Exponential Laws of Computing Growth

Peter J. Denning
Ted G. Lewis

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W.B.Langdon

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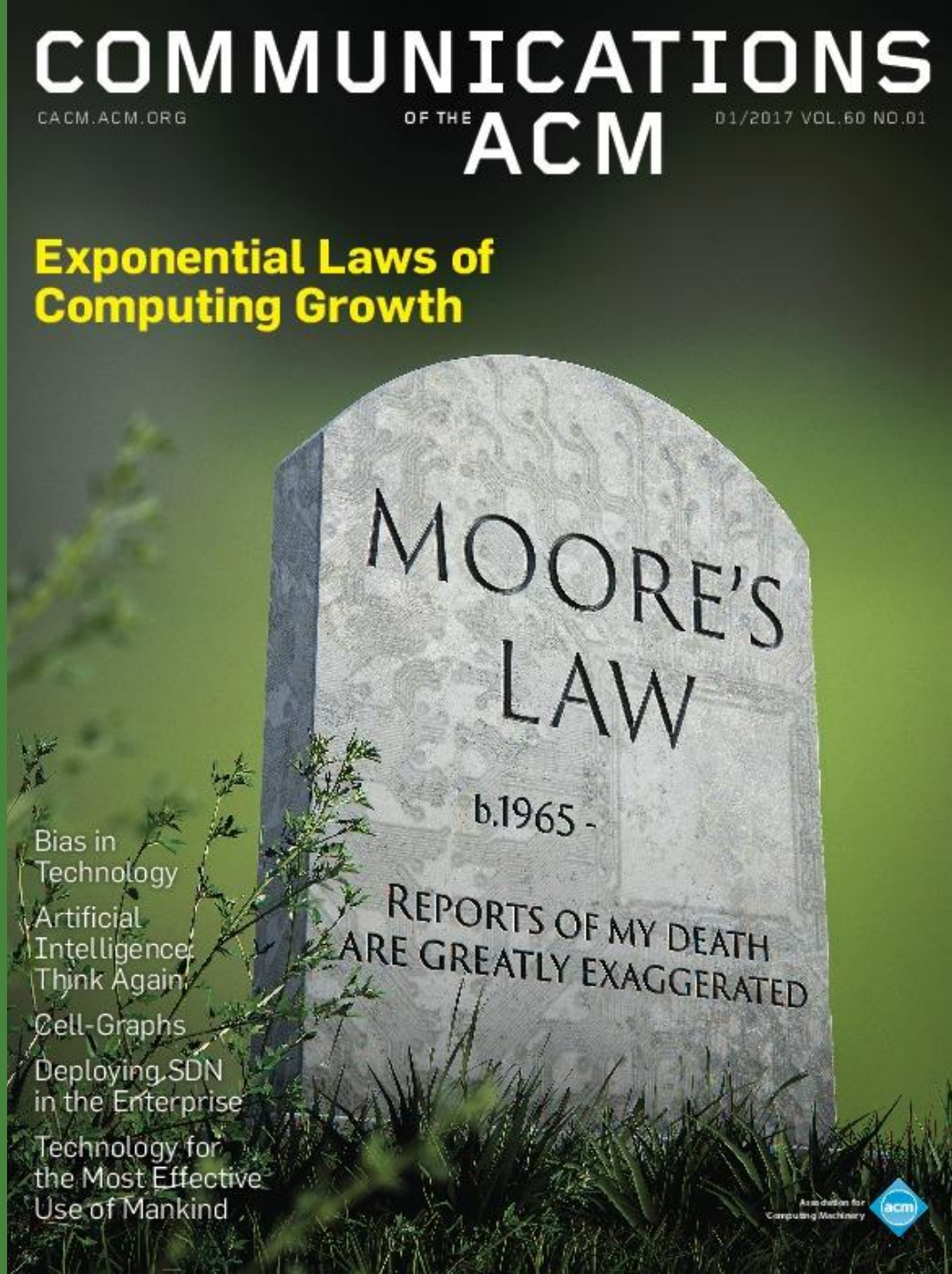

Authors

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Dr. Lewis, Prof. of Computer Science and National Security Affairs

