Artificial Intelligence & neuro-cognitive technologies for human augmentation

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Google: Wlodzislaw Duch

AI4UAM, Sapienza University, Rome 9/2022

Toruń


Rockall (U.K.)
ORKNEY ISLANDS
HEBRIDES
North Atlantic Ocean
Bergen
Oslo
Stockholm
ALAND ISLANDS
Tallinn
ESTONIA
RUSSIA
Moscow
Stavanger
Aberdeen
Göteborg
Gotland
Riga
LATVIA
Glasgow
Edinburgh
UNITED
North Sea
Skagerrak
Kattegat
Baltic Sea
Öland
DENMARK
Copenhagen
Malmö
LITHUANIA
Vilnius
Vitsyebsk
Smolensk
Mahilyow
Minsk
Kaliningrad
RUSSIA
Bornholm
BELARUS
Belfast
Isle of Man (U.K.)
Irish Sea
Dublin
IRELAND
Leeds
Manchester
Liverpool
KINGDOM
Gdańsk
Hrodna
Homyel'
Hamburg
Bremen
Berlin
Poznań
Warsaw
Brest
Cardiff
Birmingham
Amsterdam
NETH.
Rotterdam
POLAND
Łódź
Kiev
Rivne
Celtic Sea
London
Essen
Leipzig
Cologne
Wrocław
Brussels
Lille
BEL.
Bonn
GERMANY
Prague
Kraków
UKRAINE
English Channel
Guernsey (U.K.)
Jersey (U.K.)
Frankfurt am Main
CZECH REPUBLIC
Brno
SLOVAKIA
L'viv
Chernivtsi
Mykolayiv
Luxembourg
LUX.
Paris
Stuttgart
Bratislava
Chişinău
Strasbourg
Munich
Vienna
Budapest
Cluj-Napoca
Iaşi
MOLDOVA
Odesa
Nantes
LIECH.
AUSTRIA
HUNGARY
Zürich
Bern
SWITZ.
Vaduz
Geneva
FRANCE
ROMANIA
Bay of Biscay
Ljubljana
Zagreb
Bucharest
Constanța
SLOVENIA
MASSIF CENTRAL
Lyon
Milan
Venice
Turin
Bordeaux
BOSNIA AND HERZEGOVINA
Belgrade
Varna
Black Sea
Genoa
CROATIA
Bilbao
Toulouse
SAN MARINO
Sarajevo
Serbia
BULGARIA
MONACO
Andorra la Vella
Marseille
Ligurian Sea
Florence
Sofia
Porto
PYRENEES
ANDORRA
ITALY
Adriatic Sea
Podgorica
Skopje
İstanbul
Zaragoza
Corsica
Rome
F.Y.R.O.M.
Madrid
Barcelona
VATICAN CITY
Tirana
Thessaloniki
Bursa
ALB.

Toruń

Nicolaus Copernicus, born in 1473 in Toruń.
Studied in Krakow, Bologna, Padova and Ferrara

CD DAMSI

University Centre of Excellence established in 2020:
"Dynamics, mathematical analysis and artificial intelligence".

- Dynamics and ergodic theory (Math)
- Computer science – formal languages and concurrency (Theoretical CS)
- Entangled states and dynamics of open quantum systems (Math Physics)
- Neuroinformatics and artificial intelligence (Neuroinformatics). Understanding the brain and inspirations for better neural algorithms.

Neuroinformatics: a combination of brain research and artificial intelligence.

International Neuroinformatics Coordination Facility (INCF.org), coordinated by Karolinska Institutet, Stockholm: 18 countries, 120 institutions. Polish node in since 2017 run by our group.

12th INCF Congress on Neuroinformatics and INCF Assembly, Warsaw 9/2019.

Development of civilization

We are in extraordinary moment in the history of the world!

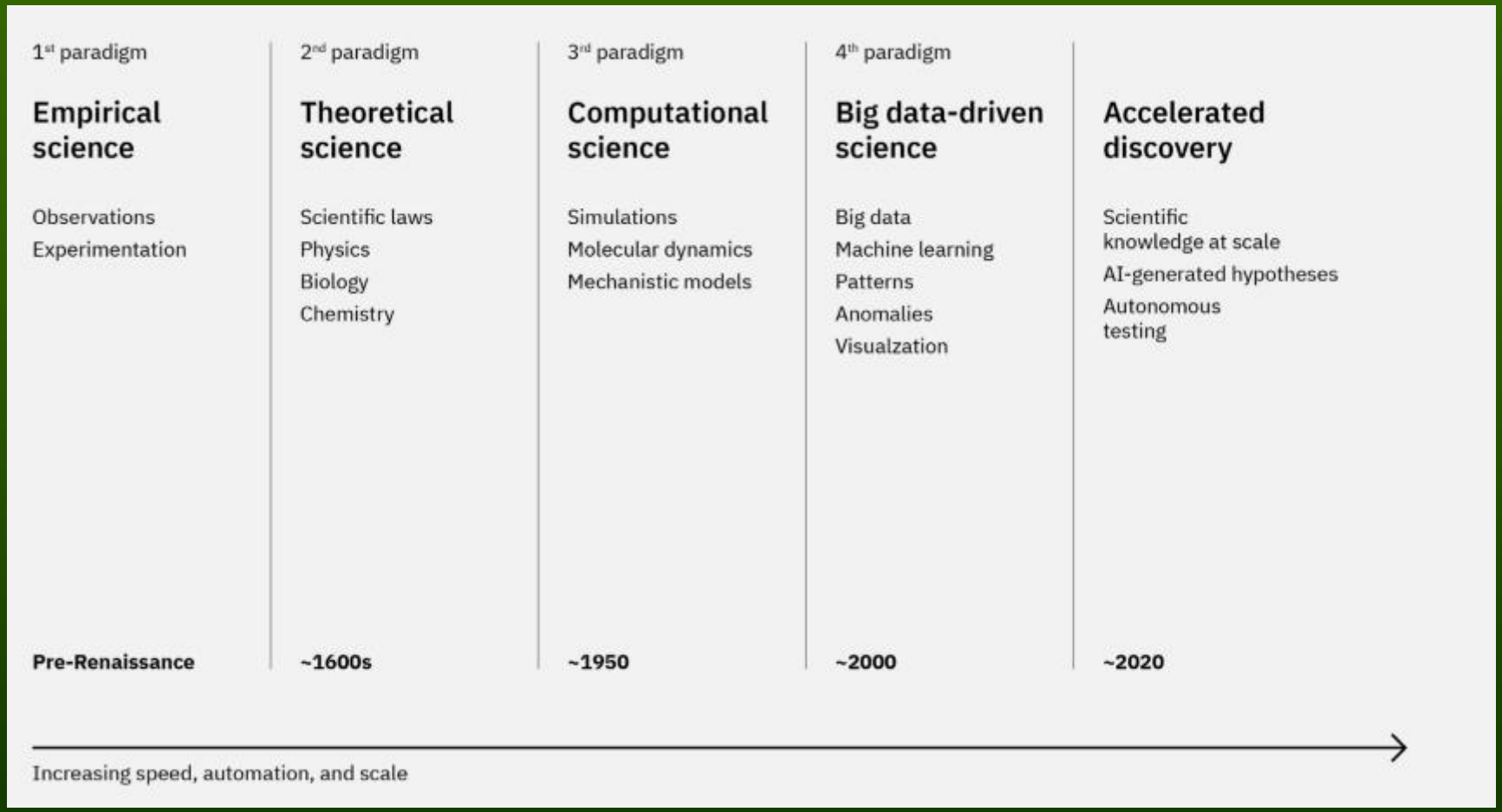
Growing understanding of the world, since antiquity:

1. Magical thinking, the whims of the gods, fatalism.
2. Causality, empirical observations, descriptive knowledge - protoscience.
3. Theories, empirical verification, math and statistics – classical science.
4. Computer simulations, complex systems, “new kind of science” (Wolfram).
5. Knowledge from data (KDD), collection and access to all information.
6. Artificial intelligence support for thinking, superhuman augmentation.
7. Autonomous AI + coupling with real brains, in near future?

5 paradigms for the development of science according to the IBM:
empirical, theoretical, simulation, data driven, and accelerated discovery.

Increasingly complex data models: IBM Watson, CyC, GPT-3, Google Mixture of Experts (MoE), models with more than trillion parameters ...

Science in the new era



IBM Science and Technology Outlook 2021.

Increasingly complex data models: CyC, IBM Watson, GPT-3, Google Mixture of Experts (MoE), WuDao, models with more than trillion parameters ...

Computational support for all

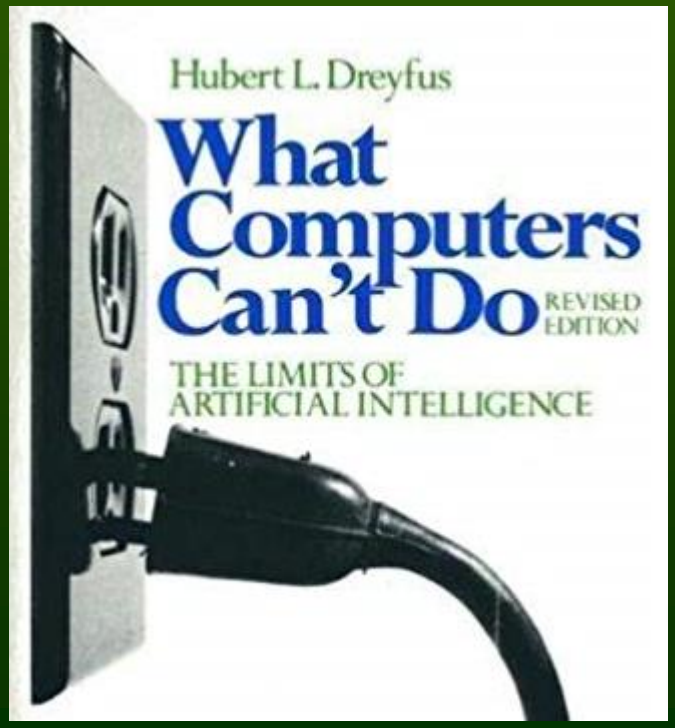
From calculators to software tools and thinking machines.

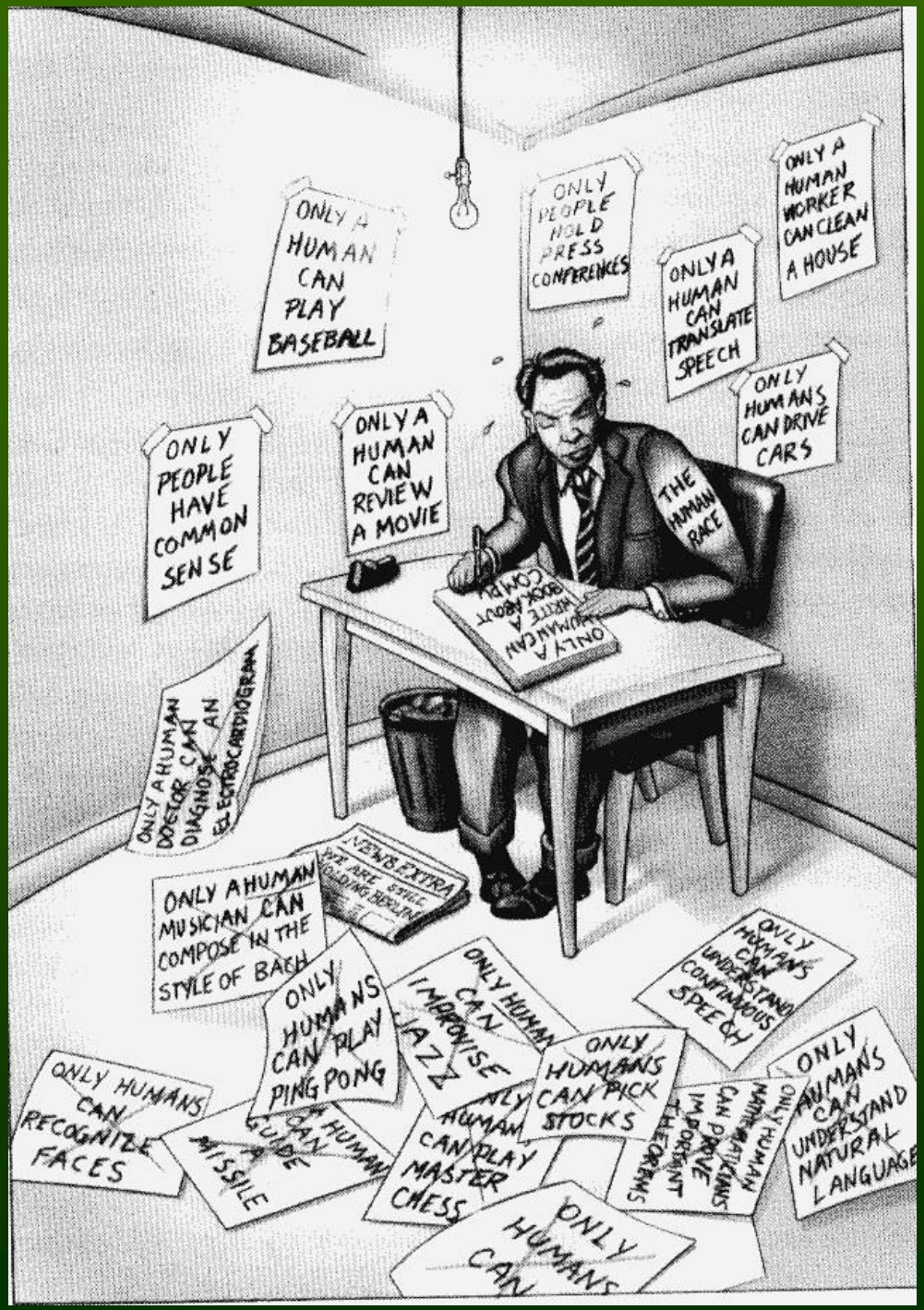
- Prehistory: Ramon Llull (13th C), Gottfried F. Leibniz (17th C), Alan Turing, John von Neumann, Marvin Minsky, Allen Newell, Herbert Simon ...
- Computational physics – Cormack, Hounsfield, Nobel 1979 CT Tomography.
- Computer chemistry – J. Pople, Nobel in chemistry 1998
- Bioinformatics – Karplus, Levitt, Warshel, Nobel in Chemistry 2013.
- Materials engineering – numerous software tools.
- In psychology, sociology, law, medicine, brain research – many tools.
- Artificial Intelligence – in all areas, numerous easy-to-use tools.

Computational science: how to use IT tools to solve difficult problems?
Teach informatics + specialization, or vice versa? Major / minor US system?

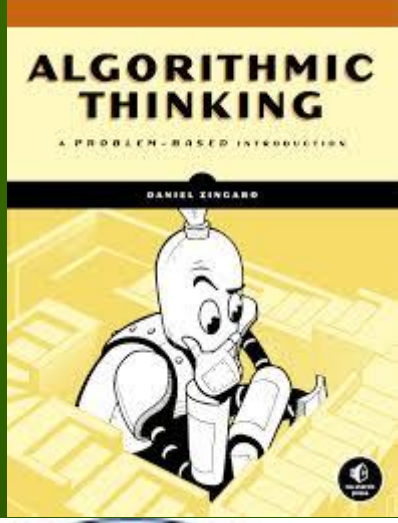
1994, Albuquerque, USA Department of Energy conference on how to use supercomputers – computational sciences that we still do not have.

Intelligence is just what artificial AI systems can't do … yet?
Dreyfus (1972, 1992) critique was true but only for the symbolic approach to AI, called now GOFAI.



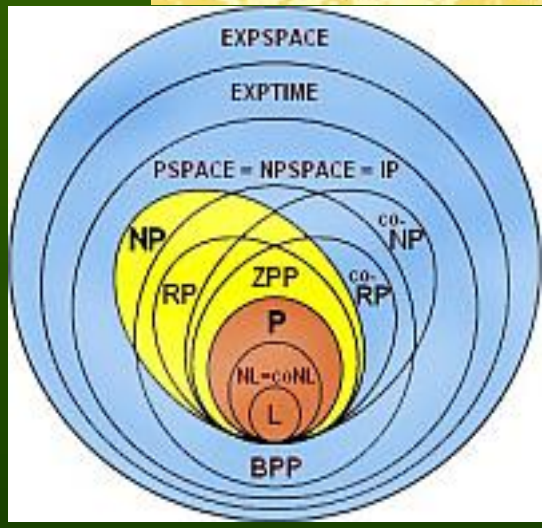


AI: computer science definition



Artificial Intelligence (AI) is a branch of computer science solving problems for which there are **no effective algorithms**.

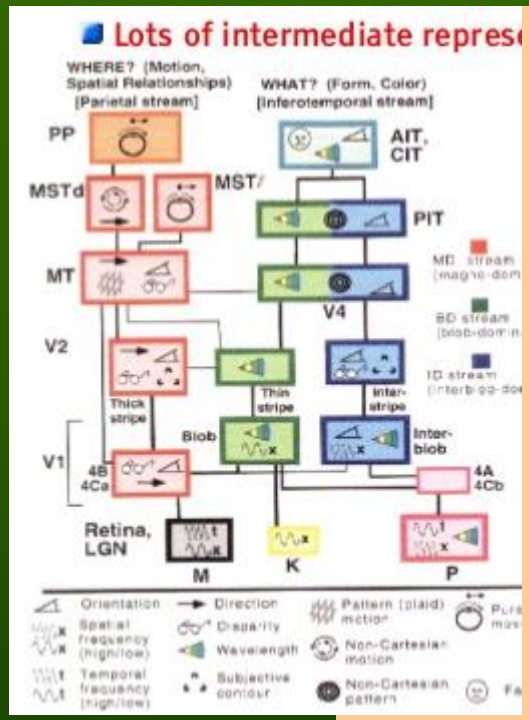
Formerly: based on modeling knowledge, presented in a verbally described, symbolic way, dealing mainly with reasoning at the conceptual level.



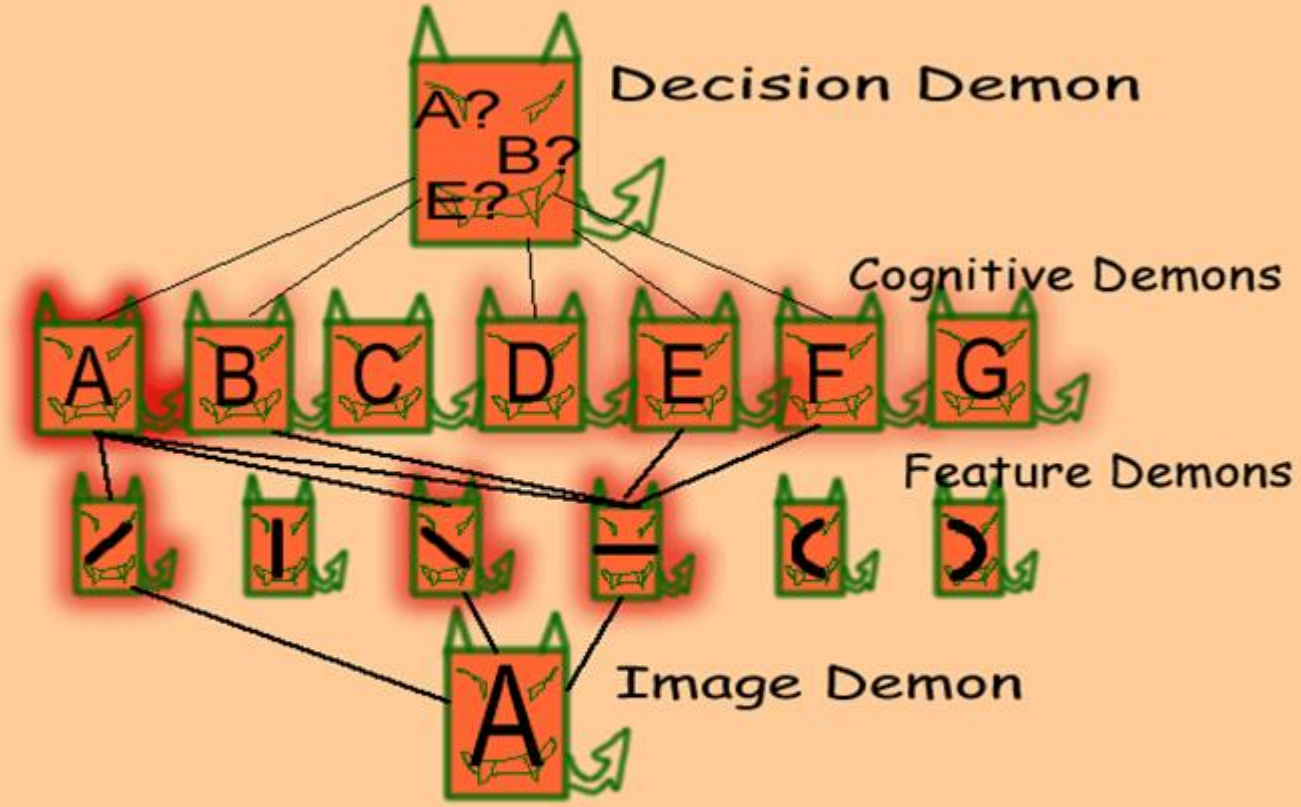
21 century: AI == machine learning, functions that are performed intuitively by animals, like visual recognition, discovering structures in complex data + reasoning.
Most important technique: multilayer neural networks.
Neurocognitive technologies: neuro => cogito.

Governments want to regulate AI? Science is not an application.
Can we regulate algorithms or math equations?
All real-world applications (AI, software or any others) should be regulated.

Selfridge NN Model (1959)

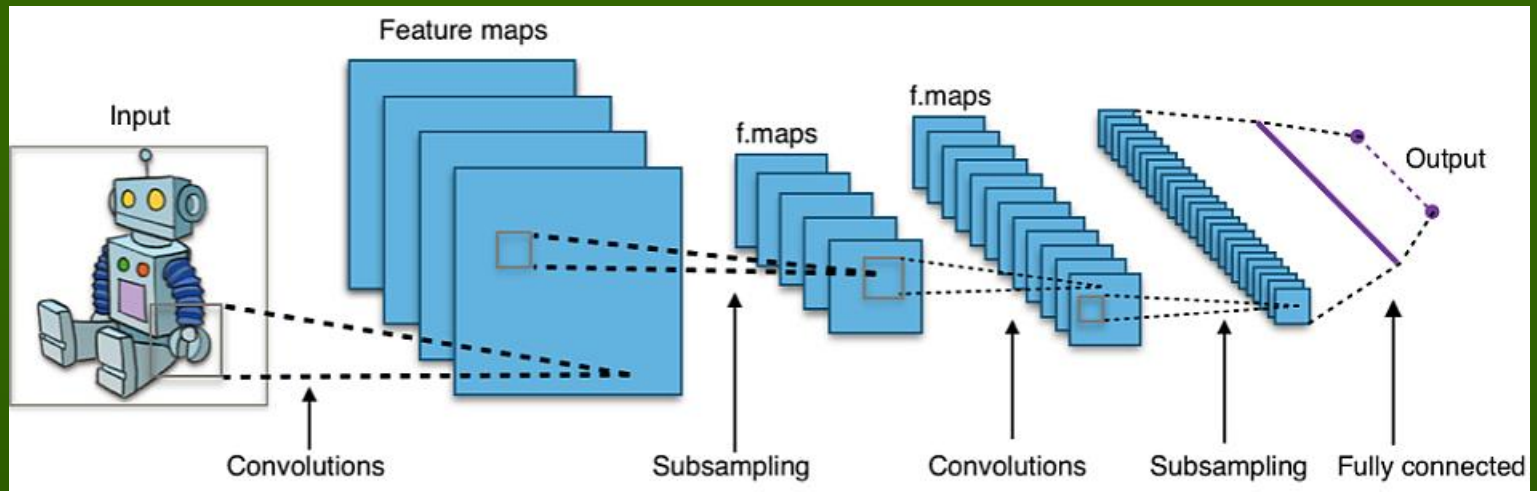


32 visual cortical areas were known in 1991!



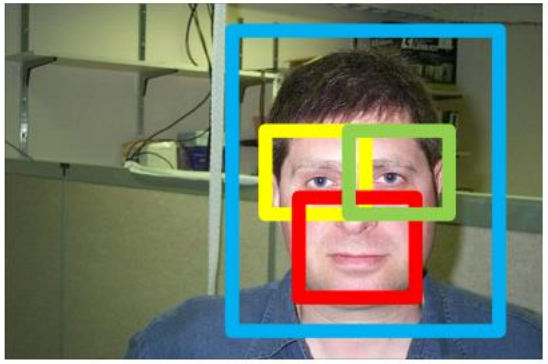
Based on:

Selfridge, O. G. (1959). *Pandemonium: A paradigm for learning.* In *Symposium on the mechanization of thought processes* (pp. 513-526). London: HM Stationery Office.



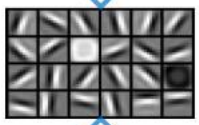
Feature representation

Input data



3rd layer
"Objects"

2nd layer
"Object parts"



1st layer
"Edges"

Pixels

Lee et al., ICML 2009;
CACM 2011

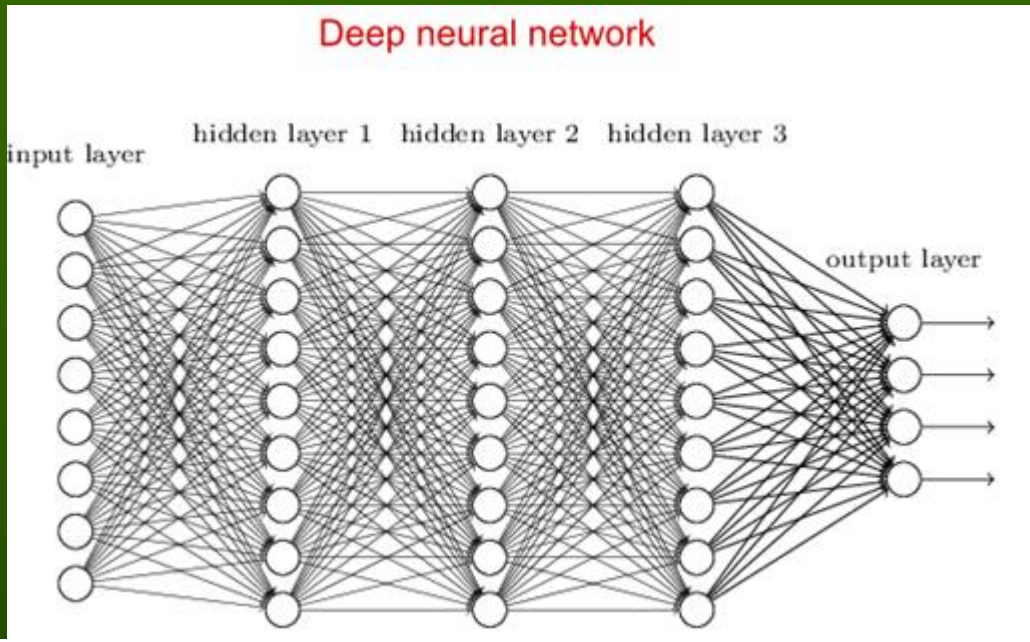
Tensorization of Convolutive Deep Learning NN

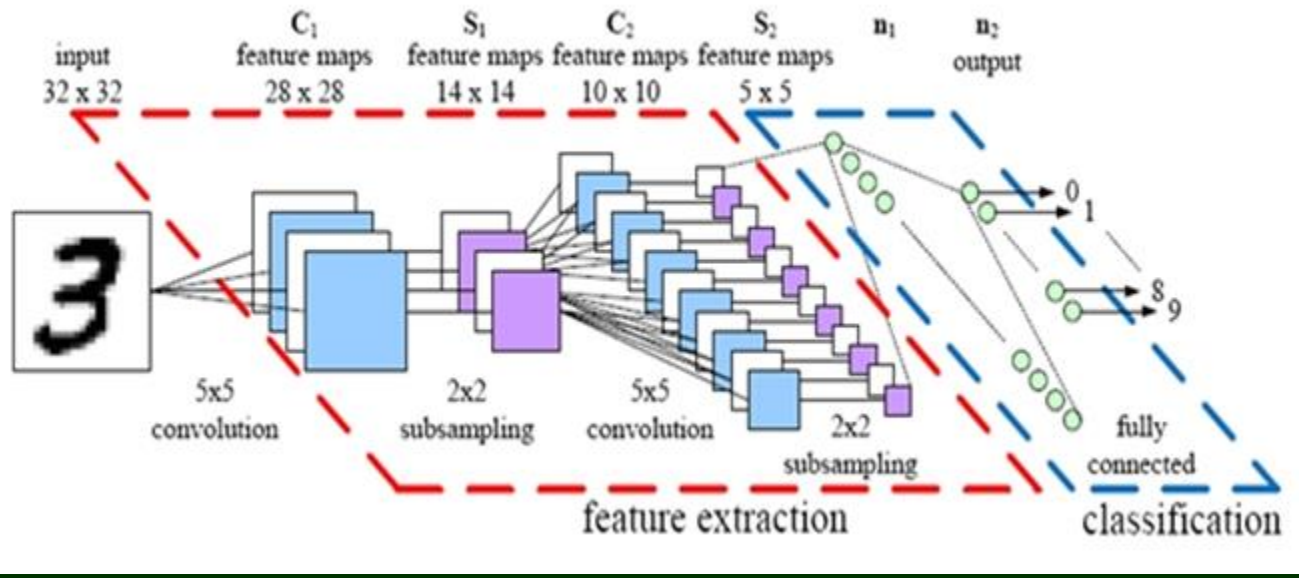
Most neural networks have simple elements, performing elementary nonlinear functions (e.g. semi-linear ReLu), exchanging information through fixed connections, correcting adaptive coefficients to learn transformations. Backprop algorithms do not have a good biological basis.

