Computational Nuclear Science & Engineering Course Goal: able to *solve problems* aided by *computer programming*

Mathematical insights into how algorithms work	Practical programming / debugging skills	Model construction & interpretation of numerical results
Intermediate Level	**Intermediate Level**	**Intermediate Level**

by **Doing** Nuclear Science and Engineering Problems!

- **incoming MIT NSE graduate students have diverse backgrounds**
- **but, NSE don't need or have time to reinvent the wheels**

22.107 Course Pre-requisite: 12.010, 18.085

-Assumes **basic** level of numerical linear algebra, probability theory, finite difference, FFT etc. (if not confident, take 18.085)

- Assumes **basic** level of programming skills (if not confident, take 12.010)

Course Approach

- No spoon feeding: lectures provide pointers (references, websites) and examples

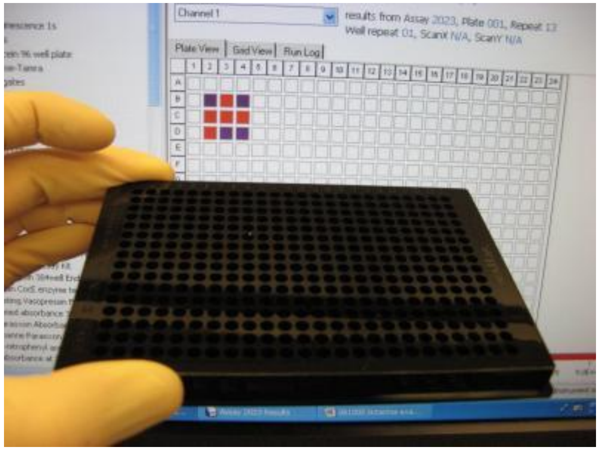
- **Self study and self-motivated programming a must**

- Problem set centric: develop critical analysis and synthetic problem-solving skills by asking them to solve problems with fewer and fewer constraints, end course with completely open-ended term project

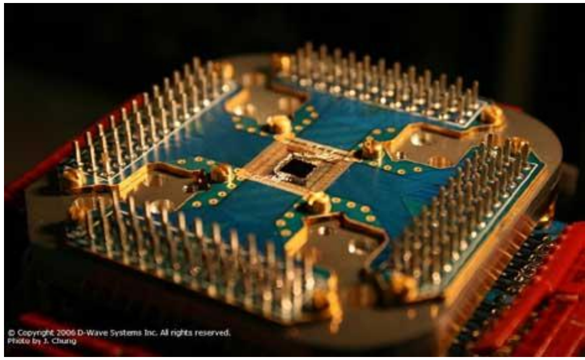
- Arbitrary programming language: ask to show excerpts of source code and intermediate data

- Have fun programming and solving problems.

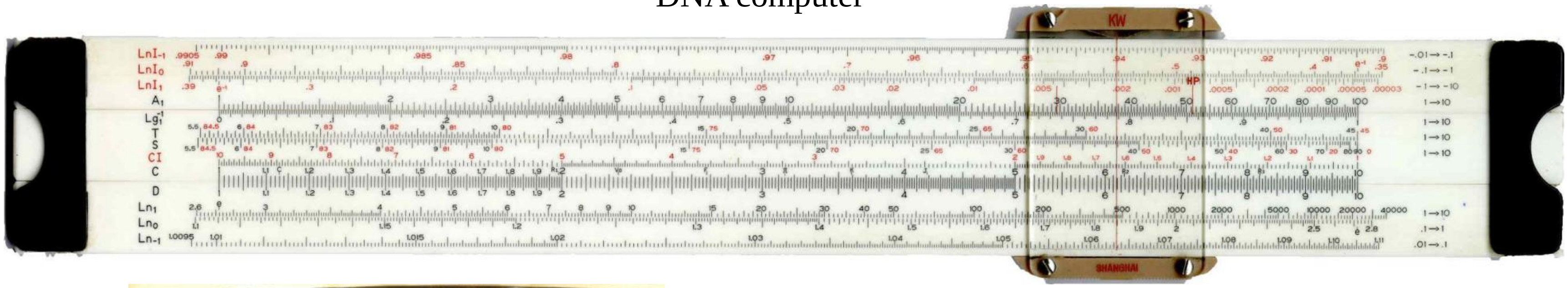
Lecture 1: What is Computation?

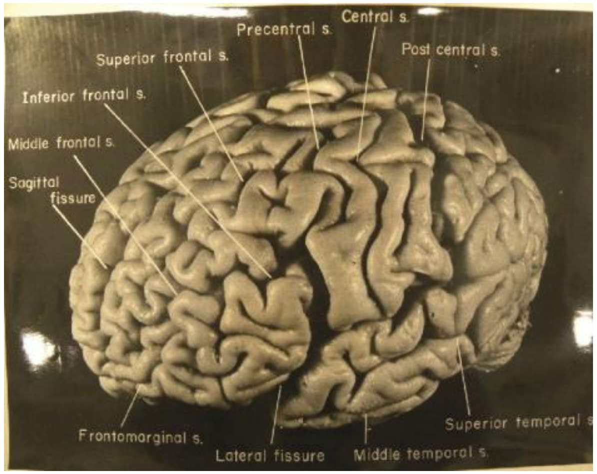


DNA computer

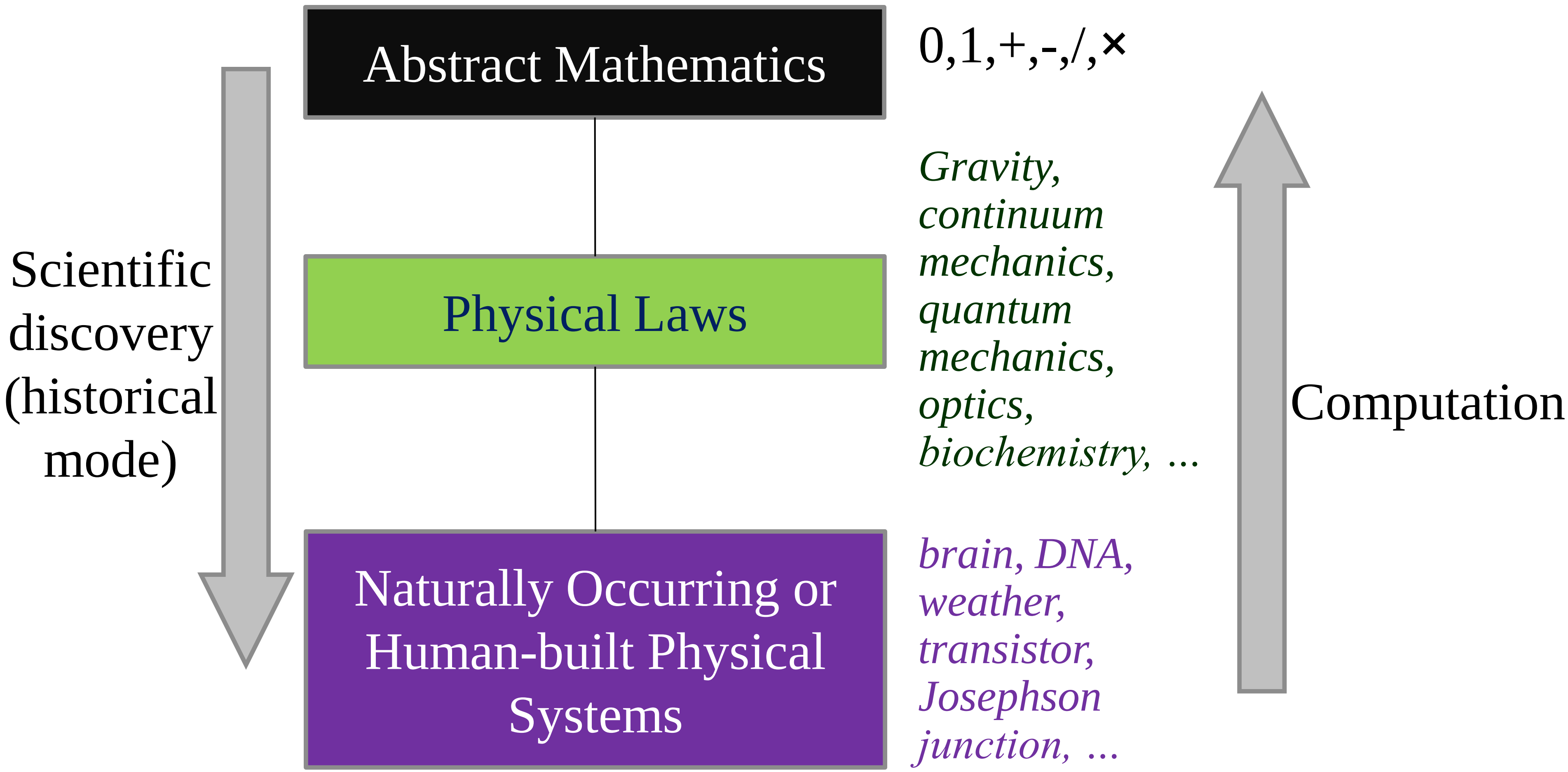


Quantum computer:
D-Wave qubit processor

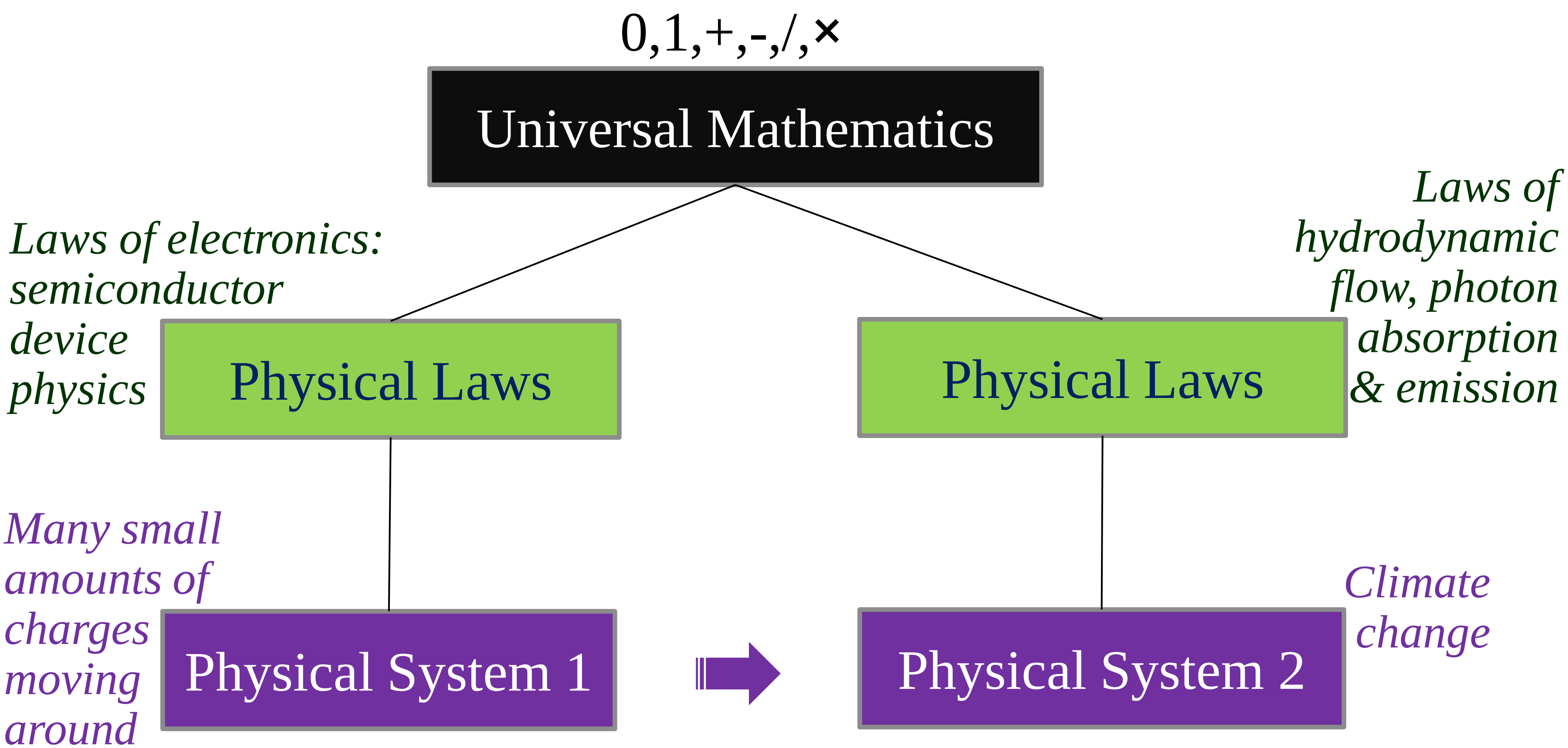




Computation is Reverse Mapping From Physical World → Mathematics



Computer Simulation



Computer: mapping of abstract, universally applicable mathematics onto *evolution* of a physical system (*internal*, *external states*). This evolution is faster, more controllable (more error free), easier to understand, etc. than unengineered systems.

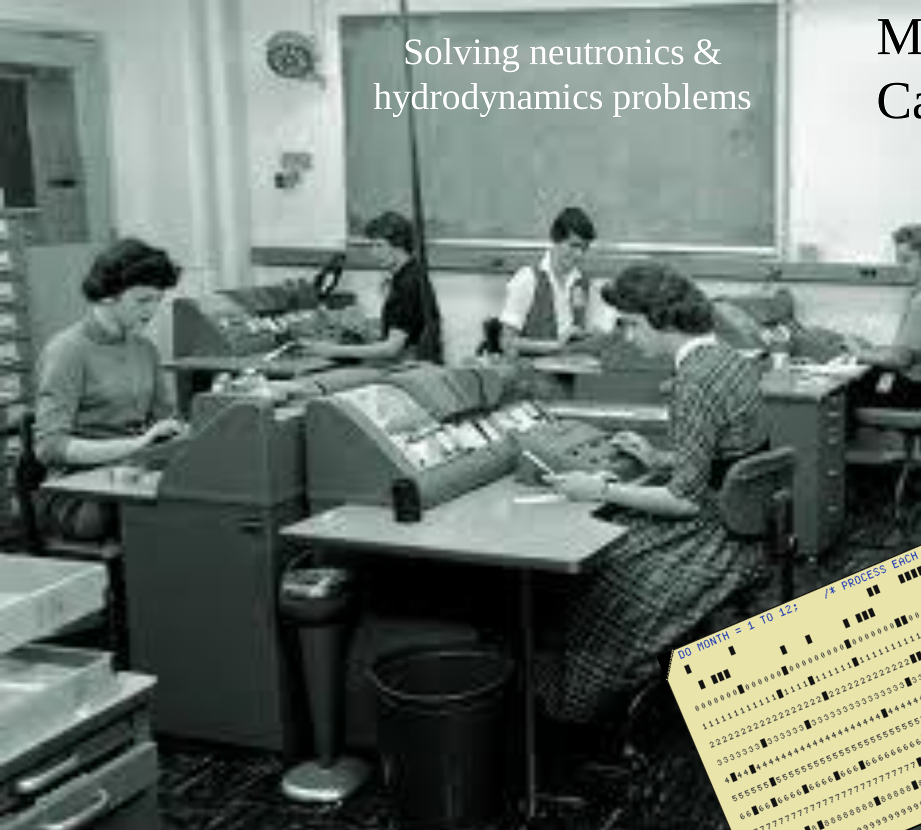
Pancomputationalism: everything happening in this world is "computation".

Most commercial computers today move electronic charges around. (However, long-haul communication network moves photons.) specially designed physical system with well-controlled internal and external states and evolutions

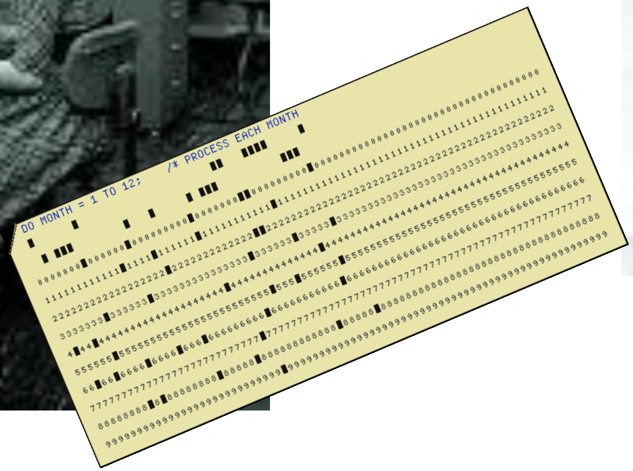
Fundamentally, computer network ≡ computer.
memory bus on a PC motherboard is a fast network.
Beowulf PC cluster based on ethernet or InfiniBand internal network

Consider computers and the network as a whole: coupled internal states: some strongly coupled, some weakly/intermittently coupled.
Analogy between neural network (neuron / synapse) and Internet / cloud computing.

CNSE: the use of computers and networks to facilitate discovery and problem solving in Nuclear Science and Engineering.



Marchant Silent Speed Mechanical Calculator. 1943



Los Alamos badge photo

Richard Feynman

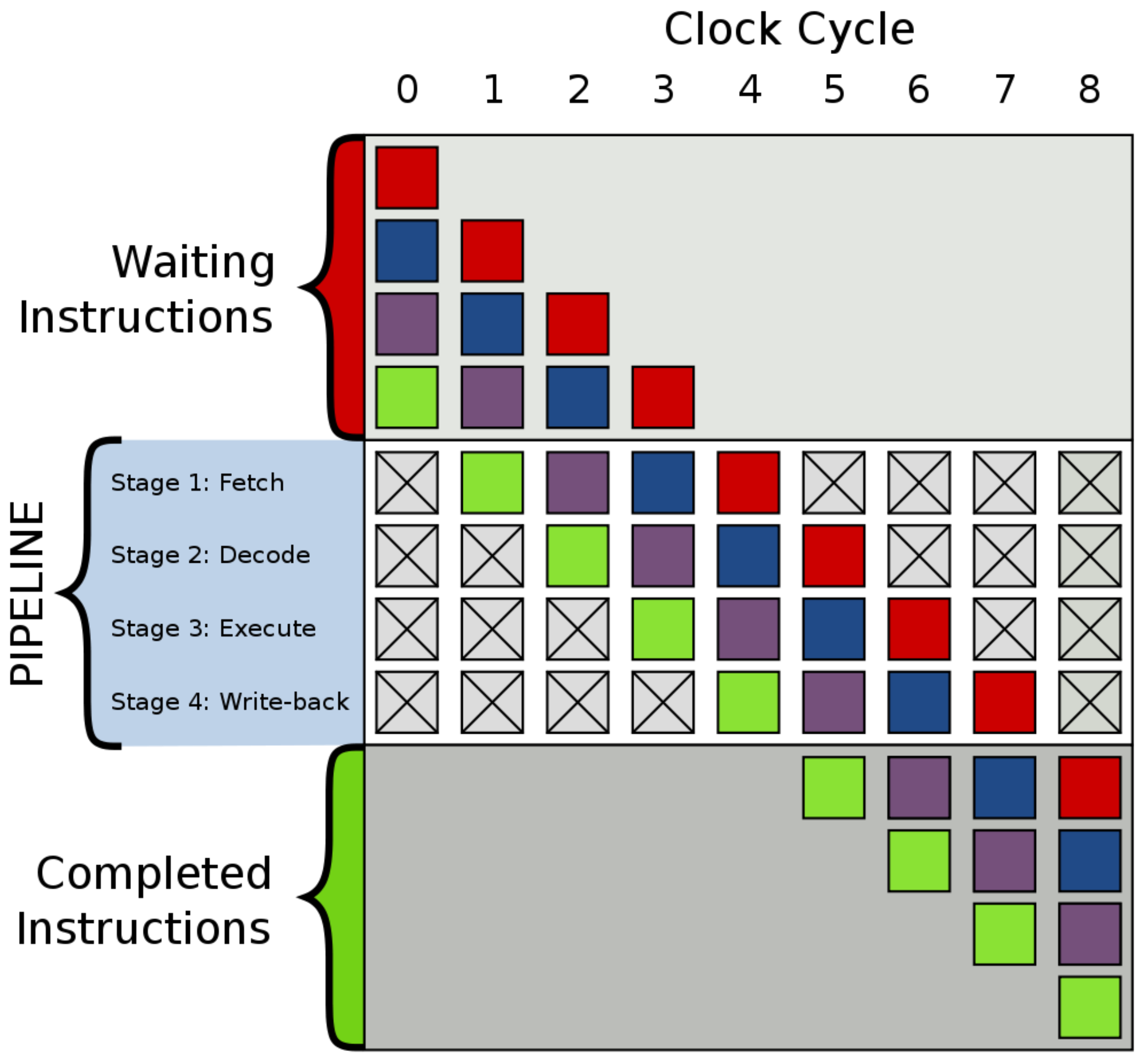
Nicholas Metropolis

From http://www.lanl.gov/history/: The new IBM punched-card machines were devoted to calculations to simulate implosion, and Metropolis and Feynman organized a race between them and the hand-computing group. "We set up a room with girls in it. Each one had a Marchant. But one was the multiplier, and another was the adder, and this one cubed, and all she did was cube this number and send it to the next one," said Feynmann. For one day, the hand computers kept up: "The only difference was that the IBM machines *didn't get tired and could work three shifts*. But the girls got tired after a while."