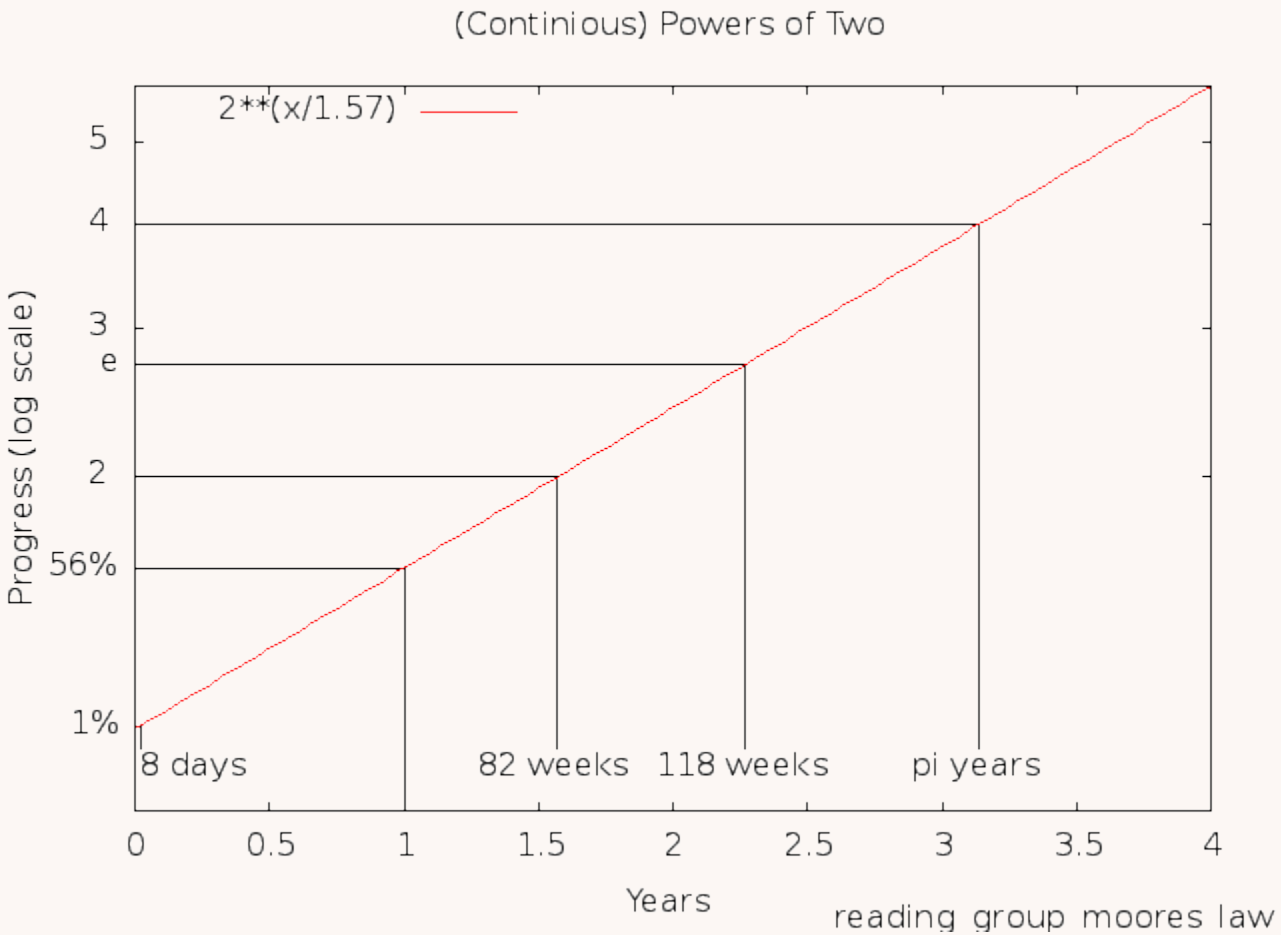
NPS is USA Navy university on pacific coast

