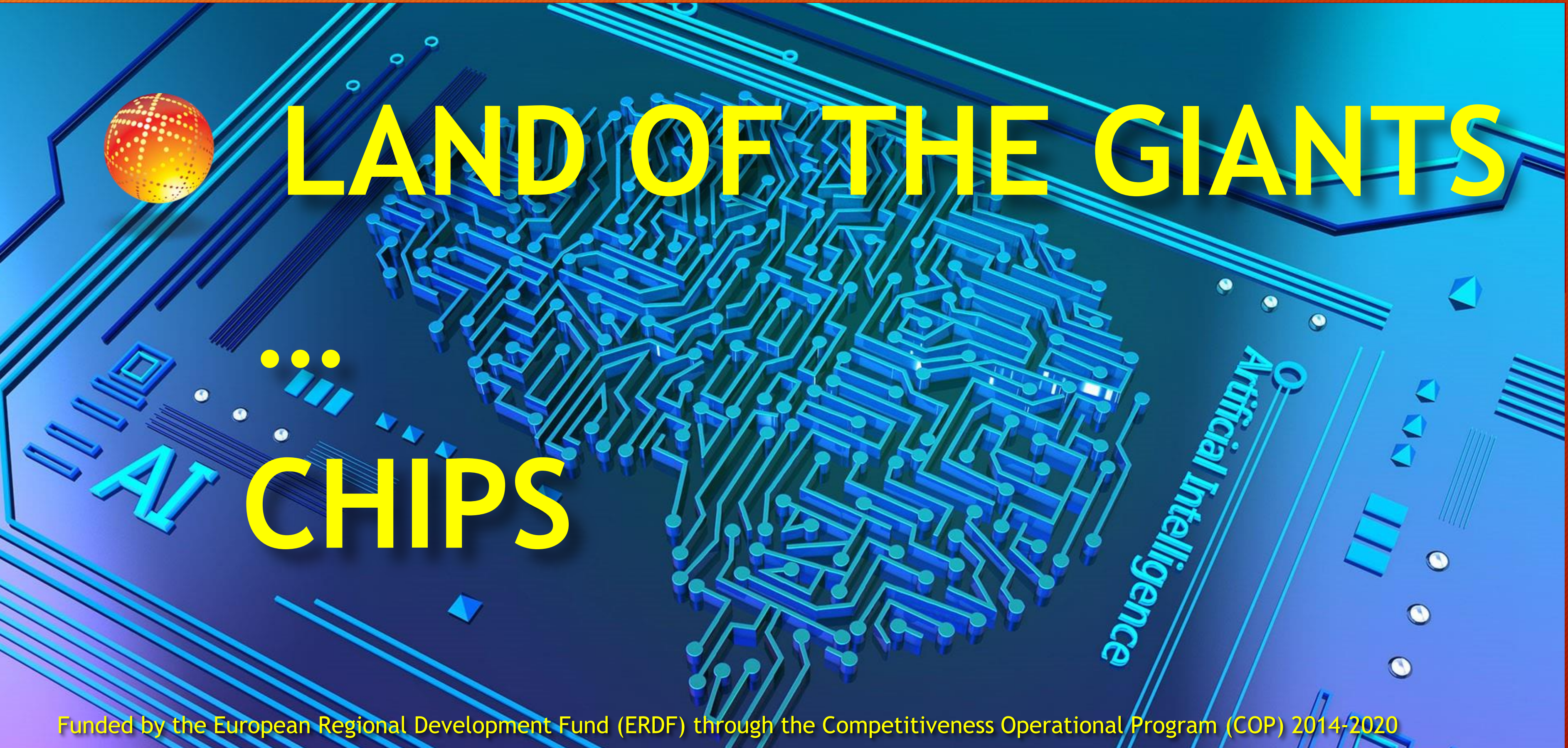
EUROPEAN UNION

Structural Instruments
2014 – 2020

LAND OF THE GIANTS

… CHIPS



Valeriu Beiu

ARAD AV
NANOART

Funded by the European Regional Development Fund (ERDF) through the Competitiveness Operational Program (COP) 2014-2020

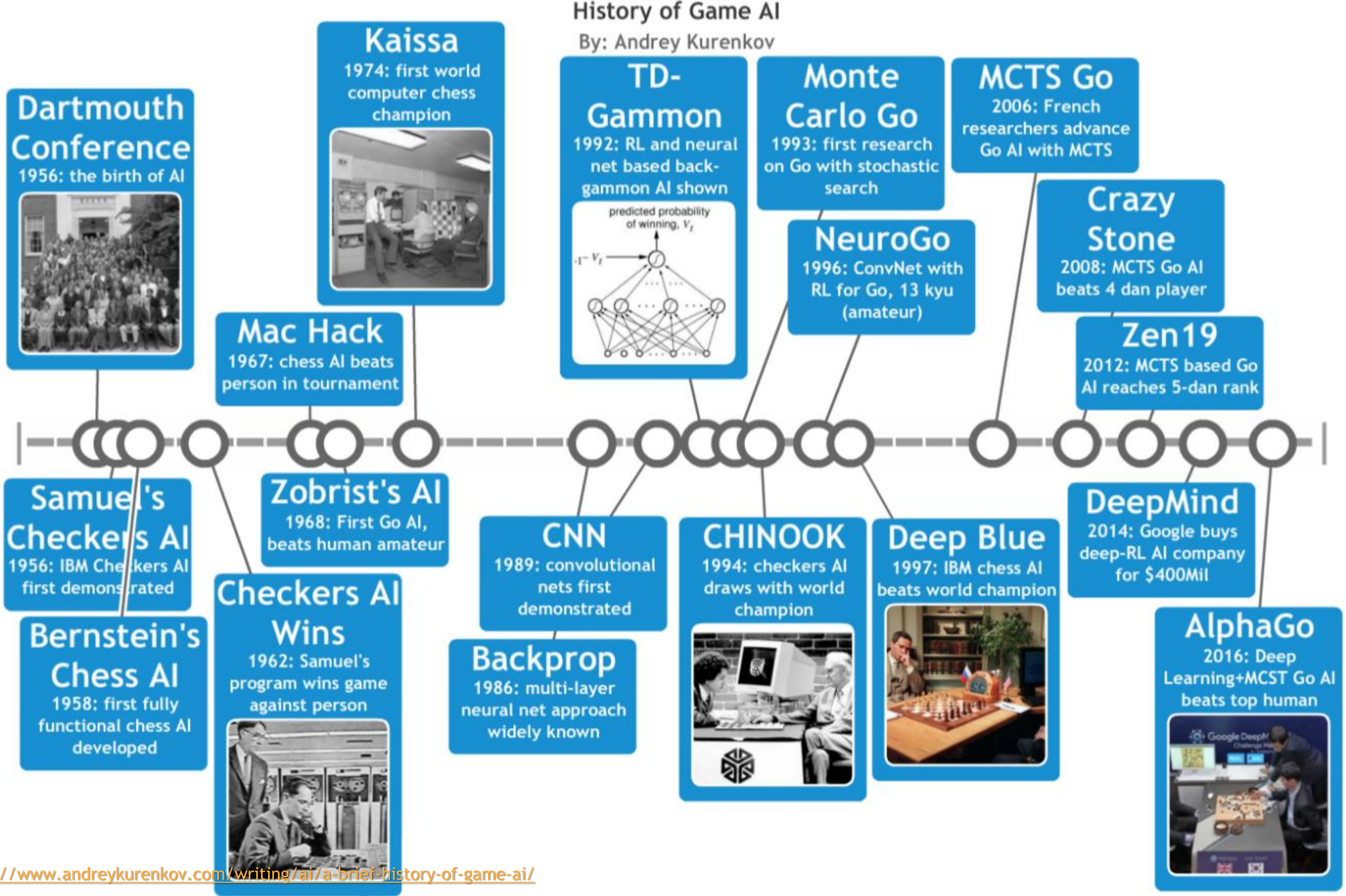
BioCell-NanoART ● P-37-744 nr. 30/01.09.2016

Jurassic World: Fallen Kingdom ● https://en.wikipedia.org/wiki/Jurassic_World:_Fallen_Kingdom

Structure of the presentation

- Intro
- **Part 1** AI from the early beginnings
- **Part 2** Follow the money
- **Part 3** AI hardware (growing land of the giant AI chips)
  - GPU Nvidia https://www.nvidia.com/en-us/
  - TPU Google https://ai.google/
  - IPU Graphcore https://www.graphcore.ai/
  - WSE Cerebras https://www.cerebras.net/
  - Quantum approach (Google, IBM, and many others)
- Fast … and, hopefully … green

AI …



From https://www.andreykurenkov.com/writing/ai/a-brief-history-of-game-ai/

ARTIFICIAL INTELLIGENCE

IS NOT NEW

ARTIFICIAL INTELLIGENCE

Any technique which enables computers to mimic human behavior

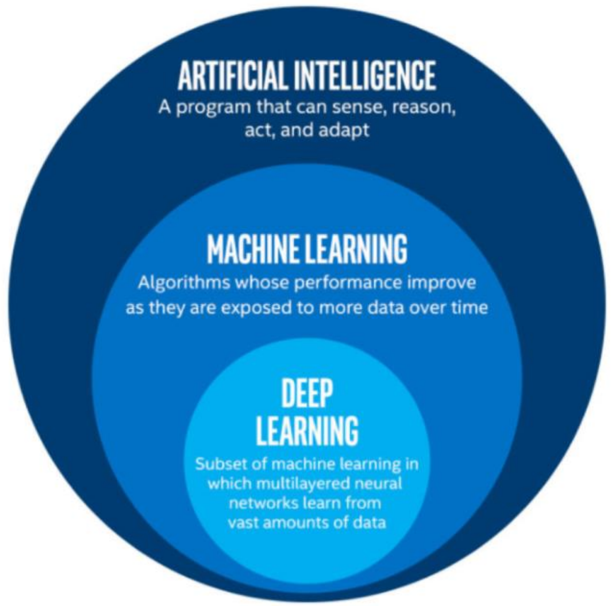
MACHINE LEARNING

AI techniques that give computers the ability to learn without being explicitly programmed to do so

DEEP LEARNING

A subset of ML which make the computation of multi-layer neural networks feasible

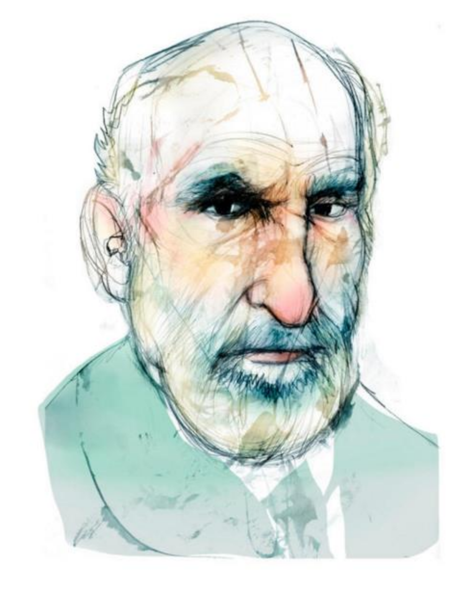
1950's 1960's 1970's 1980's 1990's 2000's 2010s



ORACLE

“ As long as our brain is a mystery, the universe, the reflection of the structure of the brain will also be a mystery.

Mientras nuestro cerebro sea un arcano, el Universo, reflejo de su estructura, será también un misterio. ”



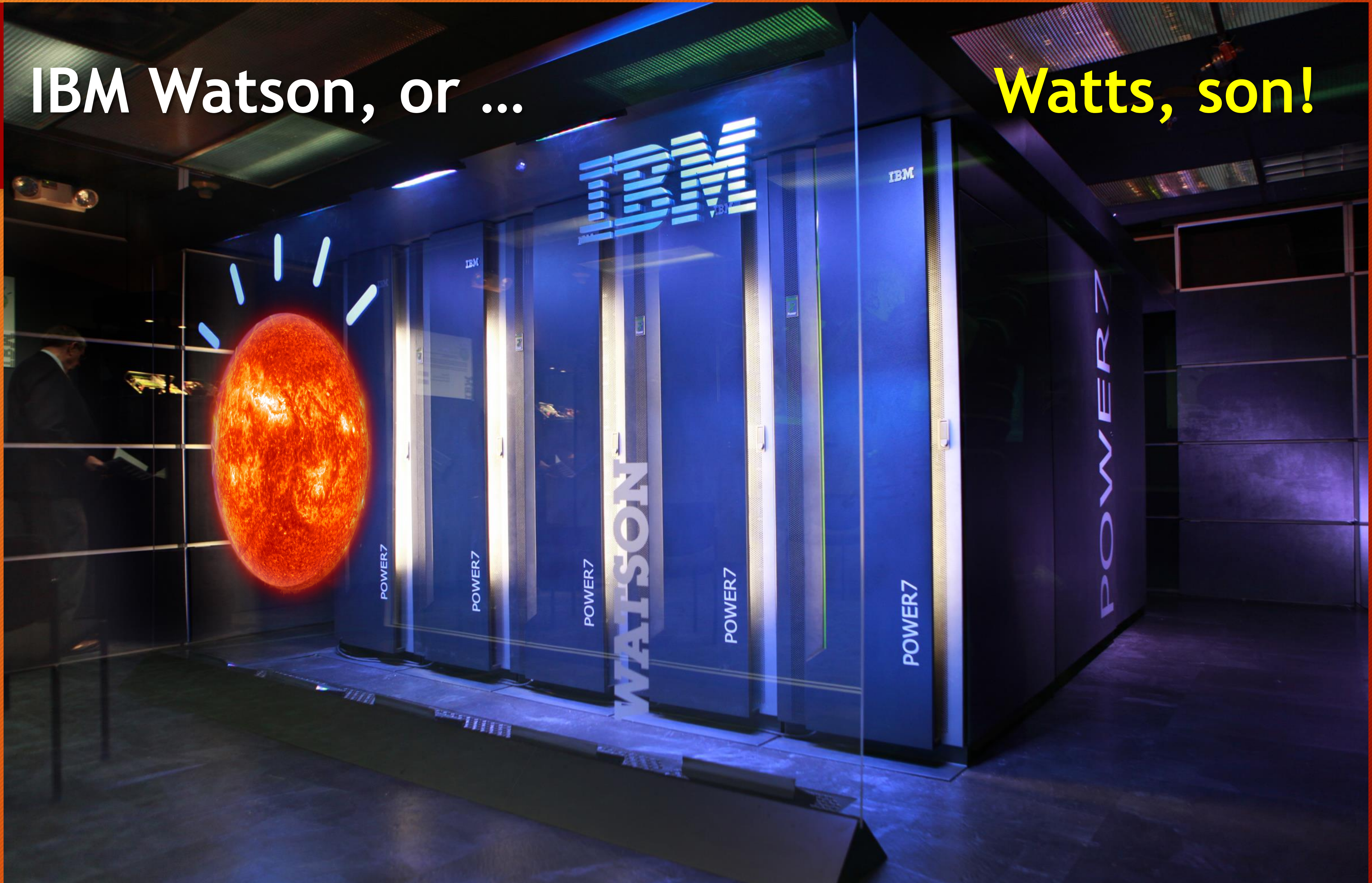
Chapter IX: Con tendencias a la literatura y al arte
Cháchara de café: Pensamientos, anécdotas y confidencias
Imprenta y Librería de Nicolás Moya, Madrid, Spain, 1920

Santiago Ramón y Cajal
Nobel Prize in Physiology or Medicine (1906)

IBM Deep Blue

See https://en.wikipedia.org/wiki/Deep_Blue_(chess_computer)

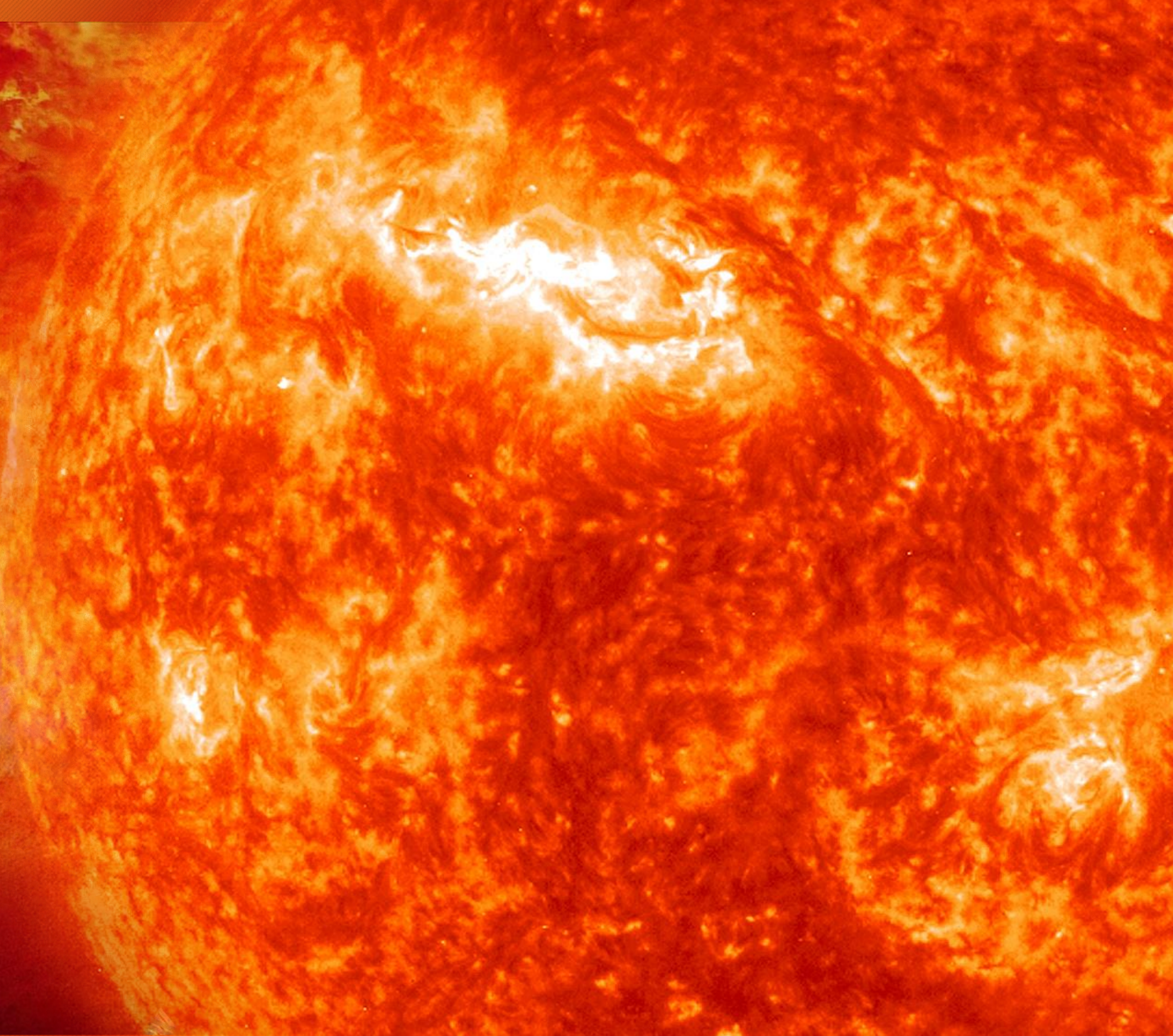
IBM Watson, or … Watts, son!



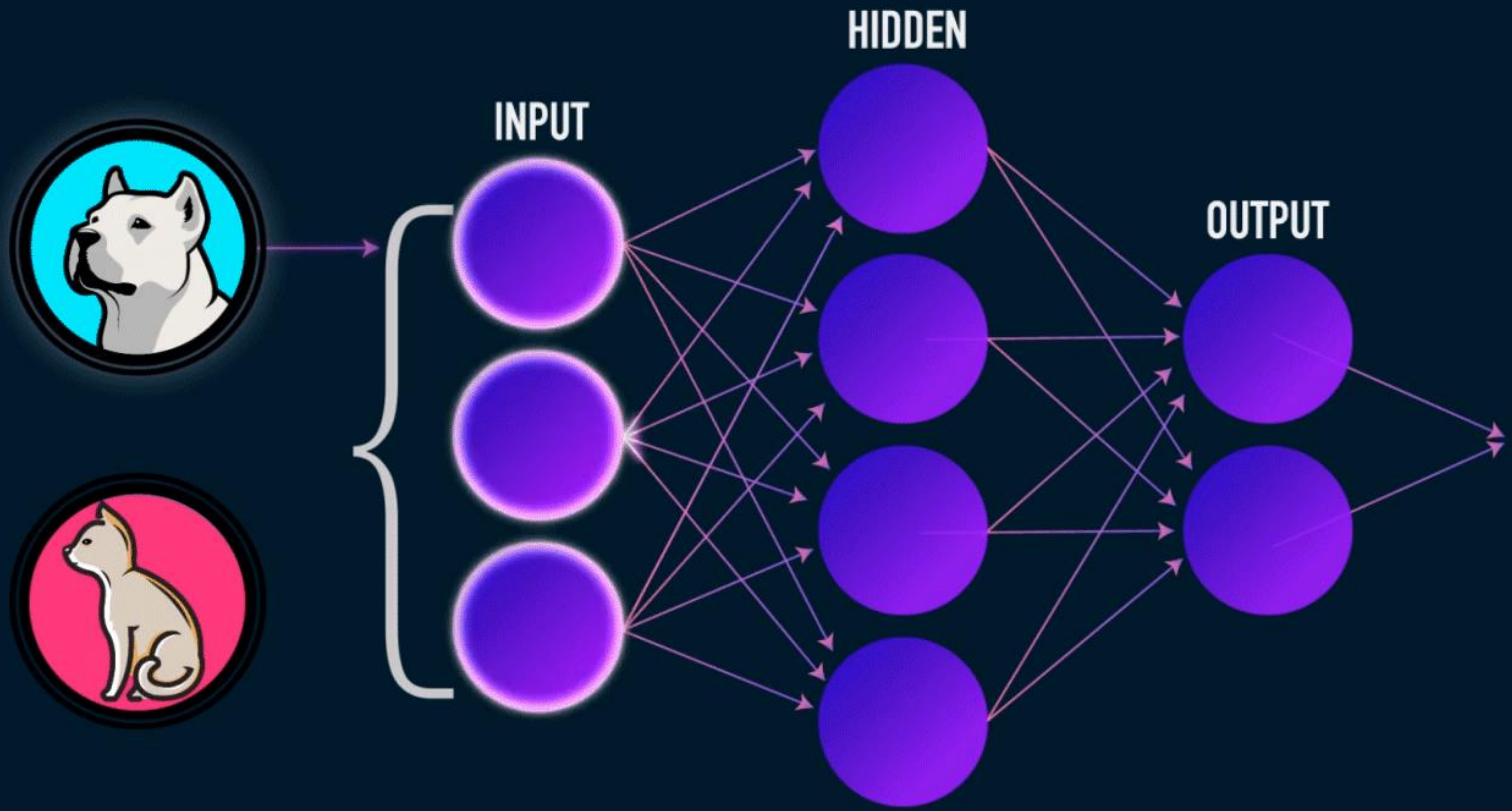
See https://en.wikipedia.org/wiki/Watson_(computer) but also https://spectrum.ieee.org/biomedical/diagnostics/how-ibm-watson-overpromised-and-underdelivered-on-ai-health-care

Heat (power)

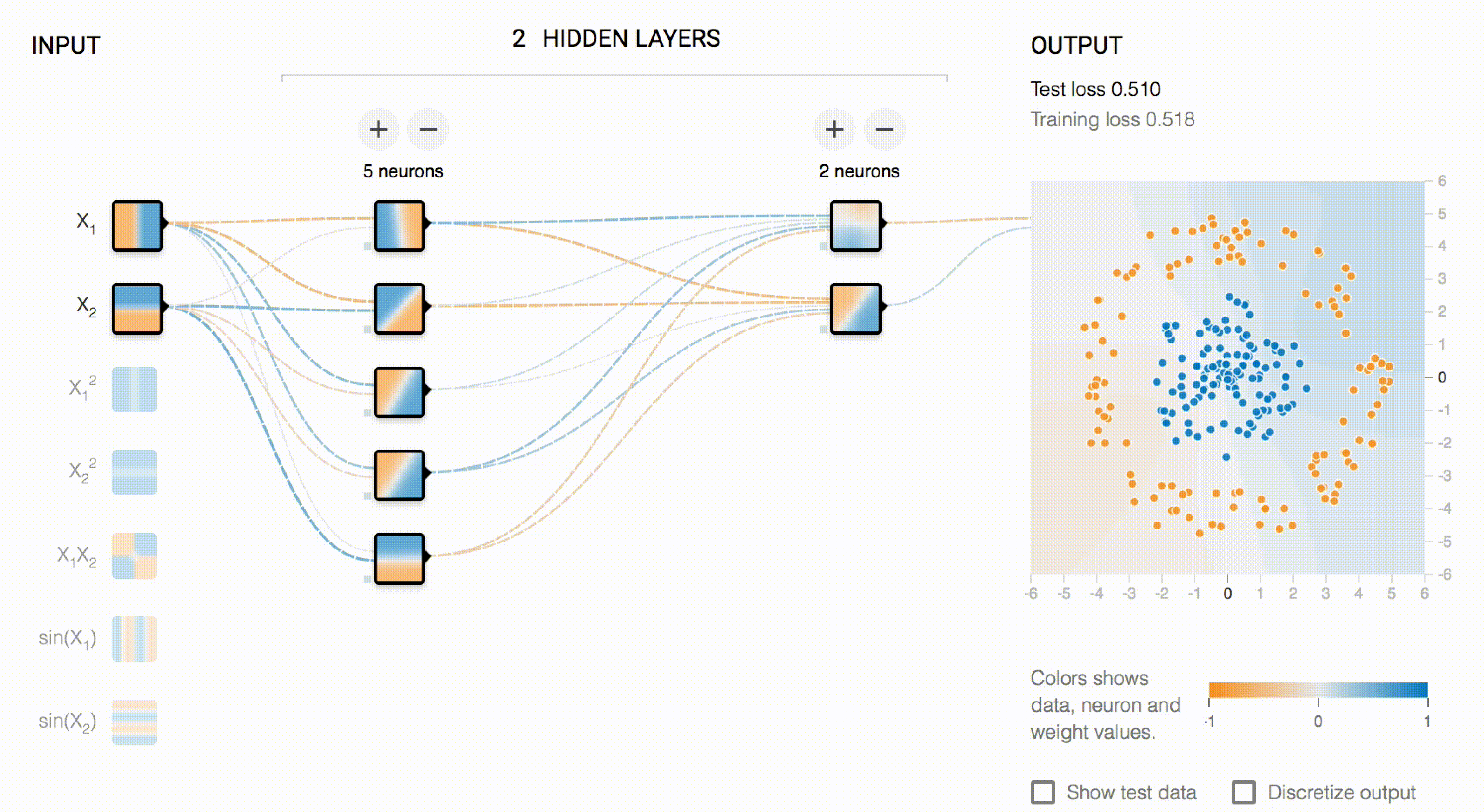

温控更灵便!
The Emerson logo is a trademark and service mark of Emerson Electric Co. © 2004 Emerson Electric Co.



