Cognitive Enhancement

via

Electronics and Artificial Intelligence

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Introduction to Cognitive Enhancement

Let’s Play a Game…

$3 \times 2 = ?$

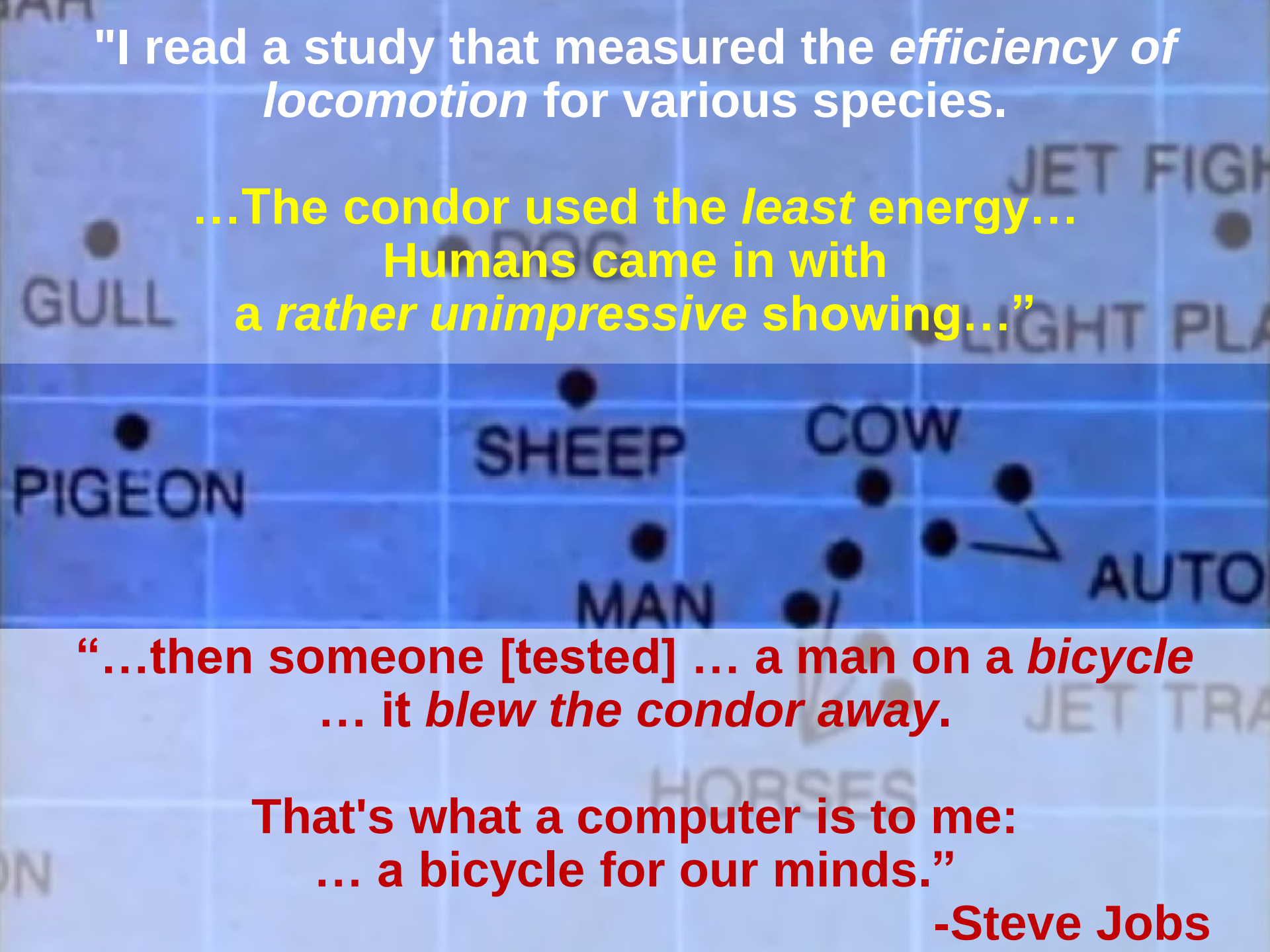
$3 \times 1020 = ?$

$$3471 \times 4192 = ?$$

3471 x 4192 = ?

(Who used a calculator?)
(Is this *cheating?*)

Simple Cognitive Enhancement



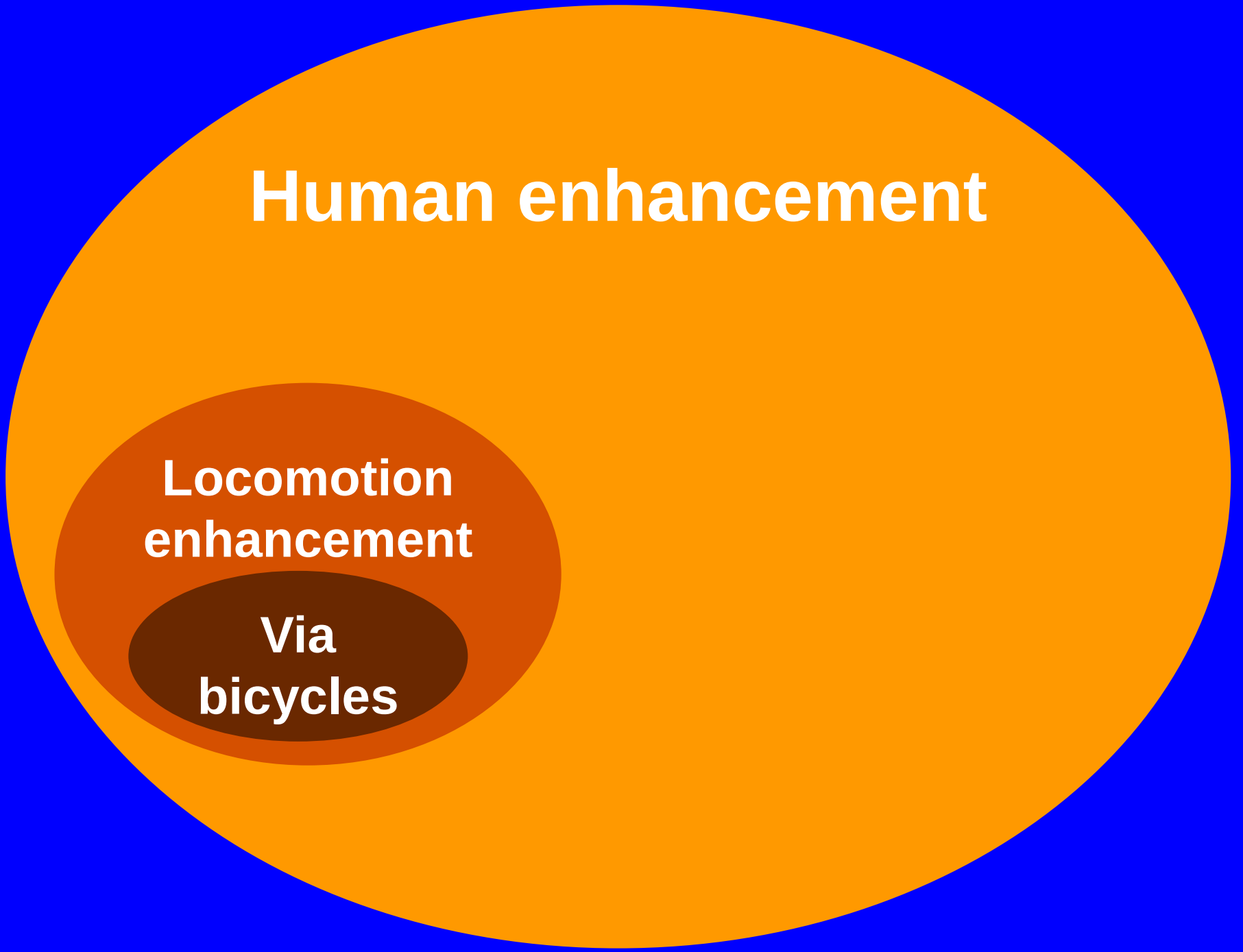
"I read a study that measured the *efficiency of locomotion* for various species.

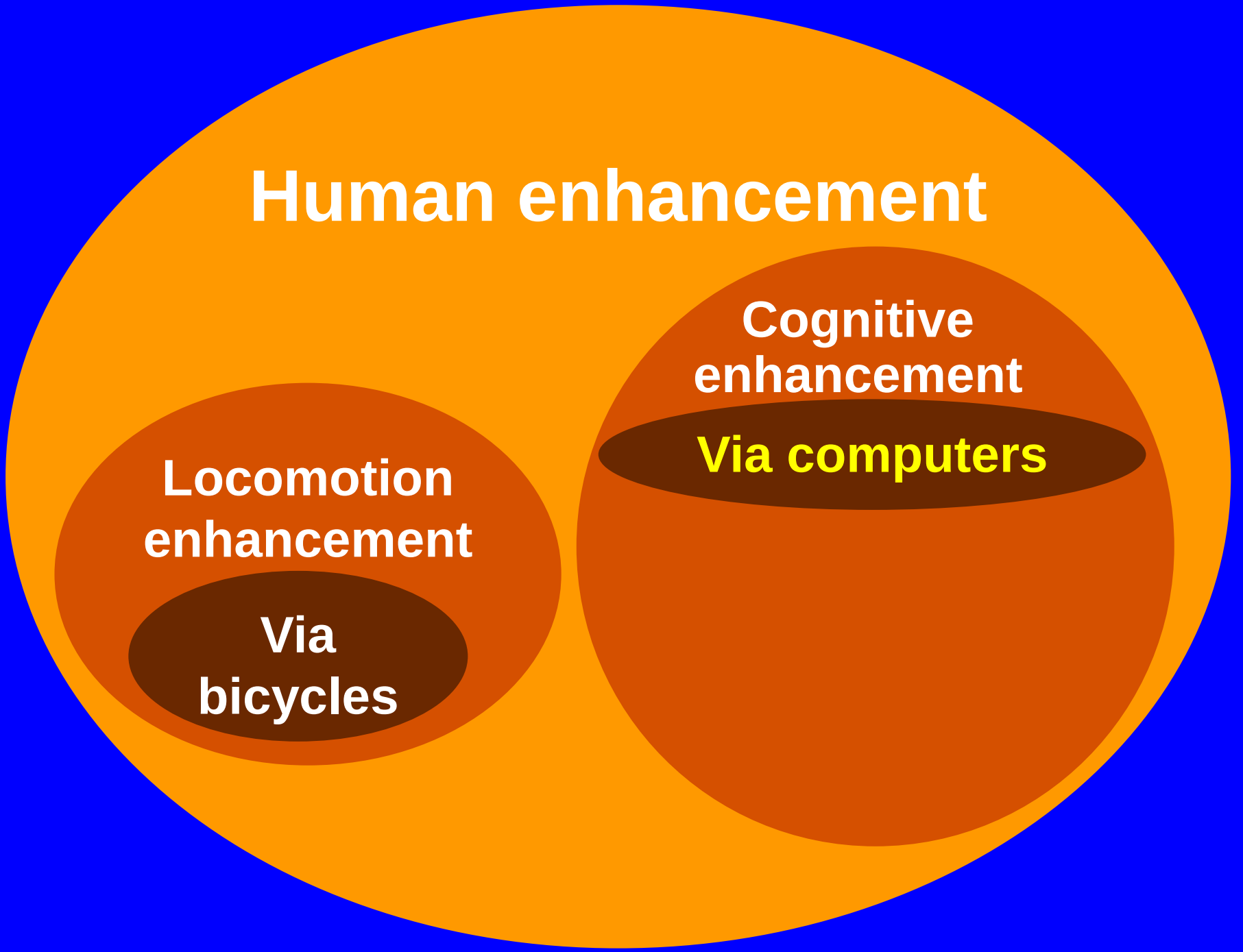
…The condor used the *least* energy…
Humans came in with
a *rather unimpressive* showing…"

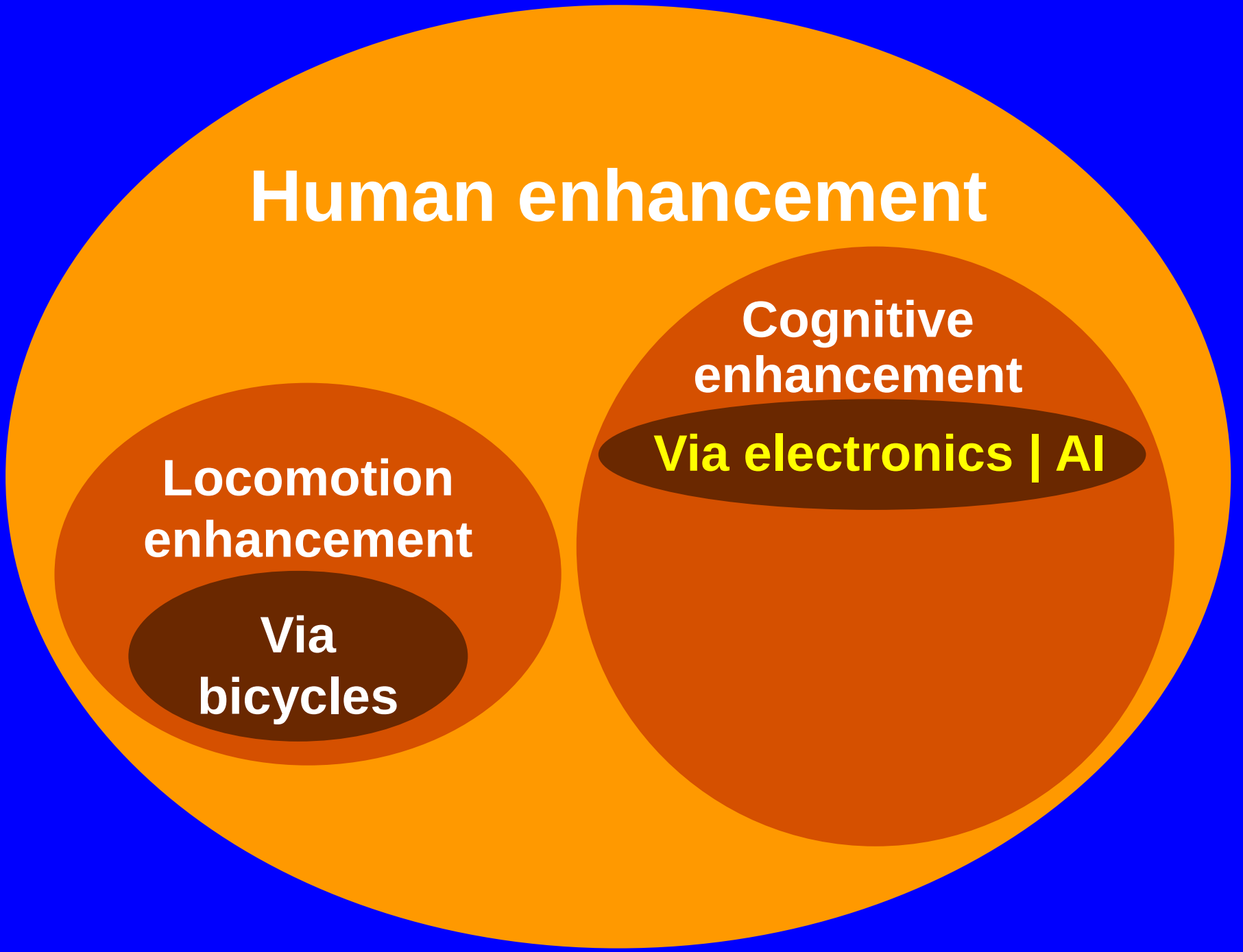
"…then someone [tested] … a man on a *bicycle*
… it *blew the condor away*.