Ex: tensor networks Cichocki Lab, RIKEN BSI

WD: Support Feature Machines (2011).

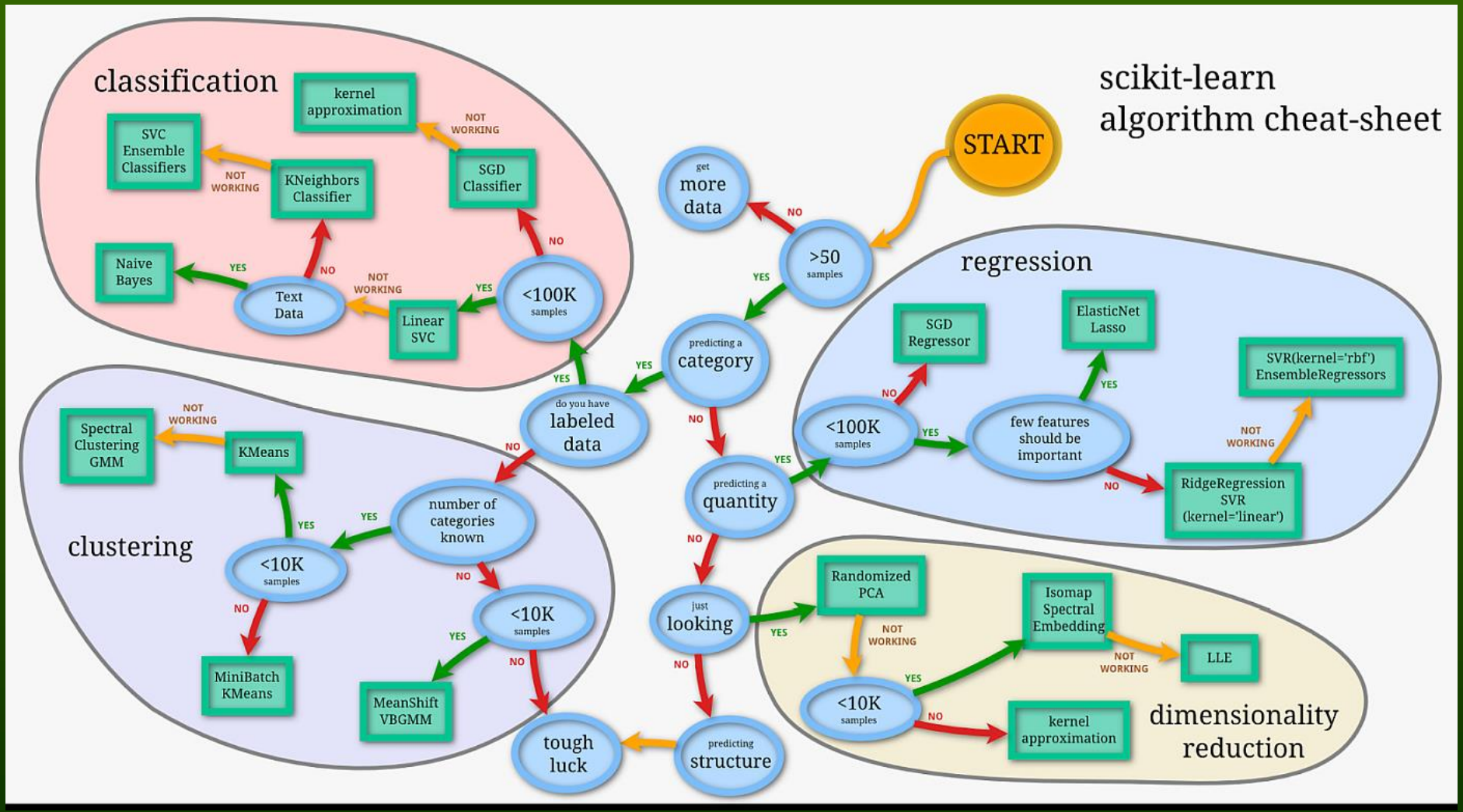
We don't know how to use oscillators for calculations.





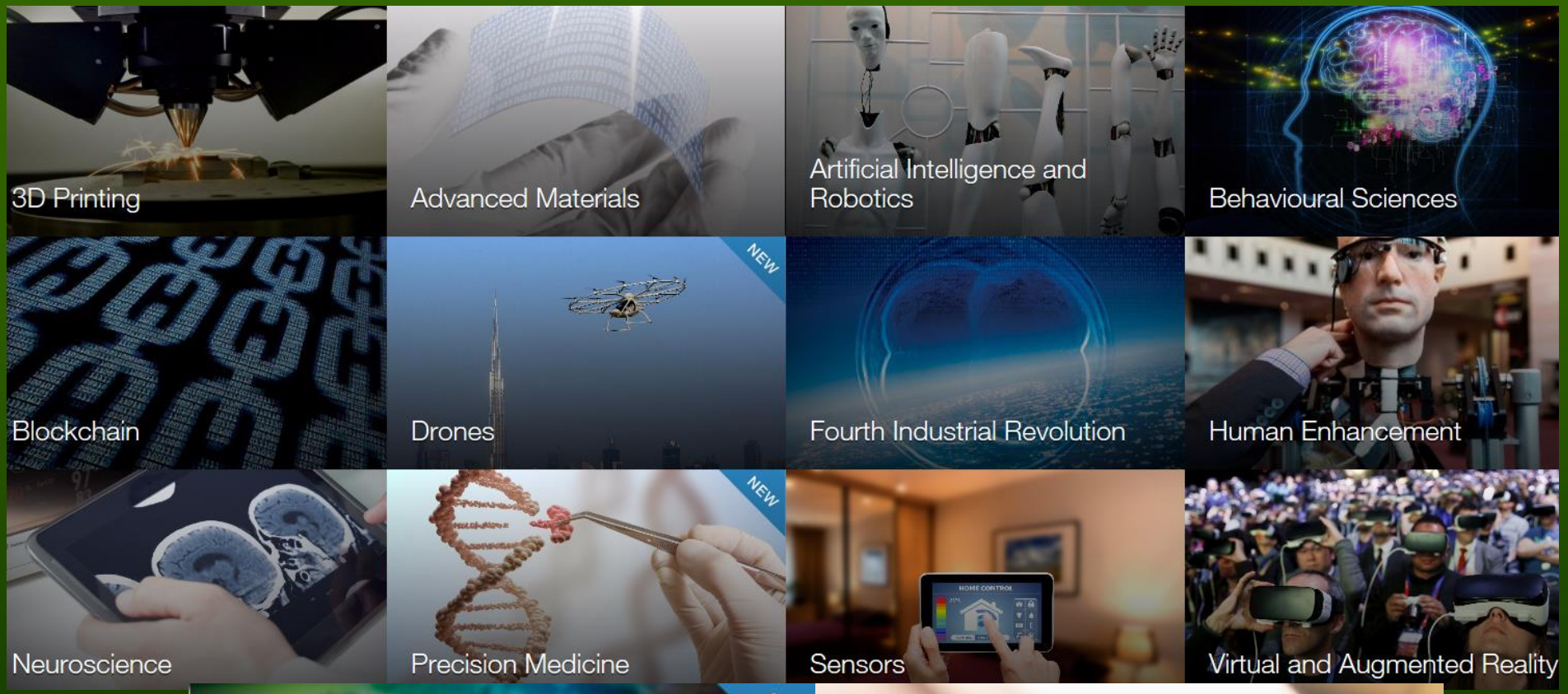
Meta-learning, or how to learn to be able to learn, discovering new models. Transformation-based learning, Support Feature Machines, Universal Learning Machines and many other interesting ideas – see papers on this page.

Just pick up your method ...



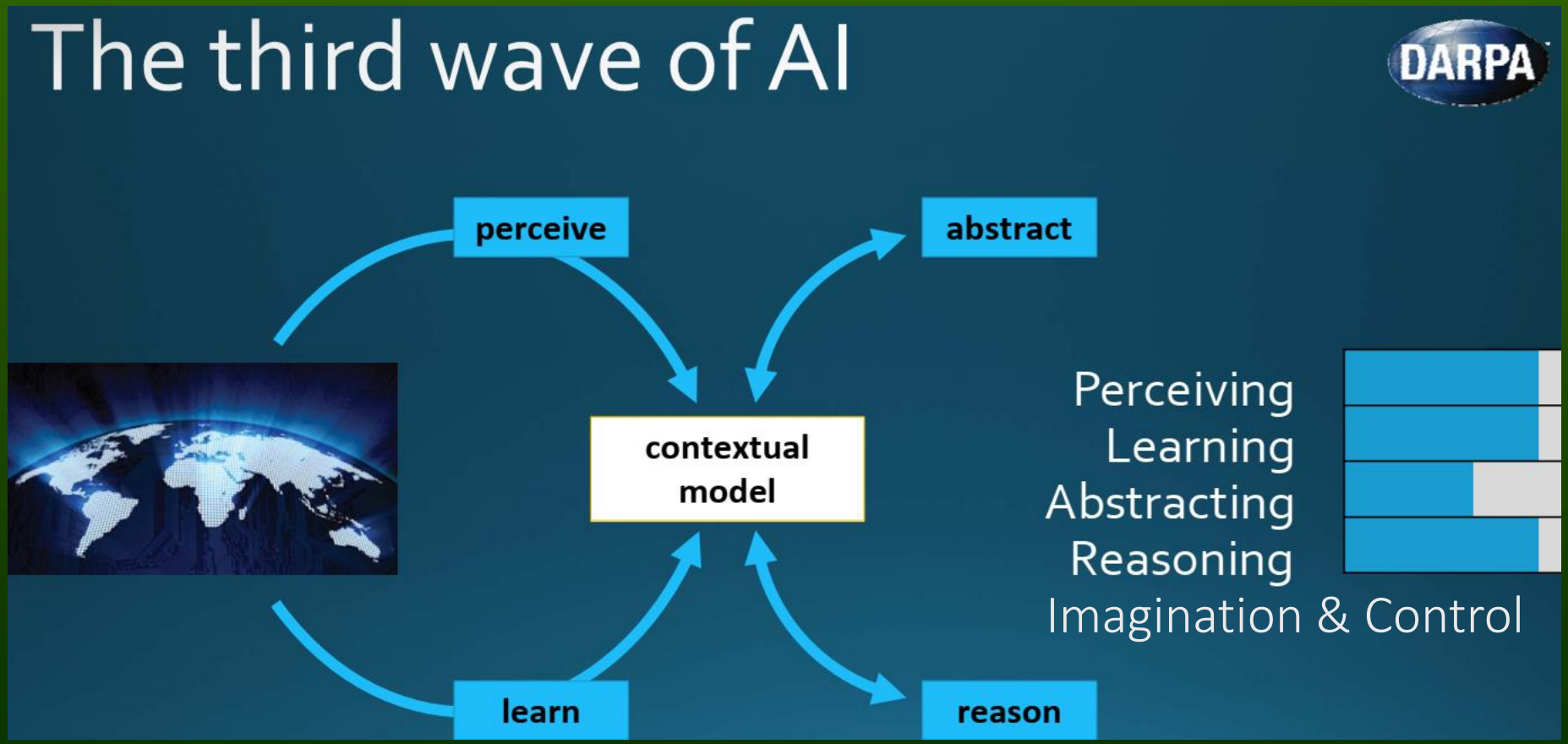
Thousands of applications of machine learning are made using free powerful large systems, such as TensorFlow, Scikit-learn, Keras, MS Cognitive services …

WEF: 4th Industrial Revolution driven by AI/neuro

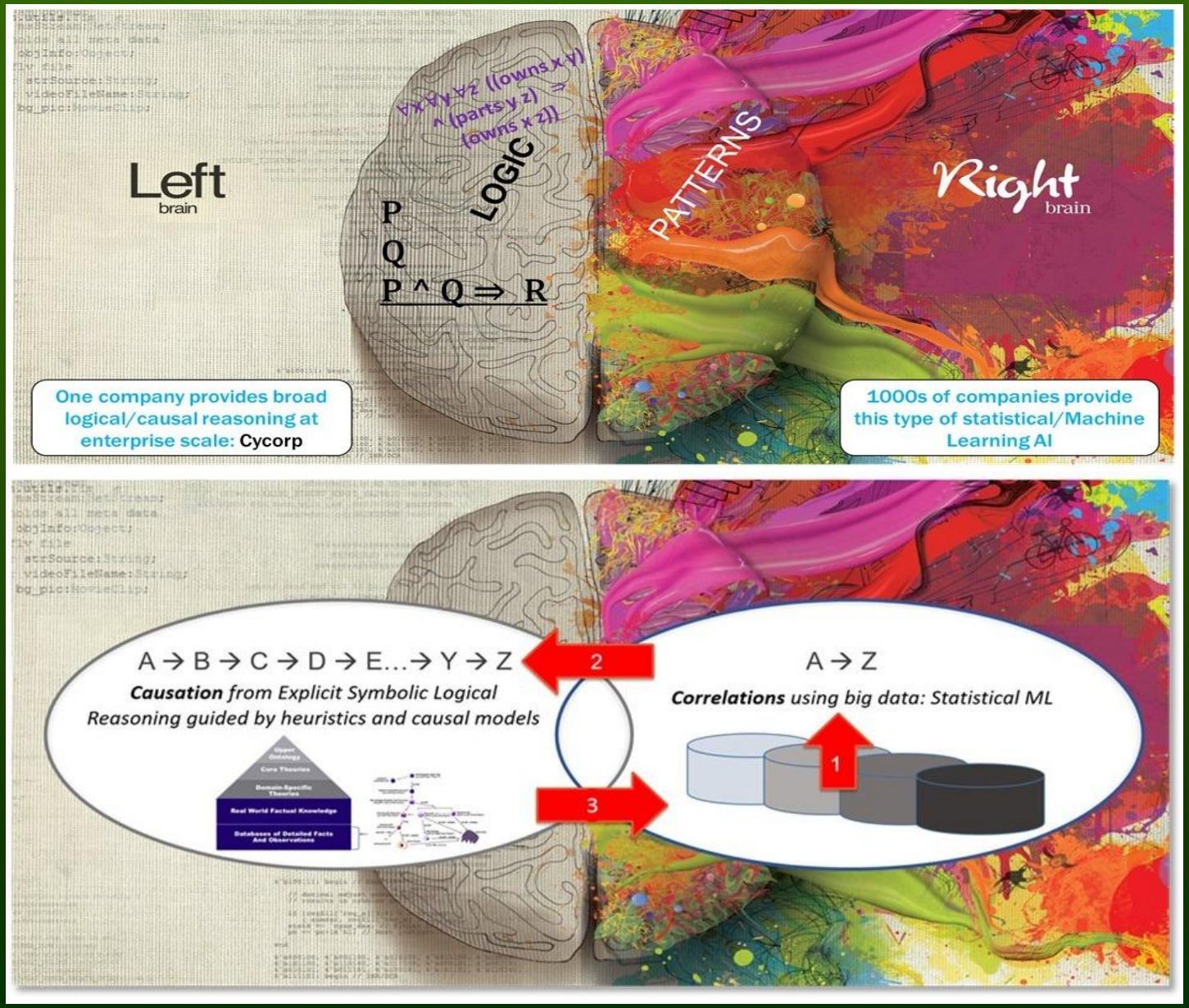


AI history

The First AI Wave (1980): rule-based, expert systems, classic GOFAI systems.
The Second AI Wave (2000): statistical, data-driven approaches, KDD.
Since 2014: GAN, Generative Adversarial Networks, artificial imagination!



Third AI wave and brains



Cogni
Cognitive sciences

Biohybrids

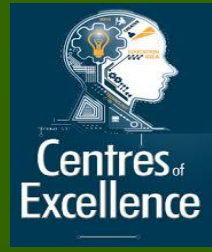
Bio
Neuroscience

Nano
Quantum
Technologies

Neurocognitive
Informatics

Info
Artificial/Computational Intelligence,
Machine Learning, Neural Networks

AI Centers of Excellence



European Commission Communication (4/2018): "The way we approach artificial intelligence will define the reality in which we live."

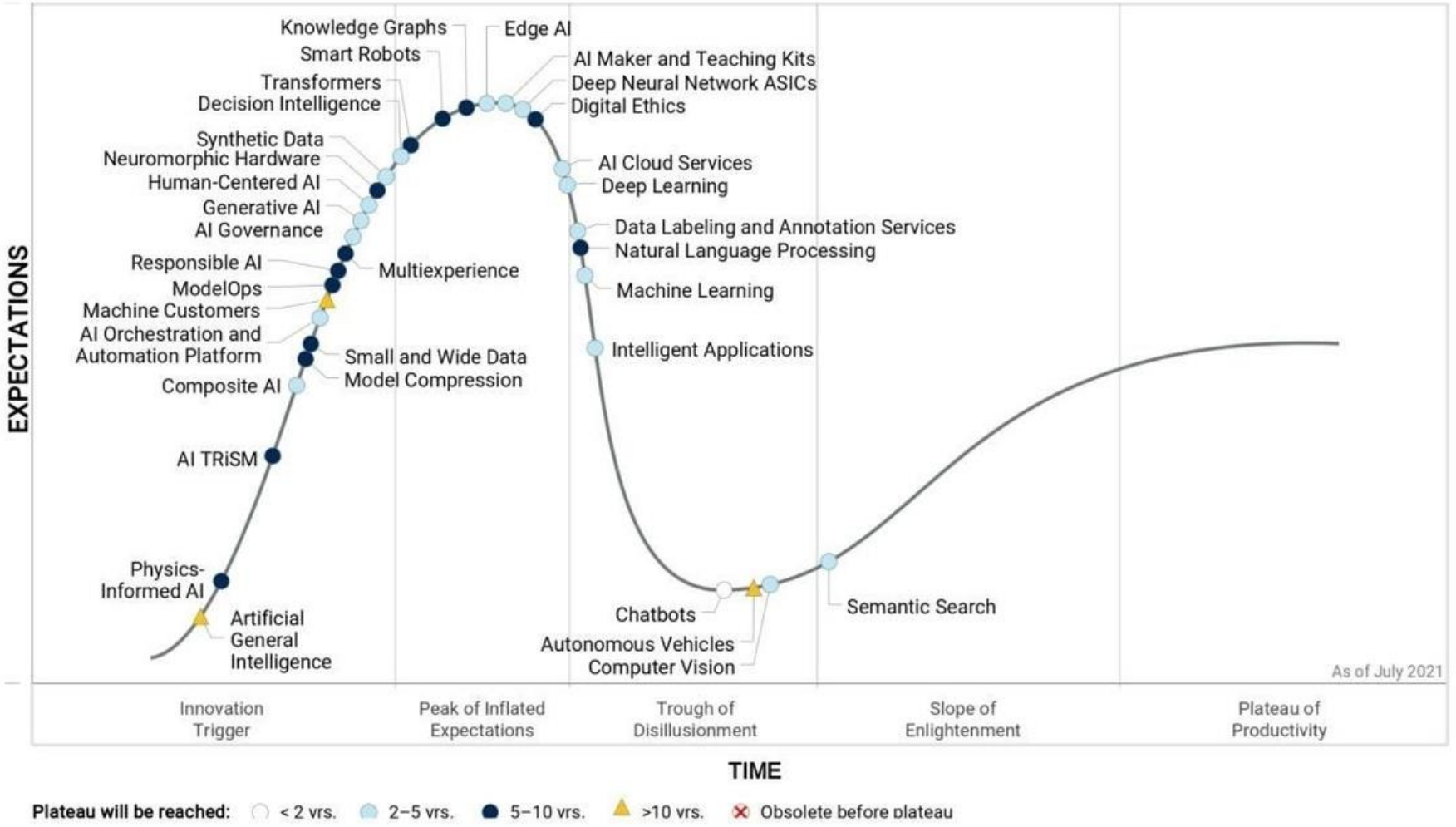
European Network of Artificial Intelligence (AI) Excellence Centers.
Large consortia (2/20-10/20), €50 mln for a good start.

- AI4Media: ethical and trustworthy AI, technology at the service of society.
- ELISE: various forms of inference, understandable, trustworthy AI systems.
- HumanE-AI-Net: supports new forms of human-computer interaction.
- TAILOR: practical applications, building science-public administration-industry cooperation networks, learning, inference, optimization.
- VISION: networking – fostering synergy and collaboration between research groups in the EU.

- PP-RAI: Polish Alliance for AI Development, unites 5 associations, created in 2018, but so far no government support ...

Gartner Hype Cycle

Hype Cycle for Artificial Intelligence, 2021



Source: Gartner (July 2021)

747539

Neuromorphic future

Wall with 1024 TrueNorth chips, equivalent of 1 Billion neurons, 256 B synapses. 1/6 of chimp brain. Cerebras CS-2 chip has 2600 B transistors, almost 1M cores!

Integration:

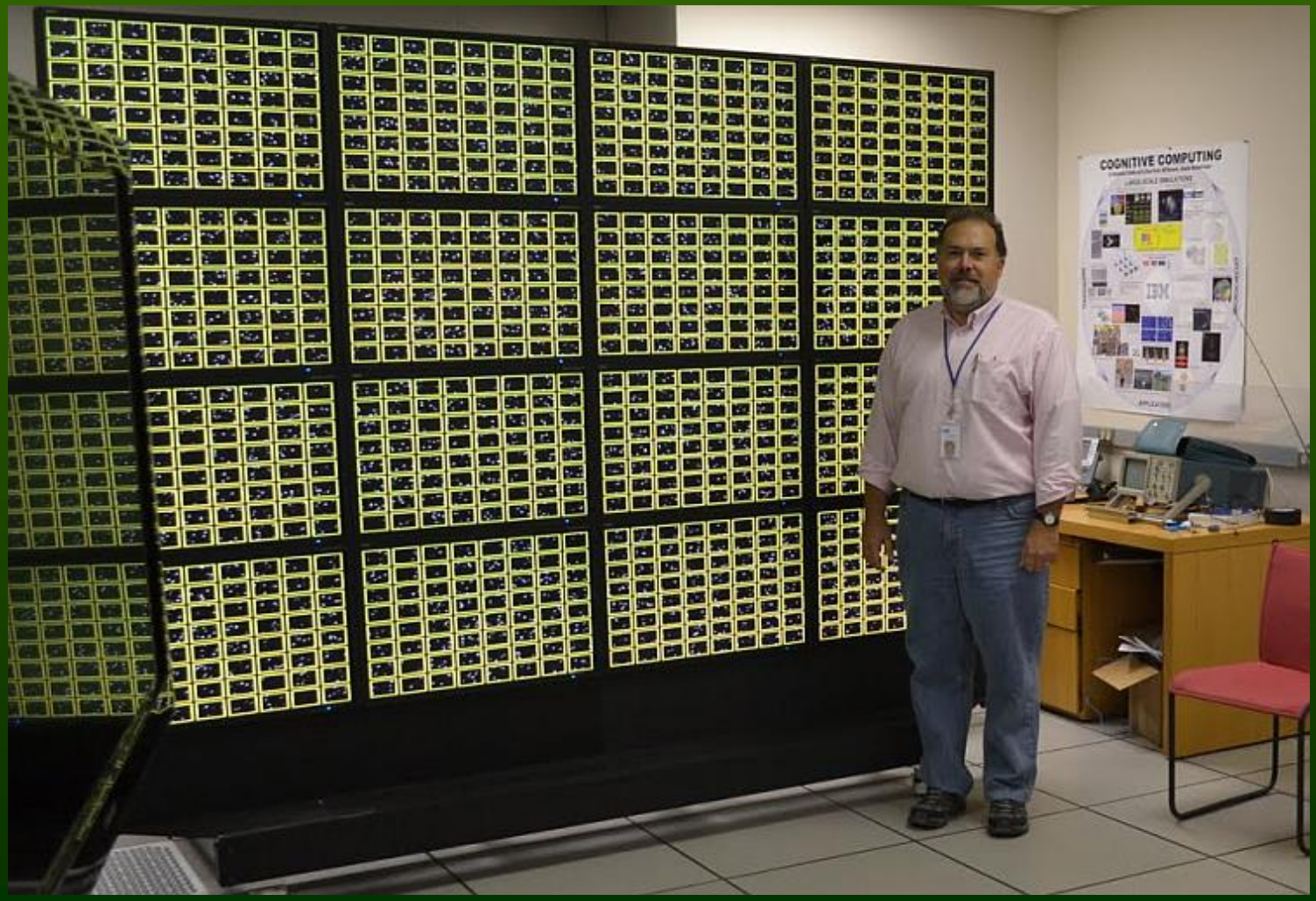
Nano +

Neuro +

Info +

Kogni

Neural AI accelerators AD 2021 200 x CS-2, models > 10^{14} parameters.