Classification



From https://medium.com/@thegrigorian/rolling-in-the-deep-cnn-c8d3f7108c8c



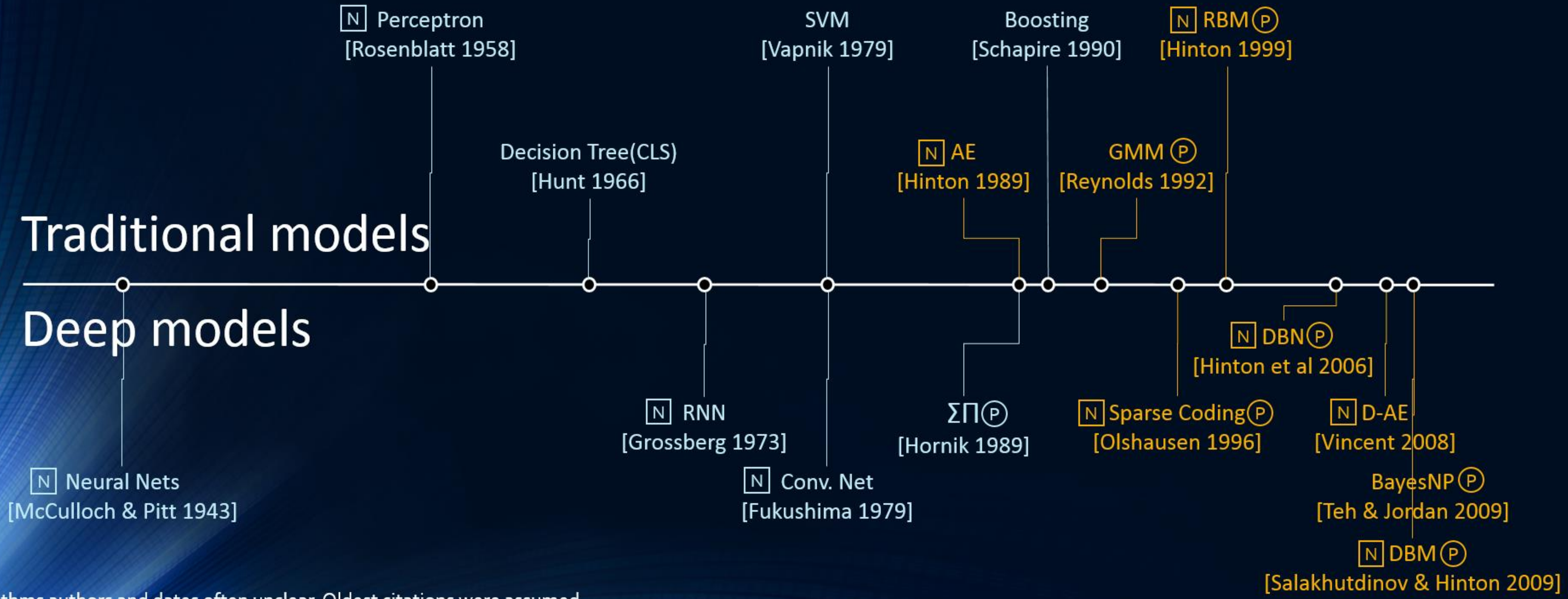
From http://playground.tensorflow.org/

On speech … with Richard (Rick) Rashid

See https://www.youtube.com/watch?v=Nu-nlQqFCKg

Deep Learning evolution

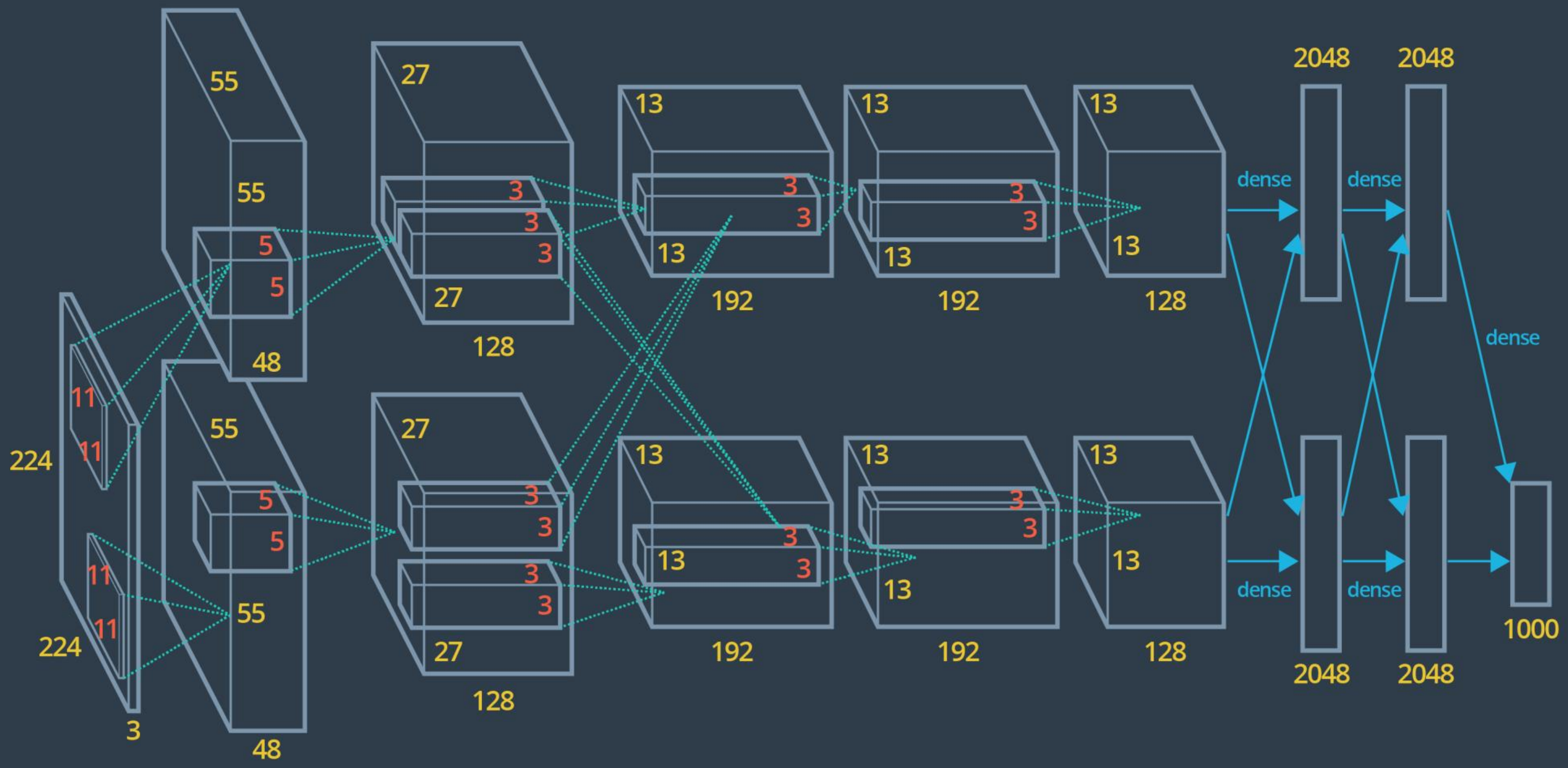
N Neural Network
P Probabilistic Model
Supervised learning
Unsupervised learning



Algorithms authors and dates often unclear. Oldest citations were assumed
Classifications based on Yann LeCun's Deep Learning class at NYU – spring 2014

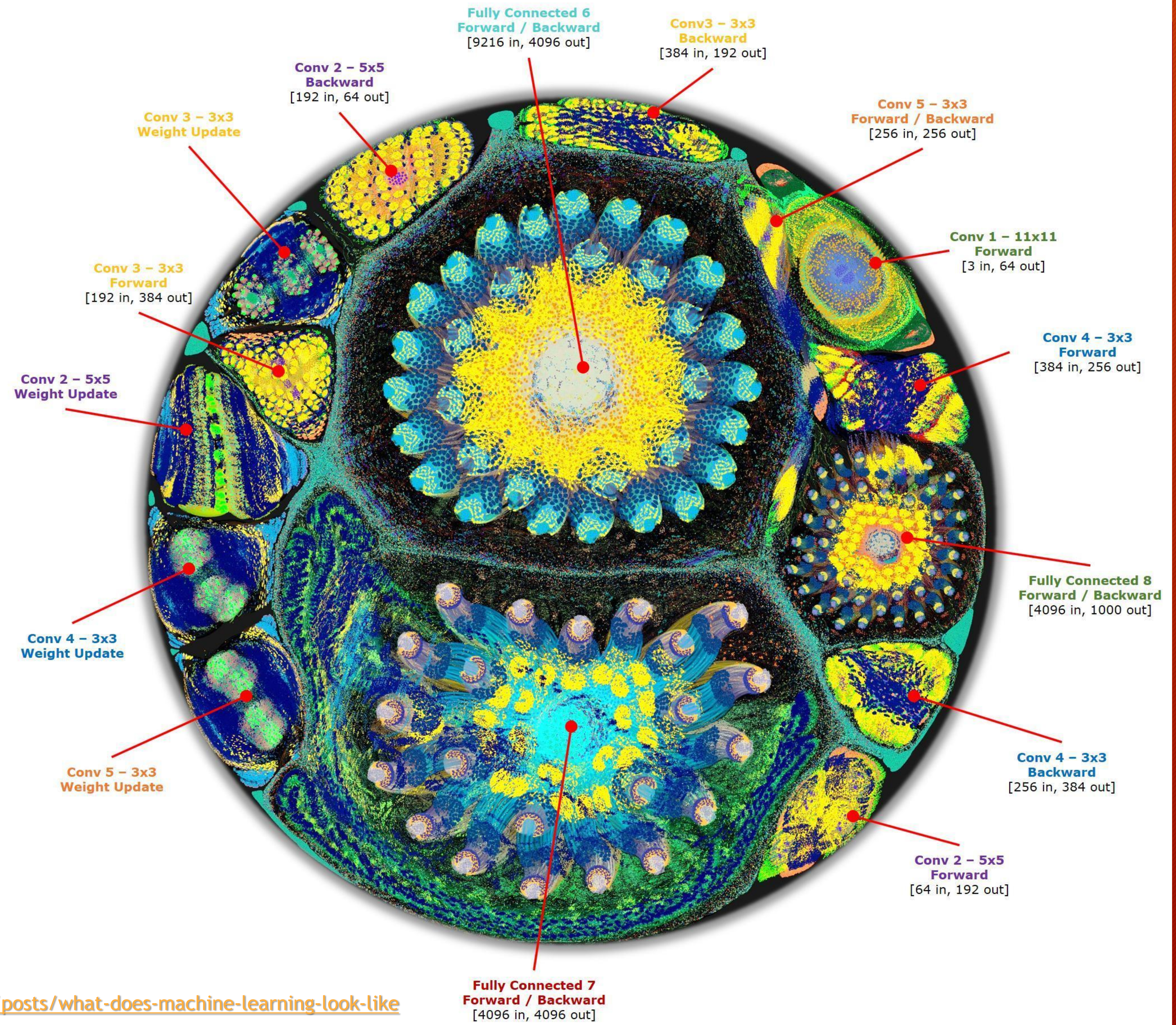
From https://www.youtube.com/watch?v=OVNXybMoavc

AlexNet



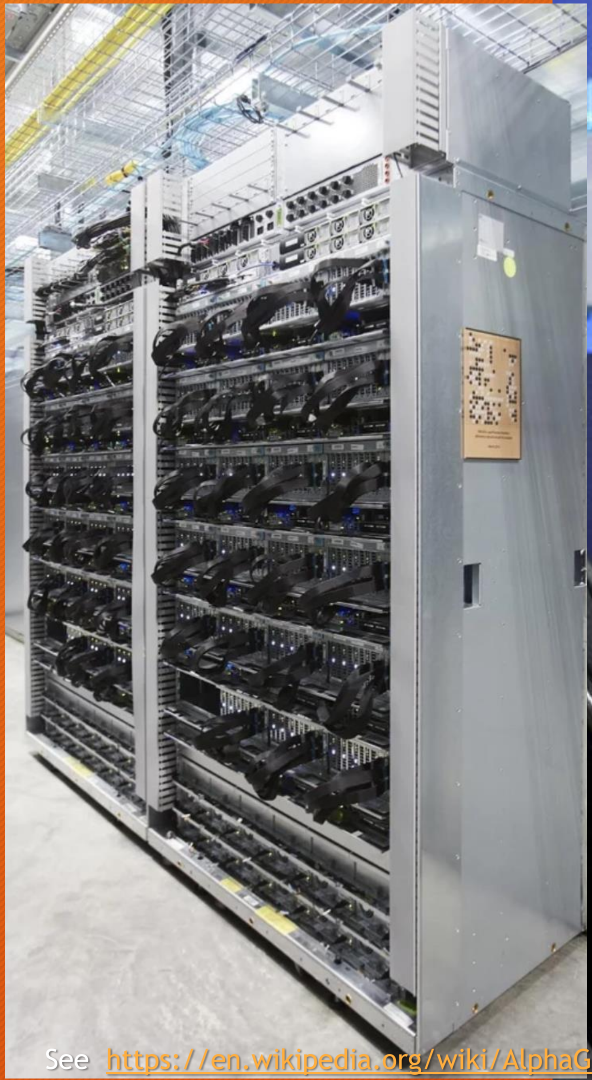
See https://en.wikipedia.org/wiki/AlexNet and https://github.com/AntonioRoldan/Deep-learning-nd

AlexNet



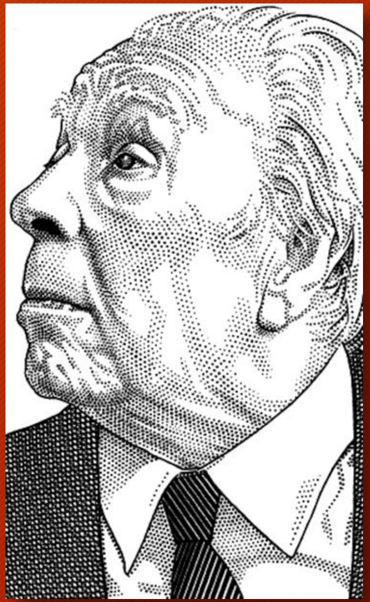
From https://www.graphcore.ai/posts/what-does-machine-learning-look-like

AlphaGo

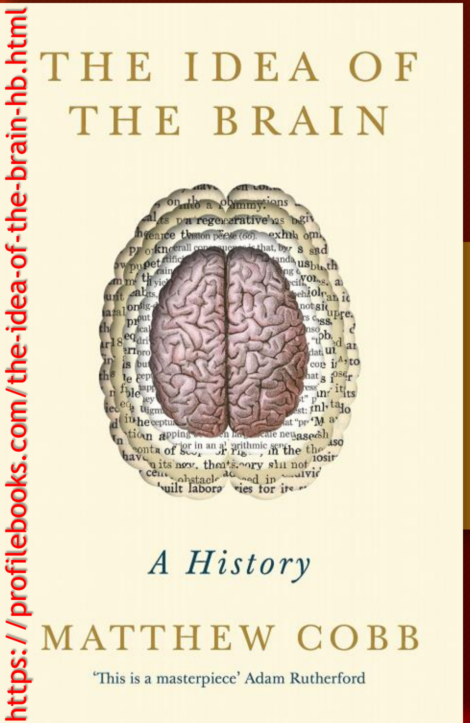


See https://en.wikipedia.org/wiki/AlphaGo and https://deepmind.com/research/case-studies/alphago-the-story-so-far incl. https://www.youtube.com/watch?v=WXuK6gekU1Y ☺

“ The solution to the mystery is always inferior to the mystery itself. ”



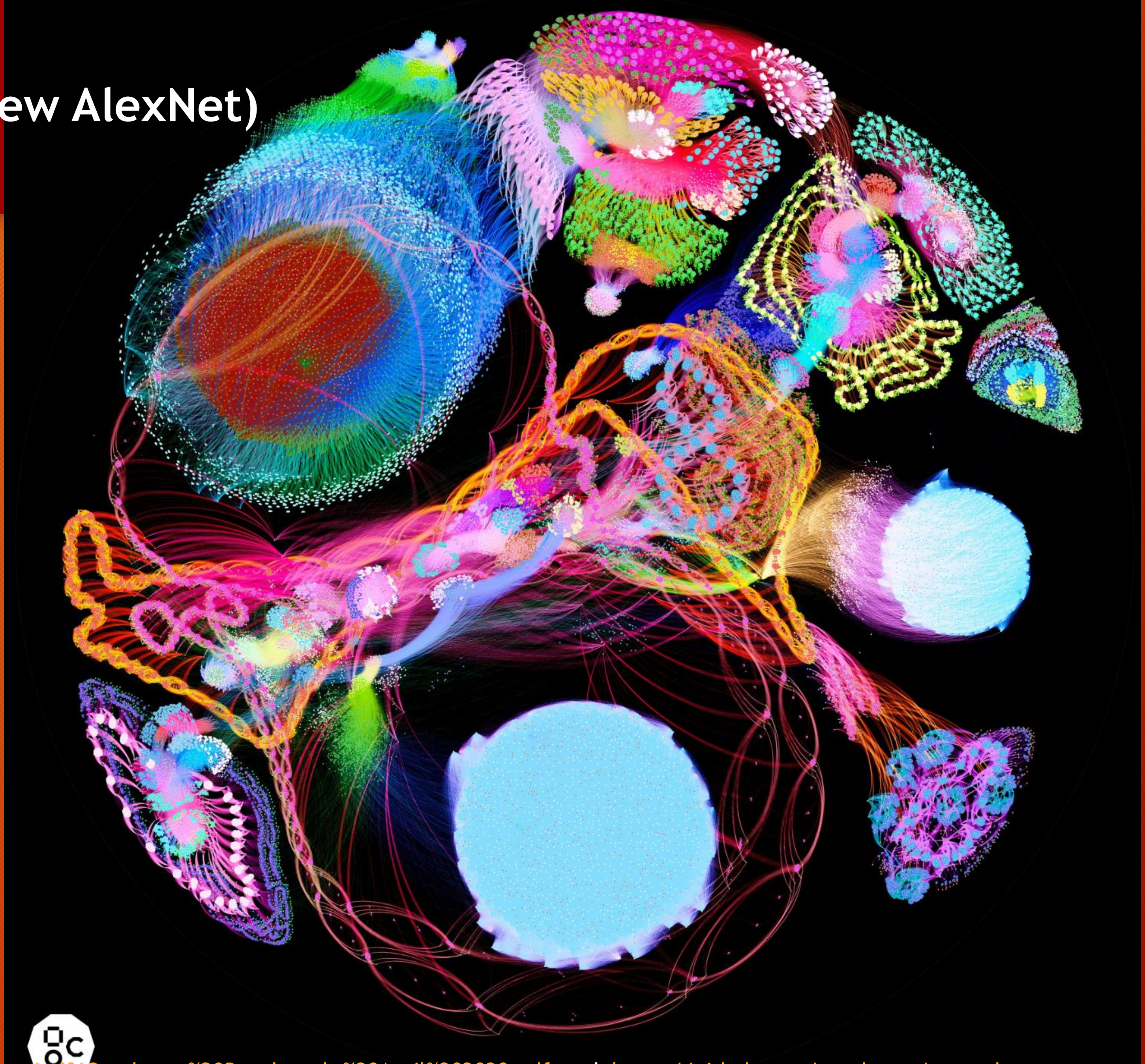
The path toward understanding the brain is long, winding, and littered with dead ends. [“…”] As *The Idea of the Brain* demonstrates, the mysteries of the mind may not just be stranger than we suppose; they may be stranger than we can suppose.



https://profilebooks.com/the-idea-of-the-brain-hb.html

Jorge Luis Borges
Received the first Prix Formentor (1961)

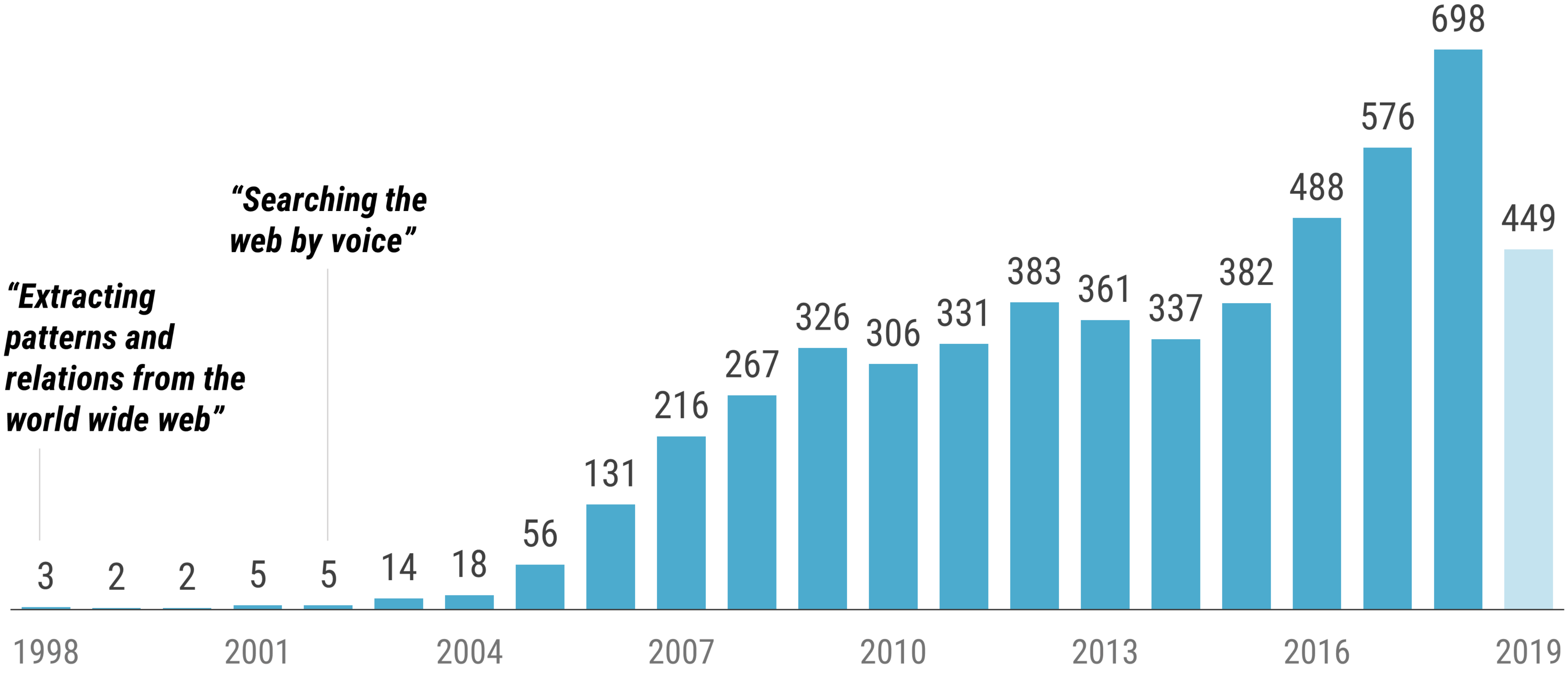
ResNet50 (the new AlexNet)



See https://cdn2.hubspot.net/hubfs/729091/assets/pdf/Graphcore%20Benchmarks%20April%202020.pdf and https://github.com/graphcore/examples

Google's AI research dates back to its founding year

AI-related publications, 1998 – 2019 (as of Aug. 5)