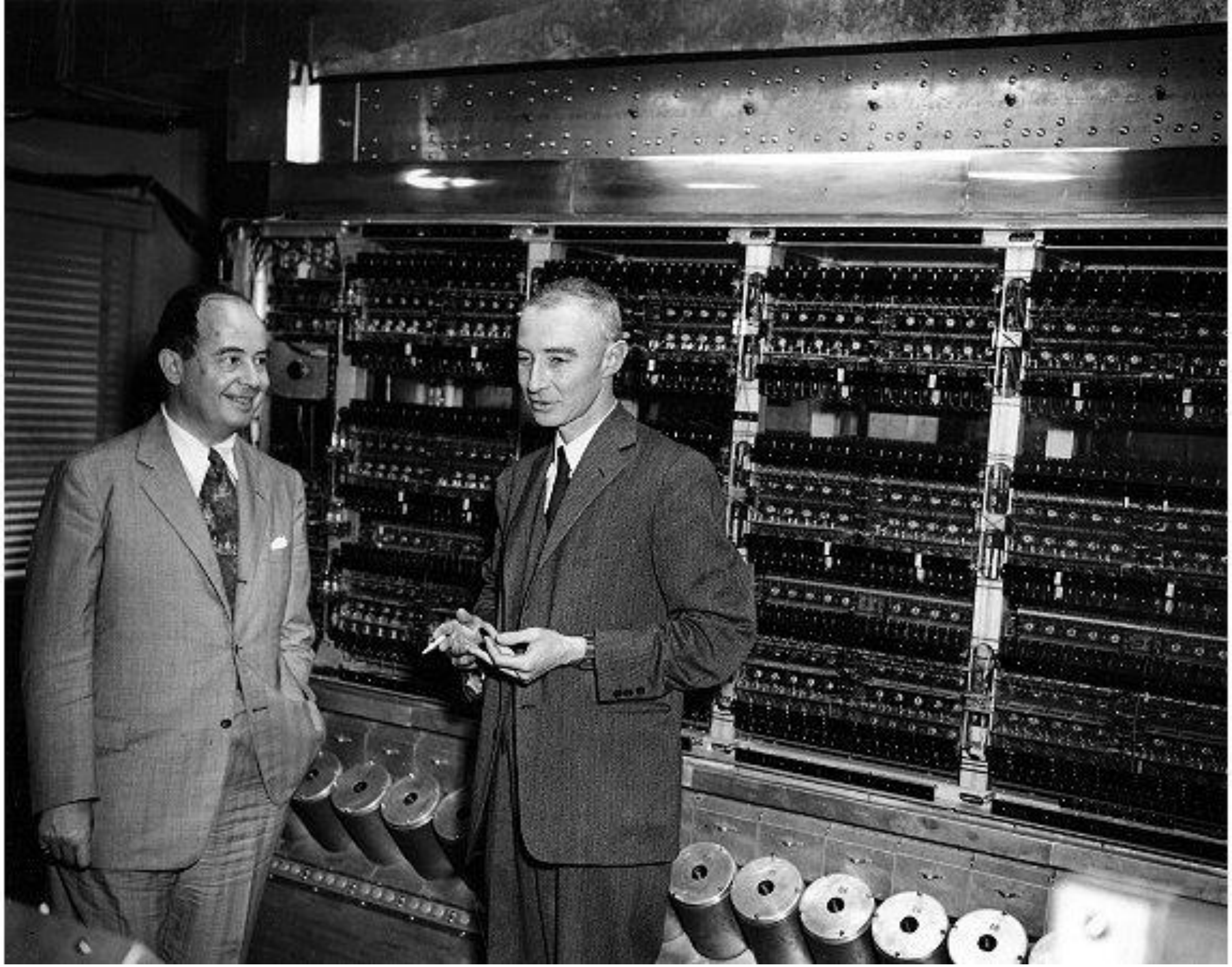
Feynmann worked out a technique to run **several calculations in parallel** on the punched-card machines that reduced the time required. "The problems consisted of a bunch of cards that had to go through a cycle. First add, then multiply, and so it went through the cycle of machines in this room - slowly - as it went around and around. So we figured a way to put a different colored set of cards through a cycle too, but out of phase. We'd do two or three problems at a time," explained Feynman. Three months were required for the first calculation, and Feynman's technique reduced it to two or three weeks.

assembly line in manufacturing → instruction pipeline stages in computer architecture

Time	Execution
0	Four instructions are waiting to be executed
1	• the green instruction is fetched from memory
2	• the green instruction is decoded • the purple instruction is fetched from memory
3	• the green instruction is executed (actual operation is performed) • the purple instruction is decoded • the blue instruction is fetched
4	• the green instruction's results are written back to the register file or memory • the purple instruction is executed • the blue instruction is decoded • the red instruction is fetched
5	• the green instruction is completed • the purple instruction is written back • the blue instruction is executed • the red instruction is decoded
6	• The purple instruction is completed • the blue instruction is written back • the red instruction is executed
7	• the blue instruction is completed • the red instruction is written back
8	• the red instruction is completed
9	All four instructions are executed

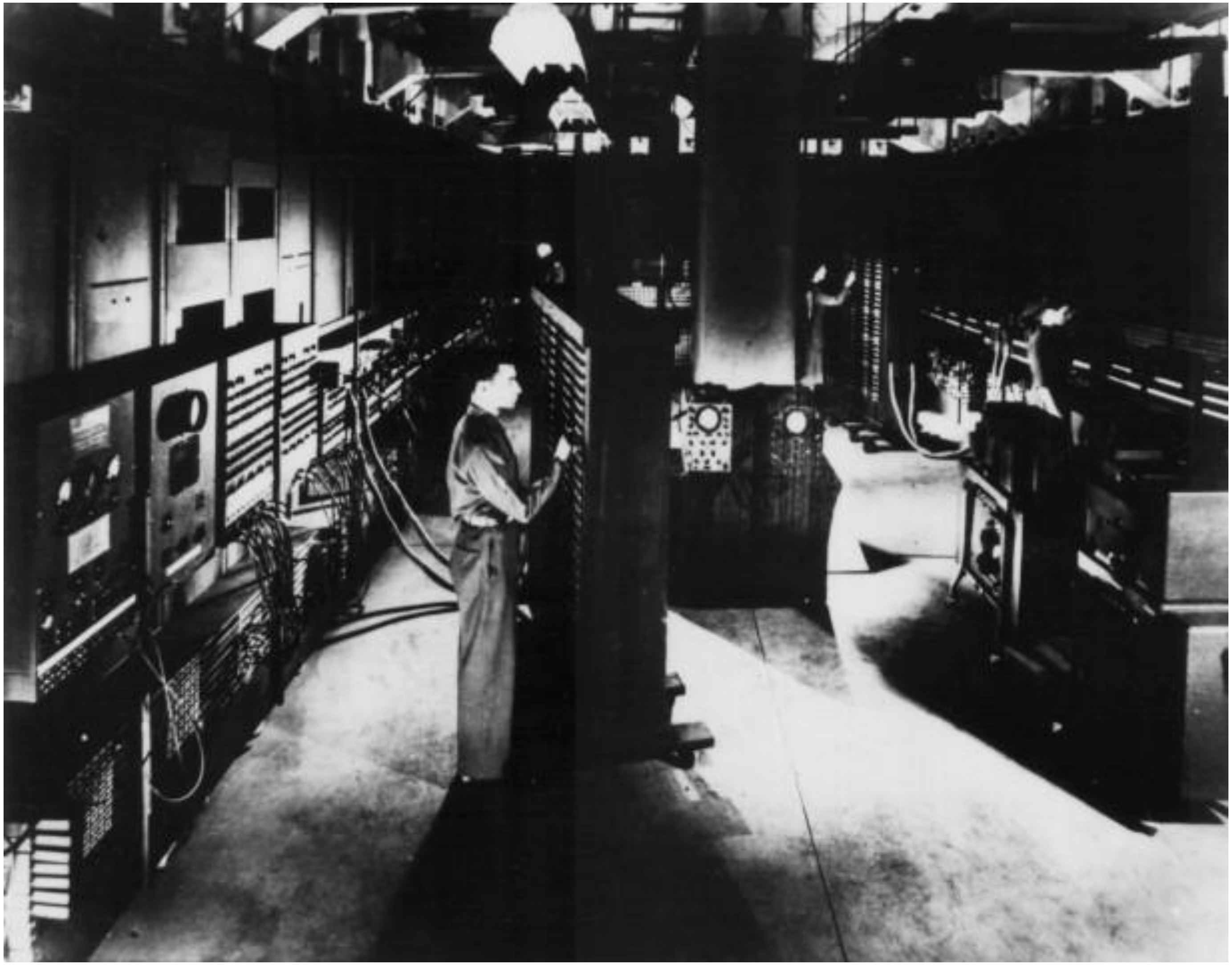


http://en.wikipedia.org/wiki/Instruction_pipeline



From http://www.computerhistory.org: John von Neumann (left) and Robert Oppenheimer, in front of Princeton's Institute for Advanced Study (IAS) computer. Operational in 1952, the IAS machine was the prototype for the first generation of digital computers.

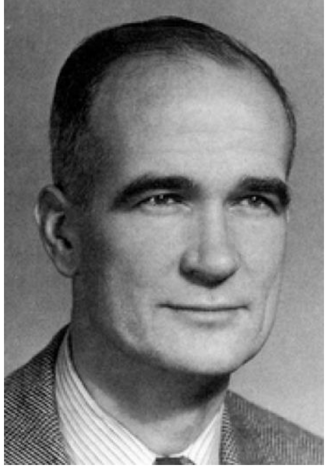
von Neumann served as consultant in the Manhattan Project.
Neutronics and hydrodynamics are still at the heart of NSE today. So one could say that CNSE was one of the **very first applications** of modern computing



ENIAC (Electronic Numerical Integrator And Computer, 1946): the first **general-purpose Turing-complete** electronic computer

at the Moore School of Electrical Engineering, University of Pennsylvania
(later transferred to Army's Ballistic Research Laboratory)

First semiconductor transistor (1947, Bell Labs)



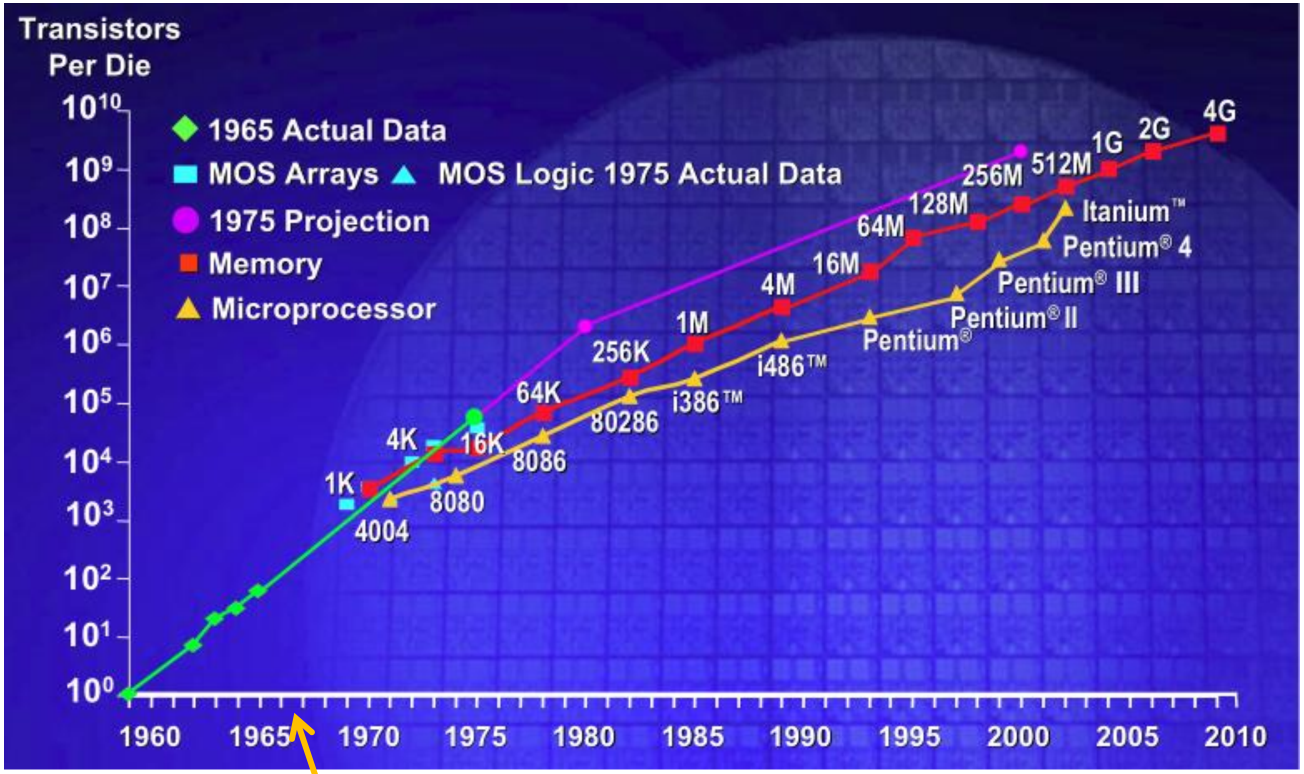
William Shockley

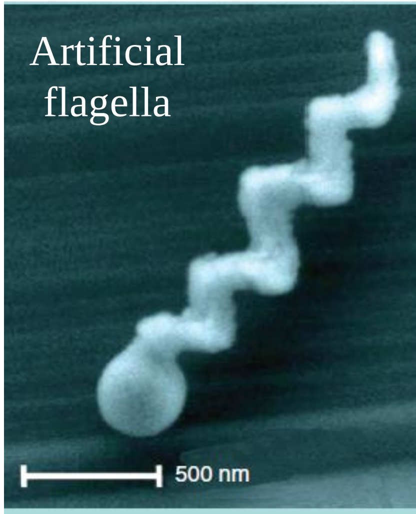
John Bardeen

Walter Brattain

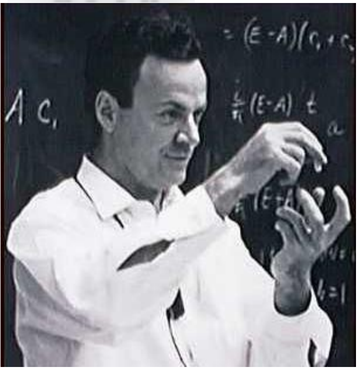
Nobel prize in Physics (1956)

Gordon Moore (1965): doubling the density of transistors on integrated circuits every two years

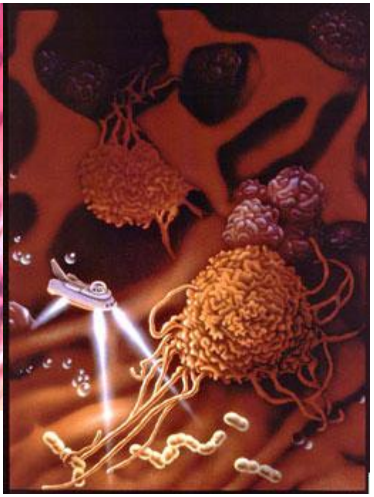




Ghosh & Fischer, "Controlled propulsion of artificial magnetic nanostructured propellers", *Nano Lett*. **9** (2009) 2243



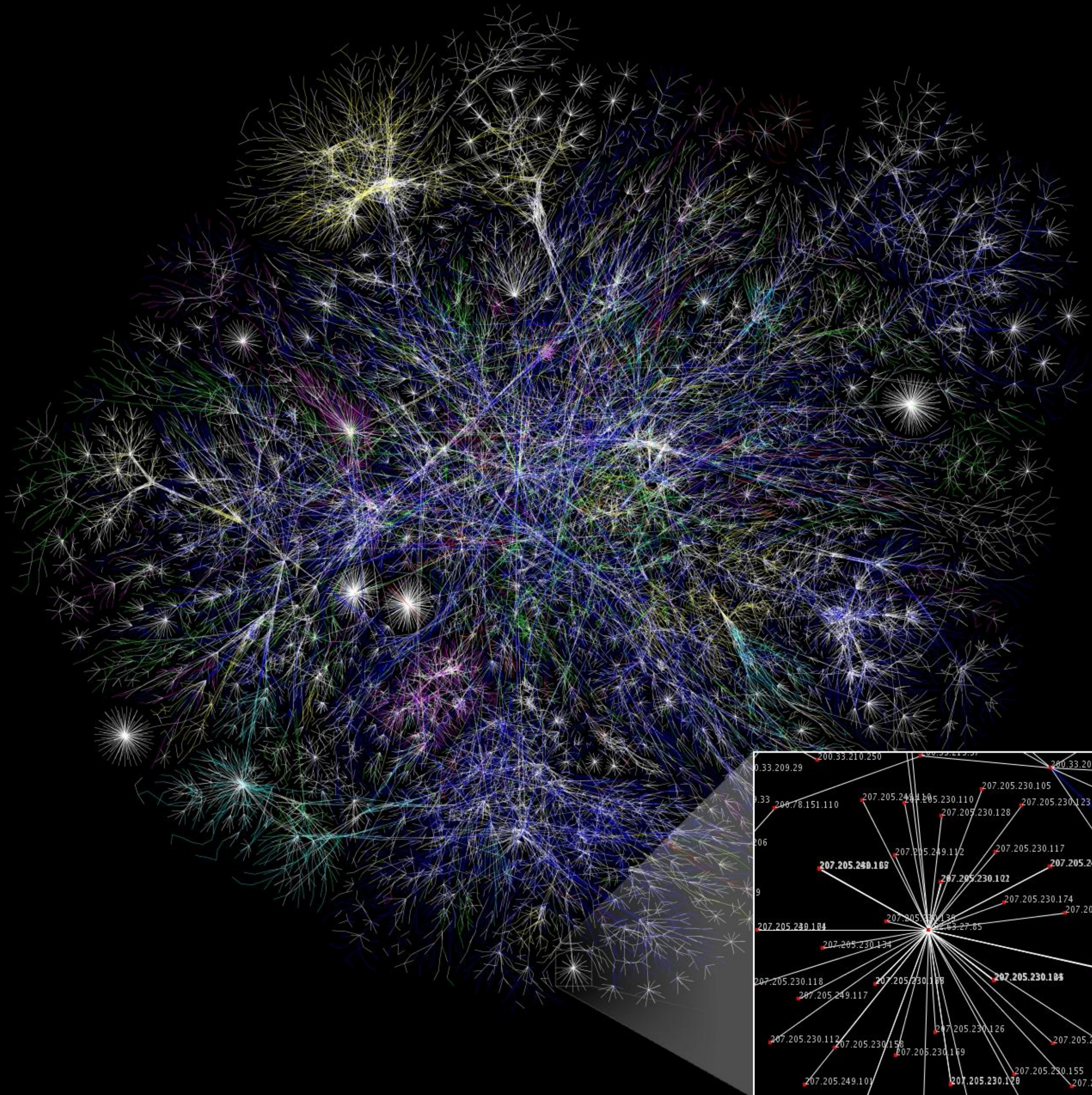
Richard P. Feynman
"*There's Plenty of Room at the Bottom*"
December 29th 1959 @ Caltech



Fantastic Voyage
1966, Twentieth Century Fox

Relentless Trend in Miniaturization

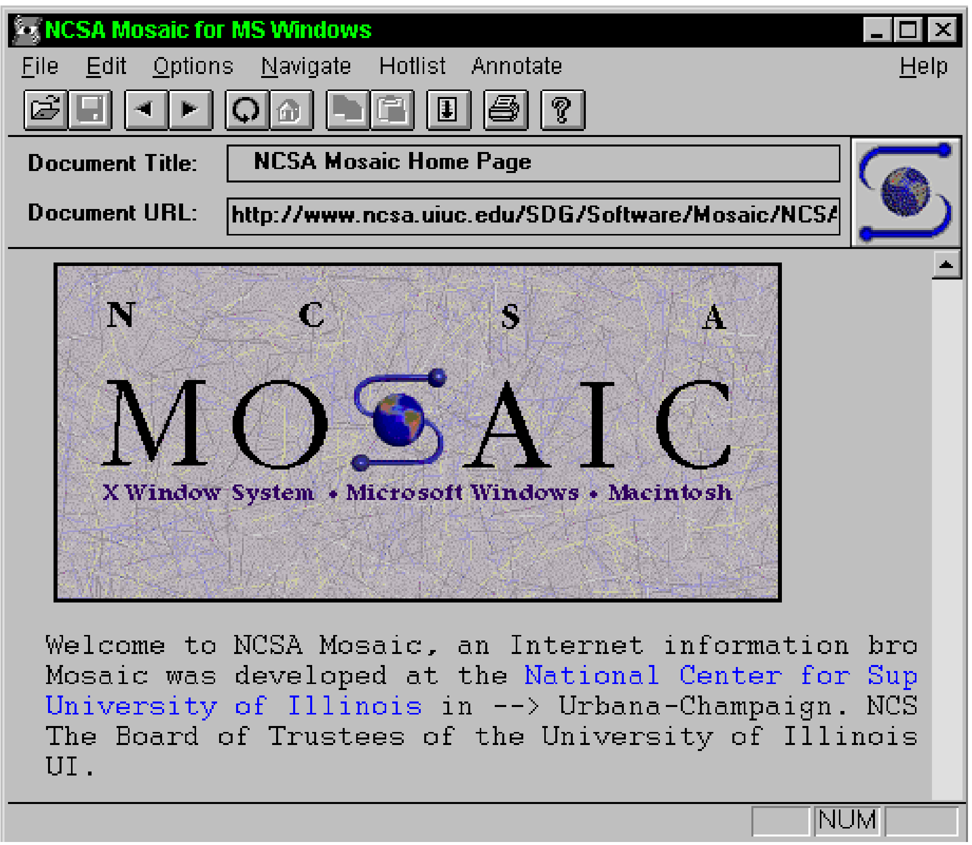
ARPANET/Internet (→TCP/IP): late 1960s



World Wide Web (Tim Berners-Lee, 1991, CERN)
→ HyperText Markup Language (HTML)

European Organization for Nuclear Research
CERN project called ENQUIRE

Vannevar Bush 1945 essay, "As We May Think.“ a theoretical machine called "memex," to enhance human memory by allowing the user to store and retrieve documents linked by associations.



2010 500 million users

Scientific Inquiry

Experimentation

replication of the physical system of interest to repeat its evolution, e.g. replicate a much smaller, but otherwise very similar, piece of the real world to *simulate* the real world

3rd pillar:

Computation

"mapping" is onto neither the human brain, nor a smaller replication of physical system, but *in silico* - a well-controlled physical system (electronic computer) with no external resemblance to the physical system of interest.

Theory

reduction of natural processes to human-comprehensible logic, and then aided by simple calculations, to predict natural processes *"in-brain mapping"*

Well-controlledness of today's digital computers is outstanding:

Almost all physical experiments we do subjected to noise.
But impression of digital computation: no noise.

Thermal fluctuations (true randomness) are entirely filtered out, by design of electronic circuits. *electronics in outer space an exception*

Pseudo randomness needs to be **artificially introduced** when needed in simulations.

Advantages of perform mapping in silico

- Compared to in-brain mapping: vast advantages in *speed*, *accuracy*, *data storage*, ...
- Compared to physical world mapping: *cost*, *better control of initial and boundary conditions* (parametric studies), *rich data* (access to all internal states), ...

Disadvantages

- Retains only key pieces of the physics in mapping - loss of physics: *no material deformation when modeling thermal conduction* BTW, this is the same for in-brain mapping.

Double-edged sword: This loss-of-physics disadvantage is also tied to the advantage of "better control of initial and boundary conditions": when modeling surface chemical reactions under ultra-high vacuum conditions, not worry about vacuum leaks like experimentalists must

- *"Curse of dimensionality"*

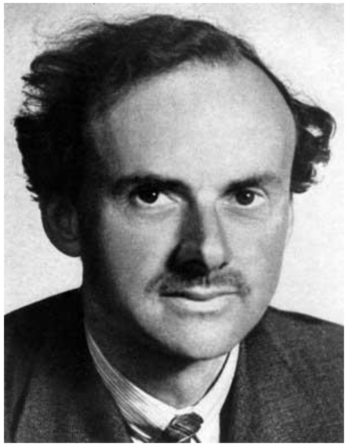
Many real-world processes are still too complex to be simulated *in silico*, at a level we would like to simulate them.

World of Atoms & Electrons

Erwin Schrödinger
Nobel Prize in Physics 1933

$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r},t) = -\frac{\hbar^2}{2m}\nabla^2\Psi(\mathbf{r},t) + V(\mathbf{r})\Psi(\mathbf{r},t)$$

$$\left(\beta mc^2 + \sum_{k=1}^{3}\alpha_k p_k\, c\right)\psi(\mathbf{x},t) = i\hbar\frac{\partial\psi(\mathbf{x},t)}{\partial t}$$



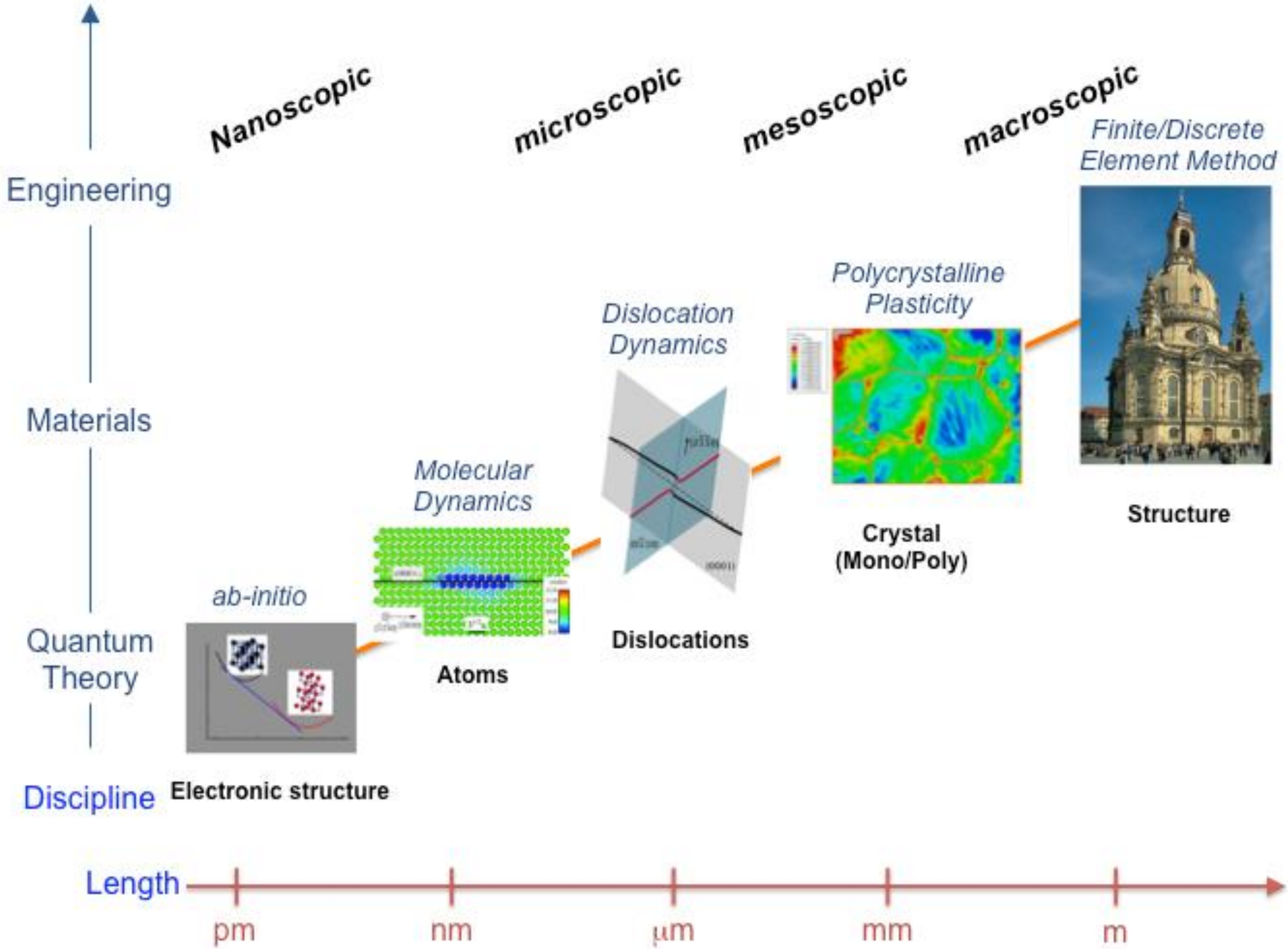
Paul A.M. Dirac
Nobel Prize in Physics 1933