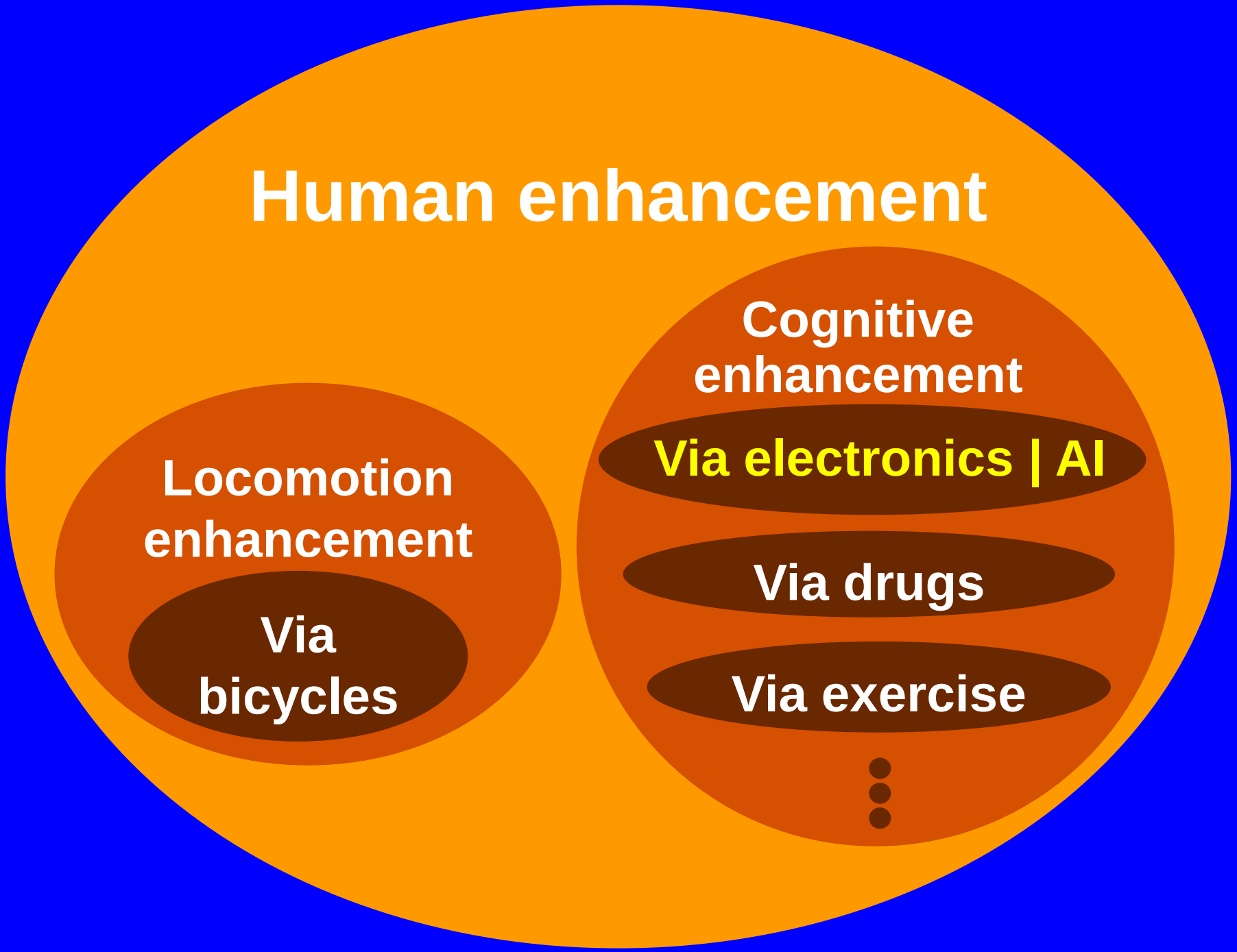
That's what a computer is to me:
… a bicycle for our minds."

-Steve Jobs


Human enhancement
Locomotion enhancement
Via bicycles


Human enhancement
Cognitive enhancement
Via computers
Locomotion enhancement
Via bicycles


Human enhancement
Cognitive enhancement
Via electronics | AI
Locomotion enhancement
Via bicycles


Human enhancement
Locomotion enhancement
Via bicycles
Cognitive enhancement
Via electronics | AI
Via drugs
Via exercise

Introduction to Electronics

What's Electronics?

Electronic Systems

Boards

Chips (Silicon + packaging)

Silicon

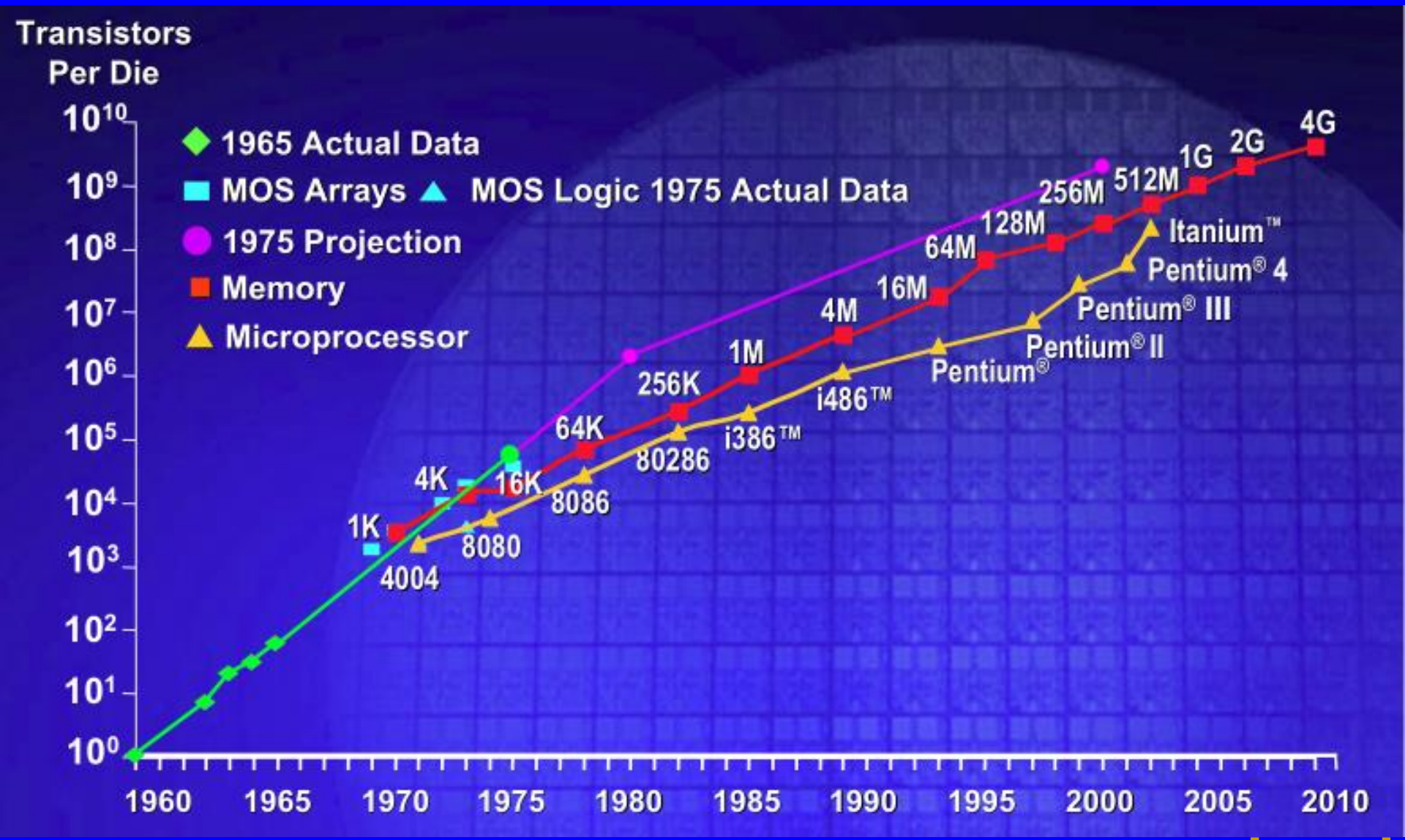
Circuit block

Transistor (32nm)

Progress in Electronics:

Moore's Law: shrink transistors exponentially

We now have billions of transistors per chip!

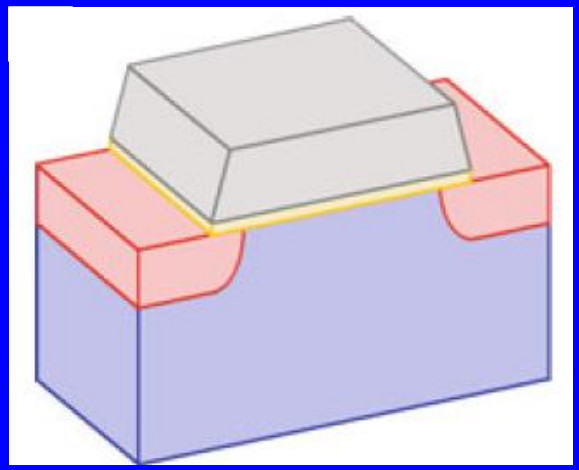


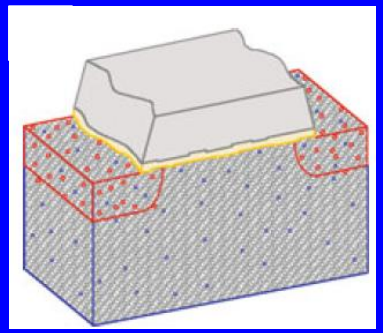
[cmg.org]

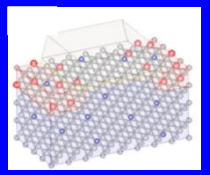
Progress in Electronics:

Moore's Law: the shrinking keeps going, to atom-scale!

Enabling the latest smartphones, autos, web apps, etc.

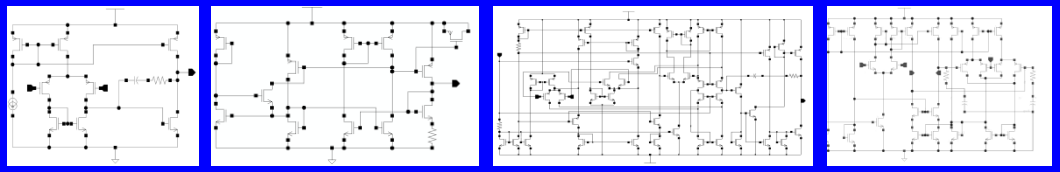




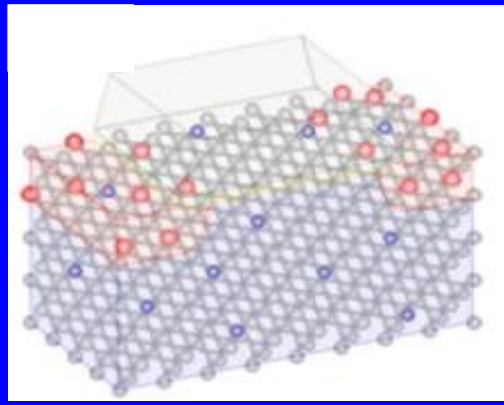


[A. Asenov, itrs.org]

Challenges in Designing Electronics



- How to design a chip with 5 billion parts?
- Each part has a tolerance of +/- 25%
- By the way:
  - It has to be twice as fast as before
  - With half the size
  - And the same power consumption



[A. Asenov]

- And the chip fails, it will cost our company $50M in manufacturing and $100M+ in lost sales
- You have 3 months, go!

(Sounds like a task needing cognitive enhancement…)

Introduction to Artificial Intelligence (AI)

What's Artificial Intelligence (AI)?

1. Original:
AI: "A machine that can replicate human cognitive behavior" [Turing test]

[ibm.com]

2. More recent:
AI: "A machine that can perform a cognitive task, that was previously only possible with a human"
[Deep Blue / Chess]

3. Most recent / pragmatic:
AI: "A machine that can perform a non-analytical information processing task, at speed / accuracy / capacity *not possible by a human*."

What's Artificial Intelligence (AI)? Cont'd

AI has a toolbox of ways to solve:

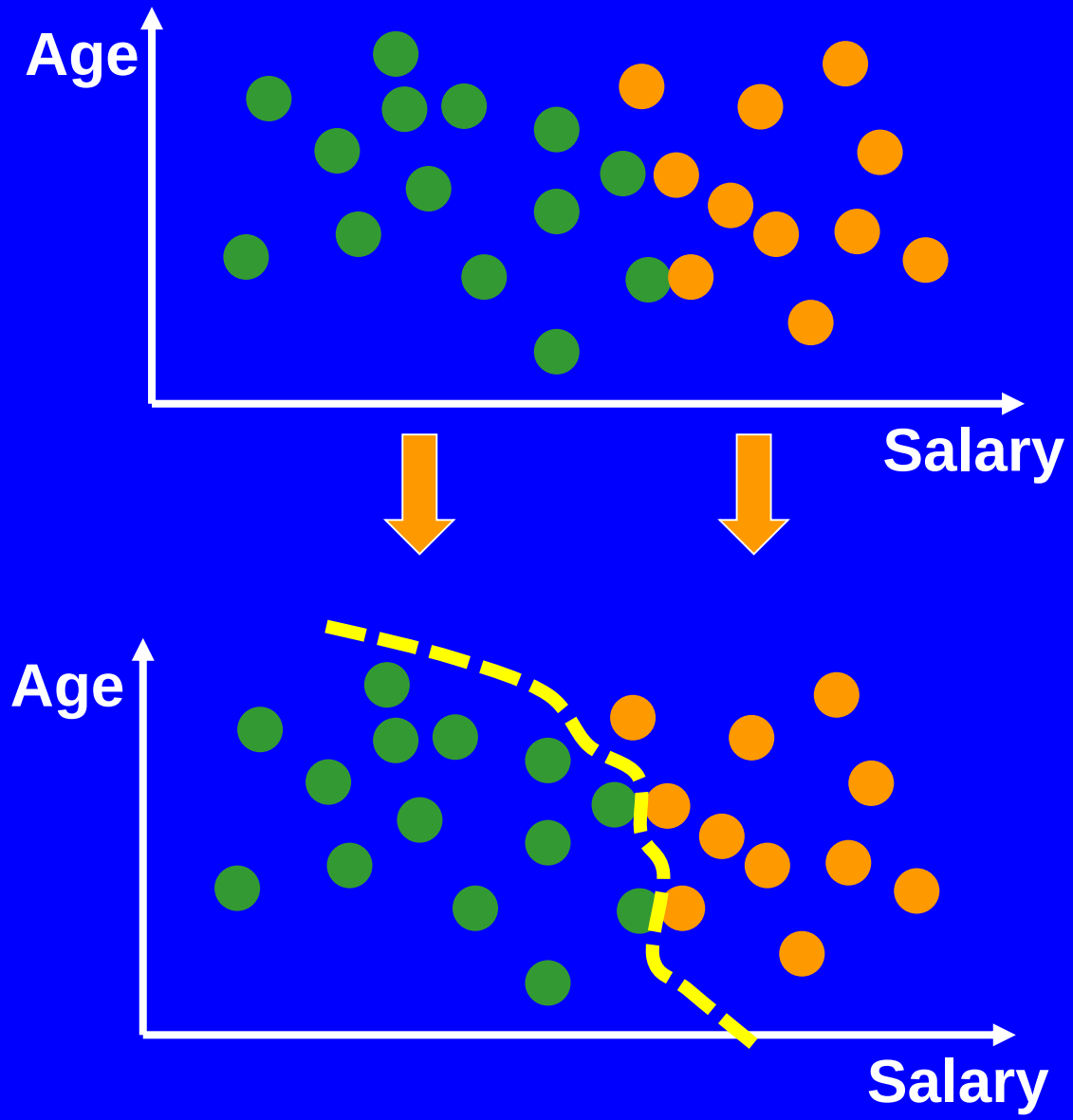
- **Classification**
- **Regression**
- **Whitebox regression**
- **Optimization**
- **Structural synthesis**
- **Pattern recognition**
- **System identification**
- **Ranking**
- **Control**
- **…**

AI sub-fields / sub-labels: machine learning, evolutionary computation, data mining, AGI, …