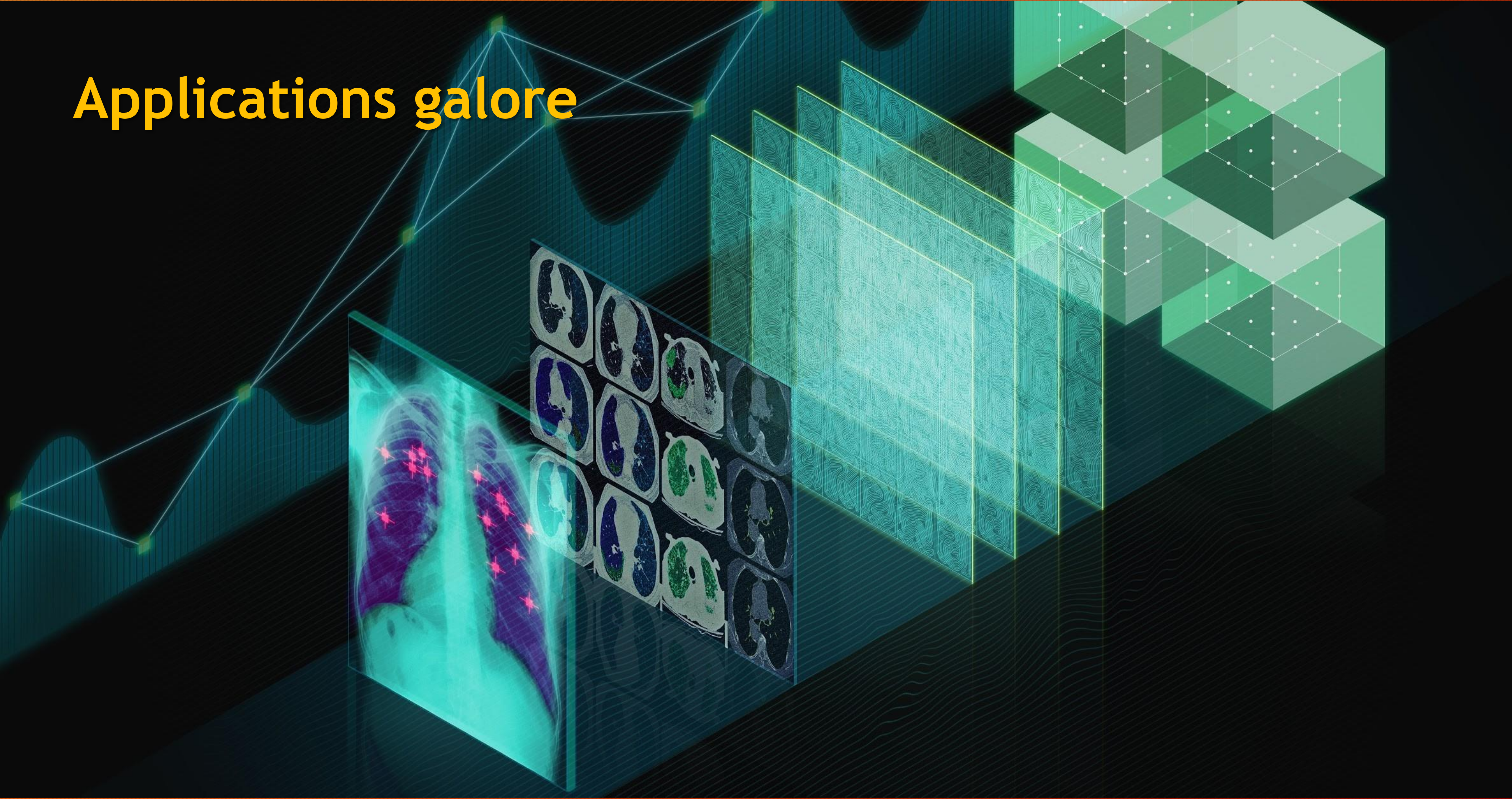


Source: Google AI

https://ai.google/ and https://www.cbinsights.com/

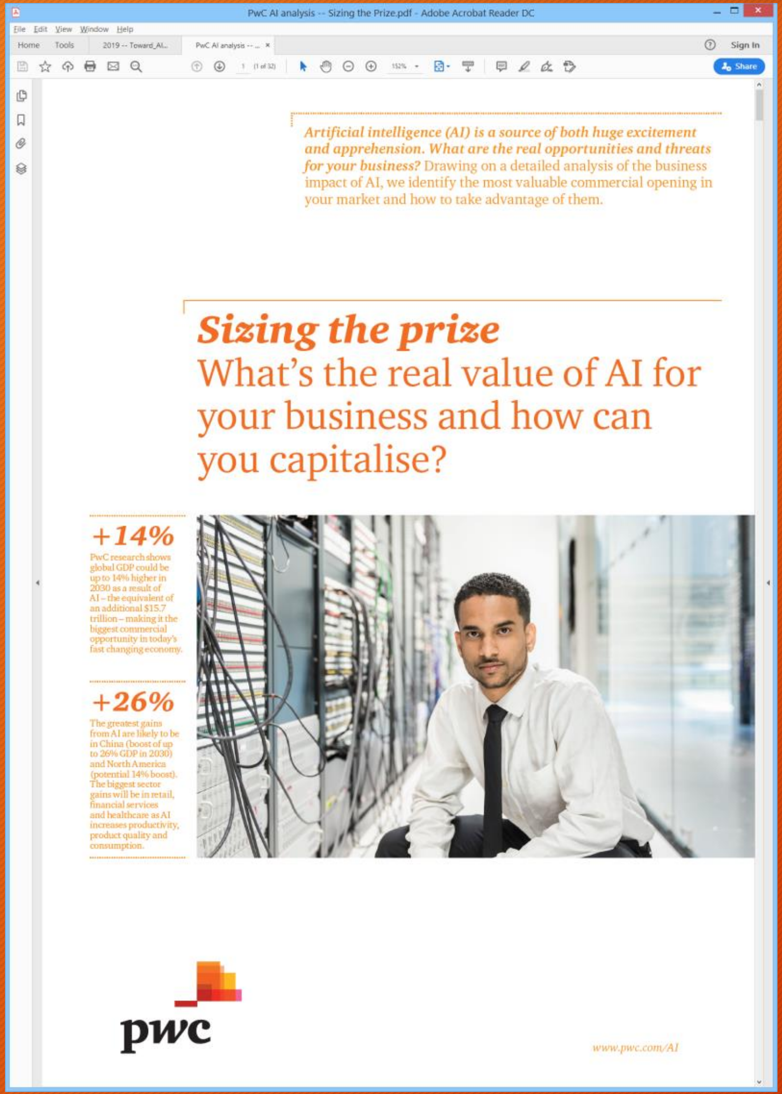
CBINSIGHTS

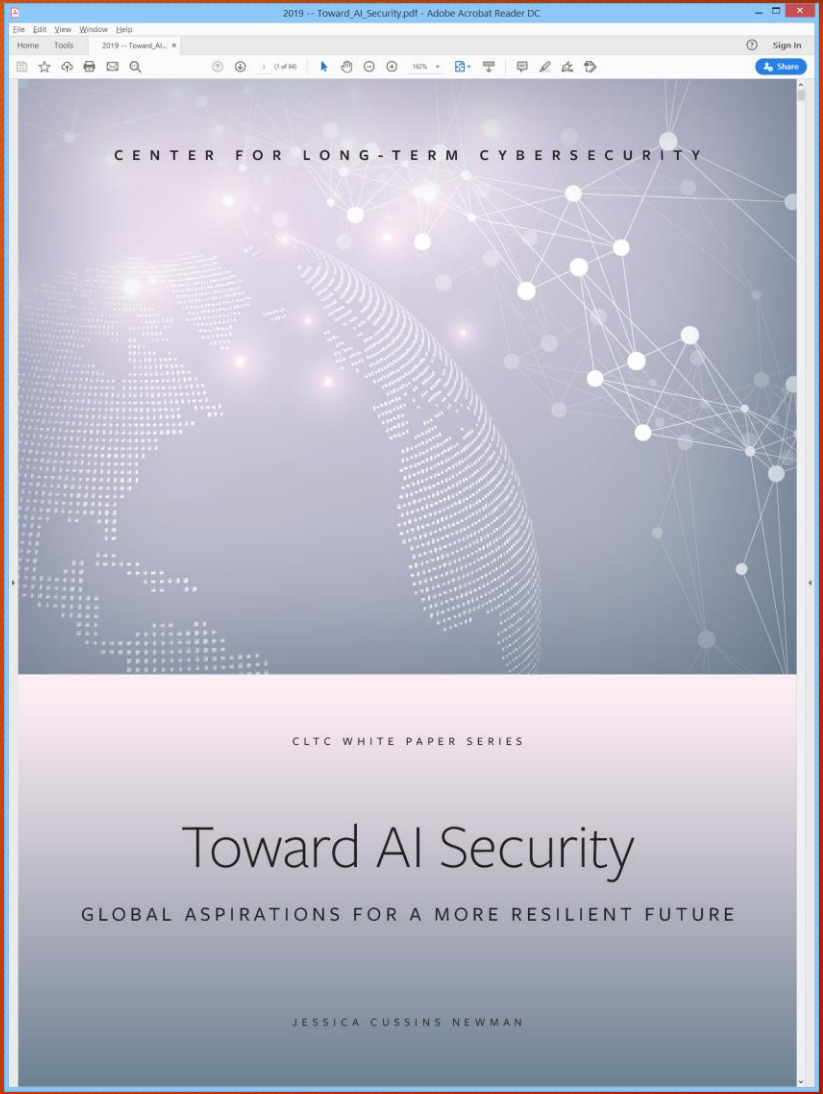
Applications galore

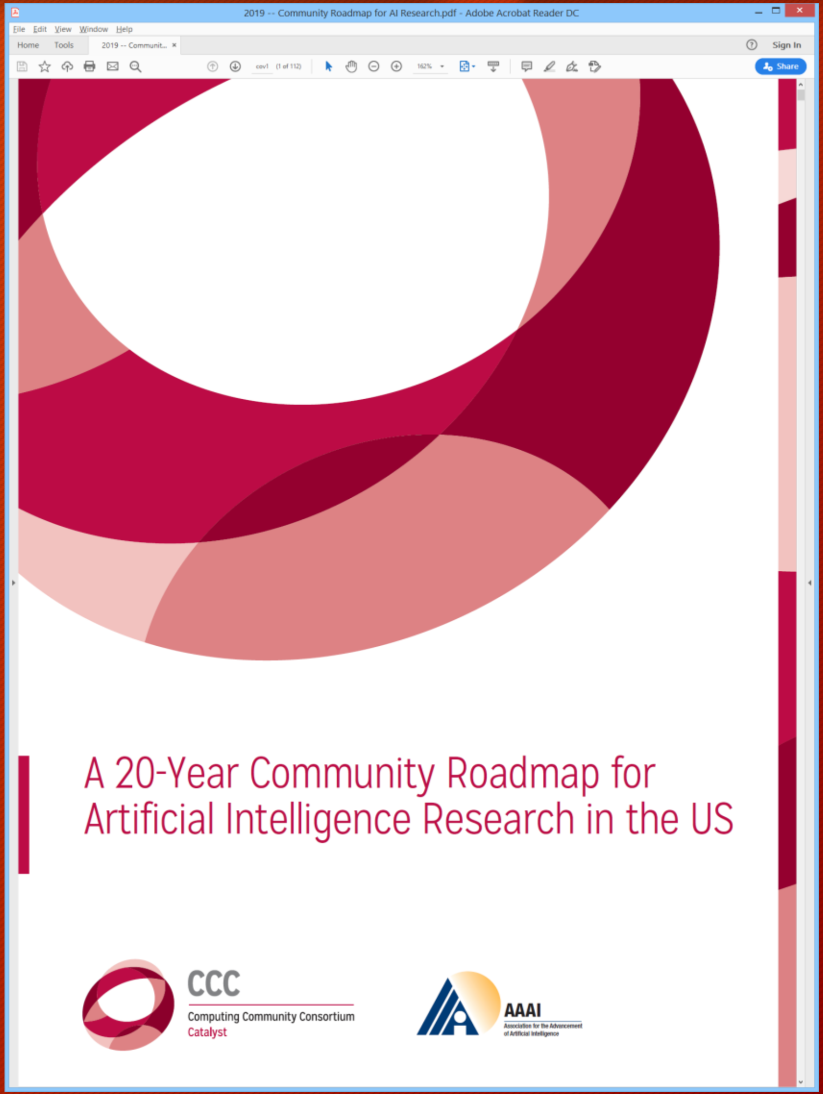


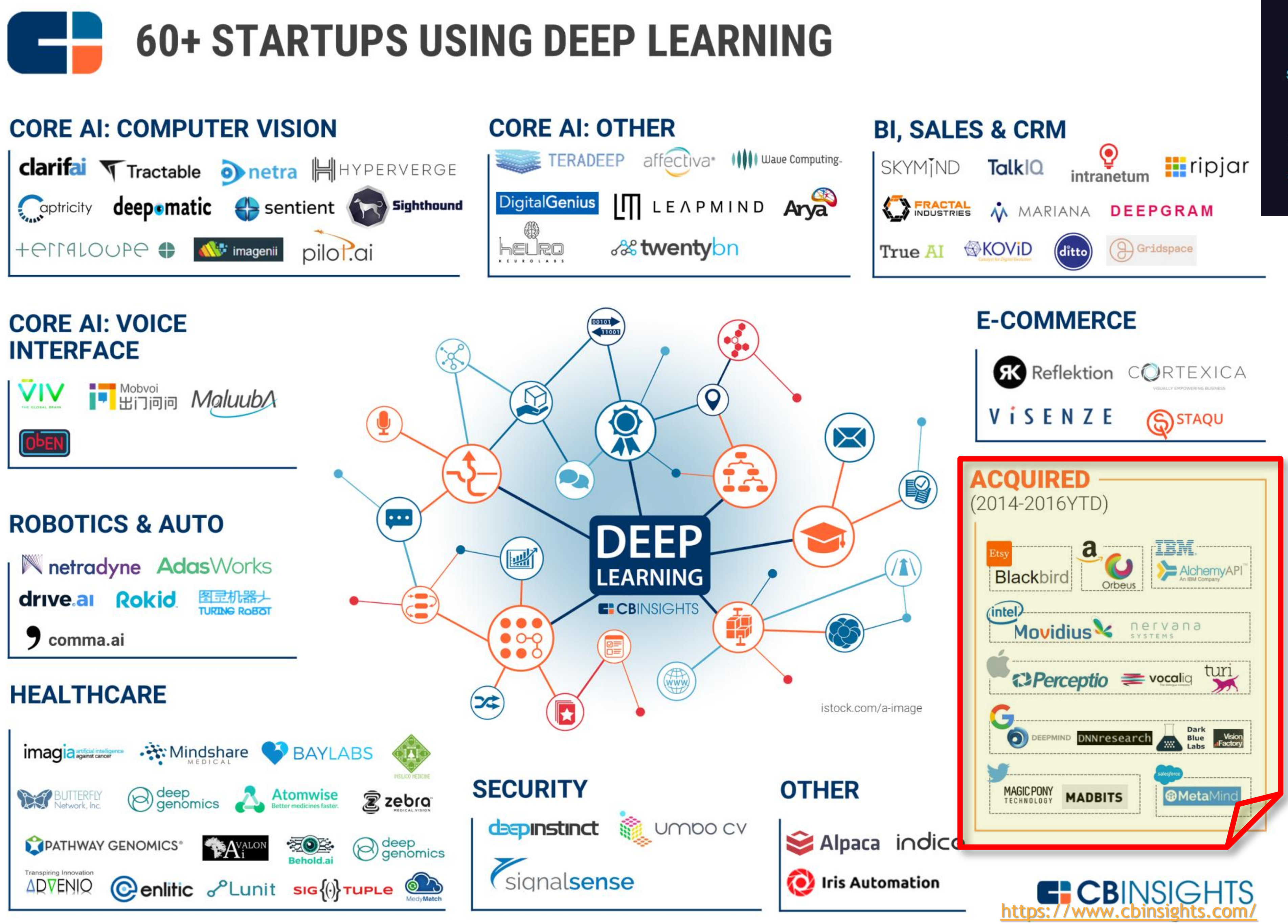
From https://www.nvidia.com/en-gb/industries/ and https://www.nvidia.com/en-us/deep-learning-ai/solutions/

2017 Feb. 2019 Aug. 2019

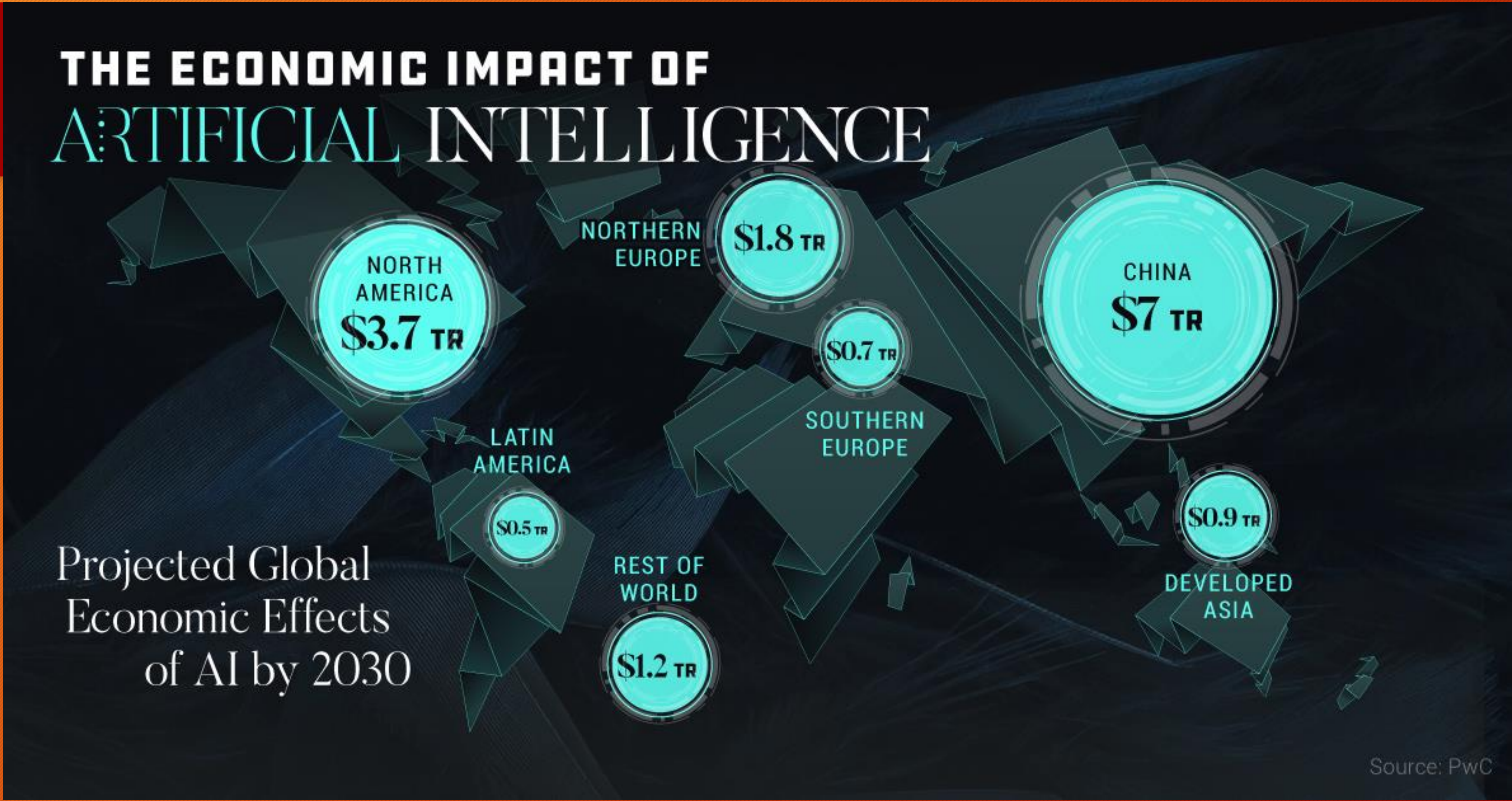








https://www.cbinsights.com/



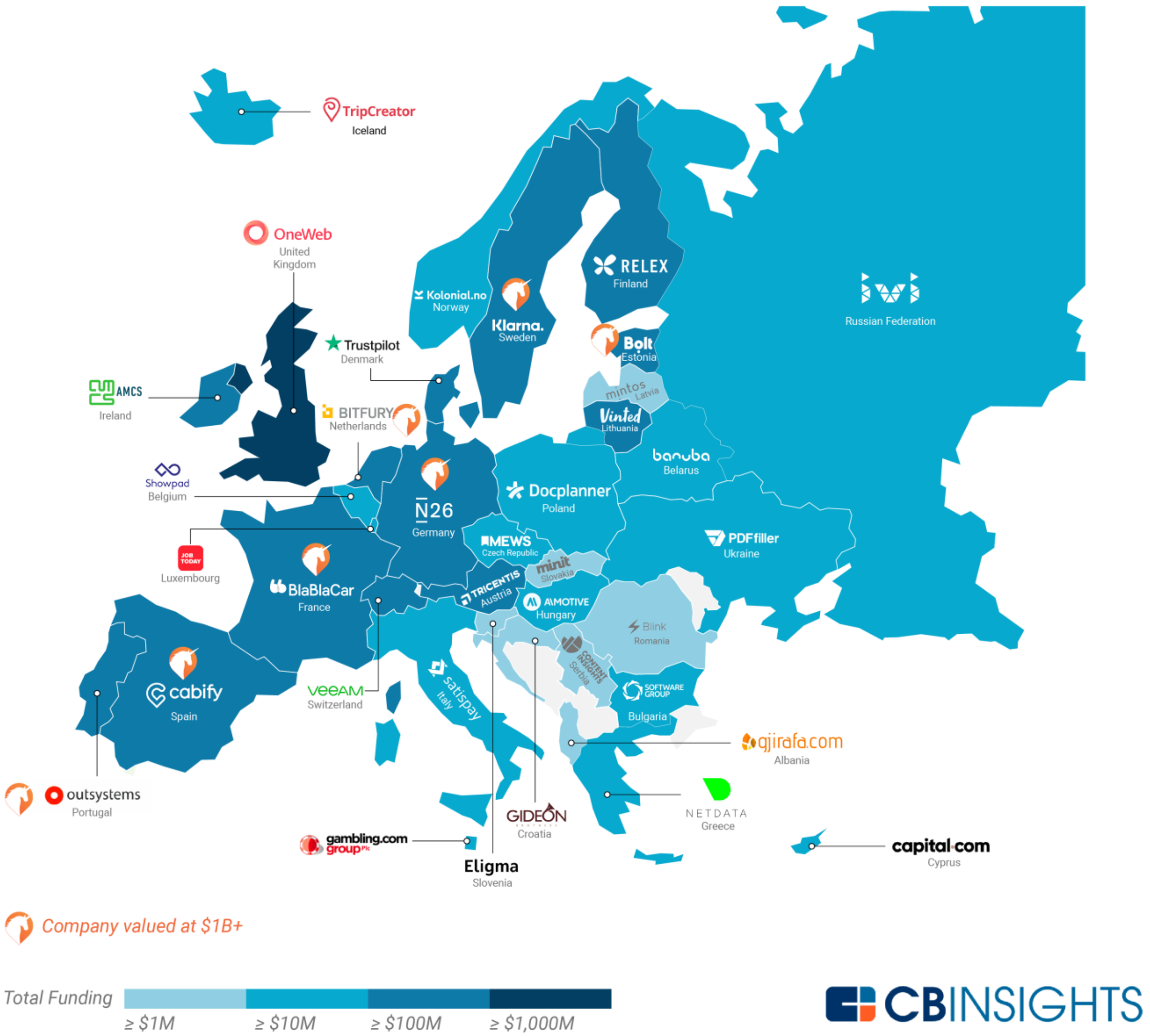
From https://www.pwc.com/gx/en/issues/data-and-analytics/publications/artificial-intelligence-study.html

Europe

STARTUP CONTINENT

THE MOST WELL-FUNDED TECH STARTUPS IN EUROPE

The most well-funded VC-backed tech companies in Europe with new funding since 2014. Excludes countries whose most well-funded start-up has not raised more than $1M. Excludes debt and lines of credit. Data is as of 10/8/2019.



https://www.cbinsights.com/

… Asia-Pacific

https://www.cbinsights.com/

THE UNITED STATES OF TECH STARTUPS

The most well-funded VC-backed tech startup in every US state.

Total Funding: ≥$1M | ≥ $10M | ≥ $100M | ≥ $1,000M | ≥$ 10,000M

Company valued at $1B+

Companies must have raised a minimum of $1M and raised any amount of equity funding since January 2014 to be considered.
Excludes debt and lines of credit. Alaska, Mississippi, and Wyoming had no companies meeting our full criteria.
Data is as of 7/24/2019.

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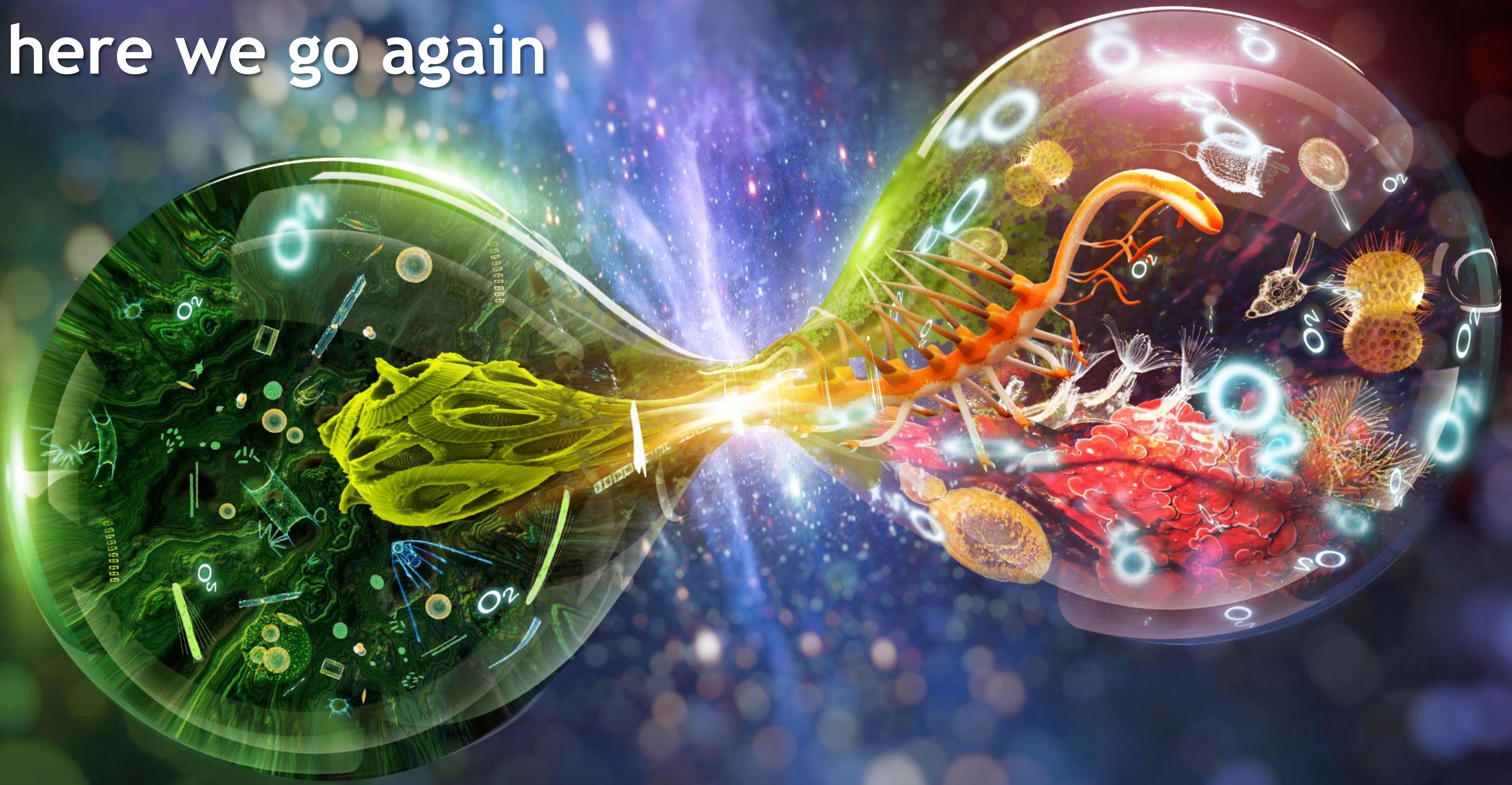
https://www.cbinsights.com/

… here we go again



From https://www.quantamagazine.org/oxygen-and-stem-cells-reshaped-animals-during-the-cambrian-explosion-20180307/

GLOBAL UNICORN CLUB: 393 PRIVATE COMPANIES VALUED AT $1B+

as of 8/27/2019

Cybersecurity

Auth0, Cloudflare, Cybereason, Illumio, Kaseya, Lookout, Netskope, Tanium

Auto & transportation

Aurora, Bird, Bolt, Cabify, Flixbus, Gett, Grab, Lime, 理想, Nuro, OLA, OLA Electric, Quanergy, 途虎养车, 小鹏汽车, Youxia Motors

Hardware

Bitfury, Bitmain, Carbon, DJI, Formlabs, Geek+, Global Switch, Infinidat, Magic Leap, Meizu, Royole, UBTech

Mobile & telecommunications

AppLovin, APUS, Branch, Cell-C, Hike, Inmobi, ironSource, Kik, 快手, LinkSure, Niantic, OfferUp, SmartNews, Starry, Tango, Yello Mobile, 一点资讯

Supply chain, logistics, & delivery

Big Basket, Convoy, 达达, Delhivery, DoorDash, ezCater, Flash Express, Flexport, Go-Jek, Infor, Instacart, Katerra, Lalamove, Loggi, 满帮集团, Postmates, Rappi, Rivigo, Swiggy, Udaan, Zipline

Travel

Airbnb, Klook, Mafengwo, Omio, OYO, Sonder, Traveloka, TripActions, 小猪, Yanolja

Edtech

Byju's, Coursera, 沪江, iTutorGroup, Knowbox, VIPKid

Data management & analytics

Actifio, Celonis, Cohesity, Collibra, Confluent, Databricks, Druva, MarkLogic, Medallia, Palantir, Rubrik, Segment, Snowflake, Sumo Logic, Trax, Tresata

Consumer & retail

Calm, Easyhome, Glossier, Impossible, JUUL, Kendra Scott, L&P Cosmetic, Miniso, Pat McGrath Labs, PAX, Supreme, Sweetgreen, Trendy International Group, 易港批

Artificial intelligence

Afiniti, Argo, Automation Anywhere, Avant, Babylon, BenevolentAI, Butterfly Network, ByteDance, Cambricon, Darktrace, Dataminr, DataRobot, Face++, Globality, Graphcore, Horizon Robotics, Icertis, Indigo, Intellifusion, Lightricks, Meero, Momenta, Orcam, Outreach, Pony.ai, Preferred Networks, Scale, SoundHound Inc., UiPath, Uptake, 依图 YITU, ZipRecruiter

Other

Improbable, Judo Bank, Knotel, LifeMiles, Rubicon, Sila, SpaceX, STX, Unity, Vista Global, WeWork

Health

10x Genomics, Clover, CureVac, Devoted Health, Doctolib, Ginkgo Bioworks, GoodRx, Grail, HeartFlow, Hims, Intarcia, LinkDoc, Medlinker, Mindmaze, One Medical, Oscar, Ottobock, Nanopore, Proteus, Roivant, Samumed, Henlius, Smile, Tempus, United Imaging, Zocdoc

E-commerce & direct-to-consumer

About You, 爱回收, Allbirds, AppDirect, Auto1 Group, Away, Casper, 瓜子, Compass, Coupang, 蛋壳公寓, Fanatics, Houzz, Ibotta, Jollychic, 口袋购物, 链家, Opendoor, ShopClues, Snapdeal, StockX, TechStyle Fashion Group, THG, Thumbtack, Tokopedia, Turo, Vancl 凡客诚品, Warby Parker, WeMakePrice, Wish, 小红书, 找钢网, Ziroom