+

http://top500.org/

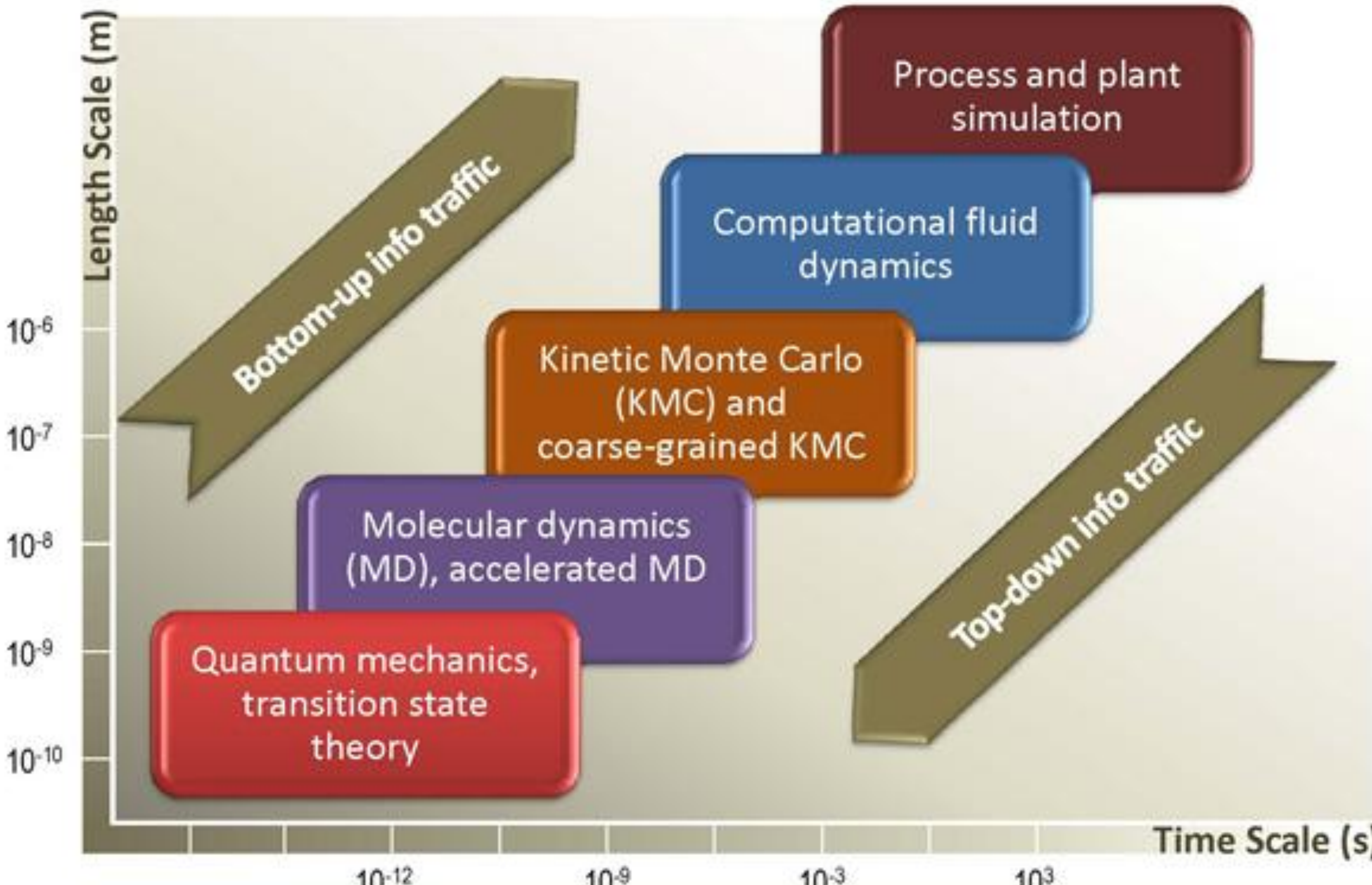
First-Principles Calculations
Atomistic Simulations: "Game of God"

Materials Chemistry Life Energy



http://tu-freiberg.de/fakult4/imfd/cms/Multiscale/multiscale.html

Multiscale Modeling Framework



Multiscale modeling framework for catalytic processes that exhibit strong coupling between scales.
Adapted from Vlachos, *Adv. Chem. Eng.* 30, 1-61 (2005)

To survive as modeler: first, be humble

- **Must respect experimental data**

Even if you do not *do* the experiment, try best to **understand**

• how the experiment *was actually done*

• what were the *raw data*

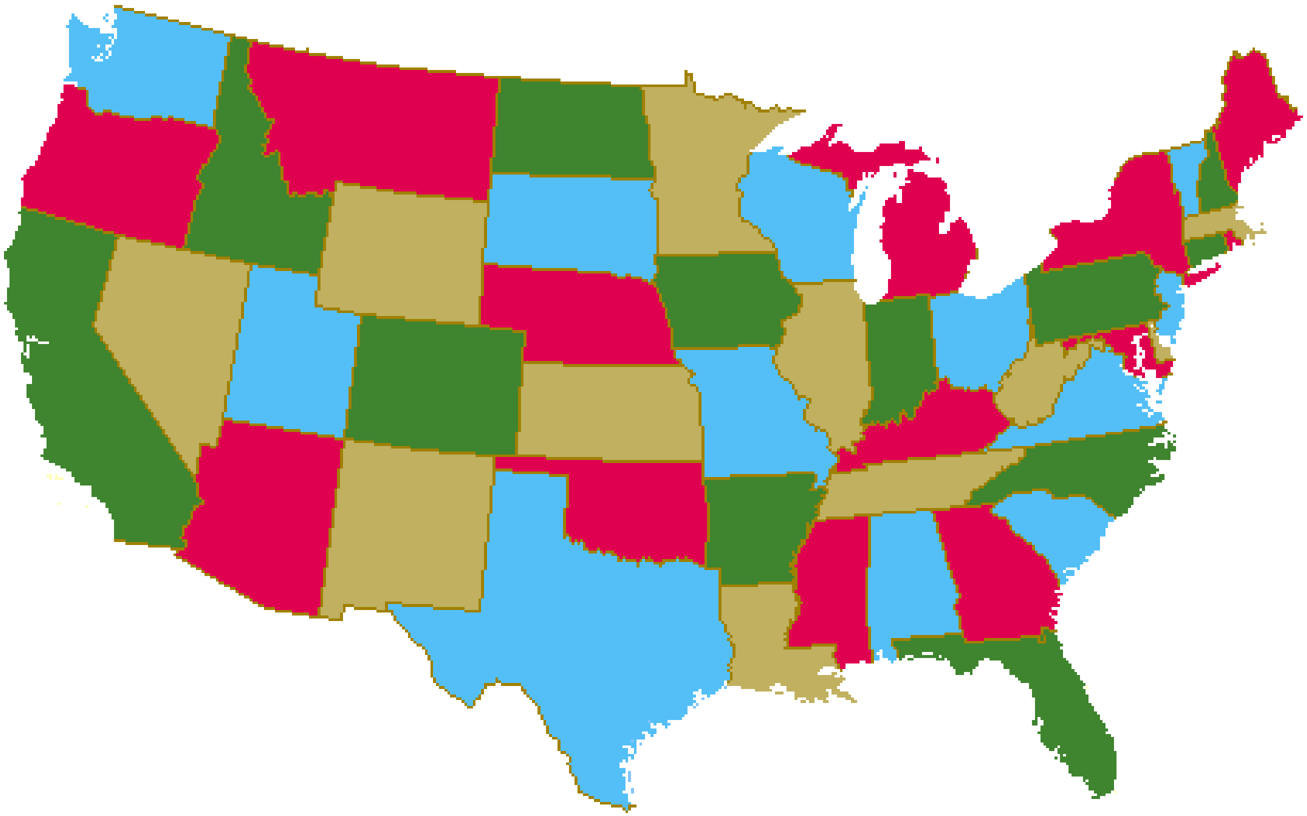
• confidence level about *data*

• respect raw data, not necessarily experimentalist’s interpretation

- **Must respect theory**

Without theory, computation is blind

- Best approach to do science and engineering is symbiosis of all three "mappings". Experiments are the ultimate check; human-comprehensible form is the ultimate desirable form; but computers can help get us there!



"Four color map" theorem first proven using computer (1976).

Logic Power

The computer proof spreads over 400 pages of microfiche.

"*a good mathematical proof is like a poem - this is a telephone directory*!"

Appel and Haken (UIUC) agreed the proof was not "elegant, concise and completely comprehensible by a human mathematical mind".

Boeing 777: the first commercial aircraft to be designed entirely on computer (CAD CATIA, 1994): **Number-crunching power**

IBM Deep Blue beat chess world champion Garry Kasparov (1997)

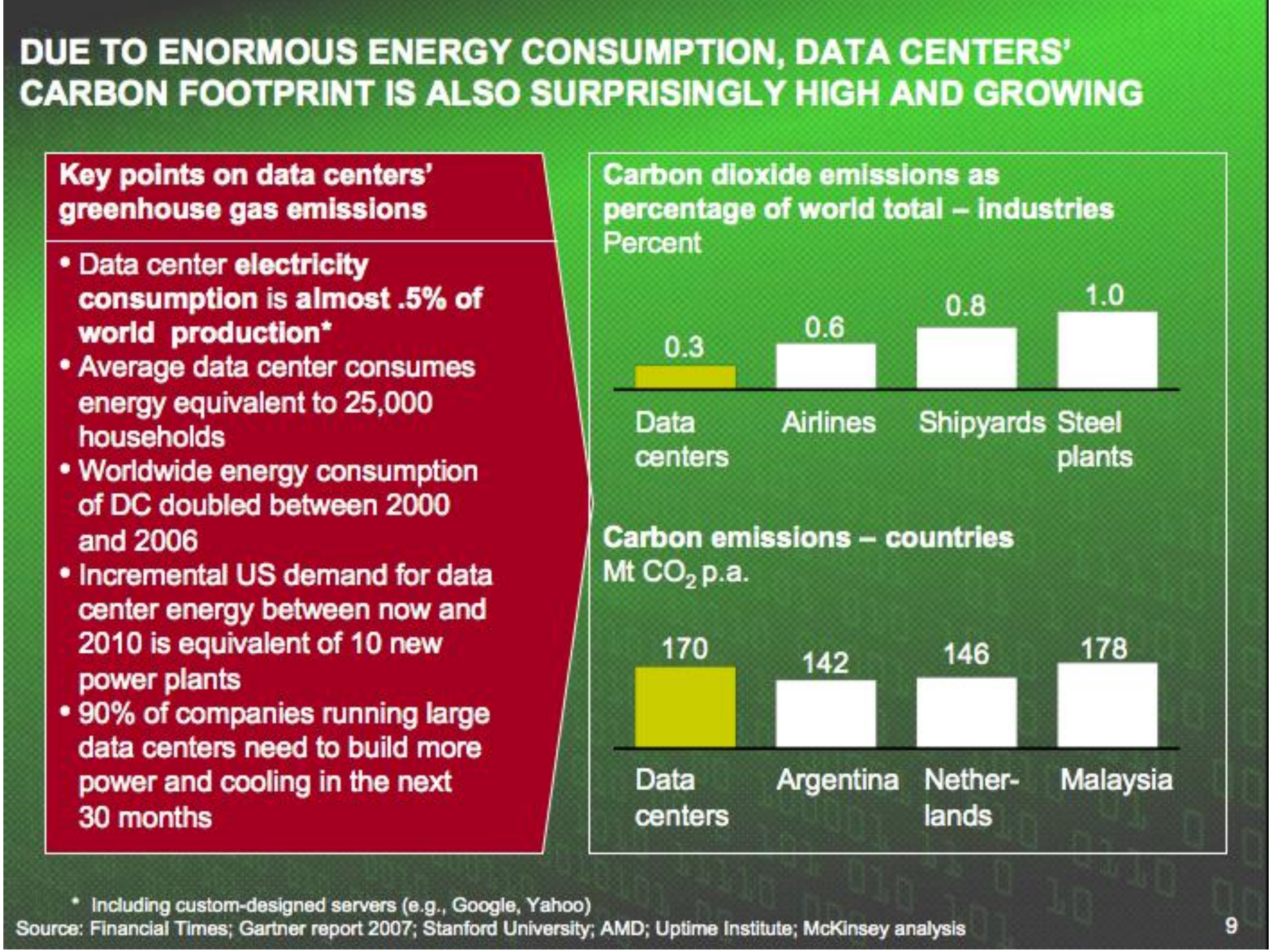
Logic / Computing power

WATSON vs. HUMANS			
Round	Watson	Rutter	Jennings
1 (Mon.)	$5000	$5000	$200
2 (Tues.)	$35,734	$10,800	$4,800
3 (Wed.)	$77,147	$21,600	$24,000
Final prize	$1,000,000	$200,000	$300,000

IBM Watson won quiz show Jeopardy! (2011)

Data Power

Natural Language Processing



"*Worldwide, the digital warehouses use about 30 billion watts of electricity, roughly equivalent to the output of 30 nuclear power plants*", *Power, Pollution and the Internet*

- by James Glanz, New York Times, September 22, 2012

Hot theoretical problem: Computation and the 2nd law of Thermodynamics

…and a day may come when NSE need to show up to save computation

Bibliometric approach (http://apps.webofknowledge.com.libproxy.mit.edu) in Nuclear Science and Engineering

- *Nuclear Science and Engineering* (ANS, 1956)
- *Nuclear Engineering and Design* (Elsevier)
- *Nuclear Technology* (ANS)
- *Progress in Nuclear Energy* (Elsevier)
- *Annals of Nuclear Energy* (Elsevier)
- *Nuclear Fusion* (IAEA / Institute of Physics-UK)
- *Physics of Plasmas* (American Institute of Physics)
- *Journal of Nuclear Materials* (Elsevier)
- *Health Physics* (Health Physics Society)
- *Nuclear Instruments and Methods in Physics Research*

…

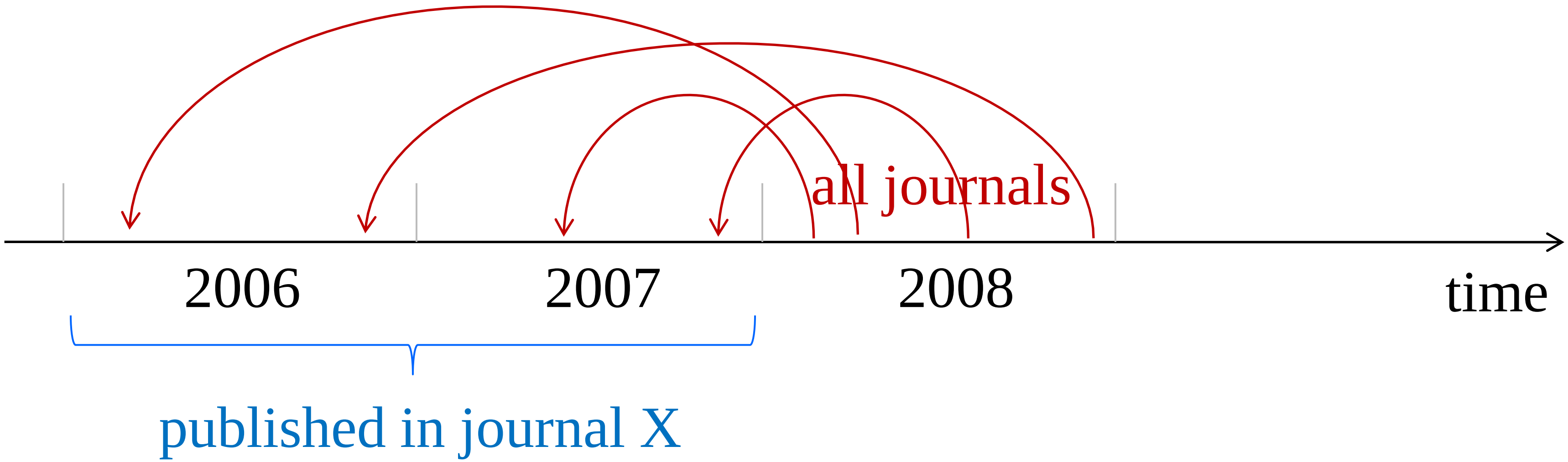
Broader Appeal Journals

- *Physical Review Letters* (American Physical Society)
- *PNAS* (National Academy of Sciences)
- *Science* (American Association for the Advancement of Science)
- *Nature* (Macmillan-UK)

…

Comparing journals (http://admin-apps.webofknowledge.com/JCR/JCR)

Mark	Rank	Abbreviated Journal Title *(linked to journal information)*	ISSN	JCR Data: Total Cites	Impact Factor	5-Year Impact Factor	Immediacy Index	Articles	Cited Half-life	*Eigenfactor*® Metrics: *Eigenfactor*® Score	*Article Influence*® Score
▫	1	NATURE	0028-0836	526505	36.280	36.235	9.690	841	9.4	1.65524	20.373
▫	1	J NUCL MATER	0022-3115	16255	2.052	2.060	0.298	1053	7.9	0.03217	0.587



2008 **impact factor** of journal X ≡
citations in year 2008 to
articles published in 2006 and 2007 in journal X
/ # articles published in 2006 and 2007 in journal X

“Impact factor = 2.1” roughly means 2.1 citations/year in 1.5 years after publication

Field (Size)	$\overline{\text{IF}}$
Molecular and Cell Biology (511)	4.763
Astronomy and Astrophysics (25)	4.295
Gastroenterology (40)	3.475
Rheumatology (20)	3.348
Neuroscience (224)	3.252
Medicine (766)	2.896
Chemistry (145)	2.61
Pharmacology (28)	2.331
Psychiatry (178)	2.294
Urology (23)	2.132
Medical Imaging (84)	2.043
Pathology (28)	1.991
Physics (503)	1.912
Ophthalmology (36)	1.905
Environmental Health (73)	1.871
Analytic Chemistry (129)	1.789
Geosciences (224)	1.768
Law (71)	1.657
Ecology and Evolution (349)	1.555
Parasitology (38)	1.527
Environmental Chemistry and Microbiology (181)	1.505
Computer Imaging (31)	1.446
Dermatology (38)	1.427
Psychology (210)	1.387
Chemical Engineering (75)	1.29

Field (Size)	$\overline{\text{IF}}$
Dentistry (43)	1.284
Orthopedics (72)	1.226
Telecommunication (37)	1.192
Applied Acoustics (36)	1.171
Crop Science (61)	1.04
Business and Marketing (101)	1.035
Geography (56)	0.986
Information Science (23)	0.918
Agriculture (56)	0.882
Anthropology (62)	0.872
Material Engineering (107)	0.826
Economics (159)	0.823
Fluid Mechanics (107)	0.804
Probability and Statistics (57)	0.796
Veterinary (77)	0.767
Sociology (96)	0.715
Media and Communication (24)	0.69
Control Theory (64)	0.681
Political Science (99)	0.68
Computer Science (124)	0.631
Education (86)	0.59
Mathematics (149)	0.556
Operations Research (62)	0.542
History and Philosophy of Science (32)	0.456
History (23)	0.416

Althouse, *J. Am. Soc. Information Sci. Tech.* 60 (2009) 27

Impact factor varies **A LOT** across fields, even sub-fields.

One has to be very careful in using citation statistics when comparing journal/researcher across different fields.

nature Vol 457|19 February 2009|doi:10.1038/nature07634

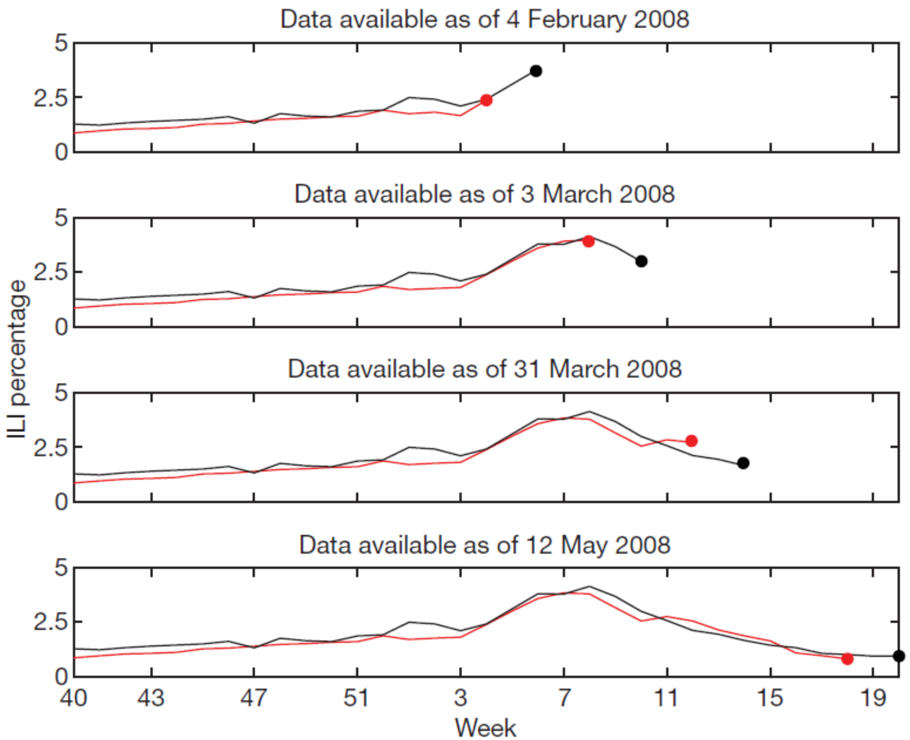
LETTERS

Data, Web and Informatics

Detecting influenza epidemics using search engine query data

[1]Google Inc., 1600 Amphitheatre Parkway, Mountain View, California 94043, USA.
[2]Centers for Disease Control and Prevention, 1600 Clifton Road, NE, Atlanta, Georgia 30333, USA.

Jeremy Ginsberg[1], Matthew H. Mohebbi[1], Rajan S. Patel[1], Lynnette Brammer[2], Mark S. Smolinski[1] & Larry Brilliant[1]



ILI: influenza-like illness physician visits

45 Google queries (informatics, no actual medicinal knowledge), like "*robitussin*", "*symptoms*", "*fever*", "*pnumonia*", "*amoxicillin*", "*strep throat*", …

Google estimates were consistently 1–2 weeks ahead of CDC ILI surveillance reports.

HyperText Markup Language (HTML)

demo.html

```
<HTML>
<HEAD><TITLE>CNSE test</TITLE></HEAD>
<FONT SIZE=+2>Instructor <a href=http://li.mit.edu>Ju Li</A></FONT>
<P>
You can find mcnp introduction <a href=http://mcnp.lanl.gov/>here</a>.
<p>A cool figure:
 <br><a href=Illustration2.jpg><img src=Illustration2.jpg width=150></a><P>Byebye!
</HTML>
<!-- http://li.mit.edu/S/CNSE/demo.html -->
```

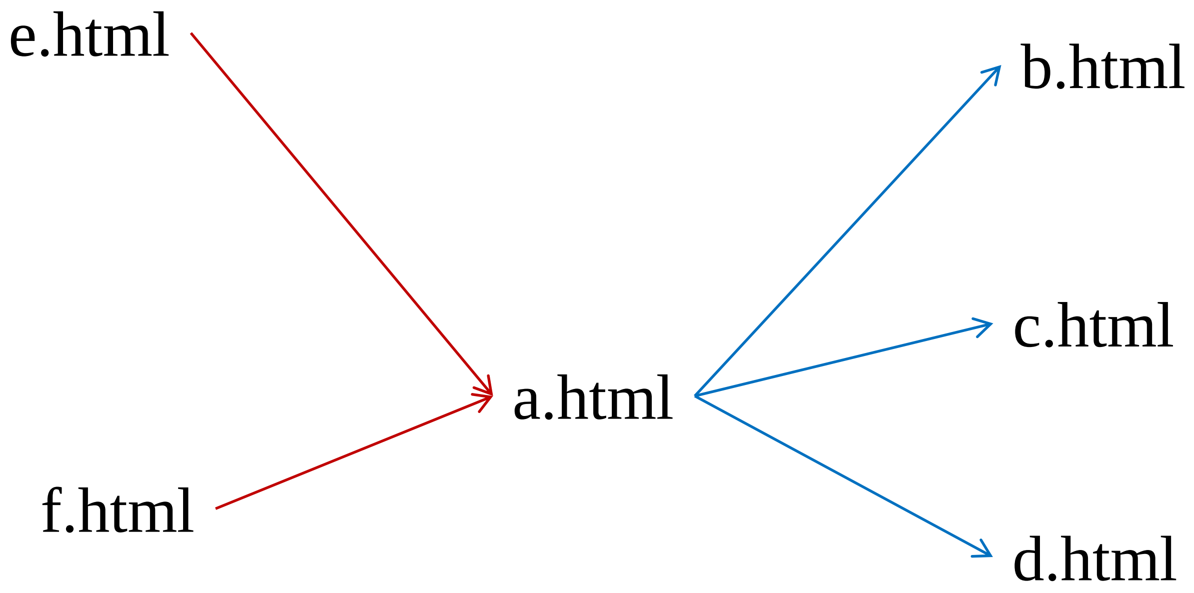
domain name

http://li.mit.edu/S/CNSE/demo.html

host name

(DNS→18.54.1.57)

Press Ctrl+U (Cmd-Opt-U on mac) to view html source



k_{in}(a.html)=2 k_{out}(a.html)=3

PageRank (U.S. Patent 6,285,999), filed by Larry Page and Sergey Brin at Stanford University in 1996, propelled Google to a Mkt Cap 0.2Trillion dollars company in 2012.