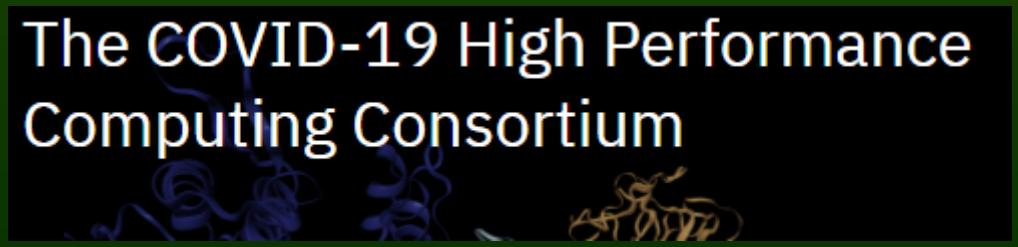
Nano: hybrid clouds

Instead of advanced computing systems, increasingly large projects will use hybrid clouds: local, public and private, traditional + new ways of processing.

Heterogeneity is designed to ensure a smooth workflow across a wide variety of resources, sensor networks, physical devices, and entire laboratories and research organizations. Distributed farms, data flow machines, FPGA, quantum computing, neuromorphic computing, advanced network ...

European Open Science Cloud (2018) Helix Nebula Science Cloud at CERN.
U.S. Department of Energy's Research Hybrid Cloud at Oak Ridge National Lab.

COVID-19 High Performance Computing consortium offering:
50,000 GPUs, 6.8 million cores, 600 Pflops, 100 medical projects.
The consortium has 43 organizations: US national laboratories, NASA, NSF, NIH, Amazon, Google, Dell, HP, IBM, Intel, Microsoft, Nvidia, MIT, RIKEN, KISTI ...



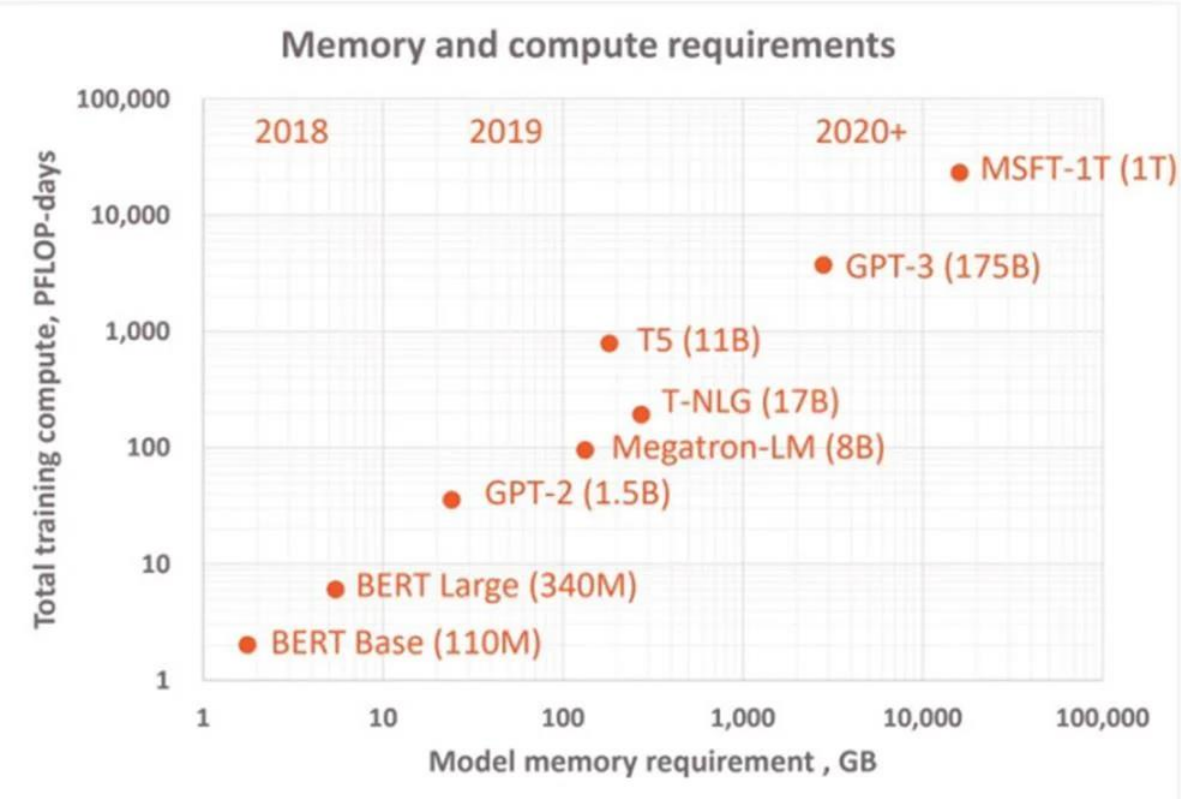
BERT

Language models may encode knowledge about relation of words in complex network structures. In 2018 Google group created BERT, language model pre-trained on a large text corpus to gain a general-purpose "language understanding". That model is then fine-tuned for specific NLP tasks such as question answering or semantic information retrieval.

- **Bidirectional Encoder Representations from Transformers** (**BERT**). Transformer-based machine learning technique for (NLP) pre-training.
- English-language BERT: two networks, smaller 110M parameters, larger model with 340M parameters in 24-layers; trained on the BooksCorpus with 800M words, and Wikipedia with 2,500M words.
- 12/2019 BERT worked in 70 languages, in 2020 many smaller pre-trained models with the whole word masking open software models were published in GitHub repository.
- The network learns to predict masked words (images, signals):
  Input: the man went to the [MASK1] . he bought a [MASK2] of milk.
  Labels: [MASK1] = store; [MASK2] = gallon
- Super-human Q/A on Stanford Question Answering Dataset (SQuAD)

Acceleration...

Exponential Growth of Neural Networks



1000x **larger models**

1000x **more compute**

In just **2 years**

Today, GPT-3 with 175 billion params trained on 1024 GPUs for 4 months. OpenAI

MS+Nvidia MLM, MSFT models

Tomorrow, **multi-Trillion** parameter models and beyond.

Such models allow to associate facts in many domains.
Science is moving beyond dedicated advanced computer systems, making greater use of hybrid clouds: local, public & private, traditional + new ways of computing

Superhuman AI

Reasoning: 1997–Deep Blue wins in chess;
2016 –AlphaGo wins in Go; 2017 Alpha GoZero beats it.

Perception: recognition of faces, images, personality traits, sexual preferences, political ...

Strategy and Controls: 2017–OpenAI wins in Poker and Dota 2; 2019-Starcraft II ... what's left?

Scientific experiments: 2015-AI uncovers genetic and signaling pathways of flatworm regeneration.
2020-AlphaFold 2 almost solves protein folding.

Robotics: 2020 Boston Dynamics' backflip and parcour, autonomous vehicles on the roads.

Creativity and imagination: AIVA and other AI music composers, DeepArt, Dall-E2 and other GANs.

Language: 2011–IBM Watson wins in Jeopardy;
2018–Watson Debater beats professionals
2020: BERT answers questions from SQuAD database.

Cyborgization: BCI, brain optimization, coming?

Artificial General Intelligence (AGI), Memphis 2008

2022: DeepMind Gato is a relatively small model, with 1.2 billion parameters. Multi-modal, multi-task, multi-embodiment, learned simultaneously over 600 tasks, games to controlling robots. Small working memory capacity.

AGI & BICA

From an engineer's perspective, to understand the brain is to build a working model that exhibits the same functions. Needed: spatial models of phenomena, actions and their causes, real world imagery.

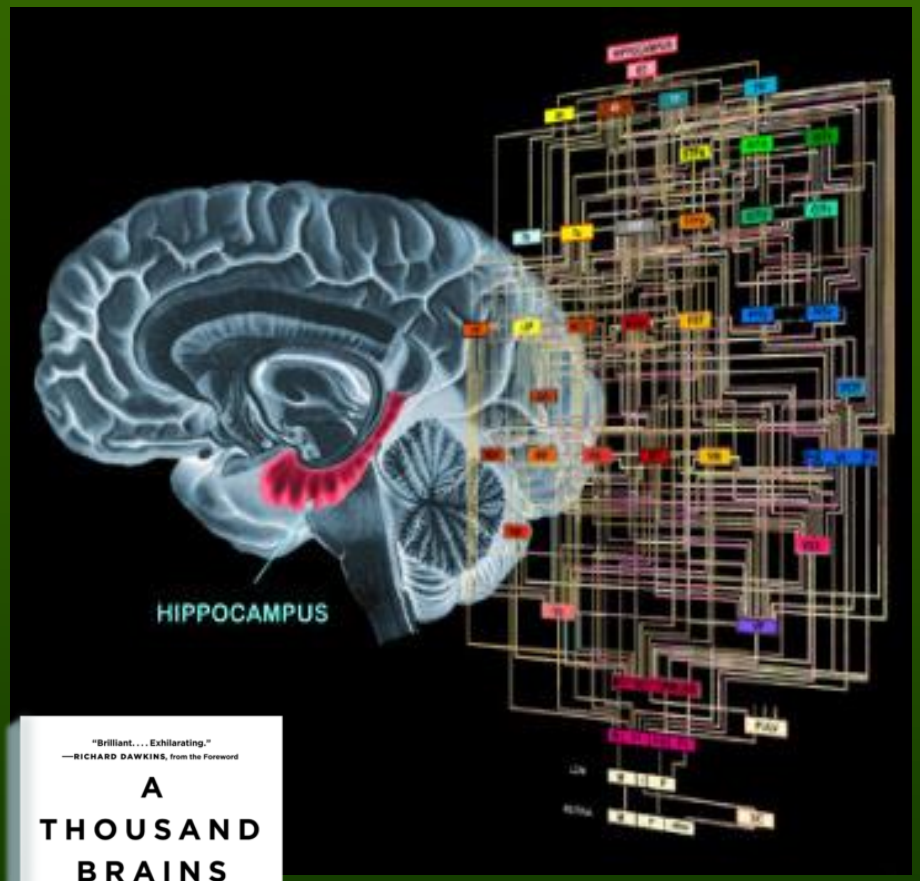
AGI = Artificial General Intelligence, learn many different things.

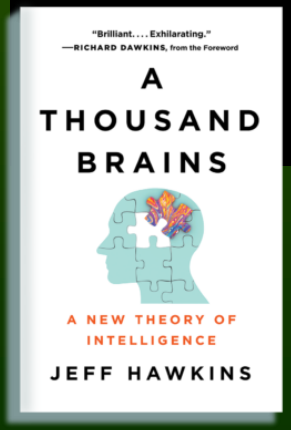
BICA (Brain-Inspired Cognitive Architecture) brain-like intelligence.

Duch, Oentaryo, Pasquier, Cognitive architectures: where do we go from here?

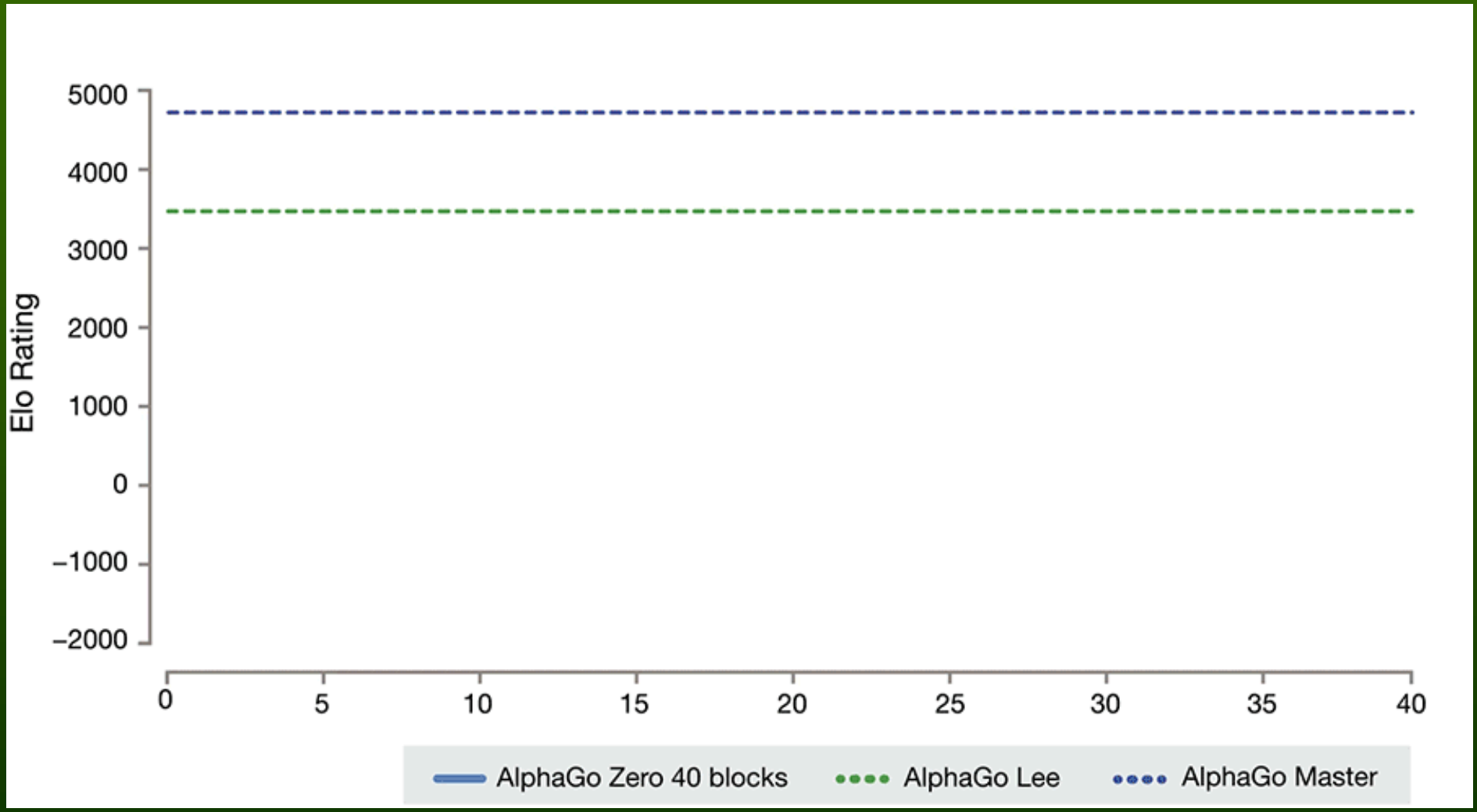
"We'll never have true AI without first understanding the brain"

Jeff Hawkins (2020).





AlphaGo Zero learns Go from 0!

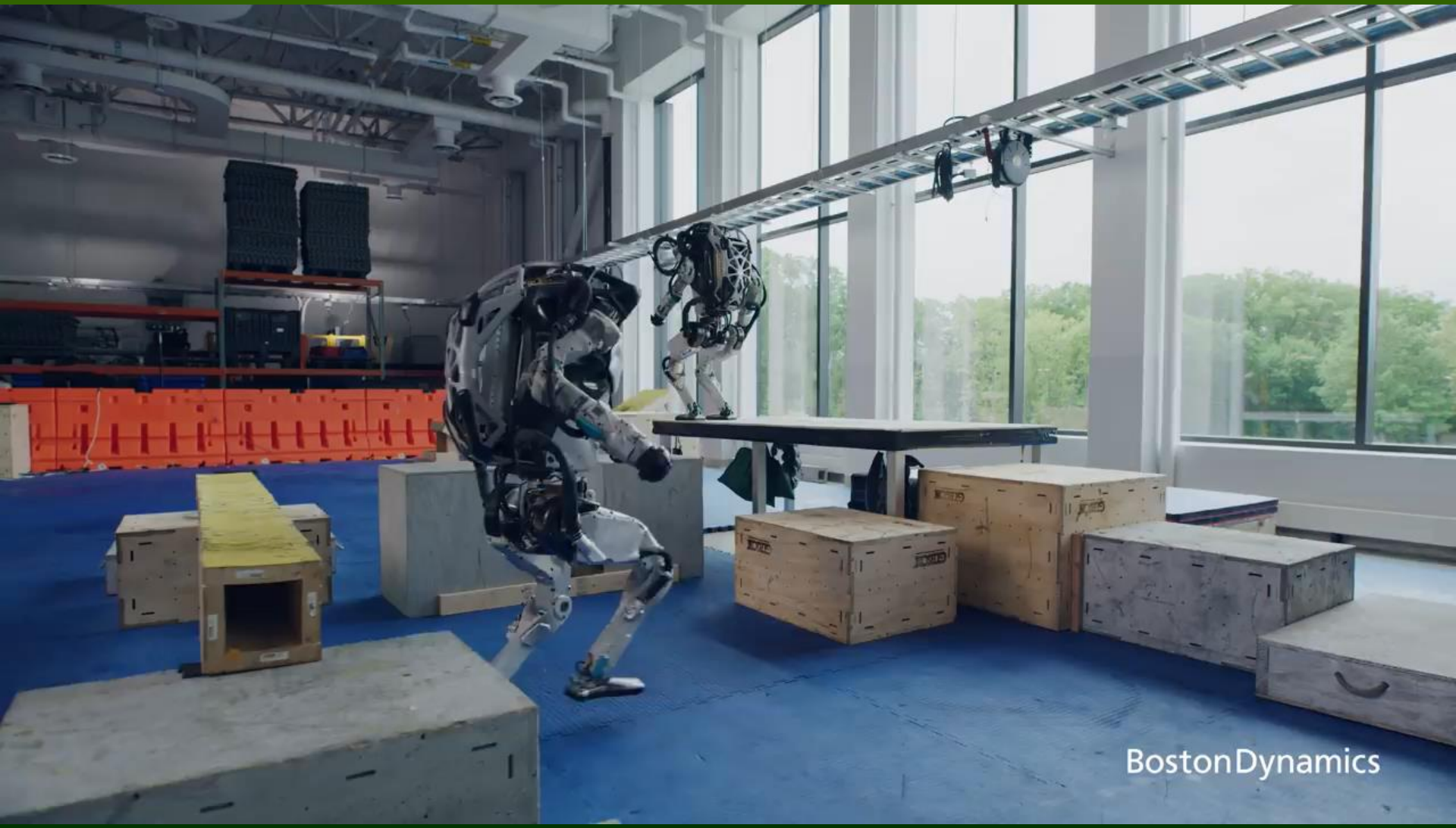


Superhuman level in the strategic game of Go. Human experience surpassed by software playing against its own copy. Search + NN as heuristics.

Control: robots

Behavioral intelligence: training a robot from “infancy”.

Cog Project, MIT Brooks lab, 1994-2003. iCube (EU). Now we have **Atlas**.



Protein folding

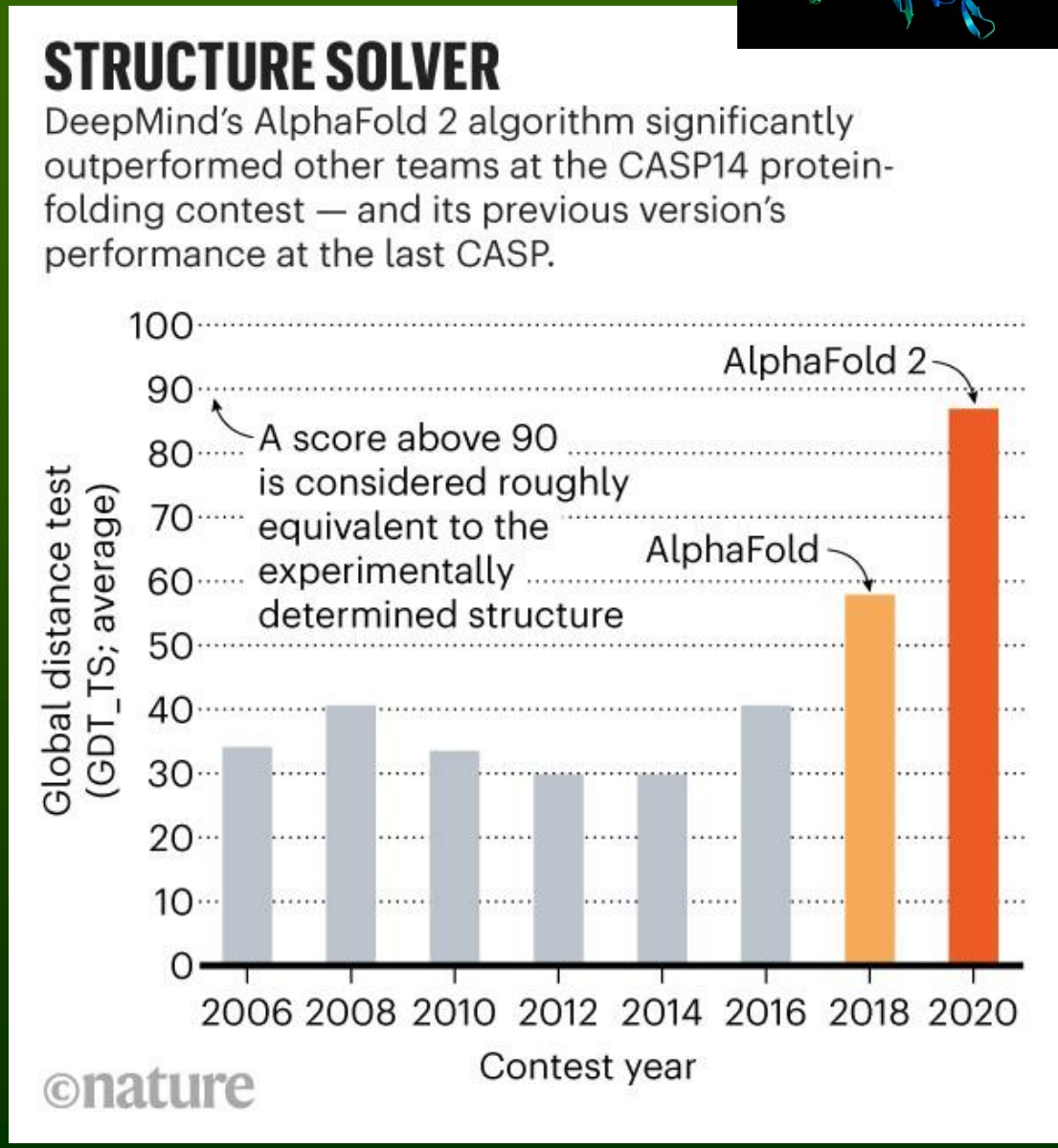
AlphaFold 2 using deep learning predicts more than 2/3 of protein structures with an accuracy equivalent to experimental!

Nature, 30.11.2020

Structure recognition + learning + inference.

Predicting protein structures based on amino acid sequences is the basis for the search for proteins and the design of drugs with the desired properties.

Predicted over 200 mln structures (DM+EMBL-EBI).



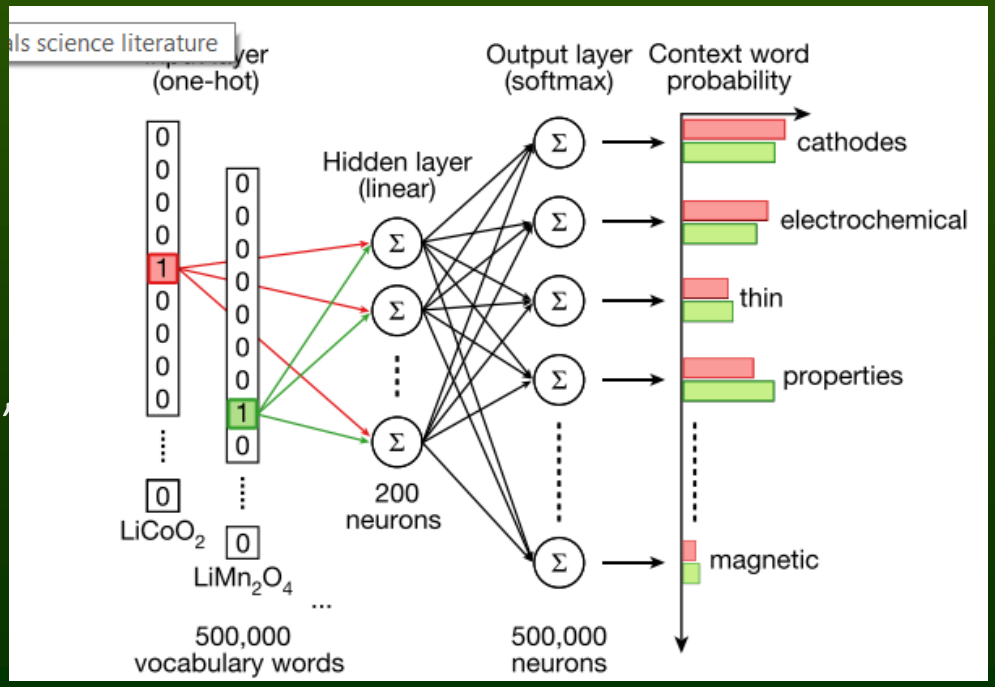
Material design

Tshitoyan, V. … Jain, A. (2019). Unsupervised word embeddings capture latent knowledge from materials science literature. Nature, 571(7763), 95.

Materials science knowledge present in the published literature can be effectively encoded as a dense informative representation of concepts. Without any explicit introduction of chemical knowledge, complex concepts such as the basic structure of the periodic table and the relationships between the structure and properties of materials can be presented.

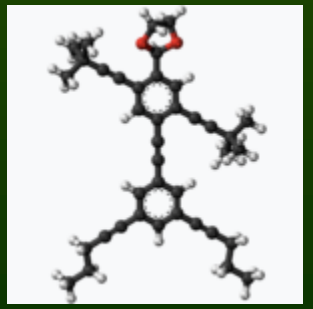
Based on previous publications unsupervised ML methods can recommend materials for functional applications a few years before they were discovery.

GPT Crush: applications in business, design, education, philosophy, research, creative writing and many other fields.



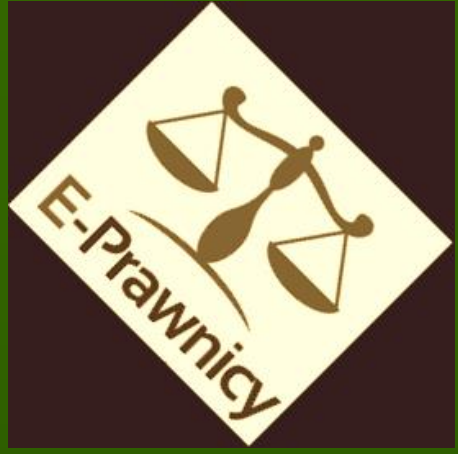
Chemistry/material science

- N. Nosengo, “Can you teach old drugs new tricks?” *Nature*, 534, (2016), 314
- L. Himanen, A. Geurts, A. S. Foster, P. Rinke, Data-Driven Materials Science: Status, Challenges, and Perspectives. *Advanced Science*, 2019.
- A. C. Vaucher, F. Zipoli, J. Geluykens, V. H. Nair, P. Schwaller, T. Laino, Automated extraction of chemical synthesis actions from experimental procedures. Nature Communications, 2020.
- P. Staar, M. Dolfi, C. Auer. Corpus Processing Service: A Knowledge Graph Platform to perform deep data exploration on corpora. *Authorea* 2020.
- C.W. Coley, N.S. Eyke, K.F. Jensenz, Autonomous discovery in the chemical sciences part I: Progress, part II: Outlook. arXiv:2003.13754v1, 2020.
- P. Zhang, Z. Wei, C. Che, Bo Jin, Computers in Biology and Medicine 142, 105214, DeepMGT-DTI: Transformer network for Drug–Target interaction prediction.