119 miles south of San Francisco

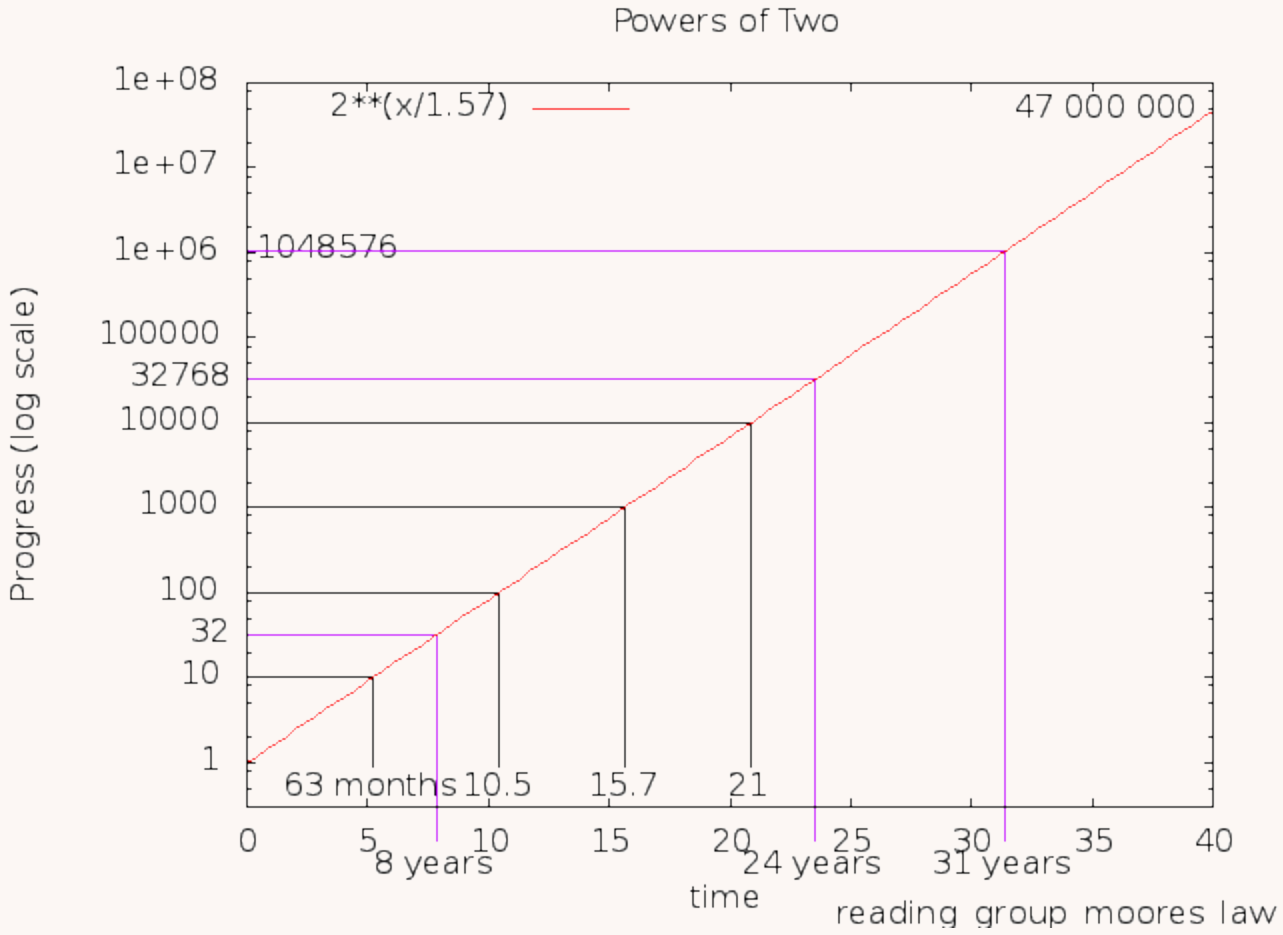
Exponential Laws of Computing Growth

- Nature of exponent.
  - Growth is proportional to current value. Ratio between current and change is fixed
  - $y = A \times 2^{time/\alpha}$ (α is the doubling time)
  - Plot log(y) versus time, get straight line
- How well has Moore's Law predicted
- Why has it worked (for computer hardware)
- Implications of technology jumps
- Consequences if true and if not
- What next

Moore's Law


(Continious) Powers of Two
2**(x/1.57)
Progress (log scale)
5
4
3
e
2
56%
1%
8 days
82 weeks
118 weeks
pi years
0
0.5
1
1.5
2
2.5
3
3.5
4
Years
reading group moores law

Moore's Law


Powers of Two
2**(x/1.57)
47 000 000