Fintech

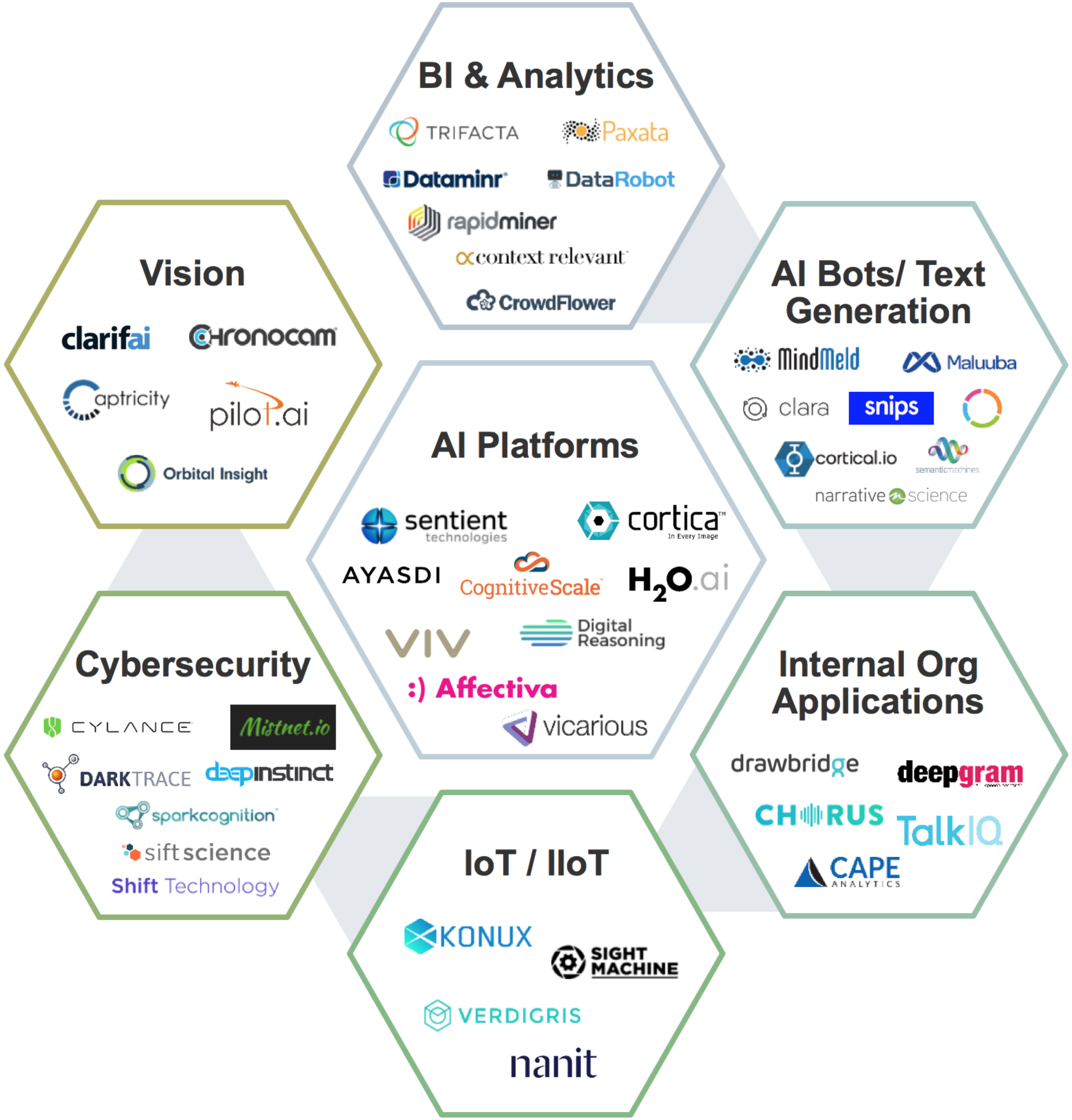
Affirm, Airwallex, Atom Bank, Avaloq, AvidXchange, Bill.com, BillDesk, Brex, C2FO, Carta, Checkout.com, Chime, Circle, Coinbase, Credit Karma, GreenSill, Gusto, Hippo, Ivalua, Kabbage, Klarna, Lemonade, Liquid, Marqeta, Monzo, N26, Numbrs, One97, Plaid, Policybazaar, Radius, Revolut, Robinhood, Root, SoFi, Stripe, Toast, Toss, Tradeshift, TransferWise, Zenefits

Internet software & services

58到家, Airtable, Asana, Automattic, BuzzFeed, Deezer, Discord, Docker, Freshworks, GitLab, Gympass, HashiCorp, Intercom, InVision, JFrog, LegalZoom, Monday.com, Nextdoor, OneTrust, Procore, Quora, Reddit, Roblox, Seismic, ServiceTitan, SMS Assist, Sprinklr, Squarespace, Symphony, Talkdesk, Vice, Vlocity, Vox Media, VTS, WalkMe, Zeta, 知乎, Zomato

https://www.cbinsights.com/

2020



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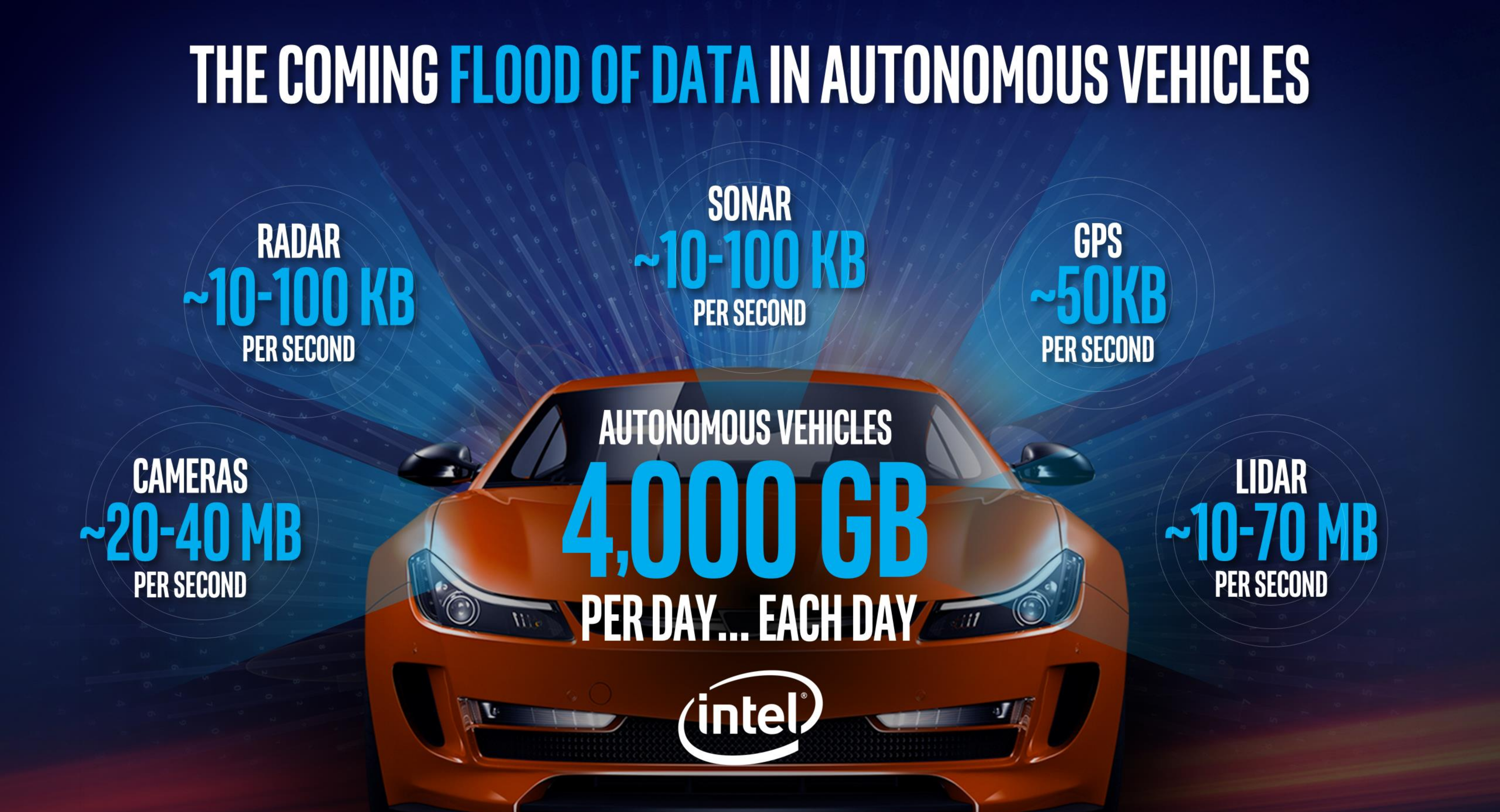

From https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/ (see also https://www.intel.com/content/www/us/en/automotive/autonomous-vehicles.html)

IoT

From various sources

2020

2020

Healthcare
RECURSION, zebra MEDICAL VISION, ProteinQure, Viz.ai, Eko, Healthy.io, CYCLICA, OWKIN, PAIGE, Atomwise, Butterfly Network, SUBTLE MEDICAL, Concerto HealthAI

Finance & Insurance
Comply Advantage, FEATURE SPACE, (h[s]) HYPERSCIENCE, zesty.ai, Lemonade, TRACTABLE

Transportation
GHOST, isee, KONUX, loadsmart, tusimple, HOLOMATIC 禾多科技, Aurora, voyage

Construction
ALICE technologies, BUILT ROBOTICS

Retail & Warehousing
grabango, THE YES, heuritech, [Sc] STANDARD COGNITION, OSARO, FAIRE, dorabot, AIFI, covariant

Govt. & City Planning
SHIELD AI, AMP ROBOTICS, Replica, Mapillary, SYNAPSE TECHNOLOGY CORPORATION

Legal
lexion

Mining
razorlabs

Food & Agriculture
BENSON HILL, NotCo, BOWERY

Media & Entertainment
SECOND SPECTRUM, FANAI, Synthesia, WELLSAID

Education
松鼠AI·智适应 Squirrel AI Learning, KORBIT

Manufacturing
noodle.ai, NAVVIS, dataprophet machine learning specialists, CITRINE INFORMATICS

Energy
BEYOND LIMITS, INVENIA LABS, TACHYUS

Telecom
DEEPSIG, METAWAVE

Real Estate
CASPAR

AI 100

CBINSIGHTS

CROSS-INDUSTRY TECH

AI Processors
SYNTIANT, LIGHTMATTER, GRAPHCORE, XANADU, Kneron

NLP, NLG, & Computer Vision
PRIMER, sherpa.ai, HUGGING FACE, 创新奇智 AInnovation, :) Affectiva

Sales & CRM
CRESTA, integrate.ai, ZHUIYI 追一科技

AI Model Development
DARWIN AI, H2O.ai, PerceptiLabs, DataRobot, dotData

Cybersecurity
SentinelOne, OBSIDIAN, onfido, ABNORMAL SECURITY, BLUEHEXAGON

BI & Ops Intel
climacell, C3.ai, falkonry

Other R&D
sparkcognition, KYNDI, 4Paradigm 第四范式, InstaDeep, Deeplite, nnaisense, HACARUS

DevOps & Model Monitoring
ALGORITHMIA, snyk, ArthurAI

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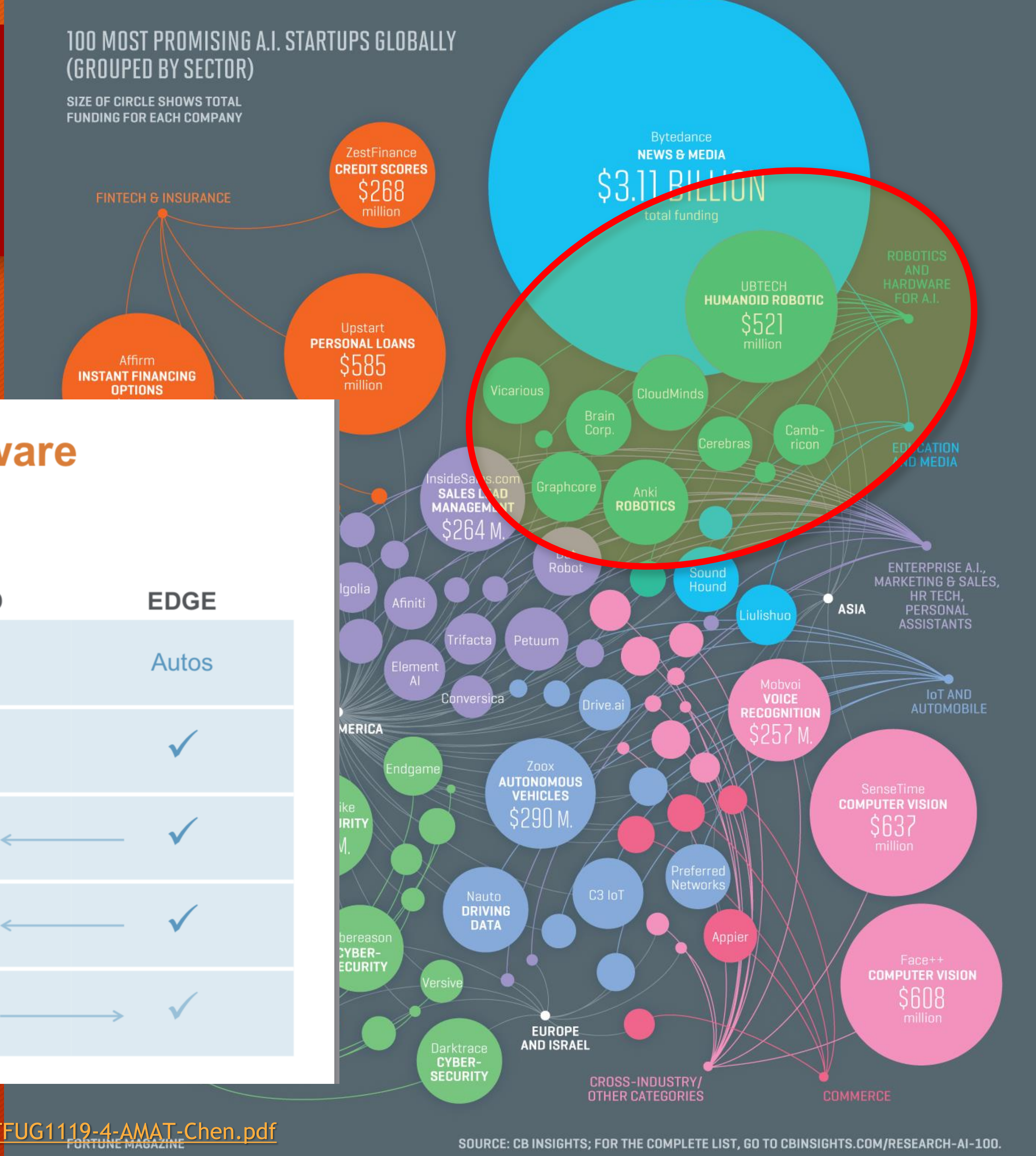
… recap

AI – Big Data Driving a Renaissance of Hardware Development and Investment

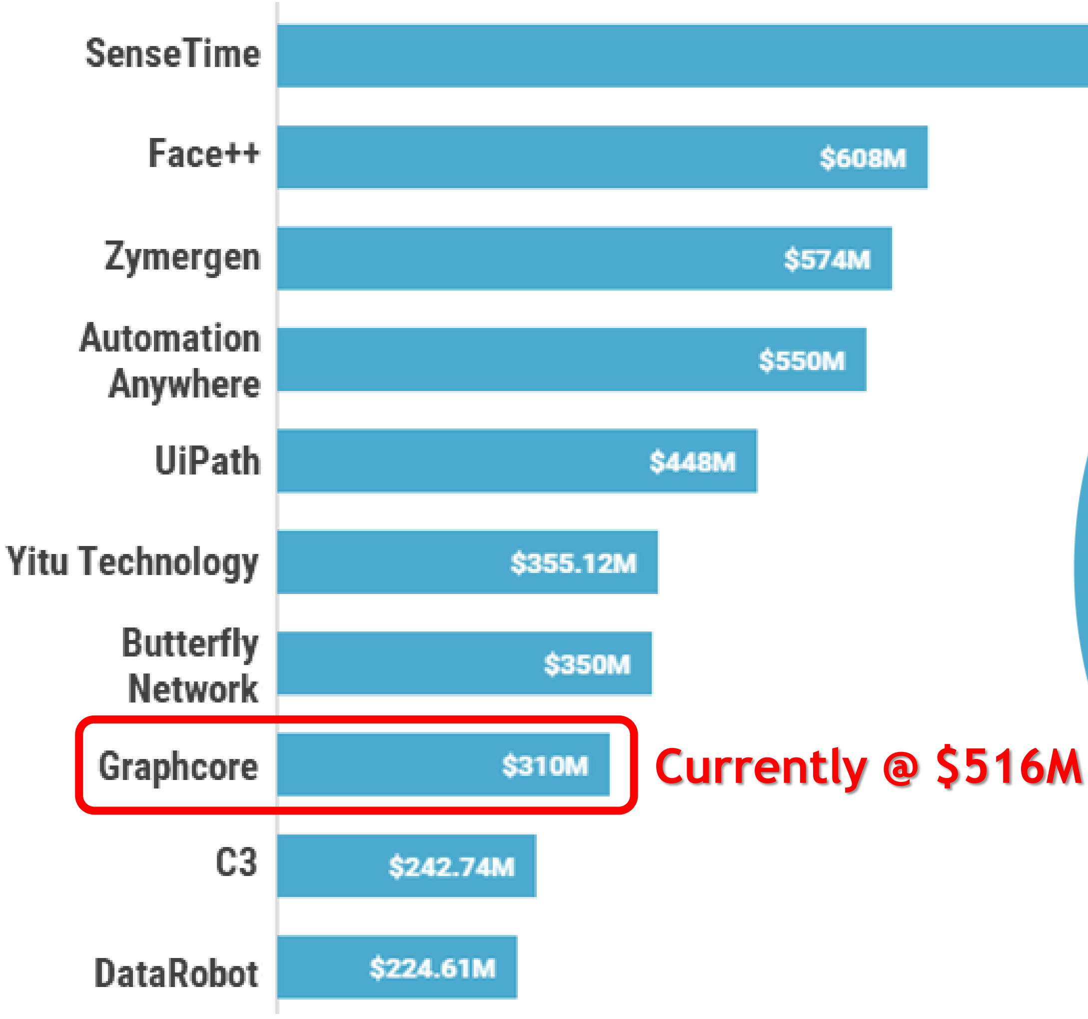
	INITIAL DEPLOYMENT	CLOUD		EDGE
Accelerators GPU, TPU, ASICS, FPGAs	Now	✓		Autos
Near Memory DDR, SRAM, HBM, NAND, SCM	Now to 2 years	✓		✓
New Memory MRAM, ReRAM, PCRAM, FeRAM	Now to 5 years	✓	←	✓
In-Memory Compute Analog, ReRAM, PCRAM	2 to 5 years	✓	←	✓
Novel HPC Quantum, Synaptic	5 to 10 years	✓	→	✓

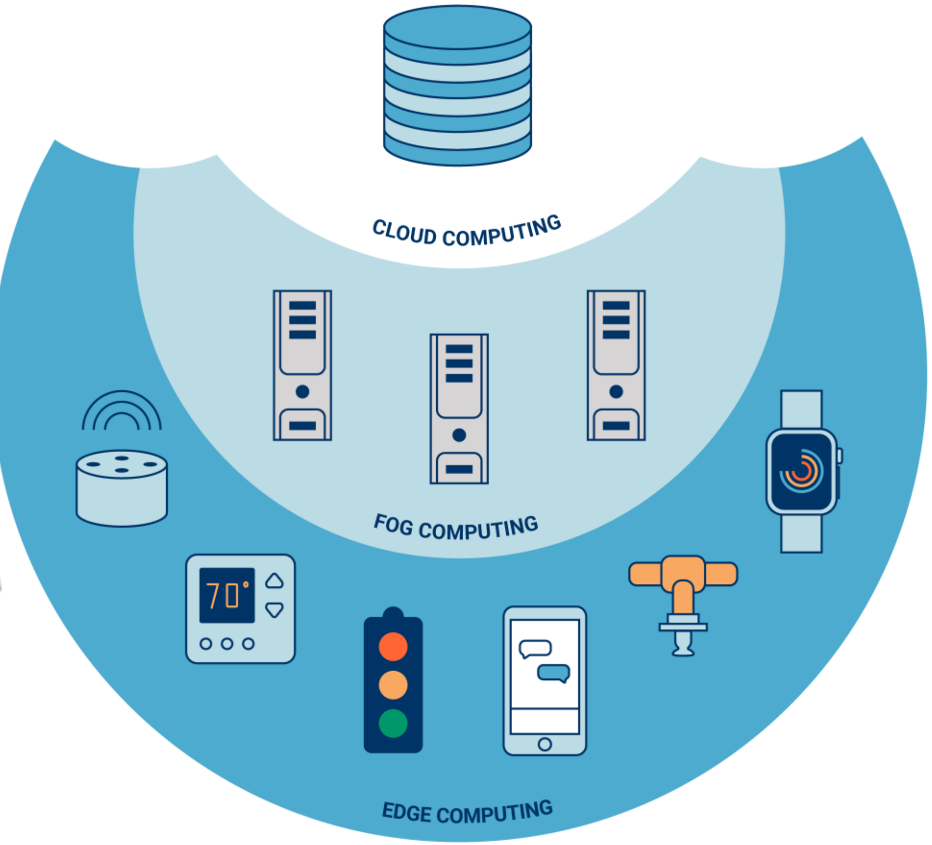


From https://nccavs-usergroups.avs.org/wp-content/uploads/TFUG2019/November2019/TFUG1119-4-AMAT-Chen.pdf

2019 AI 100: Most well-funded companies

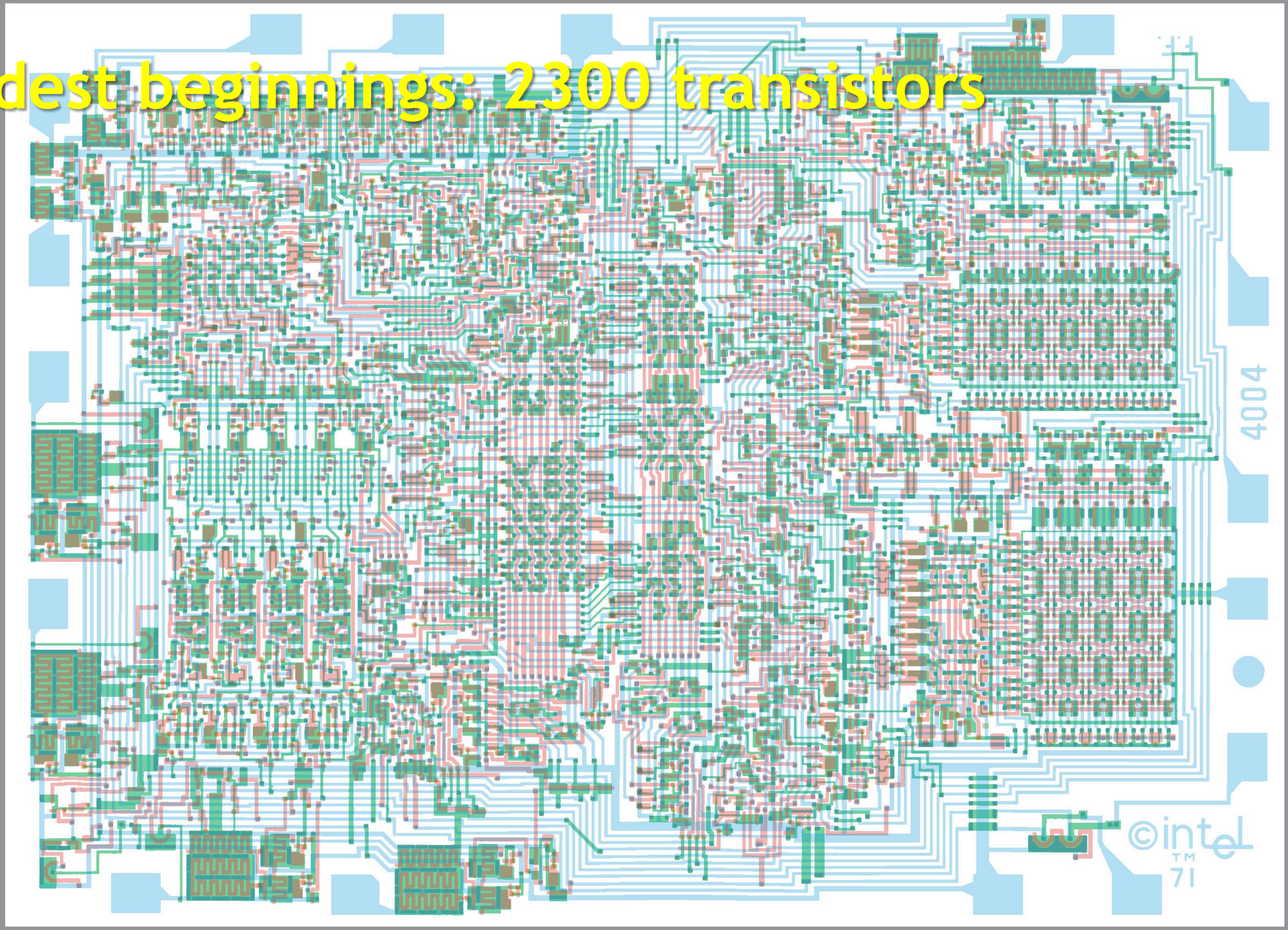
Based on total equity funding





https://www.cbinsights.com/

Modest beginnings: 2300 transistors



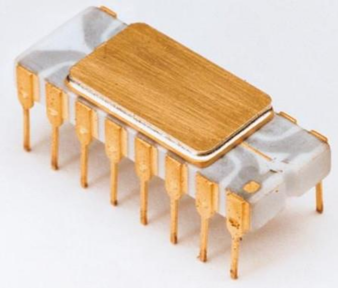
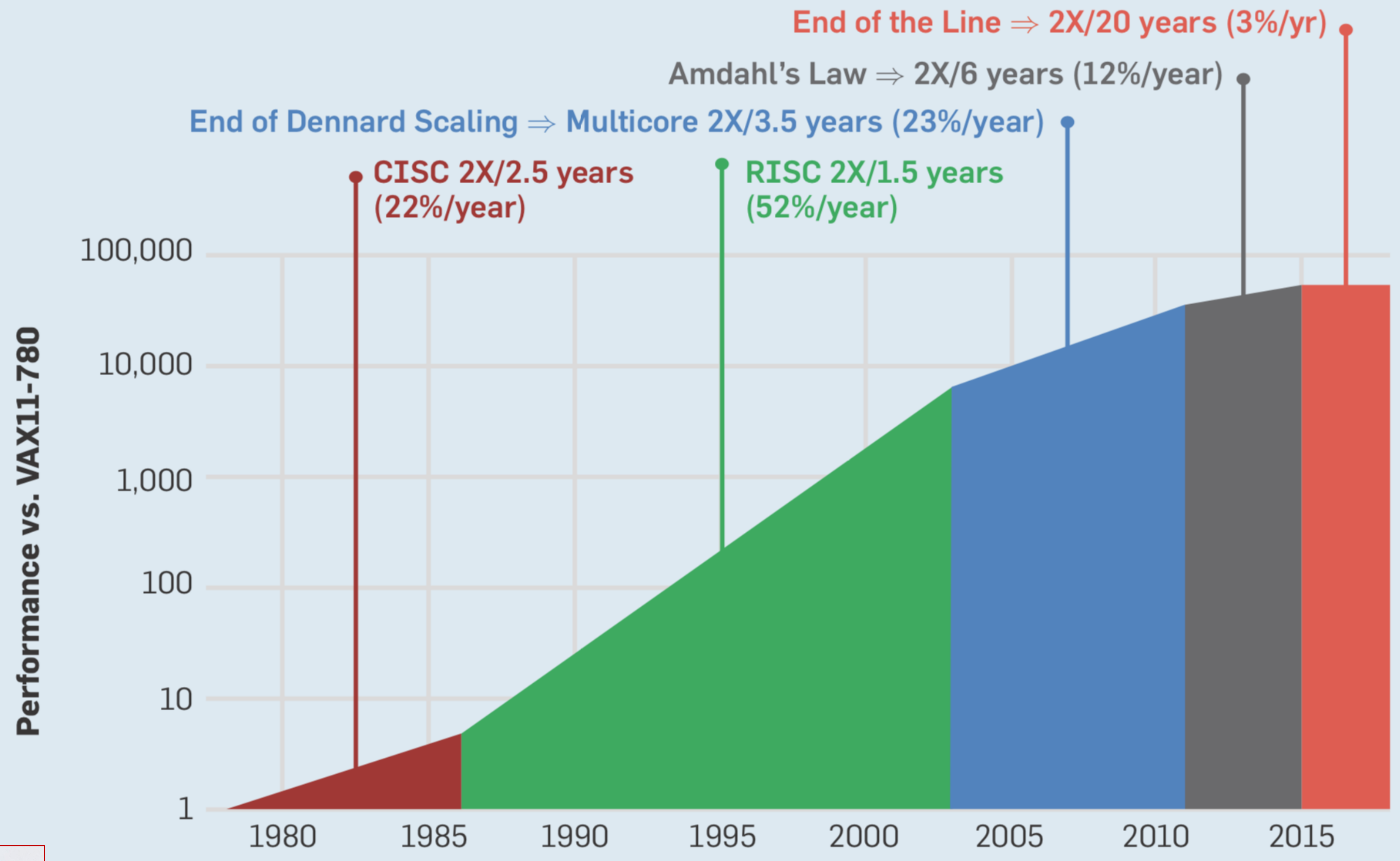


Figure 6. Growth of computer performance using integer programs (SPECintCPU).