In essence, web pages are ranked by their k_{in}

Lecture 2: Nature of the Network

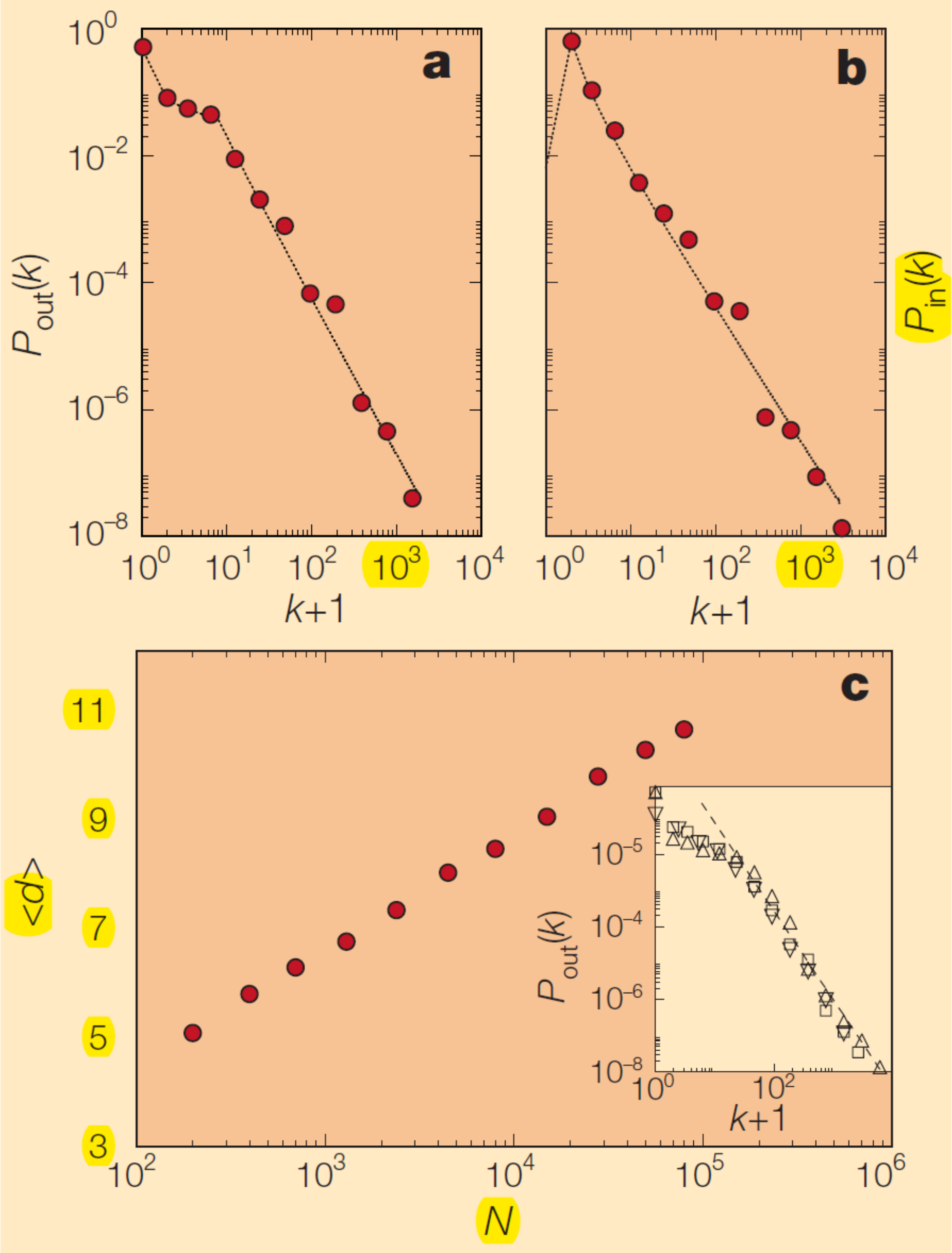
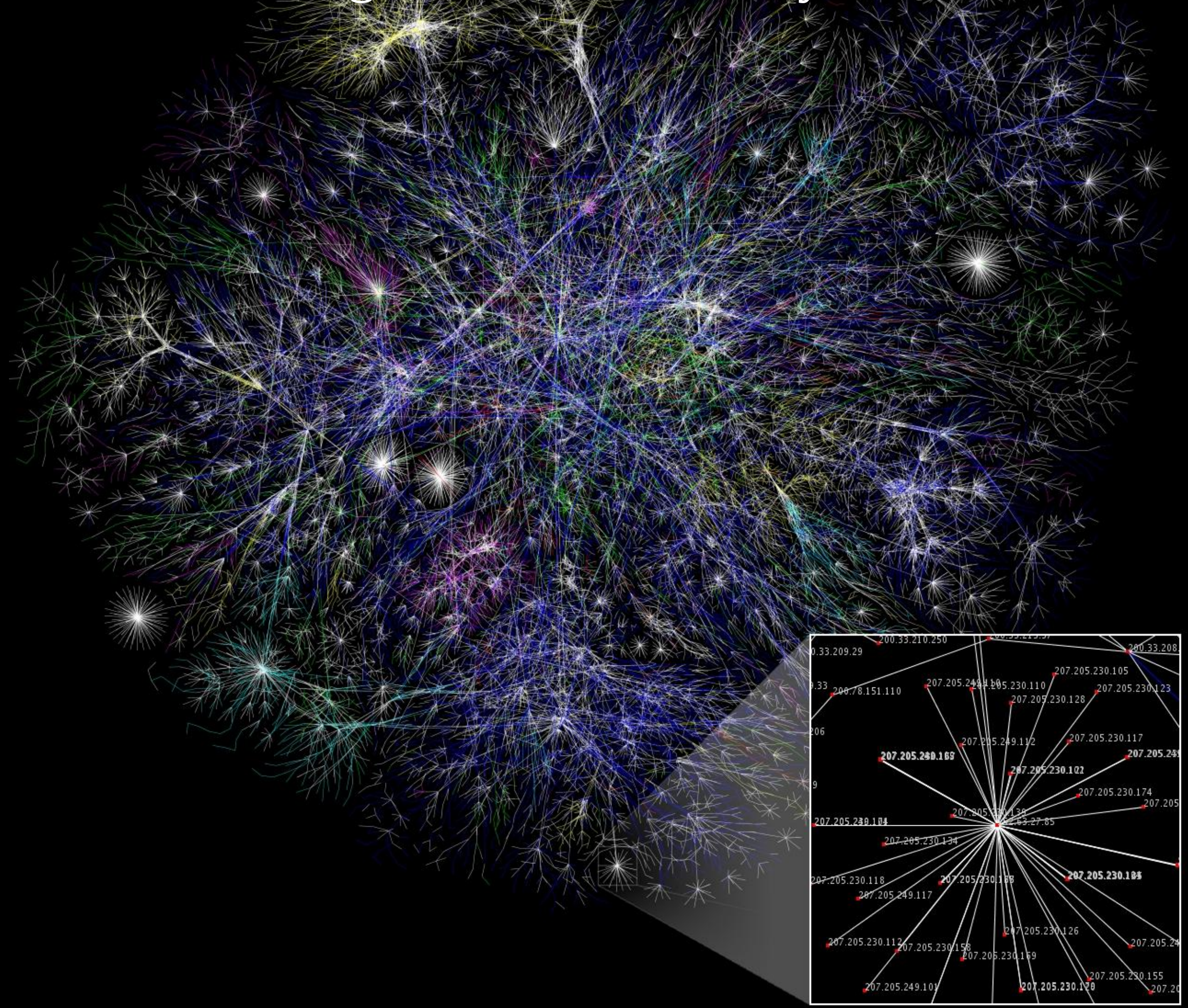


Figure 1 Distribution of links on the World-Wide Web. **a,** Outgoing links (URLs found on an HTML document); **b,** incoming links (URLs pointing to a certain HTML document). Data were obtained from the complete map of the nd.edu domain, which contains 325,729 documents and 1,469,680 links. Dotted lines represent analytical fits used as input distributions in constructing the topological model of the web; the tail of the distributions follows $P(k) \approx k^{-\gamma}$, with $\gamma_{out} = 2.45$ and $\gamma_{in} = 2.1$. **c,** Average of the shortest path between two documents as a function of system size, as predicted by the model. To check the validity of our predictions, we determined d for documents in the domain nd.edu. The measured $\langle d_{nd.edu} \rangle = 11.2$ agrees well with the prediction $\langle d_{3 \times 10^5} \rangle = 11.6$ obtained from our model. To show that the power-law tail of $P(k)$ is a universal feature of the web, the inset shows $P_{out}(k)$ obtained by starting from whitehouse.gov (squares), yahoo.com (triangles) and snu.ac.kr (inverted triangles). The slope of the dashed line is $\gamma_{out} = 2.45$, as obtained from nd.edu in **a**.

Albert, Jeong, Barabasi, "Internet - Diameter of the World-Wide Web," *Nature* **401** (1999) 130. %1382 cites

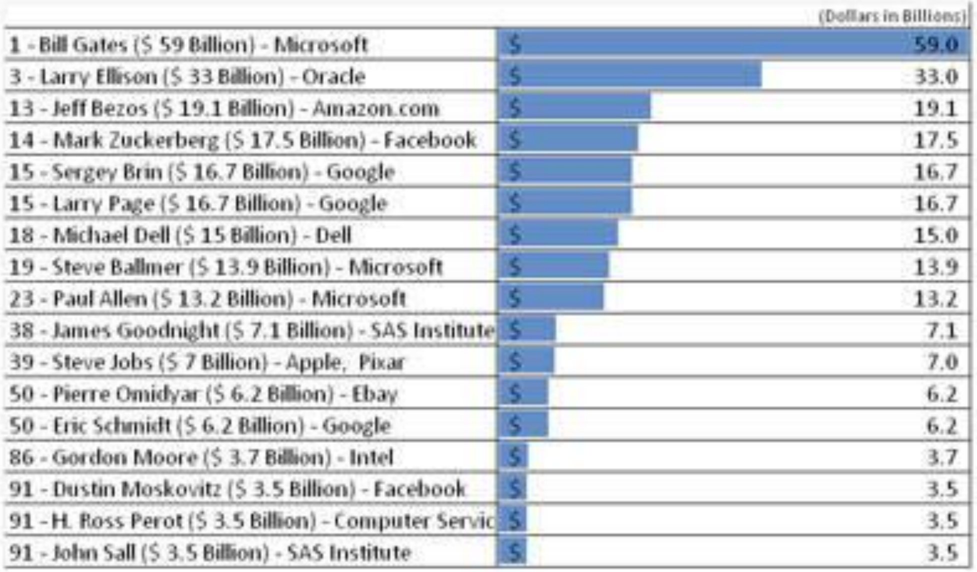
In this lecture, show connections between:

1. **Power-law distribution ("scale-free" behavior)**
2. "Network science" model: growth and preferential attachment
3. Often, hierarchical organization of society and nature



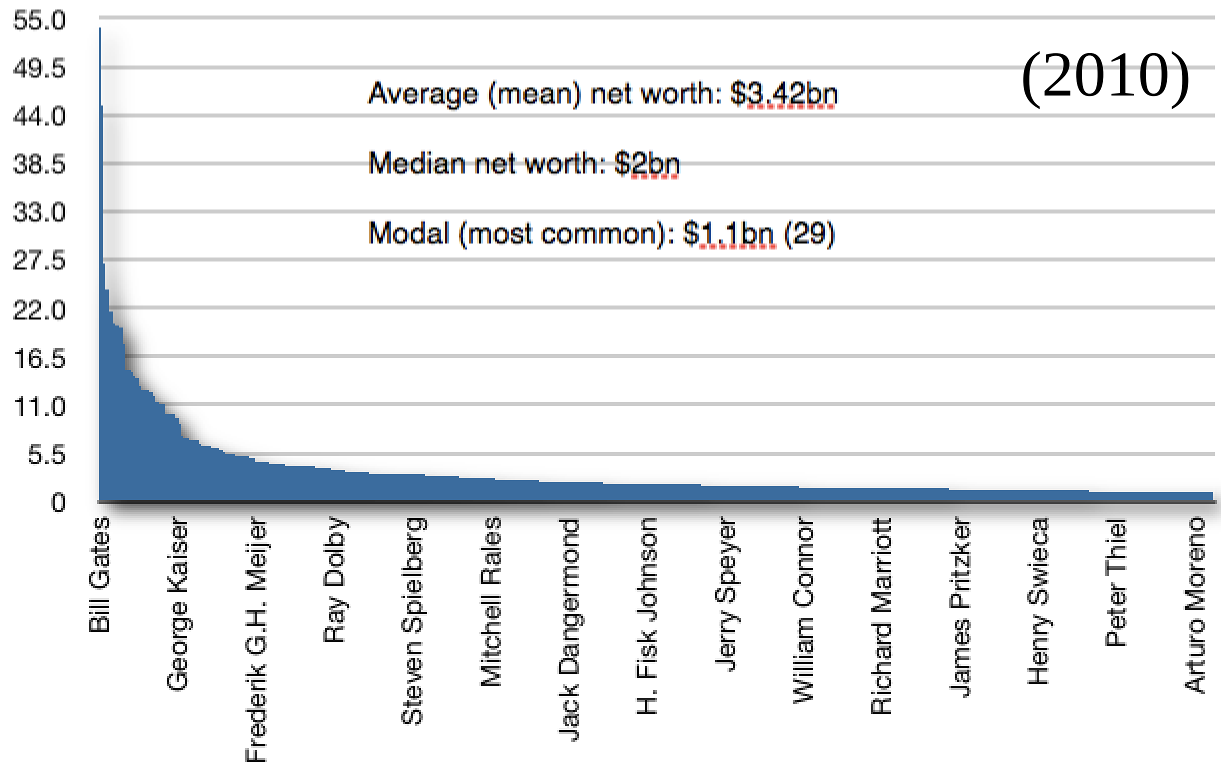
Income inequality is ***worse*** among the 400 richest Americans:

Bill Gates earns 30× median in a population of 400 !



(2011)

The US's 400 richest billionaires, from Forbes



Wealth

Wealth

NATION

The Rich, the Poor And the Oval Office

Being wealthy is no bar to the presidency. The trick is to convince voters that you can feel their pain

BY RICHARD NORTON SMITH

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It's hard to imagine Abraham Lincoln as a traitor to his class. But as a candidate for Congress in 1843, Lincoln was the target of a whispering campaign inspired by his marriage into the elite Todd and Edwards families. Lincoln professed astonishment that anyone who had known him as a $10-a-month flatboat man could really believe he had morphed into "the candidate of pride, wealth and aristocratic family distinction." Likewise, his legal work for the Illinois Central Railroad—for which he received as much as $5,000 a case—would later be cited as evidence that Lincoln was no friend of the workingman.

He inoculated himself against such charges in the spring of 1860, when Lincoln-for-President partisans marched into the Illinois Republican state convention bearing a weathered pair of fence rails purportedly split by their hero. In another bit of orchestrated spontaneity, the candidate was called upon to acknowledge his youthful handiwork. He wasn't certain of the rails in question, said Lincoln, but he had split a good many better ones since growing to manhood. In that moment, A. Lincoln, Railroad Lawyer, gave way to Abe Lincoln, Rail Splitter, a more marketable image for one who hadn't betrayed his origins so much as he had spent a lifetime escaping them.

Mitt Romney says Americans celebrate success, and he's right. But that doesn't mean they do so uncritically, still less that they agree on its meaning. The controversy surrounding Romney's wealth, how it was acquired and whether he understands those who have been less successful is part of a long-running debate over private gain and public obligation. It is inseparable from presidential politics, in which the biggest single determinant of any incumbent's chances for reelection is usually his record of economic stewardship.

No matter the era, what hasn't changed is the vulnerability of politicians in times of economic distress. No one begrudged the first George Bush his ancestral home in Kennebunkport, so reminiscent of the Kennedy compound down the coast in Hyannis Port. There the parallels end. That Kennedy lived off a $10 million trust fund established by his bootlegging father didn't preclude him from labeling price-gouging steel executives "sons of bitches." Like Theodore Roosevelt confronting "malefactors of great wealth" as embodied by J.P. Morgan, Kennedy defined himself not by his money but by his enemies. The gentlemanly Bush picked no such fights. While JFK's sailing prowess reinforced the misty legend of a classy guy, Bush's cigarette boat defined him by class. His overhyped encounter with a supermarket scanner fed the narrative of a country squire with oil on his boots, his instincts dulled by noblesse oblige. Would it have generated the same reaction had the country not been in recession? The question answers itself.

JFK was right. Life is unfair. Few questioned the tax ruling under which Dwight Eisenhower, World War II's ultimate hero, was able to treat the considerable income from his war memoirs as a capital gain. Even the IRS liked Ike. By contrast, Herbert Hoover, having earned millions as the Great Engineer and given away much of it as the Great Humanitarian, refused his salary. That didn't keep him from becoming a caricature of Depression-era heartlessness, indifference in a batwing collar.

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Symbolism matters. Long before Jimmy Carter rebuked the imperial presidency by walking down Pennsylvania Avenue on his Inaugural Day, Thomas Jefferson dispensed with his predecessors' horse-drawn coaches for his oath taking. The epicurean Jefferson was as tightfisted with the people's money as he was reckless in spending his own. As President, he slashed the military budget and shuttered foreign outposts in his determination to liquidate the national debt. "It is to be regretted that the rich and powerful too often bend the acts of government to their selfish purposes," Andrew Jackson wrote in vetoing the rechartering of a national bank. Only a President, implied Jackson (a slave master and the owner of a large plantation), can protect the humbler members of society from monopoly and crass exploitation. Theodore Roosevelt's Square Deal, Franklin Roosevelt's New Deal and Harry Truman's Fair Deal were not conceived in the spirit of us vs. them. Rather, each was envisioned as a chapter in the unfolding story of American democracy, confirming the irrelevance of bloodlines and bank accounts alike.

Put another way, fortune may favor the 1%, but history rewards those who redistribute opportunity. As in other periods of economic distress, the 2012 election promises a referendum on the Forgotten Man. Is he the victim of capitalist redundancy or Wall Street ruthlessness to whom FDR brilliantly pitched his political revolution? Or is he the patriot at war with the popular culture, feeling his talents oppressed by Washington's social engineers, who rallied to Richard Nixon in 1968? Nixon's brand of cloth-coat conservatism anticipated Reagan's religion of the marketplace and its populist offshoot, the Tea Party.

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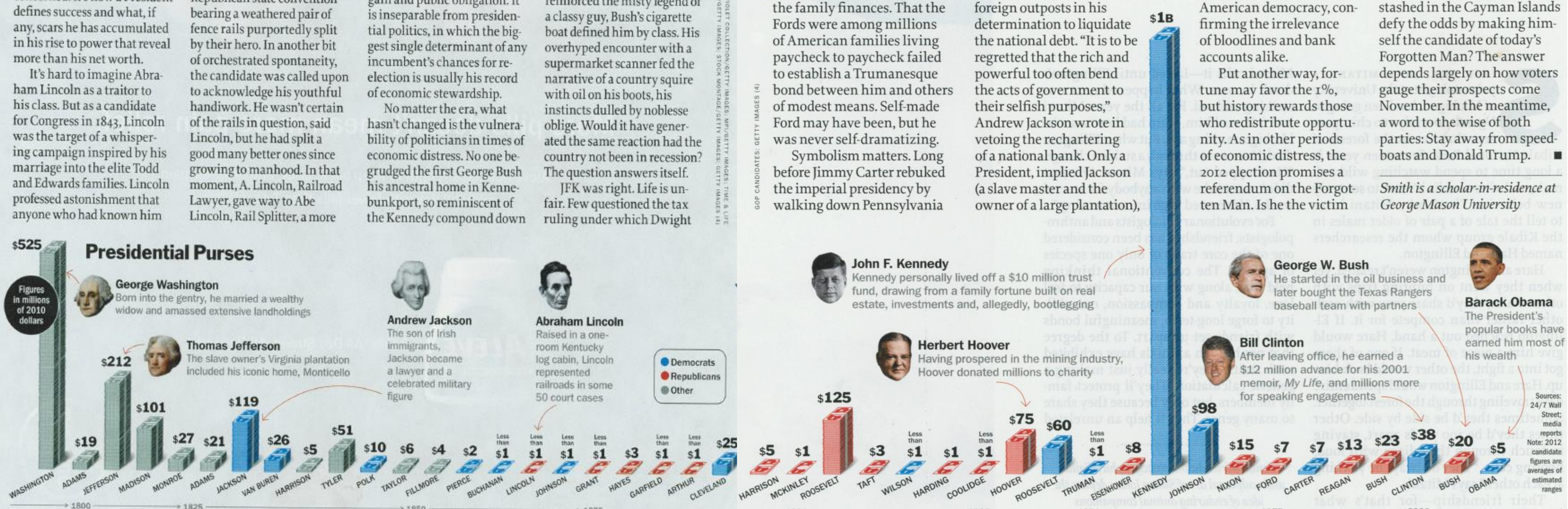
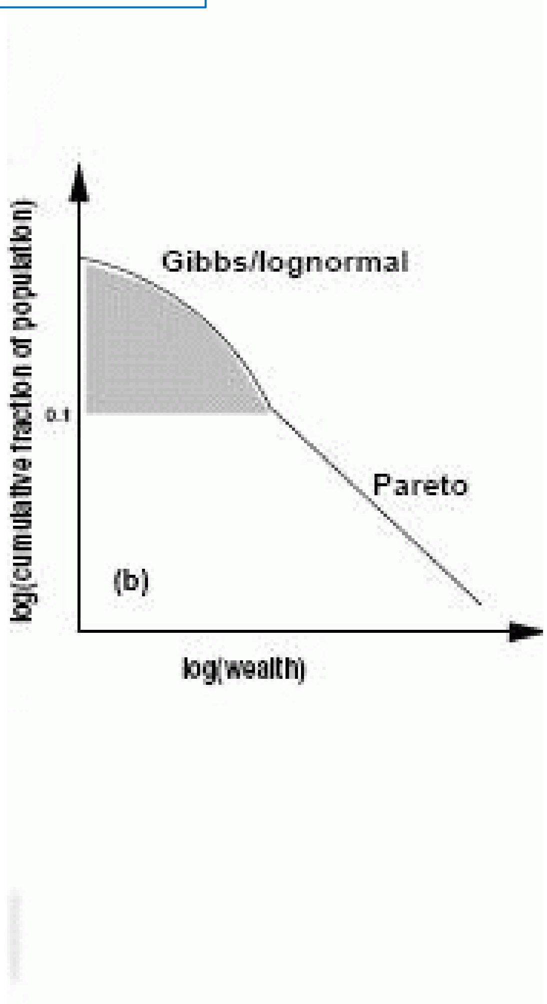
GOP CANDIDATES: GETTY IMAGES (4)

