
TECHNOLOGY
FUTURES INC.
Your Bridge to the Future

Forecasting Artificial Intelligence

Lawrence Vanston, Ph.D.
President,
Technology Futures, Inc.

lvanston@tfi.com
512-415-5965

TFI 2018

January 25-26, 2018

Marriott Courtyard Downtown
Austin, Texas

84 Waller St • Austin, Texas 78702
(512) 258-8898 • www.tfi.com

TECHNOLOGY FUTURES INC.

Excerpted from:

Forecasting Issues for the New World

Lawrence Vanston, Ph.D.
President,
Technology Futures, Inc.

lvanston@tfi.com

23rd IIF Workshop
Predictive Analytics and Forecasting
Research and Applications

Siemens AG - Corporate Technology
September 14th & 15th, 2017
Munich, Germany

TECHNOLOGY FUTURES INC.

Outline

- Fundamental Driving Forces – Old and New
- Adoption Forecast for the New Transformative Technologies
- AI is in the Middle of Everything
- Performance Trend Basics
- Performance Trends for AI
- Implications

TECHNOLOGY FUTURES INC.

Fundamental Driving Forces - 1990s View

Physical Movement	→	Telecommunications
Analog	→	Digital Communications
Low Bandwidth	→	High Bandwidth
Wireline	→	Wireless
Electronic	→	Optical
Circuit Switching	→	Packet Switching
Mass Marketing	→	Niche Marketing

TECHNOLOGY FUTURES INC.

New Fundamental Driving Forces

Humans	→	Machines
People Communicating	→	Things Communicating
Computing	→	AI /Cognitive Computing
Screen-based	→	Augmented/Virtual Reality
Client/Server	→	Cloud Computing
Small Data	→	Big Data
Slow Data	→	Fast Data

These overlap & support each other!

TECHNOLOGY FUTURES INC.

Humans ⟹ Machines

Robots





Self Driving Vehicles

Drones

TECHNOLOGY FUTURES INC.

Kognit – Cognitive Assistants for Dementia Patients

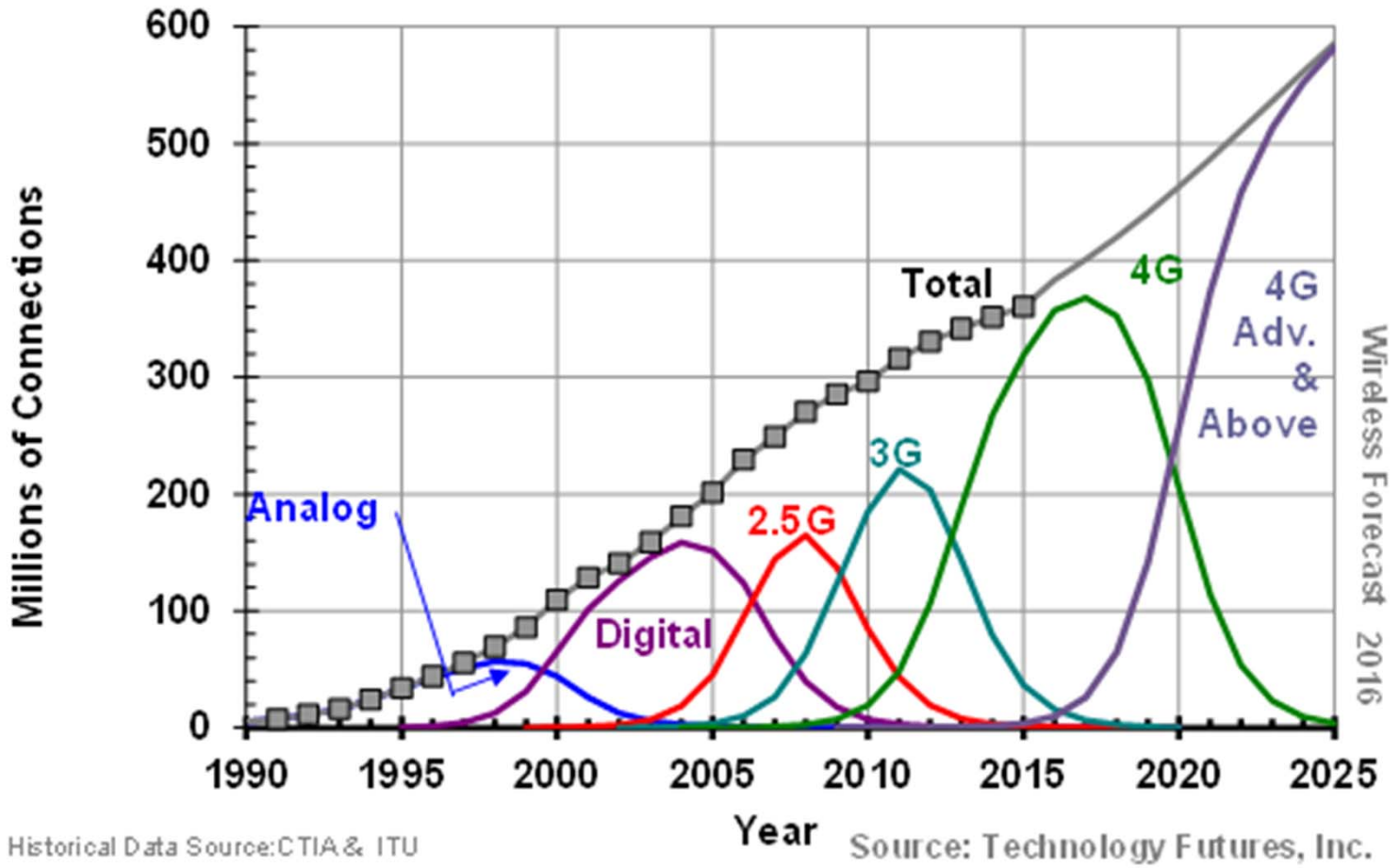
http://www.slideshare.net/diannepatricia/kognit-cognitive-assistants-for-dementia-patients

TECHNOLOGY FUTURES INC.

Adoption Forecast for the New Transformative Technologies

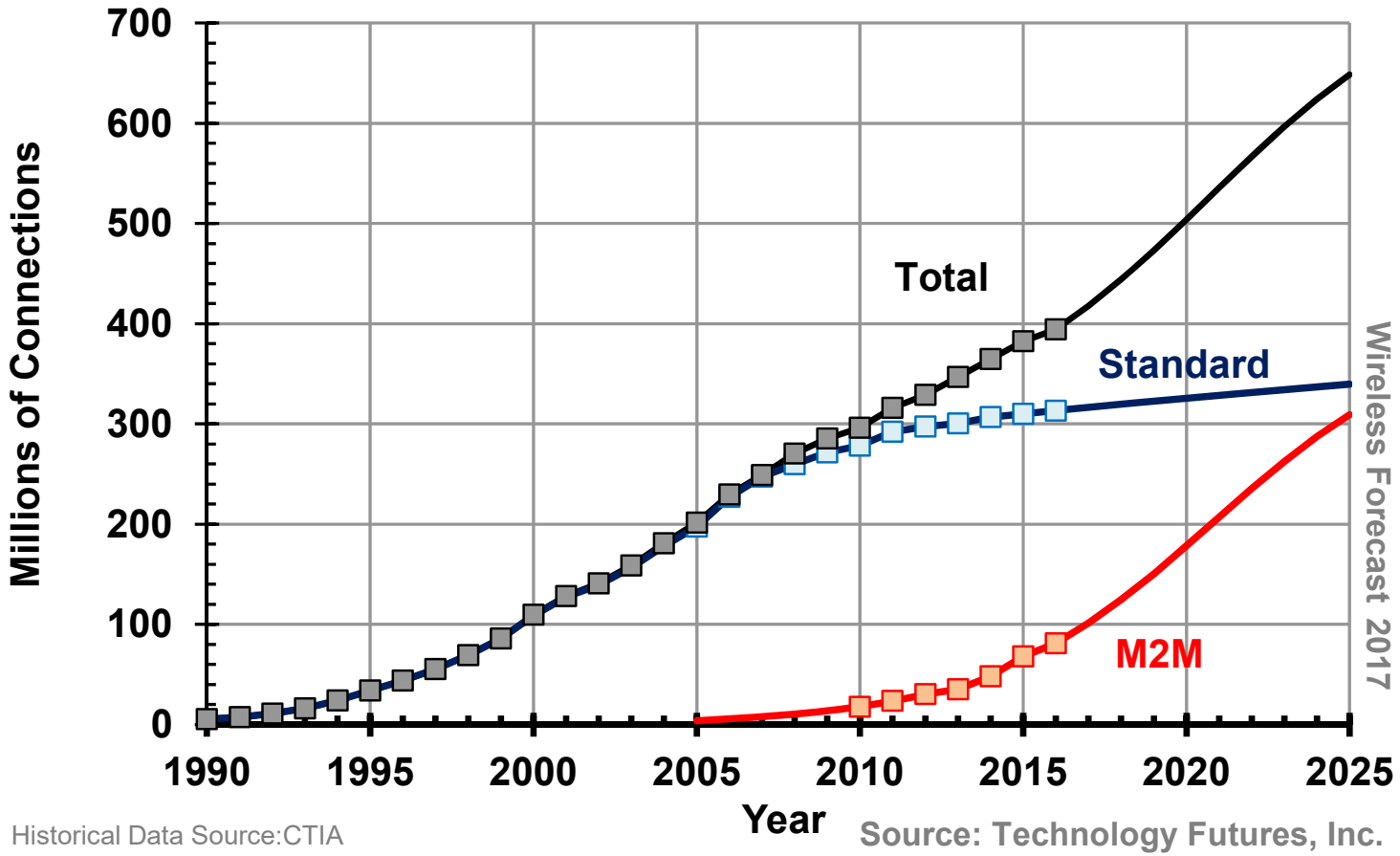
TECHNOLOGY FUTURES INC.

TFI Wireless Generations Forecast



TECHNOLOGY FUTURES INC.

TFI Wireless Connection Forecast

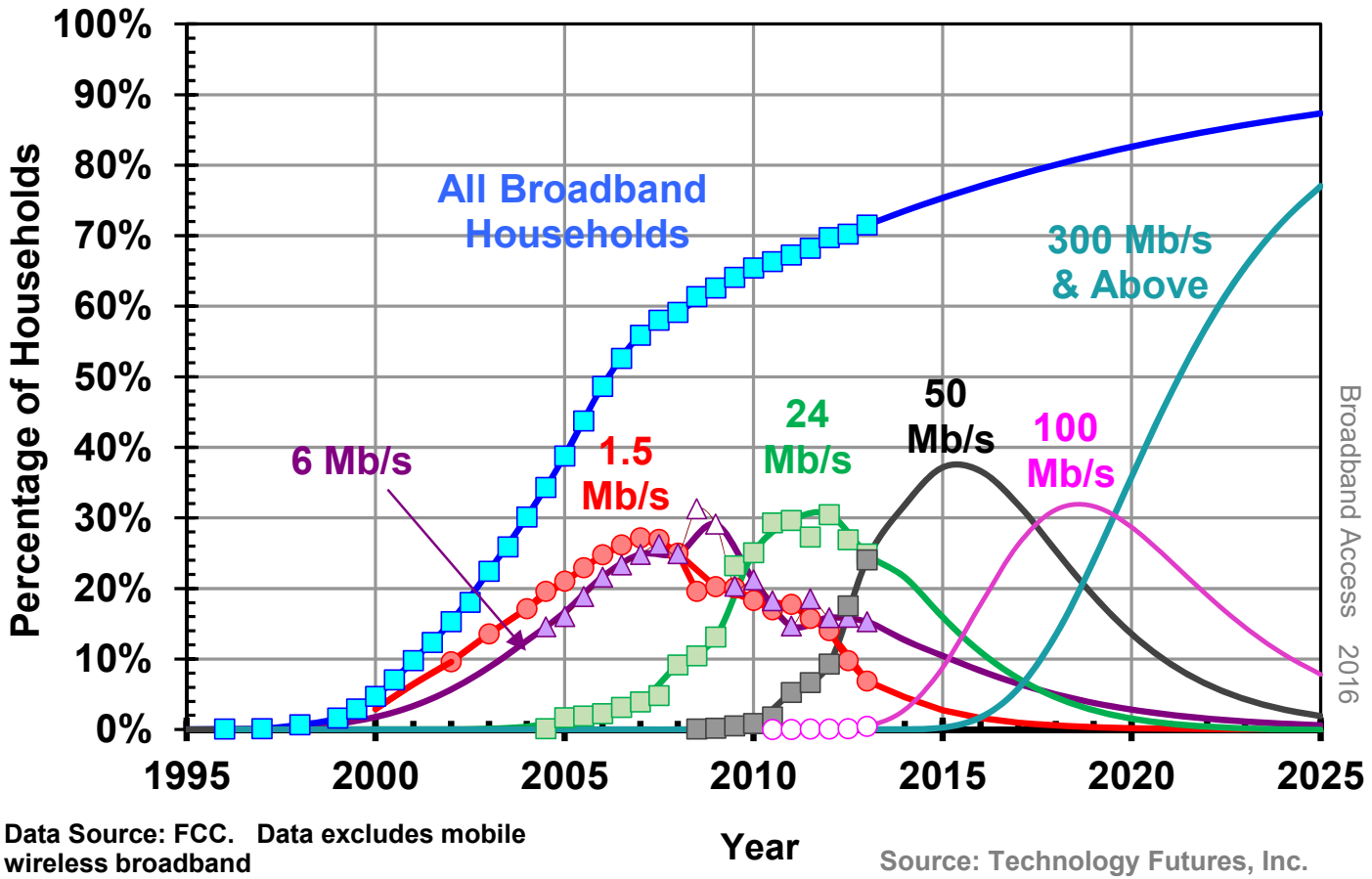


Historical Data Source:CTIA

Source: Technology Futures, Inc.

TECHNOLOGY FUTURES INC.