From https://cacm.acm.org/magazines/2019/2/234352-a-new-golden-age-for-computer-architecture/fulltext

Late 2015

Create a new type of computer that can

- proactively interpret and learn from data,
- solve unfamiliar problems using what it has learned, and
- operate with the energy efficiency of the human brain

See http://www.nano.gov/futurecomputing

http://www.nano.gov/futurecomputing

File Edit View Favorites Tools Help

Home | Sitemap | NSET Agencies | Contact Us Search Nano.gov

Nano.gov

National Nanotechnology Initiative

Nanotechnology 101 | Nanotechnology & You | About the NNI | Collaboration & Funding | Publications & Resources | Education | Newsroom | Events

A Nanotechnology-Inspired Grand Challenge for Future Computing

Announced 10/20/2015

Create a new type of computer that can proactively interpret and learn from data, solve unfamiliar problems using what it has learned, and operate with the energy efficiency of the human brain.

While it continues to be a national priority to advance conventional digital computing—which has been the engine of the information technology revolution—current technology falls far short of the human brain in terms of both the brain's sensing and problem-solving abilities and its low power consumption. Many experts predict that fundamental physical limitations will prevent transistor technology from ever matching these twin characteristics. This grand challenge will bring together scientists and engineers from many disciplines to look beyond the decades-old approach to computing based on the Von Neumann architecture as implemented with transistor-based processors, and chart a new path that will continue the rapid pace of innovation beyond the next decade.

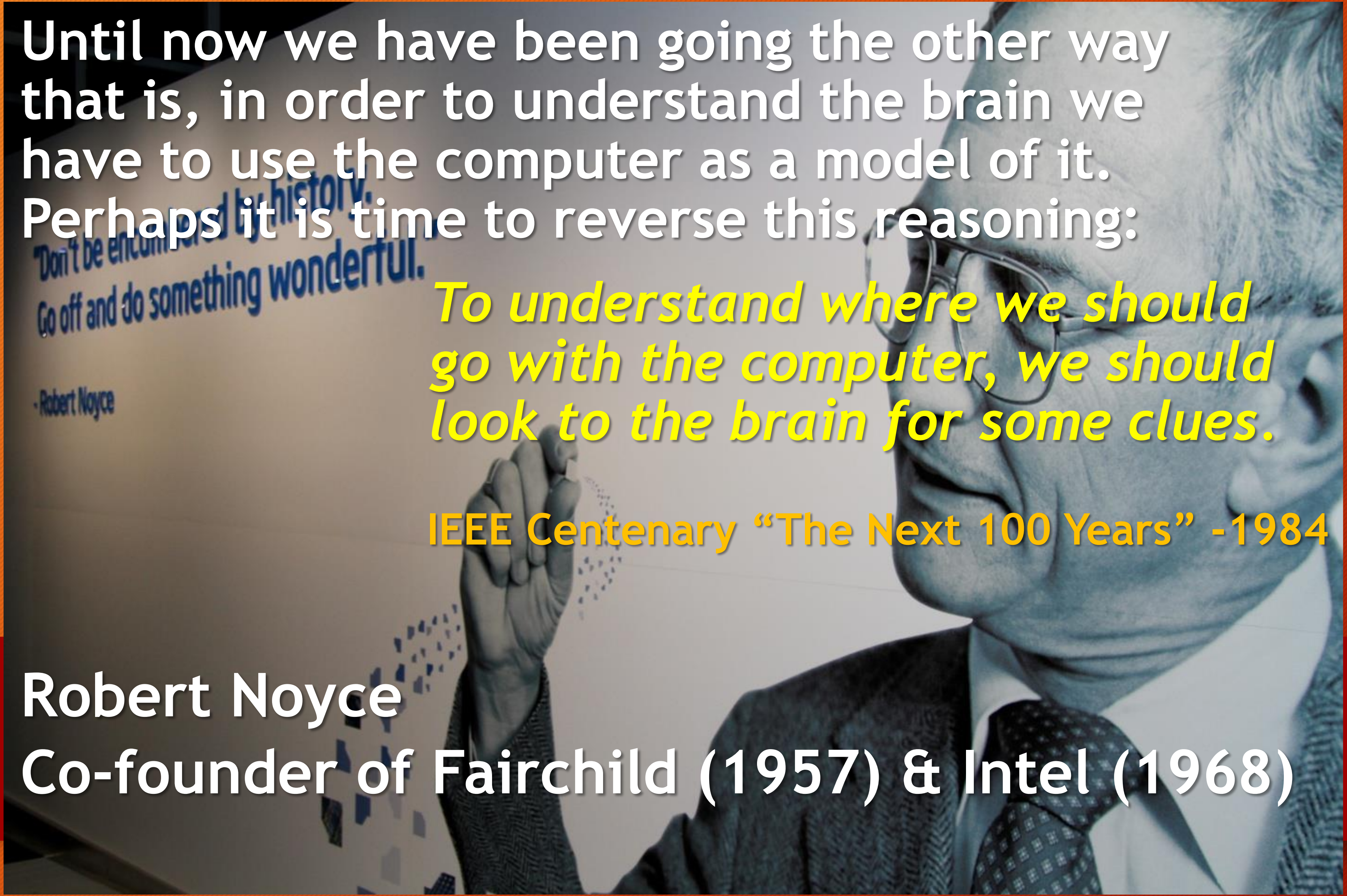
To meet this challenge, major breakthroughs are needed not only in the basic devices that store and process information, but in the way a computer analyzes images, sounds, and patterns, interprets and learns from data, and identifies and solves problems. A human can do such tasks in ways that a conventional computer cannot, with a fault-tolerant, adaptive brain that uses less energy than it takes to power an incandescent light bulb. By combining innovations in nanotechnology, computer science, and neuroscience, radically new approaches to creating both hardware and software can be developed, enabling computers capable of efficiently interpreting images and speech, proactively spotting patterns and anomalies in data, learning from data as it is received, and solving unfamiliar problems using what has been learned.

Many of these approaches will require new kinds of nanoscale devices and materials integrated into three-dimensional systems. These nanotechnology innovations will need to be developed in close coordination with new computer architectures and informed by our growing understanding of the brain. Although it may take a decade or more, enabling these transformational computing capabilities will be essential for turning the rising deluge of data that surrounds us into useful information when and where it is needed. Efficiently interpreting and responding to this data will be crucial to solving important problems facing the Nation, from delivering individualized treatments for disease, to allowing advanced robots to work safely alongside people, to proactively identifying and blocking cyber intrusions.

Read more about:

- Nanotechnology-Inspired Grand Challenges
- A Federal Vision for Future Computing: A Nanotechnology-Inspired Grand Challenge (White Paper)
- Statements of support for this challenge from Federal agencies (DoD, DOE, IARPA, NIST, NSF)
- Statements of support for this challenge from other organizations (CCC, Moore Foundation, IEEE, Kavli Foundation, SRC)
- Workshop reports and white papers relevant to this challenge
- Meetings and workshops relevant to this challenge

IEEE rebooting COMPUTING



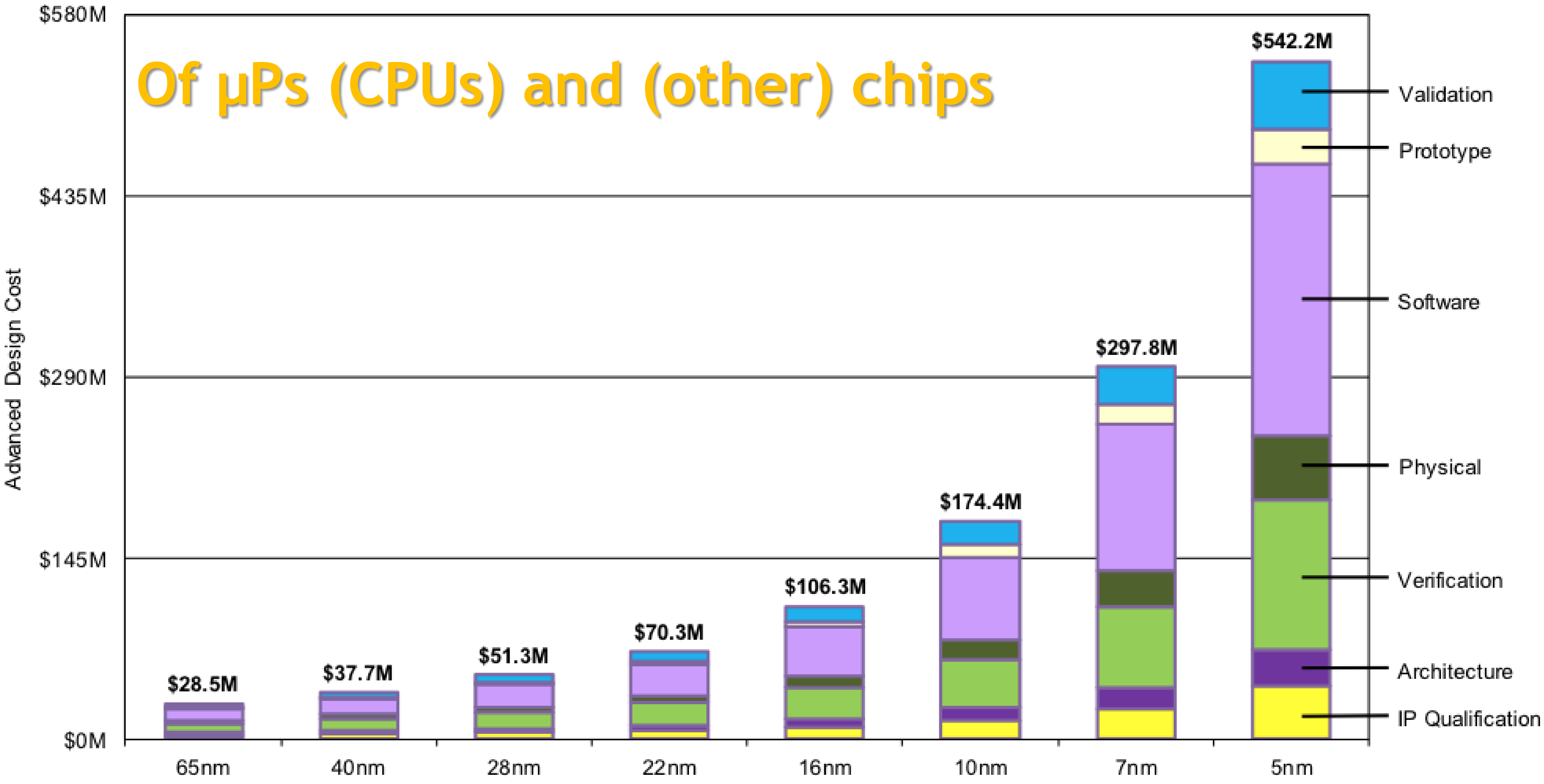
“Until now we have been going the other way that is, in order to understand the brain we have to use the computer as a model of it. Perhaps it is time to reverse this reasoning:

To understand where we should go with the computer, we should look to the brain for some clues.”

IEEE Centenary “The Next 100 Years” -1984

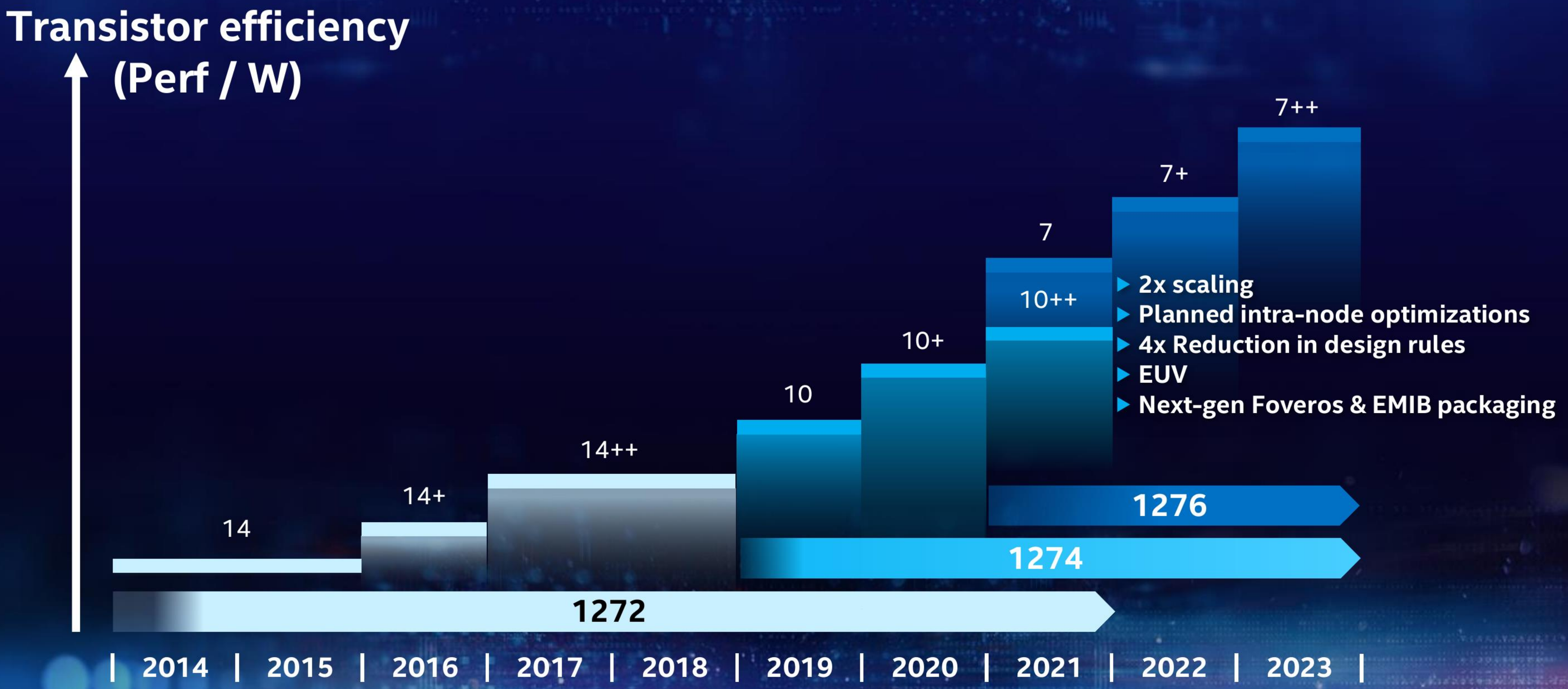
Robert Noyce
Co-founder of Fairchild (1957) & Intel (1968)

Of µPs (CPUs) and (other) chips



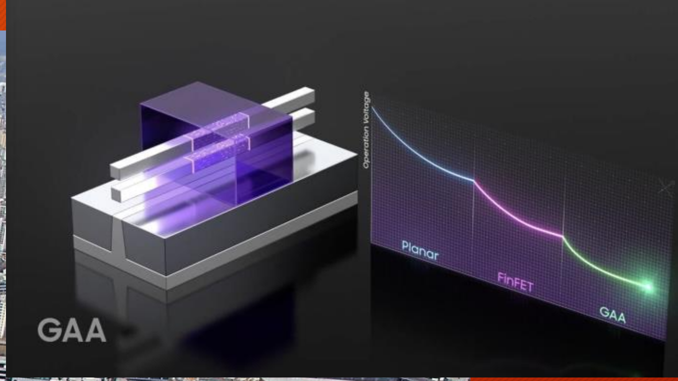
From https://www.extremetech.com/computing/272096-3nm-process-node

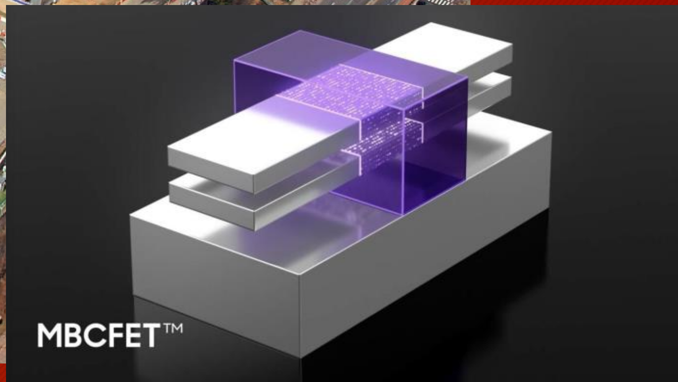
RELENTLESS INNOVATION CONTINUES



From https://www.intc.com/investor-relations/events-and-presentations/events-calendar/event-details/2019/Intel-Investor-Meeting-05-2019/default.aspx

5nm (and about 10 billion US$)





From https://www.businesswire.com/news/home/20190416005394/en/Samsung-Successfully-Completes-5nm-EUV-Development-Greater

The high volume EUV system at 170 wph: NXE:3400C

Shipping H2 2019 @ $120 M, 180 tons, 1 MW

ASML
Public

OFP:3400B (standard)
ORION
UV-LS 2nd Gen

Optics
Transmission improvement

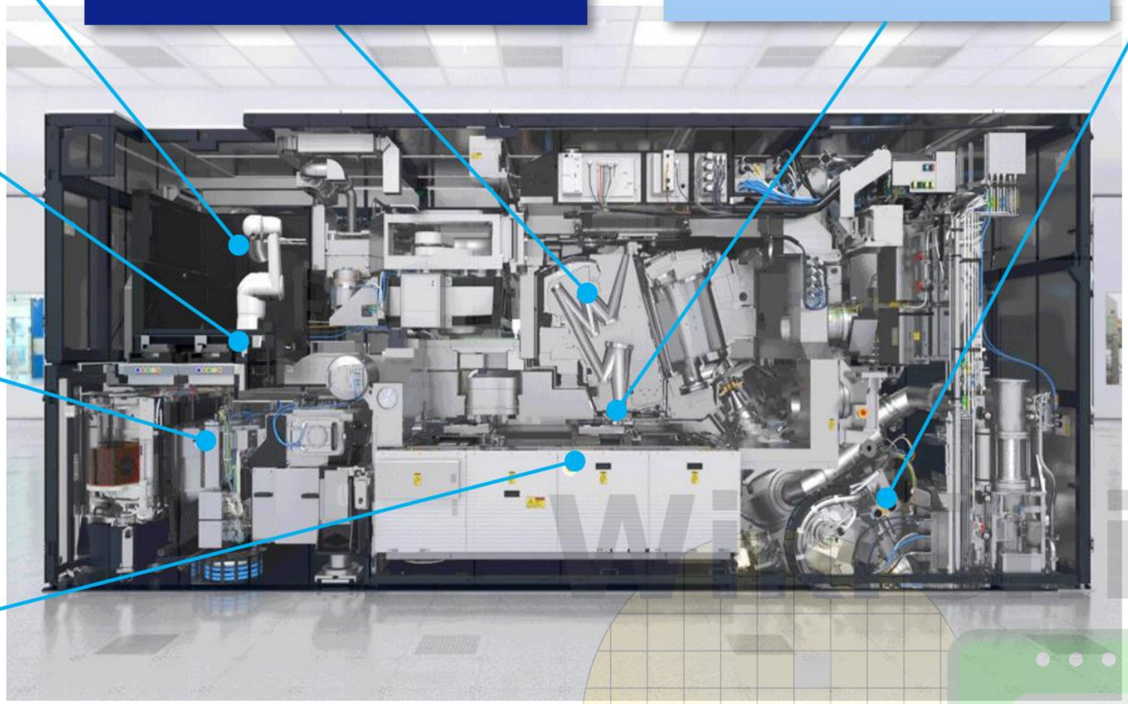
DGL Membrane (optional)

Source with Modular Vessel collector swap <8hrs
Inline tin refill

Reticle Handler
Improved productivity

Wafer Handler
@ ≥170WPH

Faster Reticle Align / reduced wafer overhead



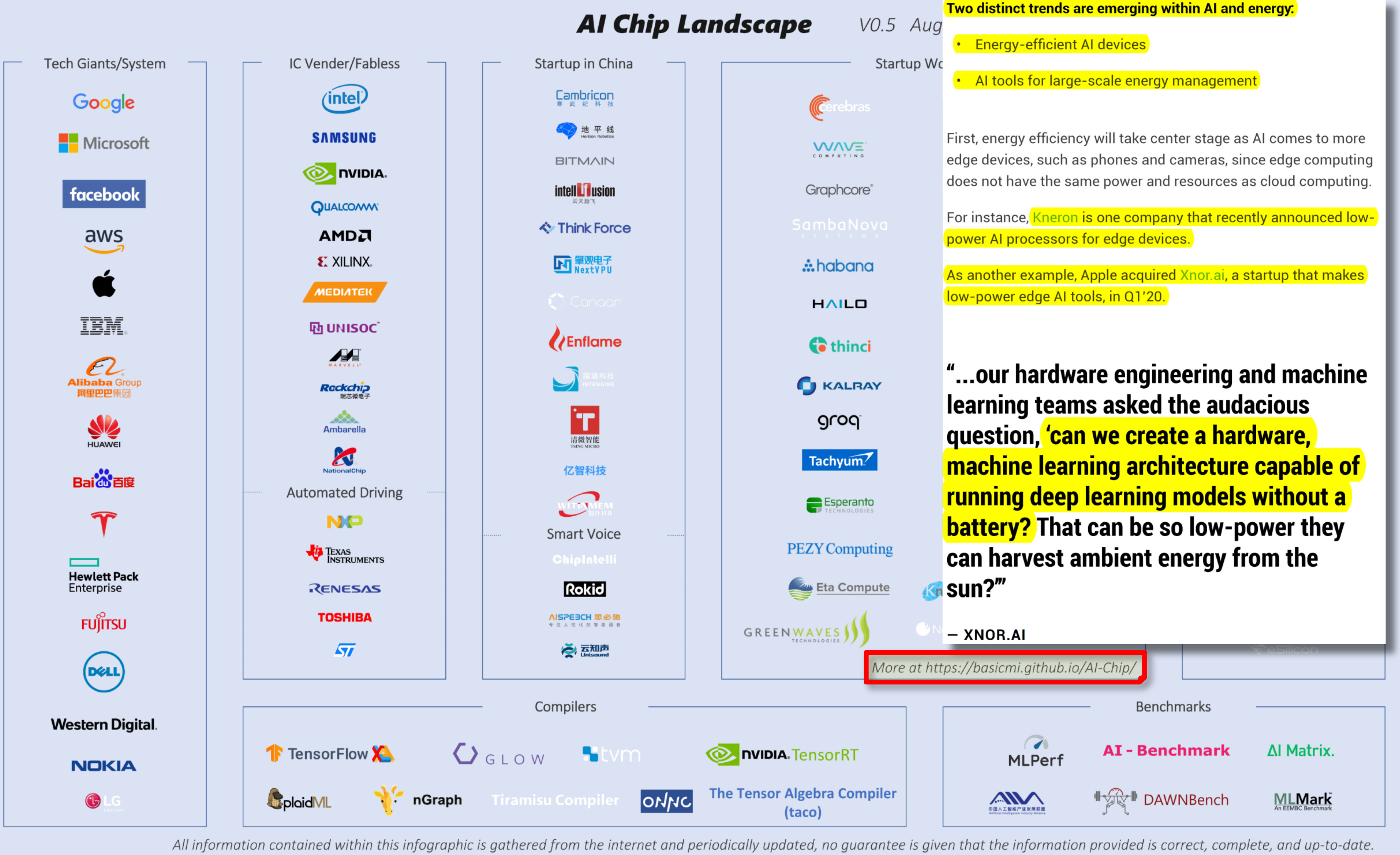
	NXE:3400B +OFP:3400	NXE:3400C
Resolution	13 nm	13 nm
Full wafer CDU	≤ 1.1 nm	≤ 1.1 nm
DCO	≤ 1.4 nm	≤ 1.4 nm
MMO	≤ 1.5 nm	≤ 1.5 nm
XMMO	≤ 1.9nm	≤ 1.9 nm
Matched to	NXT:2000i	NXT:2000i
Productivity*	≥ 125 WPH	≥ 170 WPH
OPO (M+3S)**	≤ 2.4 nm	≤ 2.4 nm
Focus control**	≤ 60 nm	≤ 60 nm

** Productivity as ATP specs, 20mj/cm2, all ATP tests no DGL-membrane, no pellicles*

*** On product overlay (OPO) and focus control are not ATP specs, but are performance targets for specific customer nodes to be achieved including Application and DUV configuration. Performance of these parameters is to be within population of NXE:3400B + OFP, but at the higher productivity*

See https://www.asml.com/en/products/euv-lithography-systems/twinscan-nxe3400c


IEEE brain
AI HARDWARE SUMMIT
IEEE BigData
EDGE AI SUMMIT
AI HARDWARE SUMMIT ASIA



Two distinct trends are emerging within AI and energy:

- Energy-efficient AI devices
- AI tools for large-scale energy management

First, energy efficiency will take center stage as AI comes to more edge devices, such as phones and cameras, since edge computing does not have the same power and resources as cloud computing.

For instance, Kneron is one company that recently announced low-power AI processors for edge devices.

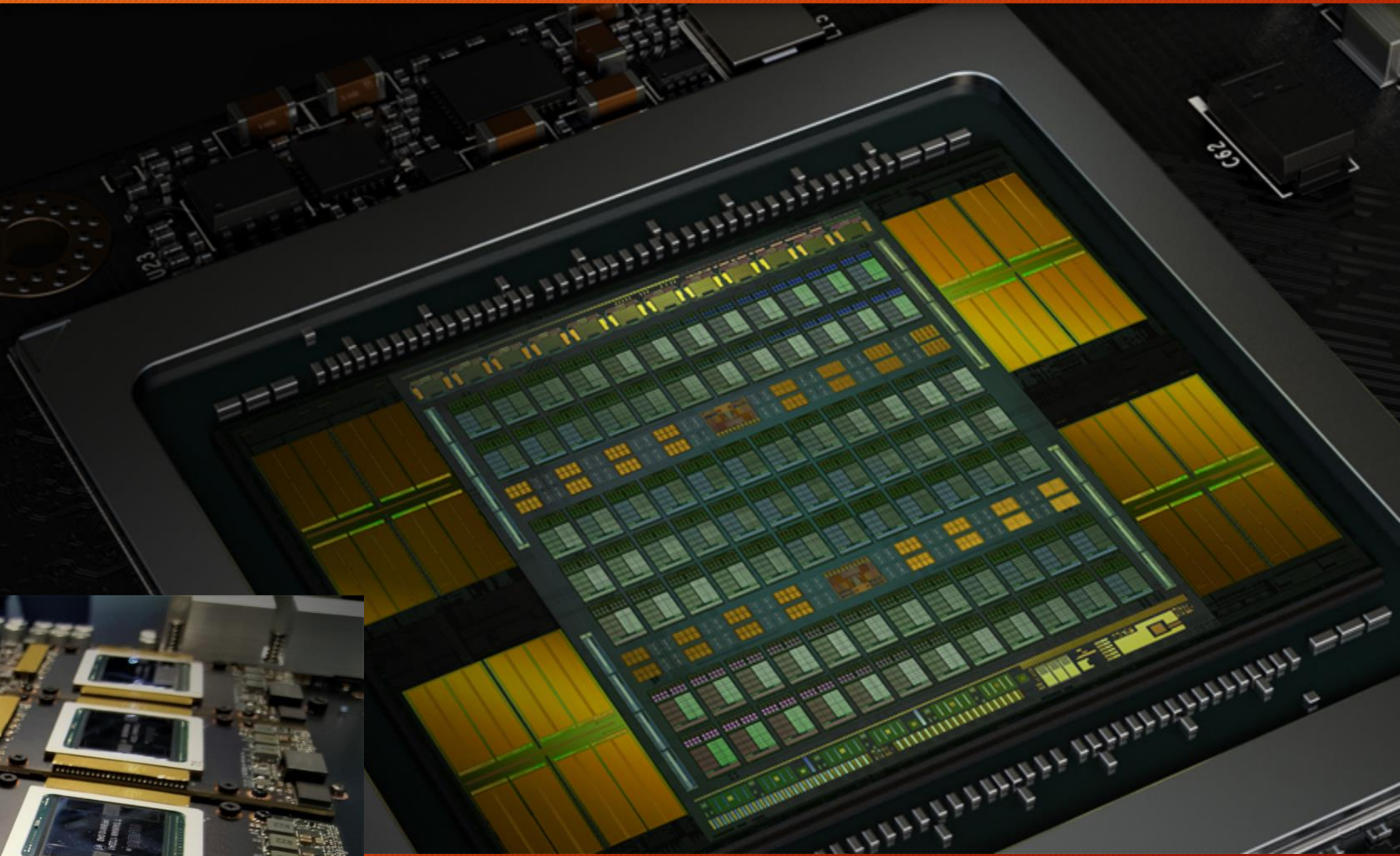
As another example, Apple acquired Xnor.ai, a startup that makes low-power edge AI tools, in Q1'20.