1048576
1e+08
1e+07
1e+06
100000
32768
10000
1000
100
32
10
1
Progress (log scale)
63 months
10.5
15.7
21
0
5
10
15
20
25
30
35
40
8 years
24 years
31 years
time
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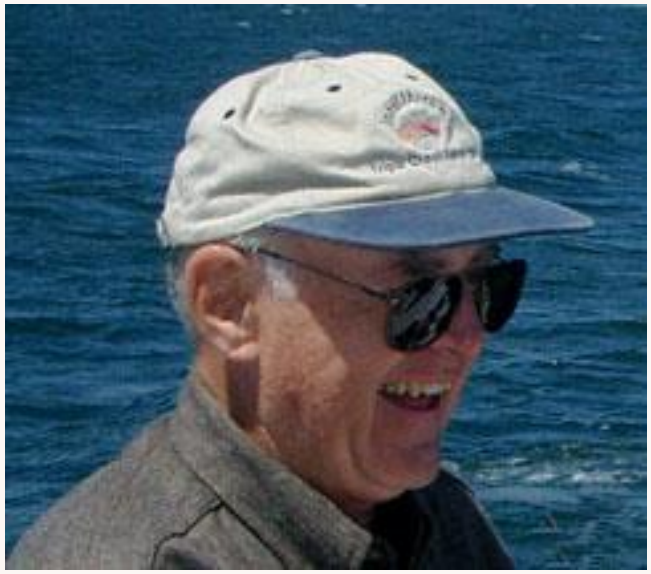
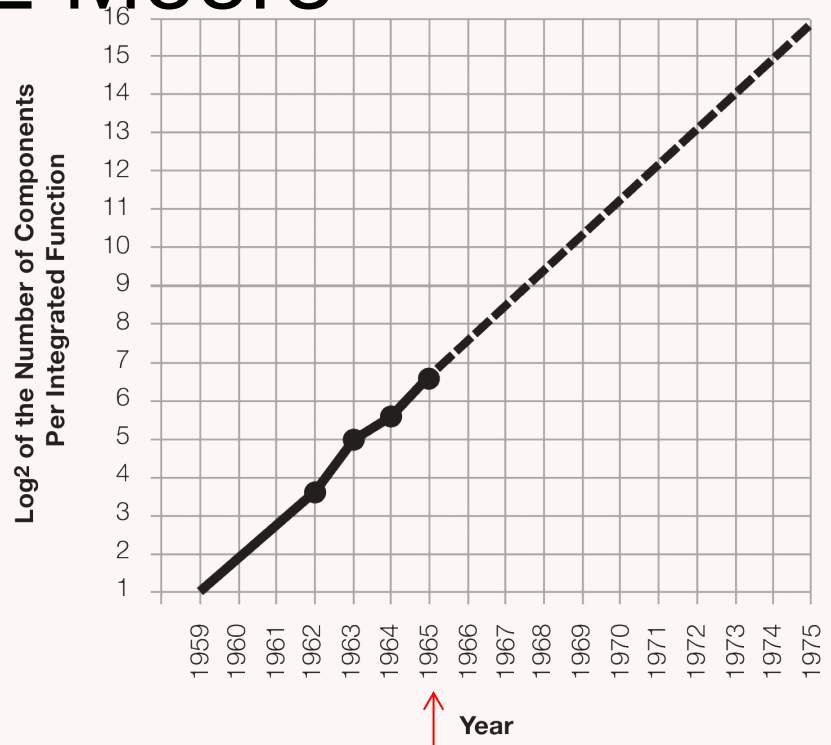
Exponential Laws of Computing Growth

- Known as “Moore’s Law”
- One of the most durable technology forecast ever made
- What is forecast?
  - Components in integrated circuit
  - Speed (clock frequency)
  - Instructions per second
  - Computations per kilowatt hour
- Each has increased exponentially

Gordon E Moore





Dr. Gordon Earle Moore (1929-)

1968 Co-founder of Intel (with Robert Noyce)

Author of Moore's Law (1965)