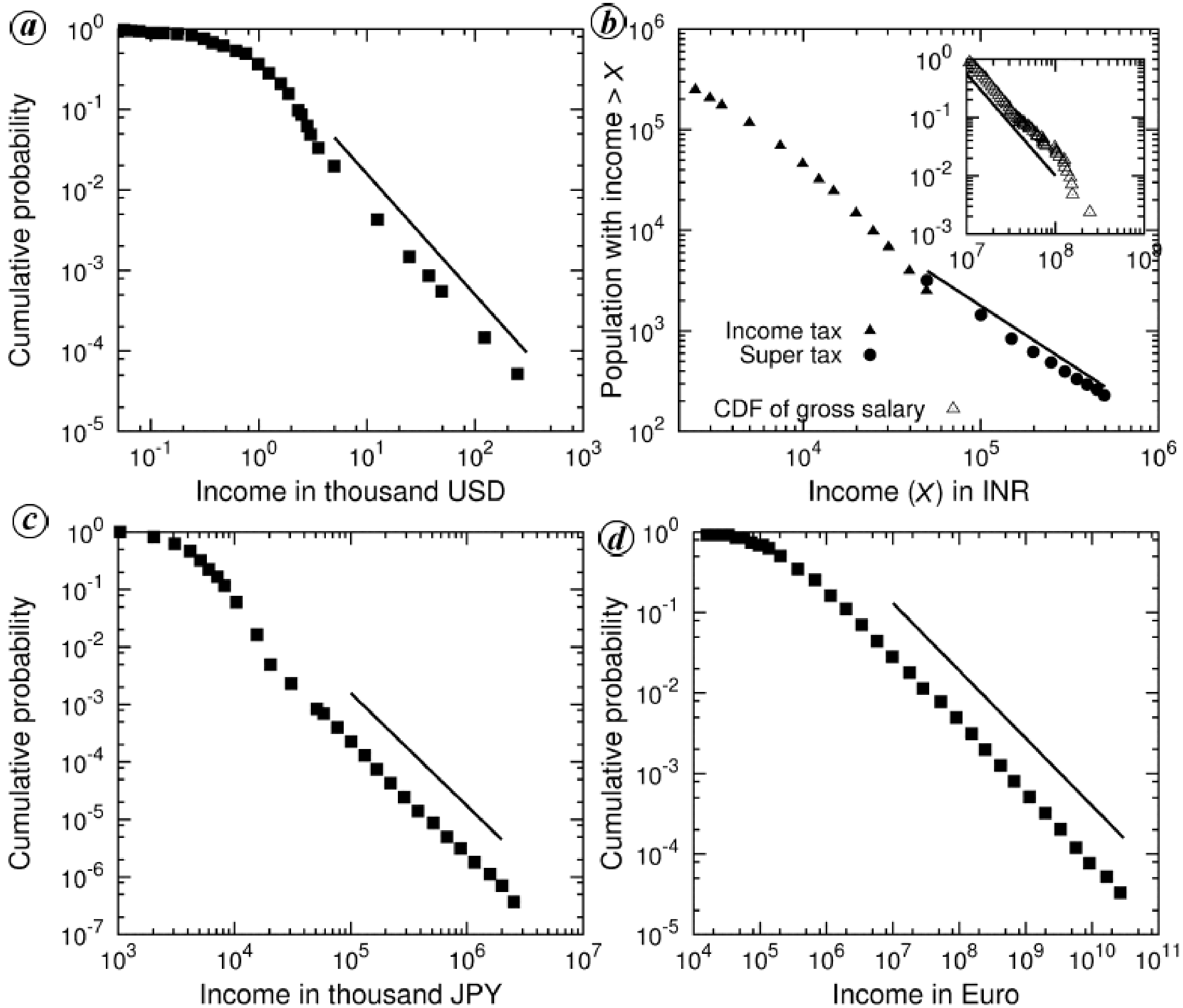
Presidential Purses



CHART, FROM LEFT: ROGER VIOLLET COLLECTION/GETTY IMAGES; MPI/GETTY IMAGES; TIME & LIFE PICTURES/GETTY IMAGES; HULTON ARCHIVE/GETTY IMAGES; STOCK MONTAGE/GETTY IMAGES; GETTY IMAGES (4)

Wealth





Left graph shows how 90% of a population follows a log-normal wealth distribution, while the richest 10% veers off in a tail following a Pareto power law distribution.

Chatterjee, Sinha, Chakrabarti, "Economic inequality: Is it natural?" *Current Science* **92** (2007) 1383

Power-law Distribution $\rho(w) \propto w^{-\gamma}$, $w \in (w_1, w_2)$

w is extensive quantity (additive: $w_{AB} = w_A + w_B$)

dollar, land, citation, degree of connection, energy, …

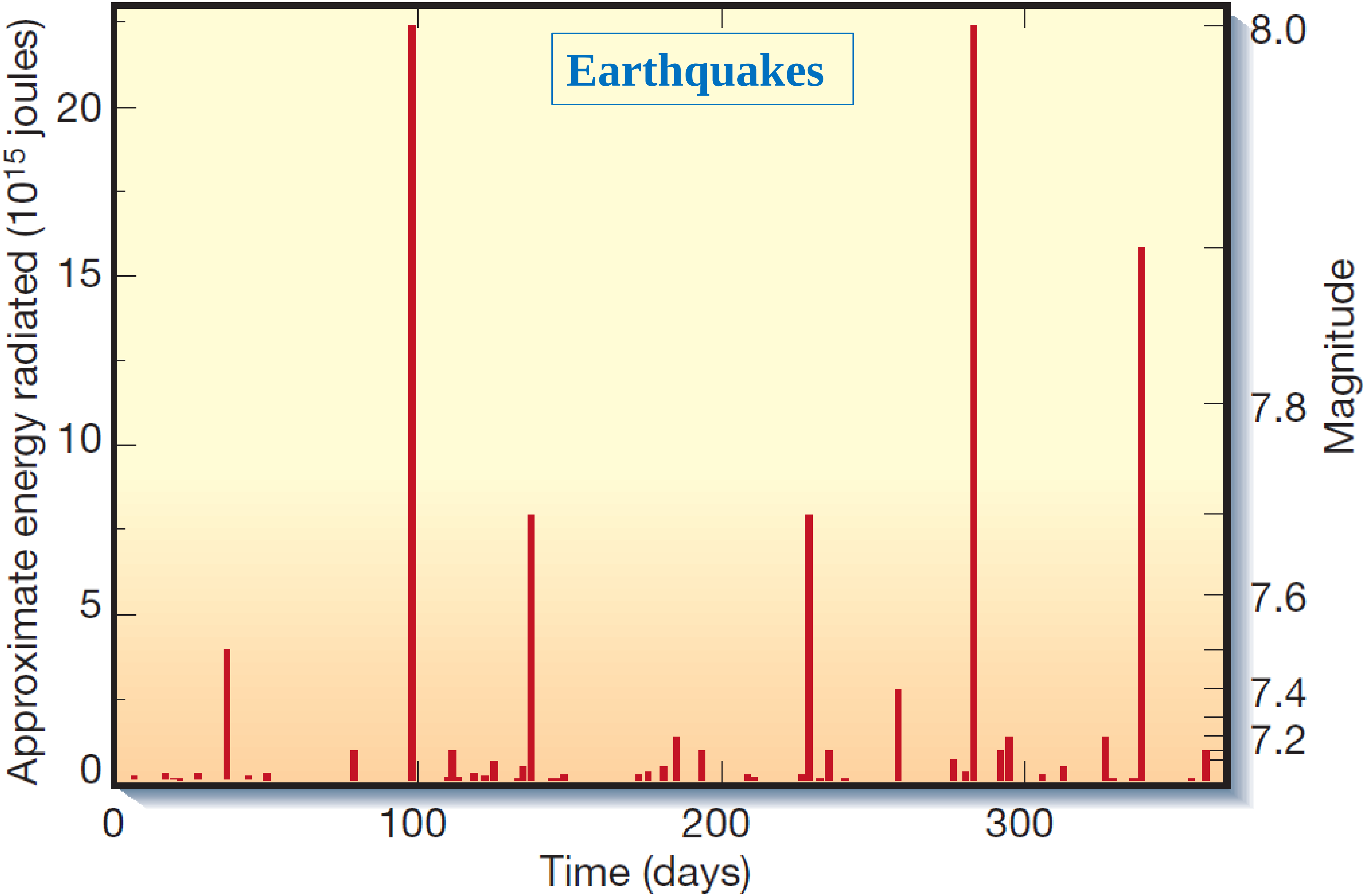
In addition to wealth, other examples include

- Earthquakes (energy)
- Nuclear Accidents (damage)
- War and Terrorism (casualty)
- Languages (Zipf's law)
- Geometry

Earthquakes

Property damages caused by earthquake

Rank	Name	Magnitude	Property damages
1	2011 Tōhoku earthquake, Japan	9.0[27]	$122 billion[28]
2	1995 Great Hanshin earthquake, Japan	6.9	$100 billion
3	2008 Sichuan earthquake, China	8.0	$75 billion[29]
4	2010 Chile earthquake, Chile	8.8	$15–30 billion[30]
5	1994 Northridge earthquake, United States	6.7	$20 billion
6	2011 Christchurch earthquake, New Zealand	6.3[31]	$12 billion
7	1989 Loma Prieta earthquake, United States	6.9[32]	$11 billion
8	921 earthquake, Taiwan (1999)	7.6	$10 billion
9	1906 San Francisco earthquake, United States	7.9[33]	$9.5 billion
10	1960 Valdivia earthquake, Chile	9.5[34]	$2.9–5.8 billion



Time history of radiated energy from earthquakes throughout all of 1995.
Sethna, Dahmen, Myers, "Crackling noise," *Nature* **410** (2001) 242.

The Rich, the Poor And the Oval Office

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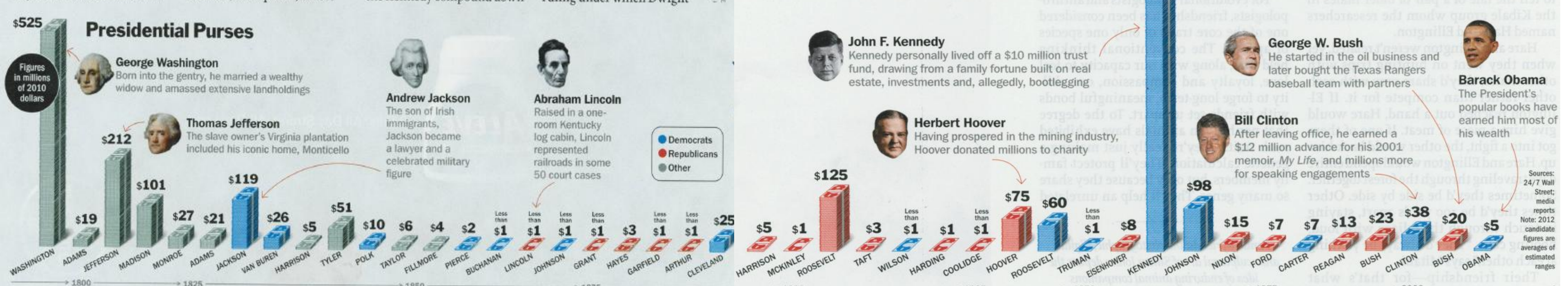
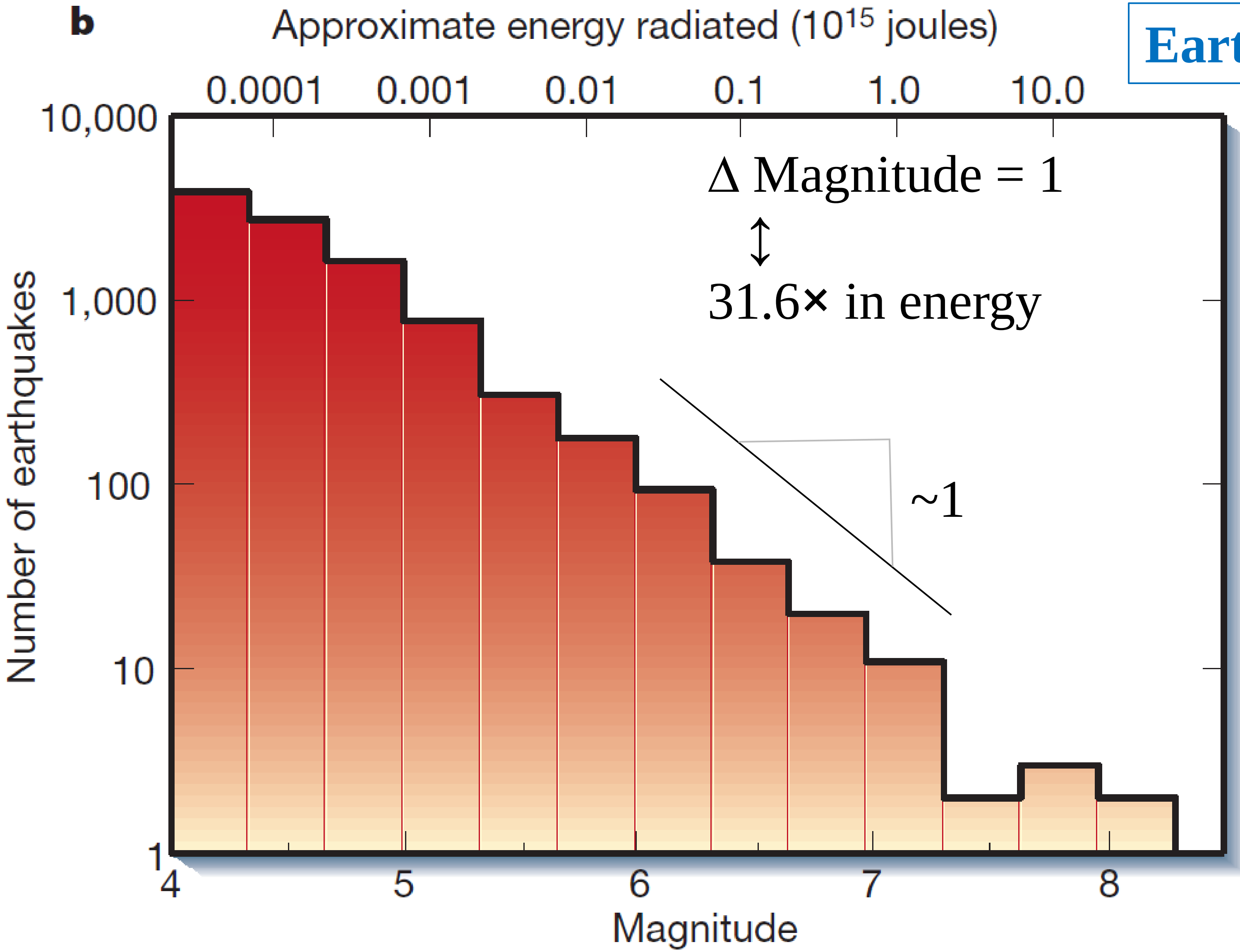


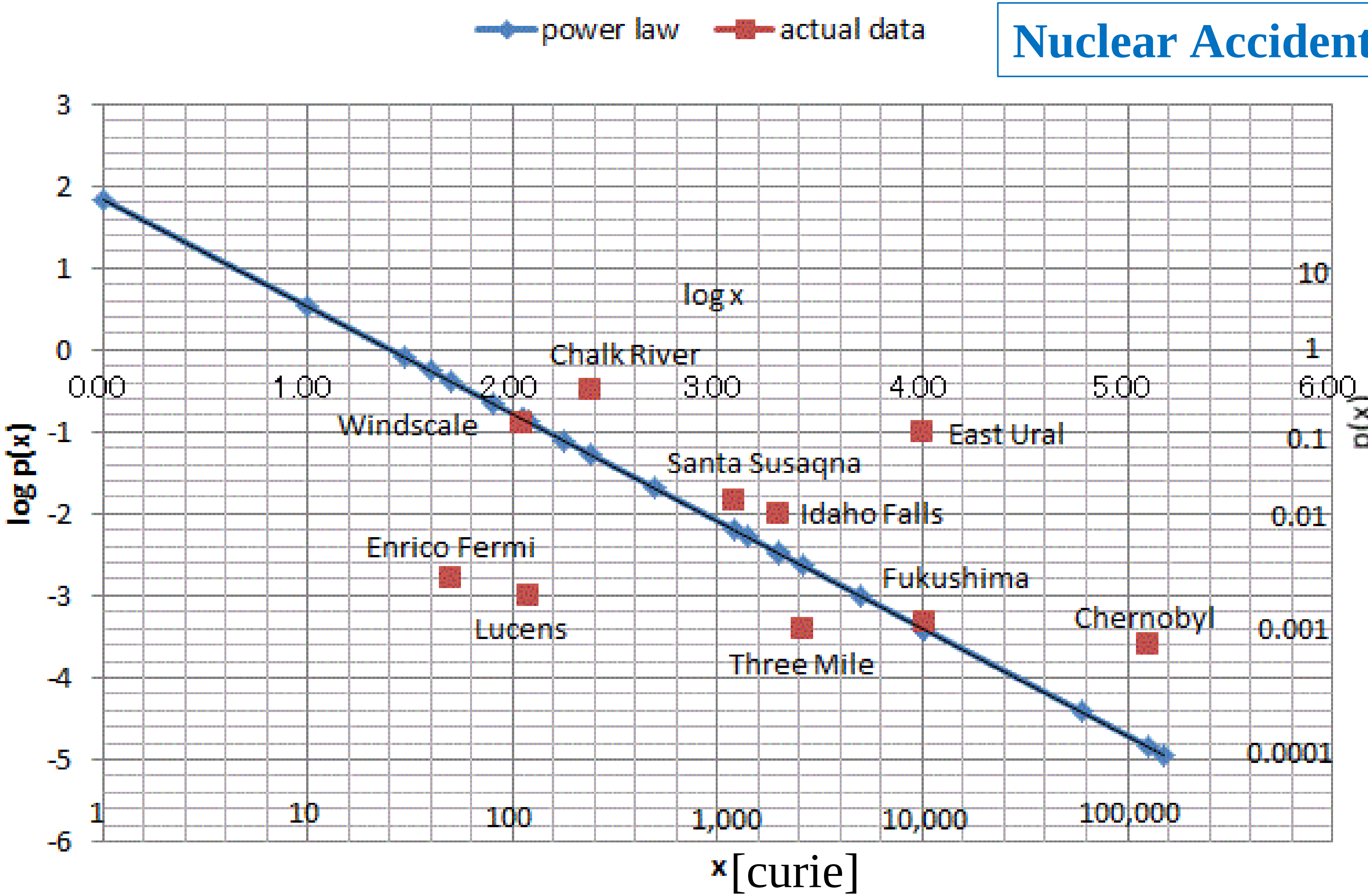
Earthquakes



Number of earthquakes on Earth in 1995 exceeding Richter magnitude *M*

Gutenberg–Richter law $N(\text{magnitude}>M) \approx 10^{a-bM}$

Nuclear Accidents

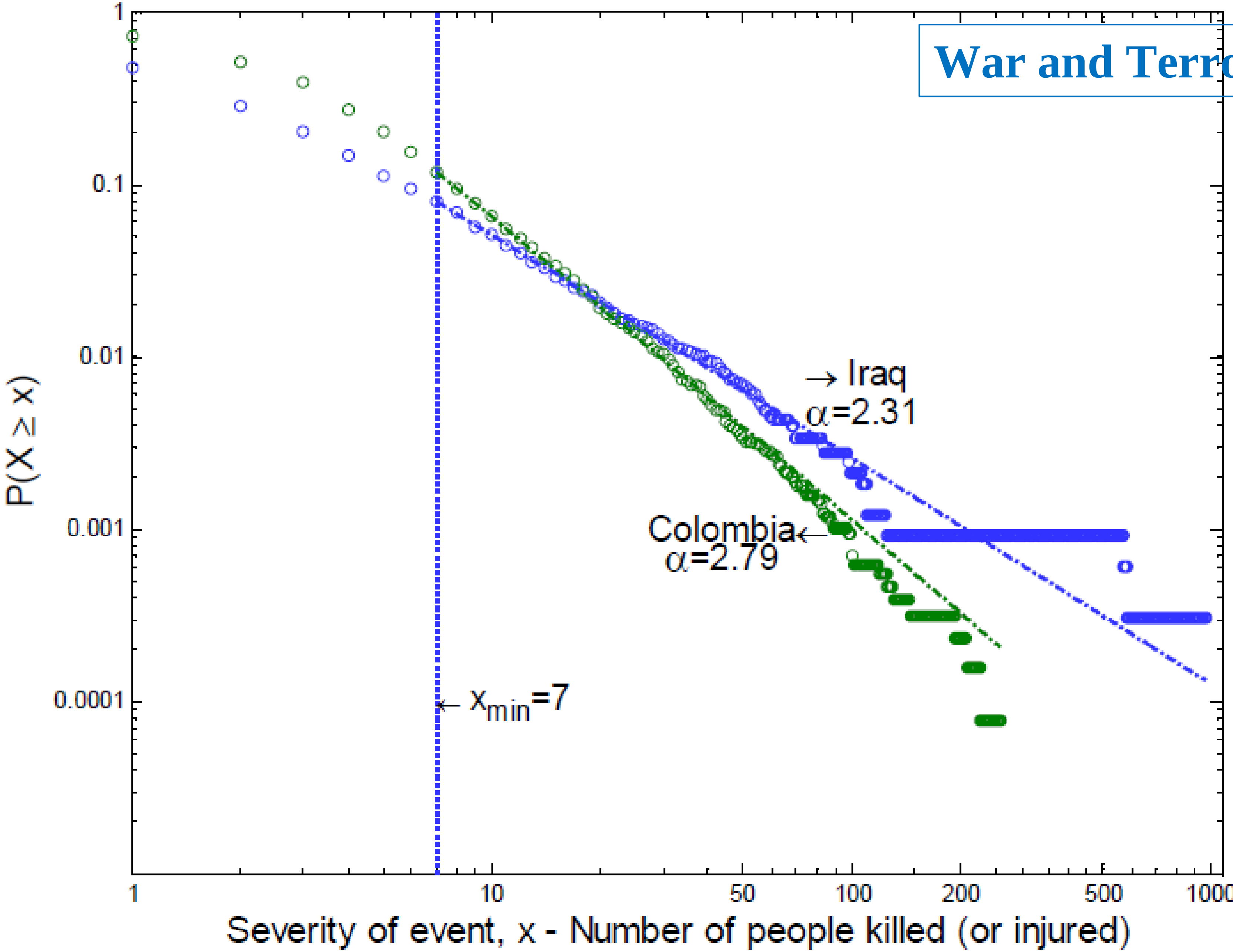


Probability vs. released Radioactive materials

1 Ci = 3.7×10[10] decays per second ~ 1 gram of radium ^{226}Ra

http://www.asahi-net.or.jp/~pu4i-aok/cooldata2/politics/fukushimameltdown.htm

War and Terrorism



Neil F. Johnson et al, “Universal patterns underlying ongoing wars and terrorism,” http://xxx.lanl.gov/abs/physics/0506213