U.S. Broadband Lifecycles



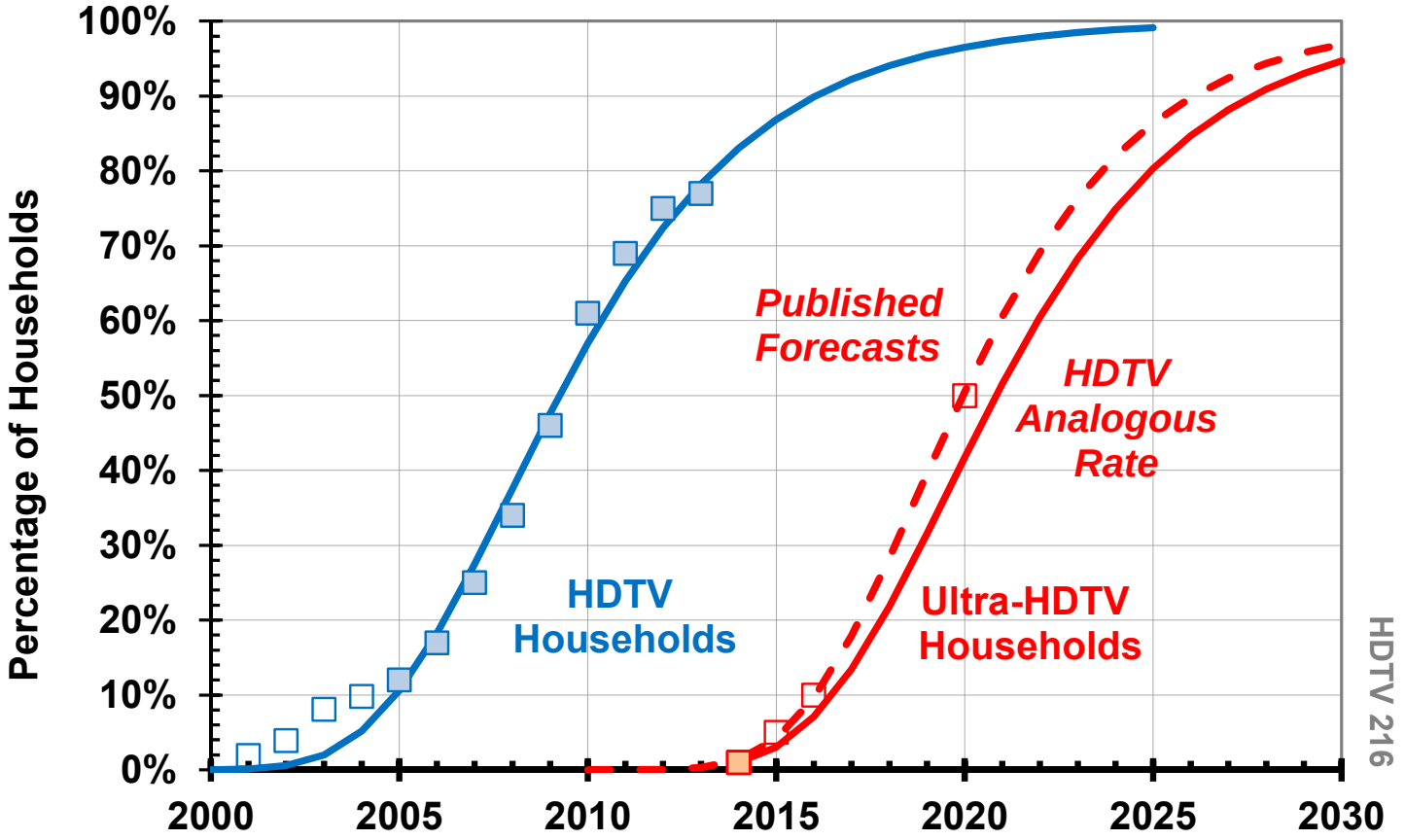
Data Source: FCC. Data excludes mobile wireless broadband

Source: Technology Futures, Inc.

Lifecycle (t) =
Substitution (t) – Next Substitution (t)

TECHNOLOGY FUTURES INC.

Ultra-HD Households (aka 4K)



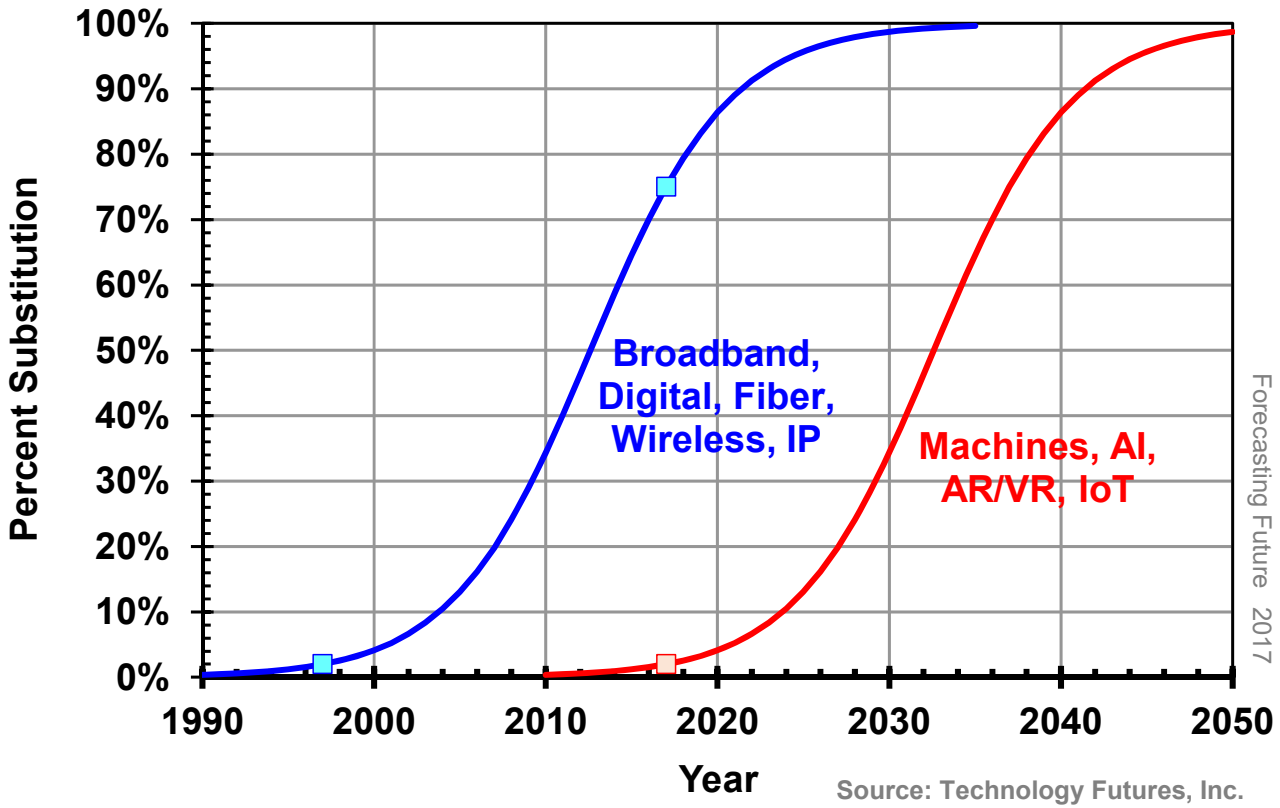
Historical data sources: 2001-2004 Misc, 2005-2015 Leichtman Research

Source: Technology Futures, Inc.

UHDTV Data Source (Red Squares): Strategy Analytics

TECHNOLOGY FUTURES INC.

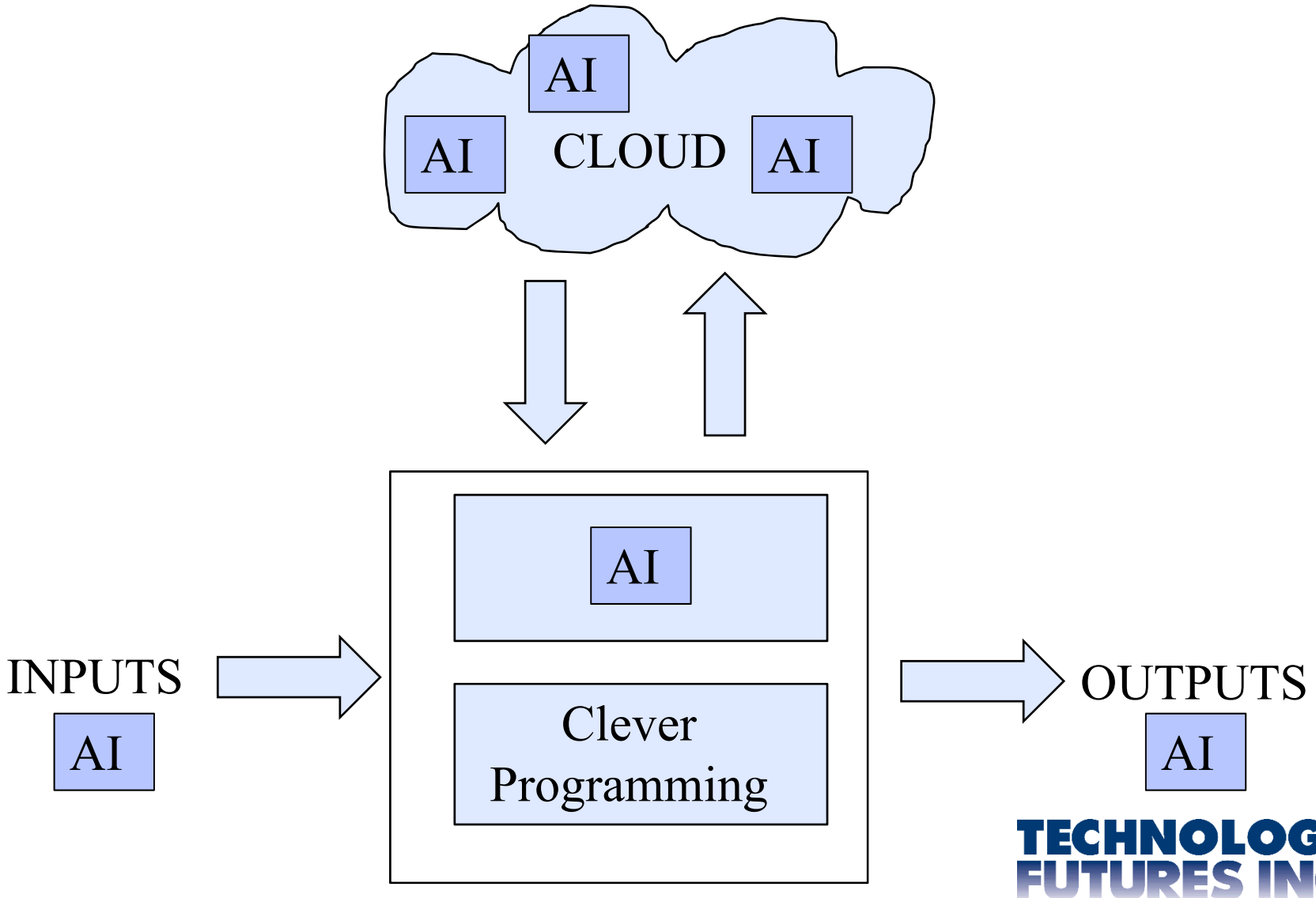
Major Transitions of our Time



Source: Technology Futures, Inc.

TECHNOLOGY FUTURES INC.

AI is in the Middle of Everything

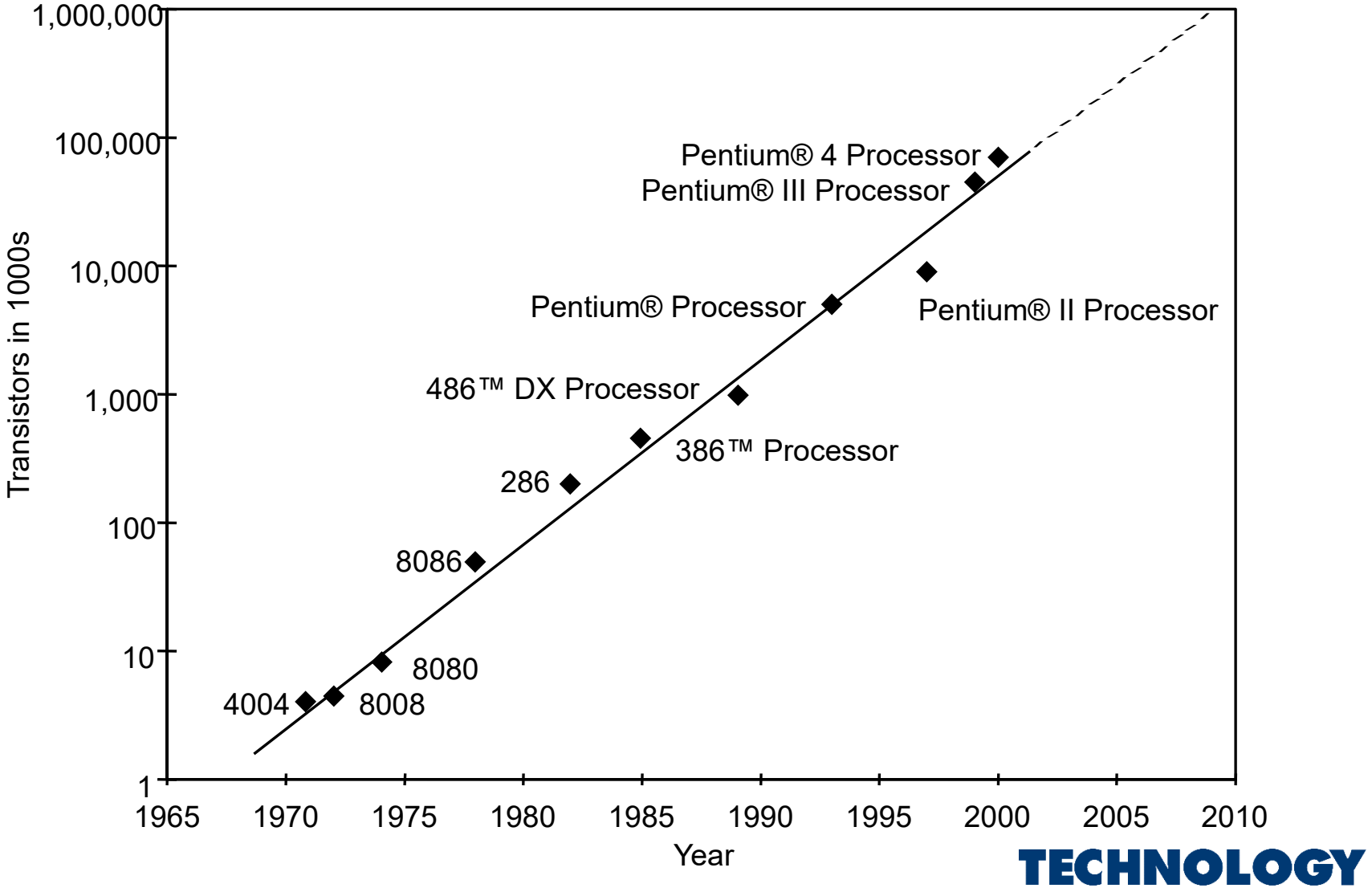


TECHNOLOGY FUTURES INC.