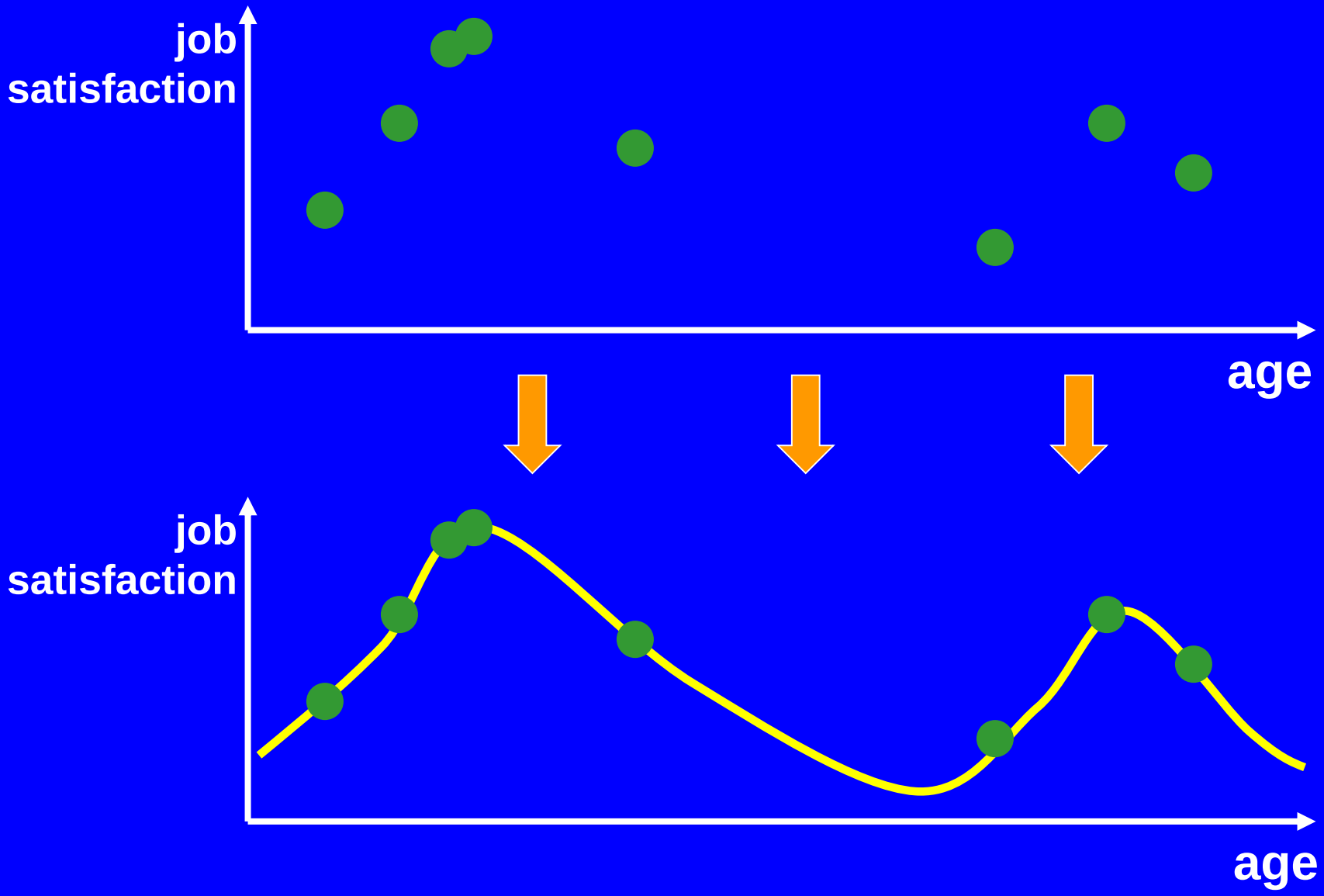
Classification, in 2D

Credit profile:

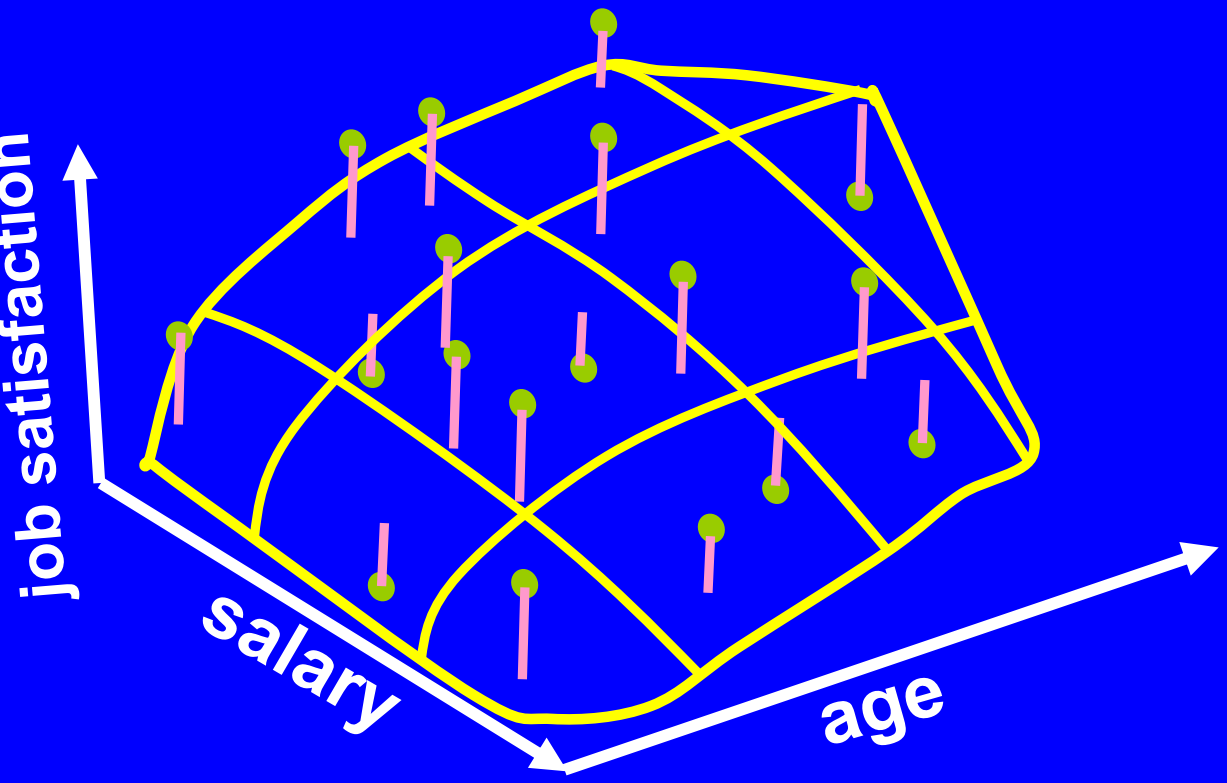
- **Paid bills**
- **Didn’t pay**



Regression, in 1D

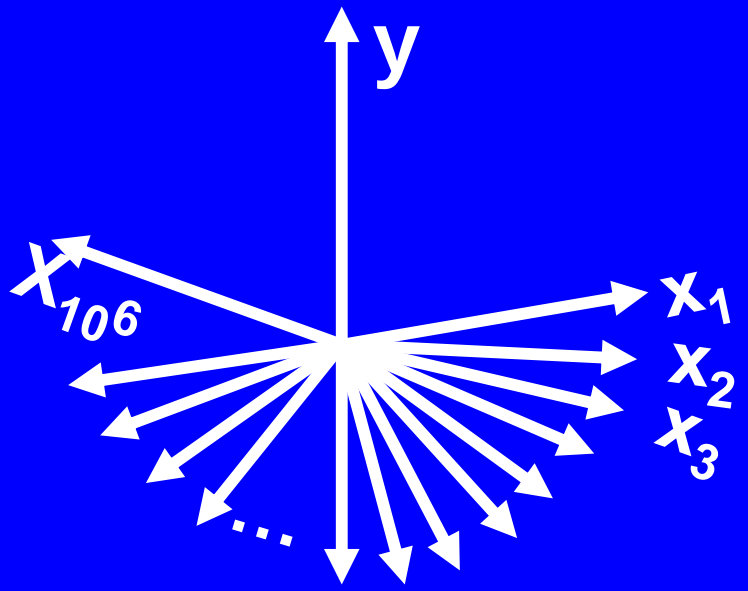


Regression, in 2D



How: Polynomials, splines, neural networks, support vector machines, Gaussian process models, boosted trees, … [many refs]

Regression in 10^6D ?

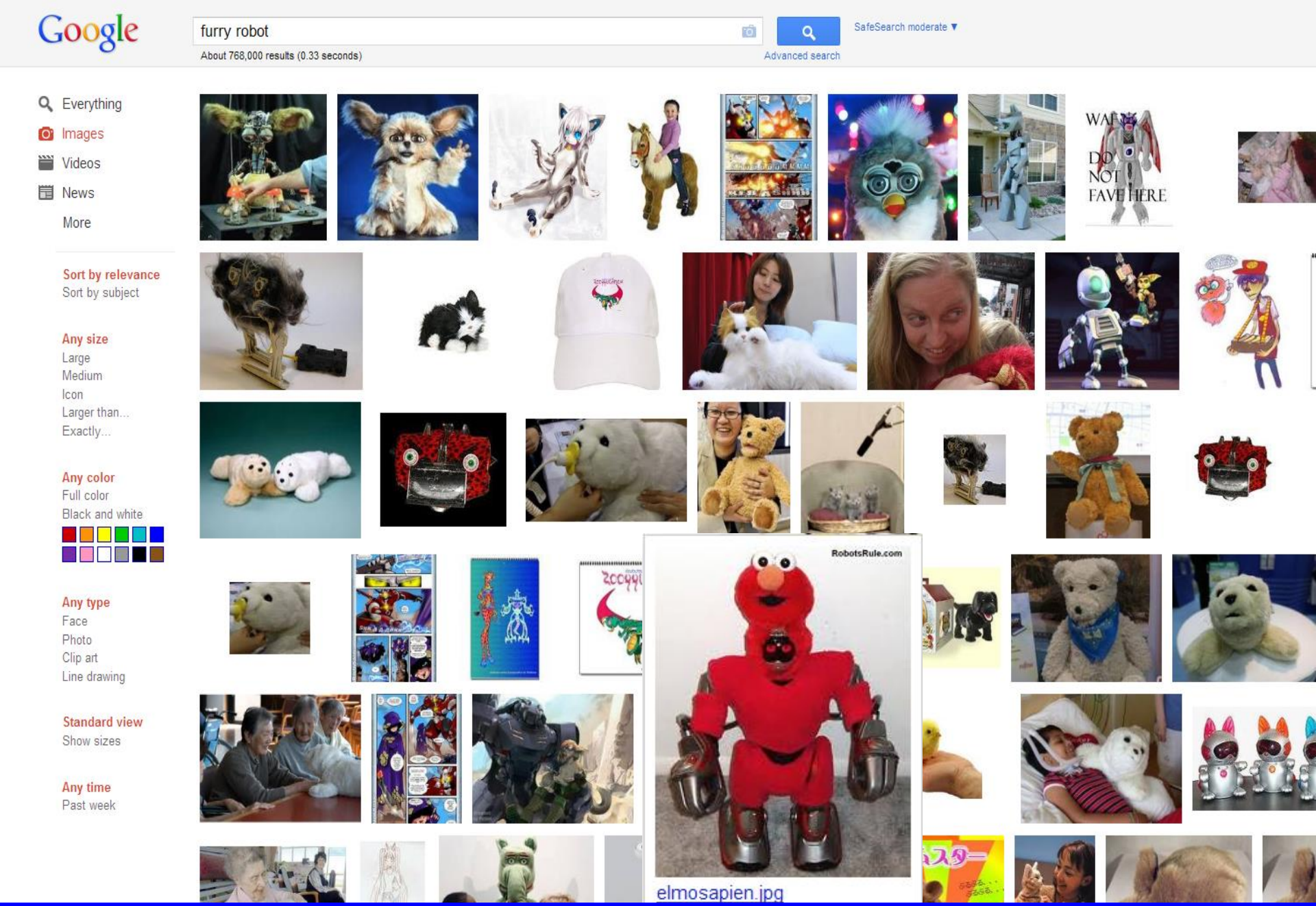


Why??

How??

furry robot

Search Images

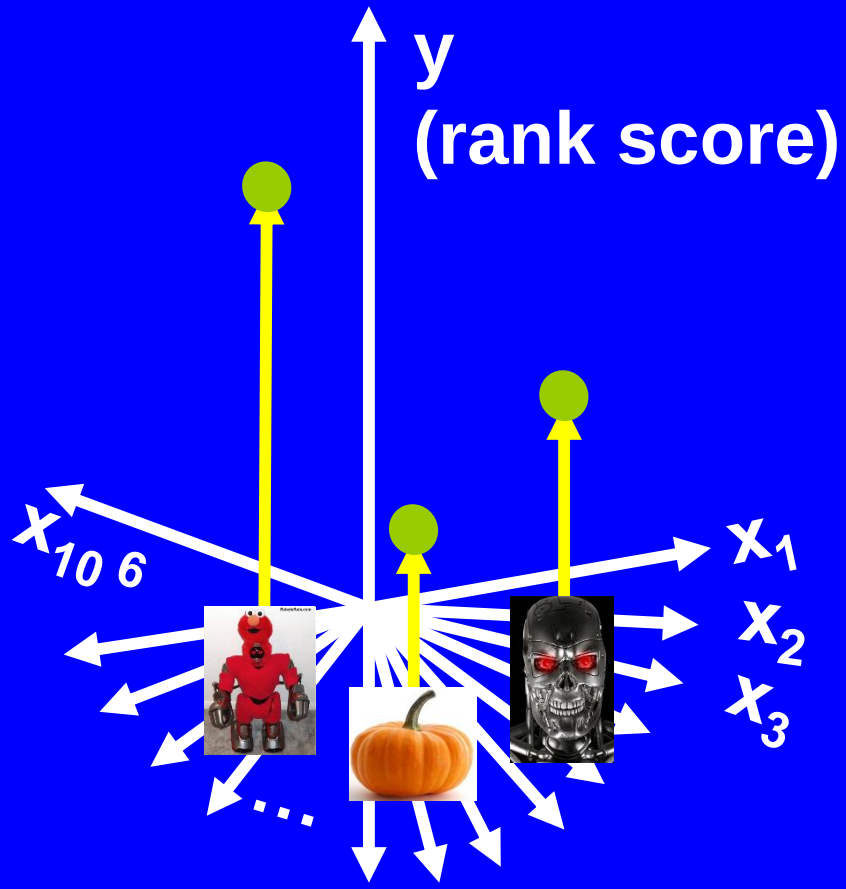


How does Google find furry robots?

Q: How does Google find furry robots?