Events before May 1st, 2003

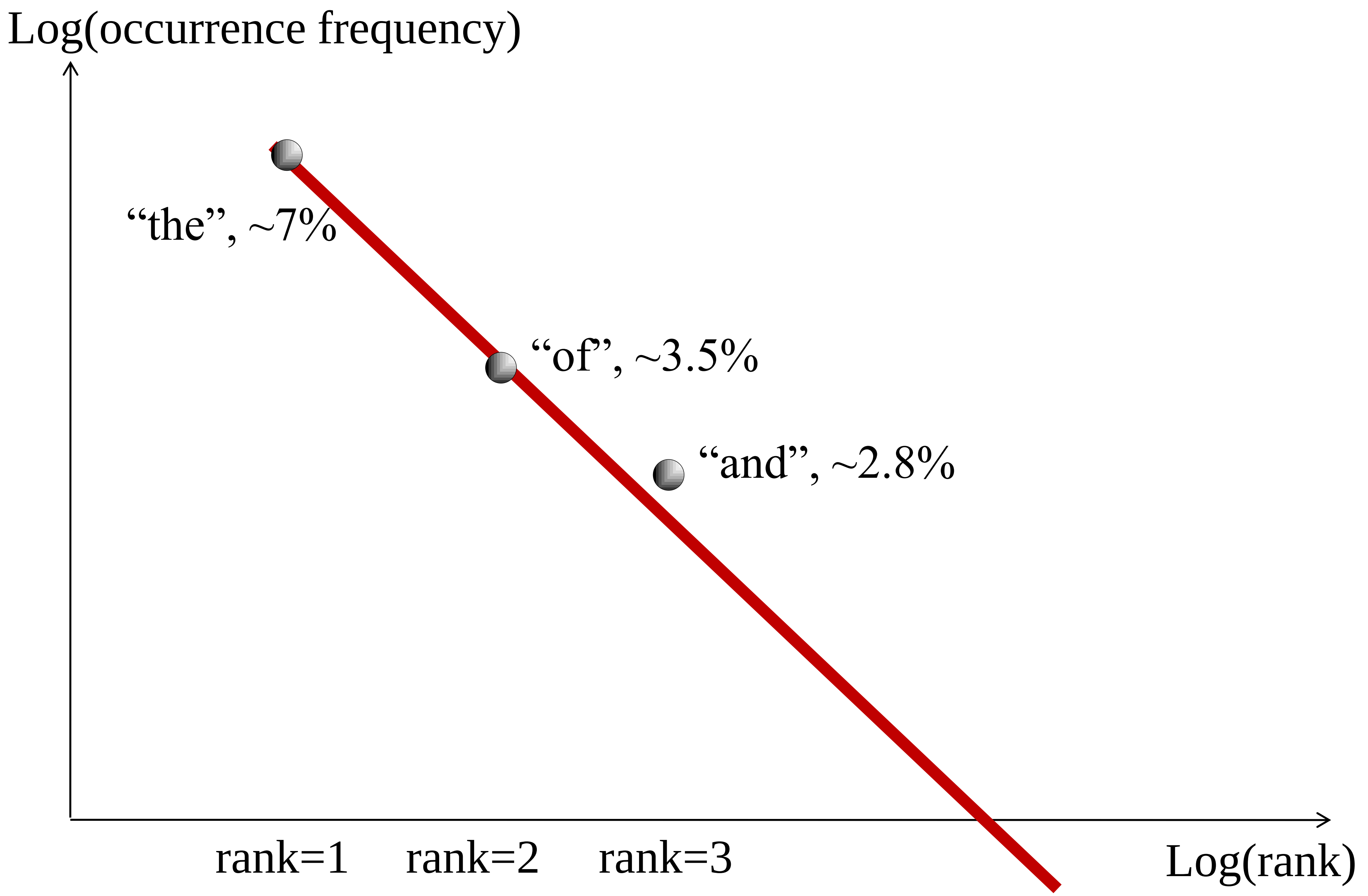
Start Date	City	Killings Min.	Killings Max
3/20/03	Baghdad	1473	2000
3/20/03	Najaf	224	358
3/20/03	Basra	142	200
3/20/03	Najaf, Karba, Mosul, Samawa, Madain, Diwaniyah, Kut, Tikrit	484	445
3/20/03	Baghdad	22	22
3/20/03	Rutba	1	1
3/21/03	Baghdad	0	3
3/21/03	Umm Qasr	2	2
3/22/03	ImAnas	1	1
3/22/03	Mosul	4	4
3/22/03	Nassiriya	12	12
3/22/03	Basra	50	77
3/22/03	Tikrit	4	5
3/22/03	Kurdistan	57	100
3/23/03	Najaf	3	8
3/23/03	Rutbah	5	5
3/23/03	Babel	30	30
3/23/03	Basra	14	14
3/23/03	Karba	10	10
3/23/03	Nassiriya	10	10
3/24/03	Baghdad	5	5
3/24/03	Baghdad	5	5
3/25/03	Ash Shatra	2	2
3/25/03	Nassiriya	2	2
3/26/03	Rutbah	2	2
3/26/03	Baghdad	14	14
3/26/03	Baghdad	21	21
3/27/03	Missan	2	2
3/27/03	Mosul	2	50
3/27/03	Waset	2	2
3/27/03	Baghdad	7	7
3/27/03	Babel	26	26
3/27/03	Karba	11	11
3/27/03	Hillah	78	201
3/27/03	Najaf	26	26
3/28/03	Baghdad	34	62
3/28/03	Anbar	28	28
3/28/03	Babel	3	3
3/28/03	Baghdad	6	6
3/28/03	Karba	6	6
3/28/03	Najaf	35	35
3/29/03	Unknown	1	1

Events before May 1st, 2003

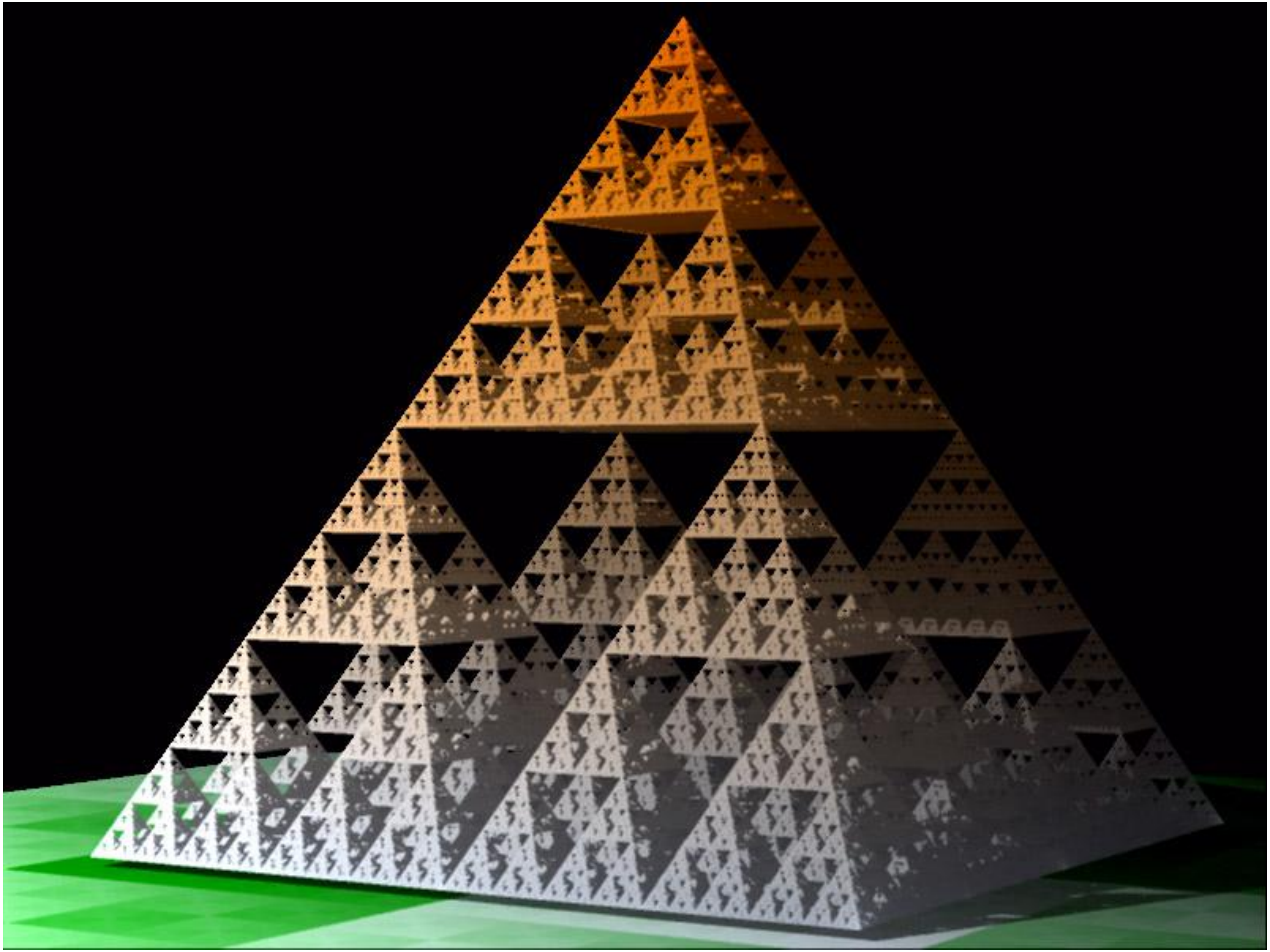
Start Date	City	Killings Min.	Killings Max
3/29/03	Janabiin	20	20
3/30/03	Baghdad	15	15
3/31/03	Baghdad	6	6
3/31/03	Mosul	21	21
3/31/03	Hillah	15	15
3/31/03	Hillah	24	24
3/31/03	Najaf and Karba	11	11
3/31/03	Baghdad	24	24
4/1/03	Baghdad	1	1
4/1/03	Shatra	1	1
4/1/03	Hillah	33	33
4/2/03	Baghdad	43	43
4/2/03	Baghdad	5	5
4/3/03	Baghdad	10	16
4/3/03	Baghdad	27	27
4/3/03	Basra	42	51
4/3/03	Karba	5	5
4/3/03	Najaf	0	40
4/4/03		17	17
4/4/03	najaf	7	7
4/4/03	Baghdad	6	6
4/5/03	Karba	1	1
4/5/03	Baghdad	22	22
4/5/03	Rashidiya	85	85
4/5/03	Basra	17	17
4/6/03	irbil	1	1
4/6/03	Baghdad	15	15
4/6/03	karbala	35	35
4/7/03	Baghdad	2	2
4/7/03	Baghdad	9	14
4/7/03	Baghdad	11	11
4/7/03	Baghdad	4	4
4/7/03	Baghdad	3	3
4/8/03	Baghdad	1	1
4/8/03	Baghdad	2	2
4/8/03	Baghdad	35	35
4/8/03	Baghdad	13	13
4/9/03	Baghdad	2	2
4/9/03	Fathlia	4	4
4/9/03	Baghdad	5	21
4/9/03	Baghdad	21	26
4/10/03	Baghdad	30	30
4/10/03	Kirkuk	40	40

Neil F. Johnson et al, "Universal patterns underlying ongoing wars and terrorism," http://xxx.lanl.gov/abs/physics/0506213

Zipf's law


Log(occurrence frequency)
"the", ~7%
"of", ~3.5%
"and", ~2.8%
rank=1
rank=2
rank=3
Log(rank)

Fractal : Power-law distribution



http://upload.wikimedia.org/wikipedia/commons/2/29/Sierpinski_pyramid.jpg

How Long Is the Coast of Britain?

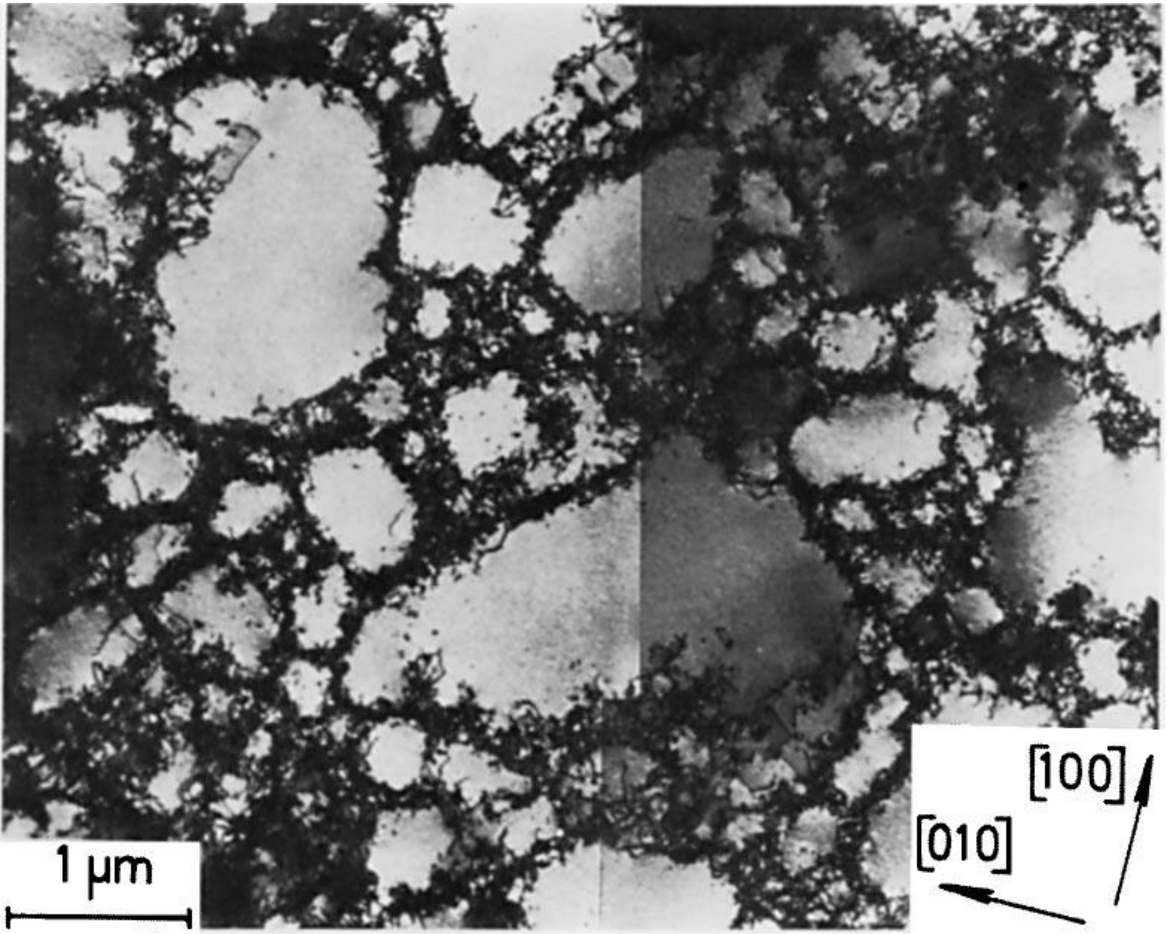
Science **156** (1967) 636

Geometry

Statistical Self-Similarity and Fractional Dimension

Abstract. *Geographical curves are so involved in their detail that their lengths are often infinite or, rather, undefinable. However, many are statistically "self-similar," meaning that each portion can be considered a reduced-scale image of the whole. In that case, the degree of complication can be described by a quantity* D *that has many properties of a "dimension," though it is fractional; that is, it exceeds the value unity associated with the ordinary, rectifiable, curves.*

BENOIT MANDELBROT
International Business Machines,
Thomas J. Watson Research Center,
Yorktown Heights, New York 10598



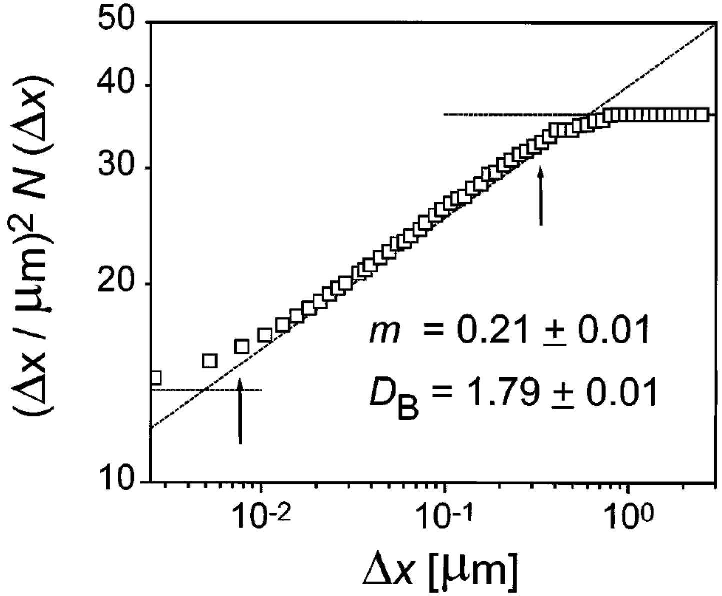
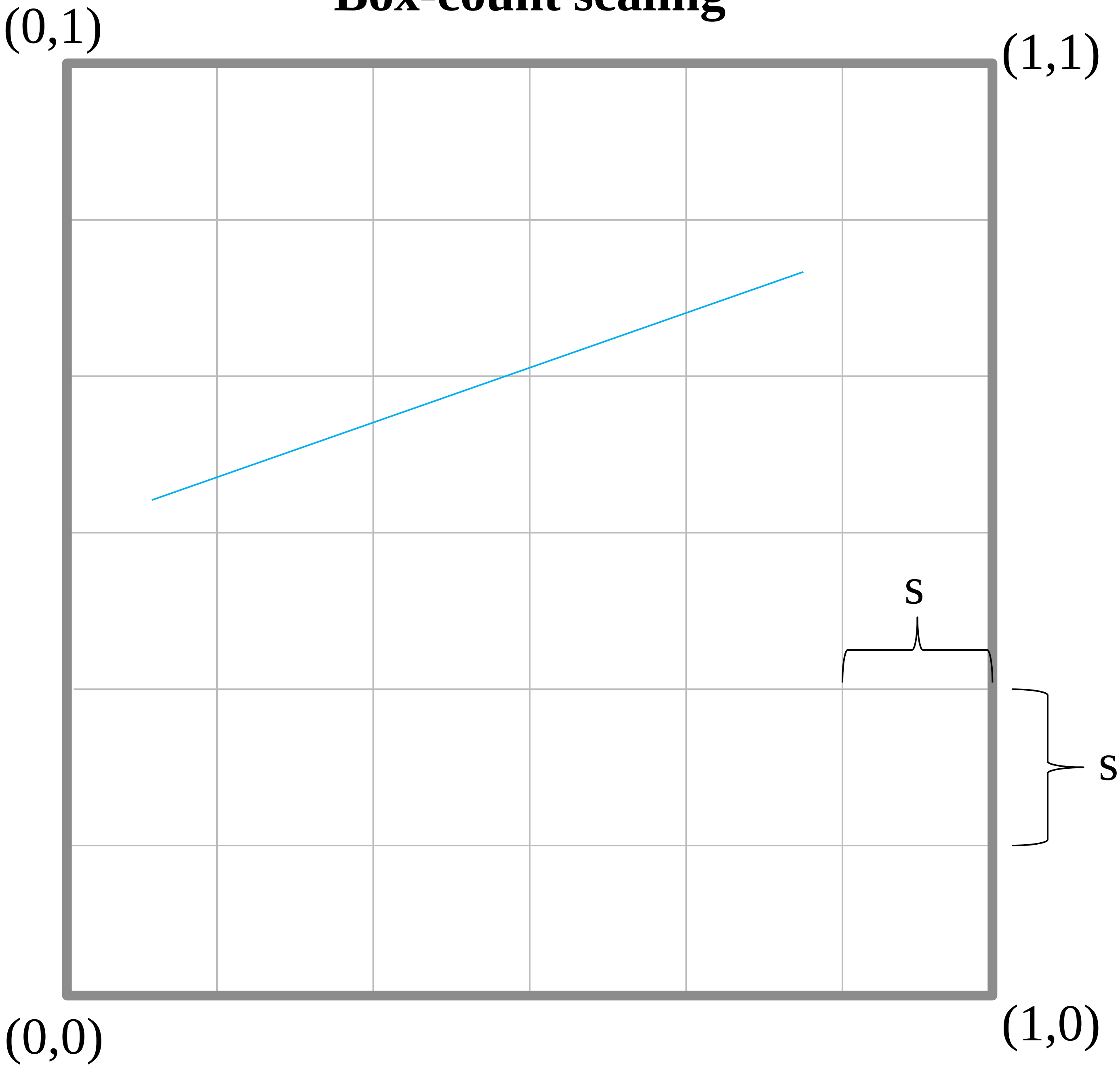


FIG. 2. Analysis of the cell structure in Fig. 1 by determining the "box dimension" D_B; for details see text.

Hahner, Bay, Zaiser, "Fractal dislocation patterning during plastic deformation," Phys. Rev. Lett. 81 (1998) 2470

Box-count scaling



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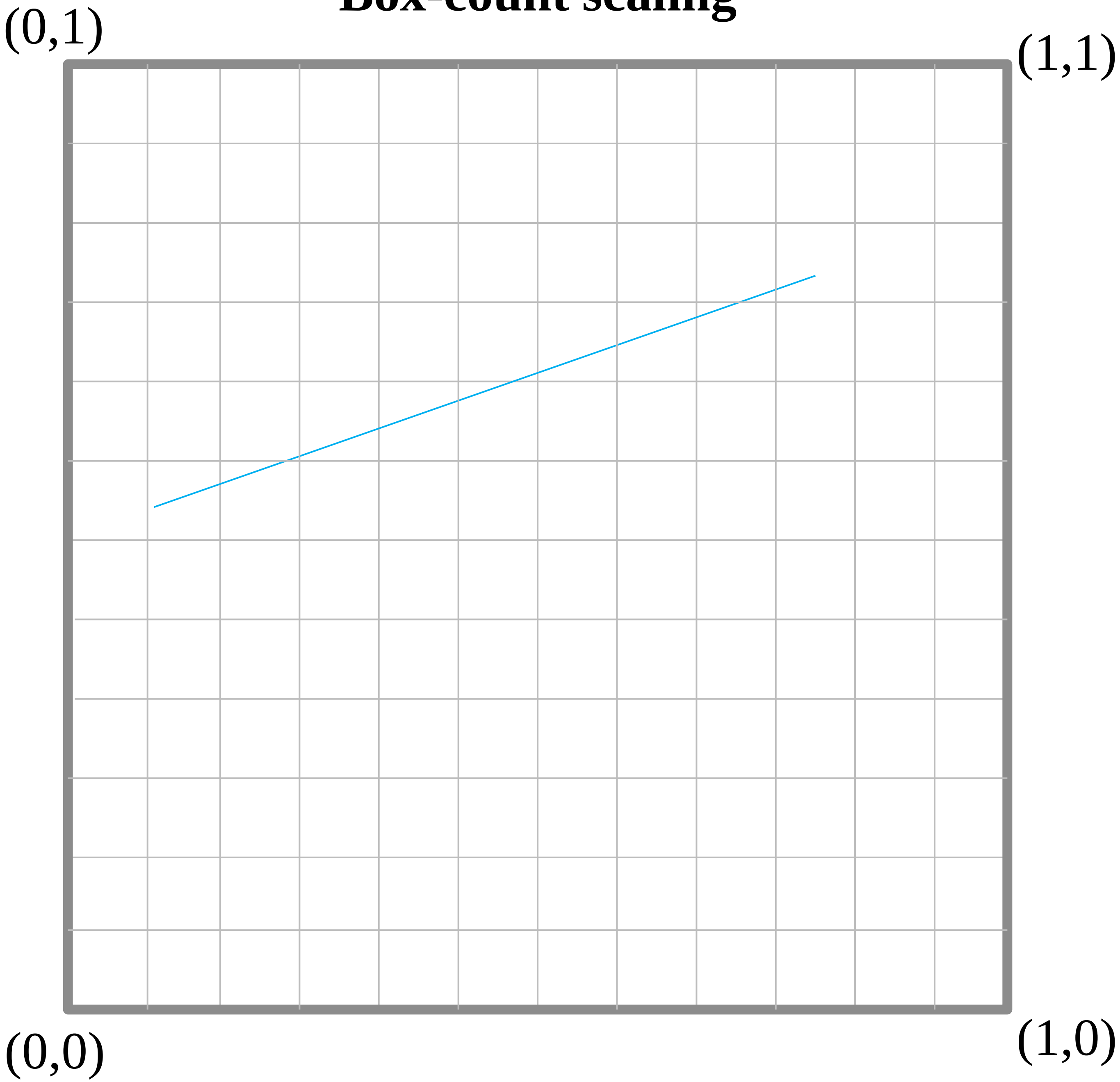