Performance Trends Basics

TECHNOLOGY FUTURES INC.

Moore's Law



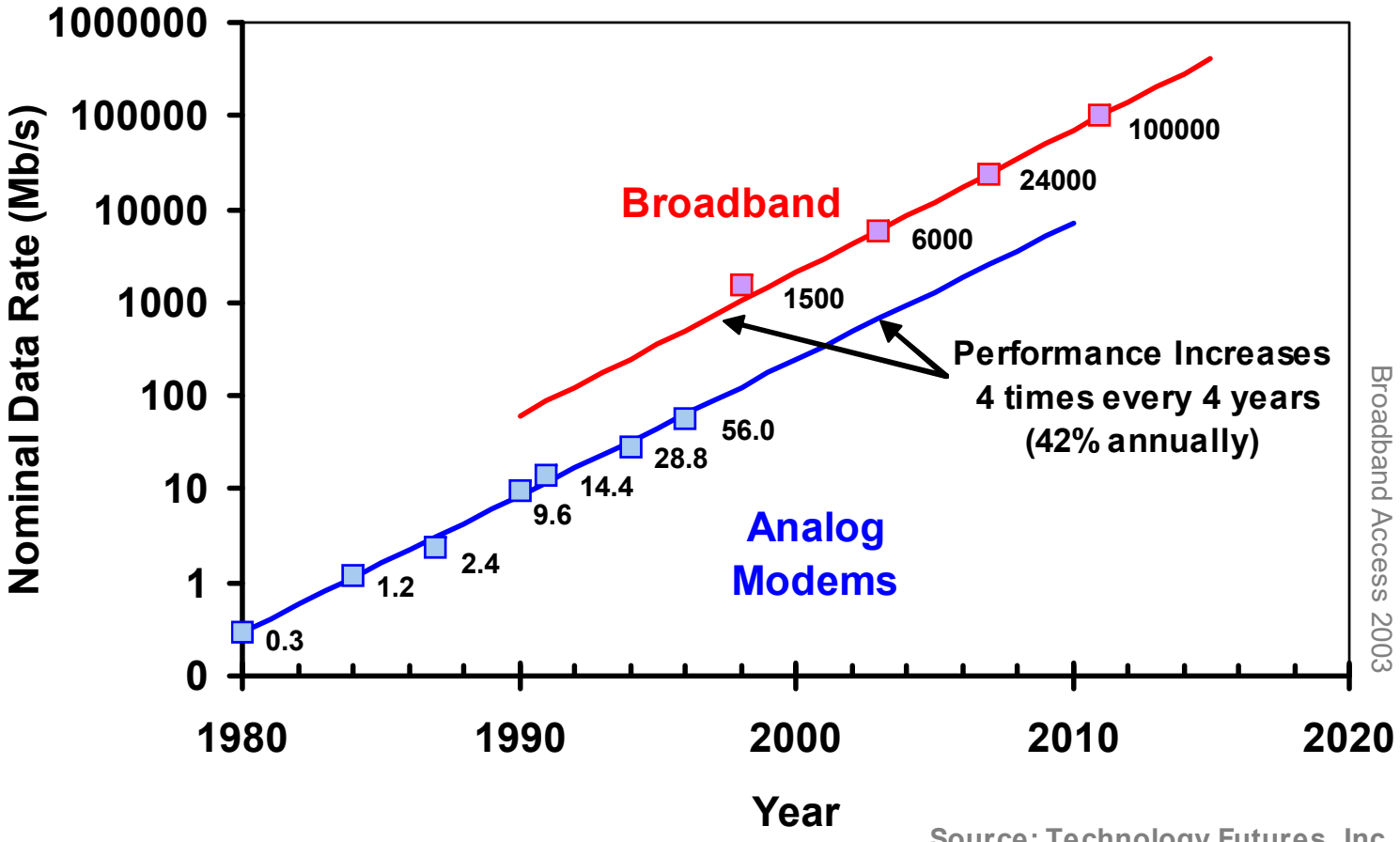
TECHNOLOGY FUTURES INC.

Constant Percentage Rate of Advance (Exponential)

- Most new technologies progress this way
- Measure must reflect utility
- Rates will continue if:
  - The improvement is technically possible
  - Utility and demand continues
  - Basic approach remains the same
- If approach changes, look for
  - Discontinuities
  - Changes in improvement rate

TECHNOLOGY FUTURES INC.

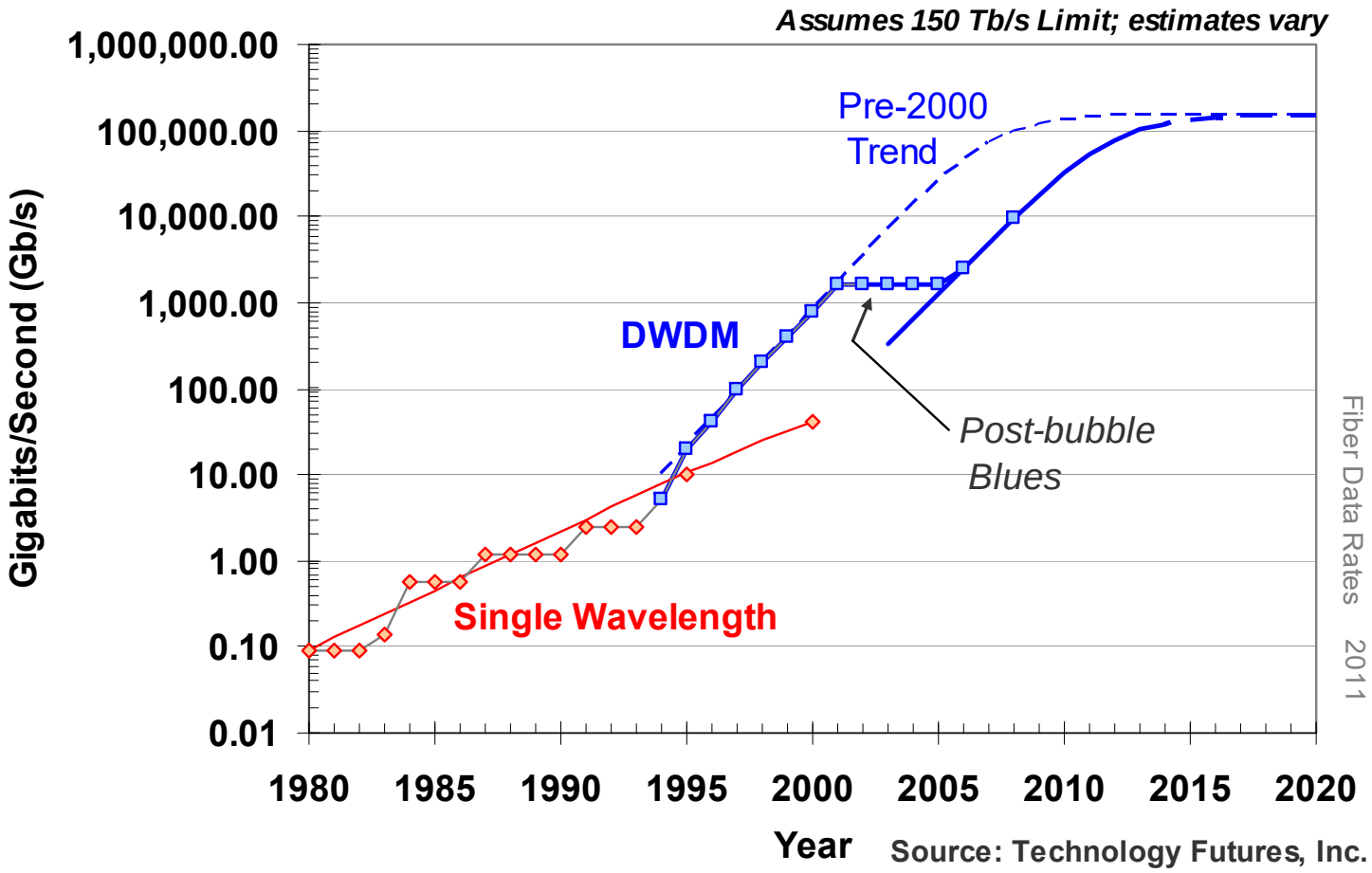
Analog Modem & Broadband Speeds



Source: Technology Futures, Inc.

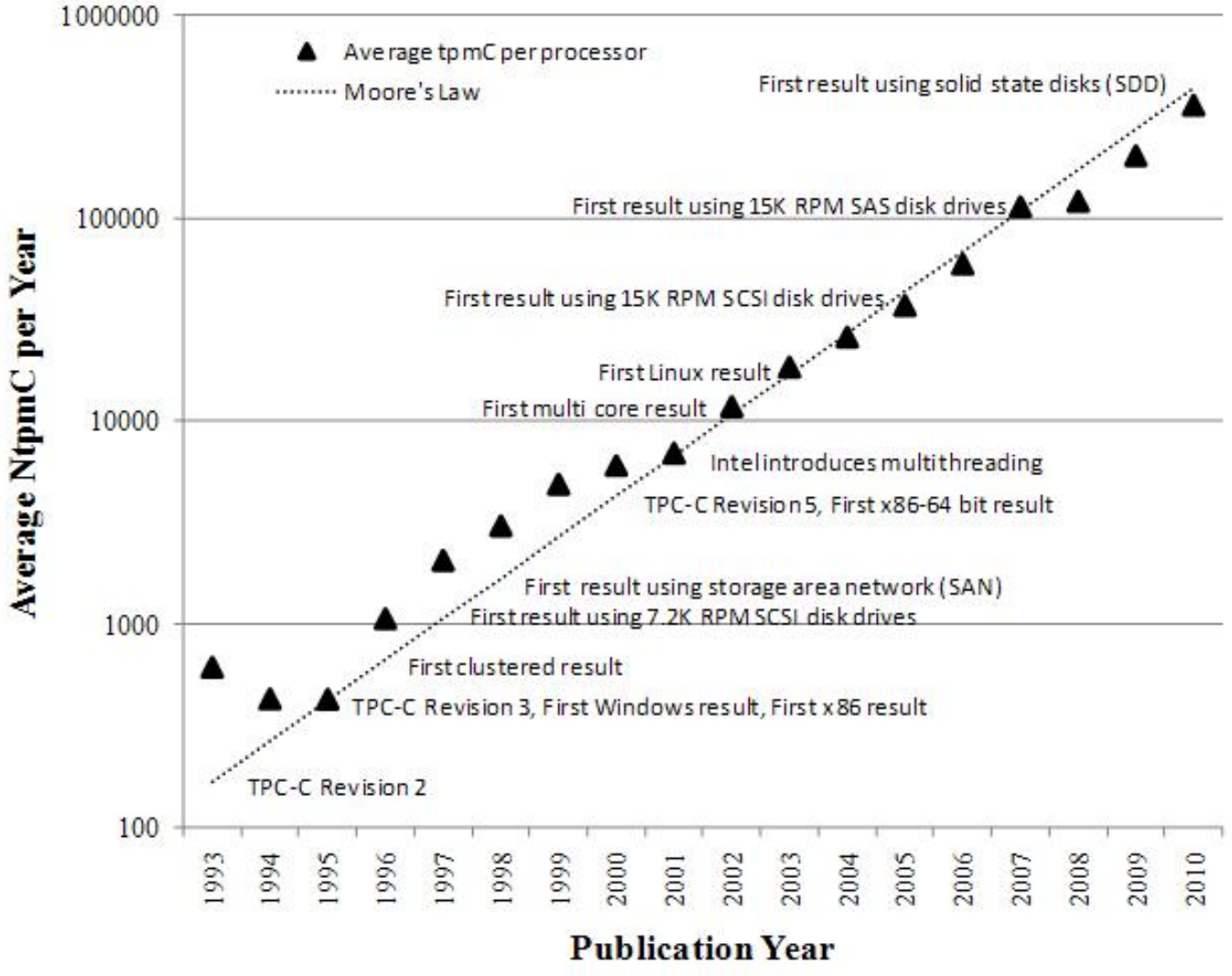
TECHNOLOGY FUTURES INC.

Maximum Data Rates for Commercial Fiber Optic Systems



TECHNOLOGY FUTURES INC.