Duch W and Diercksen GHF (1994) *Neural networks as tools to solve problems in physics and chemistry*. CPC 82, 91-103.

Lawyers



Lawyers: EMERJ.com predicts automation in 6 categories:

1. Information collection, contract review, legal research and electronic detection of inaccuracies.
2. Forecasting the outcome of court proceedings.
3. Legal analysis – data from previous case law, win/lose ratios, judge's history, study of trends and patterns.
4. Automate the filling out of documents based on data.
5. Intellectual property, analysis of large intellectual property portfolios ...
6. Electronic invoicing.

WhatSun Exterro – out of 100 lawyers, 5 remained thanks to e-Discovery.

JP Morgan – COIN (Contract Intelligence) handles 12,000 loan agreements or contracts in a few seconds, equivalent to about 36,000 hours of work. Annually makes 12,000 less errors in the analyzed contracts than humans.

eBrevia – summary and analysis of documents, writing reports.
50 long contracts in less than 1 minute, 10% fewer errors.

Vanishing professions

- World Economic Forum: 85 million jobs lost by 2025, but an increase in ITC/AI. “Dying professions”:
- 200,000 telemarketers, call/contact center in Poland.
- Mechanics, machine operators, equipment repairs ...
- Travel agents.
- Mortgage brokers, bank officials ...
- Postal officials, sellers, cashiers ...
- Employees of administration, accounting ...
- Truck and taxi drivers, farmers ...
- Journalists, reporters, booksellers, architects, photographers, artists ...
- Lawyers, middle managers ...
- Scientists? IT specialists?

Superhuman perception

Automatic analysis of facial features determines: gender, age, race, diseases, BMI.

Surprise! Also, emotions, character traits, criminal tendencies, religious, political, and sexual preferences can be read from faces with greater accuracy than people are able to recognize.

Sex: using 5 photos/person: homo or hetero men 91% accuracy, women 83%. Humans: 35 people got only 61% and 54% correct.

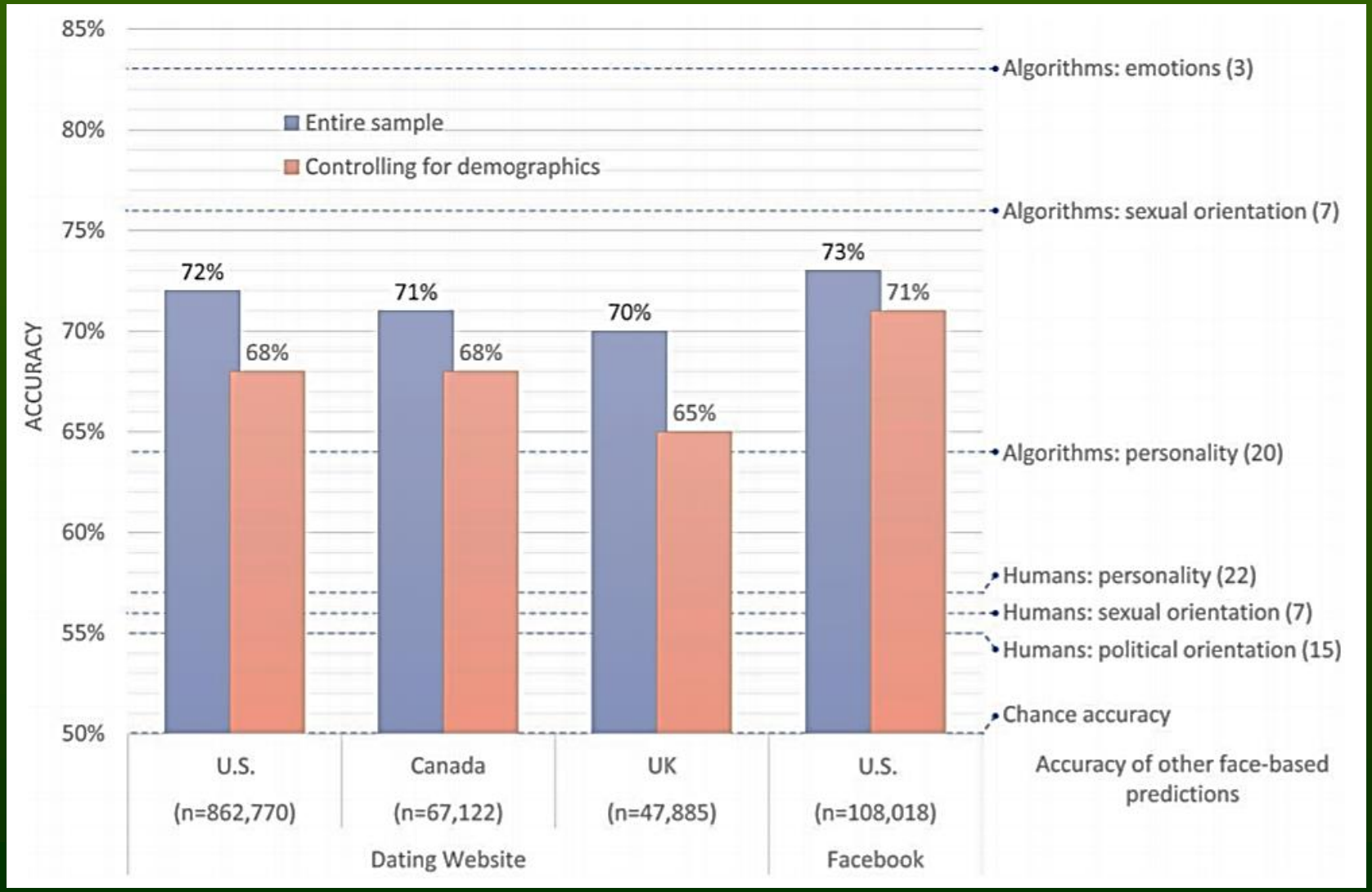
(a) Three samples in criminal ID photo set S_c.

(b) Three samples in non-criminal ID photo set S_n

Analysis of over million photos allows to determine **liberal vs conservative** political preferences in 72% of cases. People - 55% correct.
Criminal tendencies: for 5,000 prisoners and the same number of control photos, CNN gave 97% accuracy (this work was withdrawn by ethics committee).

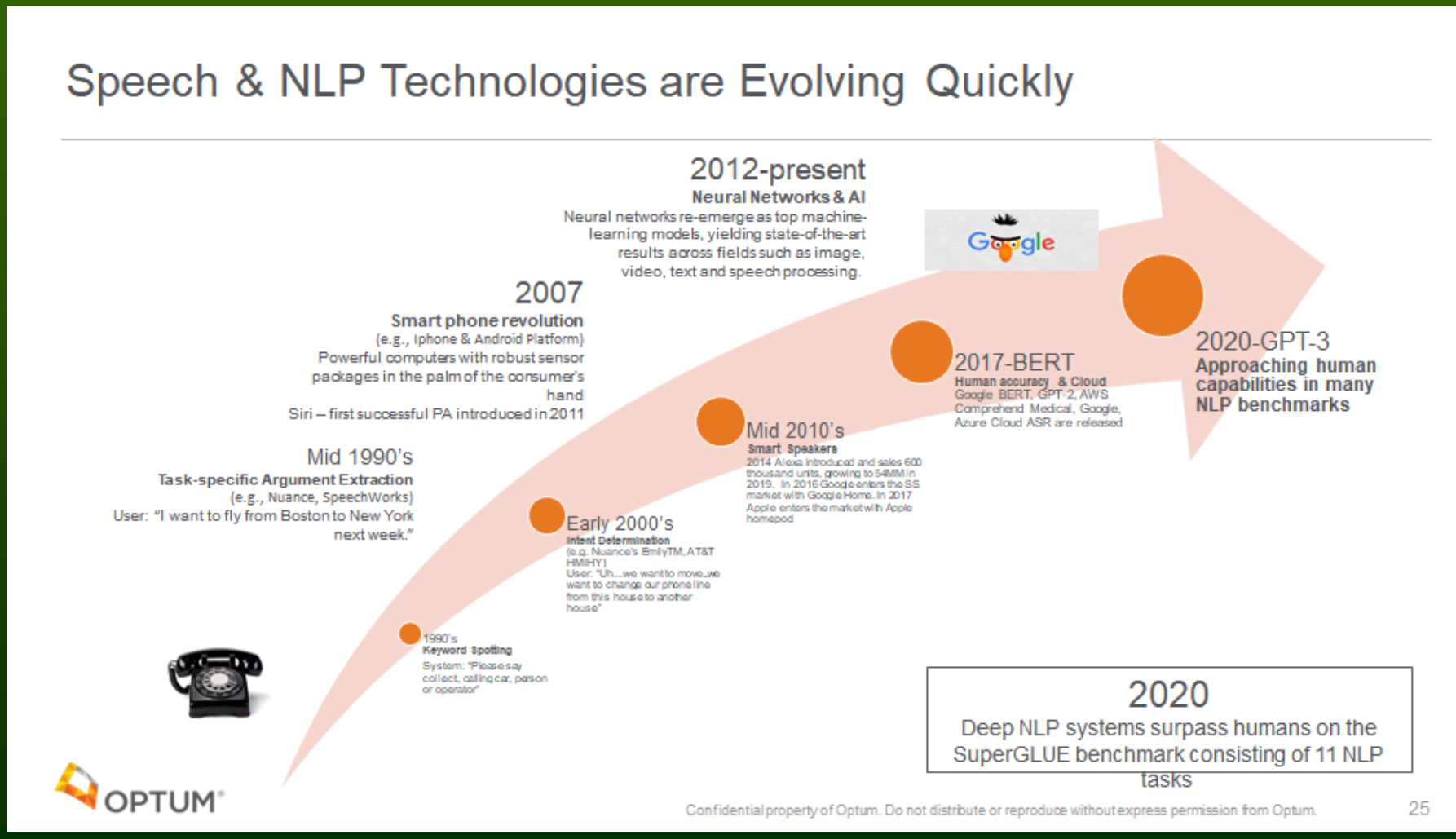
Preferences painted on the face?

Analysis of facial images of >1M people allowed to recognize conservative vs liberal orientation in 72%; human judges 55% (M. Kosiński, Sci. Rep. 2021).



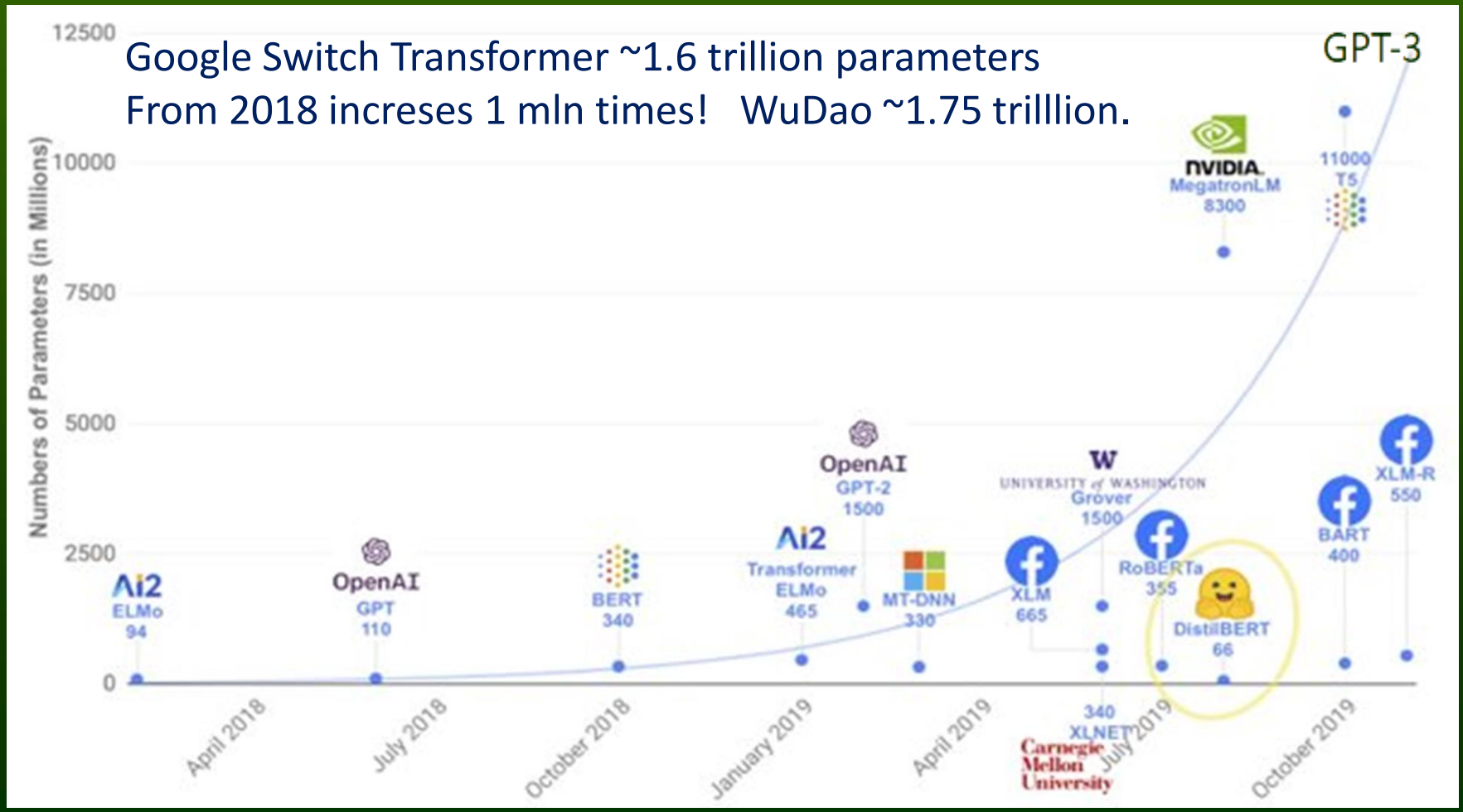
Q/A state of the art

Results for 100,000 questions from the database Stanford Question Answering Dataset (SquAD) are better than the results achieved by humans.



NLP supermodels

OpenAI GPT-3 model has 175 B parameters! One can use it on OpenAI server. First-of-its-kind API can be applied to any language task, and currently serves millions of production requests each day.

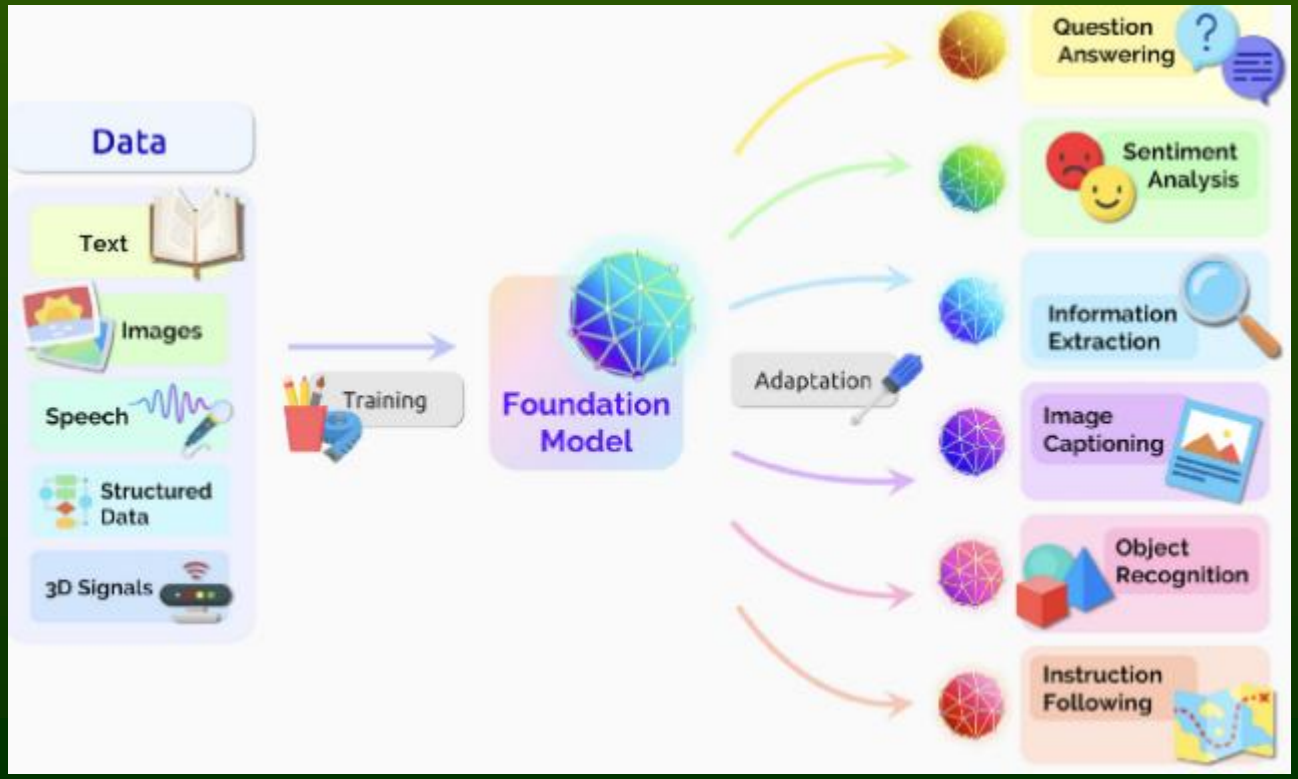


Mulitimodal models

Multimodal learning - different types of modalities with different statistical properties, embedded in **the same model**.

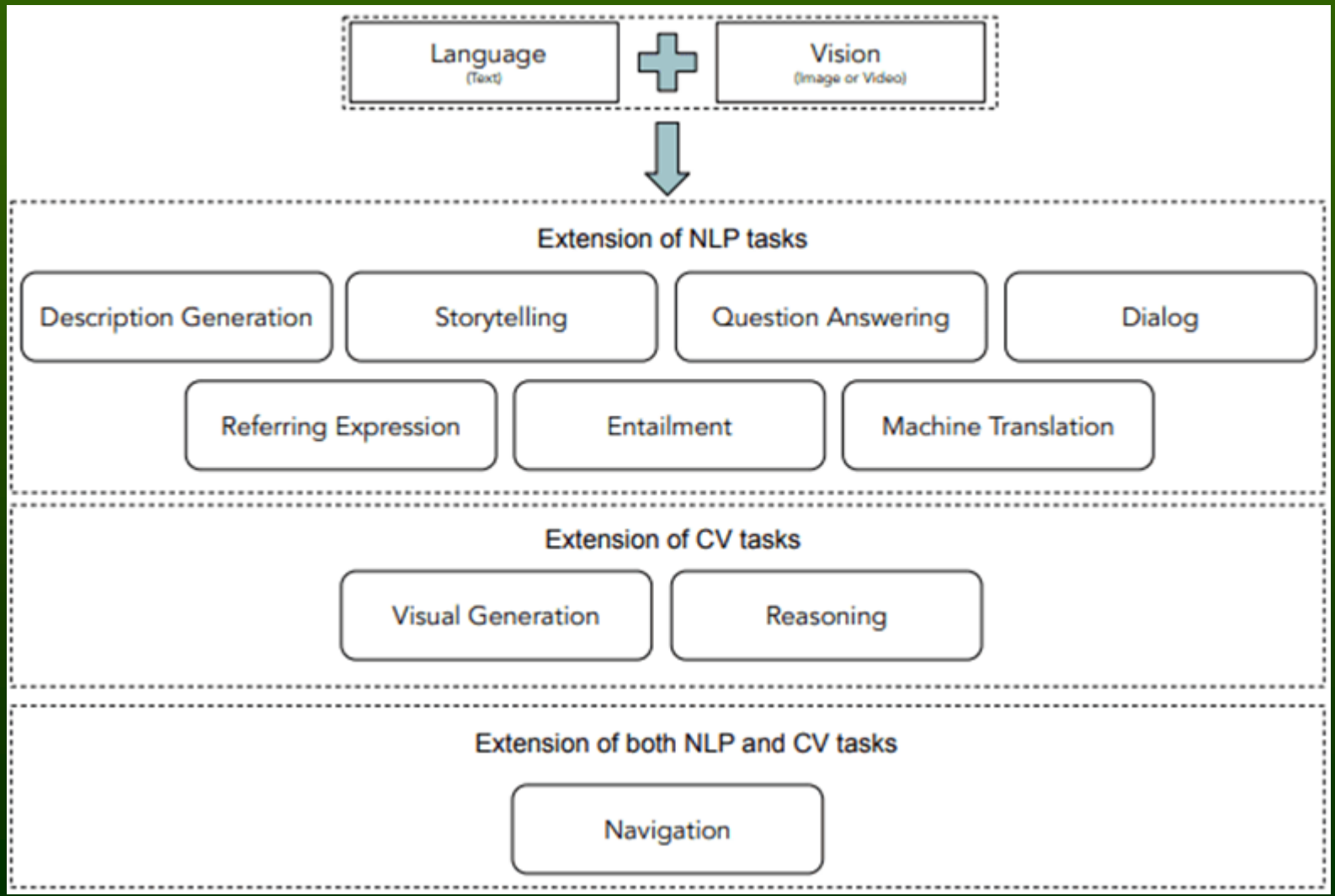
- **Multimodal Affective Computing (MAC)**, sentiment analysis.
- **Natural Language for Visual Reasoning (NLVR)**.
- **Multimodal Machine Translation (MMT)**.
- **Visual Retrieval (VR)** and **Vision-Language Navigation (VLN)**.

Image: Center for Research on Foundation Models (CRFM), Stanford Institute for Human-Centered Artificial Intelligence (HAI)



Vision-language models

Vision-Language Pre-Trained Models (VL-PTMs), convergence of language, vision, and multimodal pretraining => general-purpose foundation models can handle be easily adapted to multiple diverse tasks with zero-shot learning.



Vision-language models

MS BEiT-3 (BERT Pretraining of Image Transformers), a general-purpose state-of-the-art multimodal foundation model for vision-language tasks.

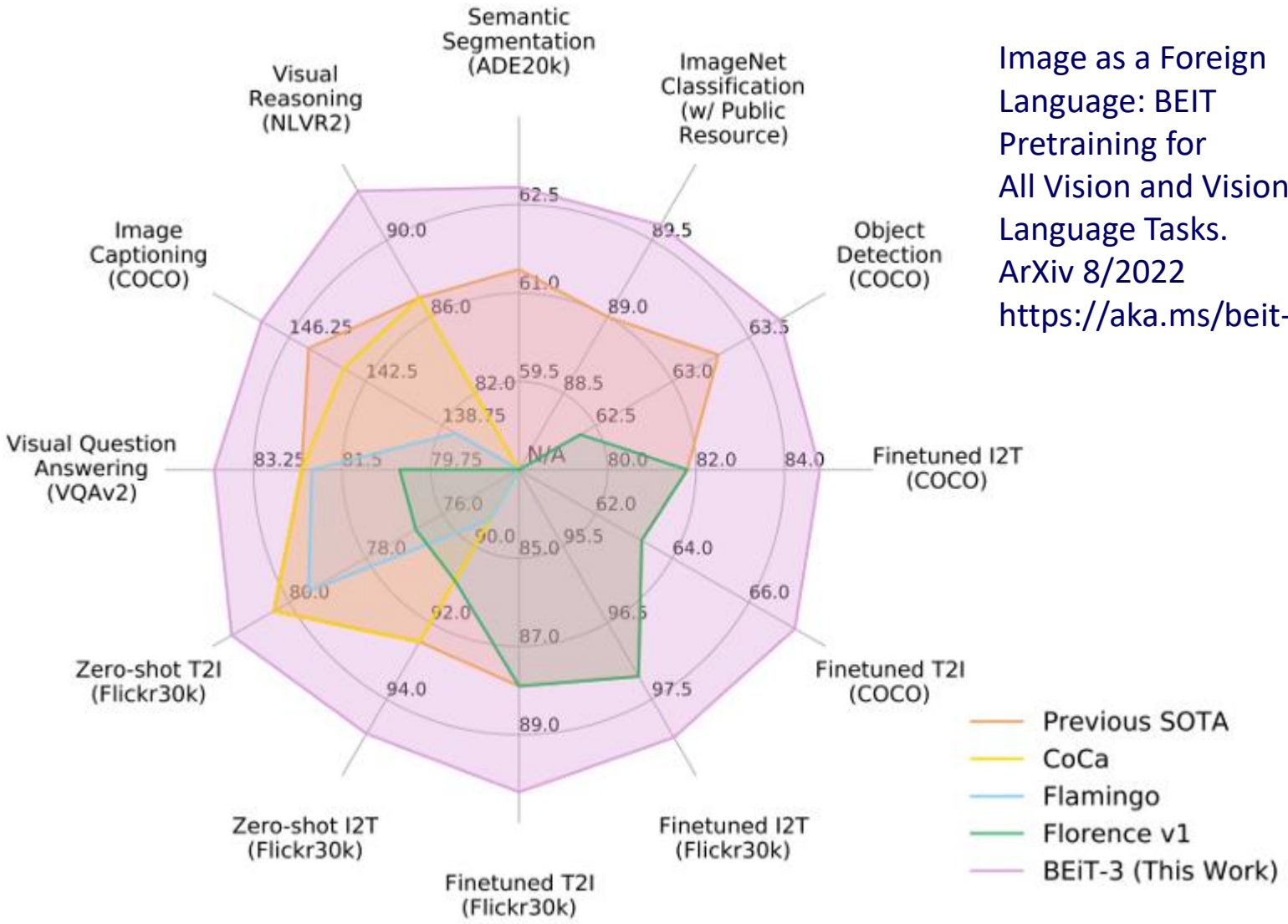
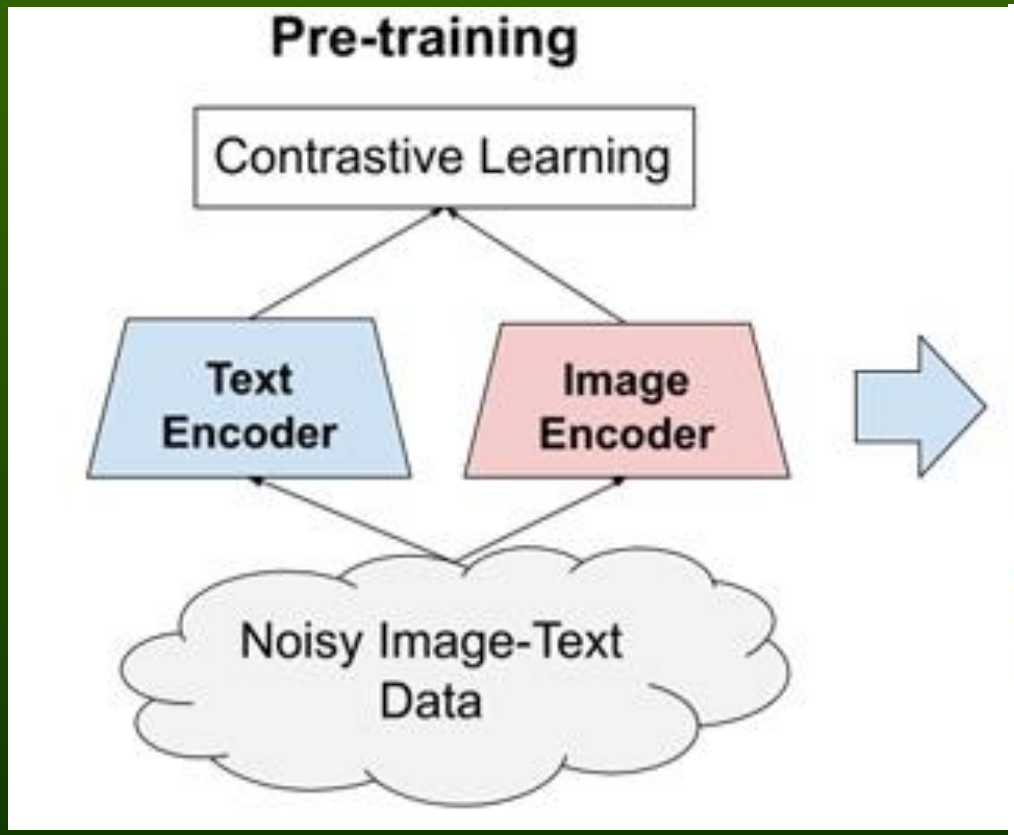
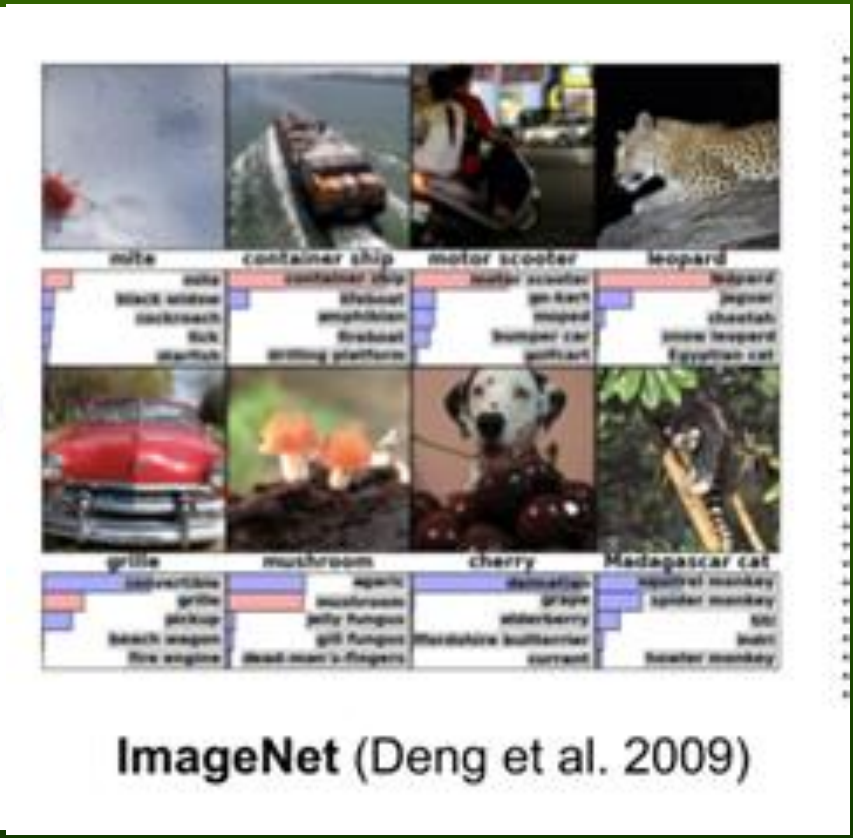


Image as a Foreign Language: BEIT Pretraining for All Vision and Vision-Language Tasks. ArXiv 8/2022 https://aka.ms/beit-3

Vision-language models

Vision-Language Pre-Trained Models (VL-PTMs)production requests each day.