$7.3 billion

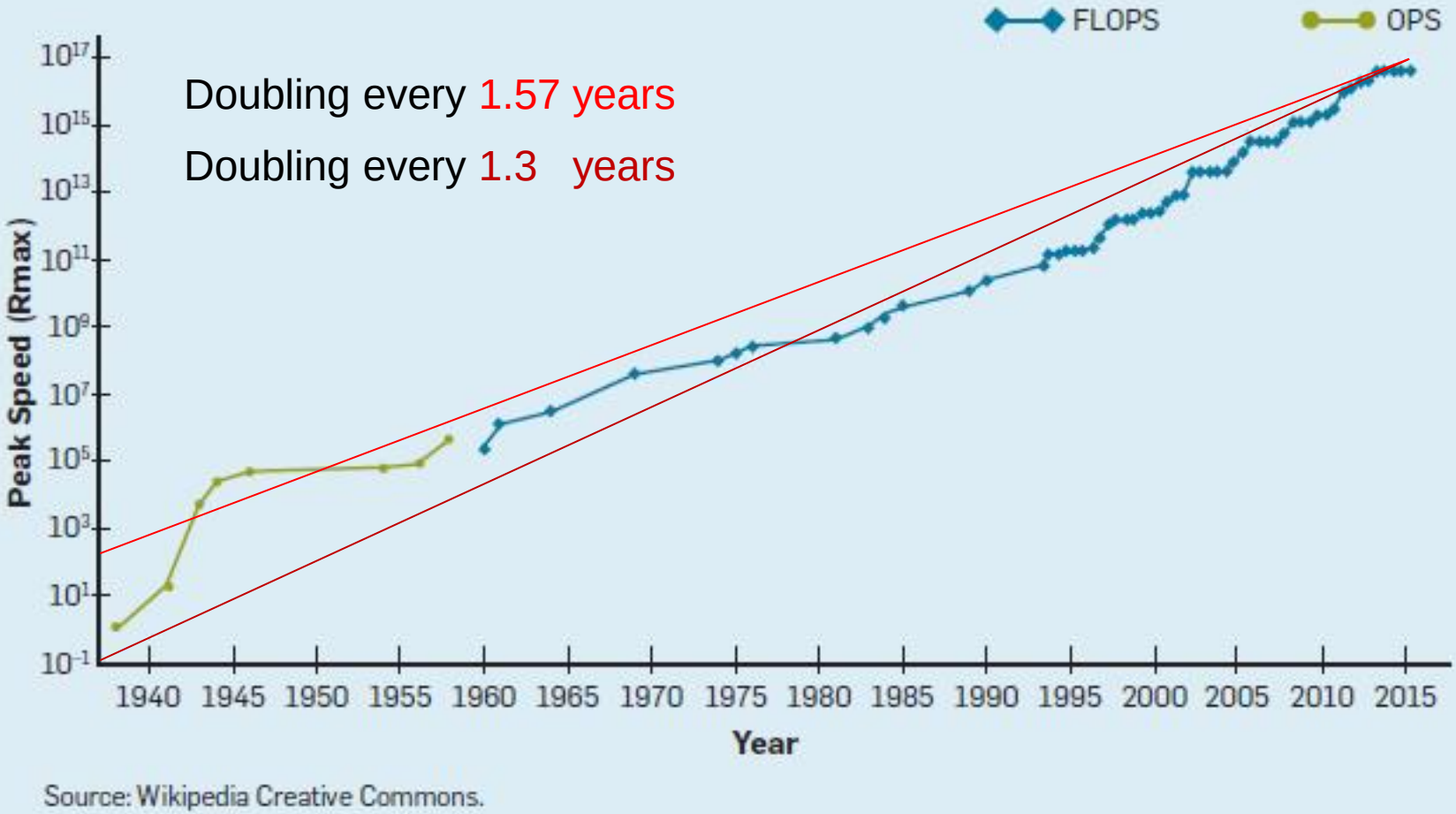
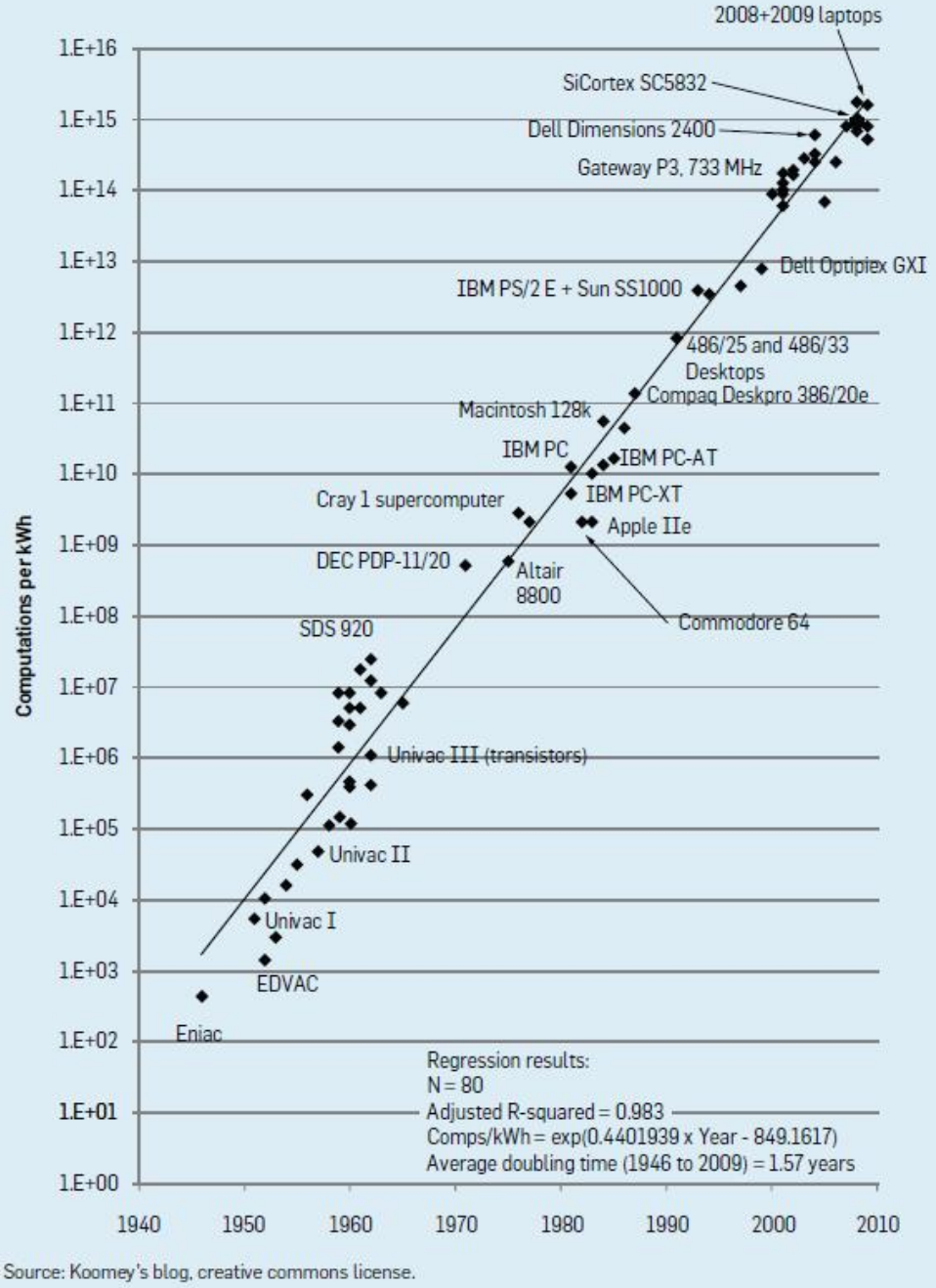