Average transactions-per-minute per processor



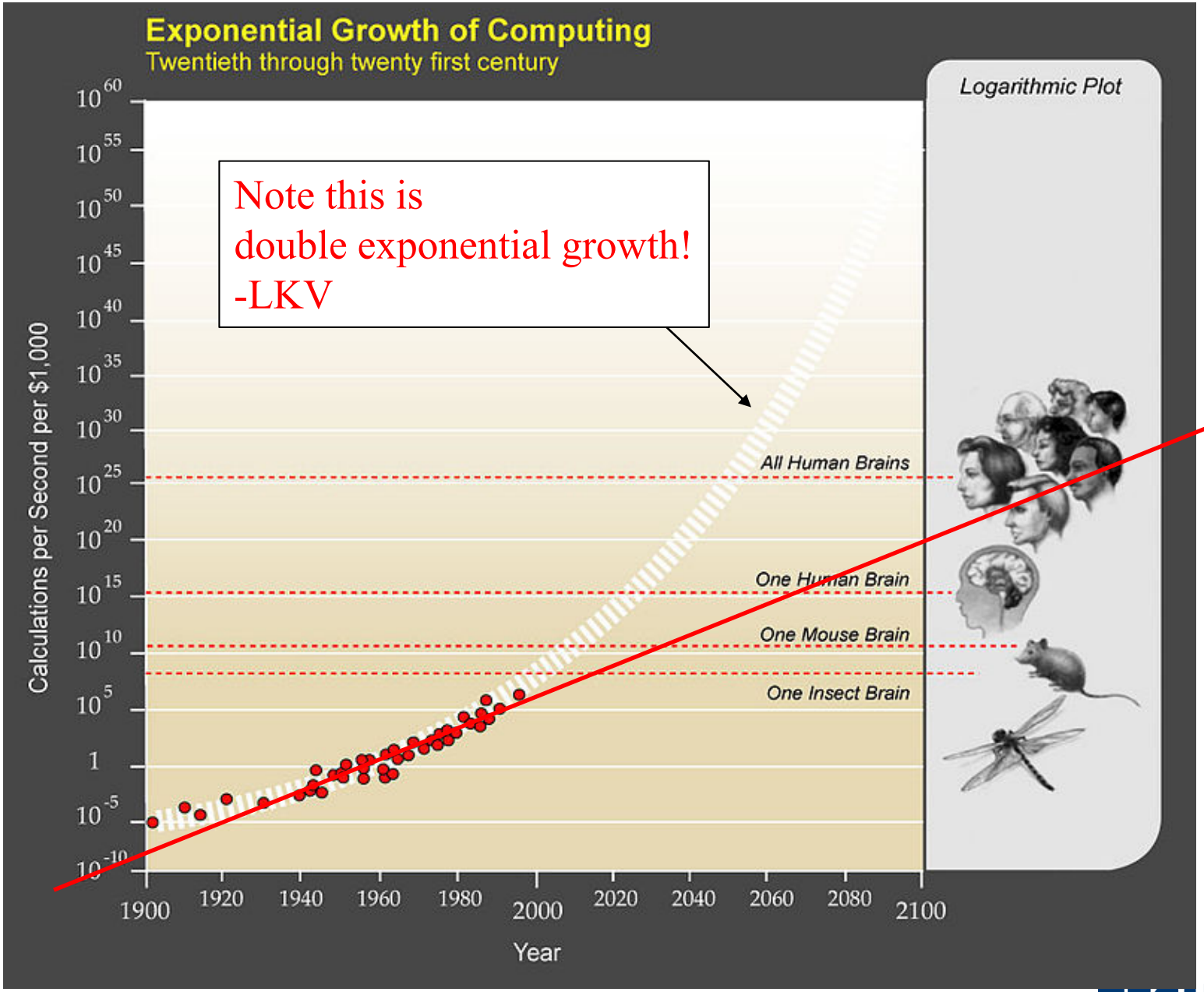
Source: Raghunath Nambiar , Cisco, http://tech4b.blogspot.com/2012/04/fast-data-brief-analysis-on-trends.html

TECHNOLOGY FUTURES INC.

Performance Trends for AI

TECHNOLOGY FUTURES INC.

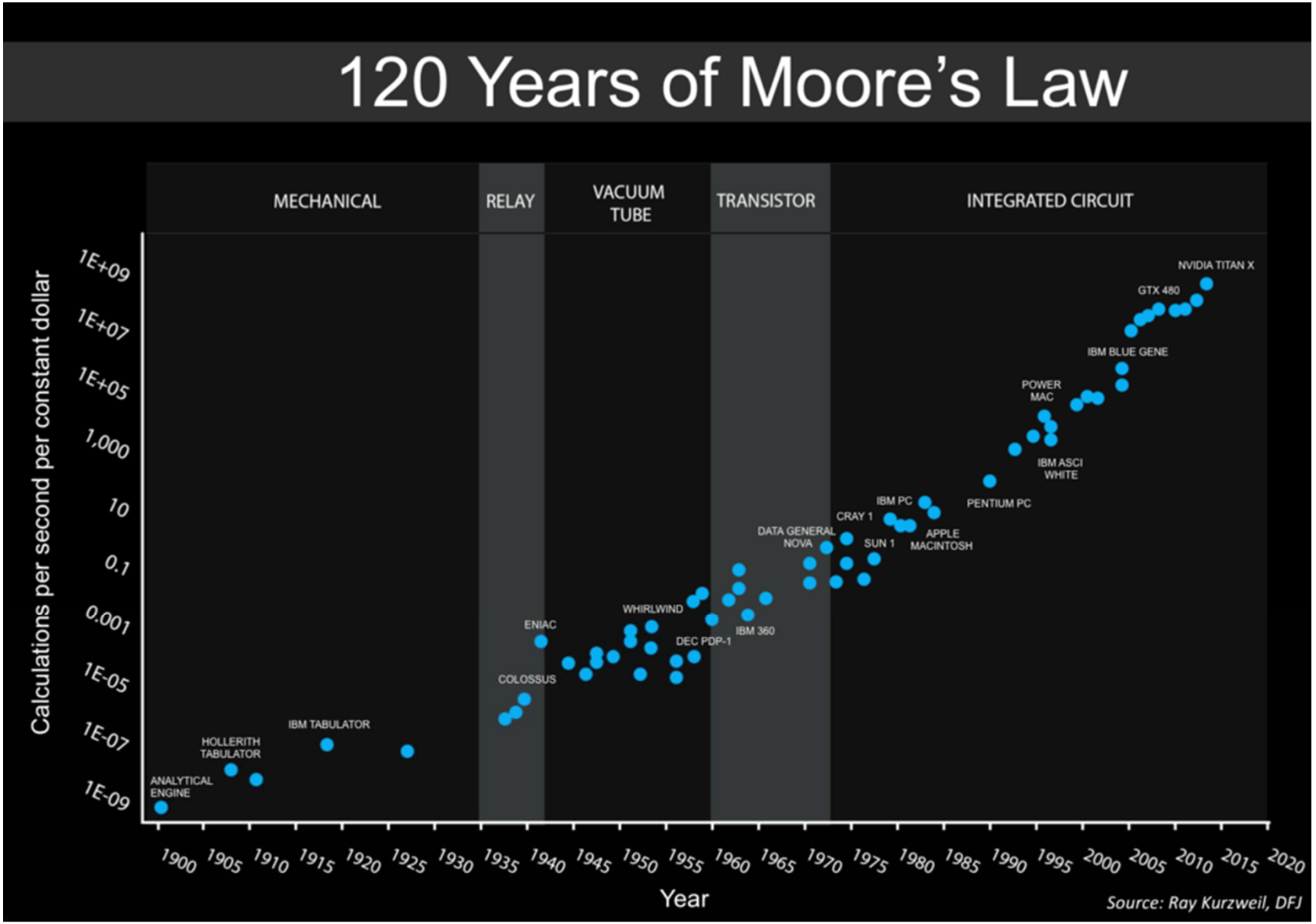
Kurzweil's Computer Performance Forecast



This is exponential growth!

By Courtesy of Ray Kurzweil and Kurzweil Technologies, Inc.
en:PPTExponentialGrowthof_Computing.jpg, CC BY 1.0,
https://commons.wikimedia.org/w/index.php?curid=3324354

TECHNOLOGY FUTURES INC.



By Steve Jurvetson - https://www.flickr.com/photos/jurvetson/31409423572/, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=55002144

TECHNOLOGY FUTURES INC.

Exponential Performance Trends

- Exponential

  $f(t) = e^{bt}$ — Typical

- Multiple Exponentials

  $f(t) = e^{b_1 t}\, e^{b_2 t} = e^{(b_1+b_2)t} = e^{bt}$ — Happens

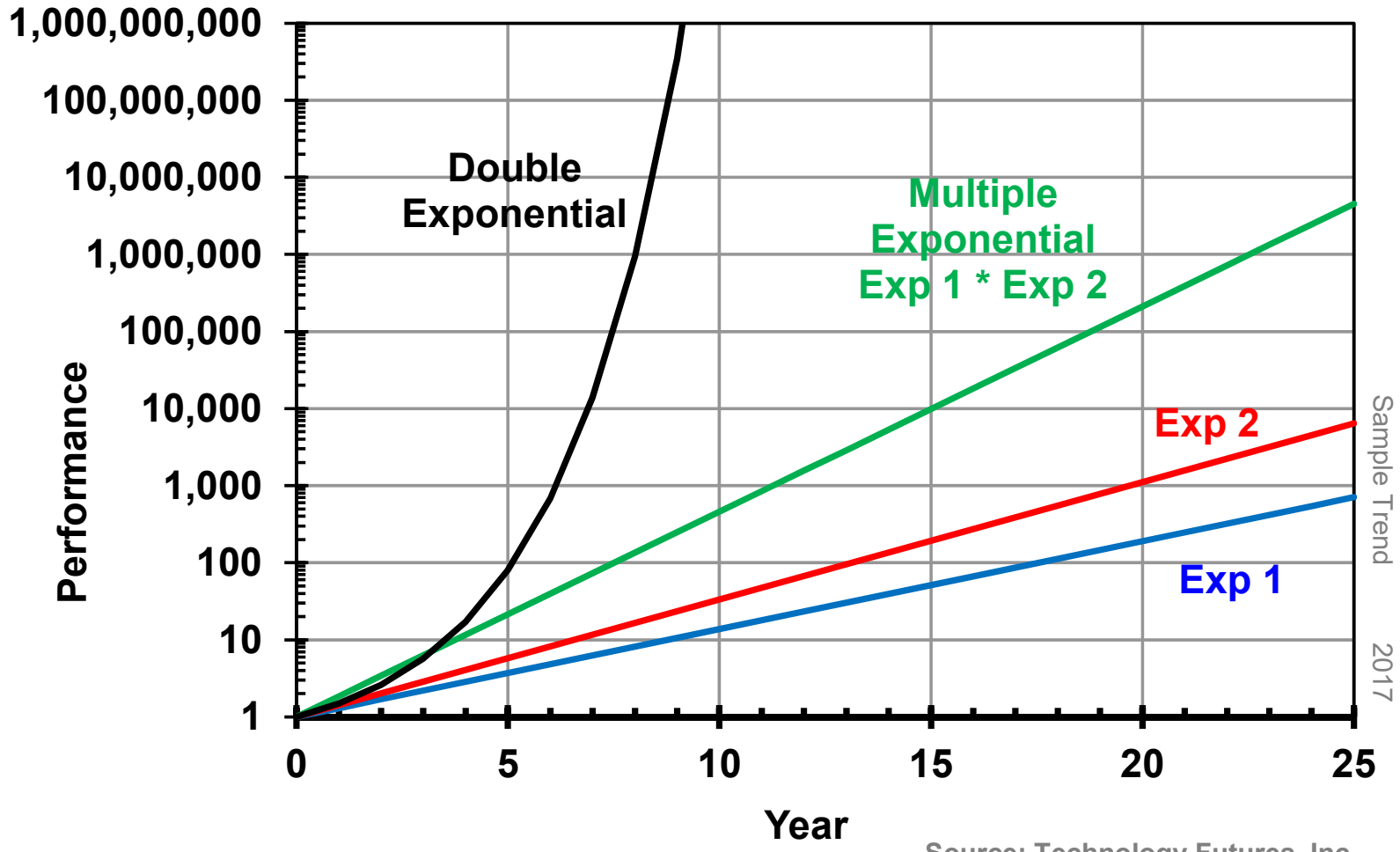
Note that Multiple Exponential is Exponential

- True Double Exponential

  $f(t) = e^{b^x} = e^{(b^x)}$ — NO!

TECHNOLOGY FUTURES INC.

Multiple vs Double Exponentials



Source: Technology Futures, Inc.

TECHNOLOGY FUTURES INC.

Elon Musk on AI Progress and Threat at International Space Station Research and Development Conference, July 19, 2017

Clip from CNN Money/Tech

Full interview at
https://www.youtube.com/watch?v=BqvBhhTtUm4

TECHNOLOGY FUTURES INC.

A Premise for Moving Forward

- Kurzweil means true double exponential, based on logic that better argues for multiple exponential.
- Musk means multiple exponential when he says “double exponential” (I think)
- Let’s assume that exponential is the most solid basis to explore the promise and impact of AI
- However, there’s a catch

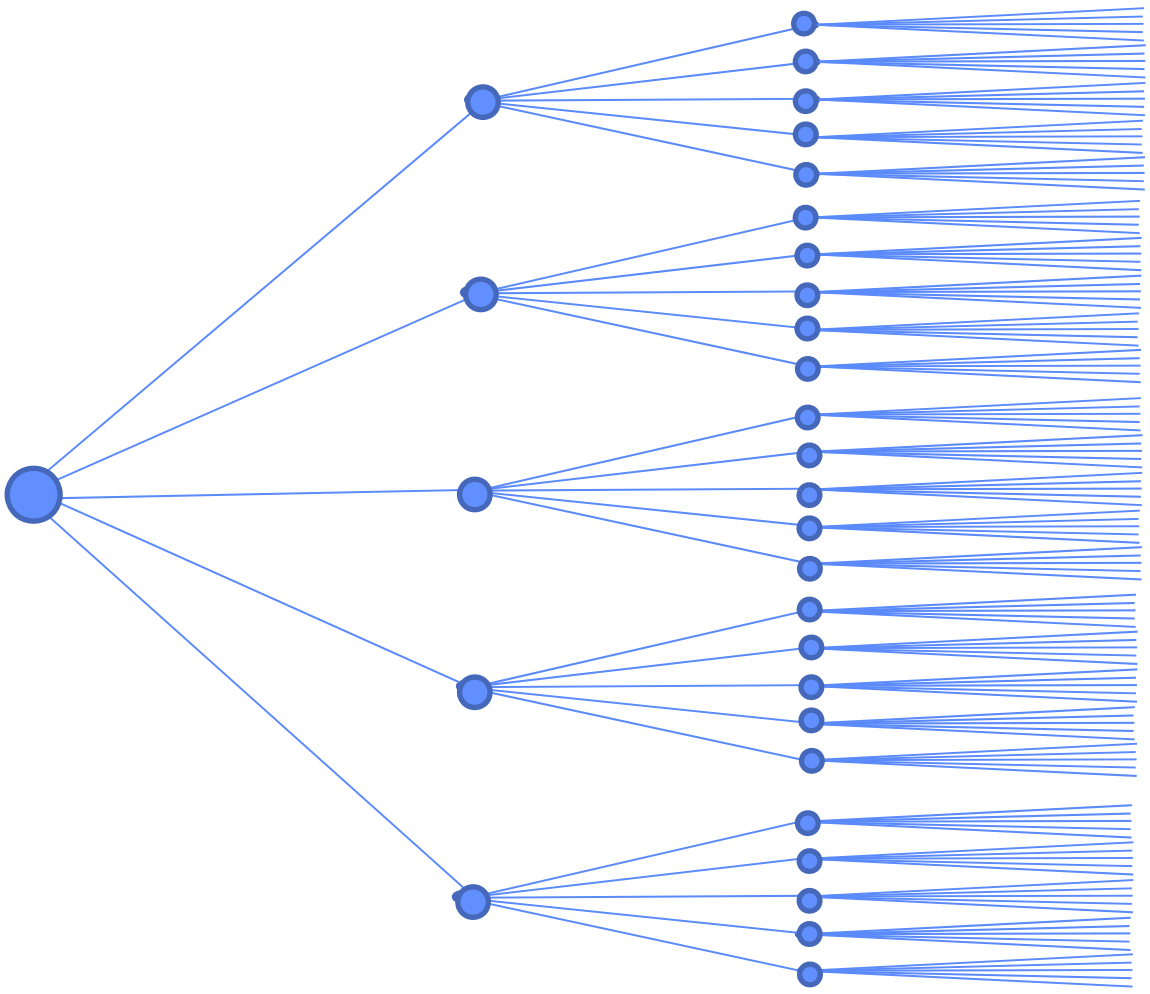
TECHNOLOGY FUTURES INC.