A:

1. Treat images as 1000x1000 = 10^6 input variables (!)
2. Do regression on “known” images (furry vs. non)
3. Rank the other images. Easy! ☺

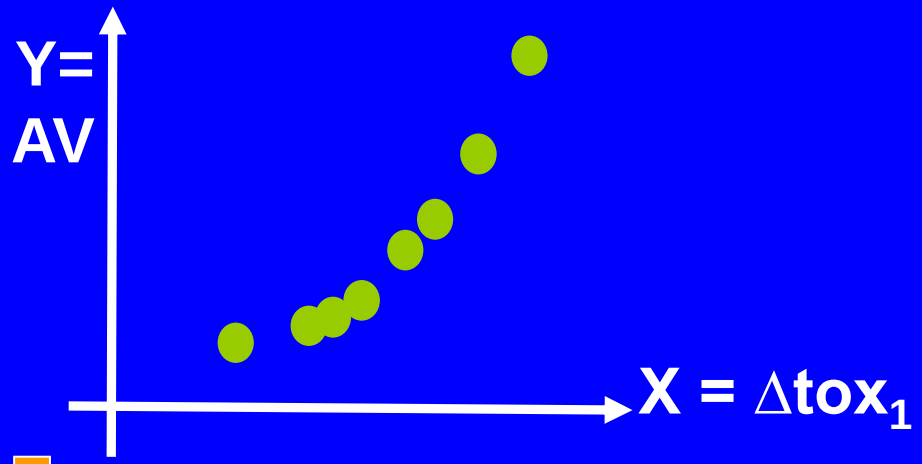


[NIPS 2010]

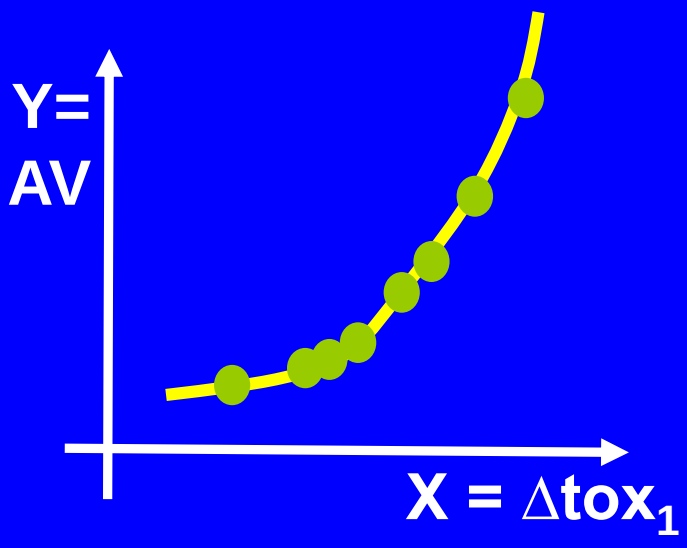
Example 2 (ascribe): Solution:
Share securely via blockchain (security) + analytics (visibility)

Whitebox Regression

(Like regression, but output a whitebox model too)



and



Whitebox model:

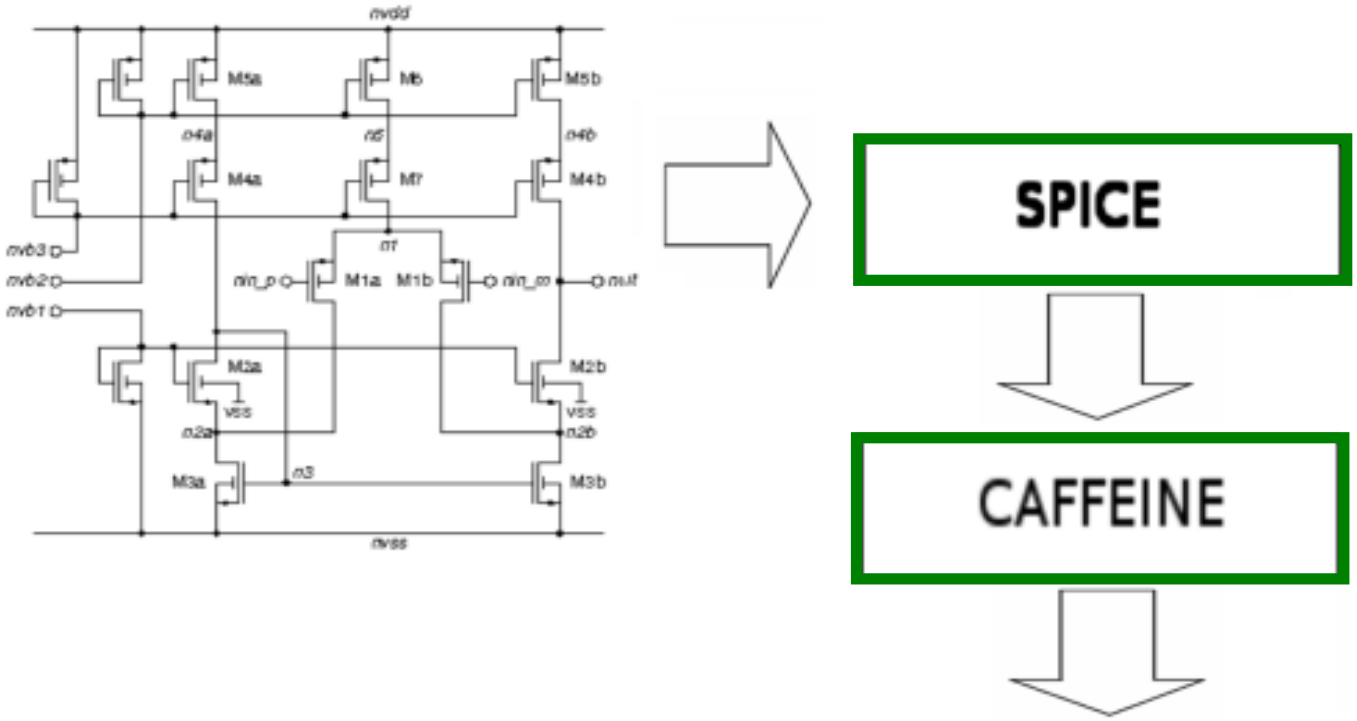
$$AV = 50.2 + 9.1 \cdot \Delta tox_1 + 3.2 \cdot \max(0, \Delta tox_1^2)$$

[e.g. McConaghy 2005; McConaghy 2011]

Whitebox Regression on Circuits

Designers use the equations for further manual analysis

(My work)

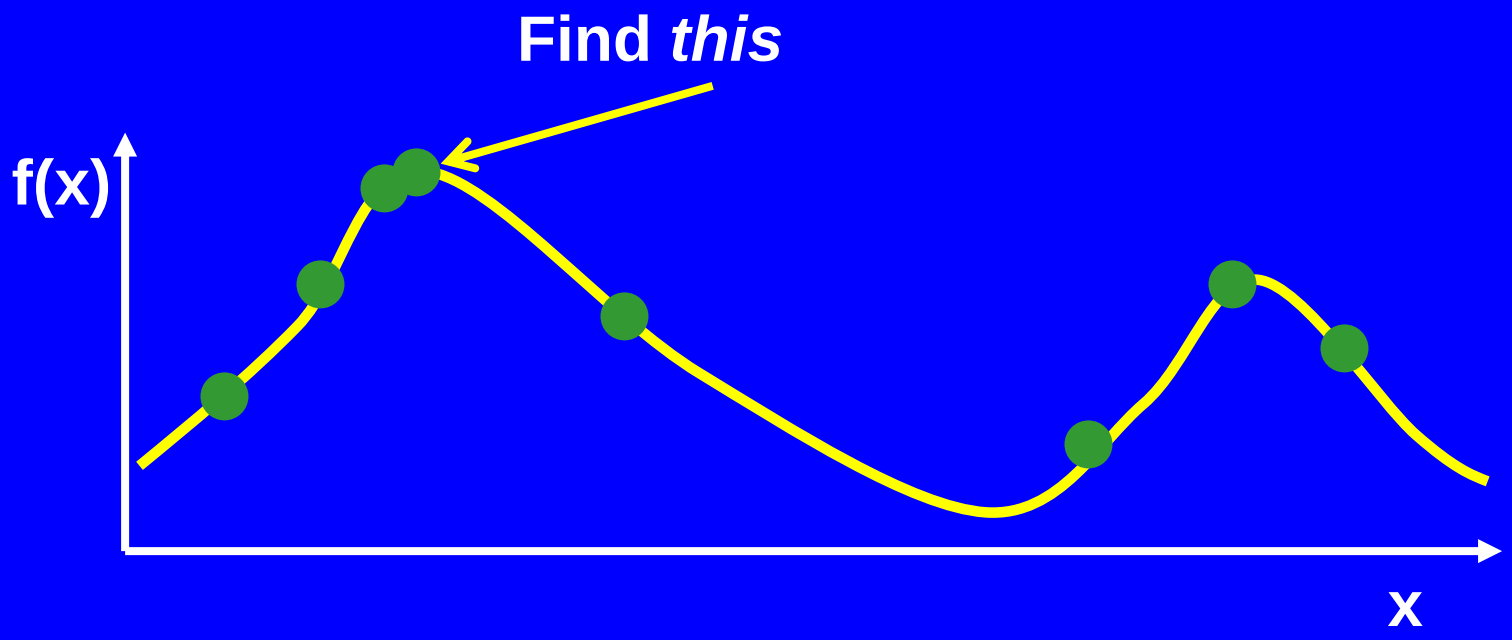


Perf.	Expression
A_{LF}	-10.3 + 7.08e-5 / id1 + 1.87 * ln(-1.95e+9 + 1.00e+10 / (vsg1*vsg3)+ 1.42e+9 *(vds2*vsd5) / (vsg1*vgs2*vsg5*id2))
f_u	10^(5.68 - 0.03 * vsg1 / vds2 - 55.43 * id1+ 5.63e-6 / id1)
PM	90.5 + 190.6 * id1 / vsg1 + 22.2 * id2 / vds2
v_{offset}	- 2.00e-3
SR_p	2.36e+7 + 1.95e+4 * id2 / id1 - 104.69 / id2 + 2.15e+9 * id2 + 4.63e+8 * id1
SR_n	- 5.72e+7 - 2.50e+11 * (id1*id2) / vgs2 + 5.53e+6 * vds2 / vgs2 + 109.72 / id1

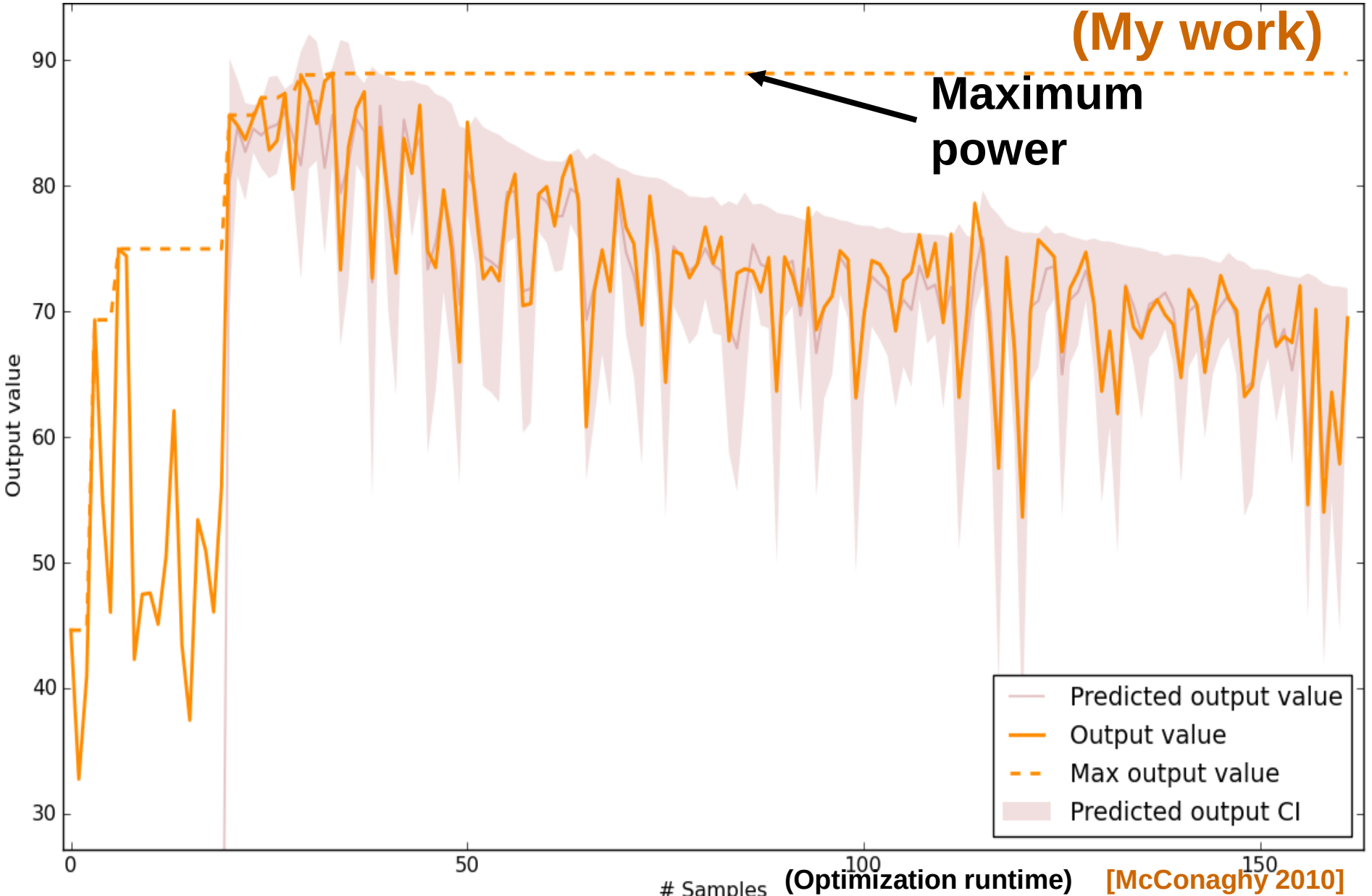
[McConaghy 2005]

Optimization

"Find the x that maximizes f(x)"
(With as few evaluations of f(x) as possible)



Optimization to Verify Circuits for Power, Across Different Temperatures, Voltages, etc



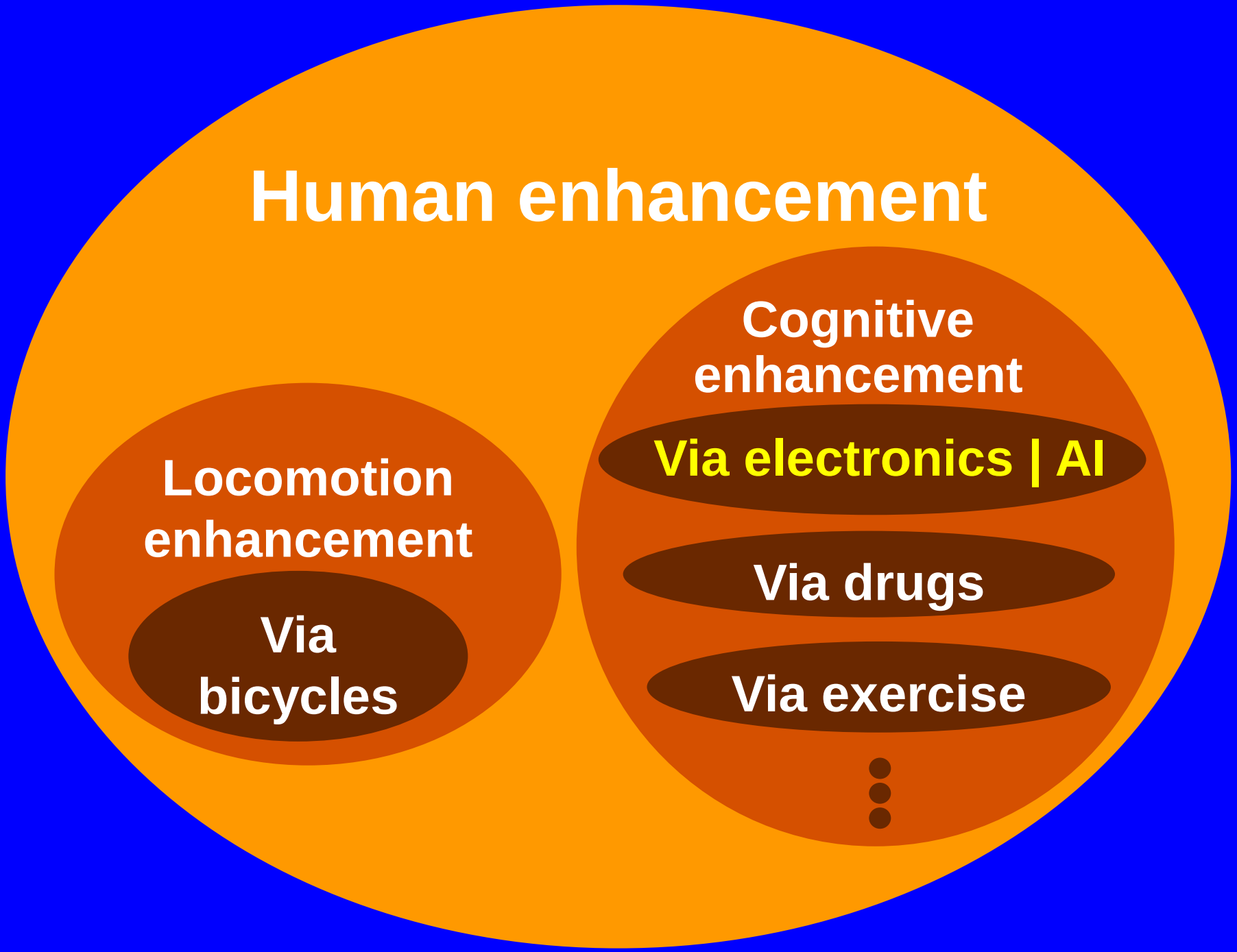
What's Artificial Intelligence (AI)?