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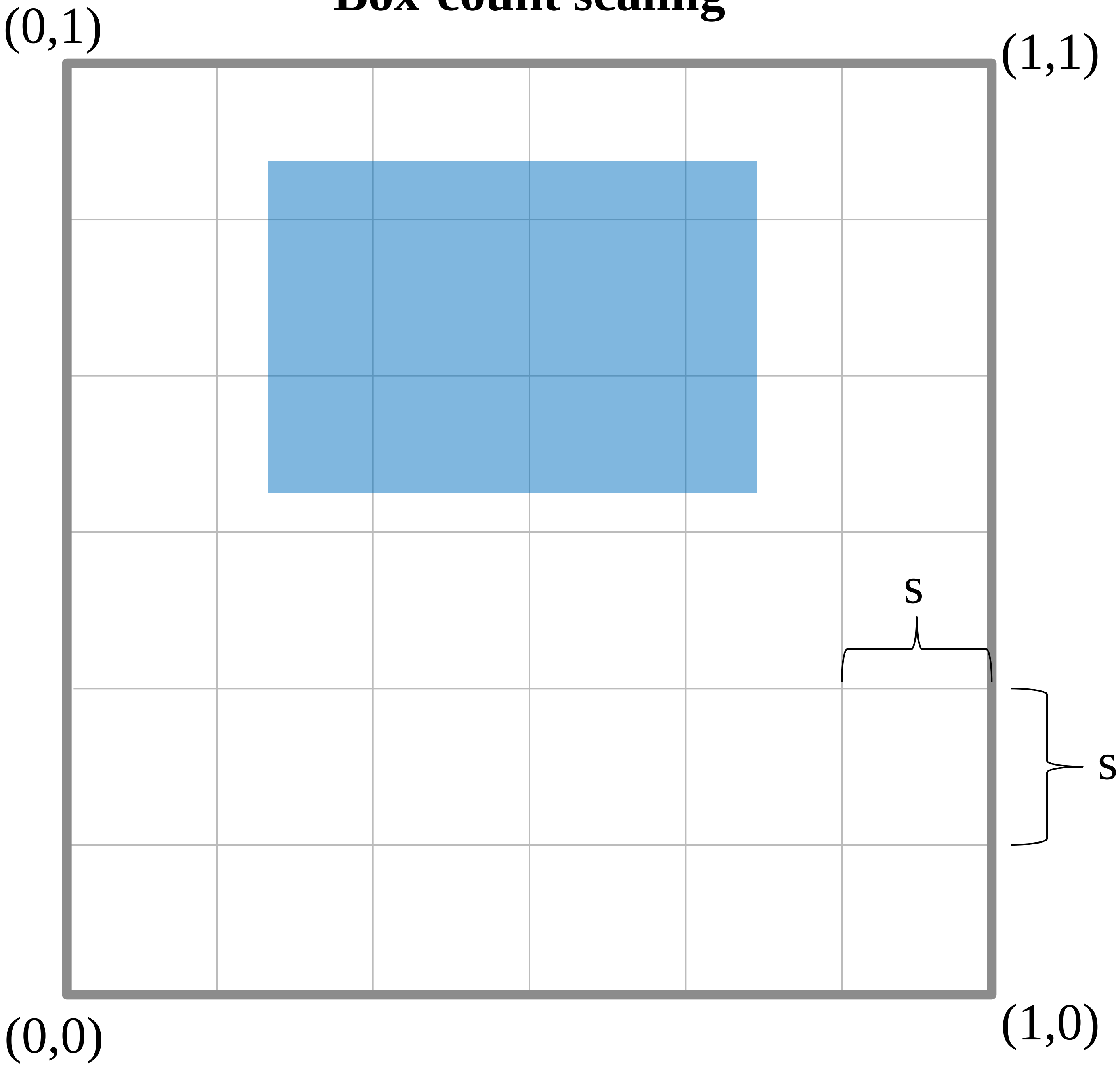
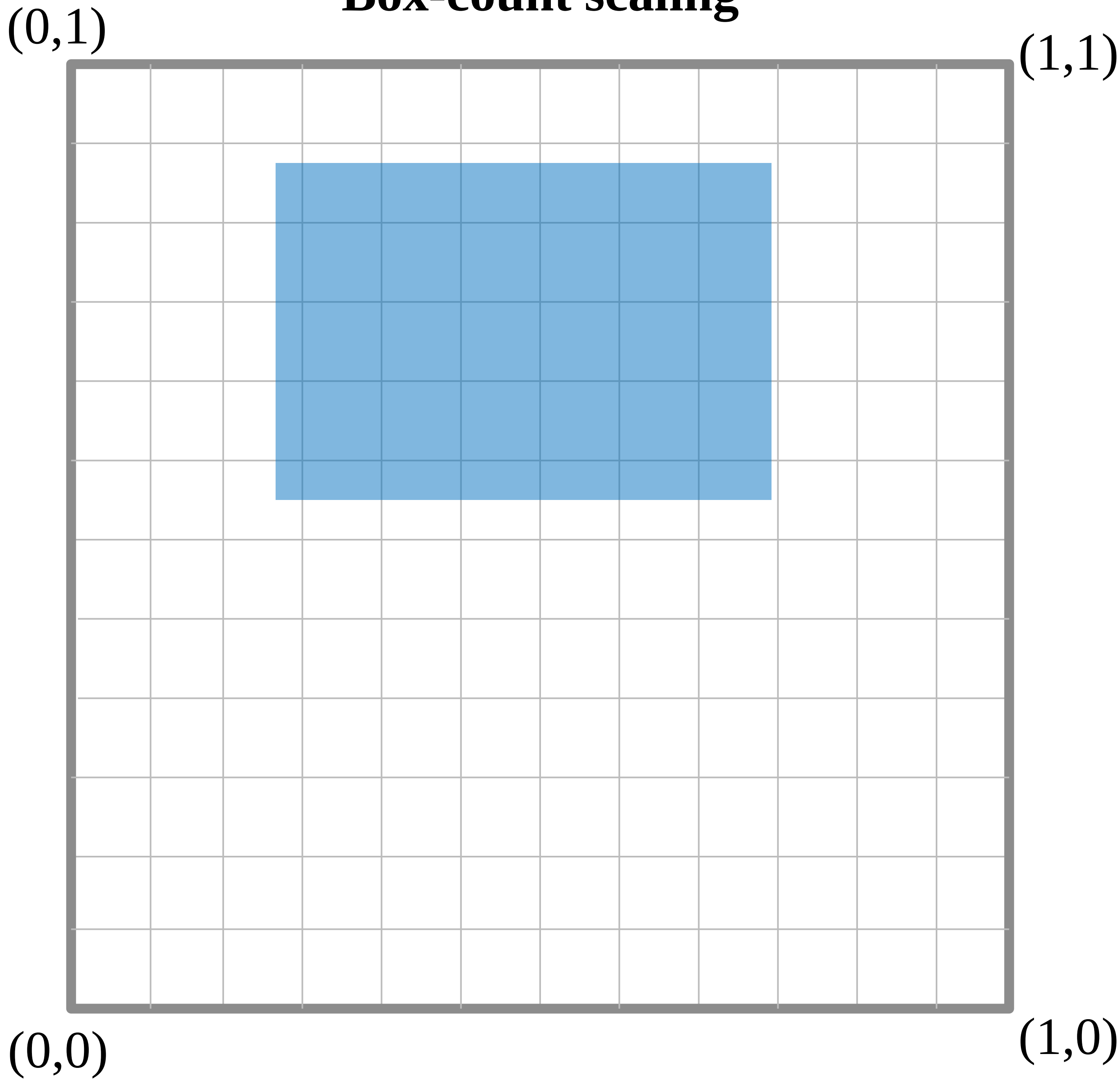
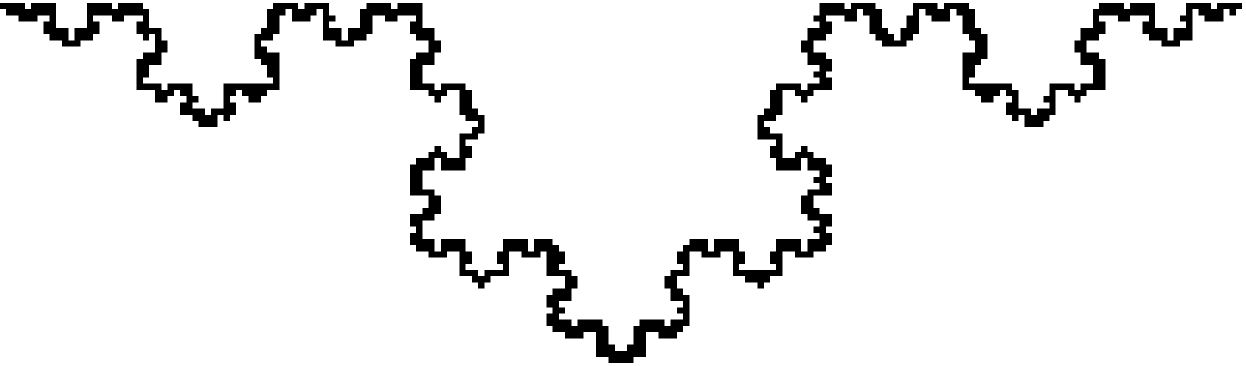


Box-count scaling



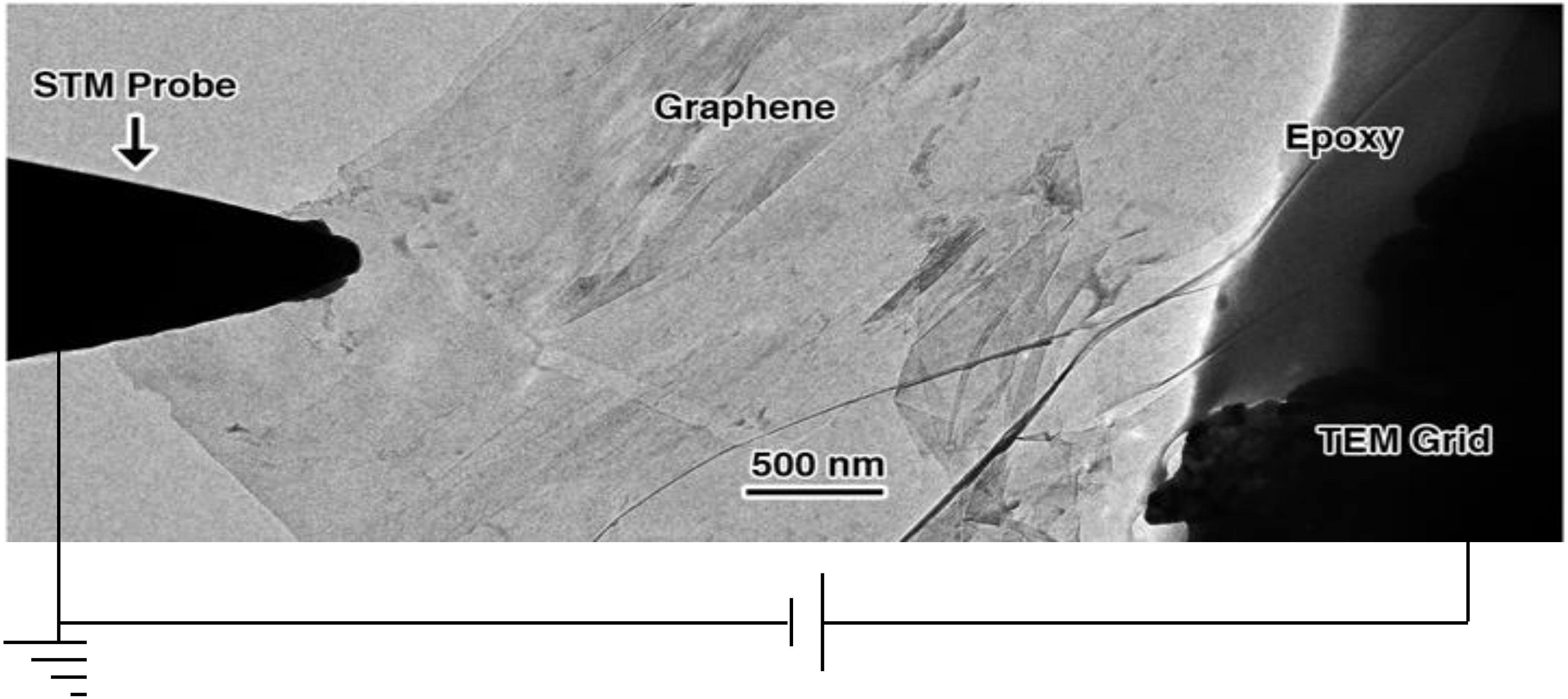
Fractal Dimension f

- Simple Line: box count $N \propto s^{-1}$
- Simple rectangle set: box count $N \propto s^{-2}$
- Not so-simple, but self-similar point set: box count $N \propto s^{-f}$



Koch snowflake
$f = 1.2619$.

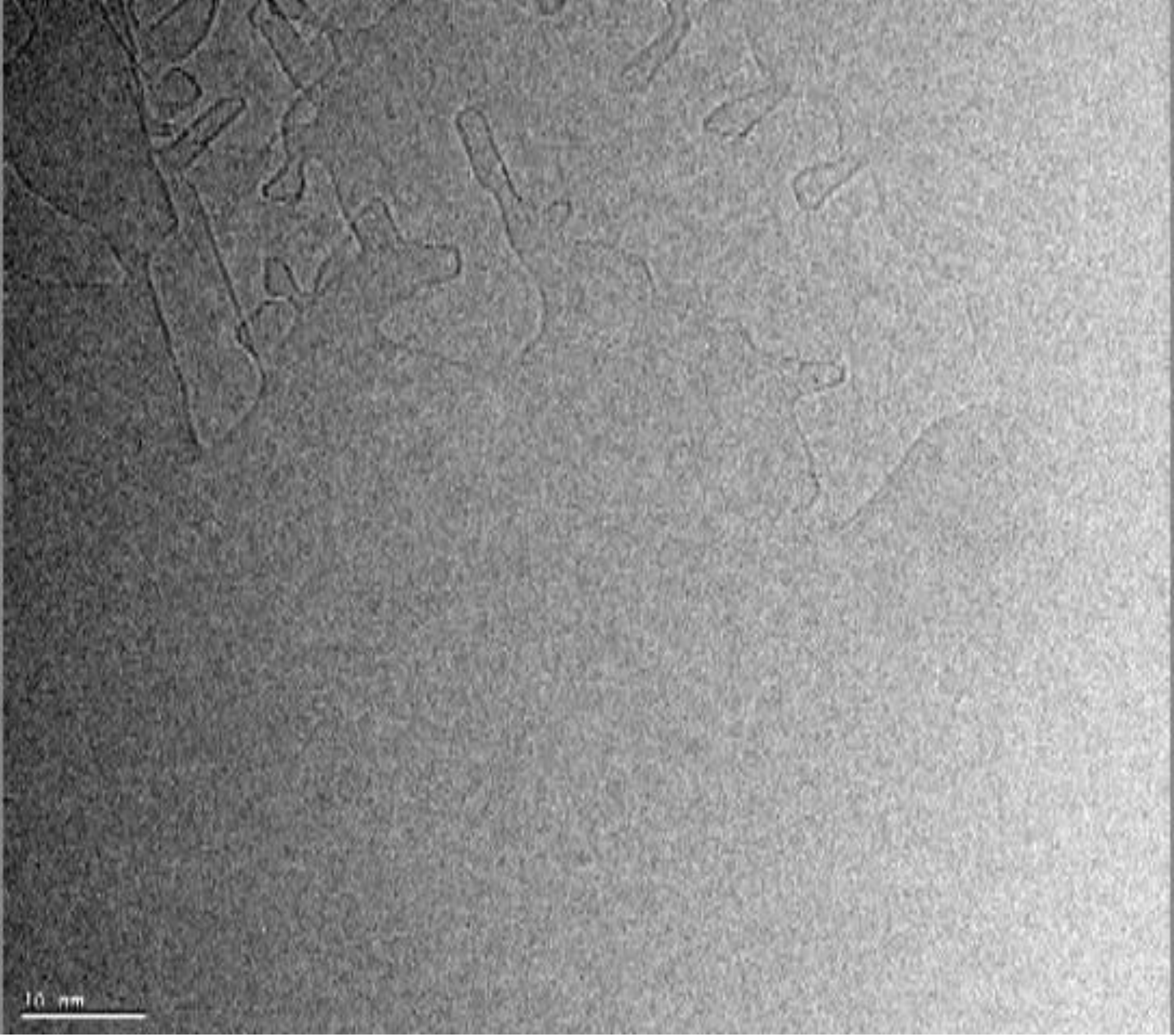
Nanofactory™ TEM-STM
Center for Integrated Nanotechnologies (CINT)
@ Sandia National Lab

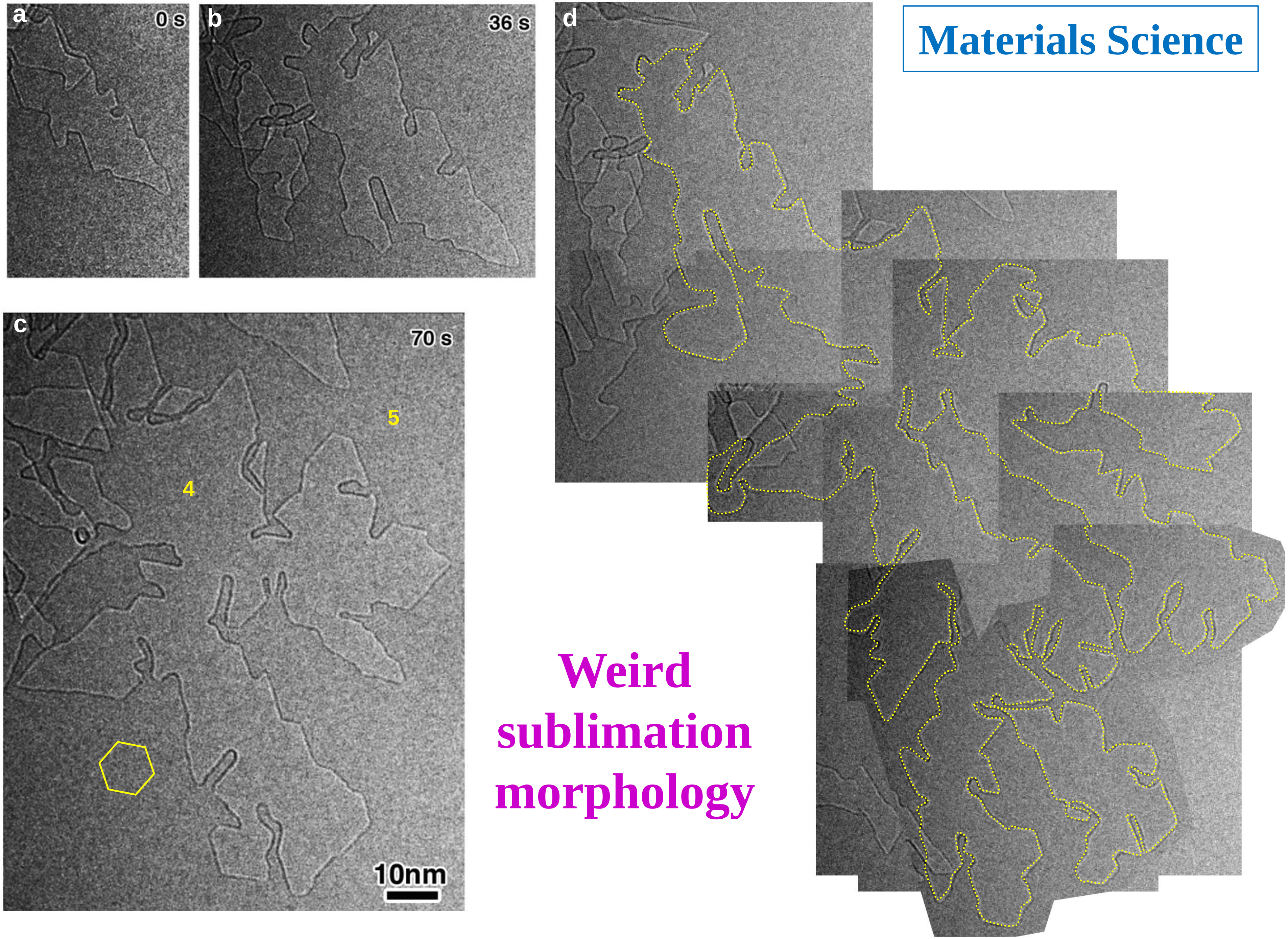


electric current ~ 10^8 Ampere/cm^2

Joule heated to ~ 2000 °C to induce sublimation

Tecnai F30 @ 300 kV


10 nm



Materials Science

Weird sublimation morphology

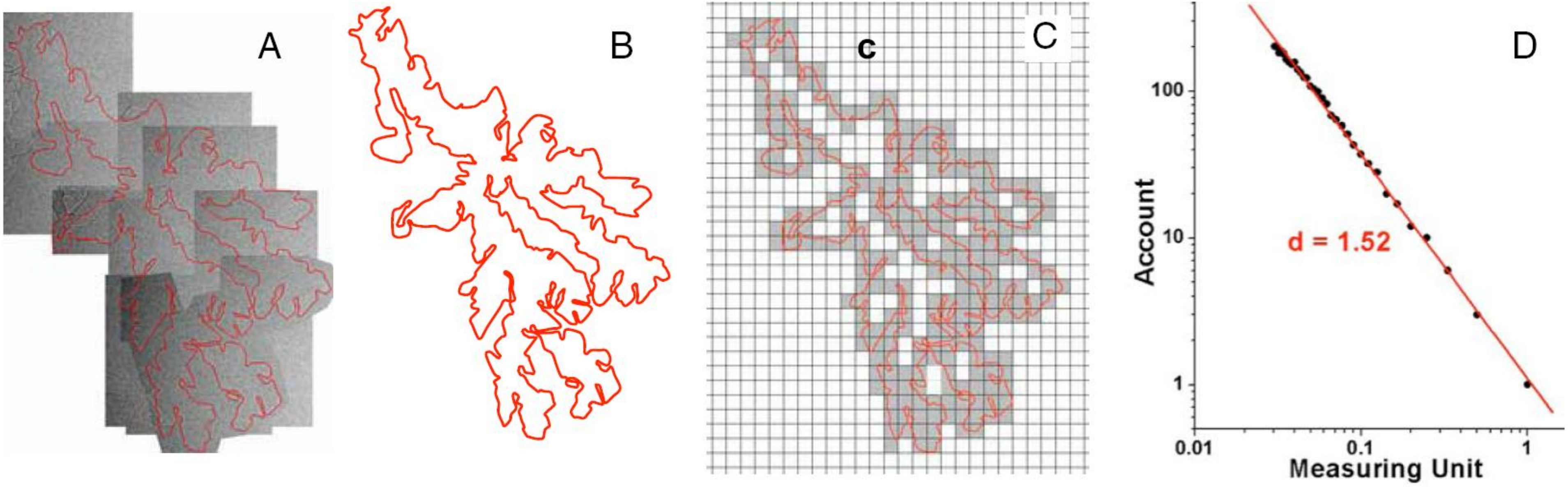
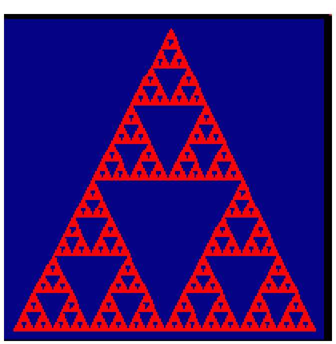


Fig. S2. Fractal dimension measurement procedures. The fractal dimension of the propagating front pattern was measured by the same method as that used to measure the coastline [Sapoval B, Baldassarri A, Gabrielli A (2004) *Phys Rev Lett* 93:098501]. First, a close loop was drawn by fitting the experimental propagating sublimation front (Fig. S2 *A* and *B*). Then the close loop was measured on a 2D square lattice. In the measurement, only those squares that intersect with the close loop were accounted (e.g., the gray squares in Fig. S2*C*). By varying the size of the squares, the number of accounted squares as a function of a square size (i.e., the measuring unit) was plotted (Fig. S2*D*). According to the definition of the fractal dimension, the fractal dimension of the loop or the propagating loop is calculated as:

$$d = -\frac{d\log(N)}{d\log(l)},$$

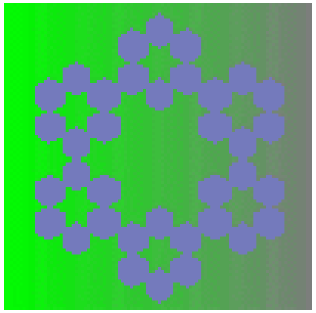
where *N* is the number of the accounted squares and *l* is the size of the squares or the measuring unit. For the propagating front shown in Fig. S2*A*, the fitted fractal dimension is 1.52.

Benoit Mandelbrot, "How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension." *Science* **156** (1967) 636.