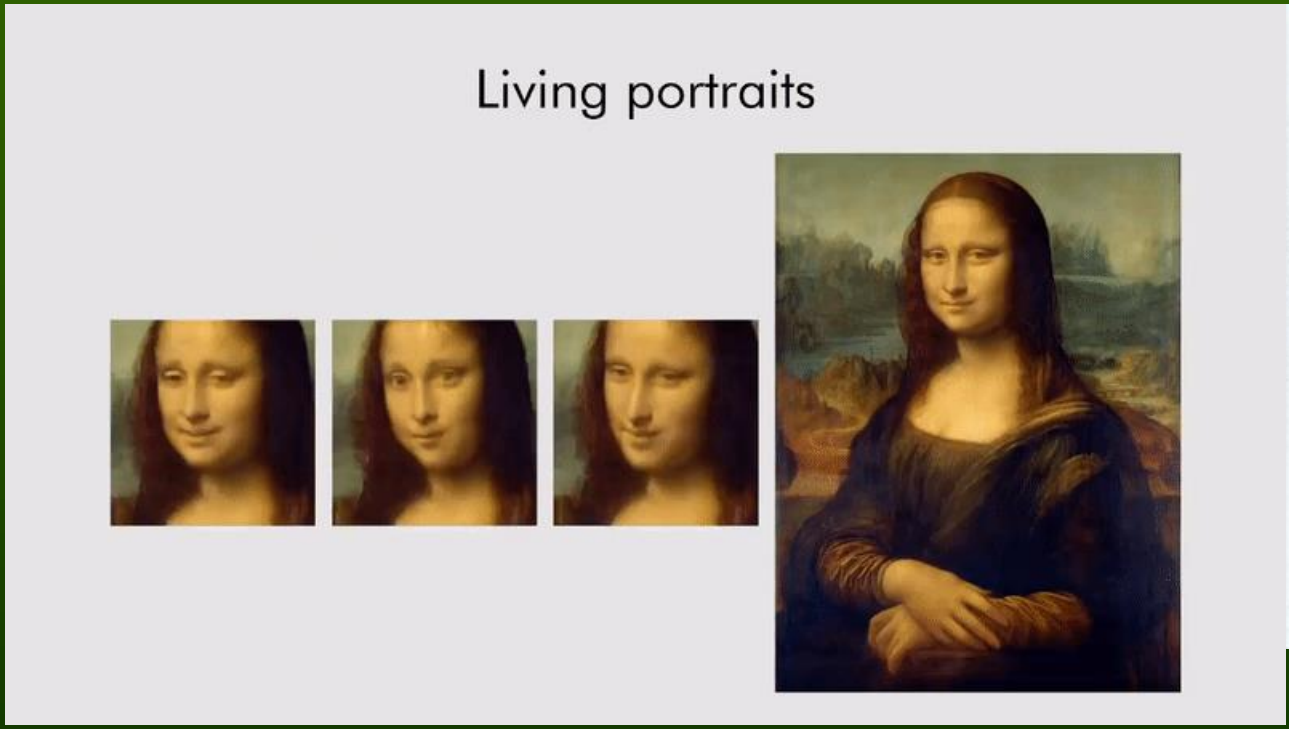


GAN, Generative Adversarial Networks

Idea (2014): one network generates false examples by distorting training data, the other evaluates whether it is real data. To see is to believe! Not anymore!

GAN-animation

Images are revived or automatically turned into caricatures.
A realistic model requires several photos or images.
You can also add different expressions imitating personality and voice.



Gender swap of composers, AI can change your gender!
No pills secretly thrown into children's satchels are needed to do it!

Deep fake video

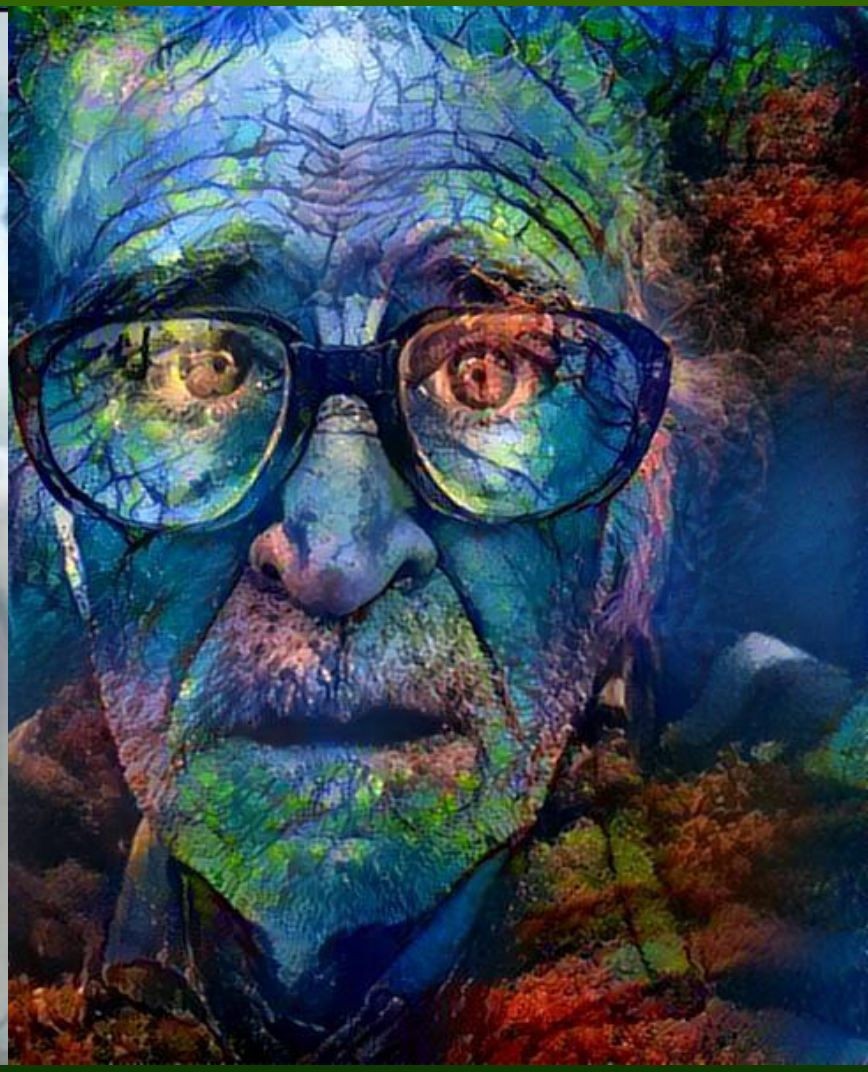
Anyone can create „deep fake”.
You can also add different expressions imitating personality and voice.

Deepfake Videos Are Getting Real, Gender swap of composers
Google Deep Dream, or androids really dream of electric sheep!

Deep Dream

Artificial imagery: Google Deep Dream/Deep Style & Generator, Gallery
LA Gatys, AS Ecker, M Bethge, A Neural Algorithm of Artistic Style (2015)

Deep Dream



Artificial imagery: Google Deep Dream/Deep Style & Generator, Gallery
LA Gatys, AS Ecker, M Bethge, A Neural Algorithm of Artistic Style (2015)

Vision-language generative models

Dall-E2, Craiyon, Imagen, Midjourney, Nightcafe, Artbreeder, Hotpot AI, Deep Dream Generator, Deep AI Text to Image, Generative Engine, Starry AI, My Hertitage …

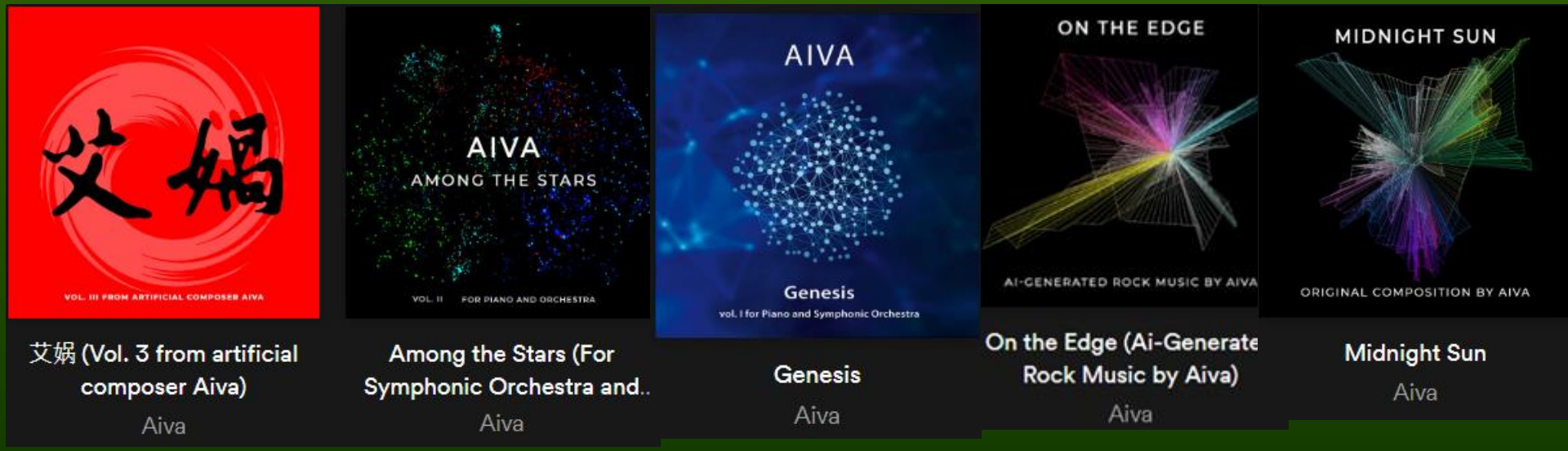
PromptBase is at the center of the new trade in prompts for generating specific

Creativity: AI Virtual Artist

AIVA – AI Virtual Artist, admitted to SACEM (Association of Authors, Composers and Music Publishers of France), 239 utworów.

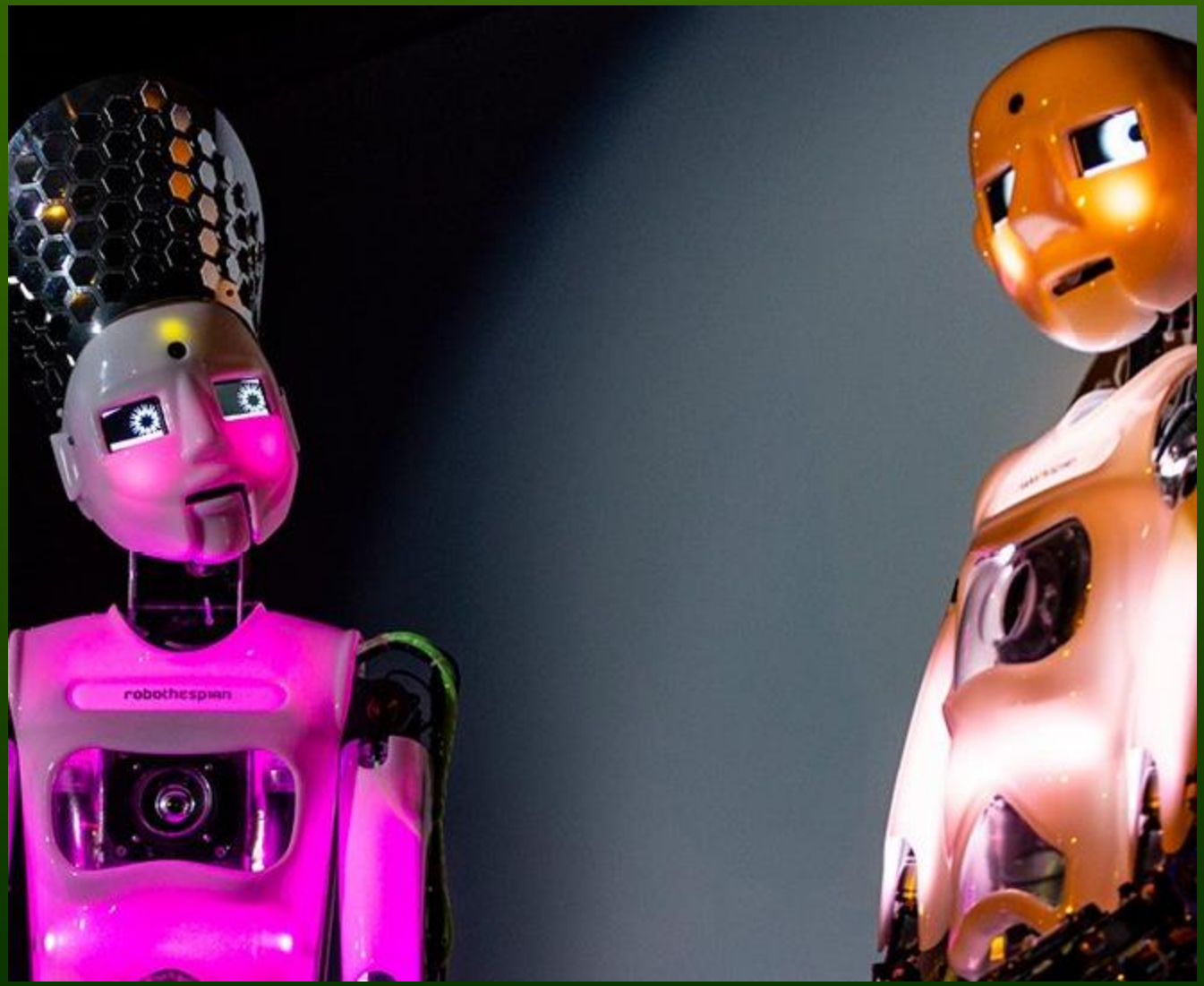
AIVA YouTube channel, Youtube „Letz make it happen", Op. 23

SoundCloud channel Spotify i Apple channel



Duch W, *Intuition, Insight, Imagination and Creativity*.
IEEE Computational Intelligence Magazine 2(3), August 2007, pp. 40-52

S. Lem: About prince Ferrycy and princess Crystala. Intelligent bladaviec? Is it possible?



AI and the development of science

Scientific research cycle

1. Explore the scientific literature

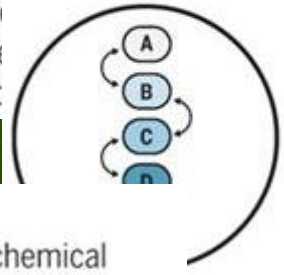
Find the most relevant papers in a sea of millions, track new topics as they emerge.

Semantic Scholar
A search engine that extracts not just words from papers, and "influenti

Iris.AI
A browsing to scientific pape concepts that

2. Design experiments

Find the right trade-off between exploration of ground and exploitation of well-trodden pheno



Zymergen
A company with an AI that tracks thousands of variables while tv microbe genome main story, p. 18)

3. Run experiment

Keep track of thousands of tiny tubes, molecules, and cells, minimizing the imprecision and mistakes that ruin careers.

Transcriptic, Emerald Cloud Lab
Cloud-based robotic laboratories for remotely doing automated molecular and cellular biology experiments.

4. Interpret data

Make sense of the flood of genetic and biochemical results that now flow from biological experiments.

Nutonian
A software platform that ingests very large data sets and spits out a mathematical theory that explains the patterns in the data.

5. Write scientific paper

So far the closest thing to a paper-writing AI is a postdoc. But even writing papers can be enhanced with software that can read the draft of your paper.

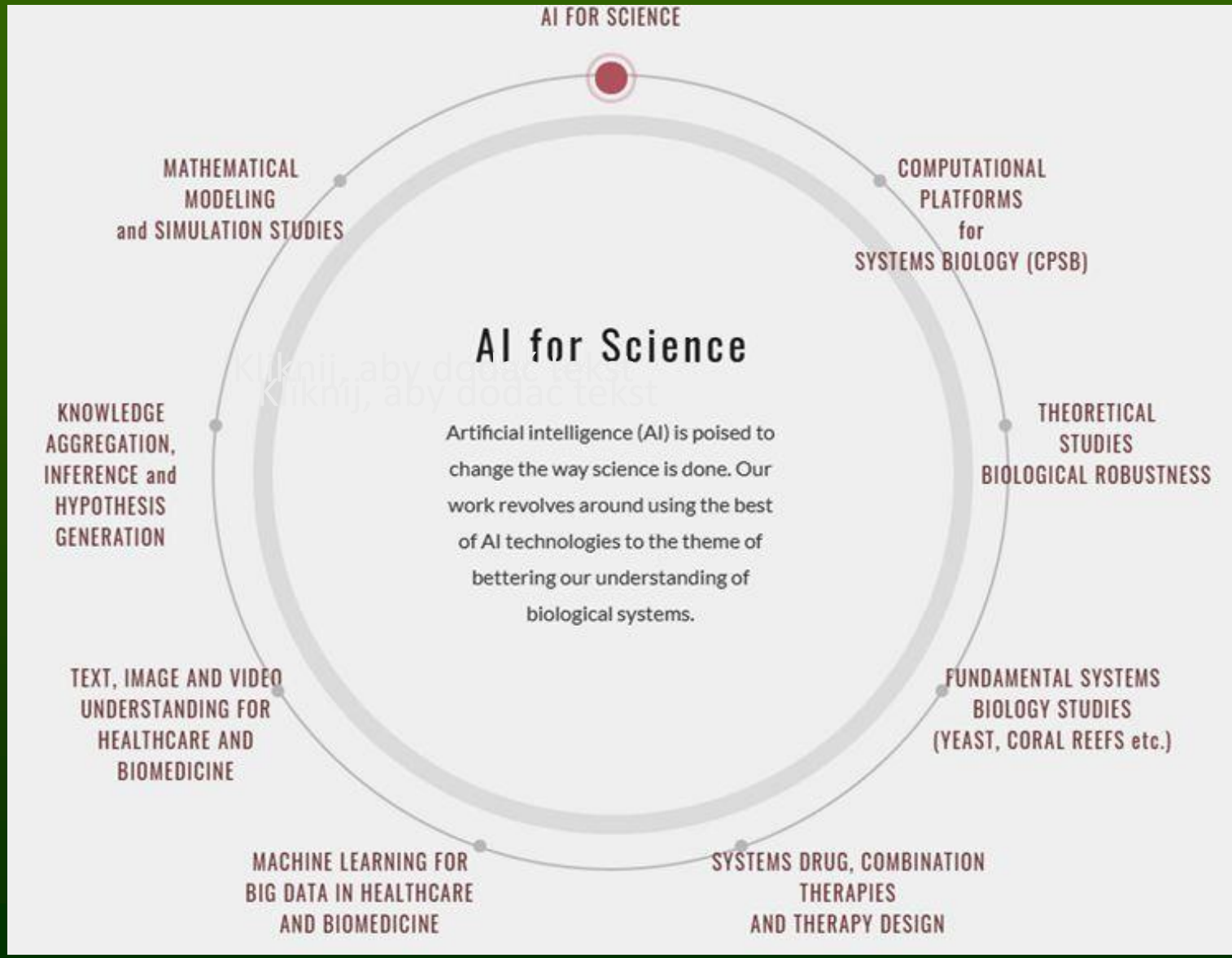
Citeomatic
A free online tool that reads your paper and predicts what citations are missing.

Can science leverage AI systems that learn from existing literature?
Science 2017, Cyberscientist: … the ultimate goal is "to get rid of human intuition".

Garuda Tools from SBI

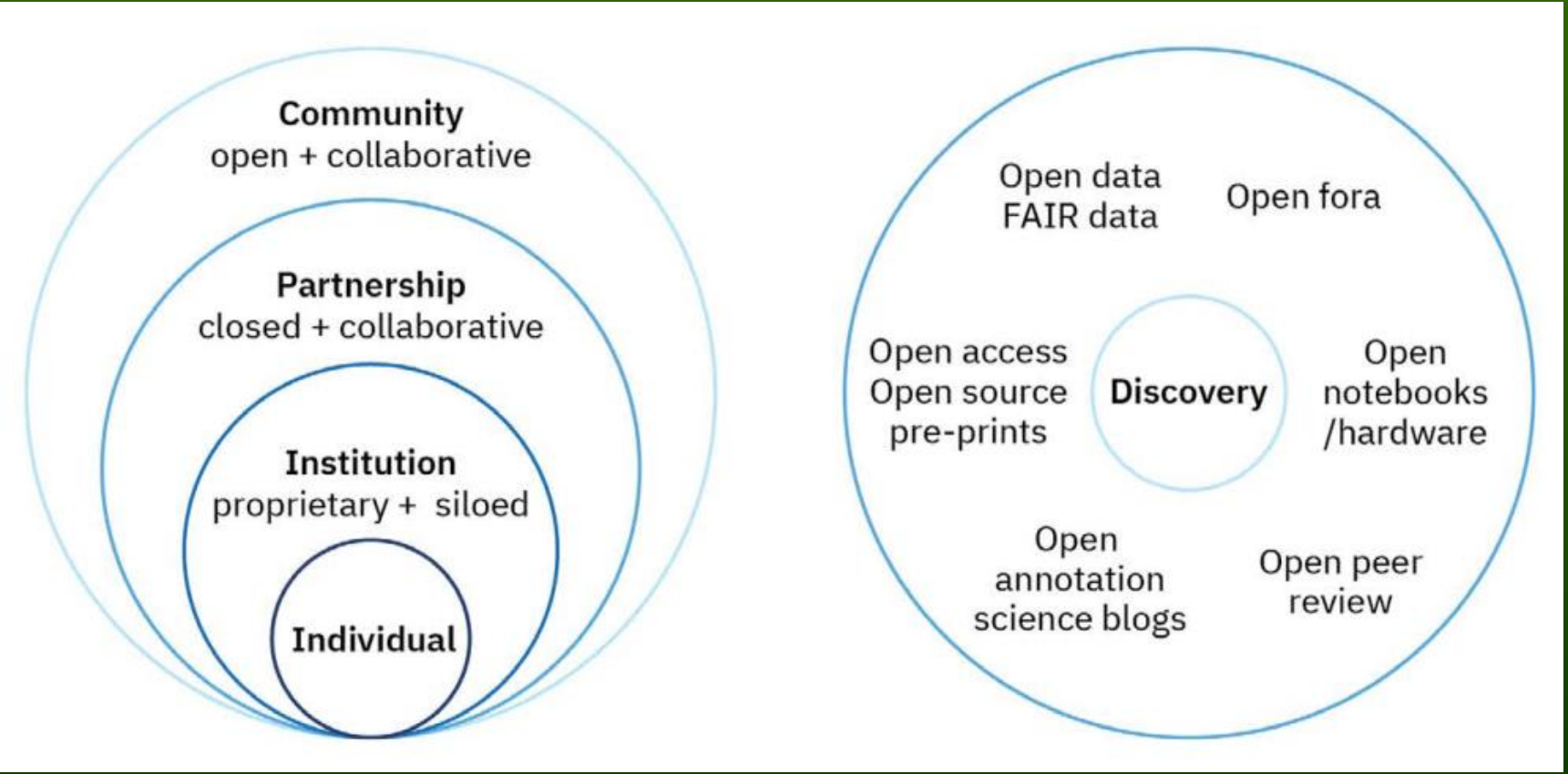
H. Kitano Nobel Turing Challenge: creating the engine for scientific discovery.

Garuda: open, community-driven, common platform. A framework to connect, discover and navigate through applications, databases and services in biology and medicine.



Communities of Discovery

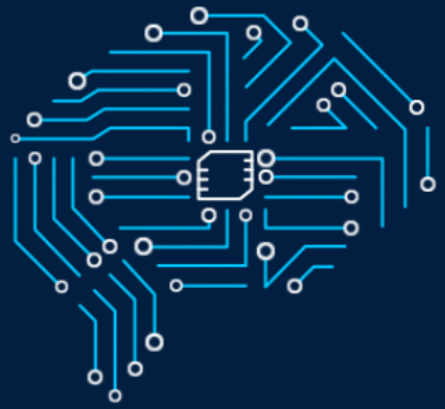
Share resources and skills in an open collaborative environment.