The AI tools in turn solve many other problems:

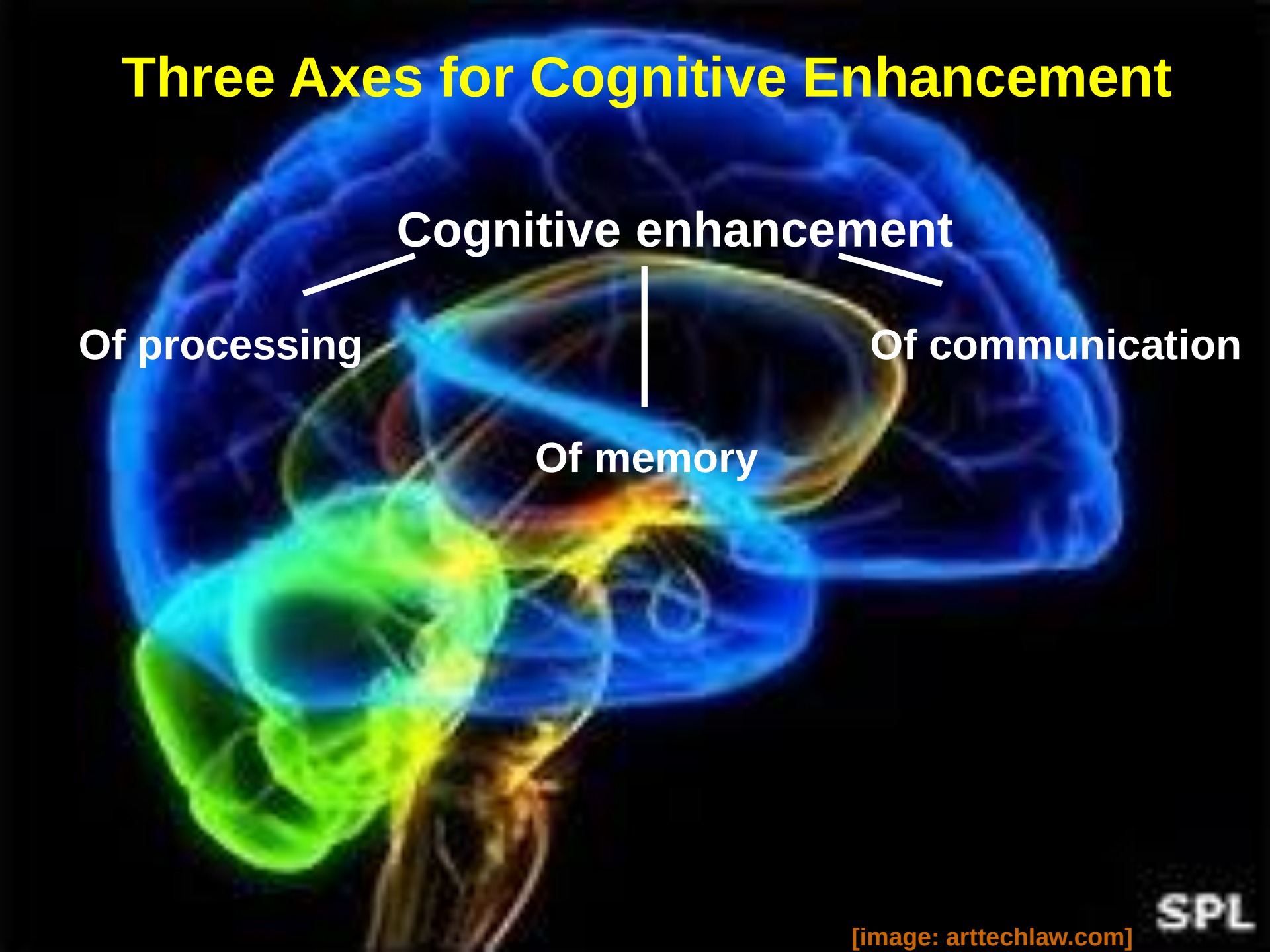
- **Classification – Fraud detection, spam filtering …**
- **Regression – Stock prediction, sensitivity analysis …**
- **Whitebox regression – Scientific discovery …**
- **Optimization – Airfoil design, circuit simulation …**
- **Structural synthesis – Analog synthesis, robotics …**
- **Pattern recognition – Face recognition, object recog …**
- **System identification – Scientific discovery …**
- **Ranking – Web search, ad serving, social discovery …**
- **Control – Auto-driving autos, spacecraft trajectories …**
- **…**

(And of course each of these tools has *or will have* applications in neuroscience ☺)

Cognitive Enhancement via Electronics and via AI


Human enhancement
Locomotion enhancement
Via bicycles
Cognitive enhancement
Via electronics | AI
Via drugs
Via exercise

Three Axes for Cognitive Enhancement

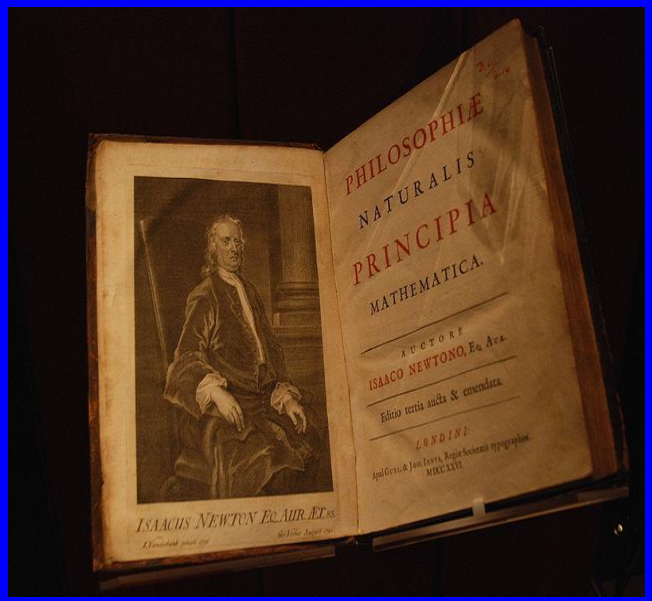


Classical Approaches to Cognitive Enhancement

Cognitive enhancement

Of processing
Via Abaci

Of memory
Via Books



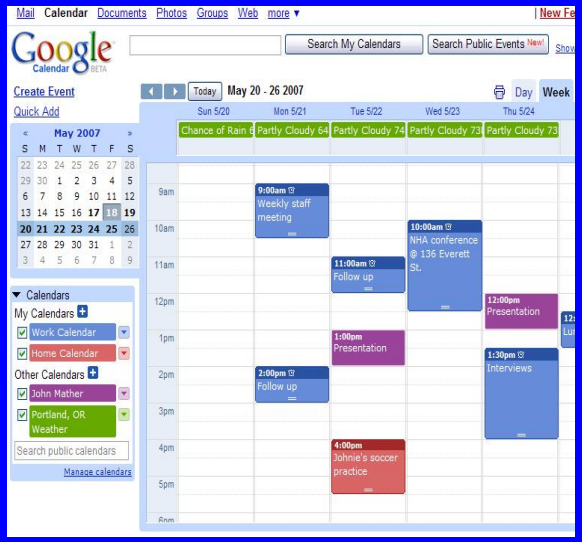
Of communication
Via Mail

Electronics Approaches to Cognitive Enhancement

Cognitive enhancement

Of processing
Via Calculators

Of memory
Via Online Calendars

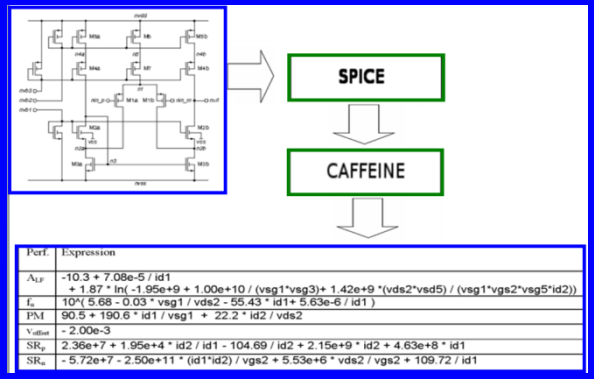


Of communication
Via Texting

Artificial Intelligence Approaches to Cognitive Enhancement

Cognitive enhancement

Of processing Via Computer-Aided Design (CAD)



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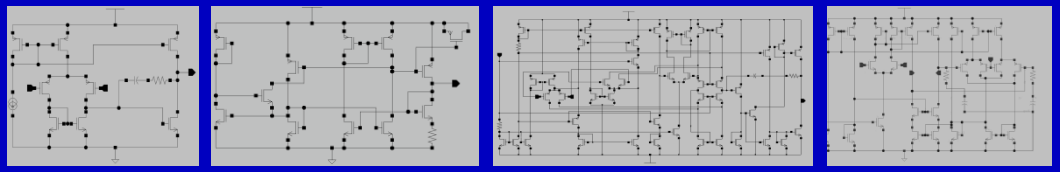
SR_R	- 5.72e+7 - 2.50e+11 * (id1*id2) / vgs2 + 5.53e+6 * vds2 / vgs2 + 109.72 / id1

Of memory Via Google

Of communication Via Facebook

Challenges in Designing Electronics



- How to design a chip with 5 billion parts?
- Each part has a tolerance of +/- 25%

How to handle: AI-Based Computer-Aided Design (CAD) Tools *Everywhere* in Design Process

The tools *augment* the human designer's processing, memory, and communication cognitive abilities.

"AI, standing on the shoulders of ~~giants~~ brains."

This enables modern electronics! ☺

Cognitive Enhancement of Communication
Via Classical and Via Electronics

Each advance has at least one of:

- Bandwidth up
- Convenience up
- Distribution up

What Cognitive Factors Improve, Specifically?

Each *communication* advance has at least one of:

- **Bandwidth up**
- **Convenience up**
- **Distribution up**

Similarly….

Each *processing* advance has at least one of:

- **Speed up**
- **Throughput up**
- **Reliability up**

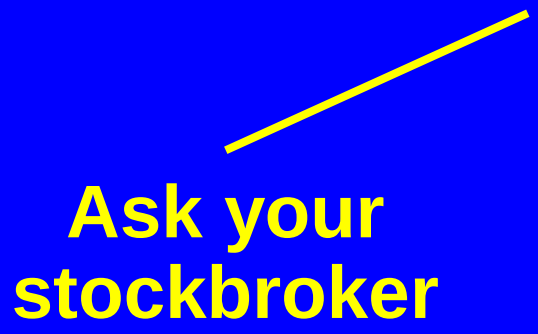
Each *memory* advance has at least one of:

- **Capacity up**
- **Read / write rate up**
- **Volume down**
- **Reliability up**

(Electronics jargon is natural – it's all computation!)

What's Next?
How to Predict?

How to predict the future?



How to predict the future?

~~Ask your stockbroker~~

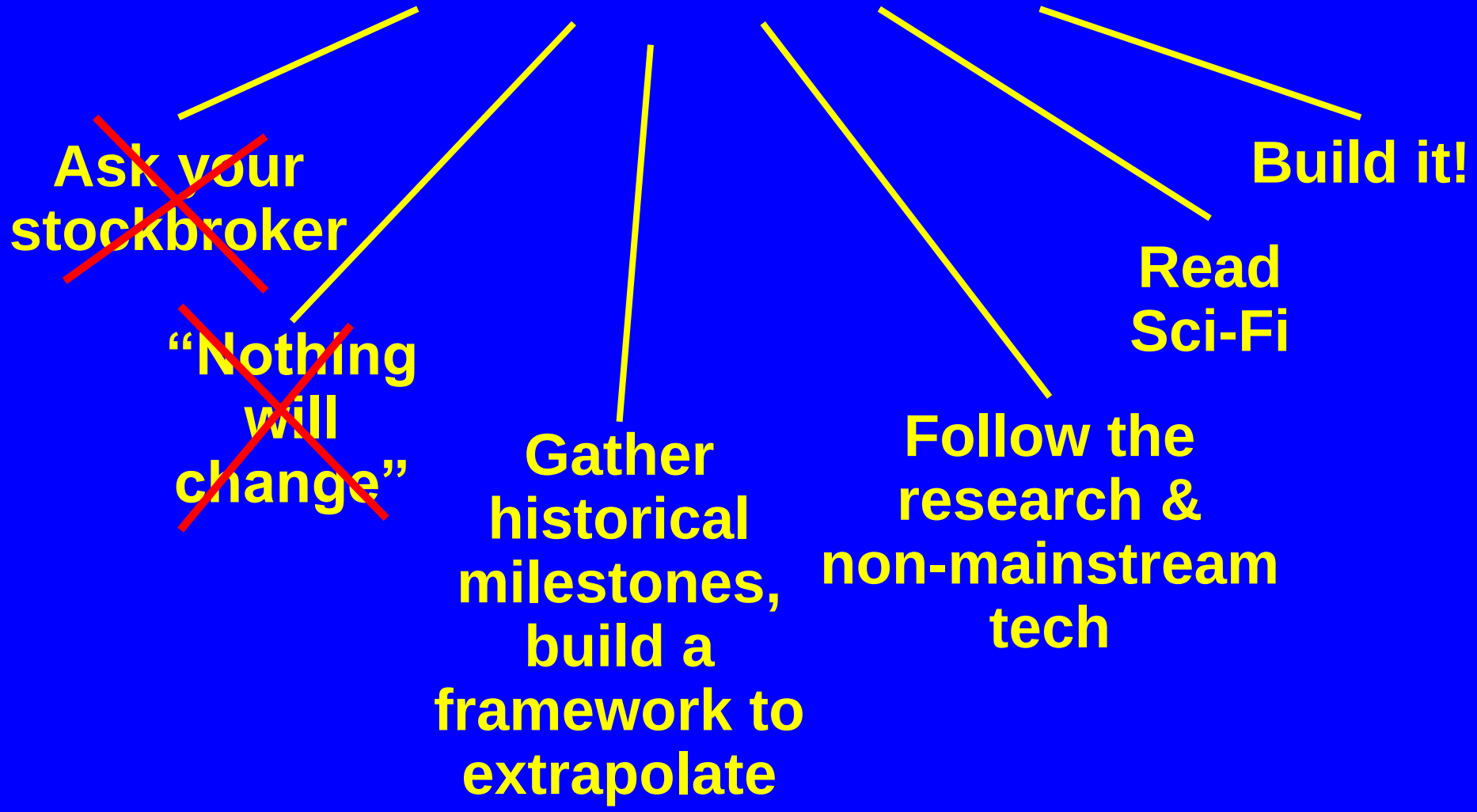
How to predict the future?