Sierpinski Triangle: Fractal dimension 1.5849625

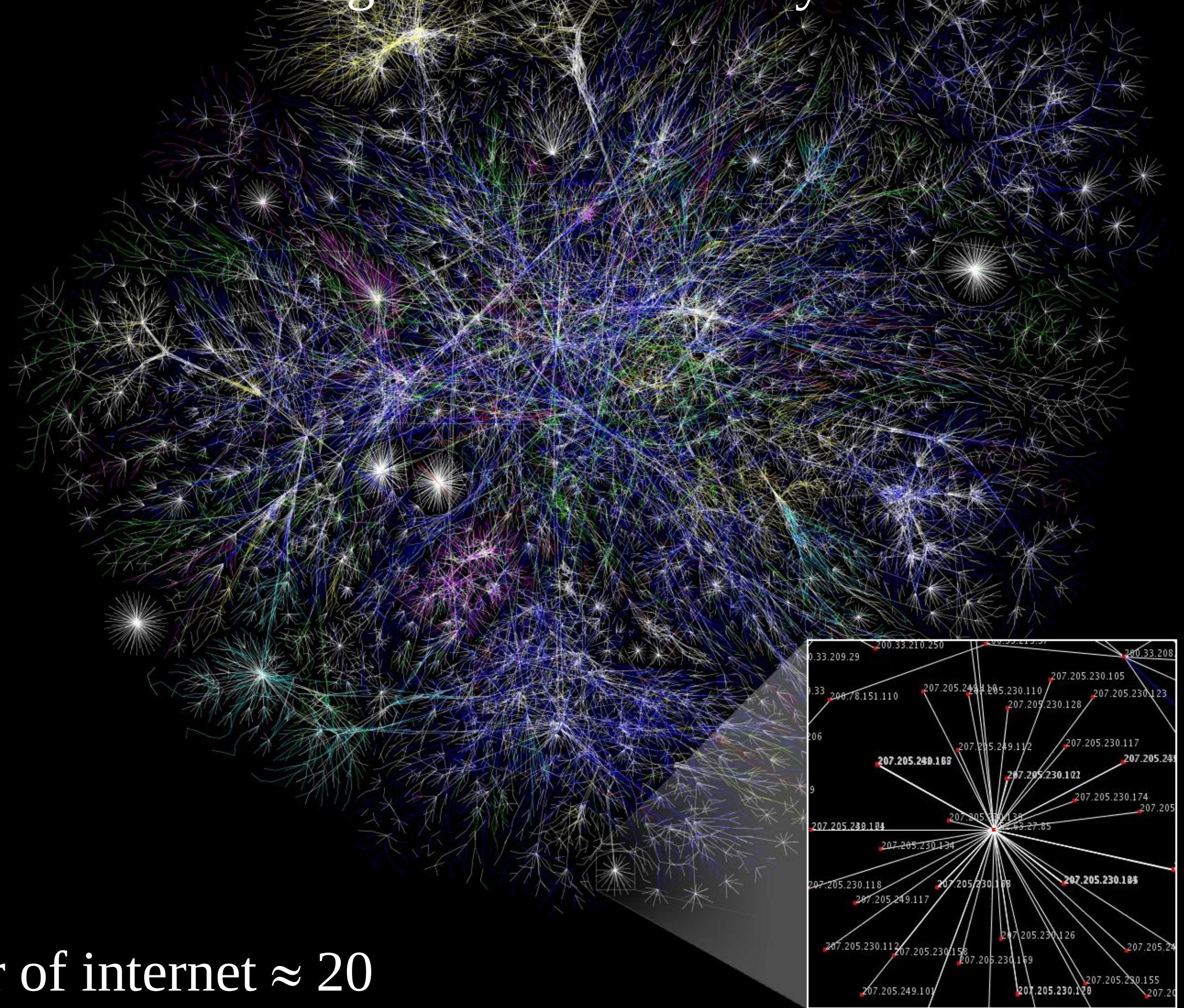
www.tgmdev.be/curvesierpinskiobj.htm



Sierpinski Hexagon: Fractal dimension 1.6309297

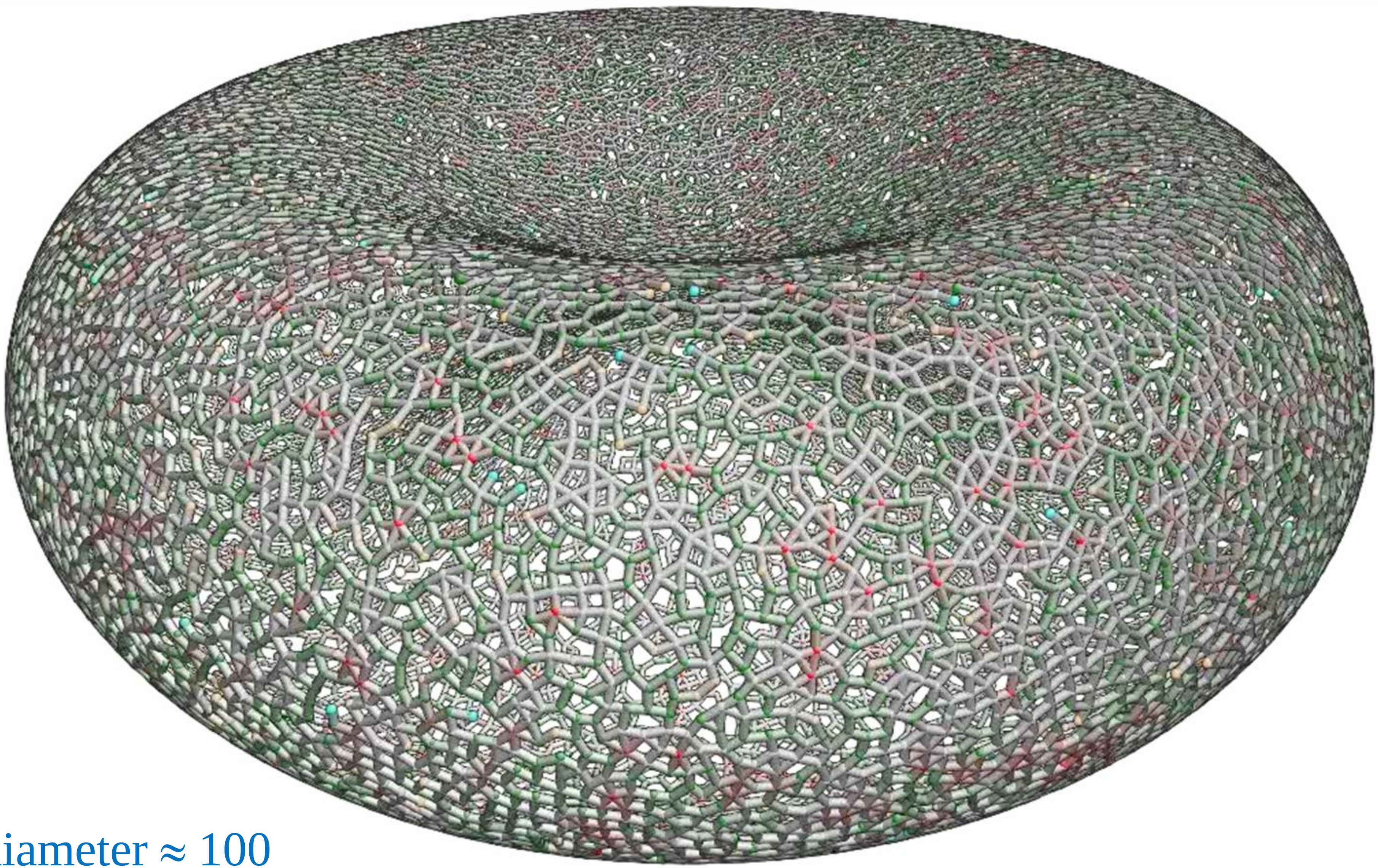
In this lecture, show connections between:

1. Power-law distribution (“scale-free” behavior)
2. **“Network science” model: growth and preferential attachment**
3. Often, hierarchical organization of society and nature



diameter of internet ≈ 20

A real-space network



diameter ≈ 100

To go from one vertex to another, takes many bond hops

Social Network, WWW, Genetic Network, … “**Small-World Network**”

problem with this terminology: “small-world network” is not small, but often huge.

Humans on earth (7×10^9) form a relationship network of diameter 6.

$<d> = 0.35 + 2.06\log_{10}N$ clicks from go from any document to any other document in a N-vertex WWW.

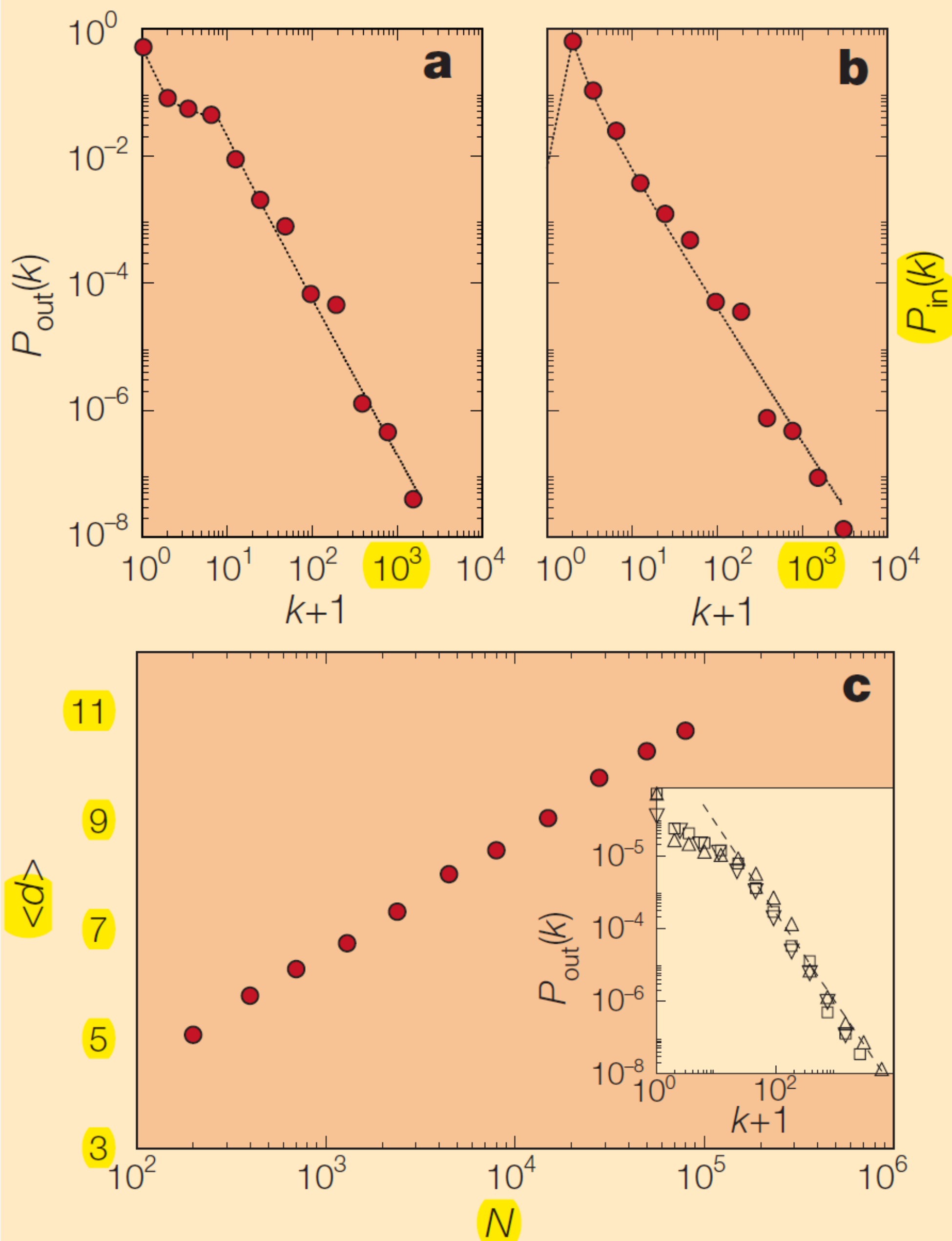


Figure 1 Distribution of links on the World-Wide Web. **a,** Outgoing links (URLs found on an HTML document); **b,** incoming links (URLs pointing to a certain HTML document). Data were obtained from the complete map of the nd.edu domain, which contains 325,729 documents and 1,469,680 links. Dotted lines represent analytical fits used as input distributions in constructing the topological model of the web; the tail of the distributions follows $P(k) \approx k^{-\gamma}$, with $\gamma_{out} = 2.45$ and $\gamma_{in} = 2.1$. **c,** Average of the shortest path between two documents as a function of system size, as predicted by the model. To check the validity of our predictions, we determined d for documents in the domain nd.edu. The measured $\langle d_{nd.edu} \rangle = 11.2$ agrees well with the prediction $\langle d_{3\times10^5} \rangle = 11.6$ obtained from our model. To show that the power-law tail of $P(k)$ is a universal feature of the web, the inset shows $P_{out}(k)$ obtained by starting from whitehouse.gov (squares), yahoo.com (triangles) and snu.ac.kr (inverted triangles). The slope of the dashed line is $\gamma_{out} = 2.45$, as obtained from nd.edu in **a**.

Albert, Jeong, Barabasi, "Internet - Diameter of the World-Wide Web," *Nature* **401** (1999) 130. %1382 cites

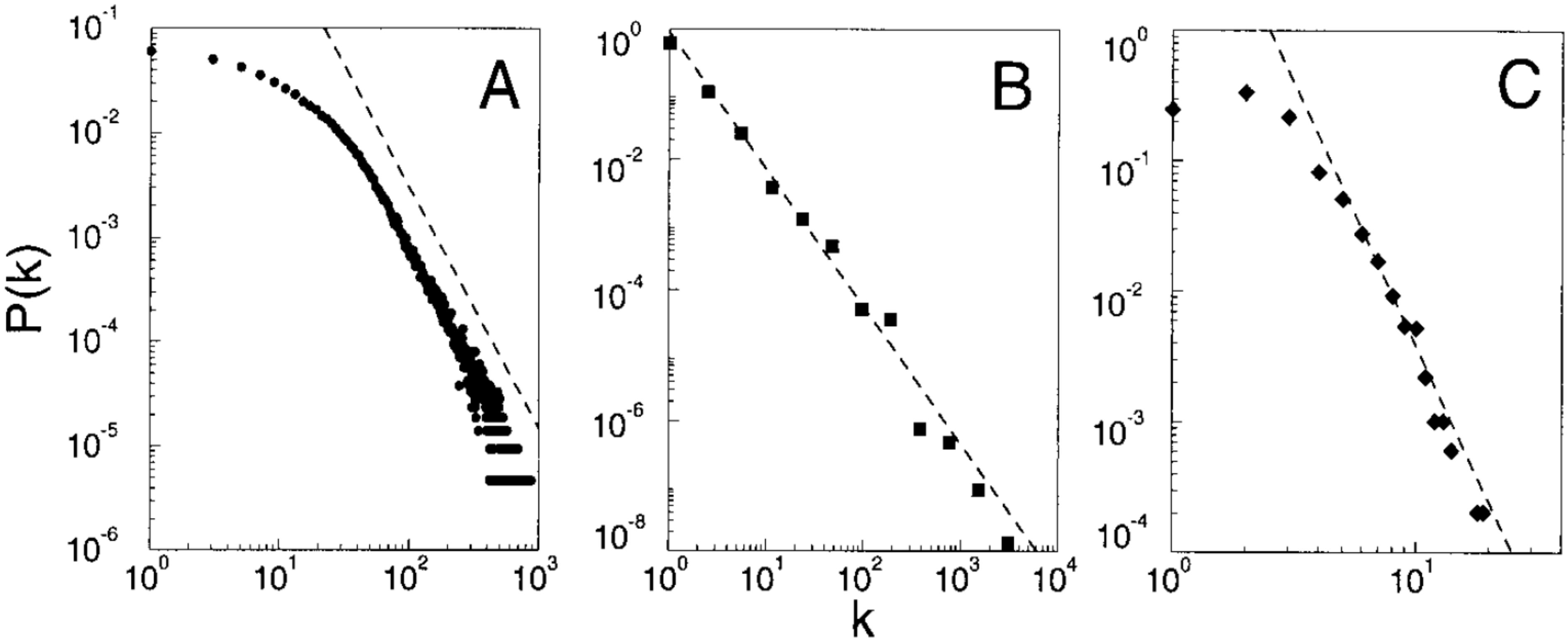


Fig. 1. The distribution function of connectivities for various large networks. **(A)** Actor collaboration graph with $N = 212{,}250$ vertices and average connectivity $\langle k \rangle = 28.78$. **(B)** WWW, $N = 325{,}729$, $\langle k \rangle = 5.46$ (*6*). **(C)** Power grid data, $N = 4941$, $\langle k \rangle = 2.67$. The dashed lines have slopes (A) $\gamma_{actor} = 2.3$, (B) $\gamma_{www} = 2.1$ and (C) $\gamma_{power} = 4$.

Barabasi, Albert, "Emergence of scaling in random networks," *Science* 286 (1999) 509-512. %6316 cites

Small-World Networks

- Data, web, business associations: Relationship, rather than real-space physical / chemical attachment
- not strongly exclusive (unlike steric repulsion in chemical bonding, or marriage), possible to develop huge k
- Long tails: Scale-free power-law distribution
- Vital few: like hubs, shrinks the network diameter
- Connectivity is power

Mb = megabit = 1,000,000 bit, MB = megabyte = 8Mb

Mbps = megabit/second = 0.125 MB/s = 125 kB/s

http://www.speedtest.net/

Getting 1 Mbps in travel is pretty decent connection

But one can live with maybe 0.1 Mbps ~ 13 kB/s

From MIT office copper line, download: 6.5 Mbps, upload 7.7 Mbps ~ 1MB/s

Upper limit: Ethernet 10 Mbps, fast Ethernet 100Mbps, gigabit Ethernet 1000Mbps

1 GB = 1gigabyte = 1,000,000,000 byte

1 gibibyte = 1024^3 bytes = 1,073,741,824 byte

64-bit machines can address 18,446,744,073 GB memory

C type	ILP64 (Cray)	LP64 (MacOS X, Linux)	LLP64 (Windows)
char	8	8	8
short	16	16	16
int	64	32	32
long	64	64	32
long long	64	64	64
pointer	64	64	64

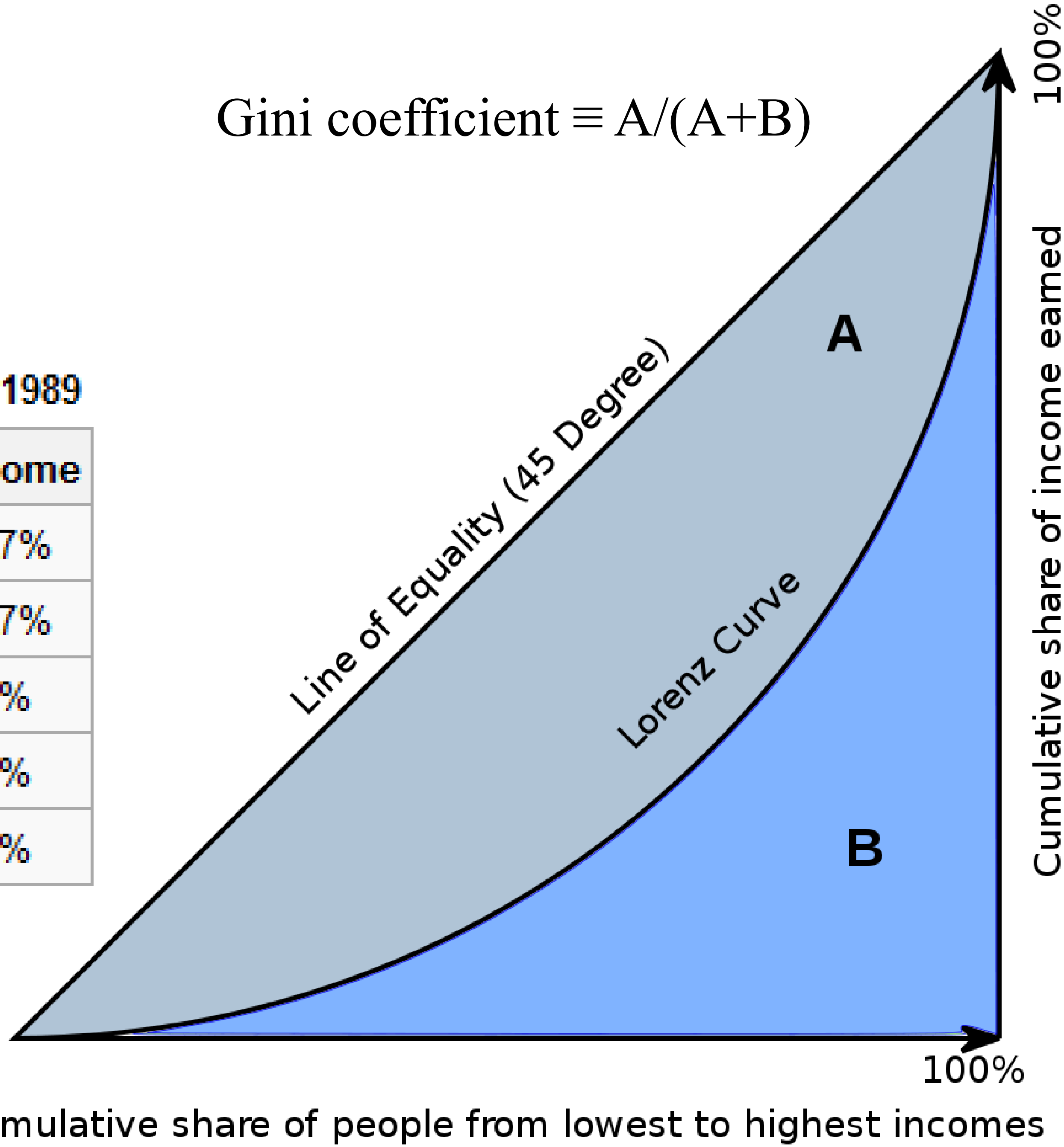
from Wikipedia

Distribution of world GDP, 1989

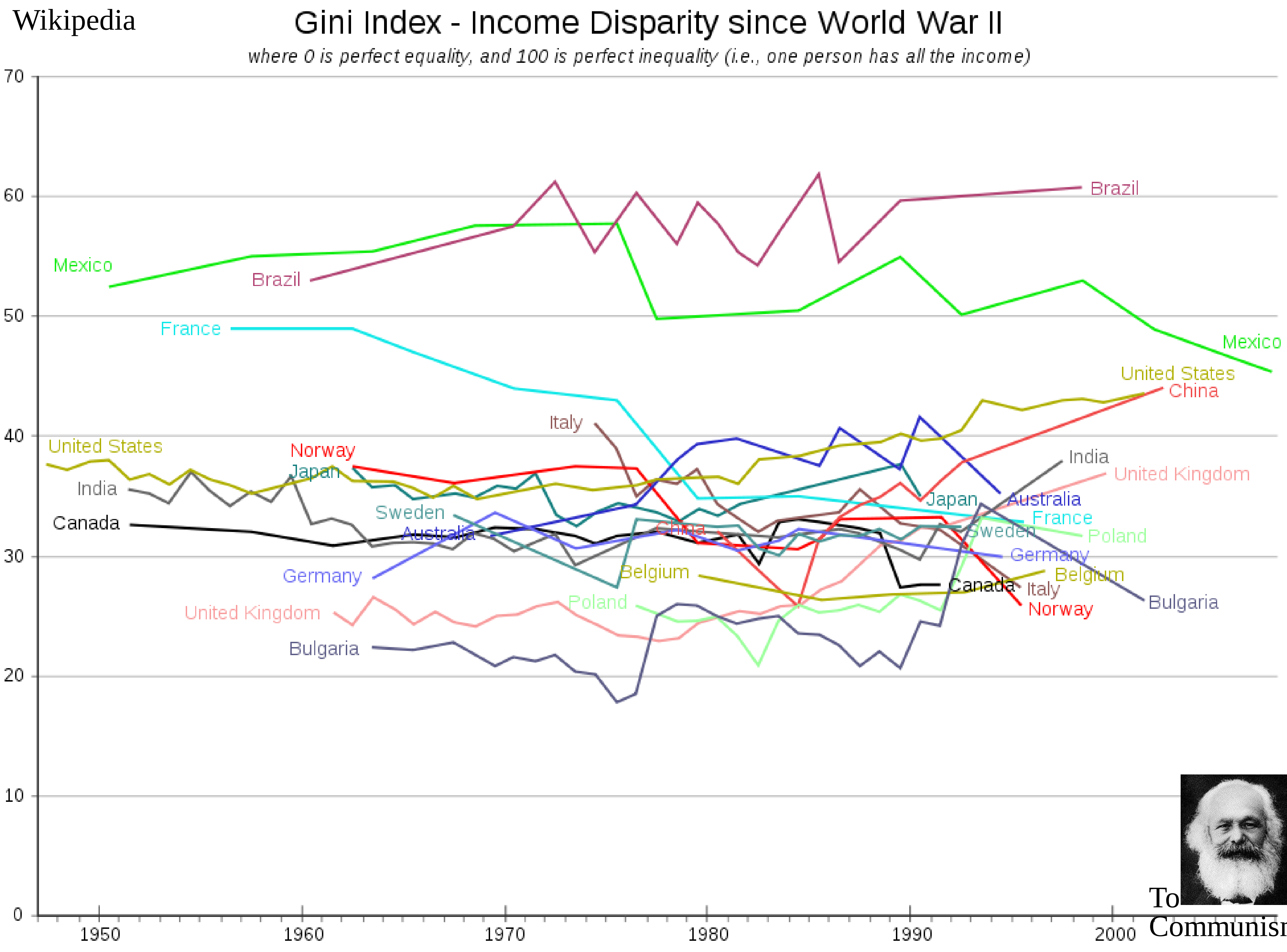
Quintile of Population	Income
Richest 20%	82.7%
Second 20%	11.7%
Third 20%	2.3%
Fourth 20%	1.4%
Poorest 20%	1.2%

SOURCE: WIKIPIDEA

Gini coefficient ≡ A/(A+B)



from
Wikipedia



To Communism

Bohorquez, Gourley, Dixon, Spagat & Johnson, *Nature* **462** (2009) 911