Figure 2. Speeds of the fastest computers from 1940 show an exponential rise in speed. From 1965 to 2015, the growth was a factor of 12 orders of 10 over 50 years, or a doubling approximately every 1.3 years.

Difference between 1.3 v 1.57 grows exponentially, 3 orders of magnitude in plot



Source: Koomey's blog, creative commons license.

Figure 8. Koomey's Law graph illustrates the continuing success of designing systems that produce more computation for the same power consumption. …

Ray Kurzweil

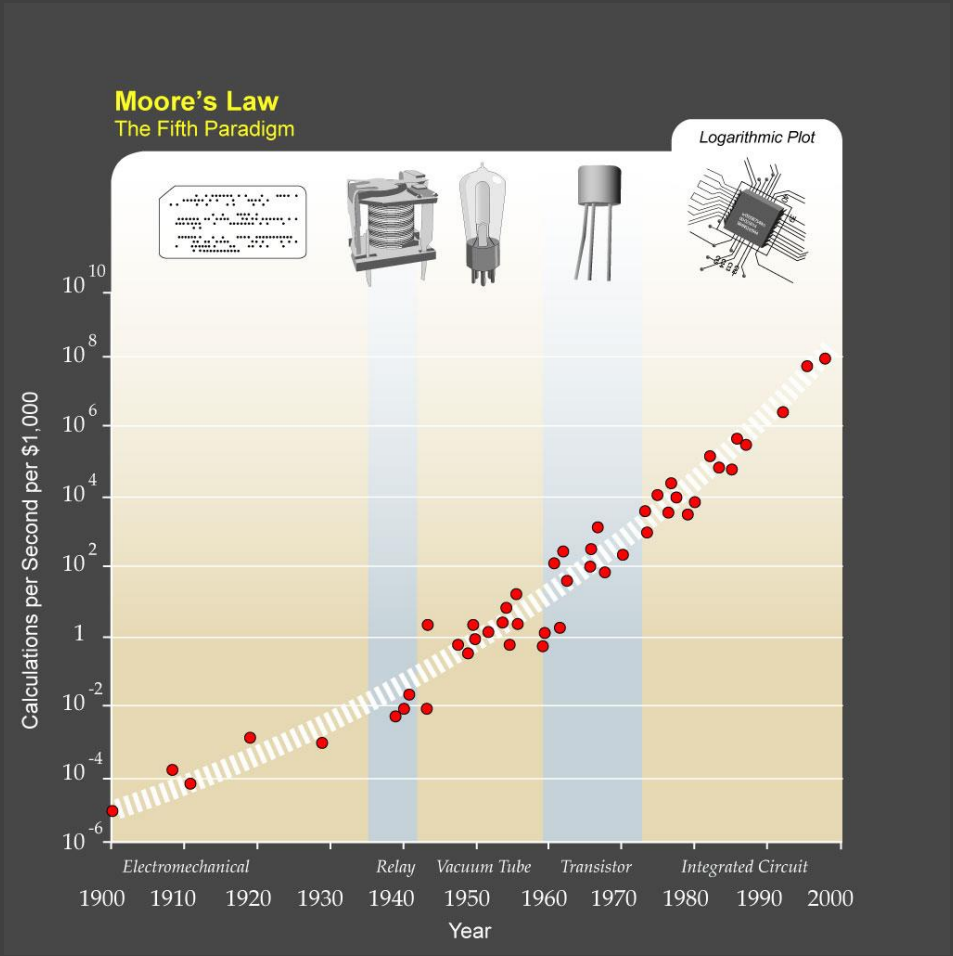
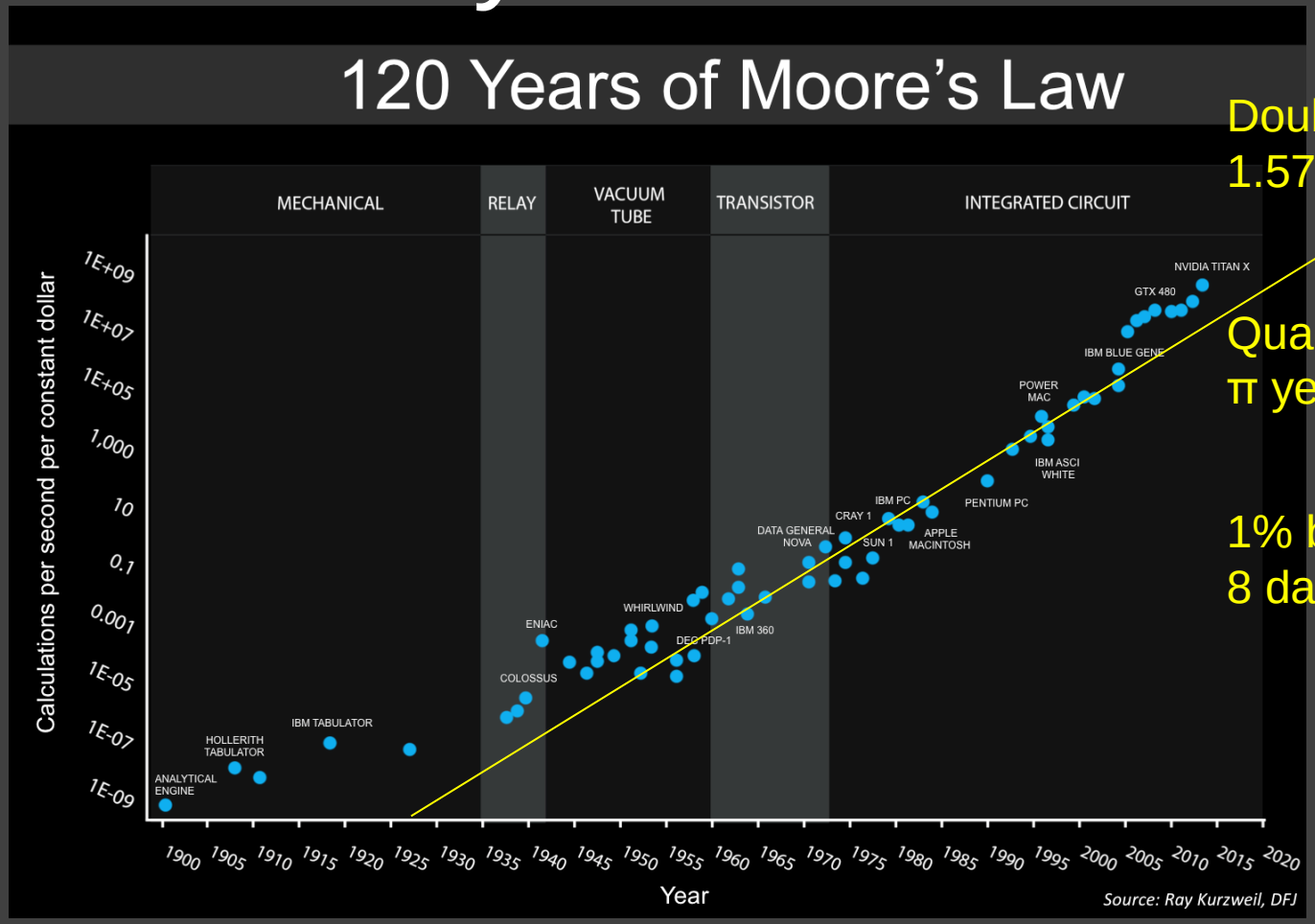


Figure 3. Kurzweil's graph of speed of information technologies since 1900 spans five families of technologies. From 1900 to 2000, the growth was 14 orders of 10 over 100 years, or a doubling approximately every 1.3 years

Ray Kurzweil



Doubling every 1.57 years

Quadruple in π years

1% better in 8 days

An updated version of Moore's Law over 120 Years (based on Kurzweil's graph). The 7 most recent data points are all NVIDIA GPUs.

NB exponential would be straight line, not curve shown

How does Moore's Law work?

Denning+Lewis say need simultaneously exponential increase in:

1. Silicon chip
2. Computer system
3. Community. This means the economy, consumers buying the latest fad and finance for new production/consumption.

Observed increase will the slowest of these3

Technology must widen most constricting bottleneck at each doubling

How does Moore's Law work? Technology Jumps

- Denning+Lewis doubling equivalent to a generation (every 82 weeks).
- Initially market can grow exponentially but after 5-9 years exponential growth (10x to 50x) market may saturate and growth follow slower logistic growth.
- Something similar in CMOS? Existing technology played out, need to jump