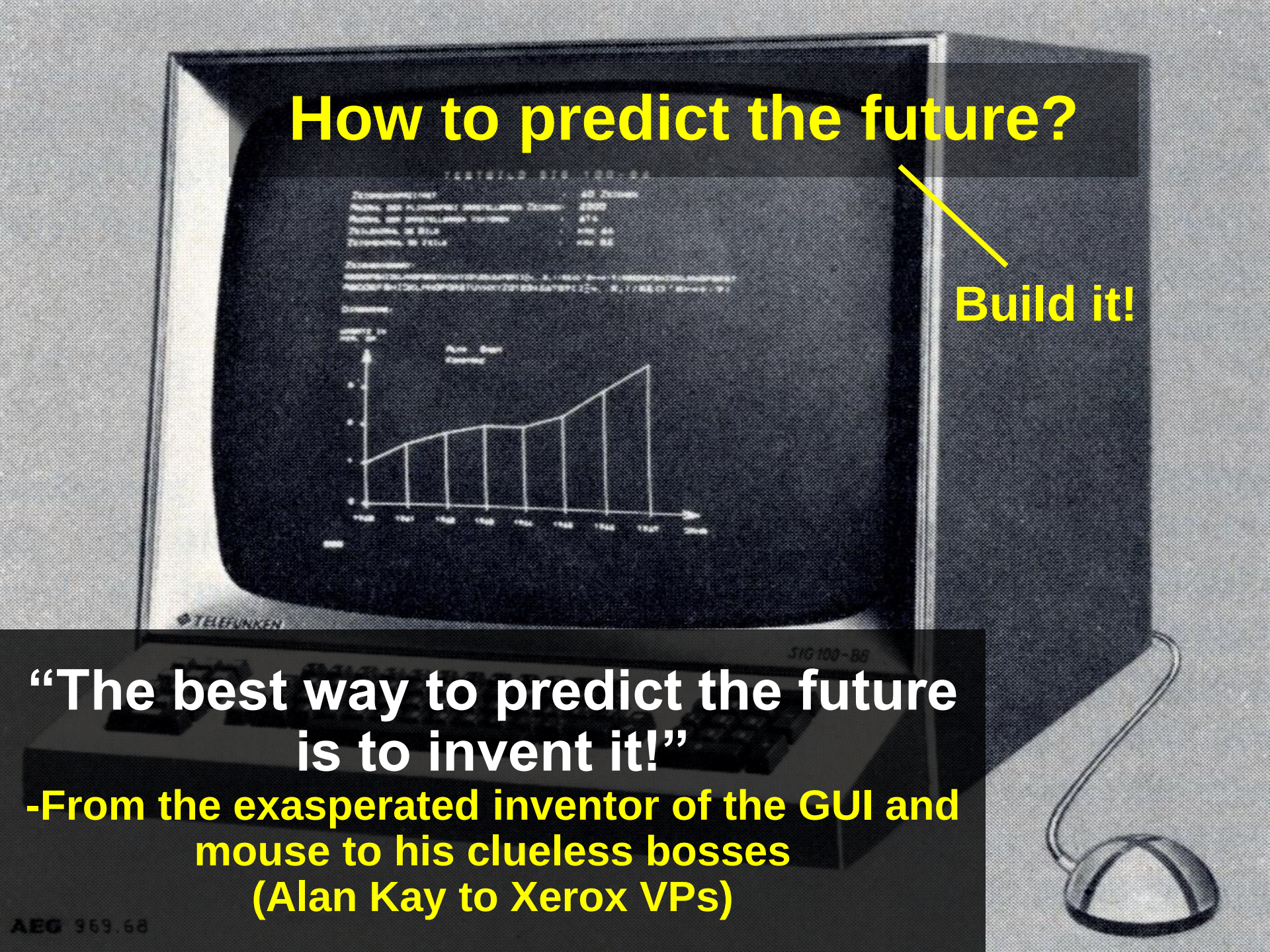
~~Ask your stockbroker~~

"Nothing will change"

How to predict the future?

How to predict the future?



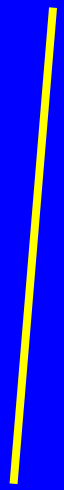


“The best way to predict the future is to invent it!”

-From the exasperated inventor of the GUI and mouse to his clueless bosses (Alan Kay to Xerox VPs)

Prediction #1…

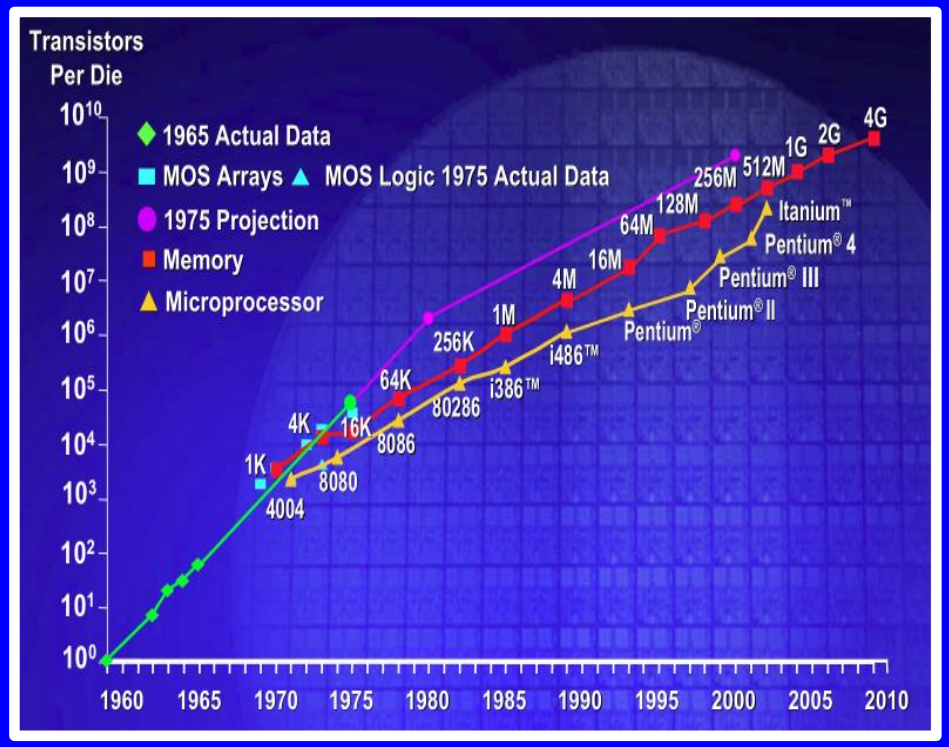
How to predict the future?

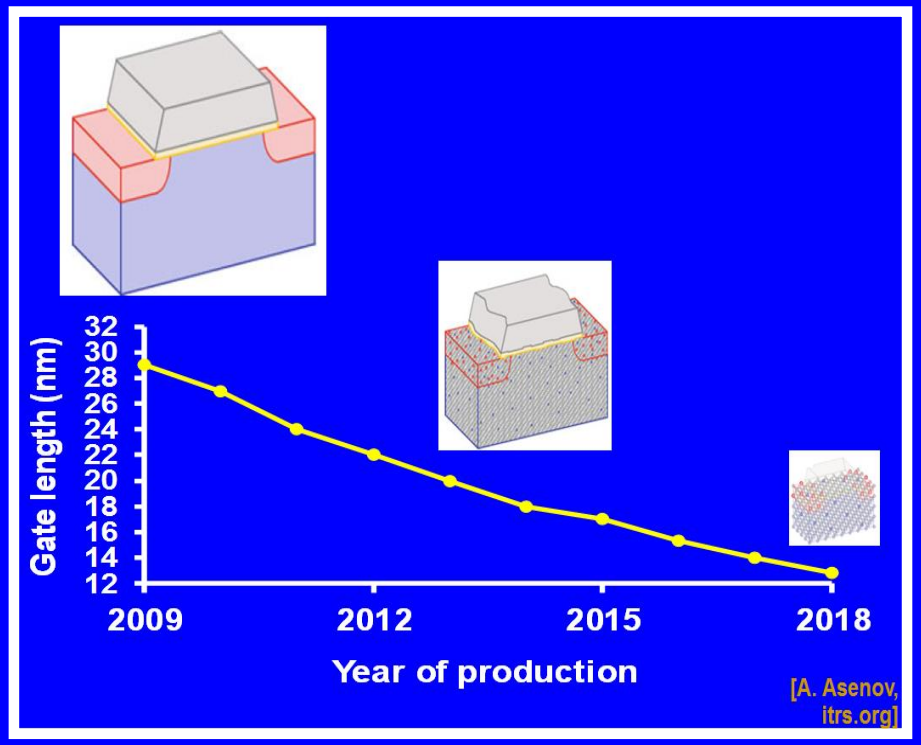


Gather historical milestones, build a framework to extrapolate

Historical Trend of Electronics Density

Framework to Extrapolate Electronics Density





1960-2010

2015-2021

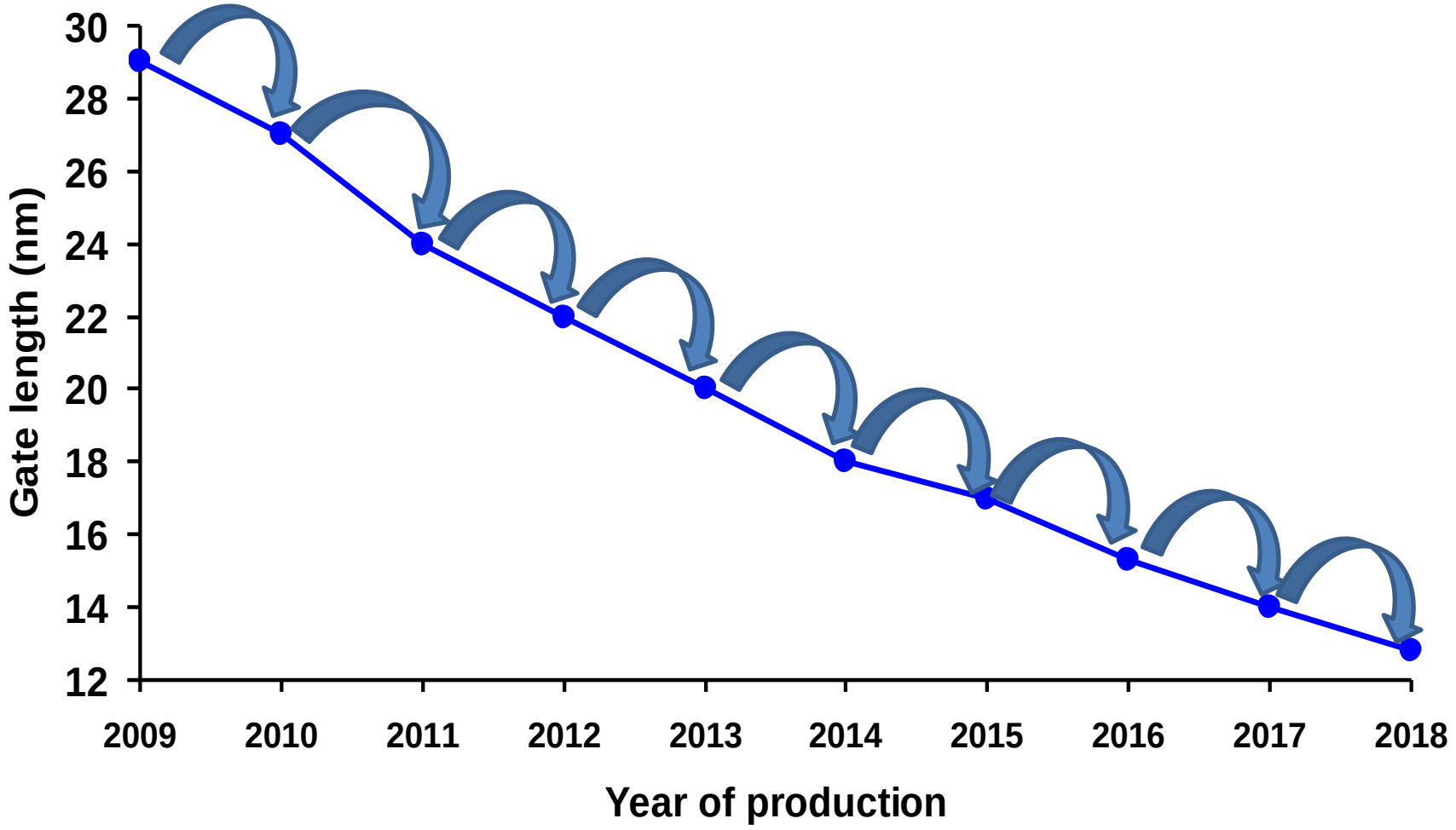
Effect: Your smartphone will be 1/3 the size in 6 years.

Effect: Storage is *ridiculously* cheap

Moore's Law: *How?*

A: Silicon Midas touch *applied to itself*

AI-powered CogE (*CAD*). One generation of machines to design the next generation. The ultimate bootstrap!



Historical Trend of Communication

Time

Vocal chords
Grunts
Spoken language
Writing
Paper
Printing press
Carrier pigeon
Pony express
Telegraph
Telephone
Radio
TV
Arpanet / Intertubes
Email
Cell phone
Web browser
Blogs
Facebook
Twitter

Framework to Extrapolate Communication

Each *communication* advance has at least one of:

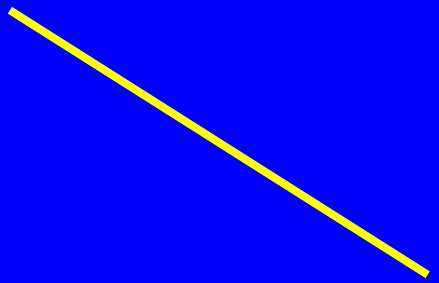
- Bandwidth up
- Convenience up
- Distribution up

Therefore we can predict that advances will further improve these.

For example, what might be…

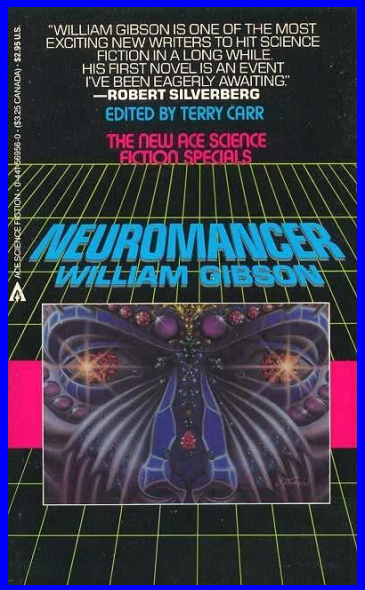
- ***More convenient than smartphones?***
- ***Higher-bandwidth than face-to-face talking?***

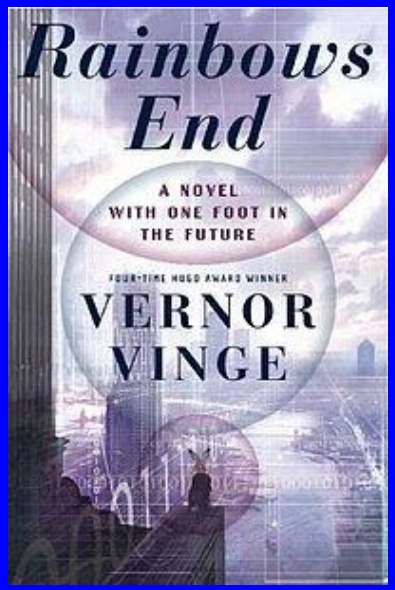
How to predict the future?
(Of Cognitive Enhancement)

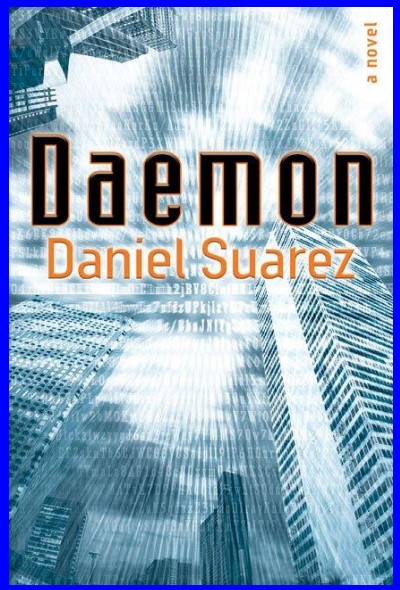


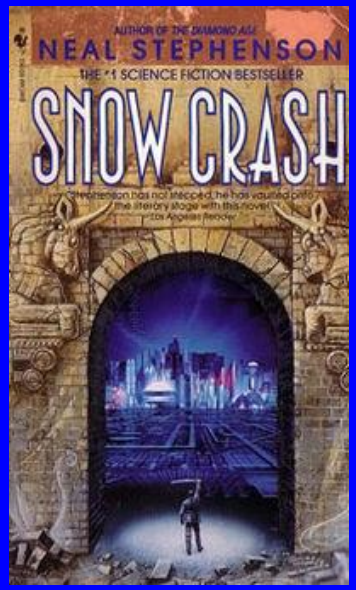
Read Sci-Fi

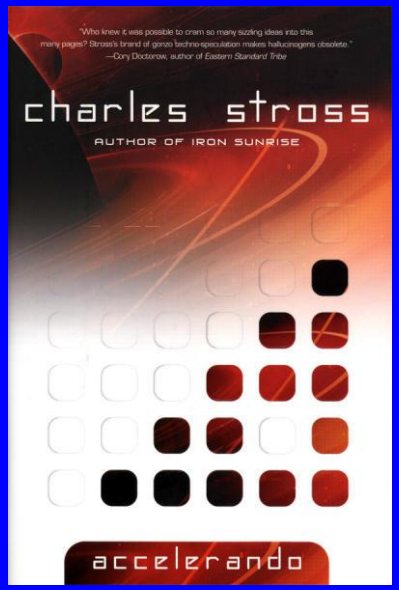
Read Sci-Fi
(Choose Your Own ~~Adventure~~ Future)

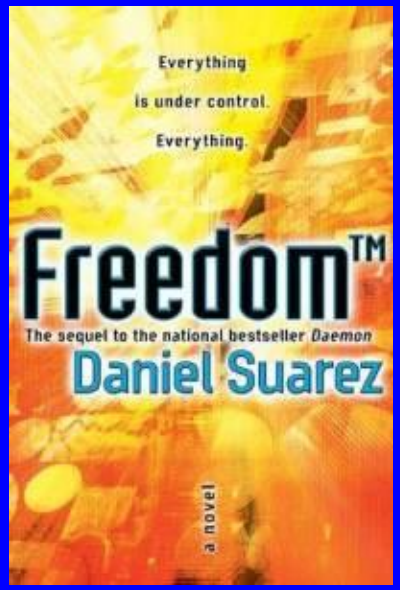












Charles Stross' Accelerando (2005)

"Then he lies down... The suite lights dim in response to commands from the thousand petaflops of distributed processing power …neural networks that interface with his meatbrain through the glasses.