COVID-19 High Performance Computing is a large public-private research partnership in the fields of molecular medicine, protein research, epidemiology, a consortium of large government and private institutions. JEDI challenge, screening of 54 B molecules that can fight COVID-19.

Neuro-inspirations

BRAIN INITIATIVE



Advance Neurotechnologies

Accelerate the development and application of new neurotechnologies.

Support multi-disciplinary teams and stimulate research to rapidly enhance current neuroscience technologies and catalyze innovative scientific breakthroughs.

IEEE brain

IEEE brain

Join the IEEE Brain Community

JOIN FREE

Human Brain Project, EU Flagship (2013), and Obama BRAIN Initiative (2013): BRAIN=**B**rain **R**esearch through **A**dvancing **I**nnovative **N**eurotechnologies.

Neuroscience => AI

Hassabis, D., Kumaran, D., Summerfield, C., Botvinick, M. (2017). **Neuroscience-Inspired Artificial Intelligence**. *Neuron*, *95*(2), 245

Affiliations: **Google DeepMind**, Gatsby, ICN, UCL, Oxford.

Bengio, Y. (2017). The **Consciousness Prior**. *ArXiv:1709.08568.*
Amoset al. (2018). **Learning Awareness Models**. ICRL, *ArXiv:1804.06318*.
Poggio T, talk in Toruń, Feb 2020.

AI Systems inspired by Neural Models of Behavior:
(A) **Visual attention**, foveal locations for multiresolution ‘‘retinal’’ representation, prediction of next location to attend to.
(B) **Complementary learning systems** and episodic control: fast learning hippocampal system and parametric slow-learning neocortical system.
(C) Models of **working memory** and the Neural Turing Machine.

(D) Neurobiological models of **synaptic consolidation**.

Comparing artificial networks with the brain networks we still have very primitive models, but adding more multimodal data will lead to a great progress.

AI=>Neuroscience

ML techniques are basic tools for analysis of neuroimaging data.

Ideas from animal psychology helped to give birth to reinforcement learning (RL) research. Now **key concepts from RL inform neuroscience**.

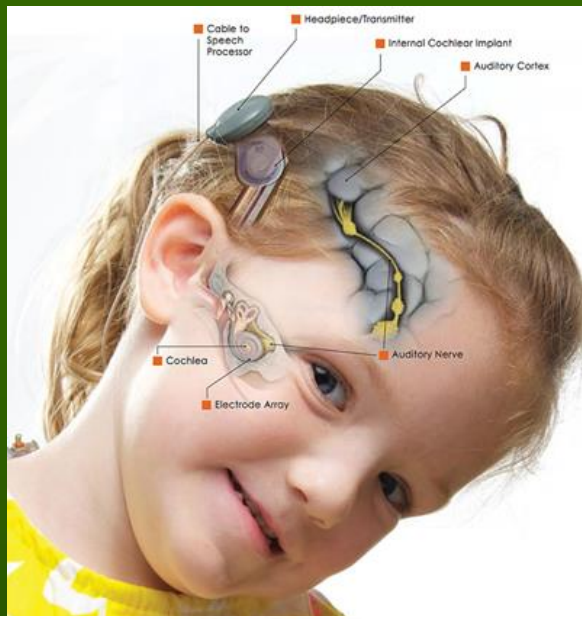
Activity of midbrain dopaminergic neurons in conditioning paradigms has a striking resemblance to temporal difference (TD) generated prediction errors - **brain implements a form of TD learning!**

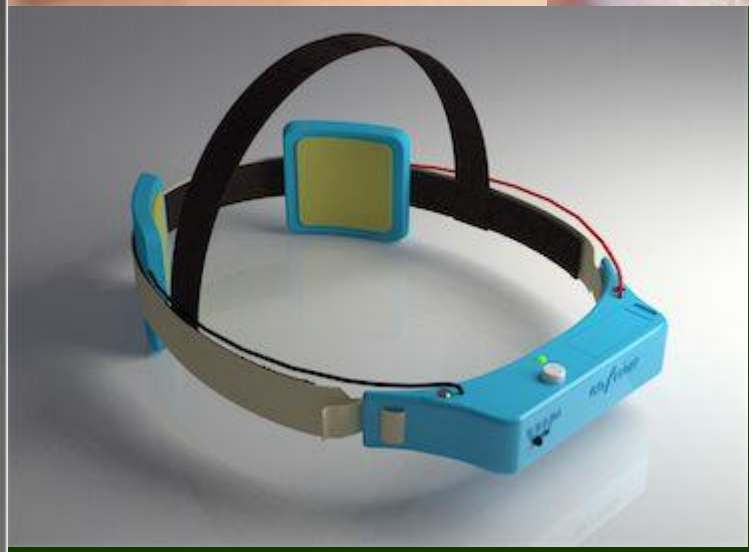
CNN ⇔ interpret neural representations in high-level ventral visual stream of humans and monkeys, finding evidence for deep supervised networks.

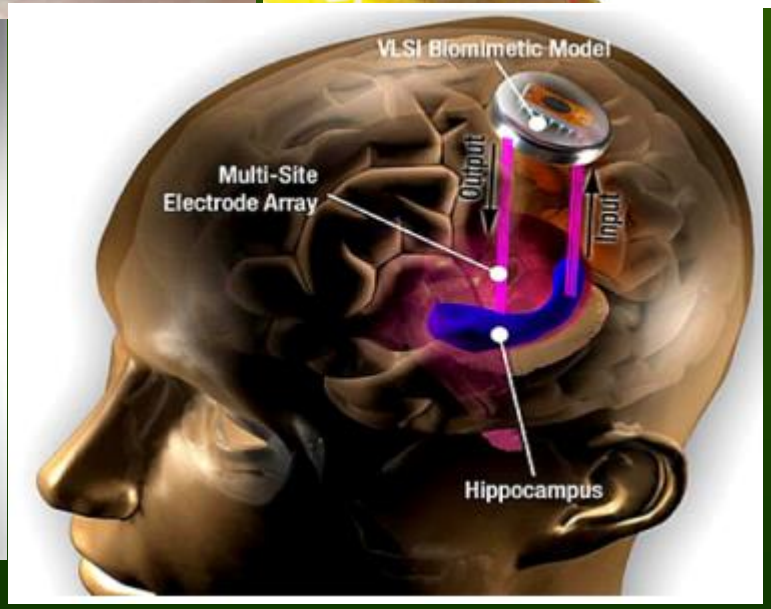
LSTM architecture provides key insights for development of working memory, gating-based maintenance of task-relevant information in the prefrontal cortex.

Backpropagation with symmetric feedback and feedforward connectivity is not realistic, but random backward connections allow the backpropagation algorithm to function effectively through a process whereby adjustment of the forward weights allows backward projections to transmit useful teaching signals.

Amplification

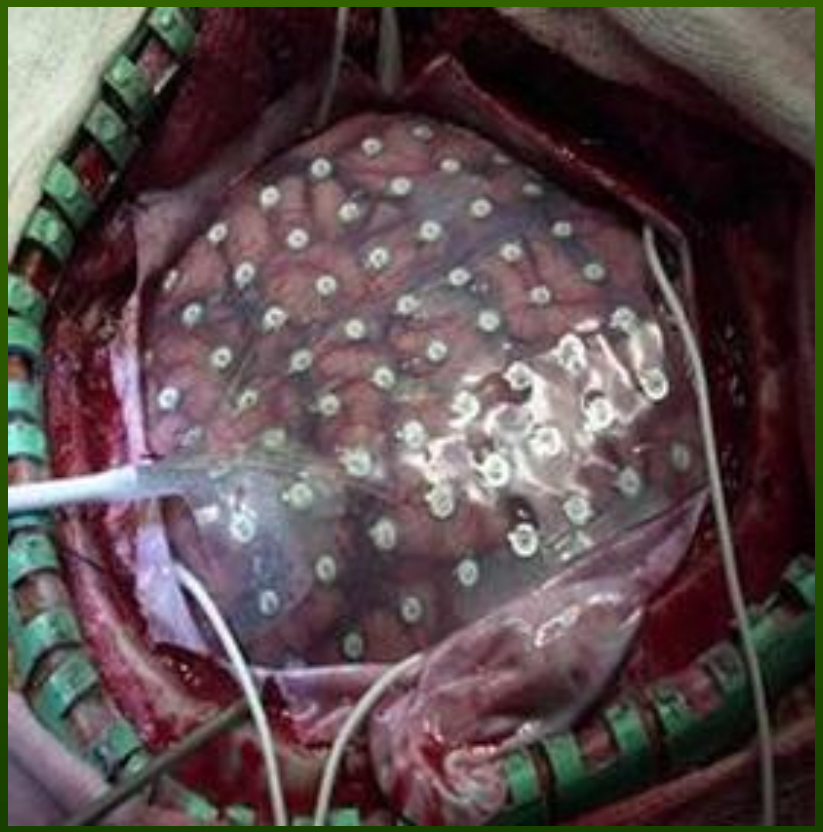






Expansion of the senses: sight, hearing, touch, memory, attention ...
Improving brains by adding new senses (Eagleman, Livewired 2020).

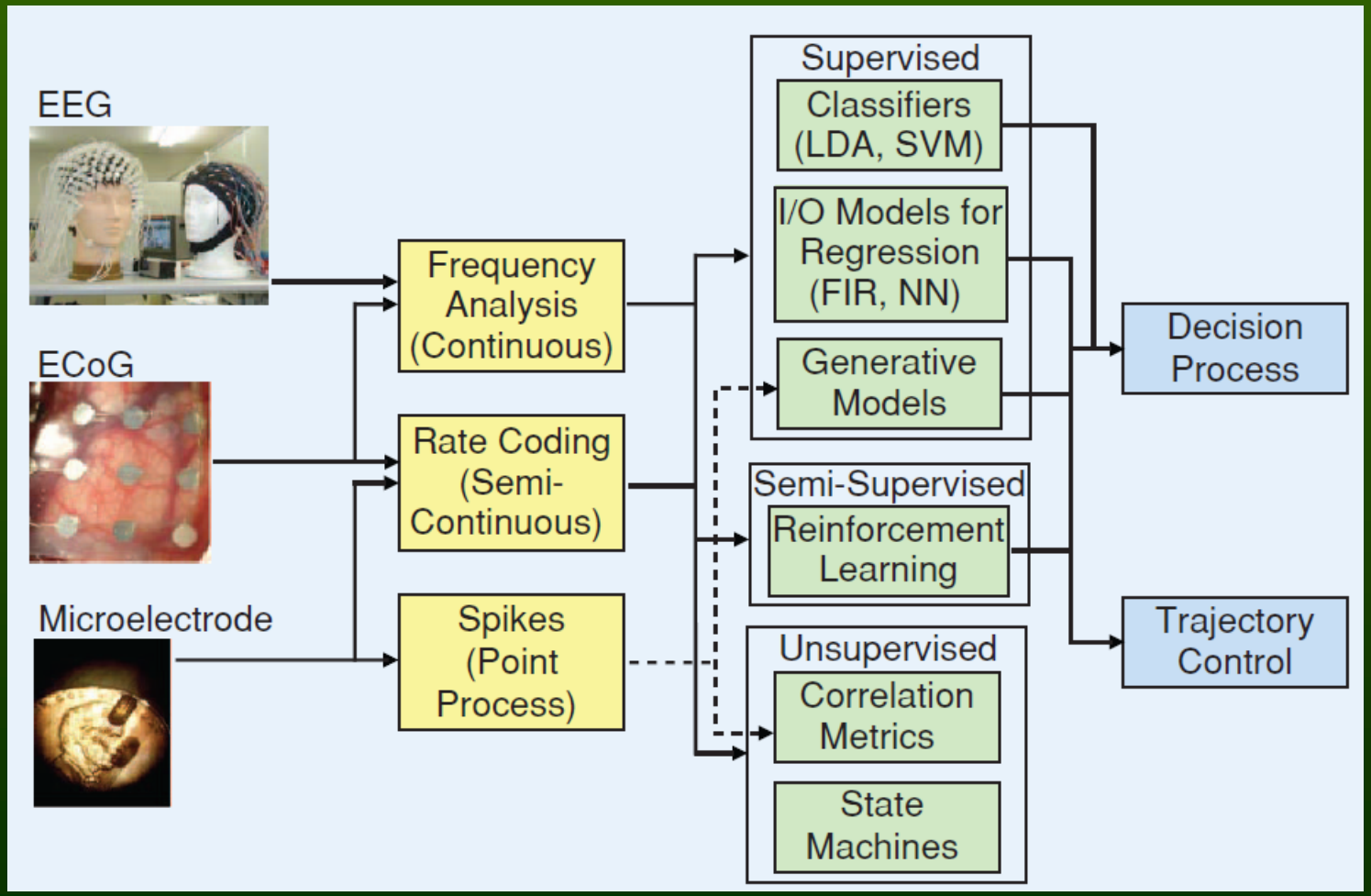
Brain computer interfaces



People with Parkinson's disease or compulsive-obsessive disorder who have pacemakers implanted in their brain can regulate their behavior with an external controller.

BCI: time to connect our brains …

Non-invasive, partially invasive and invasive methods carry increasing amount of information, but are more difficult to implement.
EEG+ML still reigns supreme!

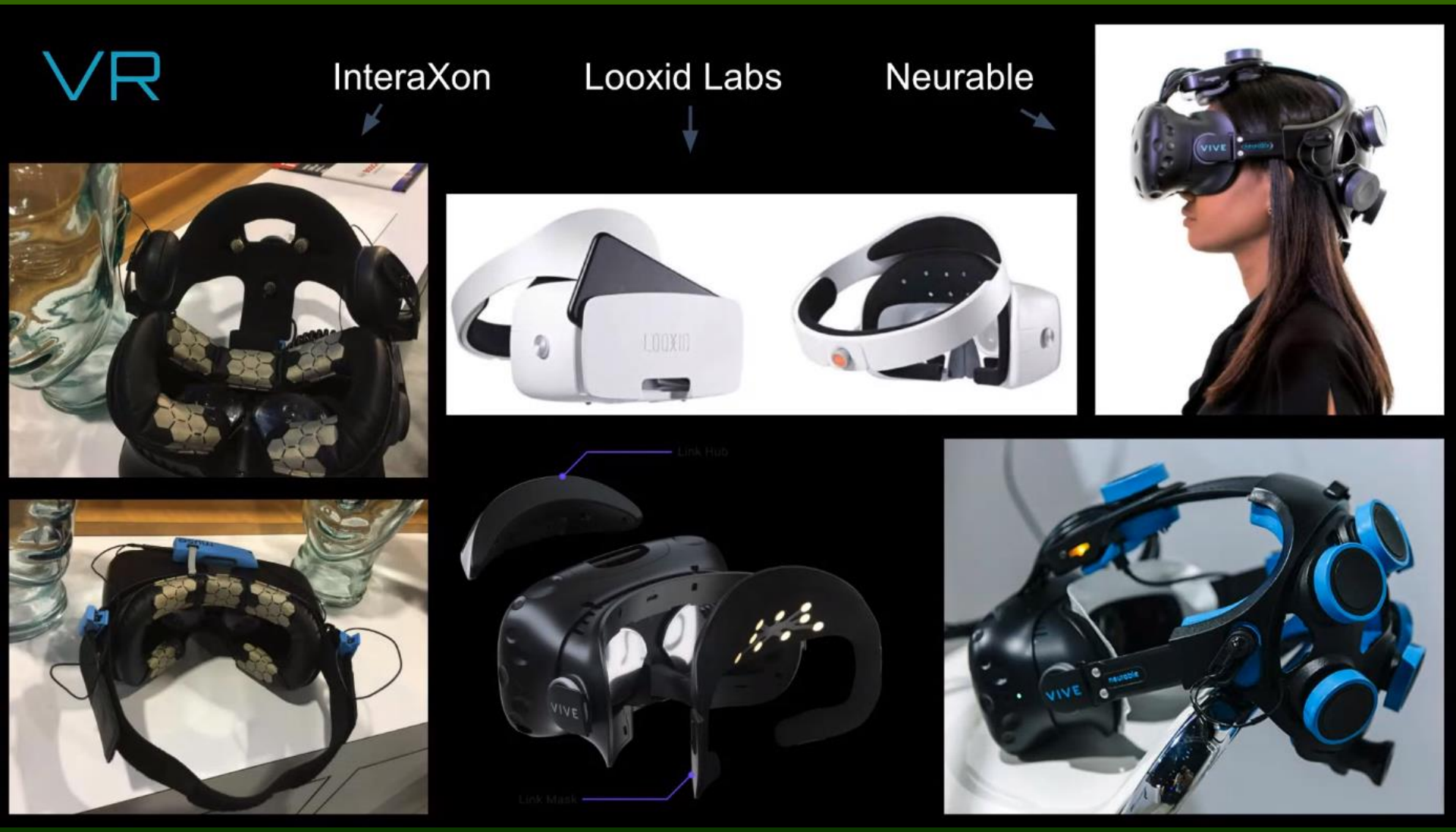


BCI tools

Many inexpensive EEG solutions, but analysis of brain signals is always hard.

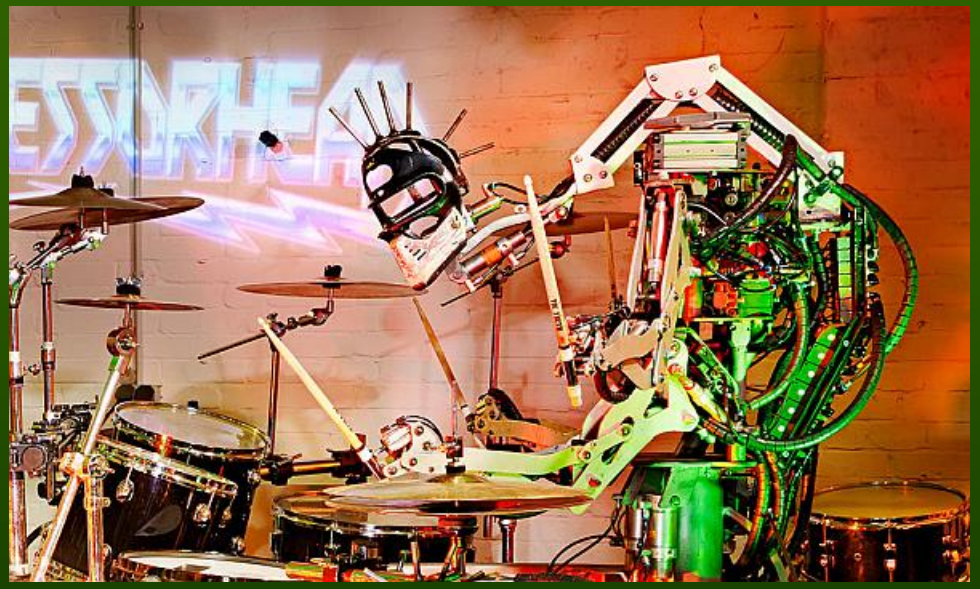
BCI tools

Combination of Virtual Reality with BCI has great potential.



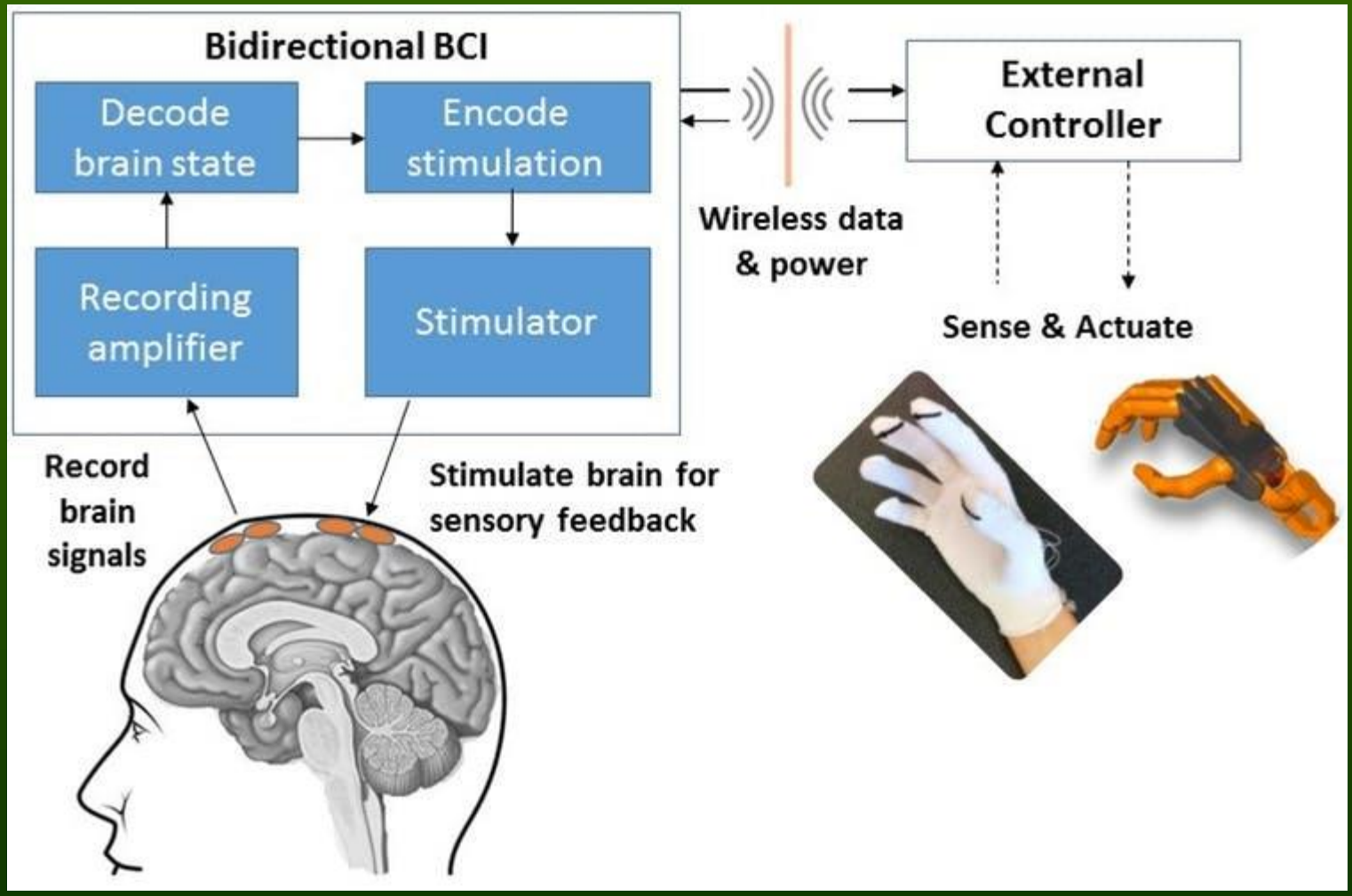
What can I do with additional hand?

If I were an octopus ... then I would play the drums!



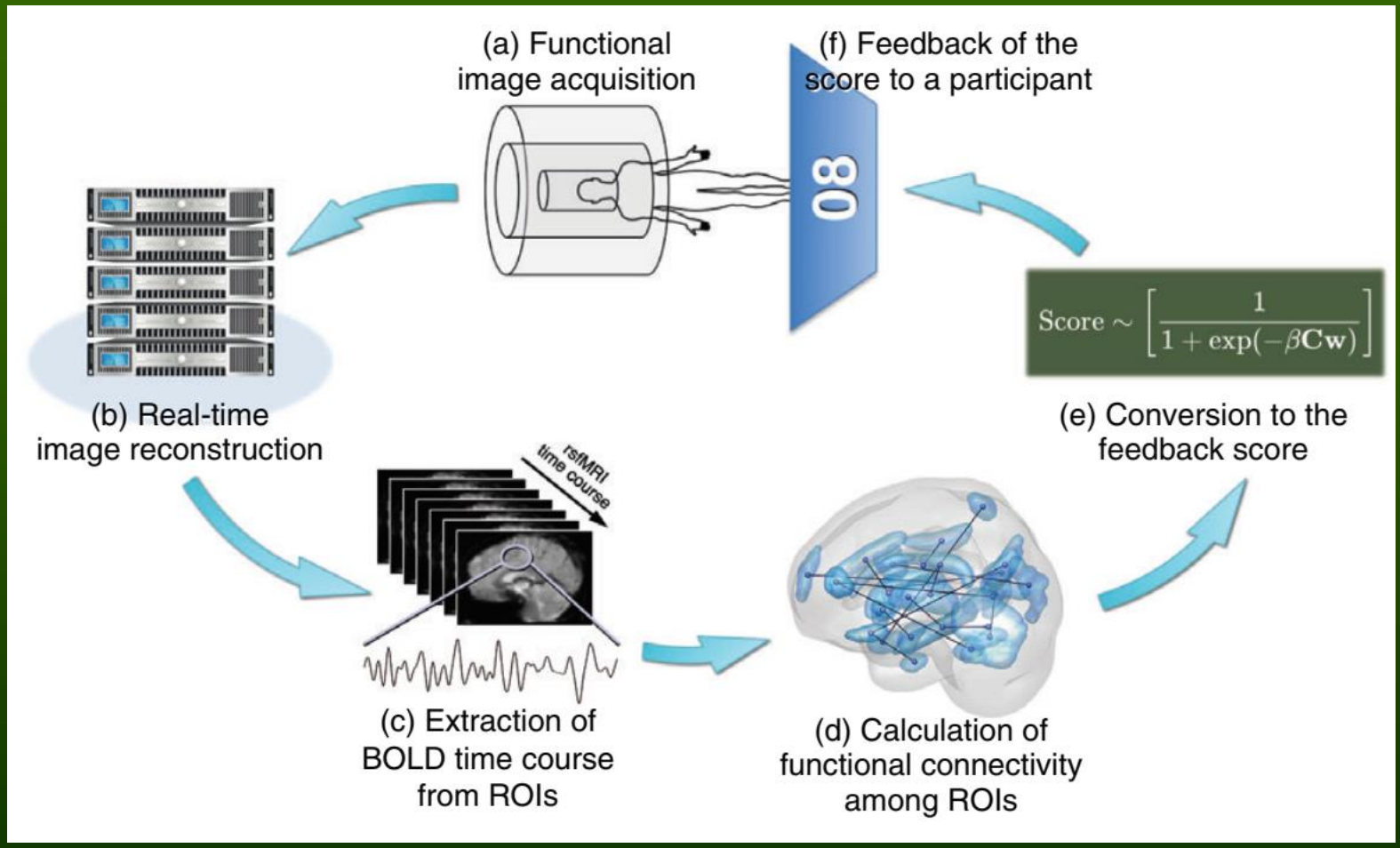
And if I were a robot, I would just play with 4 hands...
Robot group Compressorhead goes on a tour around the world.

BCBI: Brain-Computer-Brain



BCI + brain stimulation = BCBI – a closed loop through which the brain begins to restructure itself. The body can be replaced by signals in Virtual Reality.

Will neurofeedback repair our brains?



Megumi F, Yamashita A, Kawato M, Imamizu H. Functional MRI neurofeedback training on connectivity between two regions induces long-lasting changes in intrinsic functional network. *Front. Hum. Neurosci.* 2015; **9**: 160.

On the threshold of a dream …

Final goal: optimize brain processes!

