DONDERS INSTITUTE

Innoboot 2022: Implementing AI to improve Life!

Brain-inspired computing

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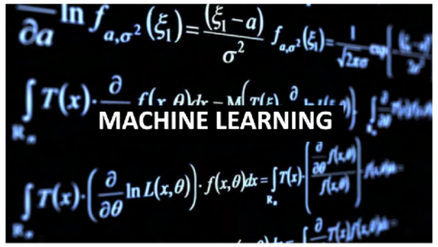
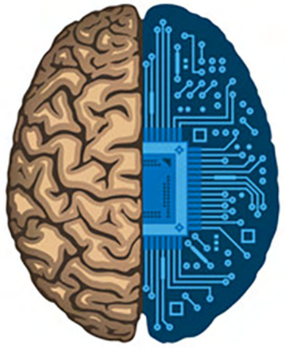
MISSION OF THE AI DEPARTMENT

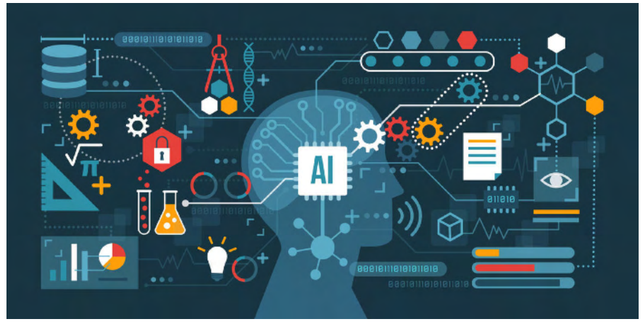
"AI is the **science** and **engineering** of making intelligent machines."
— John McCarthy —

Create general-purpose AI systems that match or even outperform human-level intelligence





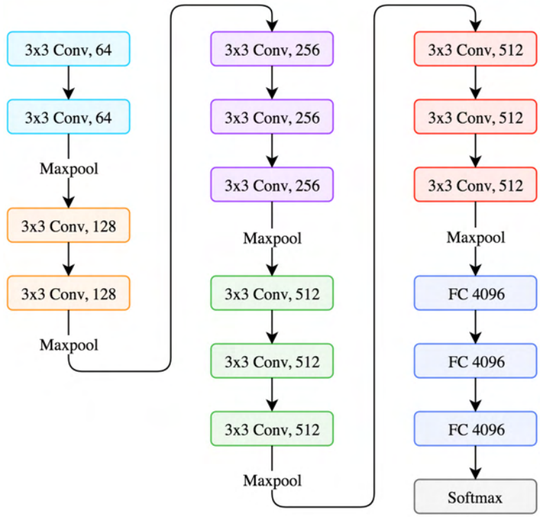
Create AI systems that help address scientific, industrial and societal challenges



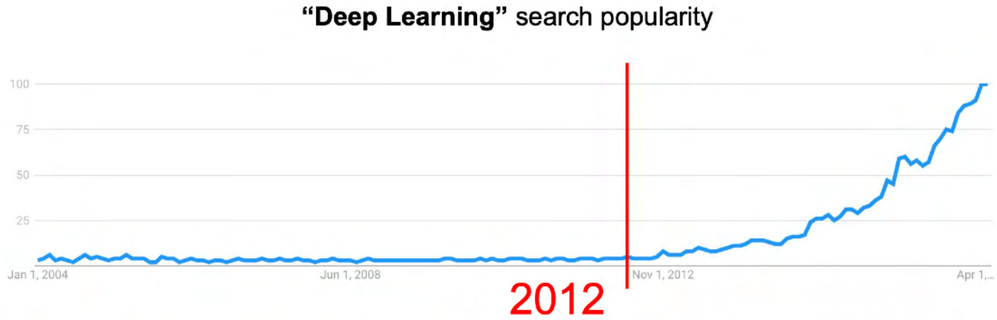
Understanding the wider societal and scientific impact of AI

DEEP LEARNING

Deep learning refers to training of large **multilayer artificial neural networks** using large amounts of **data** on **high-performance computing clusters**

