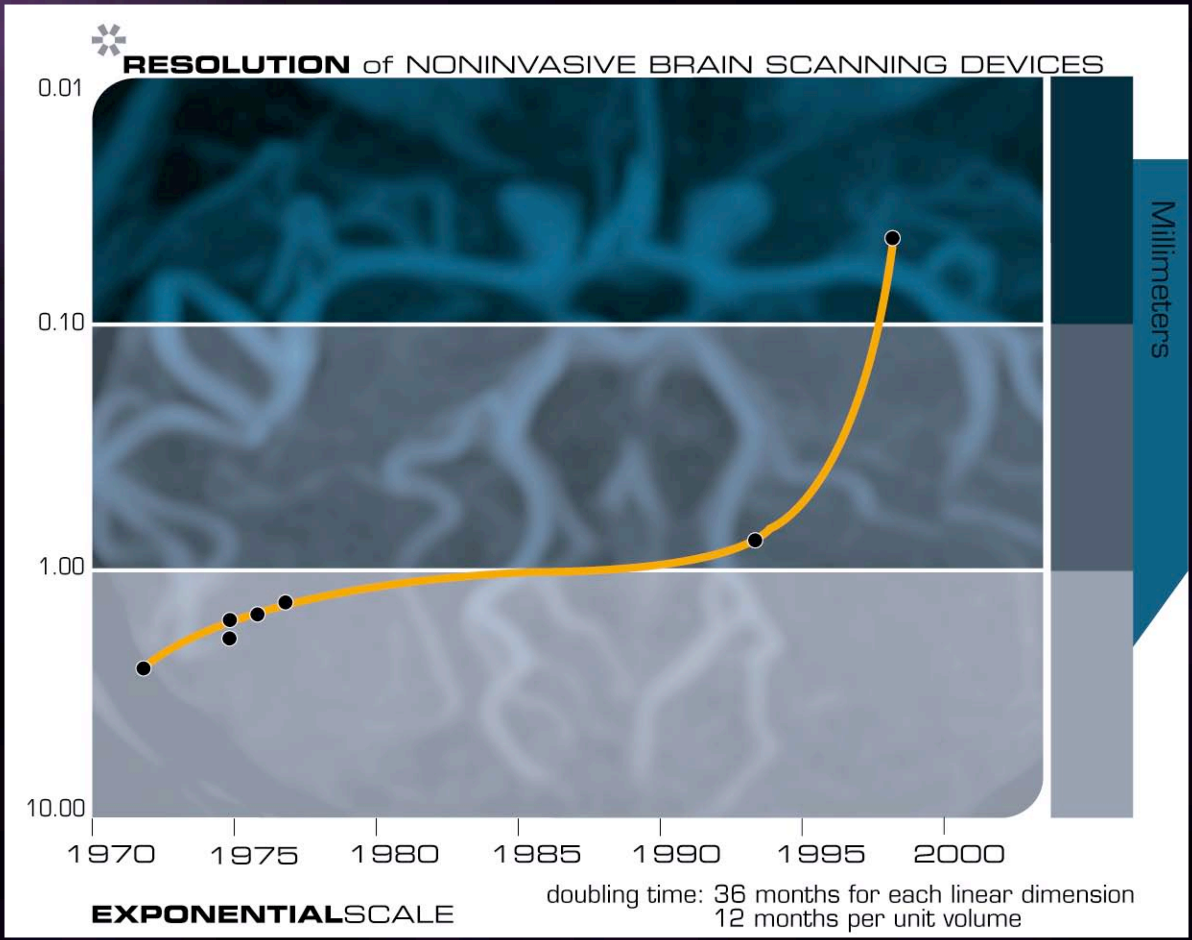
Data from: ETC Group

Doubling time: 4 years

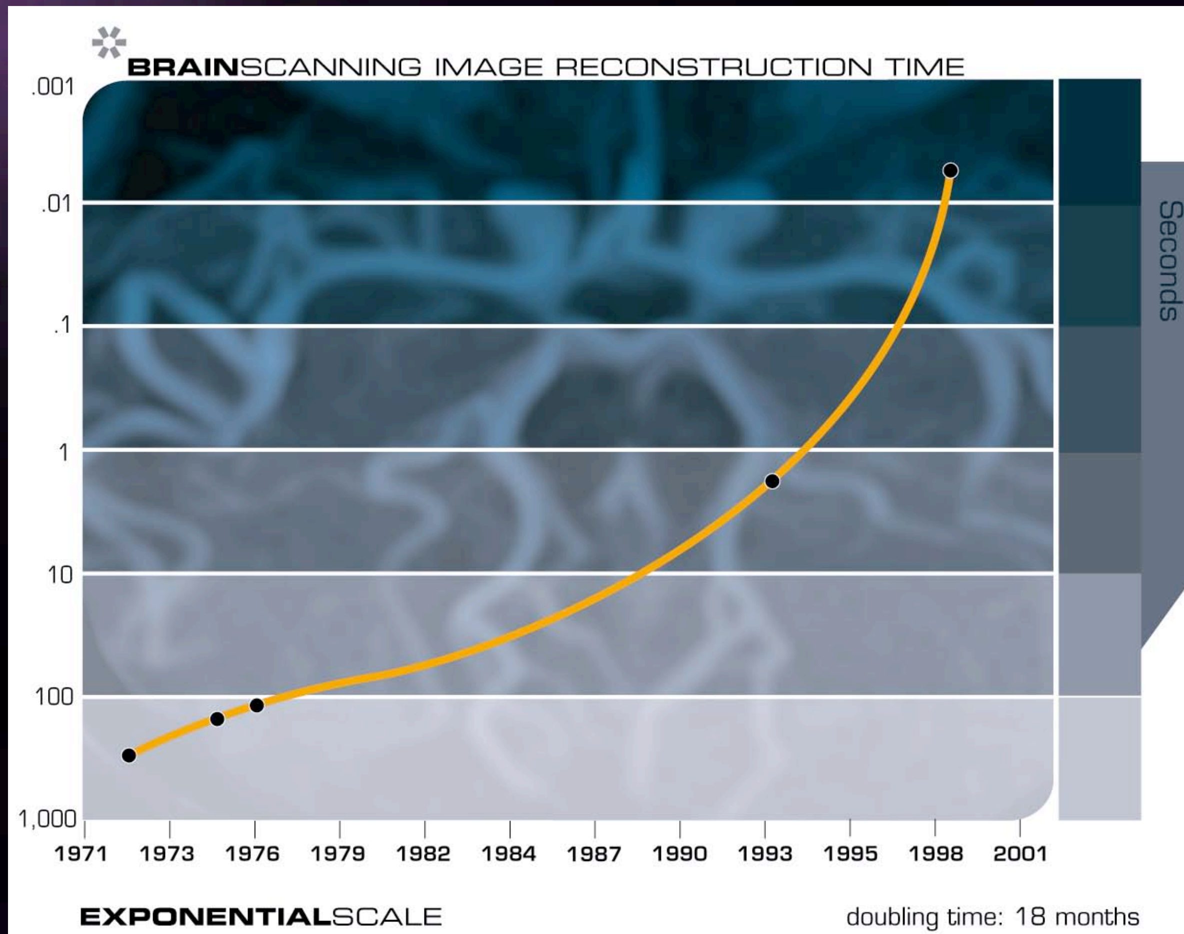

EXPONENTIALGROWTH OF COMPUTING
10^60
10^55
10^50
10^45
10^40
10^35
10^30
10^25
10^20
10^15
10^10
10^5
10
10^-5
10^-10
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
All Human Brains
One Human Brain
One Mouse Brain
One Insect Brain
Calculations Per Second Per $1,000
EXPONENTIALSCALE

Reverse Engineering the Brain:

the ultimate source of the templates of intelligence



RESOLUTION of NONINVASIVE BRAIN SCANNING DEVICES
0.01
0.10
1.00
10.00
Millimeters
1970
1975
1980
1985
1990
1995
2000
EXPONENTIALSCALE
doubling time: 36 months for each linear dimension
12 months per unit volume



BRAINSCANNING IMAGE RECONSTRUCTION TIME
.001
.01
.1
1
10
100
1,000
1971
1973
1976
1979
1982
1984
1987
1990
1993
1995
1998
2001
Seconds
EXPONENTIALSCALE
doubling time: 18 months