Hard vs Easy Problems

- Easy Problems
  - Computations grow linearly or polynomially with problem size **n**.
  - $\boldsymbol{f(n)} = a + b\mathbf{n}$
  - $\boldsymbol{f(n)} = a + b_1\mathbf{n} + b_2\mathbf{n}^2 + b_3\mathbf{n}^3 \ldots + b_k\mathbf{n}^k$
- Hard Problems
  - Computations grow exponentially with problem size **n**
  - $\boldsymbol{f(n)} = \mathbf{e}^{\mathbf{cn}}$

TECHNOLOGY FUTURES INC.

Decision Tree



1 5 25 125

n	5^n
1	5
2	25
3	125
4	625
5	3,125
6	15,625
7	78,125
8	390,625
9	1,953,125
10	9,765,625
11	48,828,125
12	244,140,625
13	1,220,703,125
14	6,103,515,625
15	30,517,578,125
16	152,587,890,625
17	762,939,453,125
18	3,814,697,265,625
19	19,073,486,328,125
20	95,367,431,640,625
21	476,837,158,203,125
22	2,384,185,791,015,620
23	11,920,928,955,078,100
24	59,604,644,775,390,600
25	298,023,223,876,953,000

TECHNOLOGY FUTURES INC.

Performance Trends for Problem Solving - Advanced

- Exponential increase in processing speed, $x(t)=e^{b_1 t}$
- Exponential increase in efficiency, $y(t)=e^{b_2 t}$
- Combined performance, $e^{(b_1+b_2)t} = e^{bt}$
- Solution time = $s(t) = f(n)/ e^{bt} = e^{-bt} f(n)$
- The maximum problem size solvable in ***S*** seconds grows with **n**:

  Exponentially if ***f(n)*** is polynomial (Easy)

  Linearly if ***f(n)*** is exponential (Hard)

TECHNOLOGY FUTURES INC.

Maximum Problem Size in S seconds

Exponential Difficulty (Hard)

$f(n) = e^{cn}$

$s(t) = e^{-bt}e^{cn}$

For a given solution time S:

$S = e^{-bt}e^{cn}$

Solving for n at time t:

$n(t) = \ln S / c + (b/c)\, t = A + Bt$

Linear Progress

Polynomial Difficulty (Easy)

$f(n) = n^{k}$

$s(t) = e^{-bt}n^{k}$

For a given solution time S:

$S = e^{-bt}n^{k}$

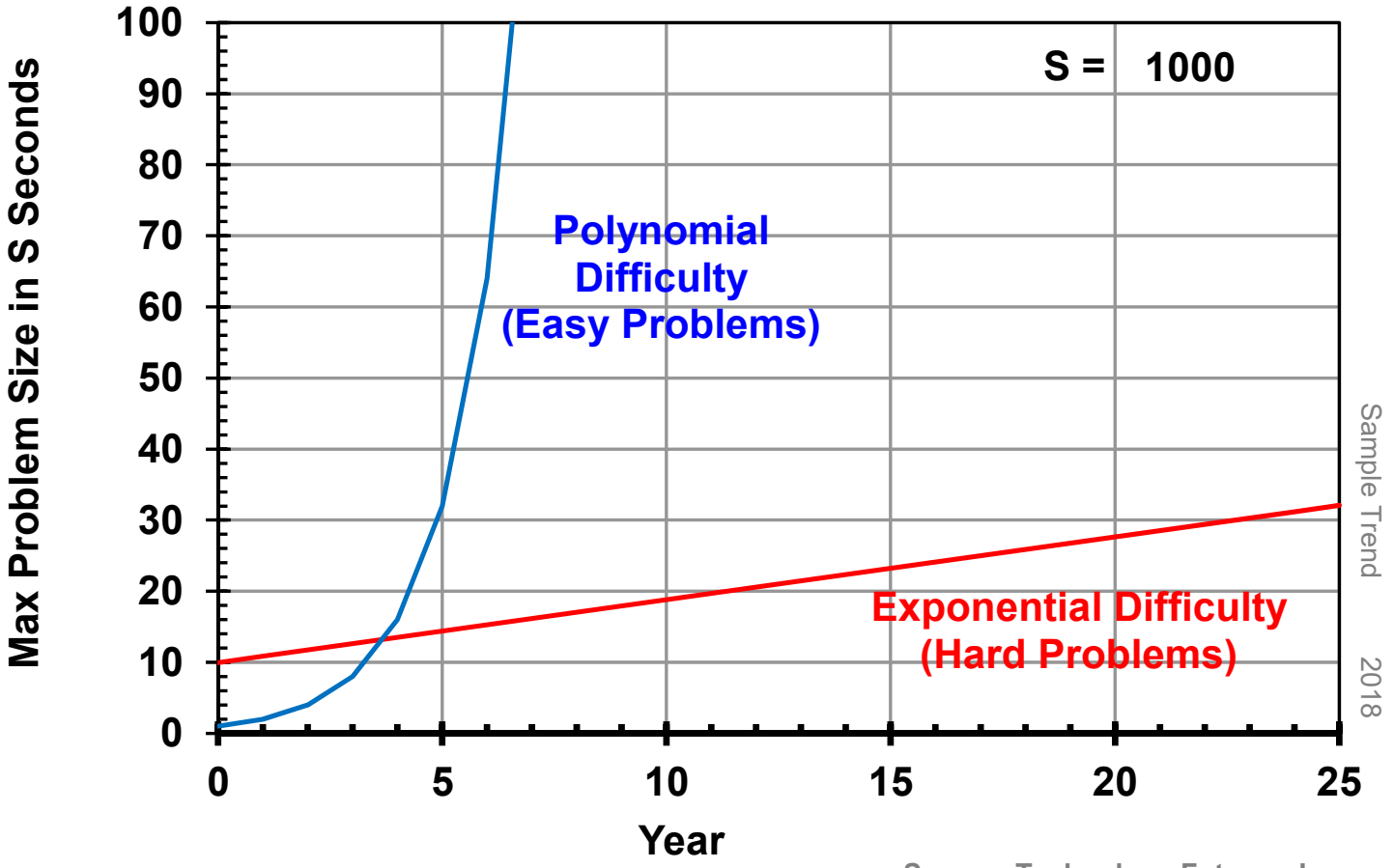
Solving for n at time t:

$n(t) = S^{1/k}e^{(b/k)t} = Ae^{Bt}$

Exponential Progress

TECHNOLOGY FUTURES INC.

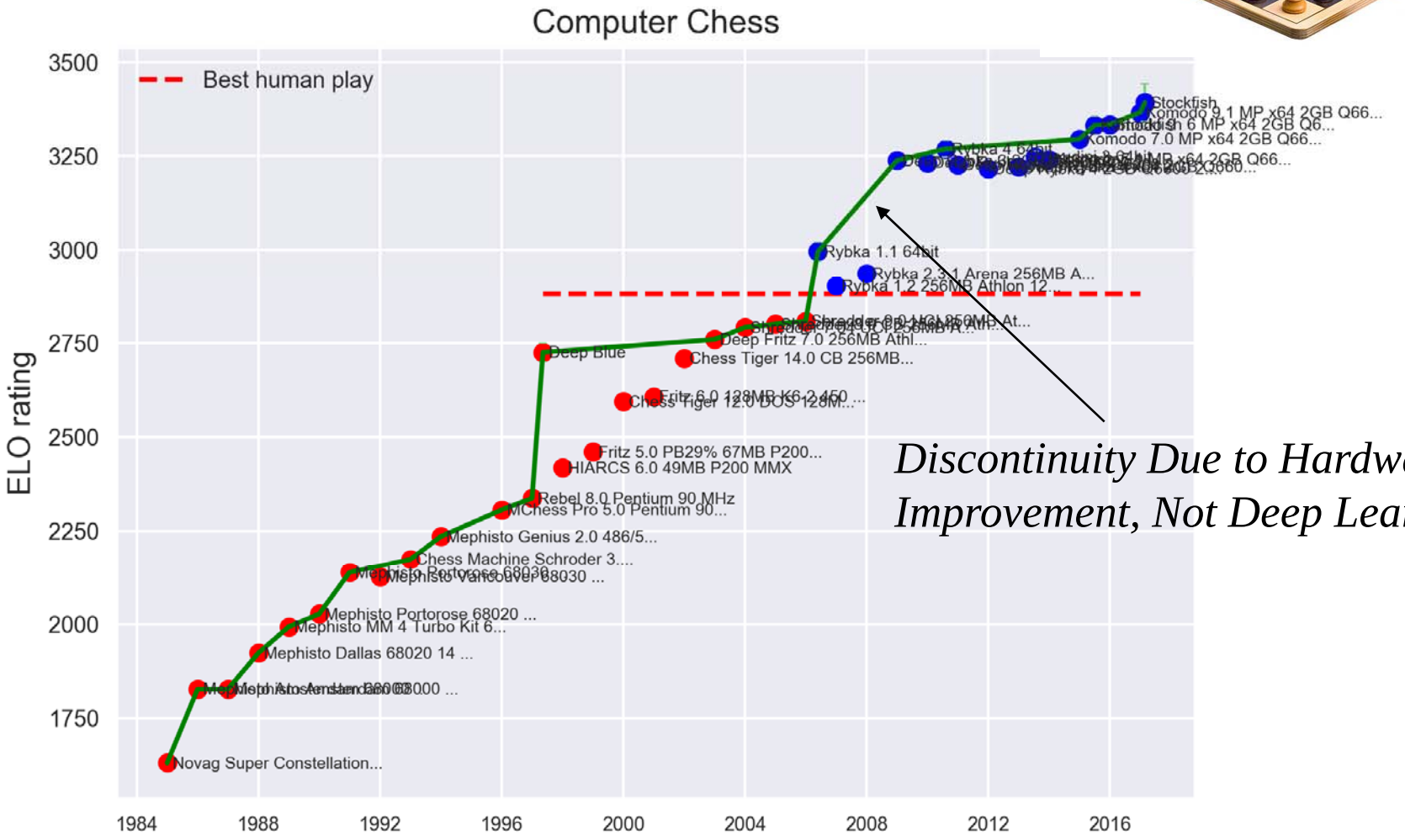
Maximum Problem Size in S seconds (Example)



Source: Technology Futures, Inc.

TECHNOLOGY FUTURES INC.

Chess

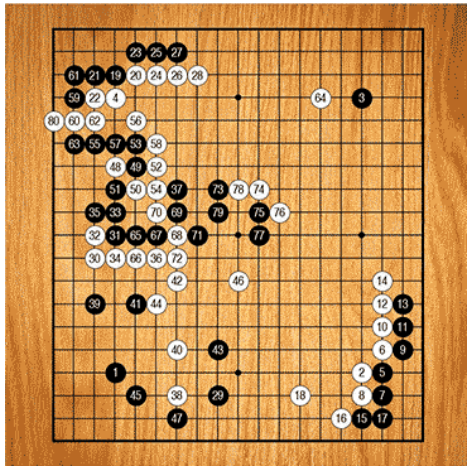


Discontinuity Due to Hardware Improvement, Not Deep Learning

https://www.eff.org/ai/metrics

TECHNOLOGY FUTURES INC.