…His glasses direct him toward one of the tour boats that lurk in the canal…

… [His] glasses zoom in … He pipes the image stream up to … his websites in real time.

…he pulls [his glasses] on and is besieged by an urgent flurry of ideas demanding attention.

…[He] plunges into one of those unavoidable fits of deep interaction, fingers twitching on invisible keypads and eyeballs jiggling as his glasses funnel deep media straight into his skull through the highest bandwidth channel currently available.

[Photo: Shutterstock]

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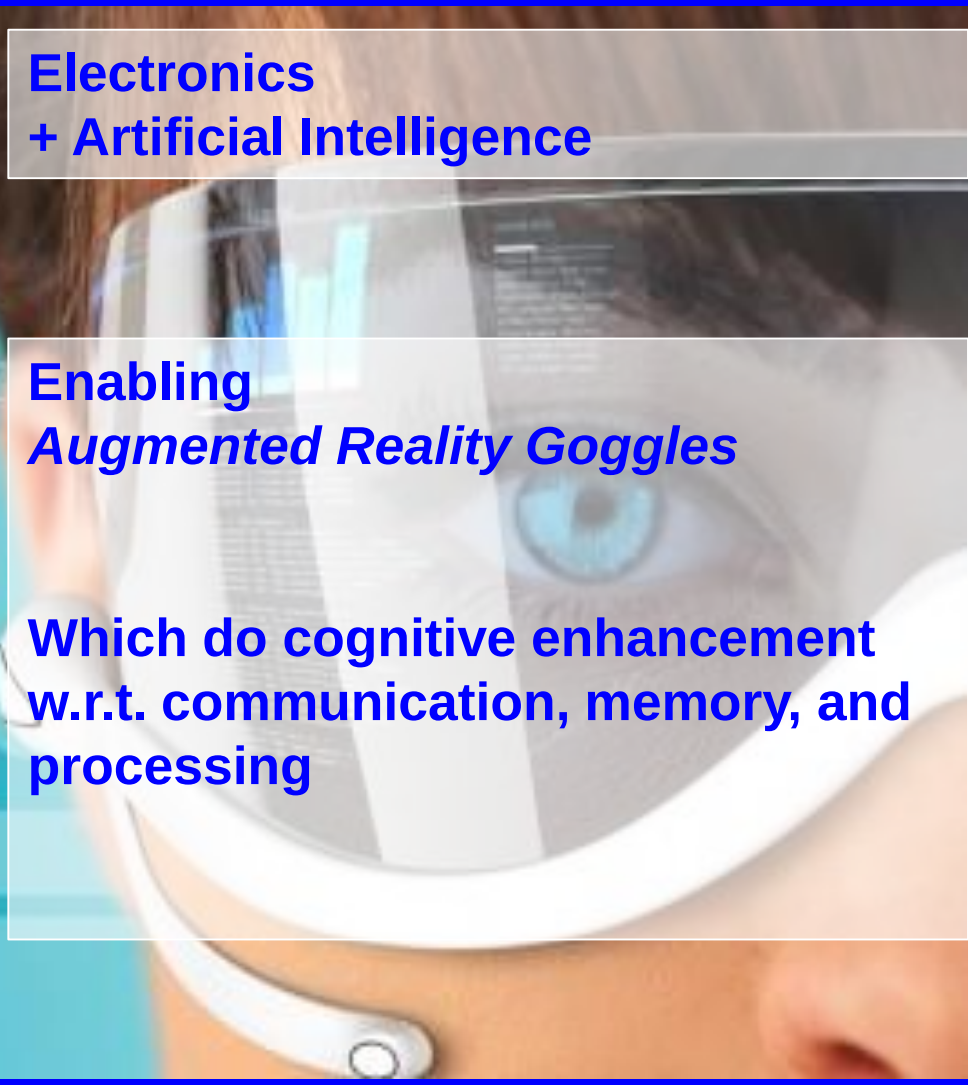


Electronics
+ Artificial Intelligence

Enabling
Augmented Reality Goggles

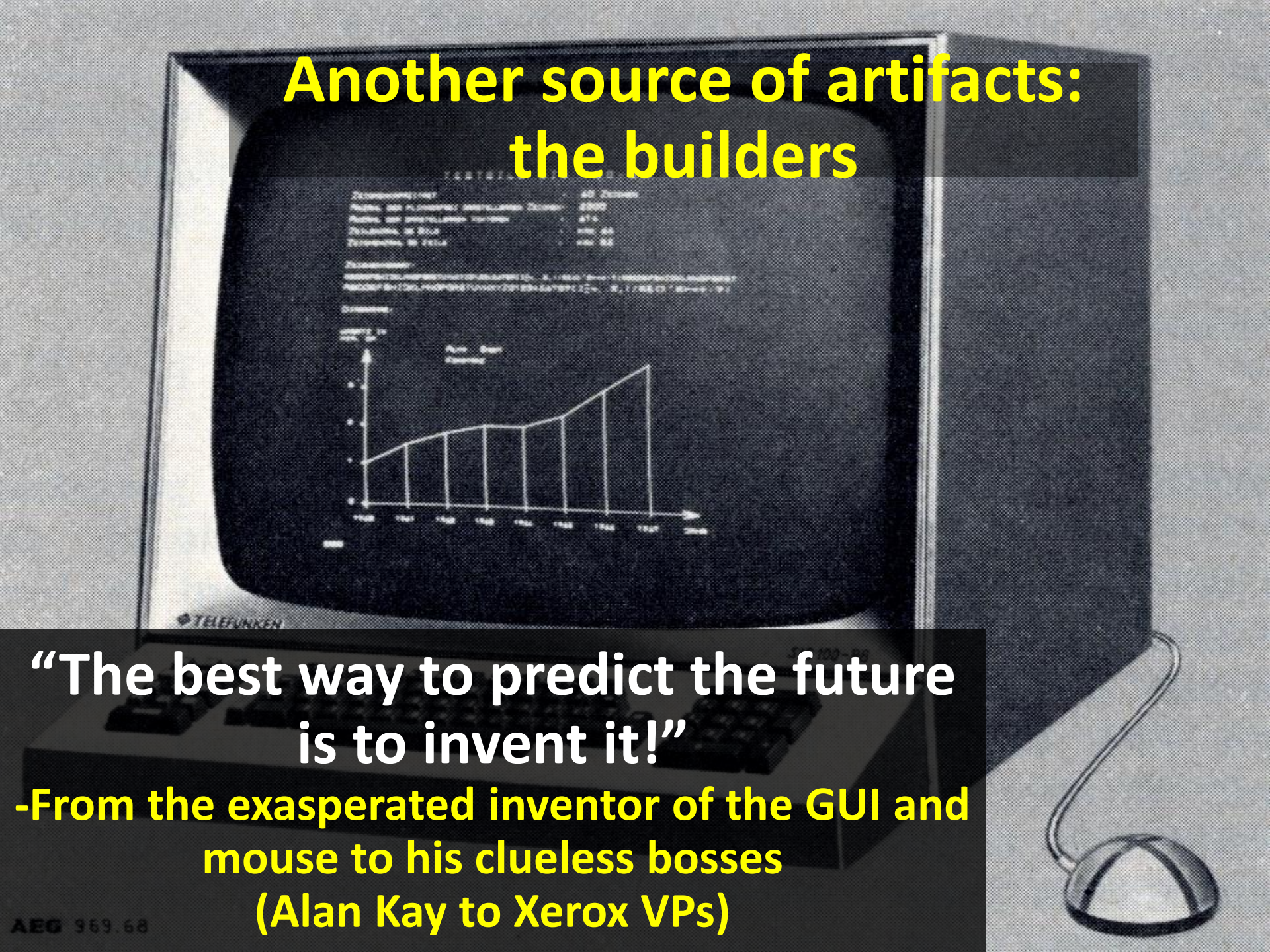
Which do cognitive enhancement w.r.t. communication, memory, and processing

[Photo: Shutterstock]

How to predict the future?

Build it!

Another source of artifacts: the builders



“The best way to predict the future is to invent it!”

-From the exasperated inventor of the GUI and mouse to his clueless bosses (Alan Kay to Xerox VPs)

The builders:
Virtual Reality-based CogE

These companies
are shipping / announcing AR Goggle projects

Read Sci-Fi: Revisiting Charles Stross' Accelerando

"Then he lies down on the bed ... The suite lights dim in response to commands from the thousand petaflops of distributed processing power … that interface with his meatbrain through the glasses.

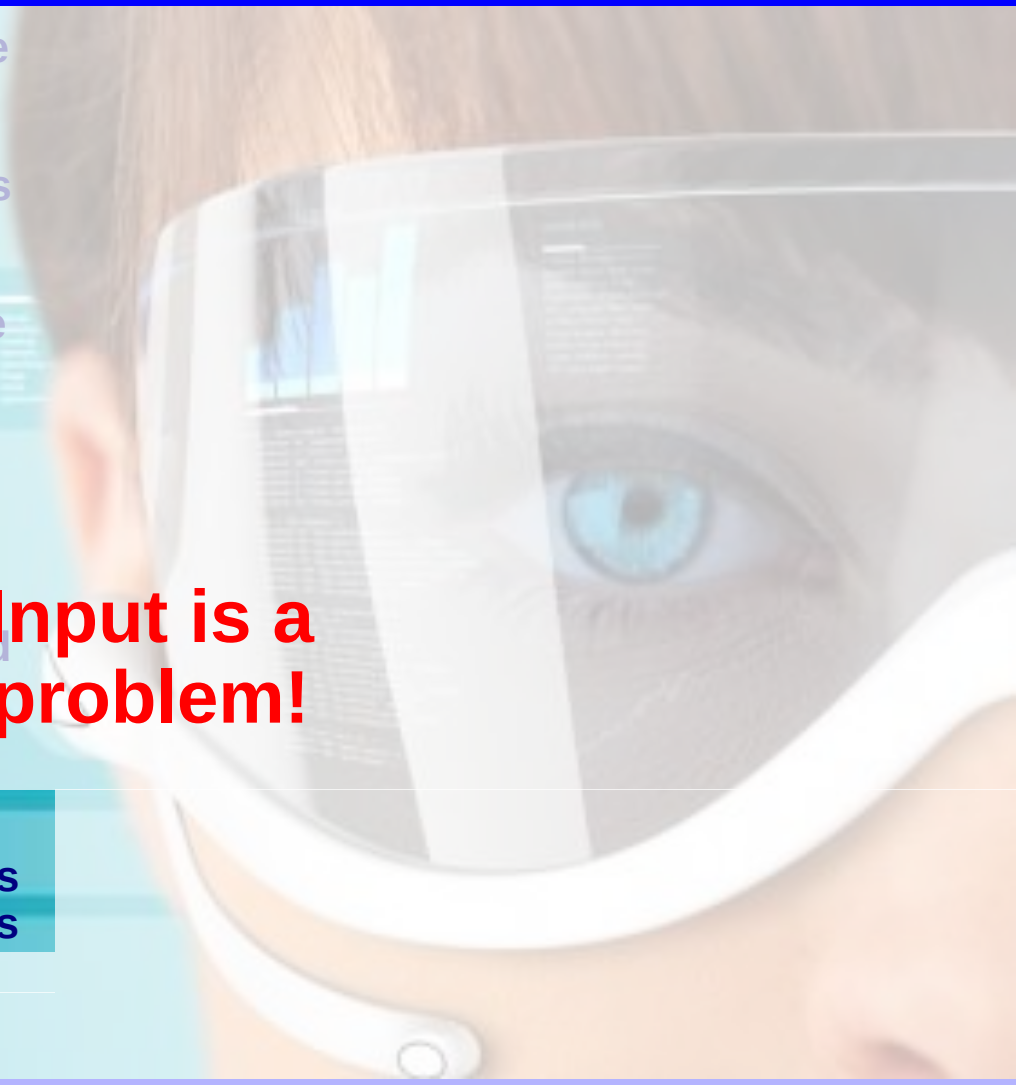
…His glasses direct him toward one of the tour boats that lurk in the canal…

… [His] glasses zoom in … He pipes the image stream up to … his websites in real time.

…he pulls [his glasses] on and is besieged by an urgent flurry of ideas demanding attention.

Input is a problem!

…He … plunges into one of those unavoidable fits of deep interaction, fingers twitching on invisible keypads and eyeballs jiggling as his glasses funnel deep media straight into his skull through the highest bandwidth channel currently available.



[Photo: Shutterstock]

Input for the Epson Goggles
… is a Handheld Trackpad!

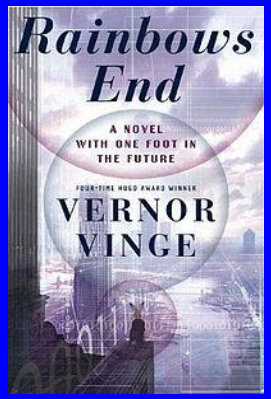
Input for the Google Glass
… is Head Tilting!

Input is a problem!

"Currently *Google* employees are testing a system of *head tilts* to scroll and click" [androidplace.com]

"A high-tech pair of glasses capable of computer-like functionality is worthless without a quick, smooth and user-friendly navigation." [augmentedtomorrow.com]

The Sci-Fi Solution,
From Vernor Vinge's Rainbows End (2006)

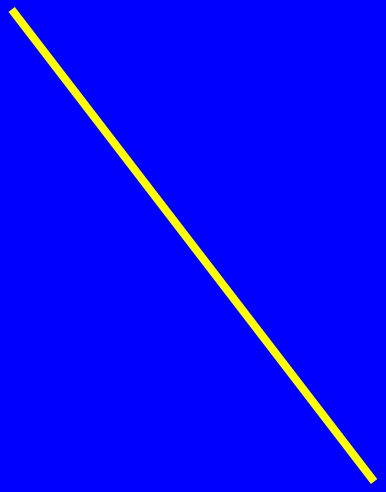


"…there was a glimmer of connectivity, enough for *sming*:
Miri --> Miri Gang: <sm>I think we're getting close.</sm>
Lena --> Miri Gang: <sm>…Get out of there.</sm>

…He *sminged* back, voice format: "…"

sming
= silent messaging
= sending text or voice
by *thinking* about it

How to predict the future?