Technology Jumps

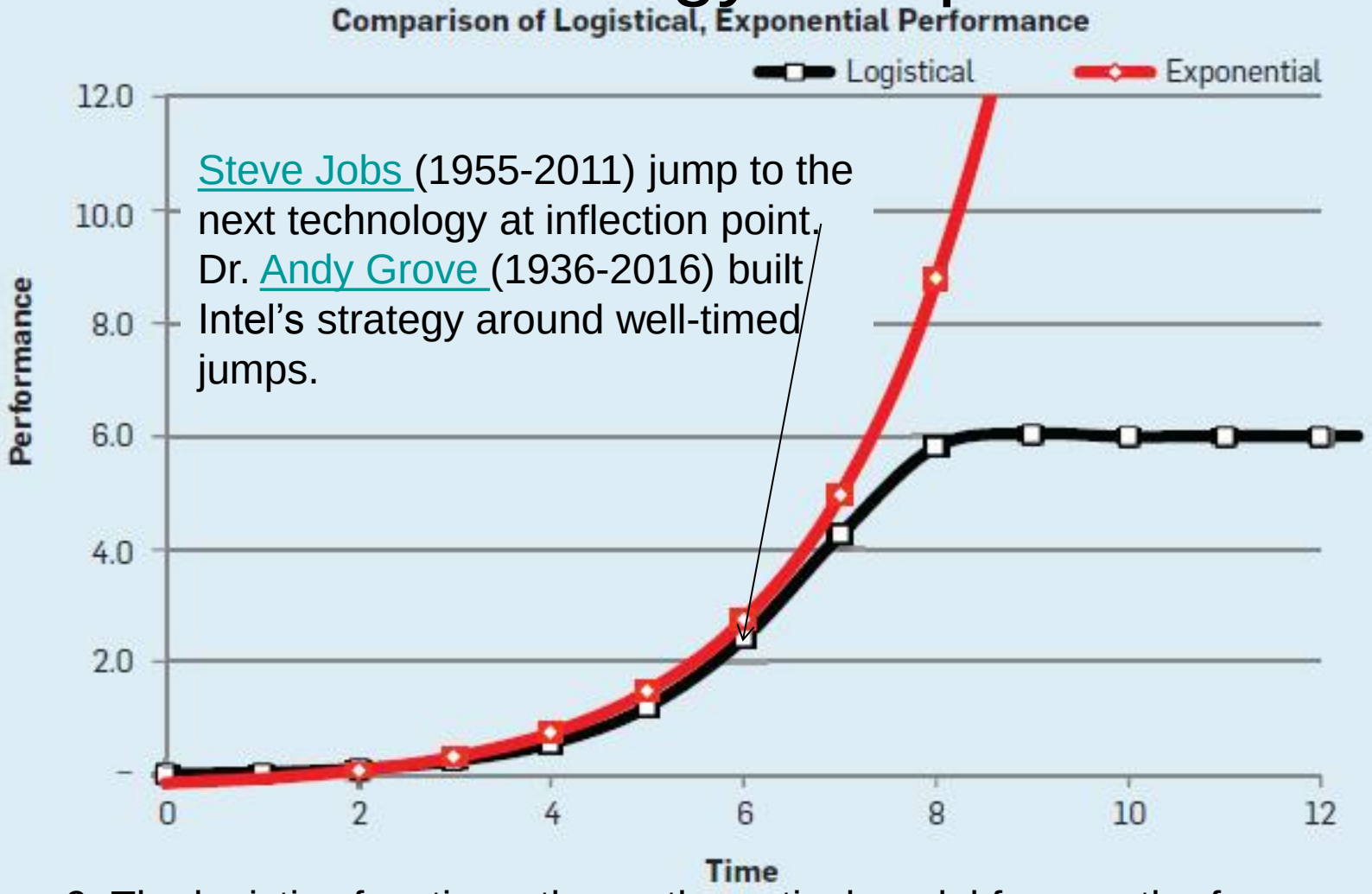


Figure 9. The logistics function—the mathematical model for growth of a population (such as adopters of a technology)—plots as an S-curve (black) over time. Initially, the curve follows an exponential (red) curve, but after an inflection point (here at time 6) it flattens out because of market saturation.

What if Jump wrong way?

- Technology jumps disrupt community.
- Market leader could change at each jump.
- Jump in the wrong direction and firm folds (gets acquired).
- Run of good luck means Intel (and so CISC x86 architecture) dominates and believes luck will continue
- Luck also believed by community, so reinforcing Intel at expense of others

Why only Information Technology

- Why computer hardware and nothing else

  CMOS complementary metal oxide semiconductor

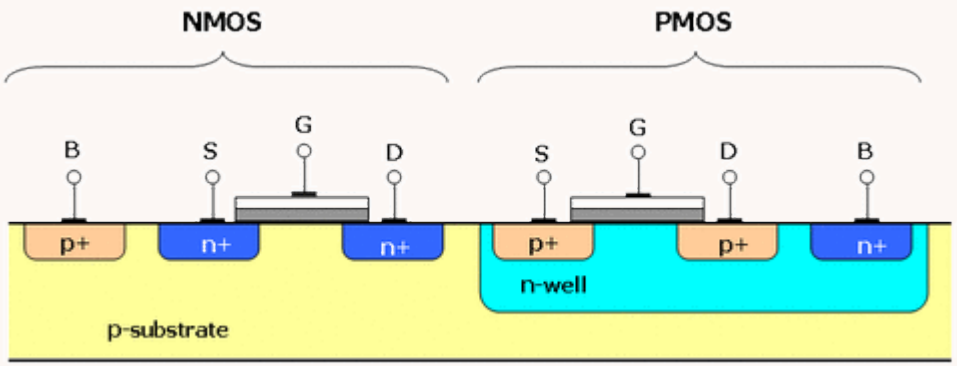
  All components etched into a single silicon crystal

- Lists cars 1000s of miles per gallon

  No technological route to 2^6 fold improvement

- Not software

  No order of magnitude improvements in software, since Hopper invented the compiler in 1952



Grace Hopper (1906-1992)

Synchronous Circuits implies Clocking

Denning+Lewis make great play of the problem of controlling skew when distributing clock signal across chip.

Non issue:

- Composed of many independent cores, which can operate asynchronously
- Chip thin enough to be transparent. Synchronise with external light (convert to electric signal all across chip)

Why 1.57 years

- Various time constants proposed: 12 months, 24 months, 1.5 years. 82 weeks empirical fit (1946–2009)
- Denning+Lewis suggest due to economic and social factors. Time to create new fab, time to sell new products. I.e. people are limiting factor.
- Automated factories, faster social communication (faster than broadcast TV?)

  => reduce time constant?