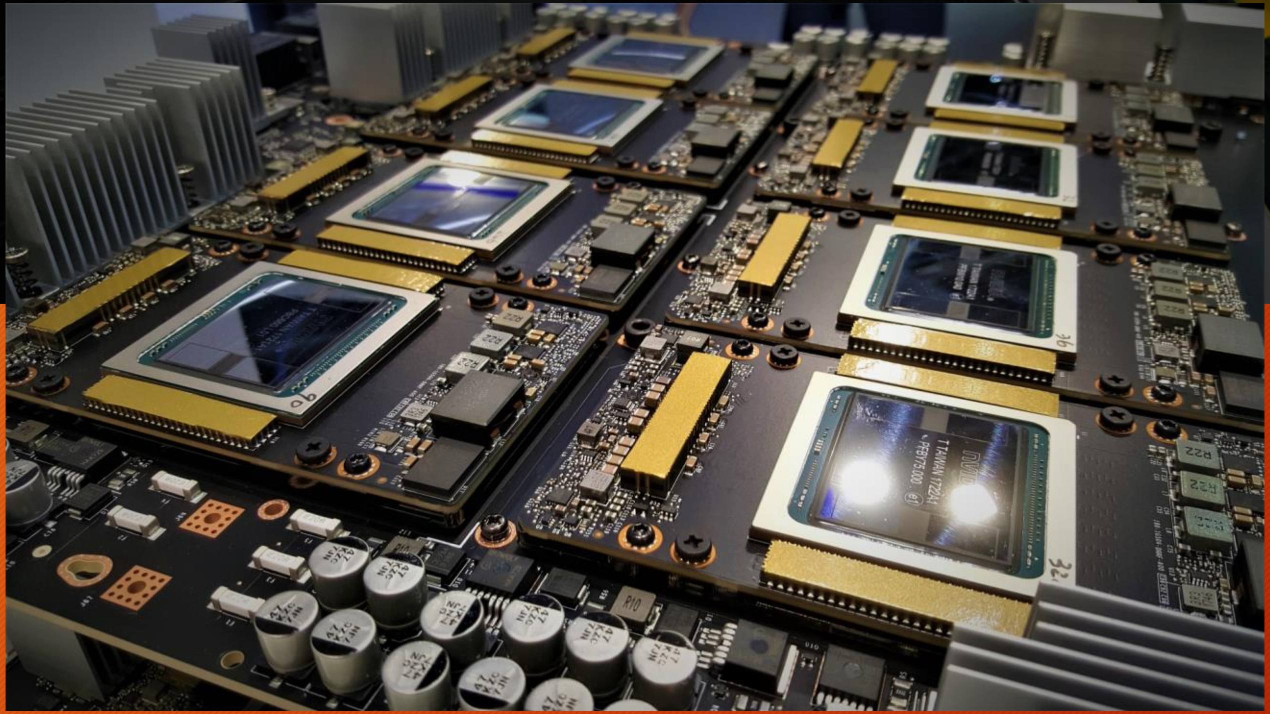
"...our hardware engineering and machine learning teams asked the audacious question, 'can we create a hardware, machine learning architecture capable of running deep learning models without a battery? That can be so low-power they can harvest ambient energy from the sun?'"

— XNOR.AI

NVIDIA VOLTA

The New GPU Architecture,
Designed to Bring AI to Every Industry.





ANNOUNCING NVIDIA DGX SUPERPOD

AI LEADERSHIP REQUIRES AI INFRASTRUCTURE LEADERSHIP

Autonomous Vehicles | Speech AI | Healthcare | Graphics | HPC

Test Bed for Highest Performance Scale-Up Systems

- 9.4 PF on HPL | ~200 AI PF | #22 on Top500 list
- <2 mins To Train RN-50

Modular & Scalable GPU SuperPOD Architecture

- Built in 3 Weeks
- Optimized For Compute, Networking, Storage & Software

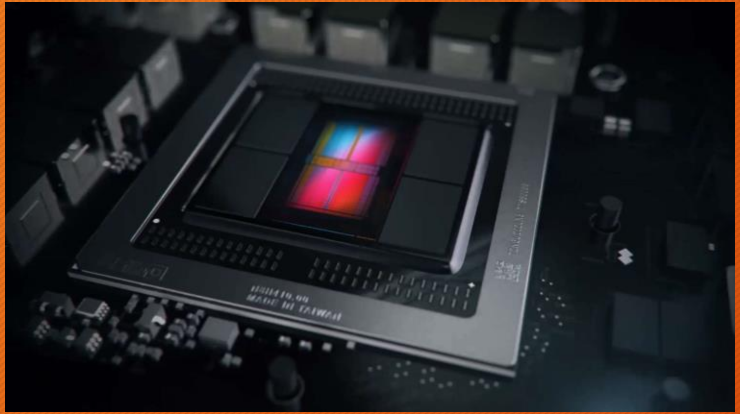
Integrates Fully Optimized Software Stacks

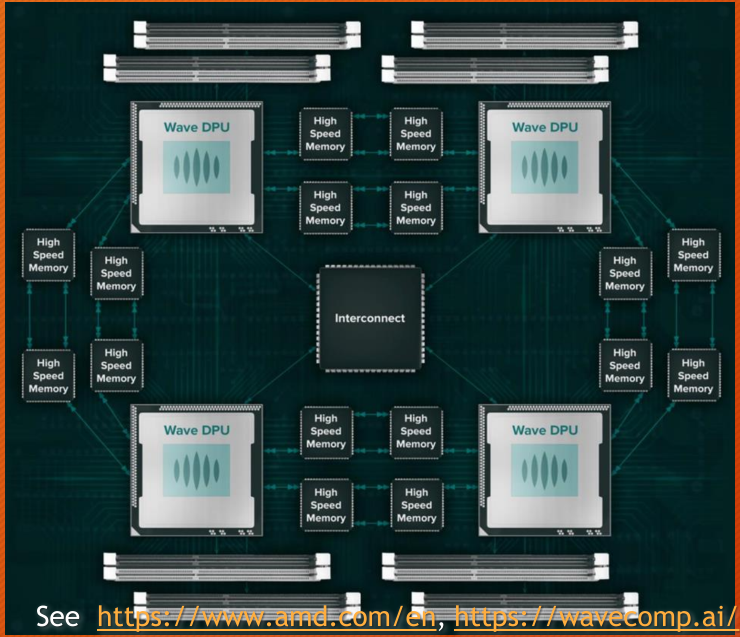
- Freely Available Through NGC

- 96 DGX-2H
- 10 Mellanox EDR IB per node
- 1,536 V100 Tensor Core GPUs
- 1 megawatt of power

See https://www.nvidia.com/en-us/

AMD, Wave (DPU), Habana

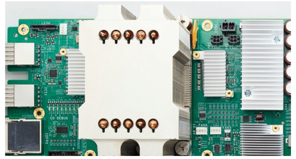




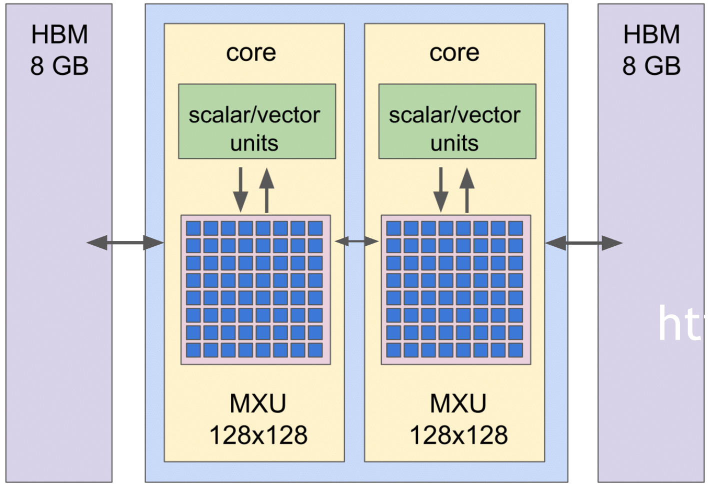
See https://www.amd.com/en, https://wavecomp.ai/ & https://habana.ai/

Google ... TPU v2

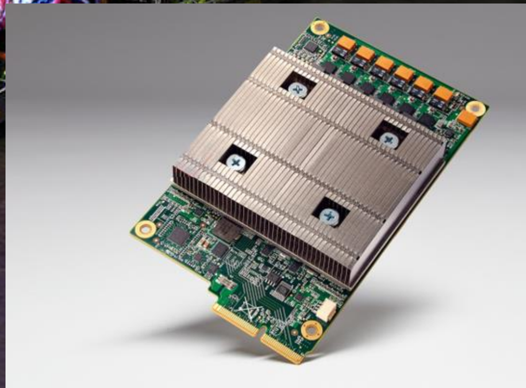
TPUv2 Chip



- 16 GB of HBM
- 600 GB/s mem BW
- Scalar/vector units: 32b float
- MXU: 32b float accumulation but reduced precision for multipliers
- 45 TFLOPS

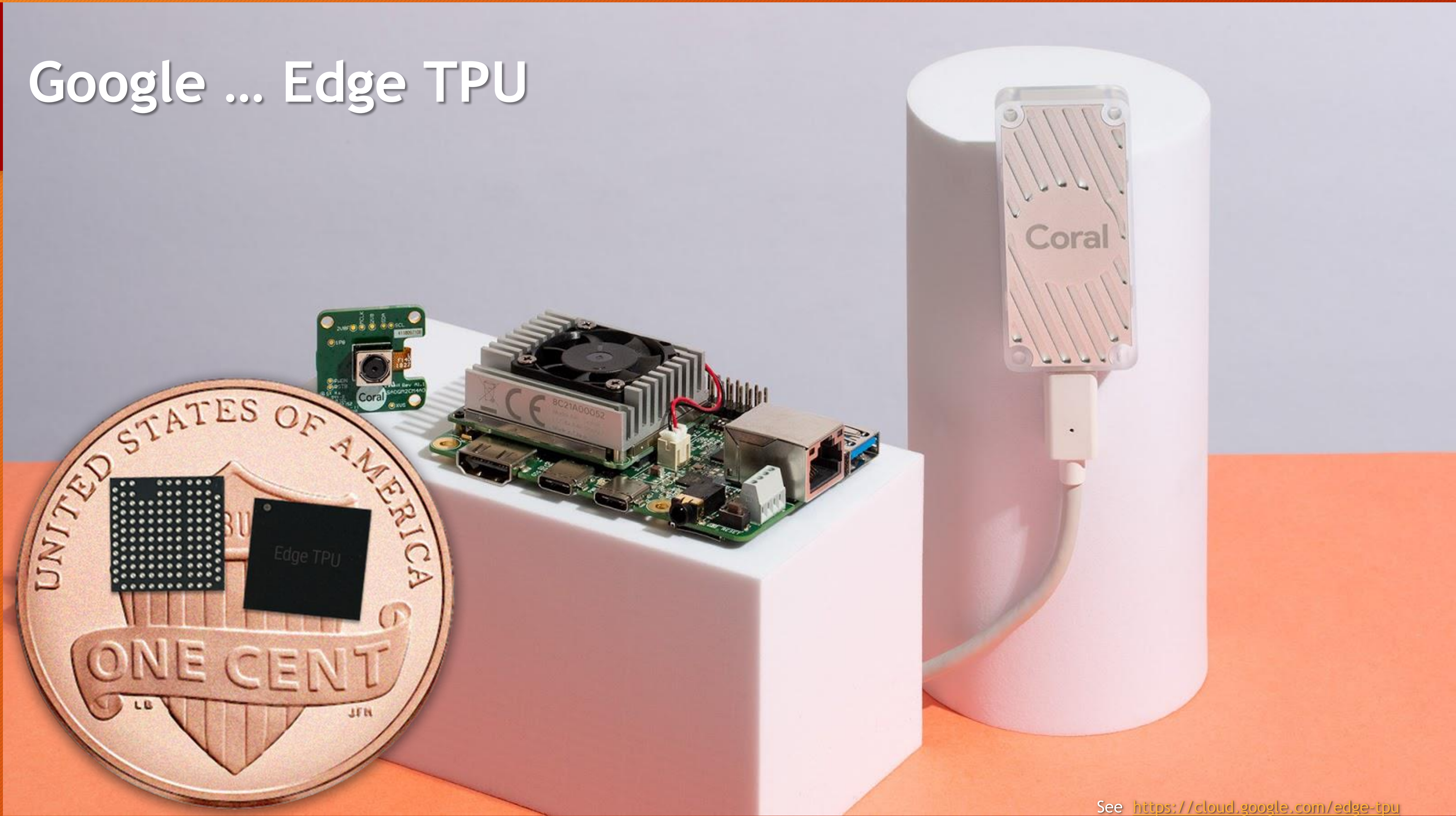


https://habana.ai/



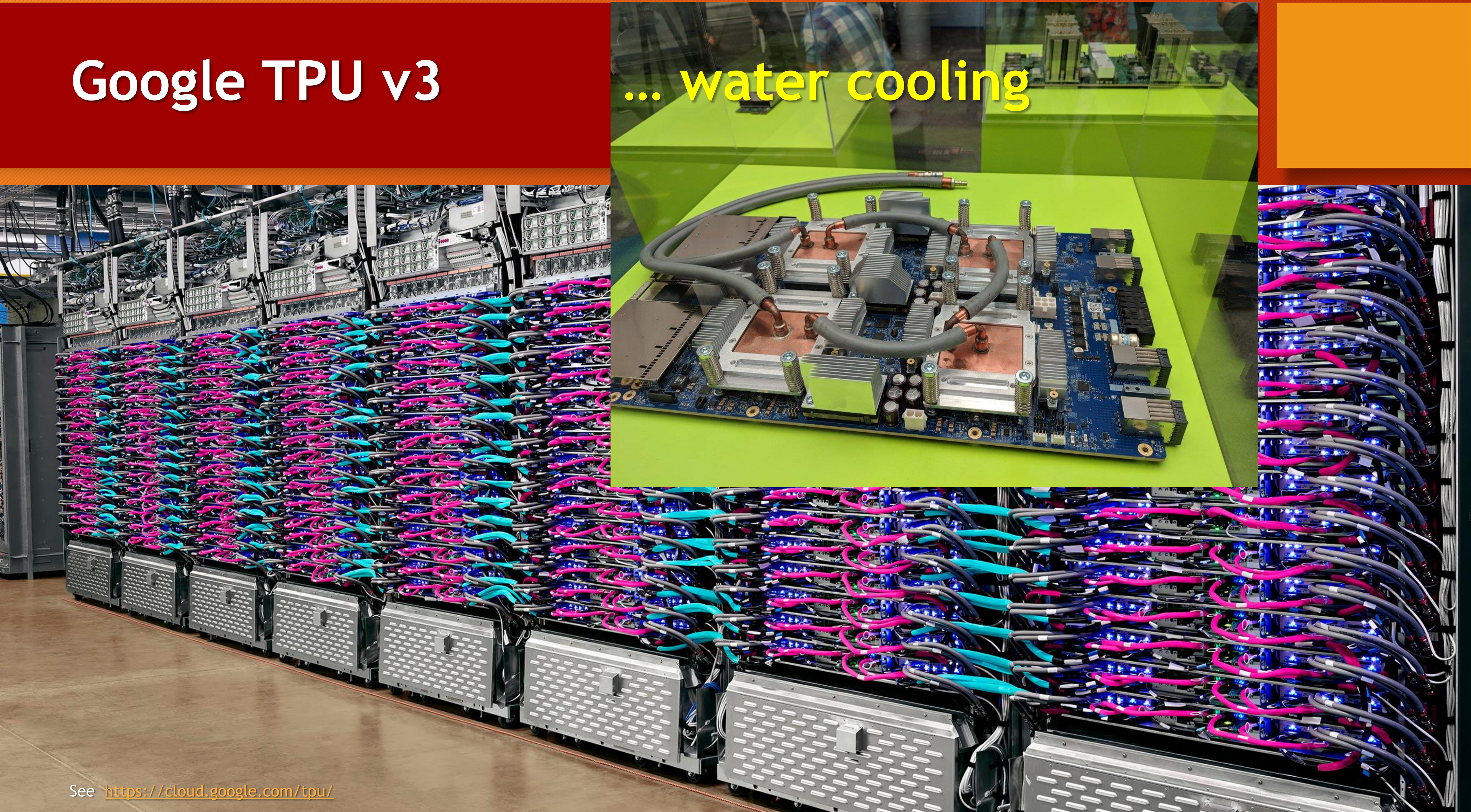
See https://cloud.google.com/tpu/

Google … Edge TPU



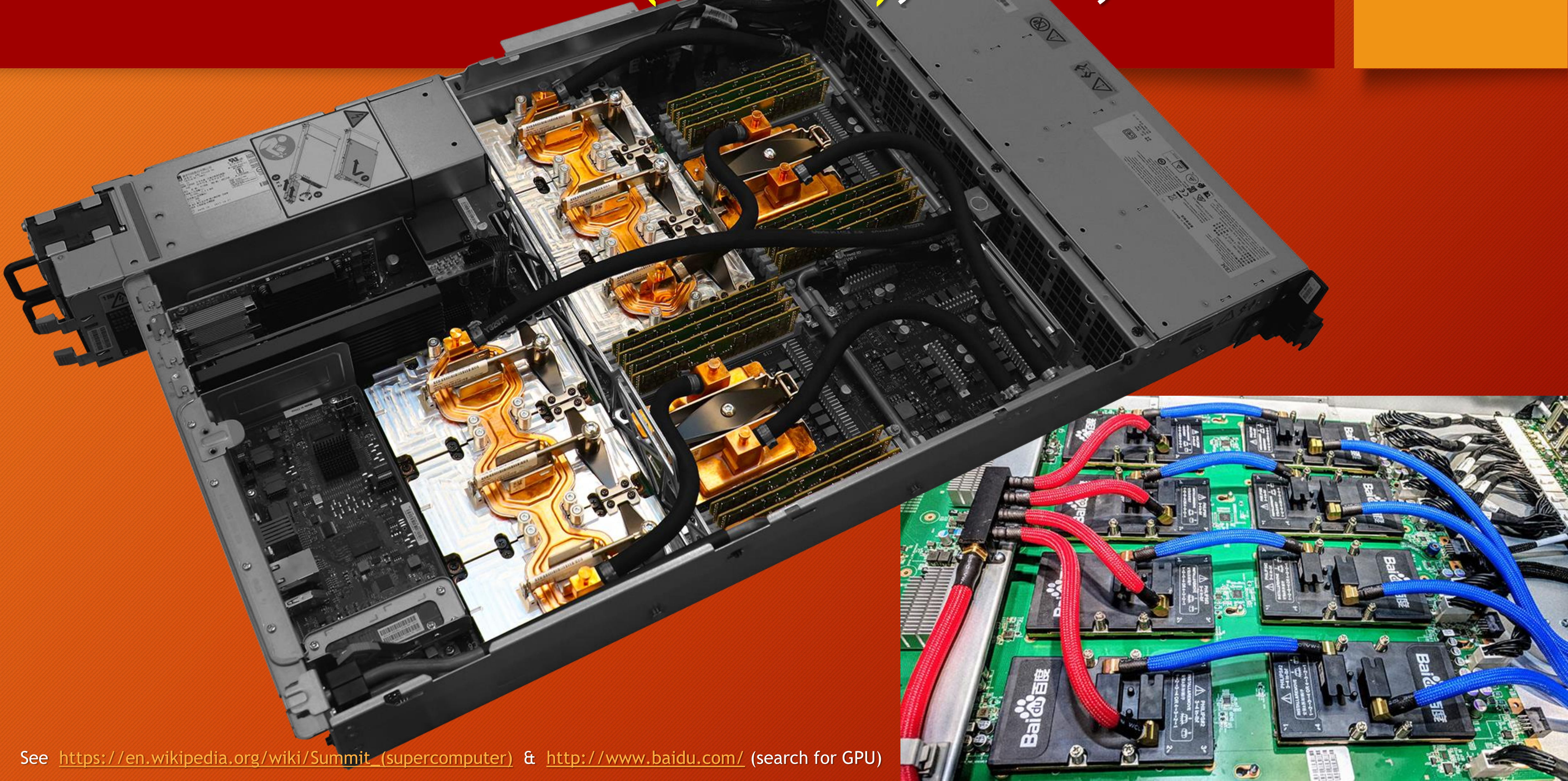
See https://cloud.google.com/edge-tpu

Google TPU v3



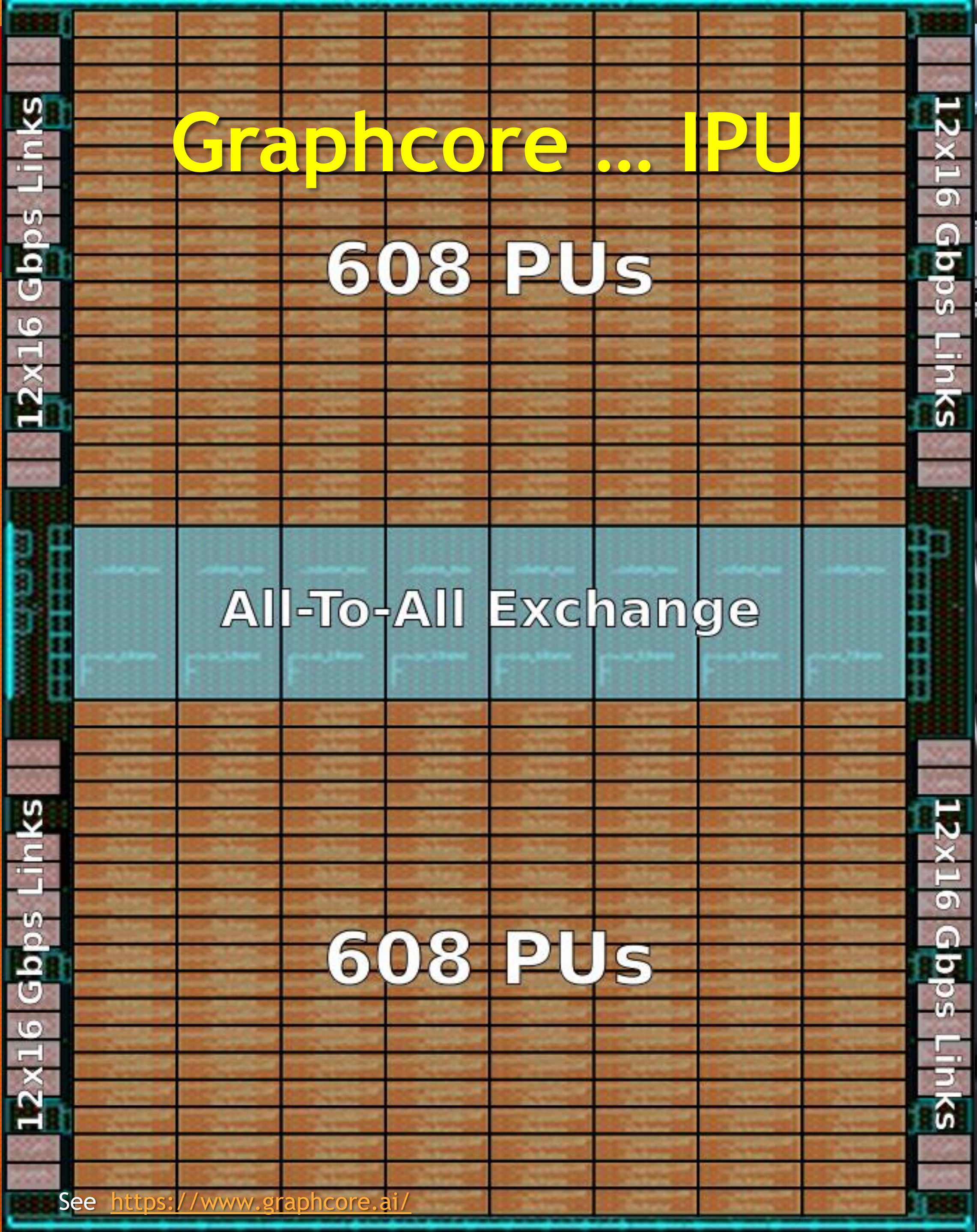
See https://cloud.google.com/tpu/

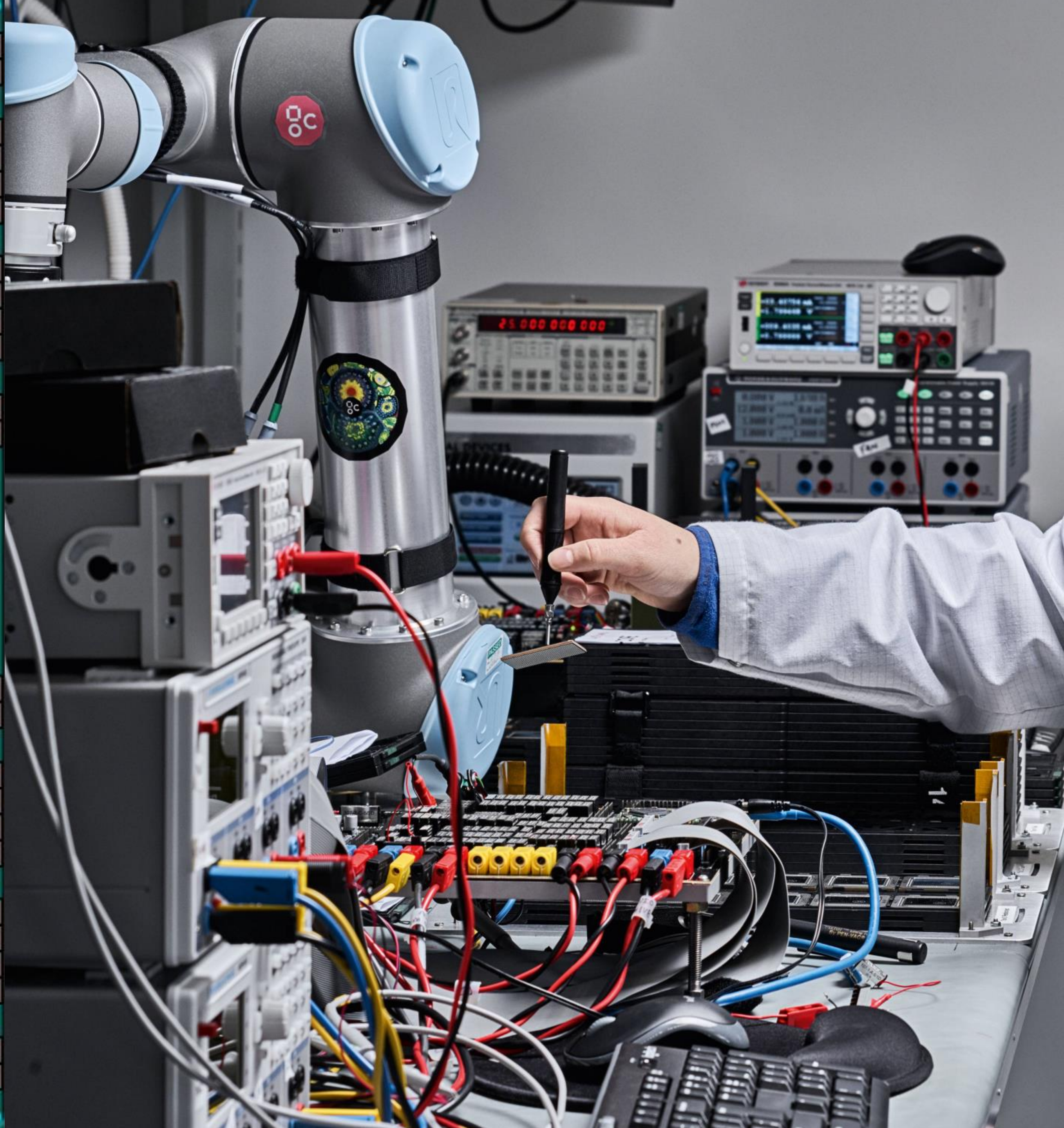
Nvidia GPUs: Summit (fastest!), Baidu, etc.