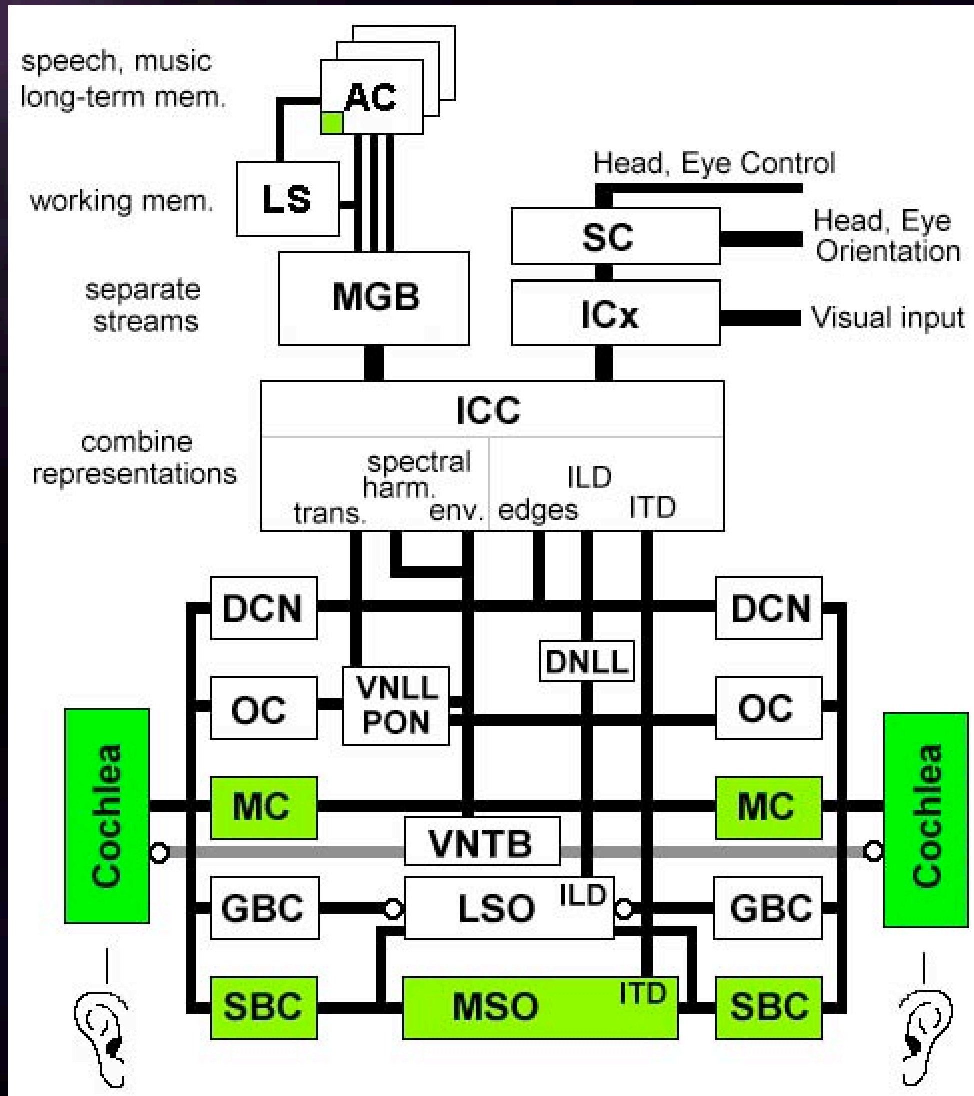


Chart by Lloyd Watts

“Now, for the first time, we are observing the brain at work in a global manner with such clarity that we should be able to discover the overall programs behind its magnificent powers.”

-- J.G. Taylor, B. Horwitz, K.J. Friston

Ways that the brain differs from a conventional computer:

- Very few cycles available to make decisions
- Massively parallel: 100 trillion interneuronal connections
- Combines digital & analog phenomena at every level
  - Nonlinear dynamics can be modeled using digital computation to any desired degree of accuracy
  - Benefits of modeling using transistors in their analog native mode

Ways that the brain differs from a conventional computer:

- The brain is self-organizing at every level
- Great deal of stochastic (random within controlled constraints) process in every aspect
  - Self-organizing, stochastic techniques are routinely used in pattern recognition
- Information storage is holographic in its properties

The Brain's Design is a level of complexity we can manage

- Only about 20 megabytes of compressed design information about the brain in the genome
  - A brain has ~ billion times more information than the genome that describes its design
- We've already created simulations of ~ 20 regions (out of several hundred) of the brain

Models often get simpler at a higher level, not more complex

- Consider an analogy with a computer
  - We do need to understand the detailed physics of semiconductors to model a transistor, and the equations underlying a single real transistor are complex.
  - A digital circuit that multiplies two numbers, however, although involving hundreds of transistors, can be modeled far more simply.

Modeling Systems at the Right Level

- Although chemistry is theoretically based on physics, and could be derived entirely from physics, this would be unwieldy and infeasible in practice.
- So chemistry uses its own rules and models.
- We should be able to deduce the laws of thermodynamics from physics, but this is far from straightforward. Once we have a sufficient number of particles to call it a gas rather than a bunch of particles, solving equations for each particle interaction becomes hopeless, whereas the laws of thermodynamics work quite well.

Modeling Systems at the Right Level

- The same issue applies to the levels of modeling and understanding in the brain – from the physics of synaptic reactions up to the transformations of information by neural clusters.
- Often, the lower level is more complex.
- A pancreatic islet cell is enormously complicated, in terms of all its biochemical functions, most of which apply to all human cells, some to all biological cells. Yet modeling what a pancreas does in terms of regulating levels of insulin and digestive enzymes, although not simple, is considerably less complex than a detailed model of a single islet cell.

The Cerebellum

- The basic wiring method of the cerebellum is repeated billions of times. It is clear that the genome does not provide specific information about each repetition of this cerebellar structure, but rather specifies certain constraints as to how this structure is repeated (just as the genome does not specify the exact location of cells in other organs, such the location of each pancreatic Islet cell in the pancreas).