Although whole brain is always active we are far from achieving full human potential. To repair damaged brains and increase efficiency of healthy brains we need to understand brain processes:

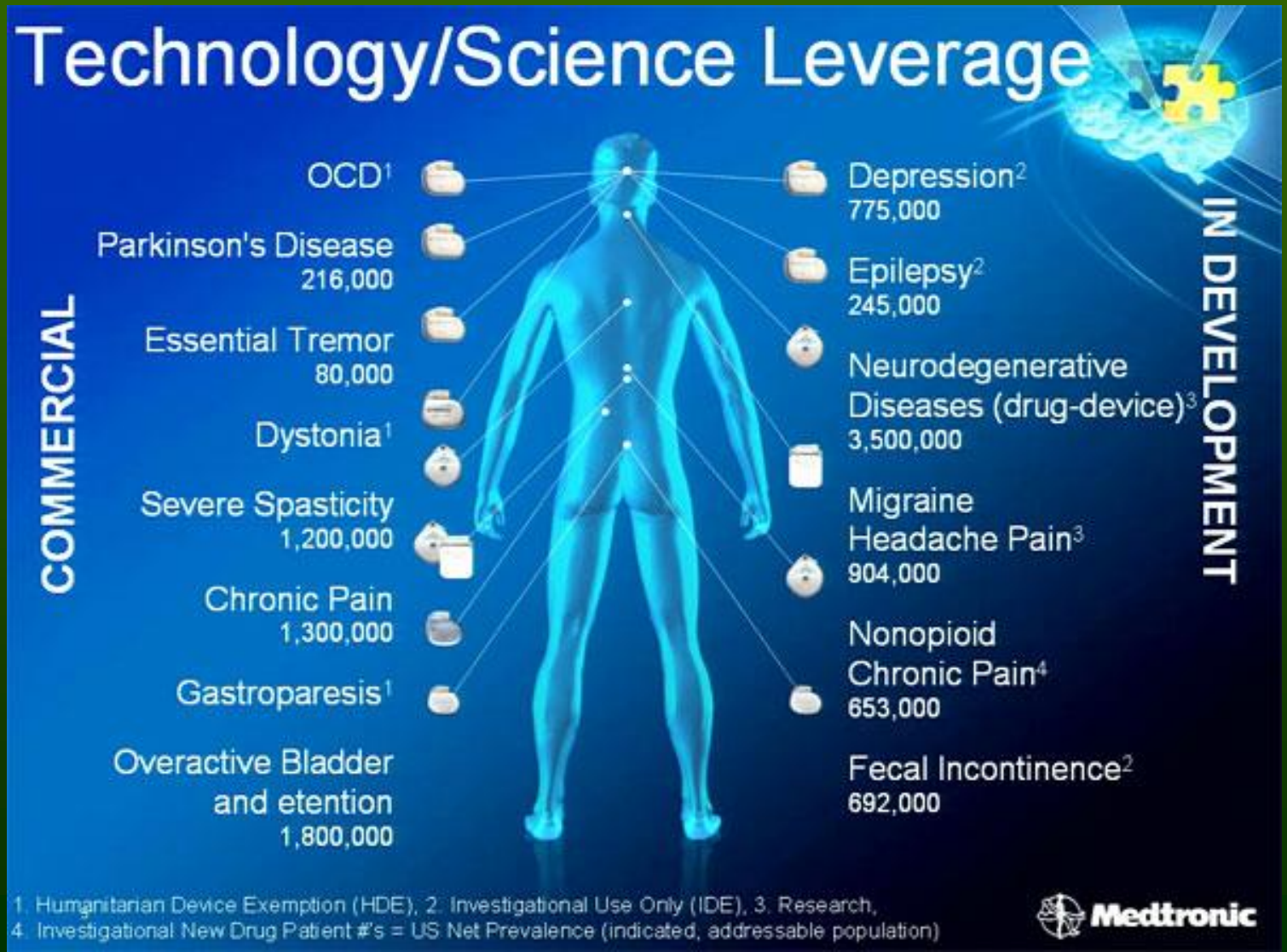
1. Find fingerprints of specific activity of brain structures using new neurotechnologies.
2. Create models of cognitive architectures that help to understand information processing in the brain.
3. Create new diagnostic and therapeutic procedures.
4. Use neurofeedback based on decoding and changes in connectivity to stimulate the brain.
5. Stimulate neuroplasticity by monitoring brain activity and directly stimulating it (TMS, DCS, EM).

G-tec wireless NIRS/EEG on my head.

Neuromodulation

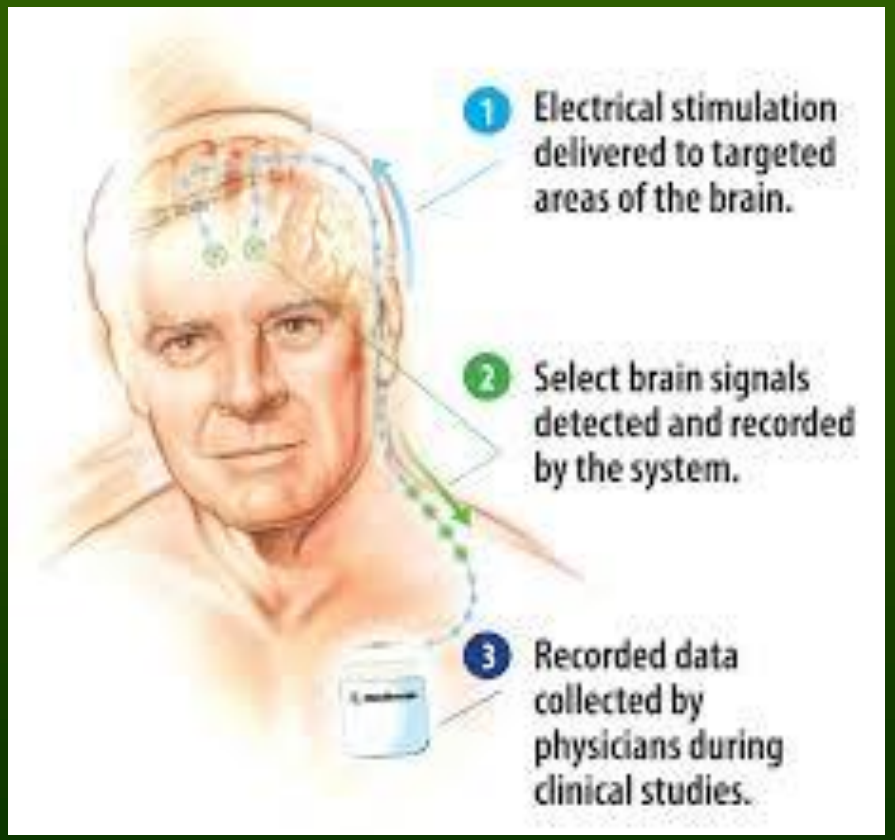
Cochlear implants are common, deep implants stimulate brain structures, not only for deficits of perception, but to regulate cortical neural processes.

Market:
10B$ (2021),
25B$ in 2027.

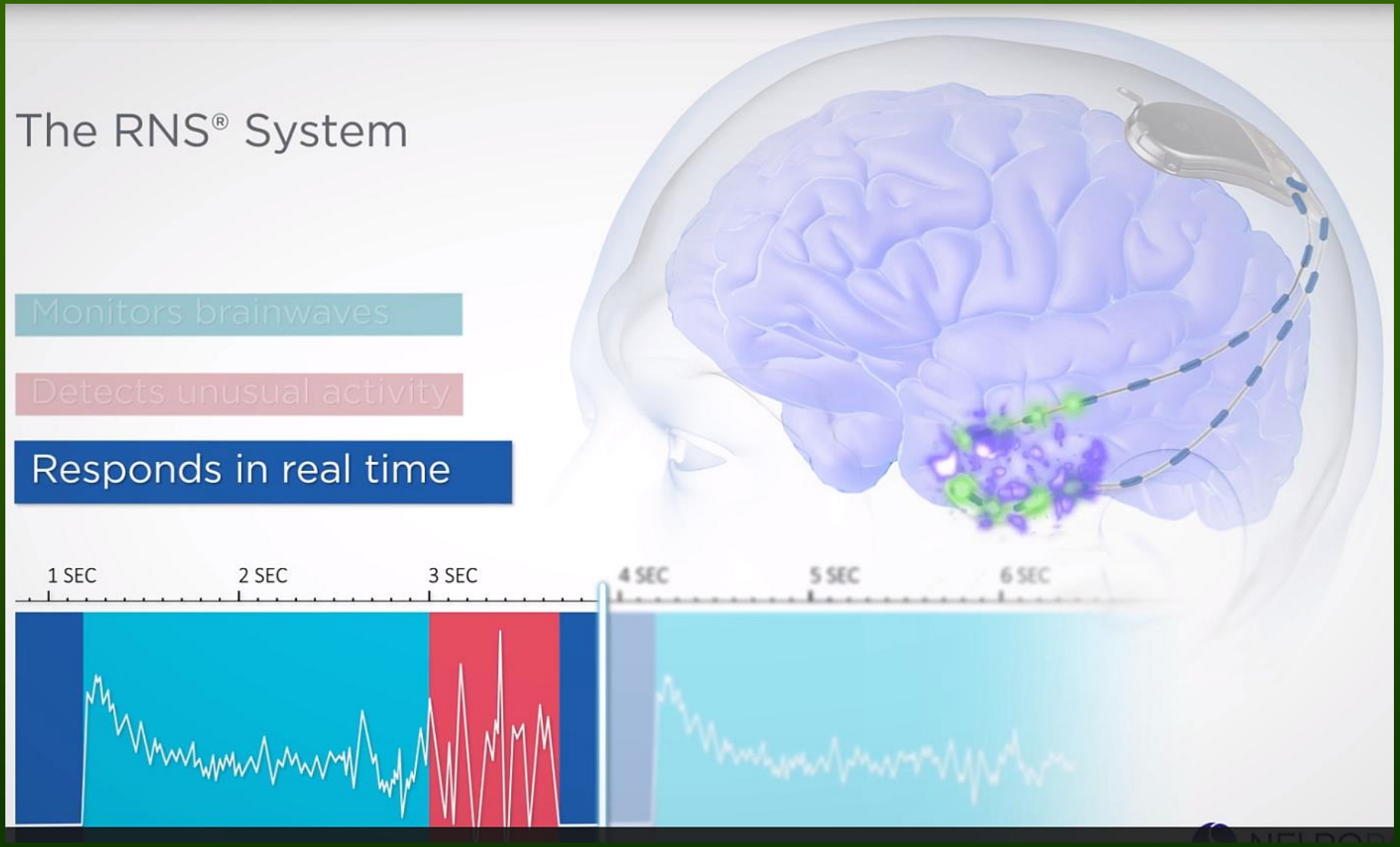


Deep brain stimulation

People suffering from Parkinson's disease or compulsive-obsessive disorder who have electrodes implanted deeply in their brain can regulate their behavior with an external controller.
Let's turn up our brains ... Can I program my brain?



Epilepsy



The neurostimulator and detector stops attacks of drug-resistant epilepsy before cramps occur. About 1% of people in the world have epilepsy.

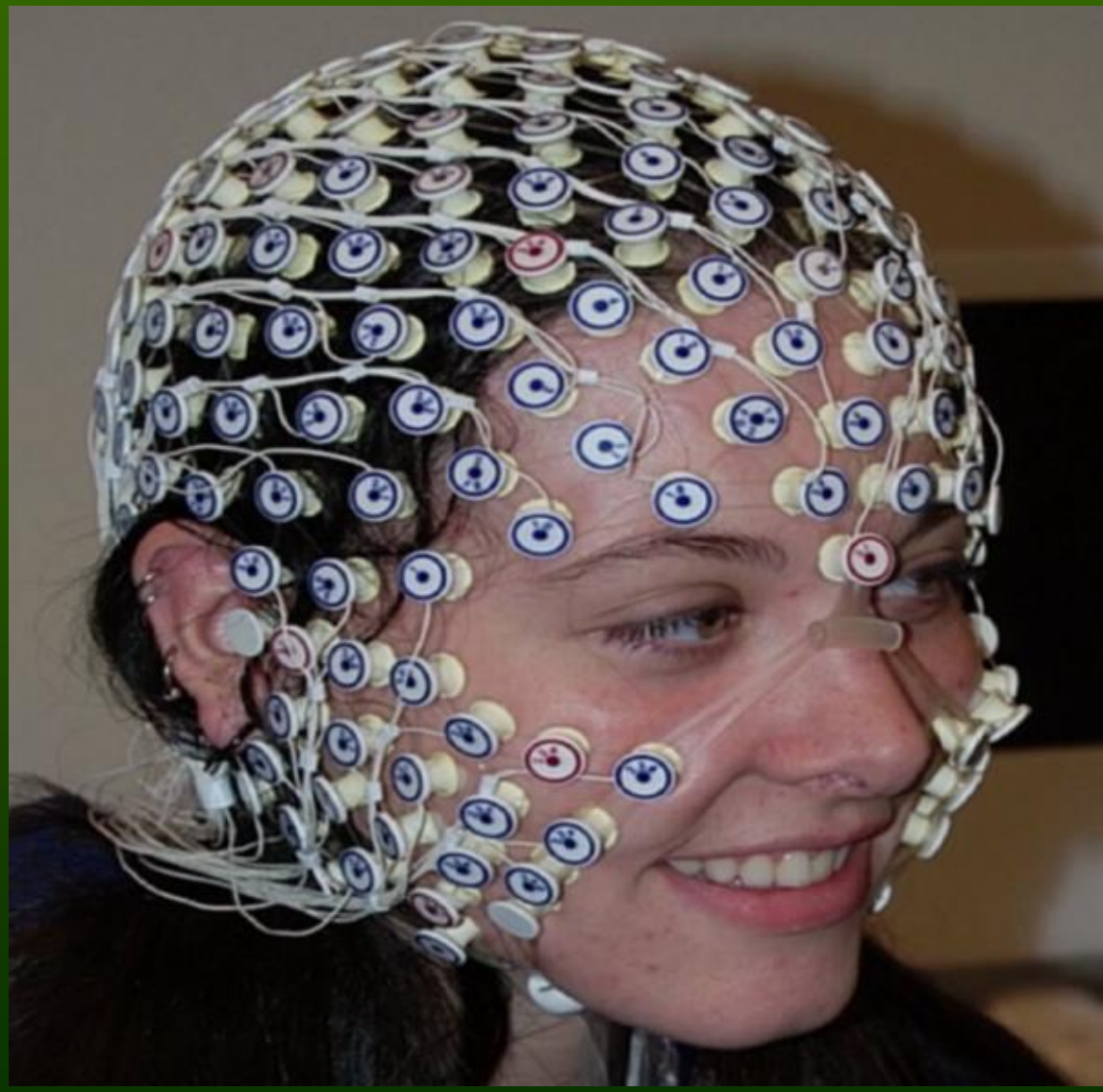
HD DCS for BCBI

Reading brain states => transforming to common space => duplicating in other brains …

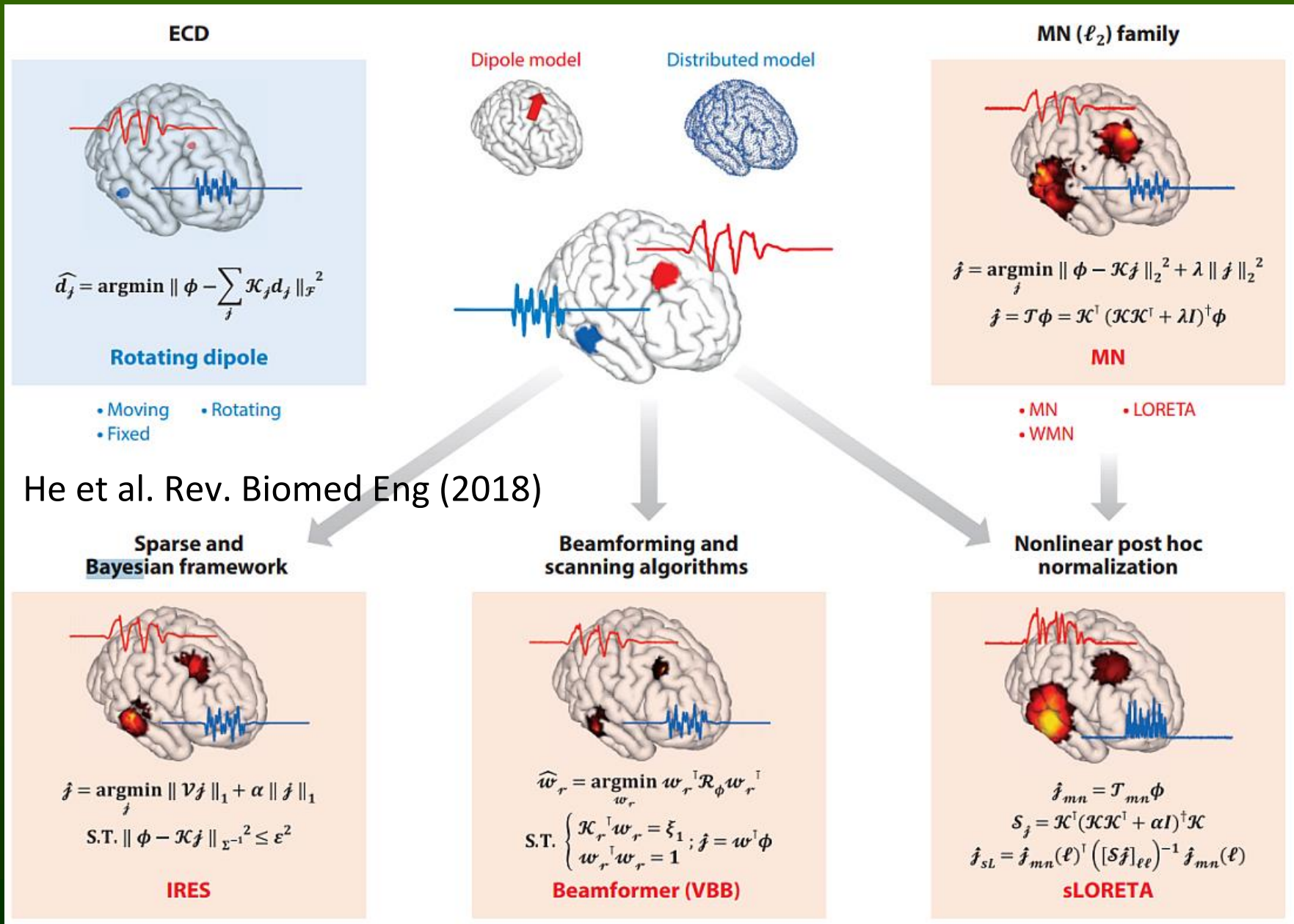
Depression, neuro-plasticity, pain, psychosomatic disorders, teaching!

Multielectrode DCS stimulation with 256 electrodes induces changes in the brain increasing neuroplasticity.

But **no-one really knows** why it works …

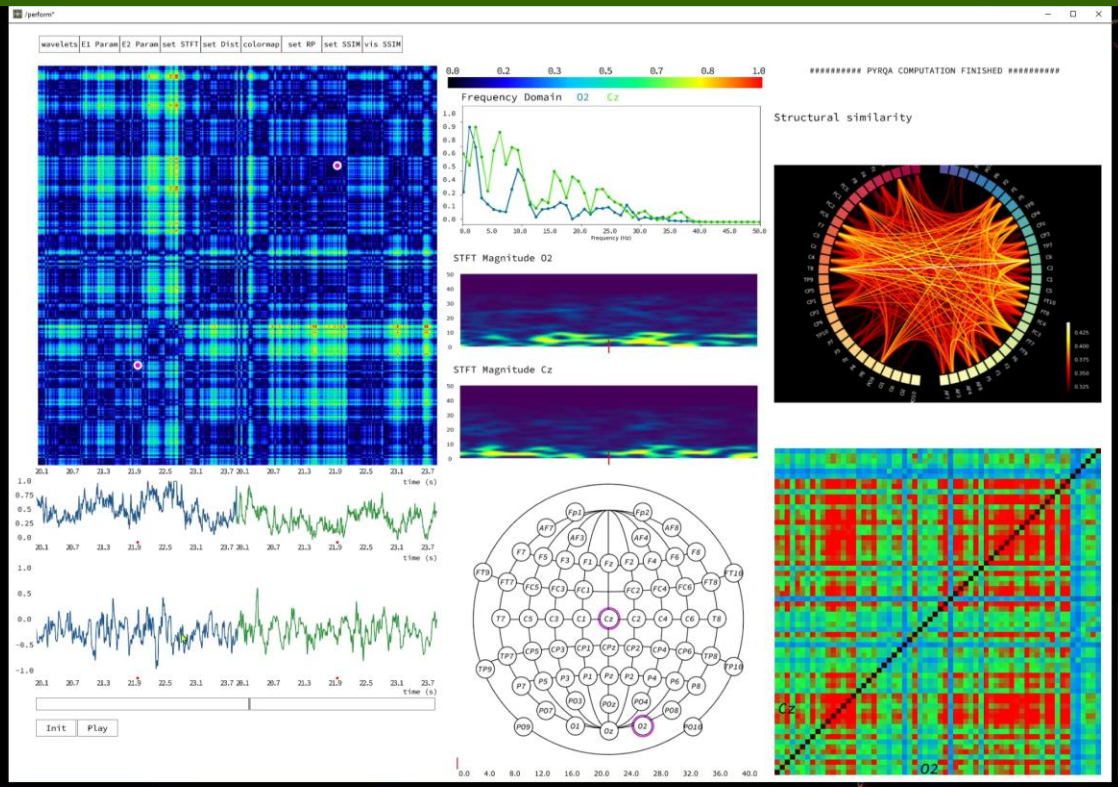


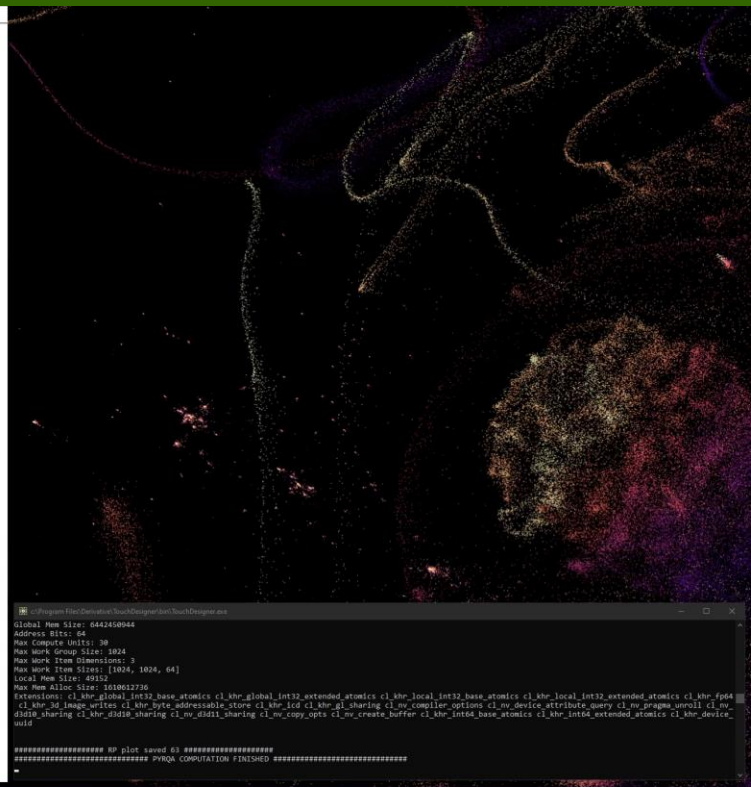
EEG source localization and reconstruction



He et al. Rev. Biomed Eng (2018)

EEG analysis





EEG data, 128 channels, recursion graphs, power spectrum for two electrodes, information flow and correlations between brain regions (Łukasz Furman).

Brain to brain

Engagement Skills Trainer (EST), procedures for training American soldiers.

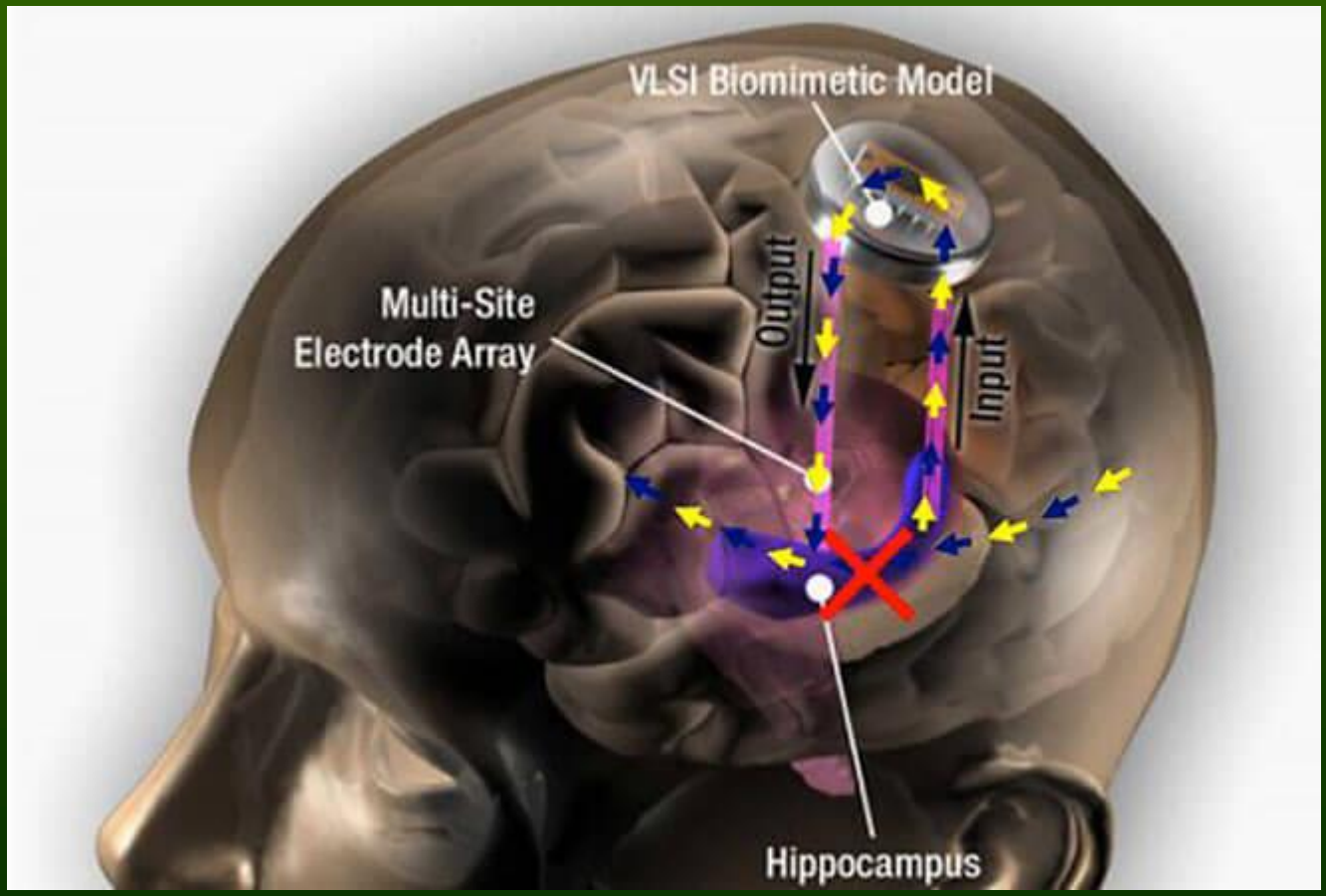
Intific Neuro-EST
a technology that uses EEG analysis and a multi-channel transcranial stimulator (MtCS) to transfer skills between master and student, brain-to-brain.