Go



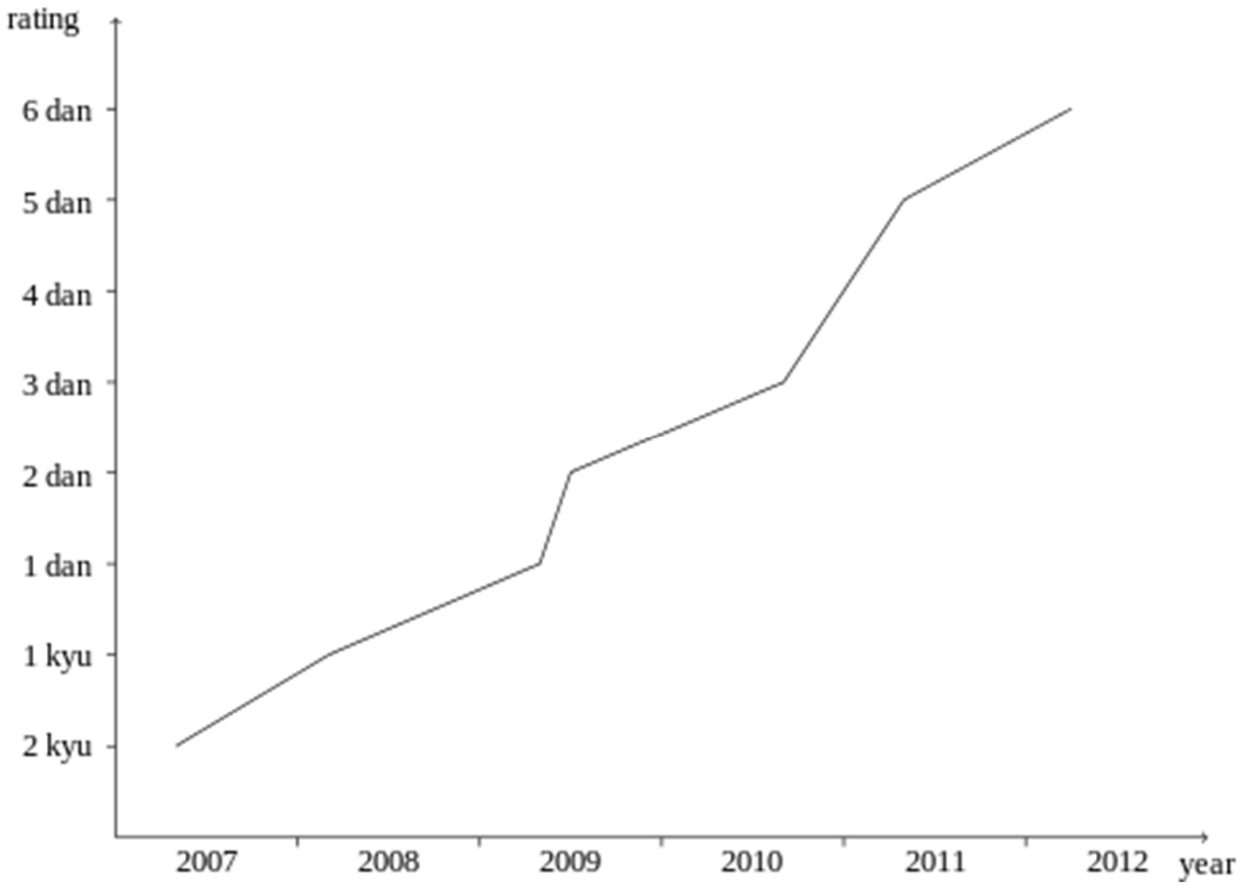
- AlphaGo performed notably better than its predecessors (all Monte Carlo Tree Search programs, but without deep learning or GPUs.)
- It uses *much* more hardware and more data.
- AlphaGo doesn't represent that much of a surprise given the improvements in hardware and data (and effort). – Miles Brundage

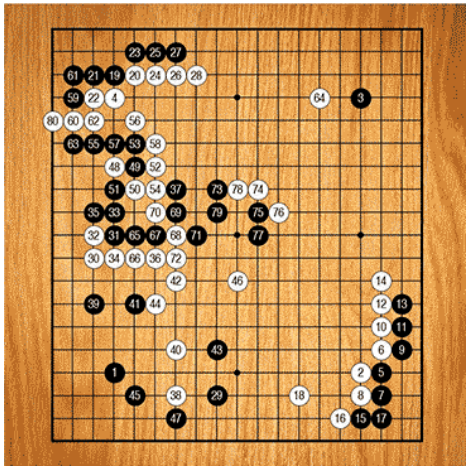
Miles Brundage (http://www.milesbrundage.com/blog-posts/alphago-and-ai-progress)

https://srconstantin.wordpress.com/2017/01/28/performance-trends-in-ai/

TECHNOLOGY FUTURES INC.

Prior AI Go Improvement

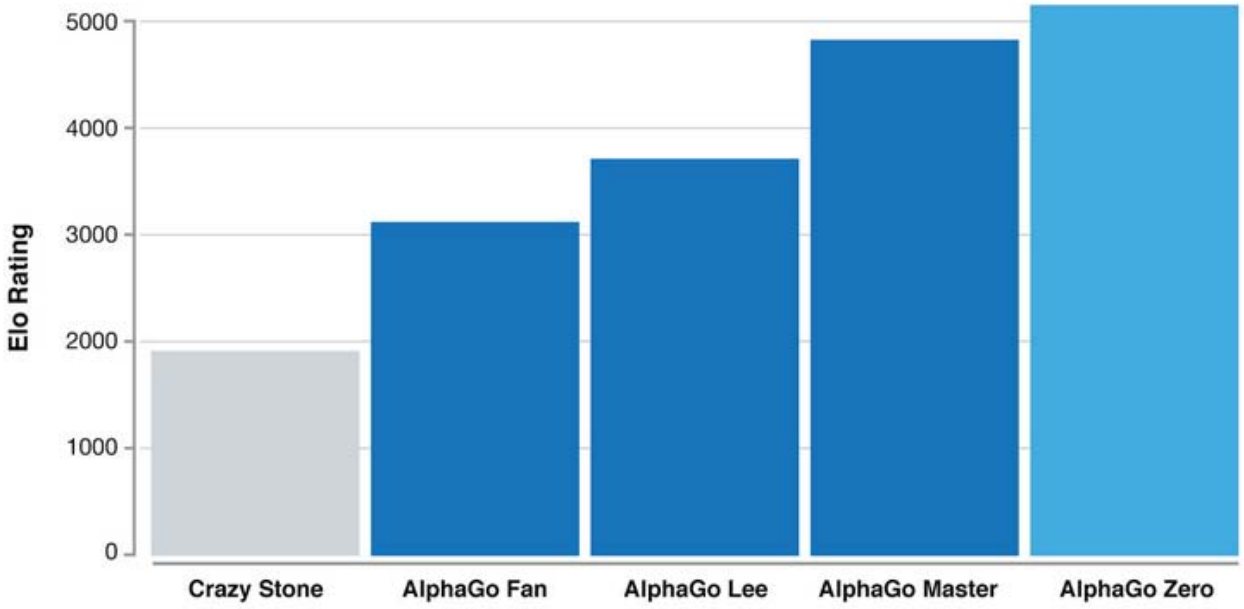


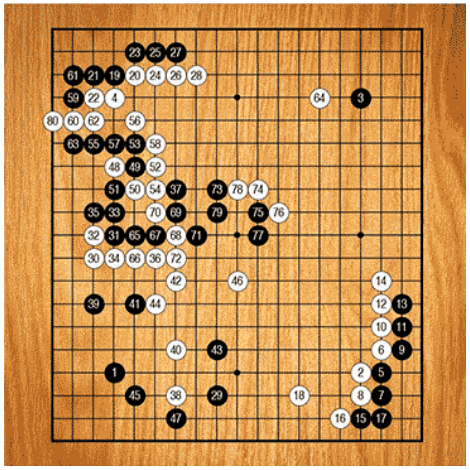


Found at: https://en.wikipedia.org/wiki/Monte_Carlo_tree_search
Referenced source for data: "Sensei's Library: KGSBotRatings". Retrieved 2012-05-03. https://senseis.xmp.net/?KGSBotRatings

TECHNOLOGY FUTURES INC.

AlphaGo Continued Progress

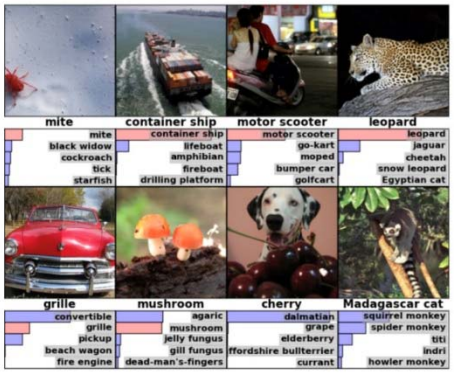


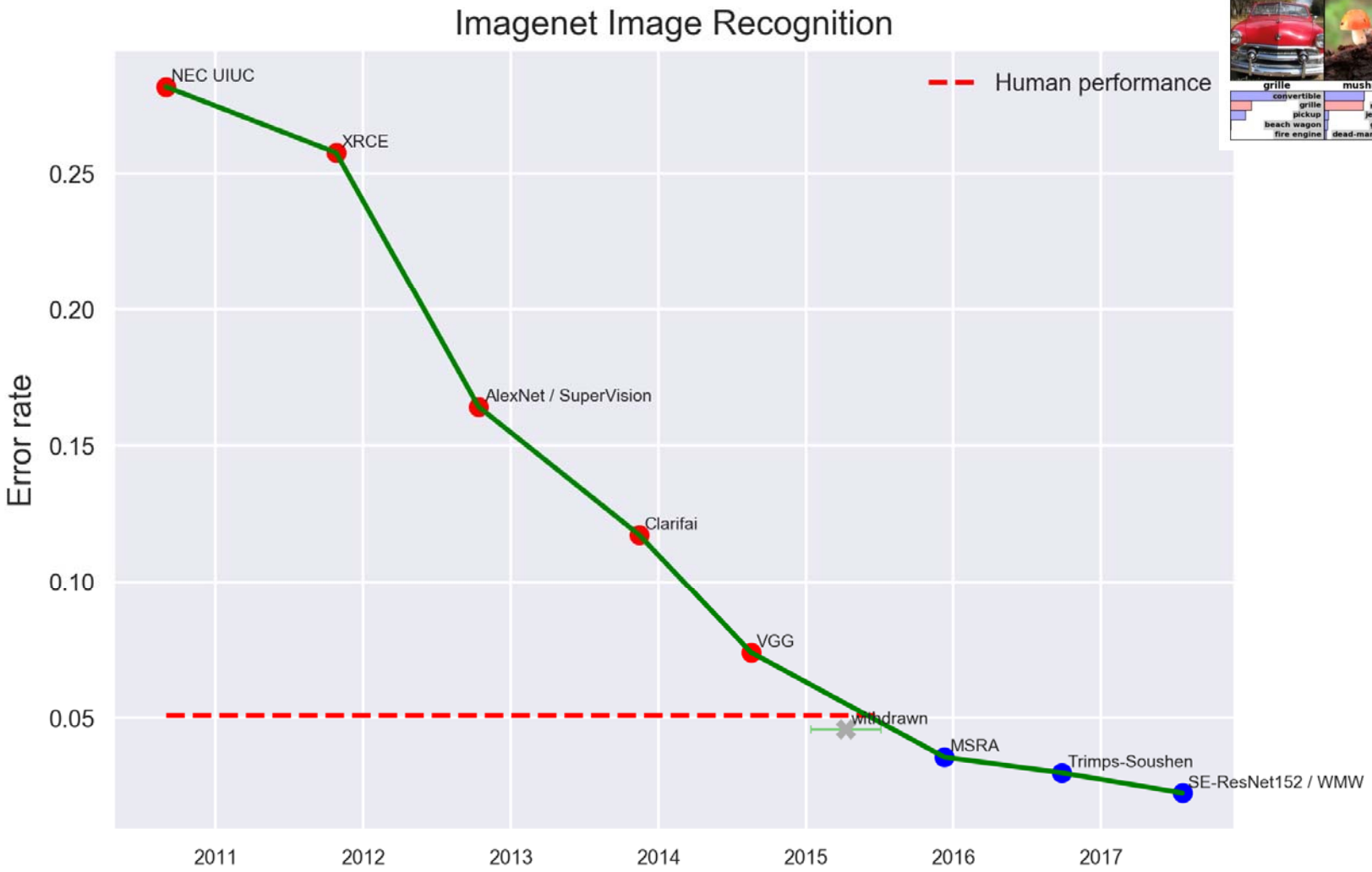


https://deepmind.com/blog/alphago-zero-learning-scratch/

TECHNOLOGY FUTURES INC.

Image Recognition

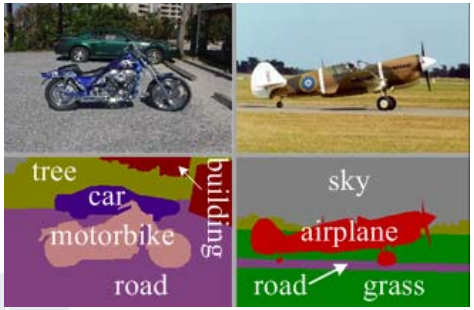


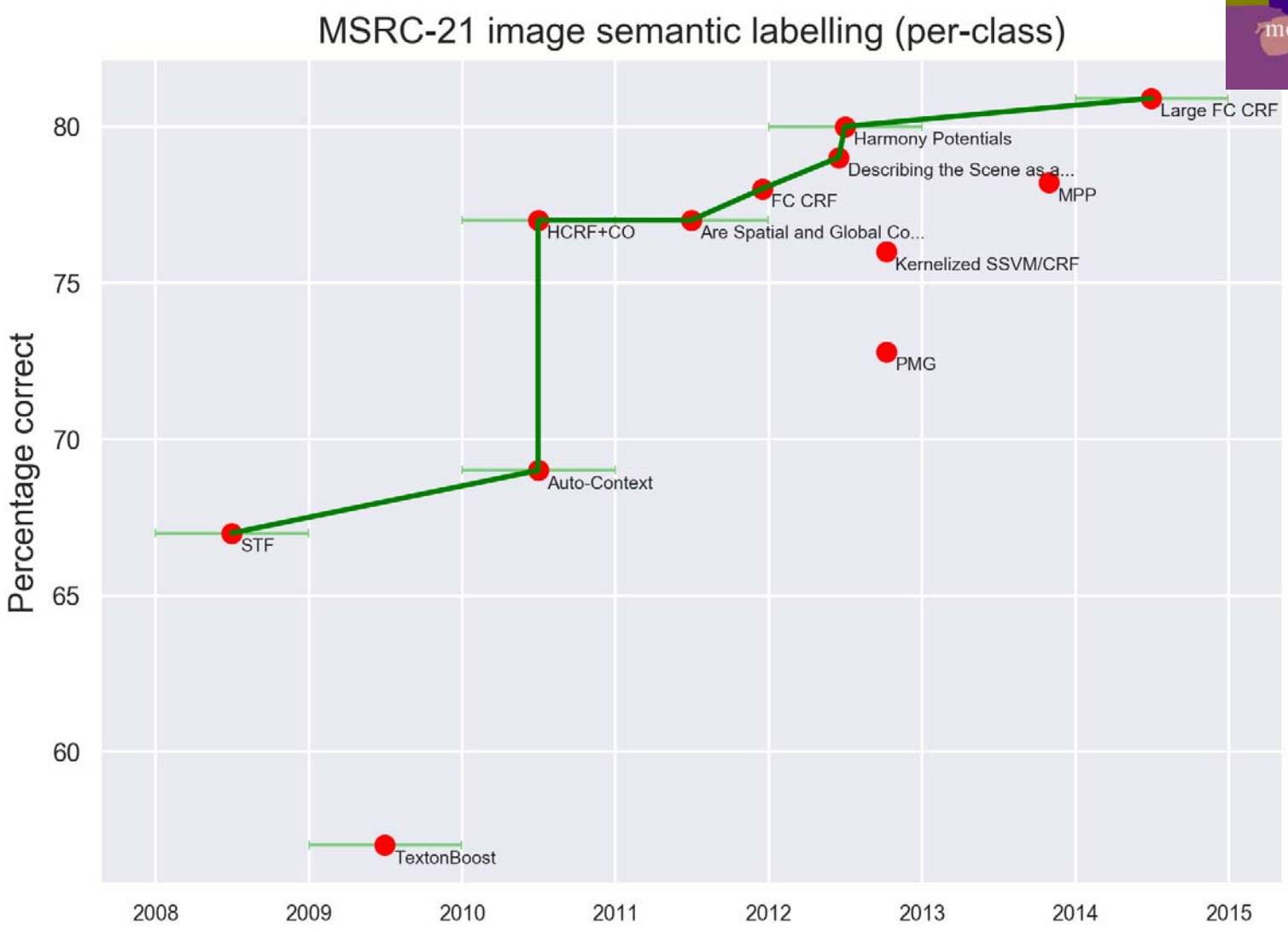


TECHNOLOGY FUTURES INC.