See https://en.wikipedia.org/wiki/Summit_(supercomputer) & http://www.baidu.com/ (search for GPU)

Graphcore … IPU

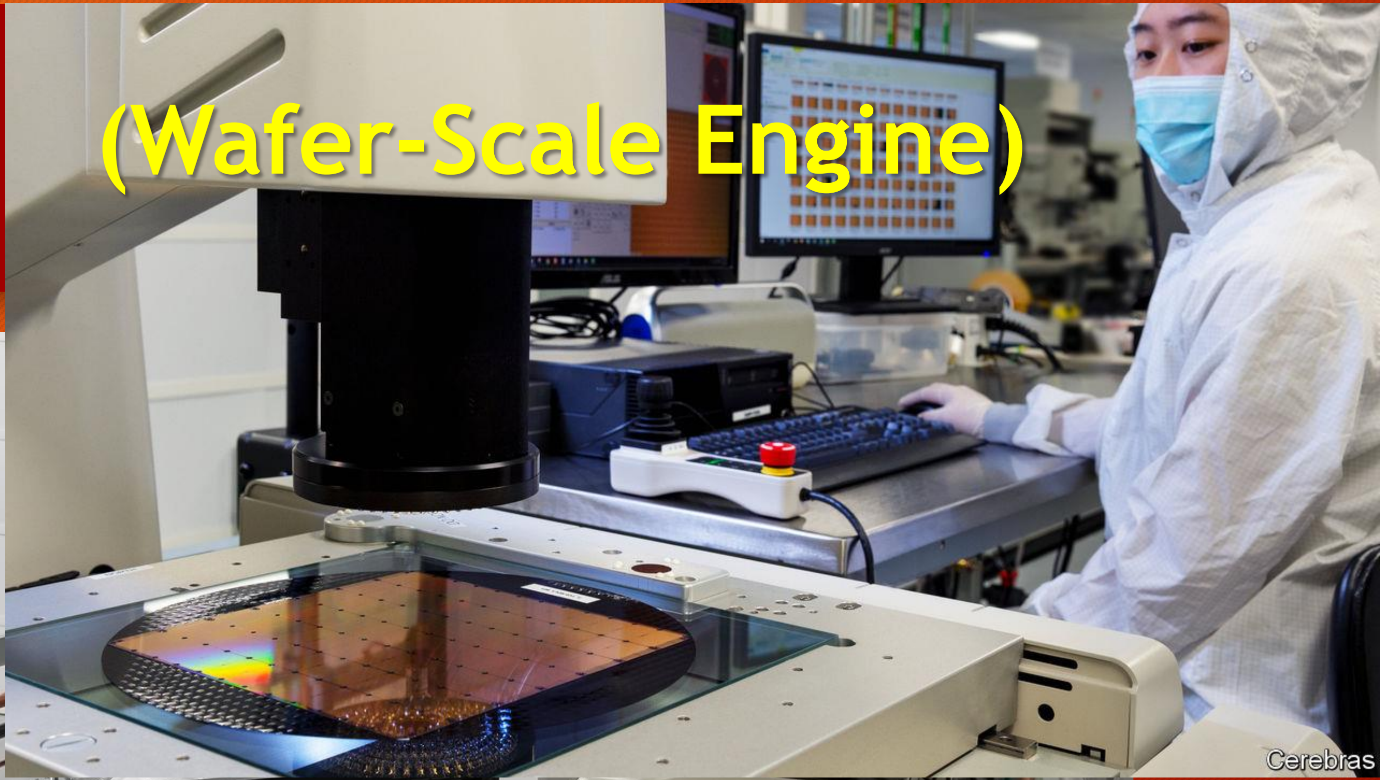


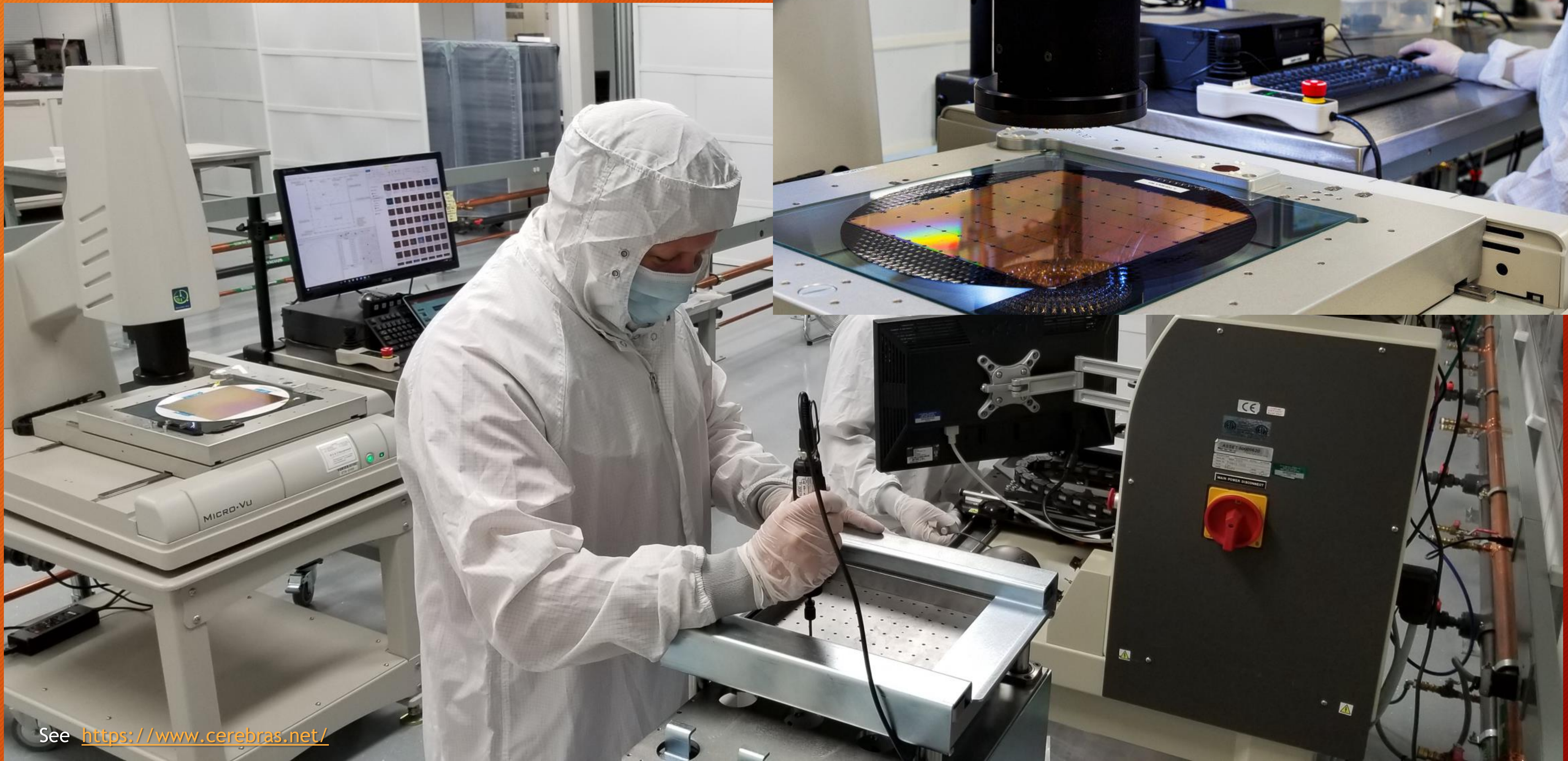


See https://www.graphcore.ai/

See https://www.graphcore.ai/

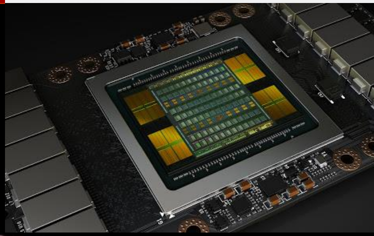
Cerebras WSE (Wafer-Scale Engine)





See https://www.cerebras.net/

21.5×21.5 cm^2 … 56× larger than the largest



The world's largest chip

46,225 mm^2 chip

56x larger than the biggest GPU ever made

400,000 cores

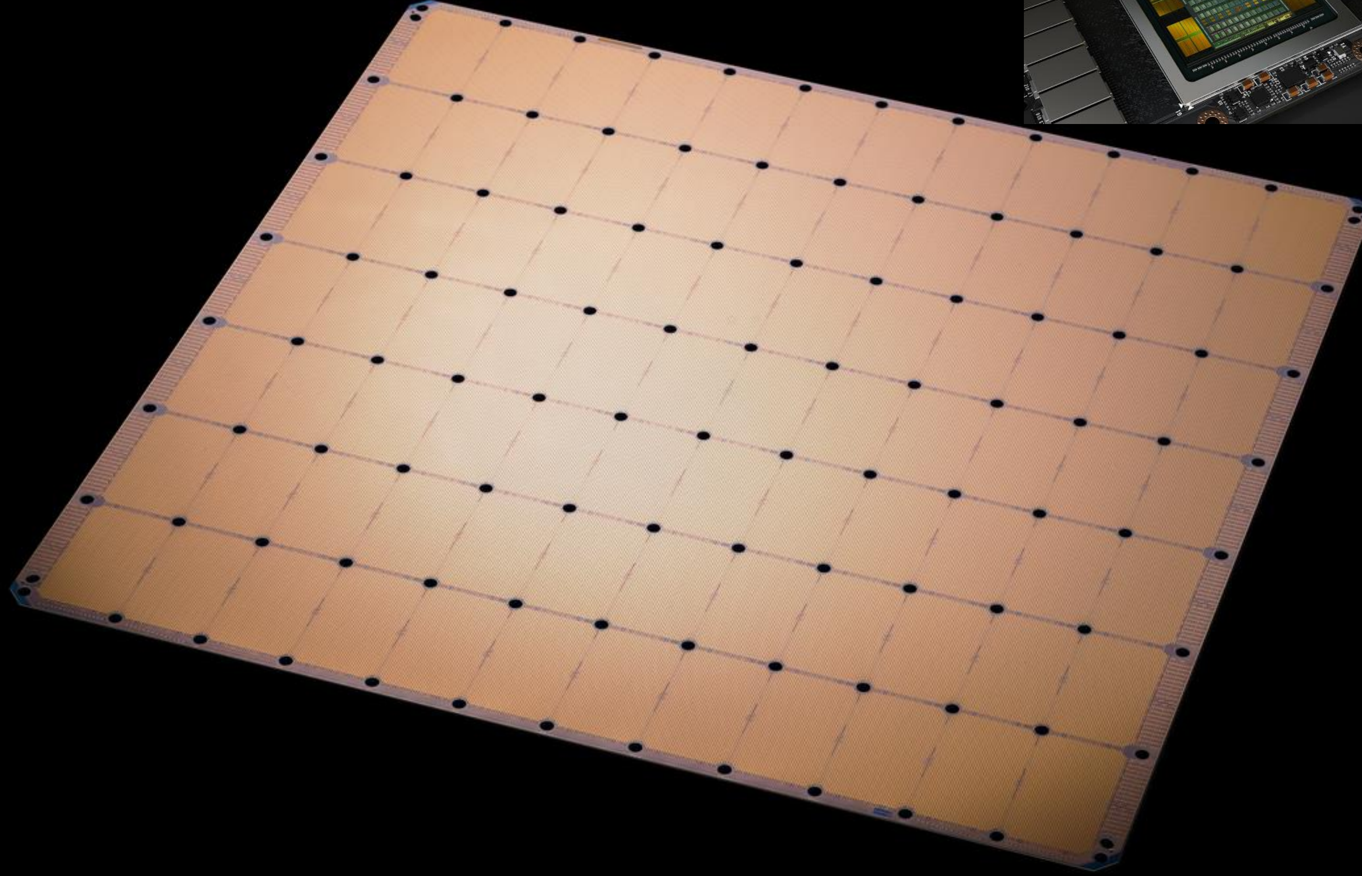
78x more cores

18 GB on-chip SRAM

3000x more on-chip memory

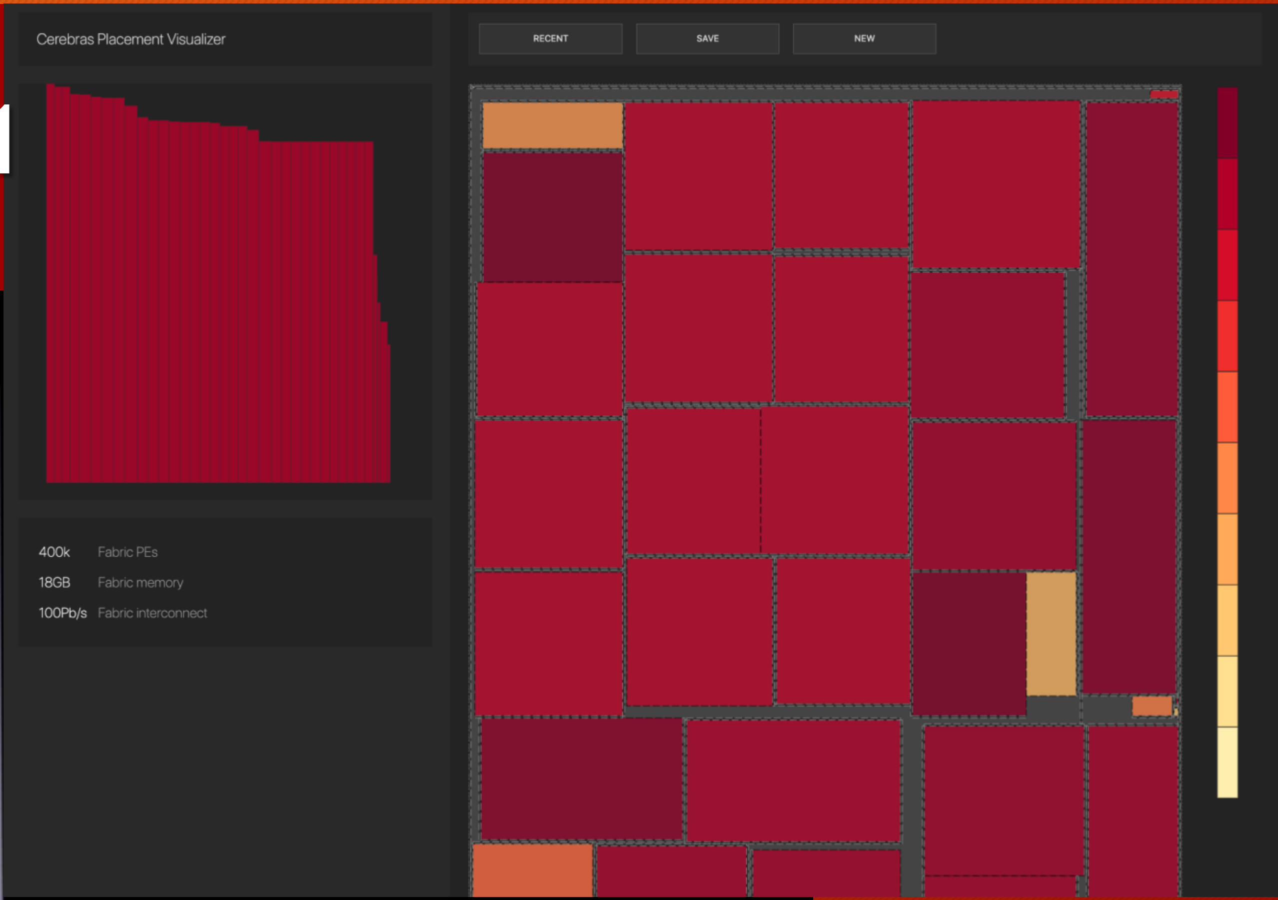
100 Pb/s interconnect

33,000x more bandwidth



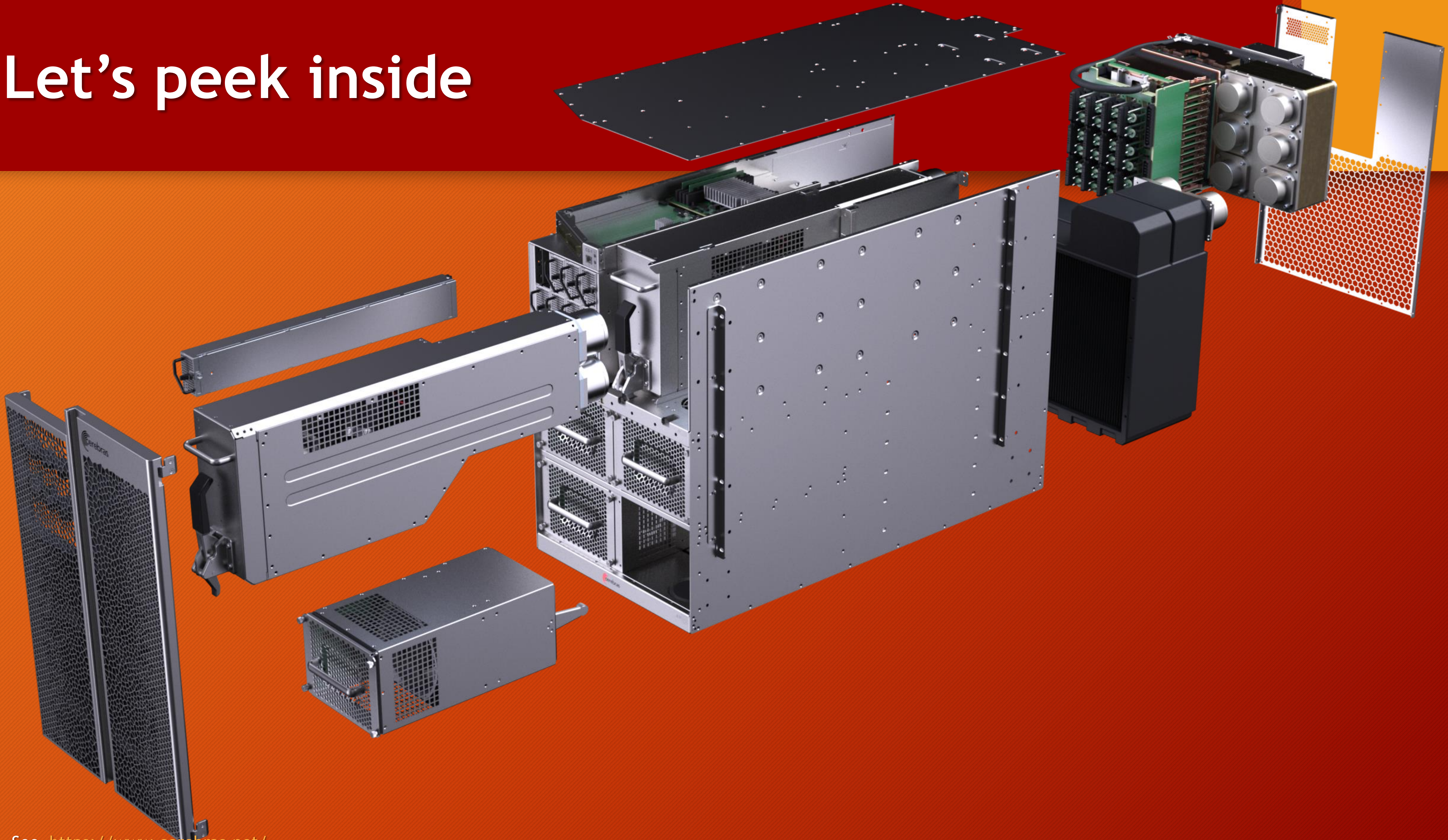
See https://www.cerebras.net/ as well as watch?v=DdlbVLrw820

Cerebras workstation CS-1



See https://www.cerebras.net/ as well as watch?v=2Xq7_5HTk1I

Let’s peek inside



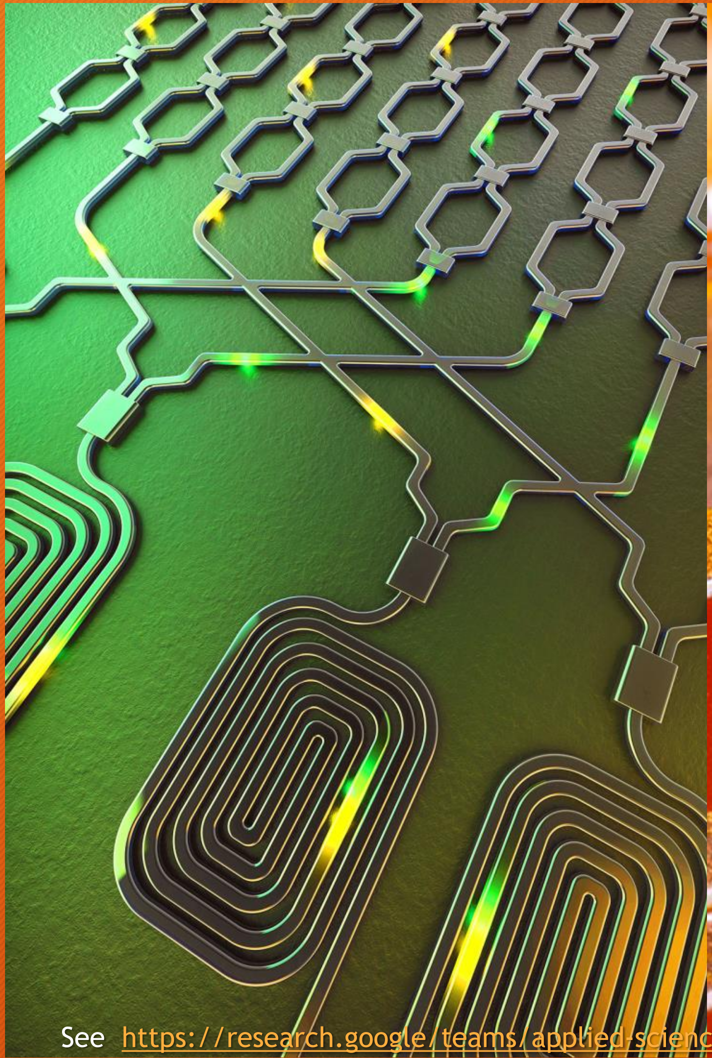
See https://www.cerebras.net/

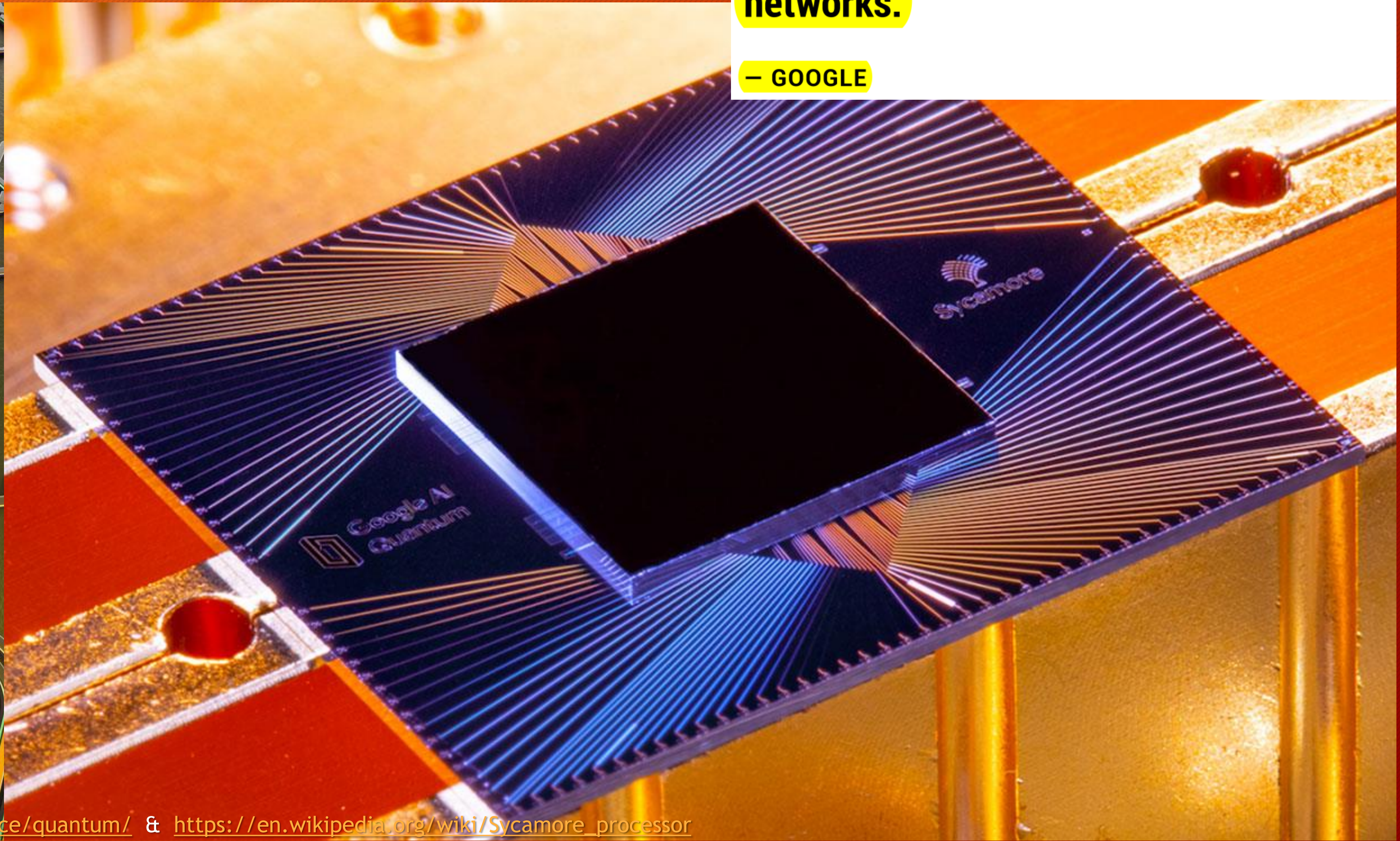
Any other options?