Memory implants

Tests on rats, monkeys, and in 2017 on 20 humans gave an improvement in memory by 30% (on rats by 35%). Ted Berger (USC, Kernel) : There are good reasons to believe that the integration of memory with electronics is possible.

DARPA: Restoring Active Memory (RAM) program, for people with brain damage (TBI), should be non-invasive.

Neurofeedback + closed-loop neurostimulation.



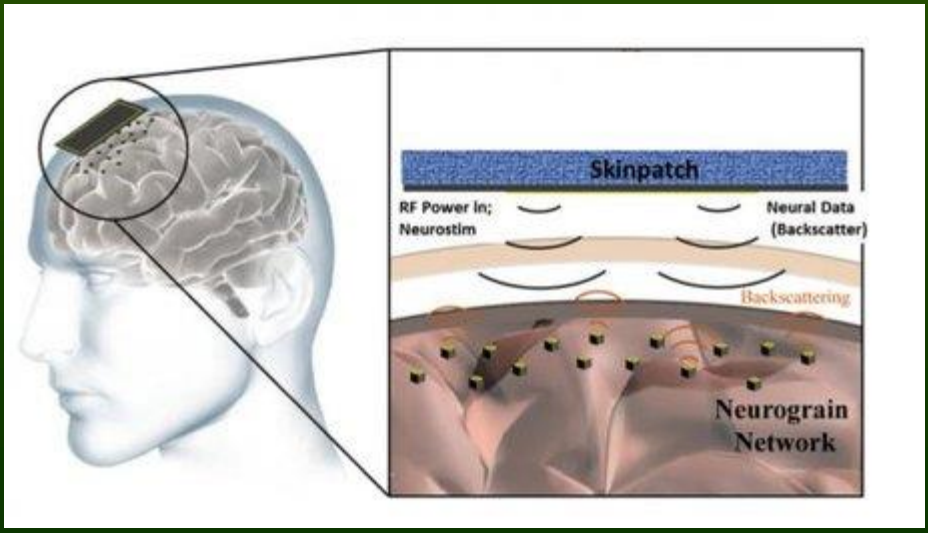
A million nanowires in the brain?

DARPA initiative: **Neural Engineering System Design (NESD)** and other projects.

An interface that reads the impulses of 10^6 neurons, stimulates 10^5 neurons, simultaneously reads and stimulates 10^3 neurons.

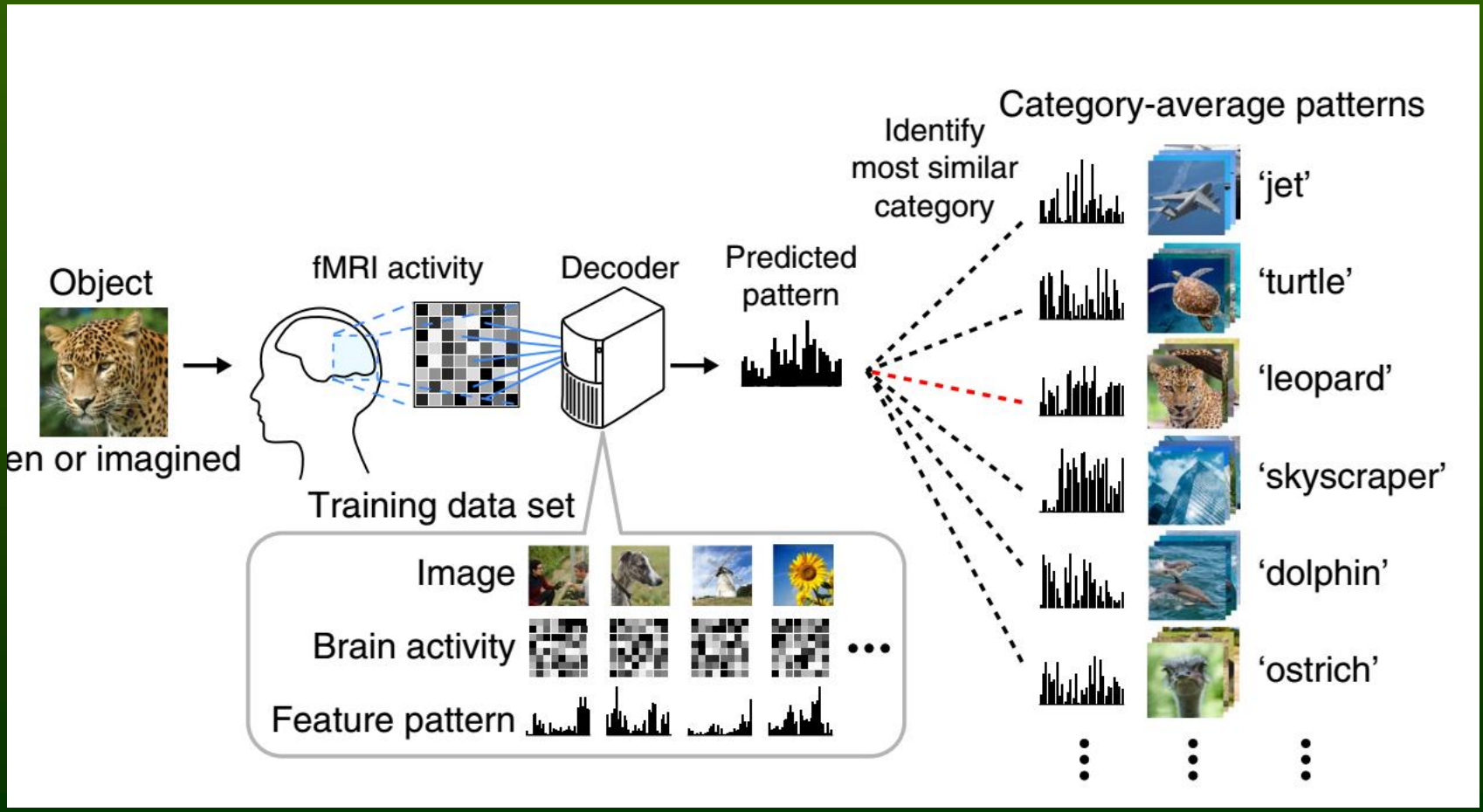
DARPA awarded grants to research groups for projects under the program Electrical Prescriptions (ElectRx), whose aim is to develop BCBI systems modulating the activity of peripheral nerves for therapeutic purposes.

Neural dust – microscopic wireless sensors in the brain.
Elon Musk and the much-heralded technology neuralink (neural lace).



Brain activations ⇔ Mental images

fMRI activity can be correlated with deep CNN network features; using these features most similar image from a large database is selected.
Horikawa, Kamitani, Generic decoding of seen and imagined objects using hierarchical visual features. Nature Communications, 2017.



Dreams

Decoding Dreams, ATR Kyoto, Kamitani Lab.
fMRI images analyzed during REM sleep or while falling asleep allow for the classification of dreams (~20 categories).
Dreams, thoughts... is it possible to hide what we have seen and experienced?

Neural screen

Features of the face image are analyzed and their combination remembered.

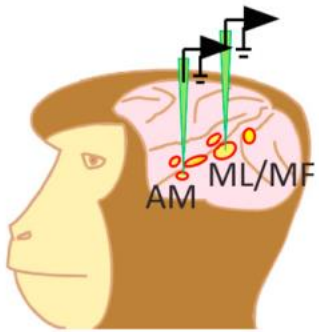
This can be decoded from brain signals if we have access to neural spikes.

It took only 205 neurons in several visual cortex areas to reproduce images of the faces from spikes.

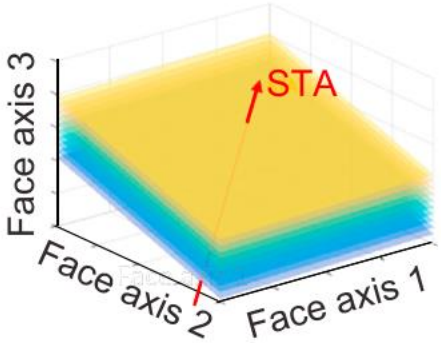
L. Chang and D.Y. Tsao, "**The code for facial identity in the primate brain**" *Cell* 2017

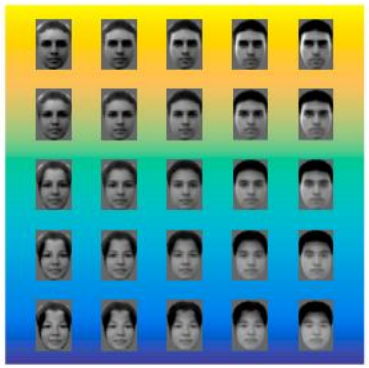
Voice, and even thoughts can be read in a similar way.

1. We recorded responses to parameterized faces from macaque face patches

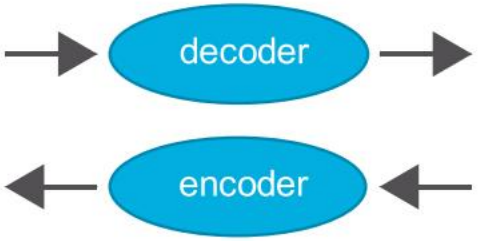


2. We found that single cells are tuned to single face axes, and are blind to changes orthogonal to this axis



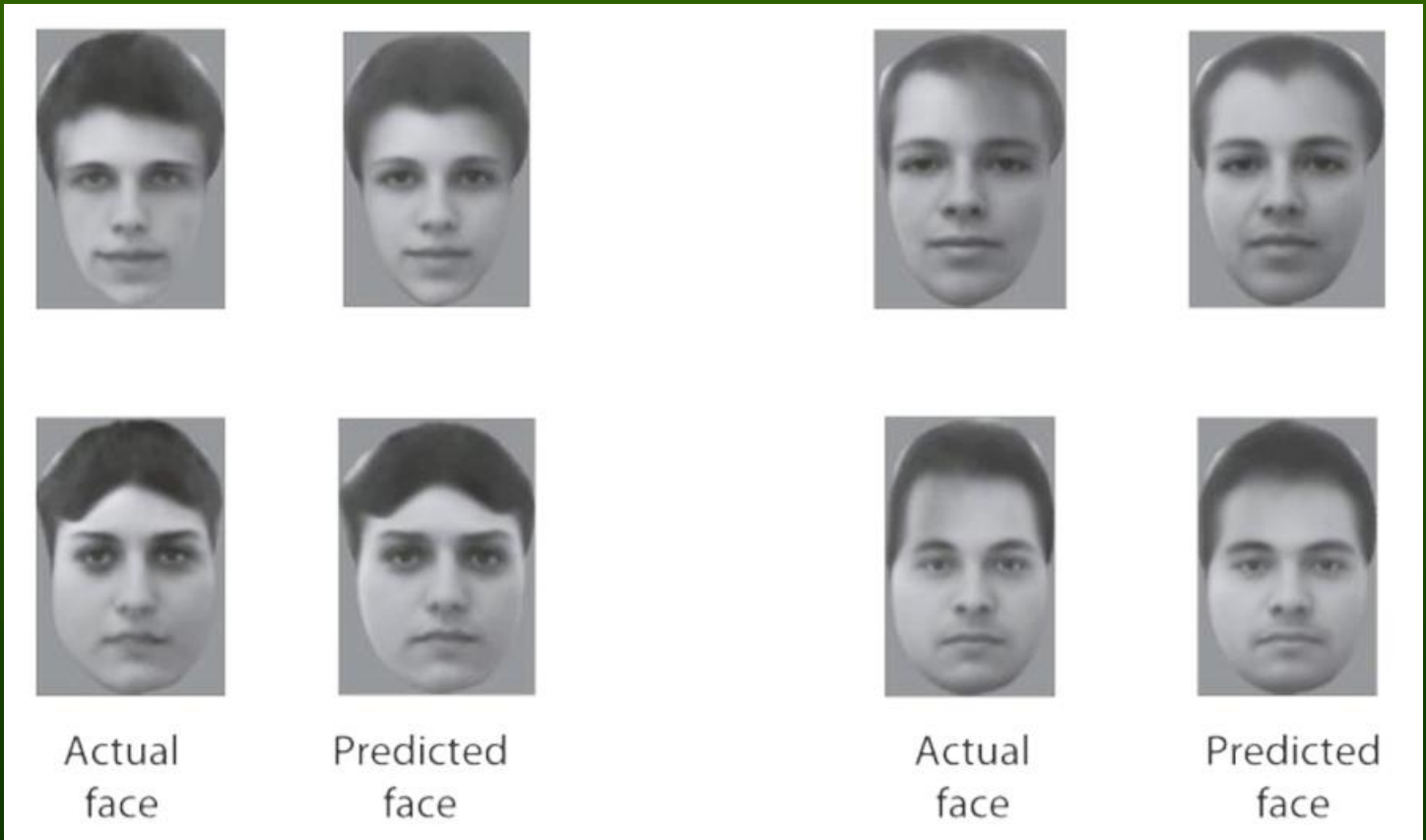


3. We found that an axis model allows precise encoding and decoding of neural responses



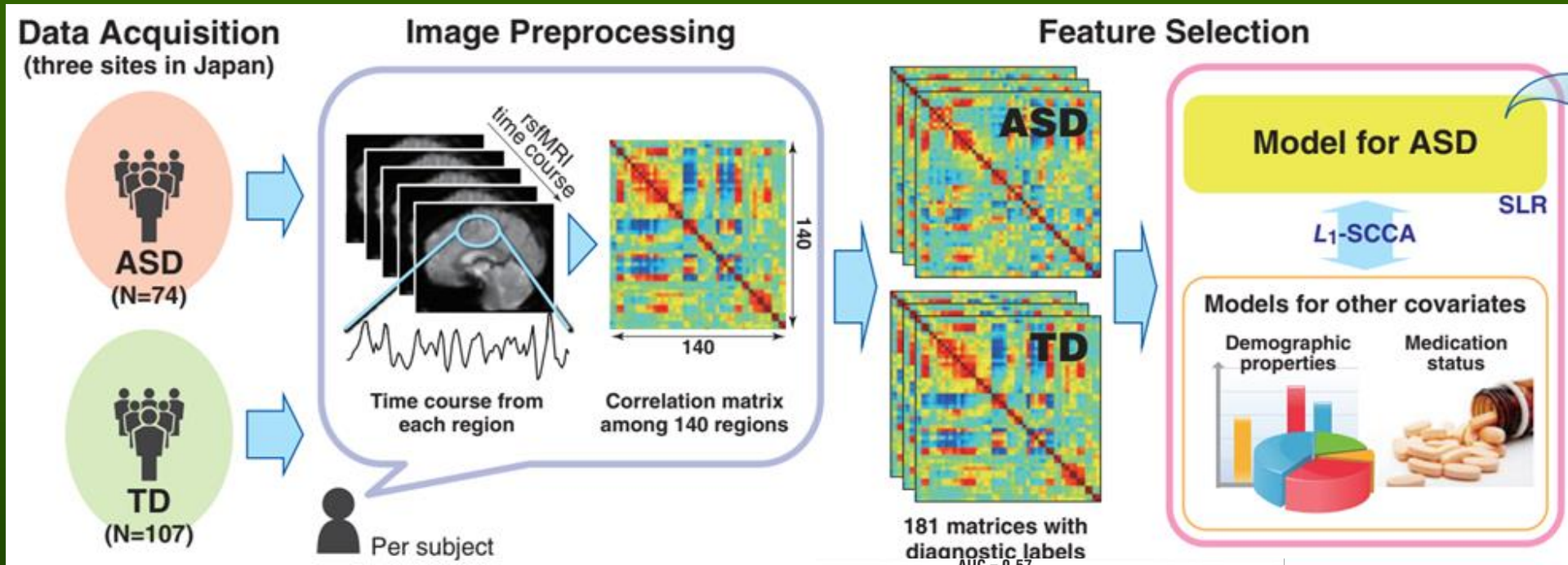
Mental images

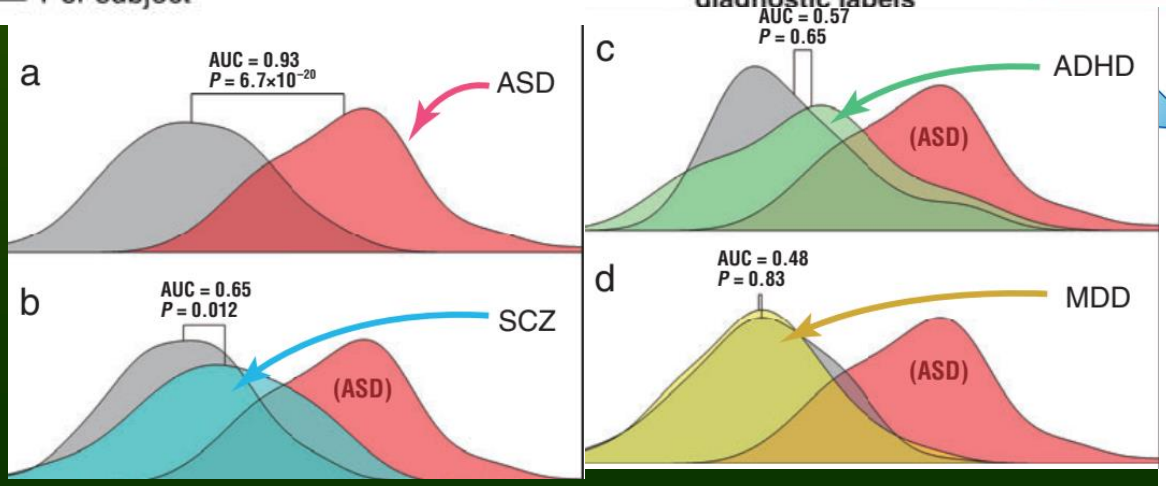
The image of the face is encoded using a simple neural code that is based on the ability of neurons to distinguish facial features along specific axes in the facial features space.

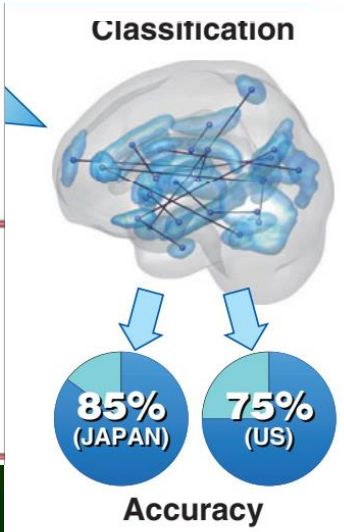


L. Chang and D.Y. Tsao, *Cell* 2017

Diagnostic biomarkers







N. Yahata et al, *Psychiatry and Clinical Neurosciences* 2017: **71**

Private Information in BCIs

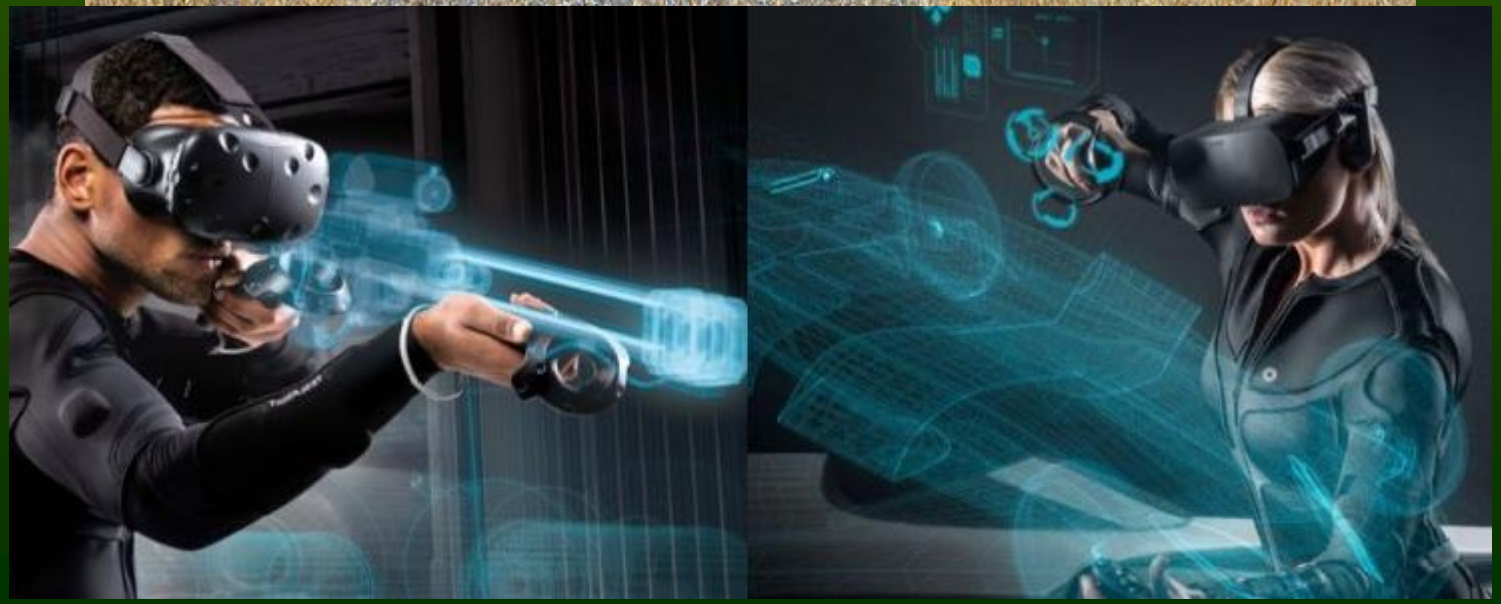
K. Xia, Y. Sun, K. Xu, W. Fang, H. Luo, Y. Zhang, D. Sang, D. Wu, X. Xu, F-Y Wang, Privacy-Preserving Brain-Computer Interfaces: A Systematic Review, IEEE Trans. on Computational Social Systems, 2022

Perspectives

- Artificial intelligence is changing everything, including the way science is done. Large companies and global consortia will be at the front.
- What was impossible yesterday tomorrow will be common. Autonomous form of AI will result from growing understanding perception and language.
- AI-based automation will force great social changes.
- The evolution of thought will move into multidimensional worlds beyond our comprehension. Robots/AI systems will quickly learn from each other.
- Machines will claim to be aware, and most people accept this; the legal status of the cyborgs is already being discussed.
- Teaching computer science should go in two directions: deeper understanding of algorithms for computer science students and high-level AI applications for experts in other domains. Can we do all?
- Neurocognitive technologies will profoundly change our selves. The integration of brains with AI will not be easy …
- The singularity may come faster than we think!

A radical change is coming...

Our politicians still have not noticed that something had changed.



Towards Human-like Intelligence

IEEE Computational Intelligence Society Task Force (Mandziuk, Duch, M. Woźniak), **Towards Human-like Intelligence**

IEEE SSCI CIHLI 2021 Symposium on Computational Intelligence for Human-like Intelligence, Orlando, FL, USA.

AGI: conference, Journal of Artificial General Intelligence comments on Cognitive Architectures and Autonomy: A Comparative Review (eds. Tan, Franklin, Duch).

BICA: Annual International Conf. on Biologically Inspired Cognitive Architectures, 11th Annual Meeting of the BICA Society, Natal, Brazil, 2020.

Brain-Mind Institute Schools, International Conference on Brain-Mind (ICBM) and Brain-Mind Magazine (Juyang Weng, Michigan SU).

In search of sources of brain's cognitive activity

Project „Symfonia", NCN, Kraków, 18.07.2016

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VIRTUAL BR41N.IO HACKATHON

April 17-18, 2021

during the

Spring School 2021*

IEEE brain g.tec

*BR41N.IO and Spring School 2021 are part of g.tec's Teaching Plan 2021 with more than 140 hours of online courses and lectures.

1. PLACE WINNER

"NeuroBeat"

BCI application

Team members: Alicja Wicher, Joanna Maria Zalewska, Weronika Sójka, Ivo John Krystian Derezinski, Krzystof Tołpa, Lukasz Furman, Slawomir Duda

IMPROVING HUMAN DAILY LIFE FUNCTIONING

NEUROHACKATOR 2021

21. - 23. MAY 2021 // ONLINE

FRIDAY
Organisers presentation
workshops with Judges

SATURDAY
Project development in groups
STARTS 10 a.m.

SUNDAY
Evaluation
ENDS 10 a.m.

working 24h

REQUIREMENTS:

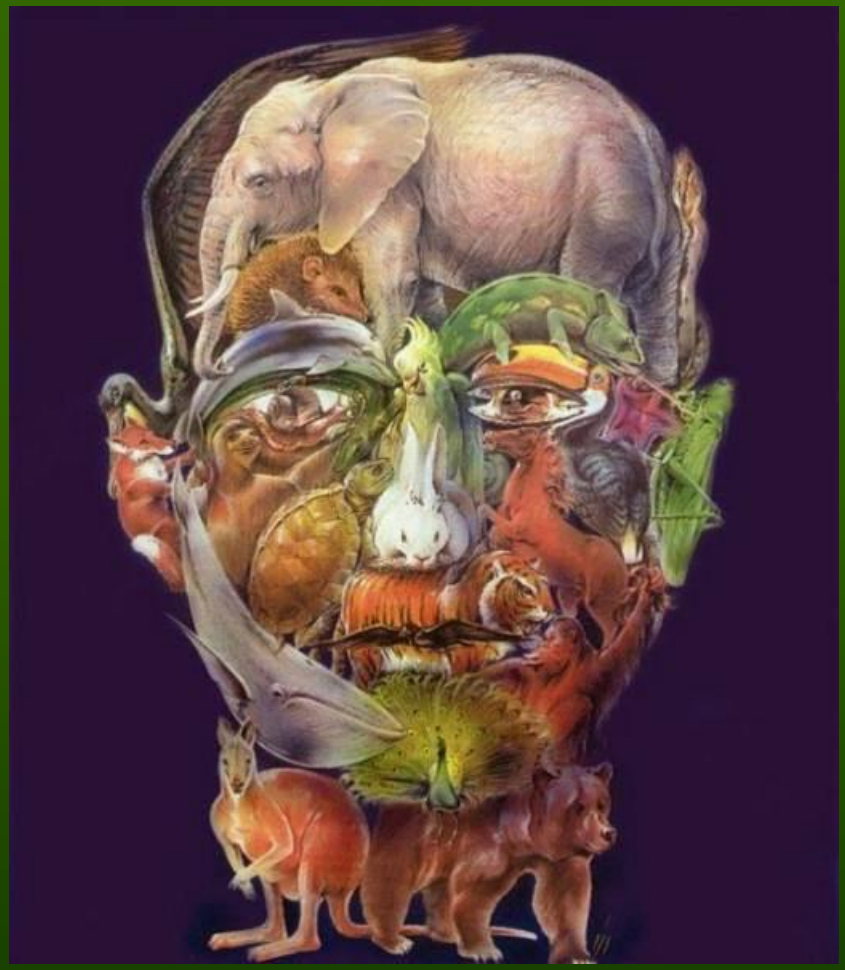
1. Create a team consisting of **3-5 people**.
2. Fill in the Registration Form (available on Facebook event).

DO YOU HAVE ANY QUESTIONS?

Write an e-mail:
NEUROTECHTOR@GMAIL.COM

Neurotechnology Scientific Club
Center for Modern Interdisciplinary Technologies
at Nicolaus Copernicus University in Toruń
Wileńska 4 Street

Intelligence?



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