How do we program a 1000 cores?

- Many programmers never trained to do parallel programming
- Re-jig training?
- Gene Amdahl (IBM 1922-2015) Amdahl's Law
  - Speed limited by serial part of calculation
- John Gustafson
  - Speed limited by number of independent data

What happens when it ends?

- Predict Moore's Law finishes when transistor shrinks to Compton wavelength of electron in 2036 (λ_c = 1% distance between silicon atoms)
  - Seem dubious. Take min feature size as distance between atoms, gives ≤2024 (2020?)
  - Move away from CMOS?

    Graphene 1nm transistor
- "Profound" impact on [USA?] economy when Moore's Law is over

Conclusions

- Stress hardware engineering, not physicists not software engineers
- Parallelism: cloud and super computers
- Importance of technology jumps. Lucky five times, does not mean 6^{th} will also be lucky
- You will be left behind
- Trend could continue for at least another several decades. $2^{30/1.57}=565152$

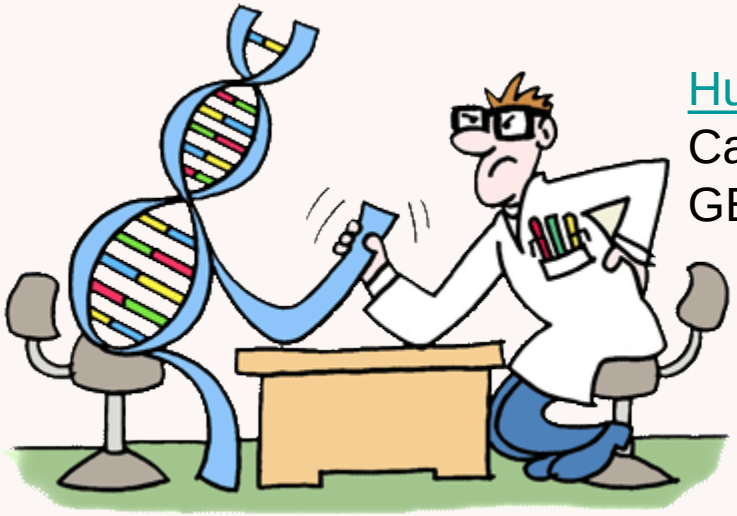
  2020—2025 seems more reasonable

WIKIPEDIA
Genetic Improvement

Genetic Improvement 2017

GI 2017, Berlin,
15/16 July 2017
GECCO workshop

Submission due
29 March 2017



Humies: Human-Competitive
Cash prizes
GECCO-2017

END

http://www.cs.ucl.ac.uk/staff/W.Langdon/ http://www.epsrc.ac.uk/ EPSRC

W. B. Langdon

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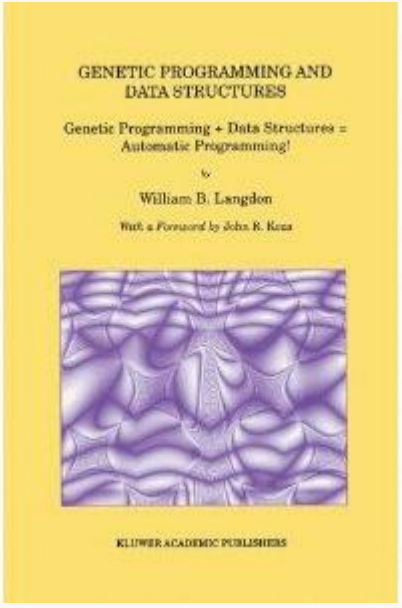
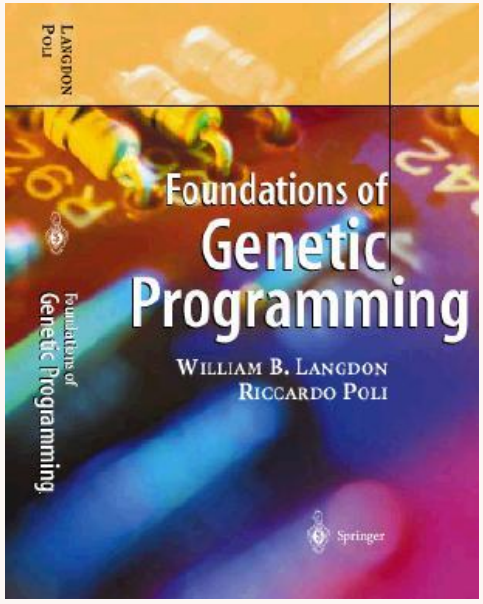
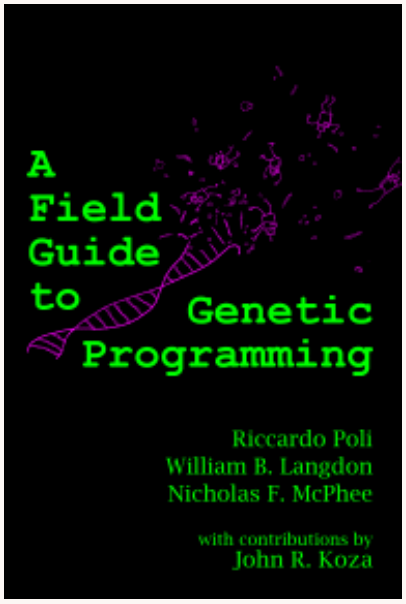
Department of Computer Science



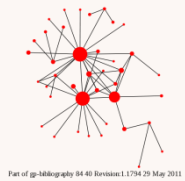




The Genetic Programming Bibliography

http://www.cs.bham.ac.uk/~wbl/biblio/

11315 references



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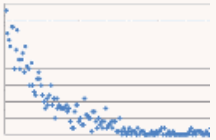

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