IEEE QUANTUM
IEEE rebooting COMPUTING
Reserve your seat by 1 October 2019 for early registrat

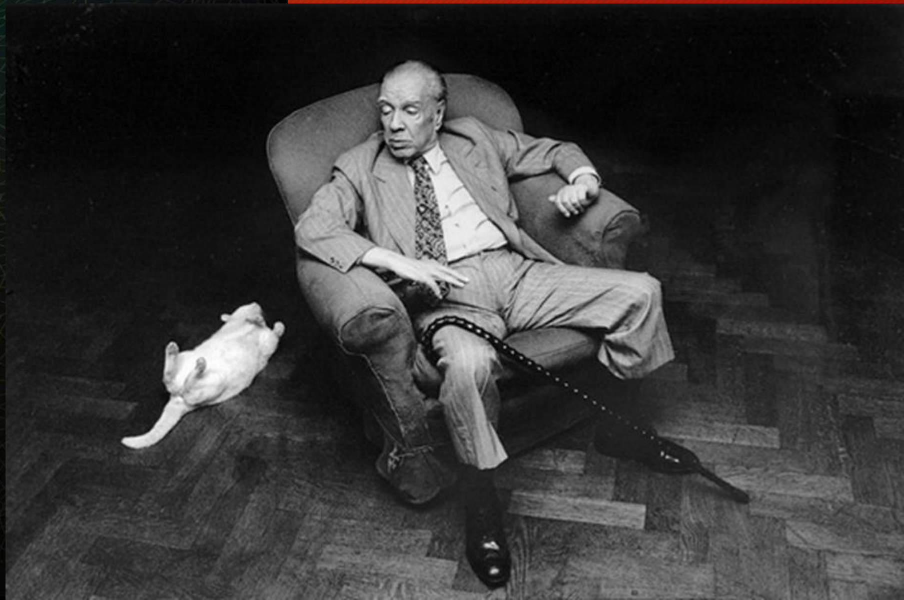
"Traditional machine learning took many years from its inception until a general framework for supervised learning was established. We are at the exploratory stage in the design of quantum neural networks."

— GOOGLE



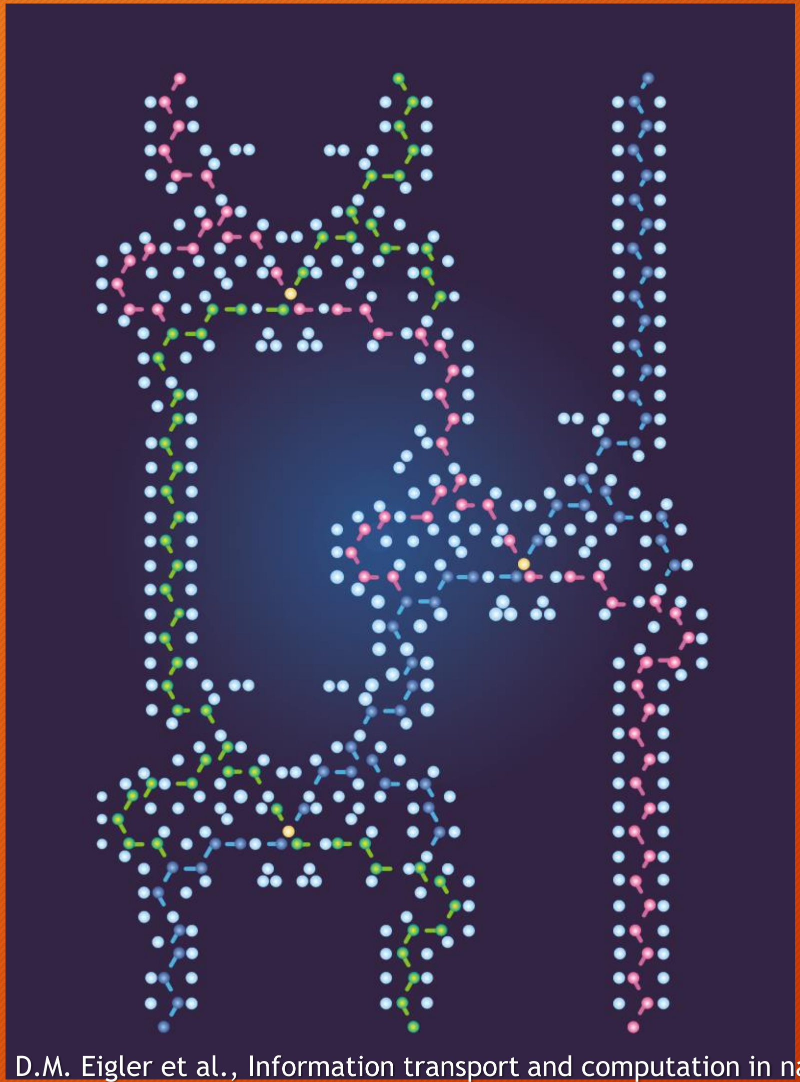


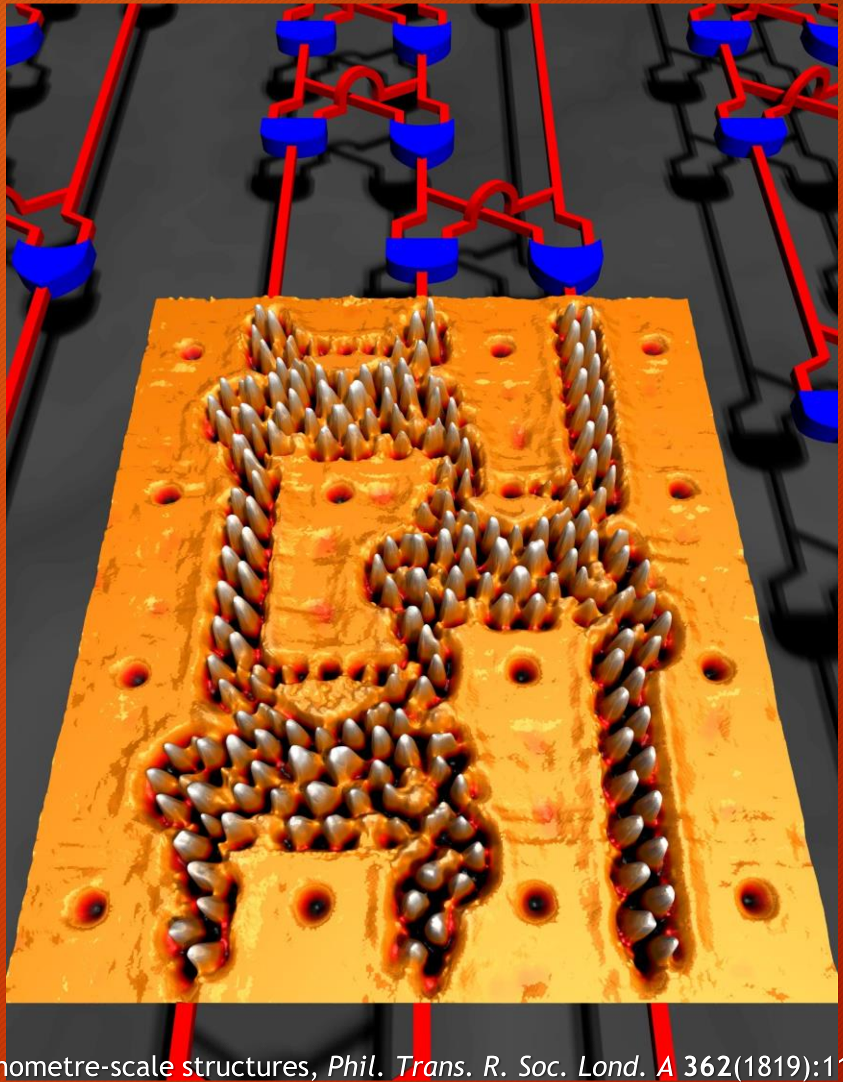
See https://research.google/teams/applied-science/quantum/ & https://en.wikipedia.org/wiki/Sycamore_processor

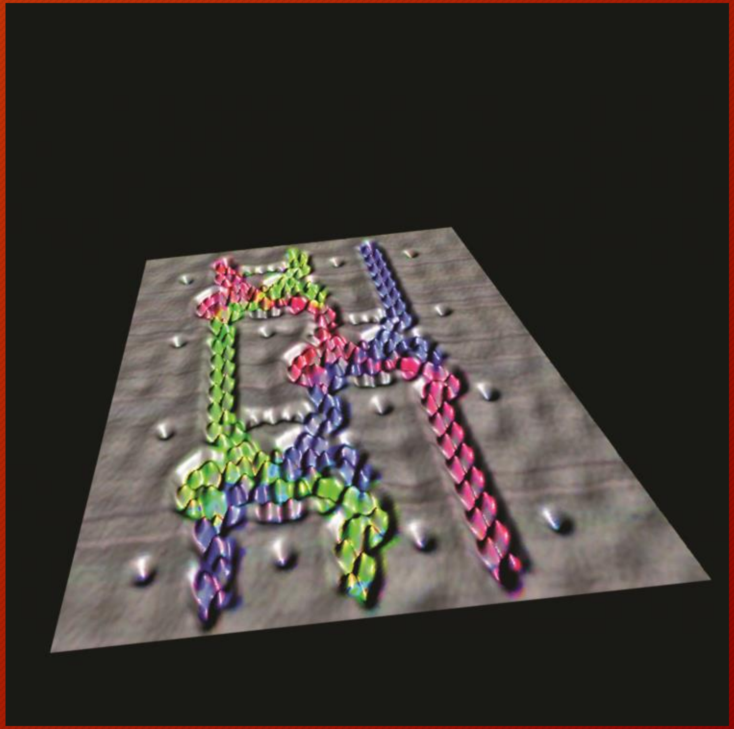


From https://discovery.princeton.edu/2019/12/09/quantum-computing-opens-new-realms-of-possibilities/

Early IBM “quantum” 3-bit sorter (1993 …)



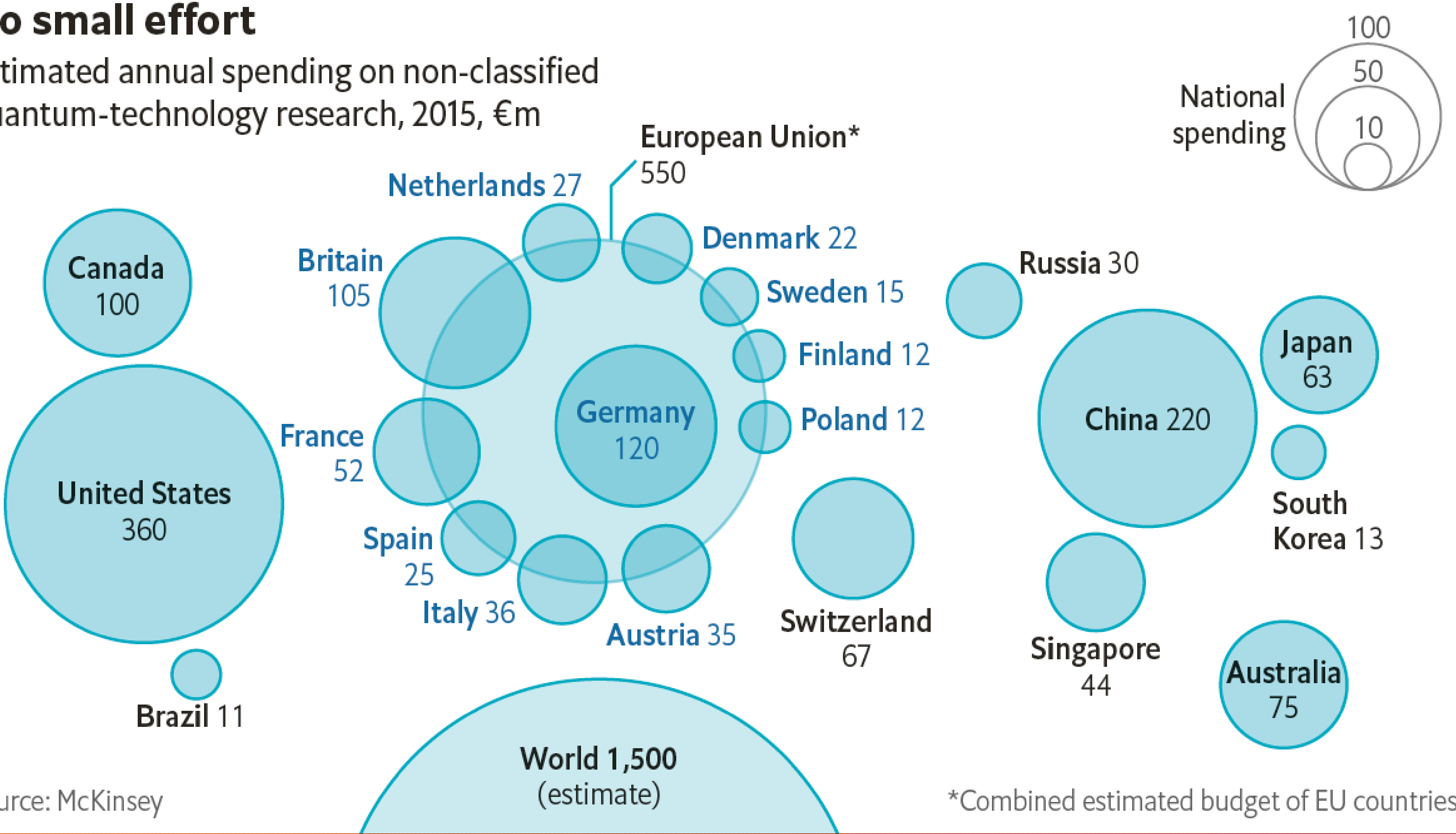




D.M. Eigler et al., Information transport and computation in nanometre-scale structures, *Phil. Trans. R. Soc. Lond. A* **362**(1819):1135-1147, Jun. 2004 (including the first 3 refs.)

No small effort

Estimated annual spending on non-classified quantum-technology research, 2015, €m



Source: McKinsey

*Combined estimated budget of EU countries

Quantum computing startups with ≥ $50M raised

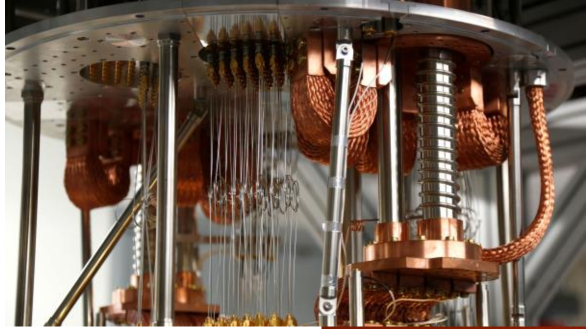
(as of 1/7/2019)

	D:Wave	rigetti	SILICON QUANTUM COMPUTING	CQC
Total disclosed funding:	$210M	$119M	$66M	$50M
Headquarters:	Canada	United States	Australia	UK

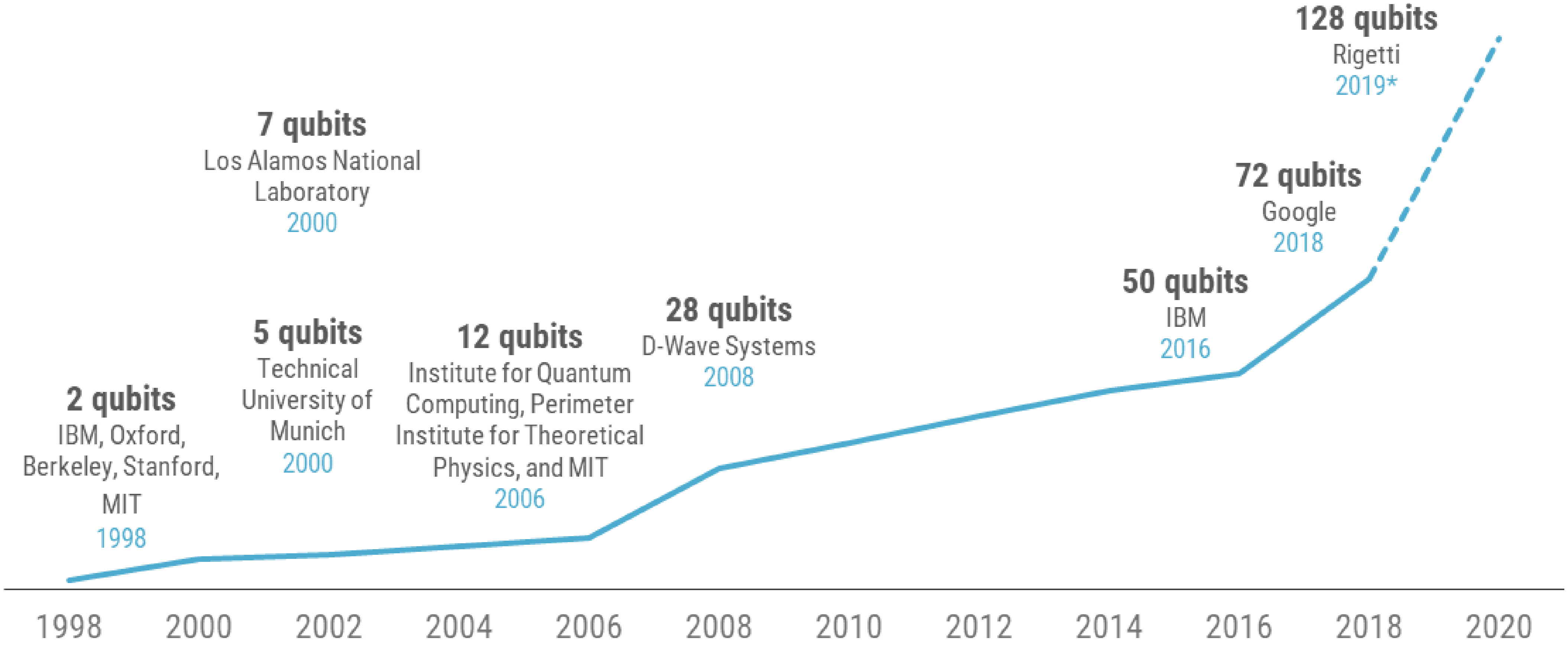
Source: cbinsights.com

CBINSIGHTS
https://www.cbinsights.com/

Quantum computers are getting more powerful



Number of qubits achieved by date and organization 1998 – 2020*



Source: MIT, Qubit Counter. *Rigetti quantum computer expected by late 2019.

CBINSIGHTS
https://www.cbinsights.com/

The three known types of quantum computing and their applications, generality, and computational power.

A very specialized form of quantum computing with unproven advantages over other specialized forms of conventional computing.

DIFFICULTY LEVEL

The most likely form of quantum computing that will first show true quantum speedup over conventional computing. This could happen within the next five years.

DIFFICULTY LEVEL

The true grand challenge in quantum computing. It offers the potential to be exponentially faster than traditional computers for a number of important applications for science and businesses.

DIFFICULTY LEVEL

Quantum Annealer

The quantum annealer is least powerful and most restrictive form of quantum computers. It is the easiest to build, yet can only perform one specific function. The consensus of the scientific community is that a quantum annealer has no known advantages over conventional computing.

APPLICATION
Optimization Problems

GENERALITY
Restrictive

COMPUTATIONAL POWER
Same as traditional computers

Analog Quantum

The analog quantum computer will be able to simulate complex quantum interactions that are intractable for any known conventional machine, or combinations of these machines. It is conjectured that the analog quantum computer will contain somewhere between 50 to 100 qubits.

APPLICATIONS
Quantum Chemistry
Material Science
Optimization Problems
Sampling
Quantum Dynamics

GENERALITY
Partial

COMPUTATIONAL POWER
High

Universal Quantum

The universal quantum computer is the most powerful, the most general, and the hardest to build, posing a number of difficult technical challenges. Current estimates indicate that this machine will comprise more than 100,000 physical qubits.

APPLICATIONS
Secure computing
Machine Learning
Cryptography
Quantum Chemistry
Material Science
Optimization Problems
Sampling
Quantum Dynamics
Searching

GENERALITY
Complete with known speed up

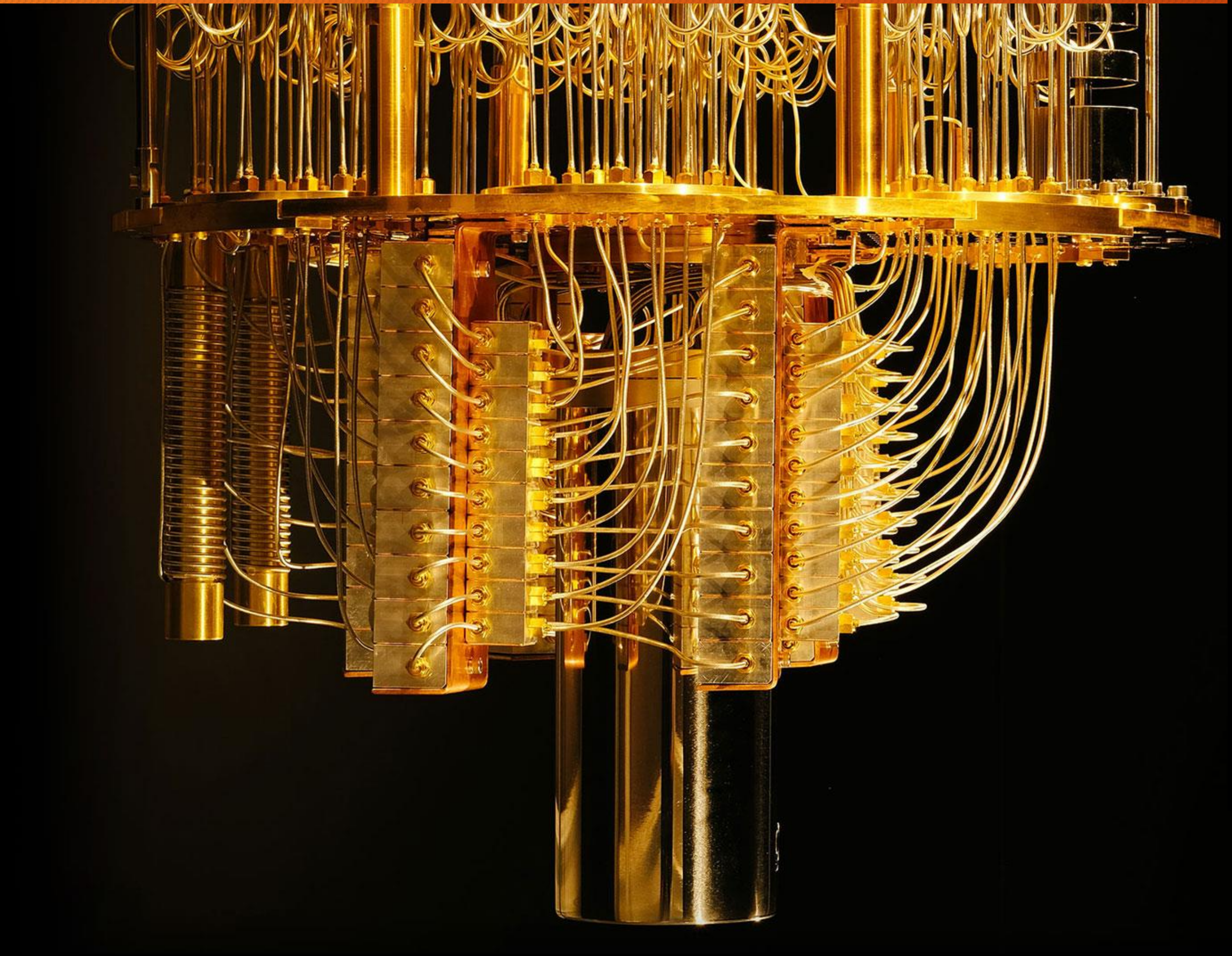
COMPUTATIONAL POWER
Very High

IBM Research

Infographic by Carl De Torres for IBM Research

https://www.ibm.com/quantum-computing/

IBM Q



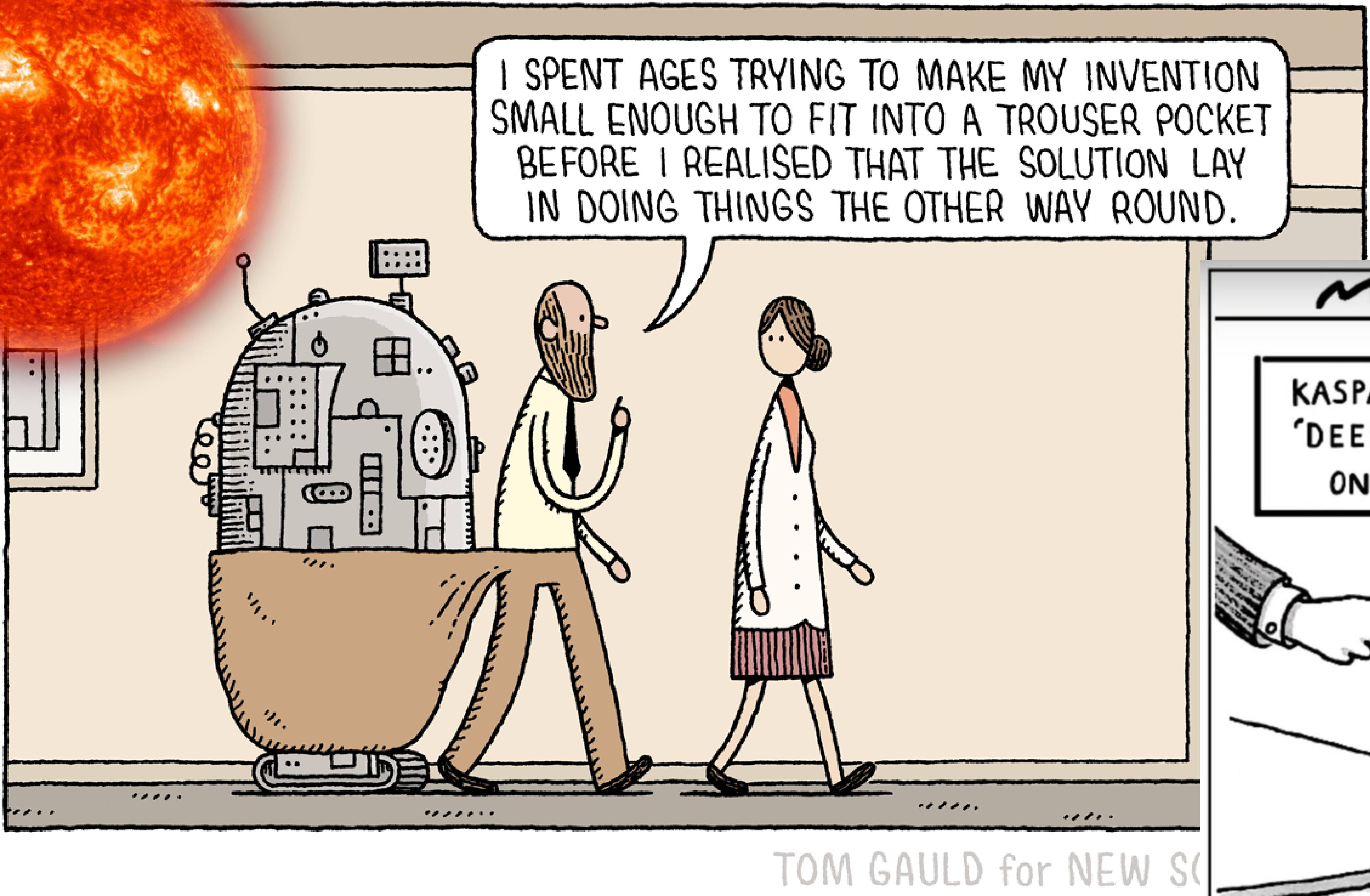
Fast … and, hopefully … green (low power)

Noblesse oblige (alternatives)

- With great power comes great responsibility*
- With great size comes great power consumption ☹
- With larger and larger chips comes … lower and lower power consumption
  1 MW ➜ 250 kW ➜ 15 kW ➜ 10 kW ☺
- … great, just that we still have a lot of work ahead (a long way to go)
  ➜ 1000 W ➜ 100 W ➜ Brain

Solution	Power (W)
Nvidia GPU	1,000,000
Google TPU	250,000
Graphcore IPU	25,000
Quantum	25,000
Cerebras WSE	15,000
Pending	1,000
Pending	100
Brain	40

* https://en.wikipedia.org/wiki/With_great_power_comes_great_responsibility , earlier versions https://books.google.fr/books?id=D55aAAAAcAAJ&pg=PA72 (1793) & the Bible



https://www.tomgauld.com/

https://en.wikipedia.org/wiki/Matt_Pritchett


2016-P-37-744: Novel Bio-inspired Cellular Nano-Architectures (A1-E-2015)
THANK YOU