https://www.eff.org/ai/metrics

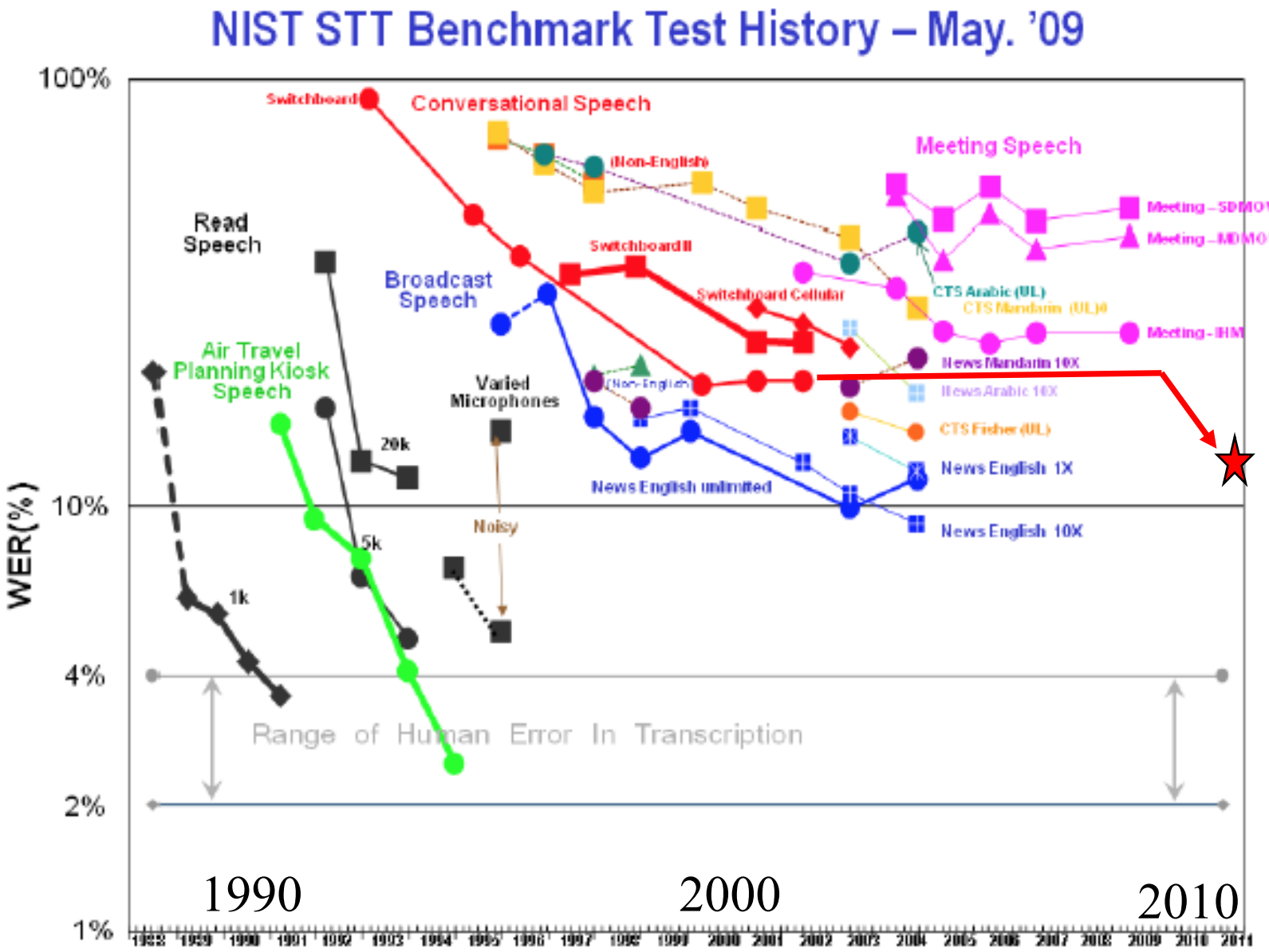
Image Recognition





https://www.eff.org/ai/metrics

SPEECH RECOG-NITION



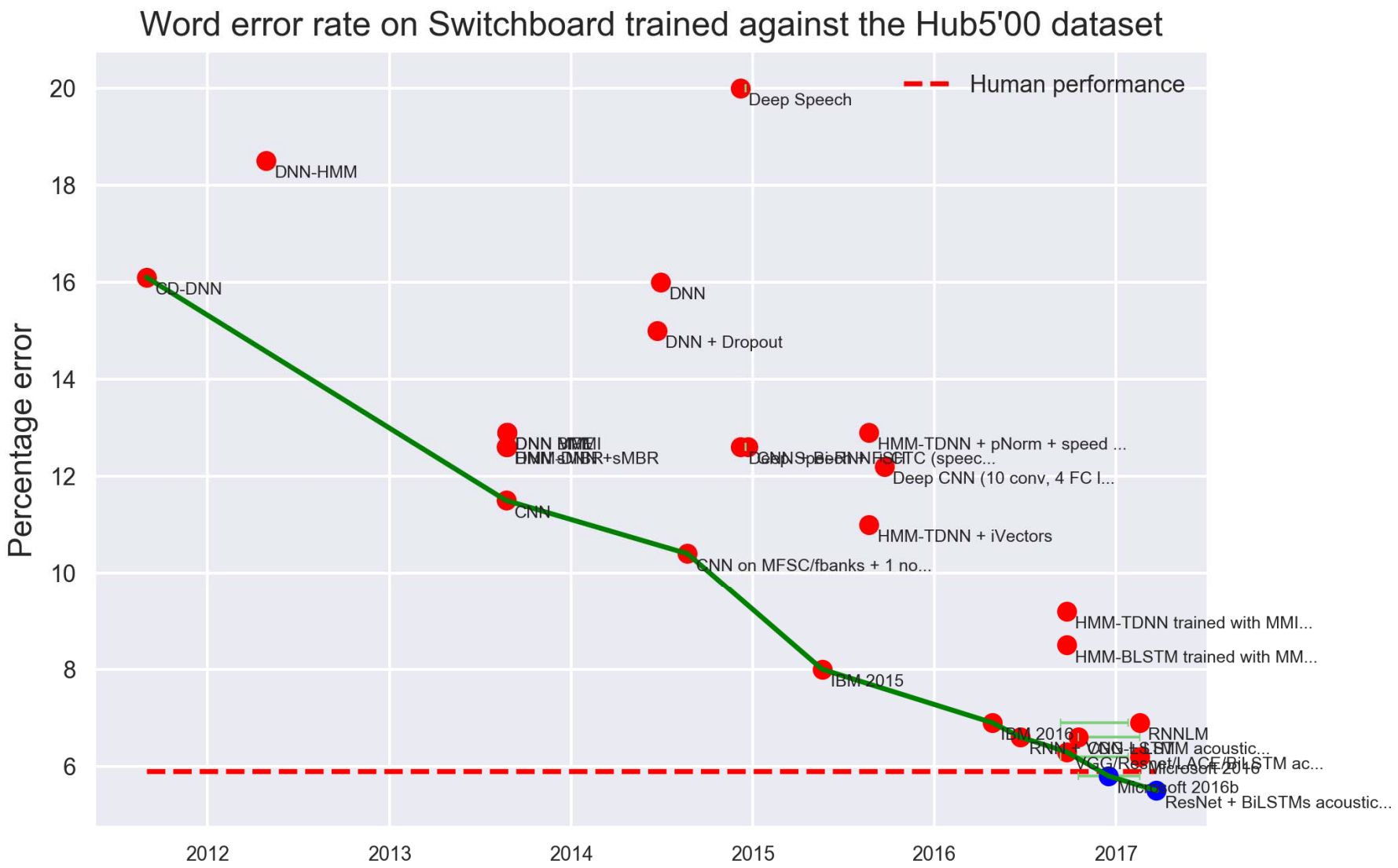
2011: context-dependent deep neural network hidden Markov models

(http://itl.nist.gov/iad/mig/publications/ASRhistory/index.html

https://srconstantin.wordpress.com/2017/01/28/performance-trends-in-ai/

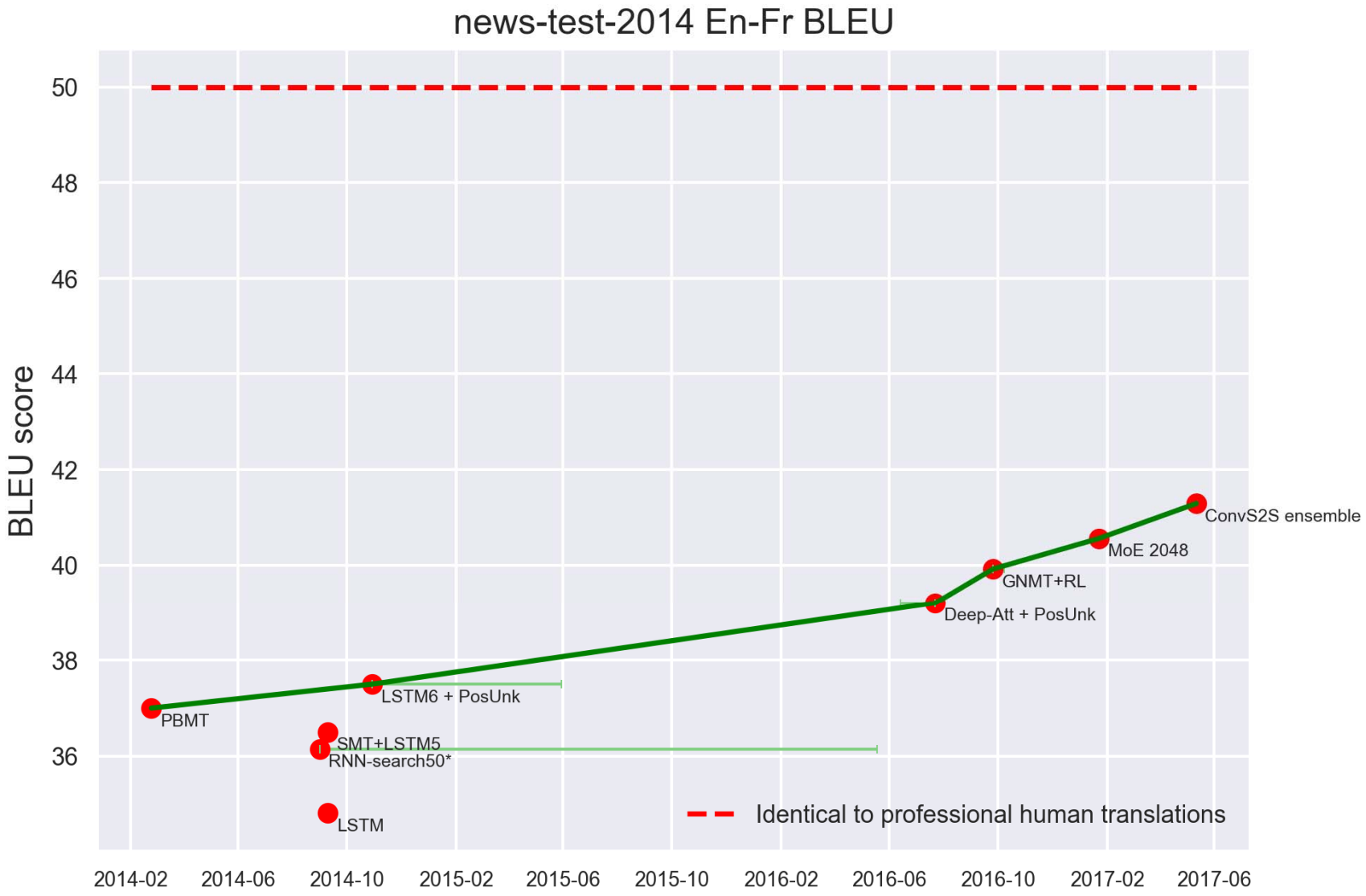
TECHNOLOGY FUTURES INC.