Follow the research & non-mainstream tech

Research in Brain-Computer Interfaces (BCI)

Typical Aims of BCI:

Medical:

- **Help the physically disabled: control wheelchair, typing, control artificial limbs**
- **And much more!**

Military:

- **DARPA research to augment soldiers.**
- **No breakthroughs.**

Commercial:

- **Neuromarketing**
- **Recent Consumer: Emotiv, OCZ, Mattel / Neurosky Force Trainer (shown)**

[Photo: hammacher.com]

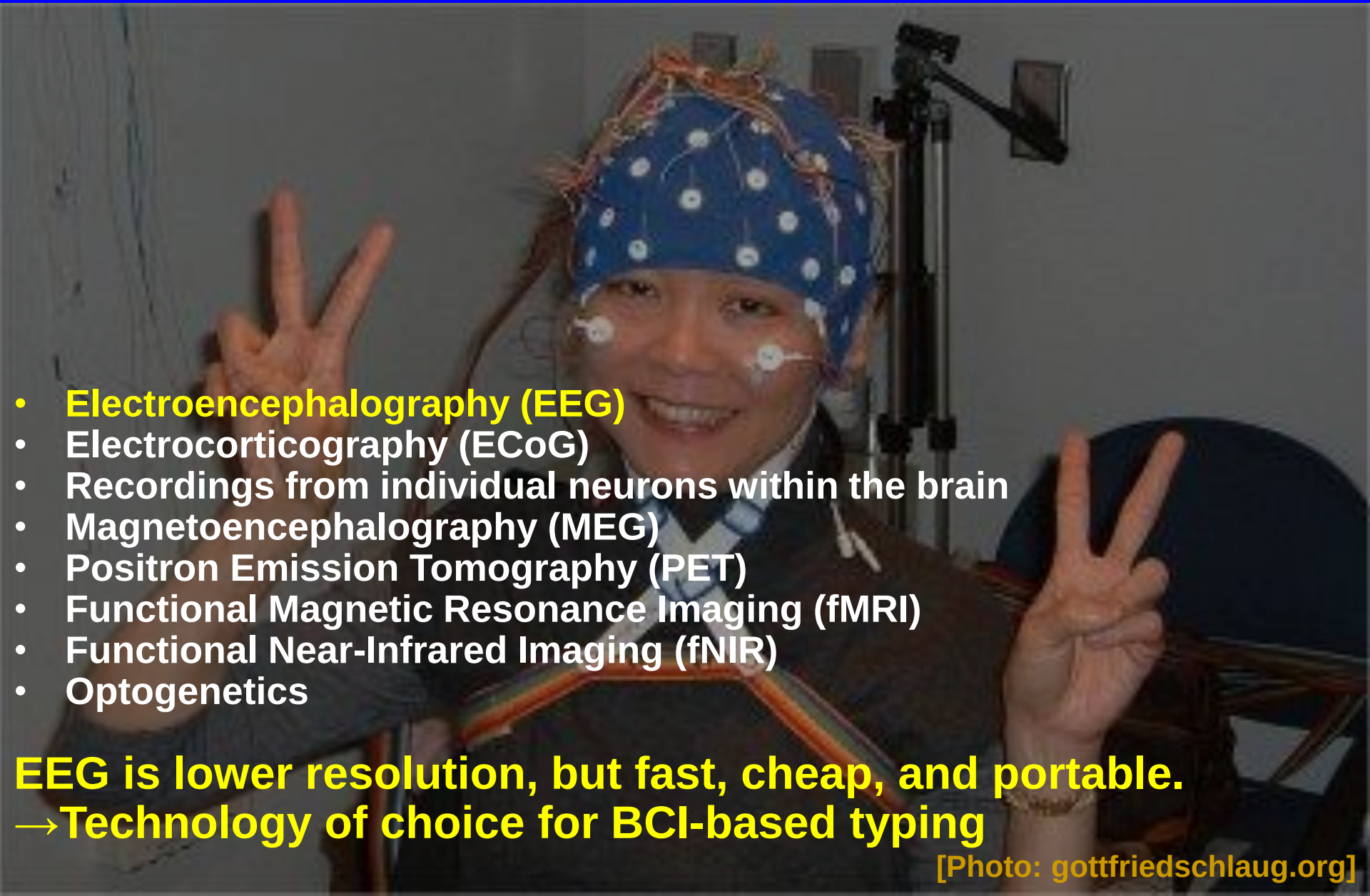
Key References:

Survey: J.R. Wolpaw et al, Brain-computer interfaces for communication and control, Clinical Neurophysiology 113 (2002), 767-791

Underlying mechanisms: S. Halder et al, Neural mechanisms of brain-computer interface control, Neuroimage 55 (2011), 1779-1790

Perspective paper: G. Schalk, Brain-computer symbiosis, IOP, January 16 (2008)

Technologies to Detect Brain Activity



- **Electroencephalography (EEG)**
- Electrocorticography (ECoG)
- Recordings from individual neurons within the brain
- Magnetoencephalography (MEG)
- Positron Emission Tomography (PET)
- Functional Magnetic Resonance Imaging (fMRI)
- Functional Near-Infrared Imaging (fNIR)
- Optogenetics

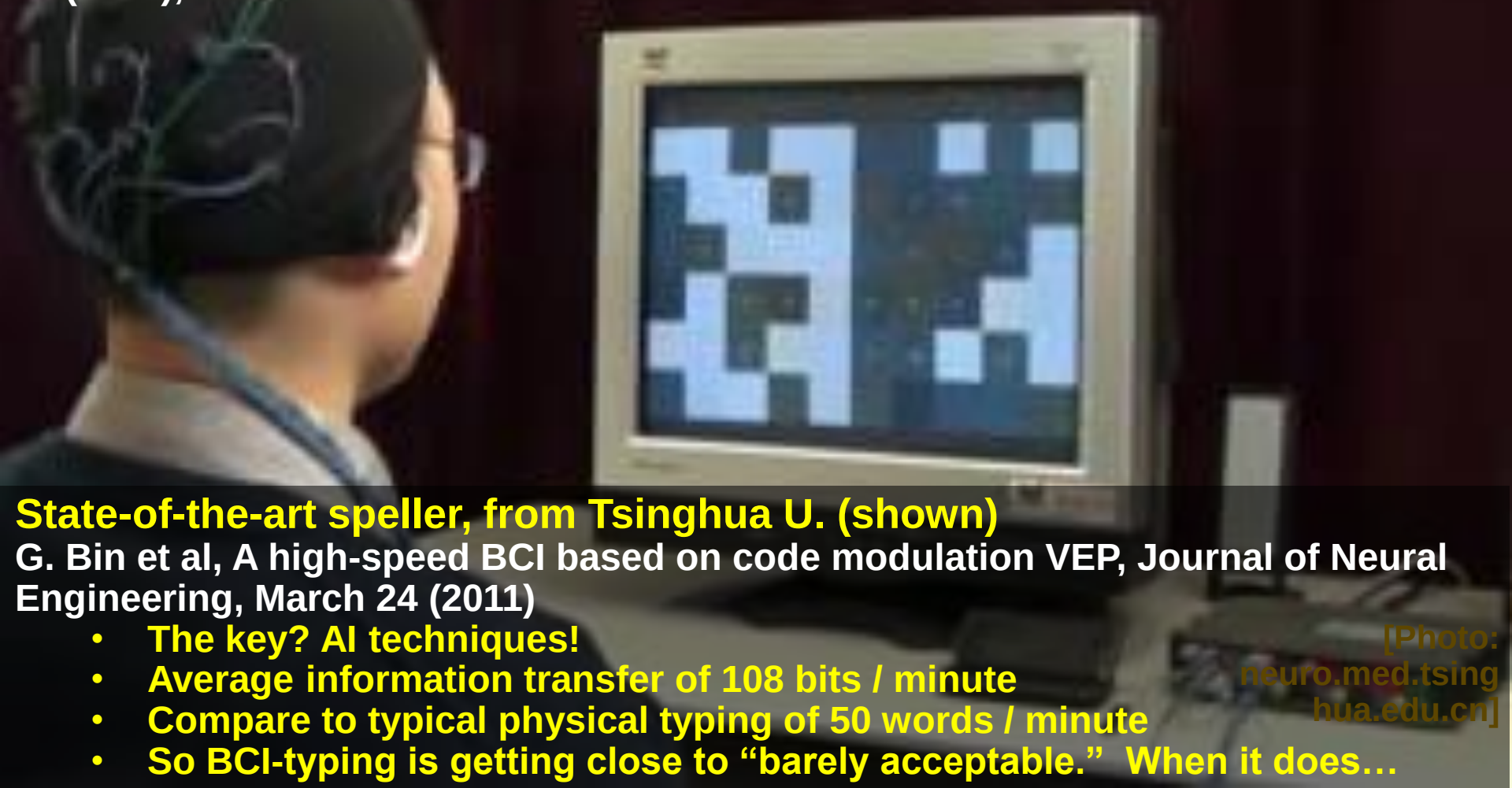
EEG is lower resolution, but fast, cheap, and portable.
→Technology of choice for BCI-based typing

[Photo: gottfriedschlaug.org]

BCI For Typing

The original "P300 Speller"

L.A. Farwell and E. Donchin, Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials, EEG Clinicial Neurophysiology 70 (1988), 510-523. >1000 citations.



State-of-the-art speller, from Tsinghua U. (shown)

G. Bin et al, A high-speed BCI based on code modulation VEP, Journal of Neural Engineering, March 24 (2011)

- **The key? AI techniques!**
- **Average information transfer of 108 bits / minute**
- **Compare to typical physical typing of 50 words / minute**
- **So BCI-typing is getting close to "barely acceptable." When it does…**

[Photo: neuro.med.tsinghua.edu.cn]

AR / BCI Goggles
Cognitive Enhancement of Communication
"Brain-Brain Communication" via sming

Trent --> Joe: <sm>hello! </sm>
(Joe sees sm on visual display)

Joe --> Trent: <sm>hi! </sm>
(Trent sees sm on visual display)

Communication advance:

- **Convenience up**

AR / BCI Goggles
Cognitive Enhancement of Memory
"Dropbox Your Brain"

- Everything you see and hear gets auto-dumped to the cloud
- Then use EEG interface to control a browser to search past memories
- Re-view past sights & sounds into goggles audio / visual

Perfect memory in the cloud (or locally)

EEG-mediated *memory interface*

Memory advances:
- **Capacity up**
- **Reliability up**

AR / BCI Goggles
Cognitive Enhancement of Communication #2
"YouTube your brain" – Stream memories to friends

EEG mediate

Your memories

Communication advances:
- **Bandwidth up**
- **Convenience up**

AR / BCI Goggles
Cognitive Enhancement of Processing
"Calculating in your Head" takes a whole new meaning

Cloud-scale computing (or local CPUs / GPUs)

EEG-mediated *computing interface*

Processing advances:

- **Speed up**
- **Throughput up**
- **Reliability up**

And it's more than a calculator in your head: online image processing, help with recognizing faces, solving math problems, wayfinding, more…

CogE – Artifact Predictions

Now:

- Prototype Low-Latency VR (Oculus)
- Prototype AR (Google Glass, annotated reality)

<1 Year:

- Production Ultra-Low Latency VR (Oculus / FB)
- Prototype next-gen virtual worlds (FB)

5-12 Years:

- "Real" AR (repainted reality)
- Production SR sming
- DropBox your brain (perfect memory)
- YouTube your brain (talk in pictures)
- BW+, +, +, …
- Then, where does "self" end? And other Q's…

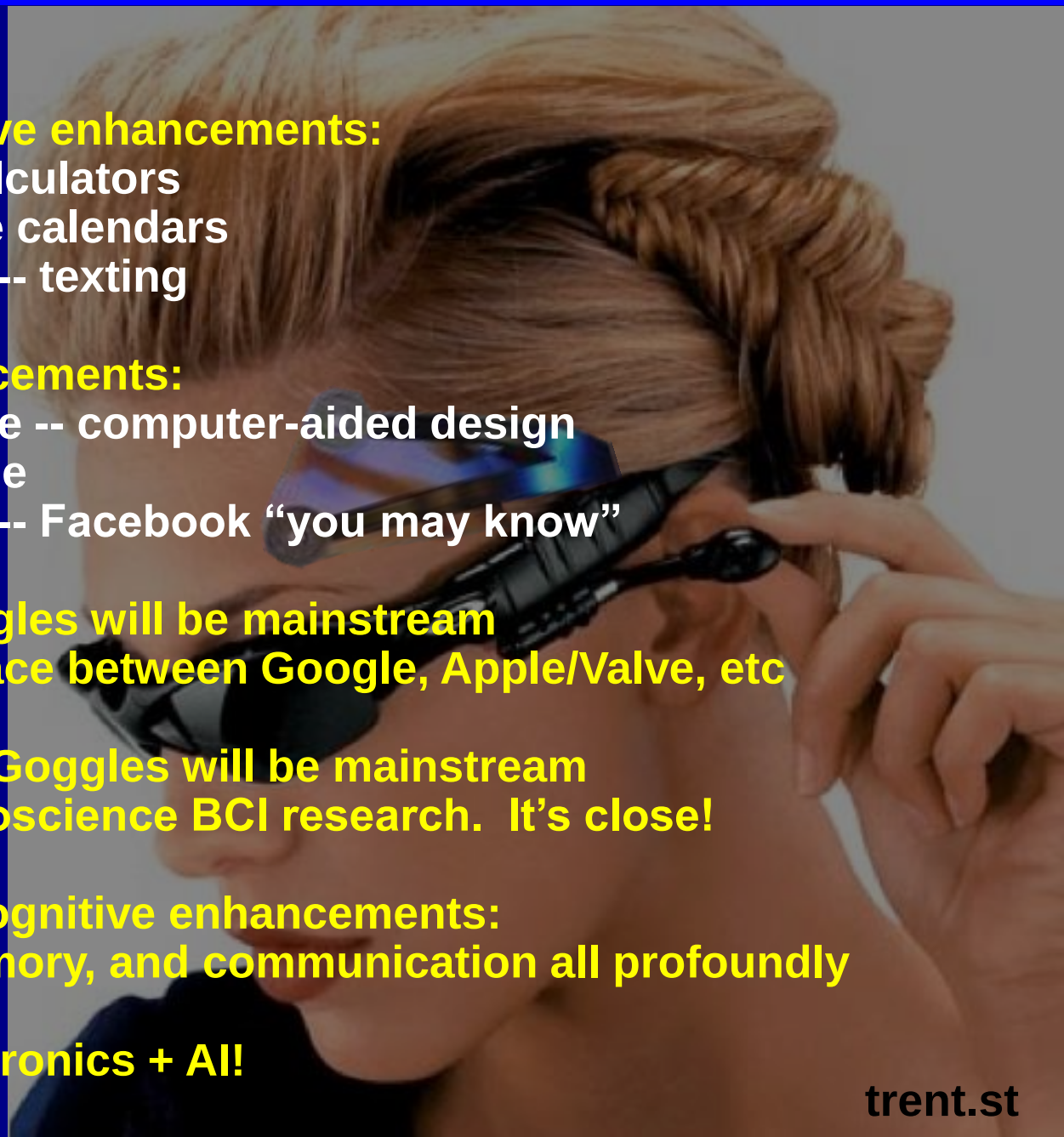
CogE - Opportunities

1. **Anything that increases communication, BW, or memory between brain and computer.**
2. **Anything that drives Moore's Law**
3. **Infrastructure / ecosystem around this**

1. Includes
   - VR, AR, AR/BCI. AI-powered. Think iPhone 15.
   - 10x+ ML algorithms, ML co-processors, ML-opt'd chips
   - Mobile-worthy brain-scanning tech (fast, low power, high-res, non-invasive)
2. Includes
   - Cheaper, higher-performing devices -> fabs
   - AI to design better devices, chips, fabs
3. Includes
   - Knowledge economy -> how to monetize -> tracking intellectual assets

Conclusion

Cognitive Enhancement via Electronics & AI: Conclusion



- AI Introduction

- Electronics for cognitive enhancements:
  - Processing -- calculators
  - Memory -- online calendars
  - Communication -- texting

- AI for cognitive enhancements:
  - Processing, more -- computer-aided design
  - Memory -- Google
  - Communication -- Facebook “you may know”

- Prediction #1: AR Goggles will be mainstream
  - Big driver: the race between Google, Apple/Valve, etc

- Prediction #2: AR/BCI Goggles will be mainstream
  - Big driver: Neuroscience BCI research. It’s close!

- AR/BCI Goggles, for cognitive enhancements:
  - Processing, memory, and communication all profoundly improved!
  - Enabled by electronics + AI!

trent.st


Questions?
[google]