Speech Recognition



https://www.eff.org/ai/metrics

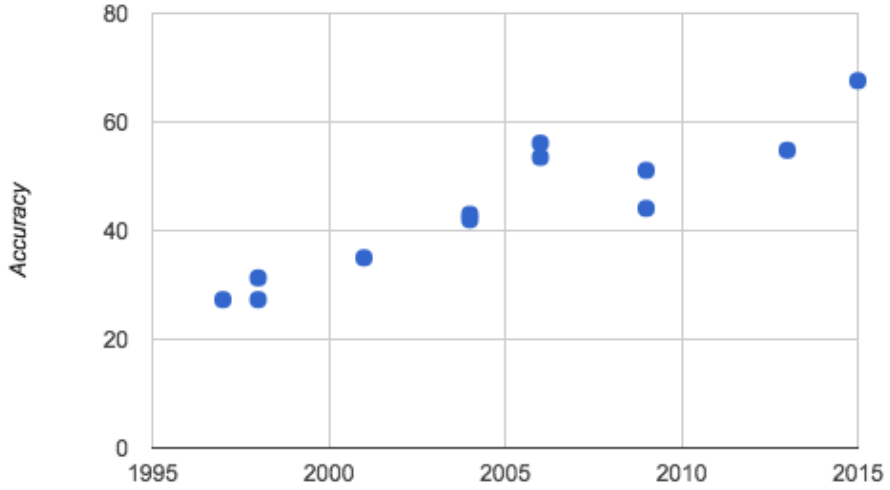
Machine Translation



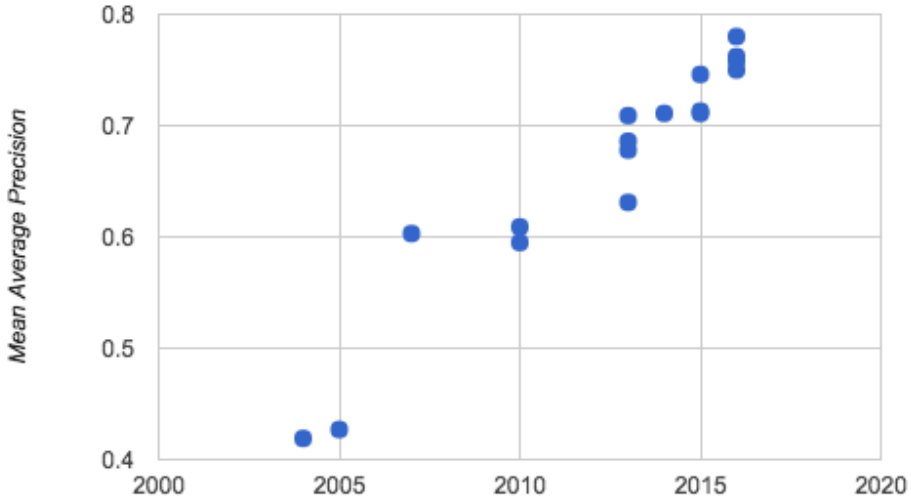
https://www.eff.org/ai/metrics

Natural Language Processing (SAT)

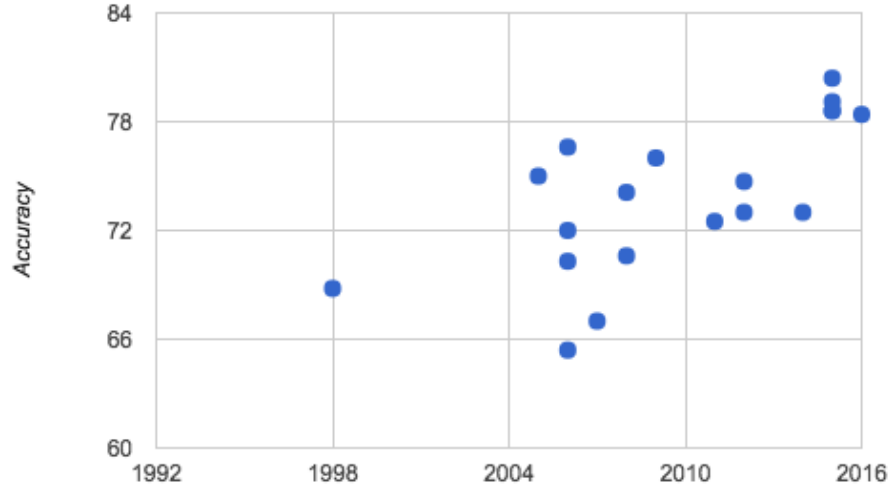
(a) SAT Analogies



(b) SAT Multiple Choice



(c) SAT Paraphrase ID

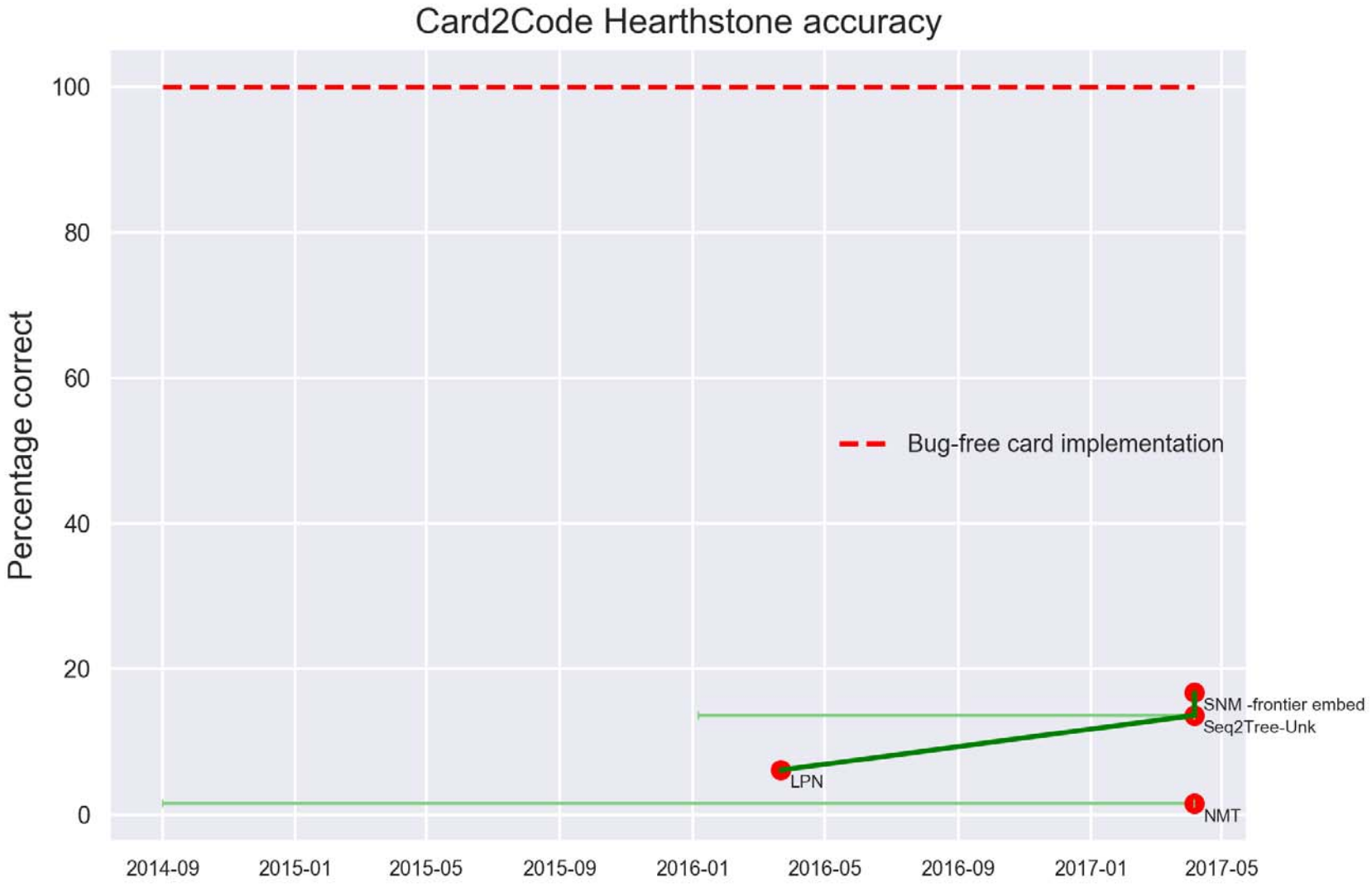


a. Analogies: No Deep Learning
b. Mult Choice: Neural Nets in 2014
c. Paraphrase ID: Top Performer was Matrix Factorization

https://srconstantin.wordpress.com/2017/01/28/performance-trends-in-ai/

TECHNOLOGY FUTURES INC.

Generating computer programs from specifications



https://www.eff.org/ai/metrics

Summary for AI Progress

- Wide Range of:
  - Problem difficulty
  - Solution status
  - Metrics
  - Progress rates and patterns
  - Distance to go
- Discontinuities and rate changes
- Deep learning has varied impact on rate
- Linear progress typical

TECHNOLOGY FUTURES INC.

Other Thoughts on AI Progress

- What are the characteristics of problems that decide the above?
- Do the problems become easier or harder as we move *toward* General Intelligence?
- How will AI systems play with each other?
- How will AI interact with the outside world?
- Does the argument that AI will "bootstrap" itself hold water?

TECHNOLOGY FUTURES INC.

What does it mean for...

- Commerce and Industry?
- Communications?
- Mankind?

TECHNOLOGY FUTURES INC.

For Commerce and Industry

- Wide range of applications across industries
- Ubiquitous
- AI embedded in other transformative technologies
- Important across processes, products, and services
- Many opportunities, but highly disruptive
- Huge employment implications

TECHNOLOGY FUTURES INC.

Implications for Communications

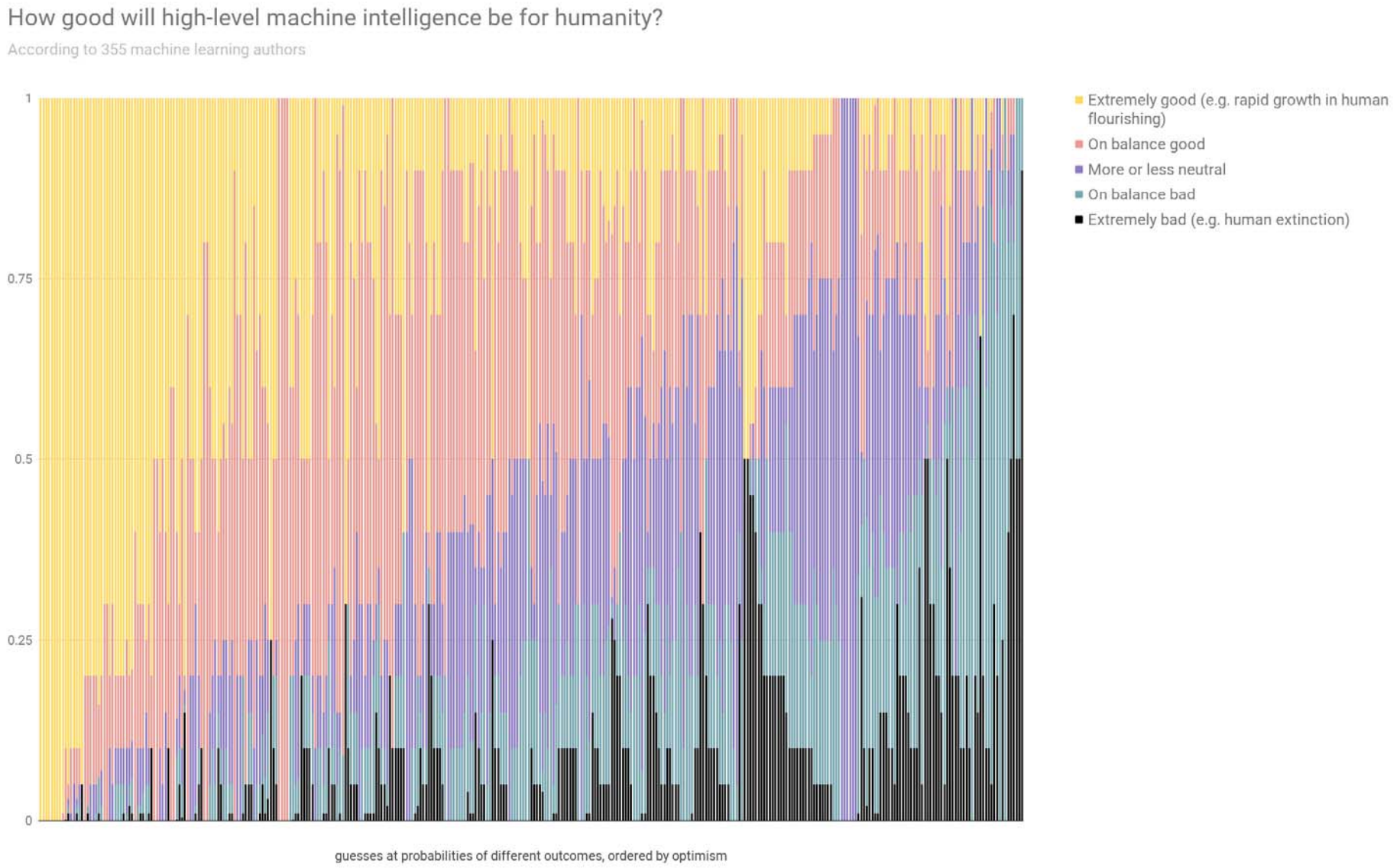
- Rapidly increasing performance requirements
- Rapidly improving technologies
- Widespread and massive investments
- Frequent upgrades and rapid obsolescence
- Changes in workforce

TECHNOLOGY FUTURES INC.

Implications for Mankind

- Tremendous opportunity for good and evil
- Existential Threats – Real and Imagined
- Challenges – political, economic, and social

TECHNOLOGY FUTURES INC.



http://aiimpacts.org/wp-content/uploads/2017/04/ESOPAI-value.png

TECHNOLOGY FUTURES INC.

It’s up to us.

TECHNOLOGY FUTURES INC.

(512) 258-8898 • www.tfi.com

Your Bridge to the Future

TECHNOLOGY FUTURES INC.