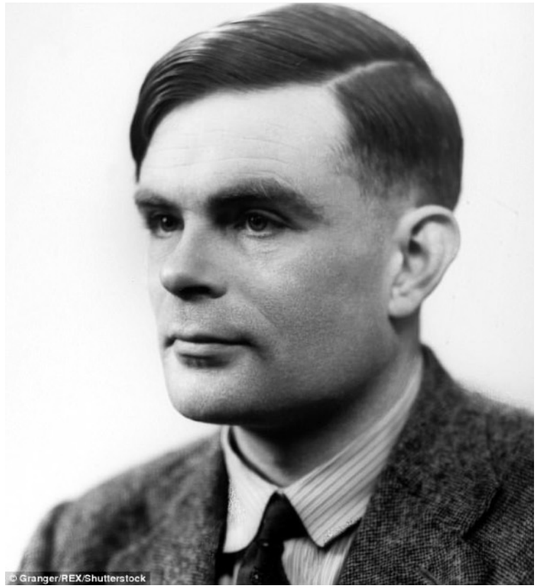


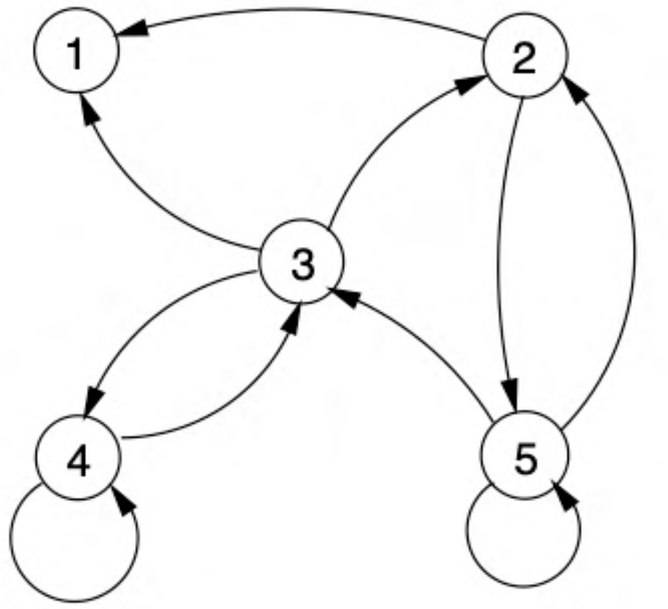
Deep learning has been a main driver of the modern AI revolution



ARTIFICIAL NEURAL NETWORKS

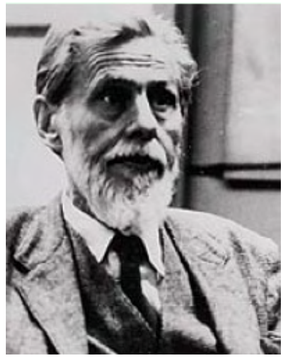
Studied since the 1940's

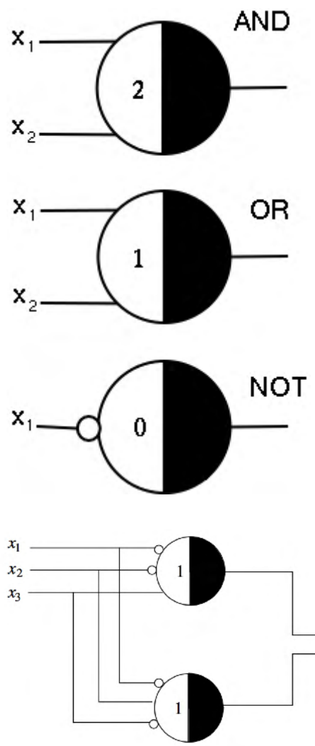




Turing's unorganised machines

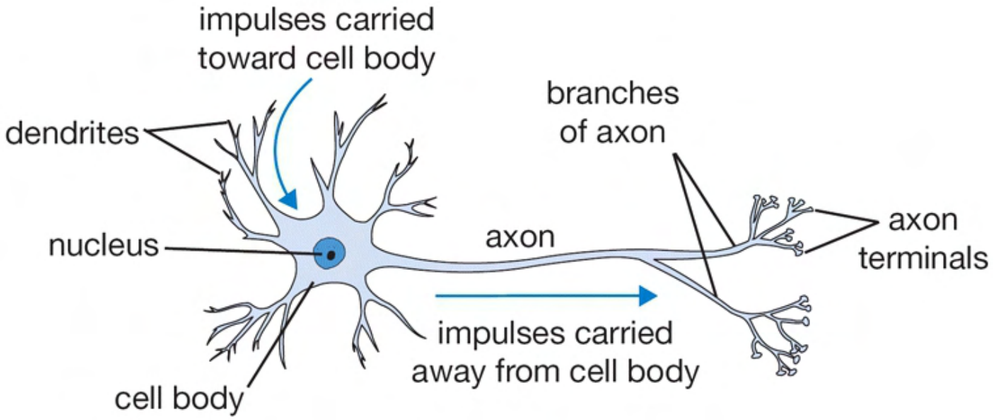
Turing AM. Intelligent Machinery. In: Ince DC, editor. *Collected works of AM Turing — Mechanical Intelligence.* Elsevier Science Publishers, 1992.

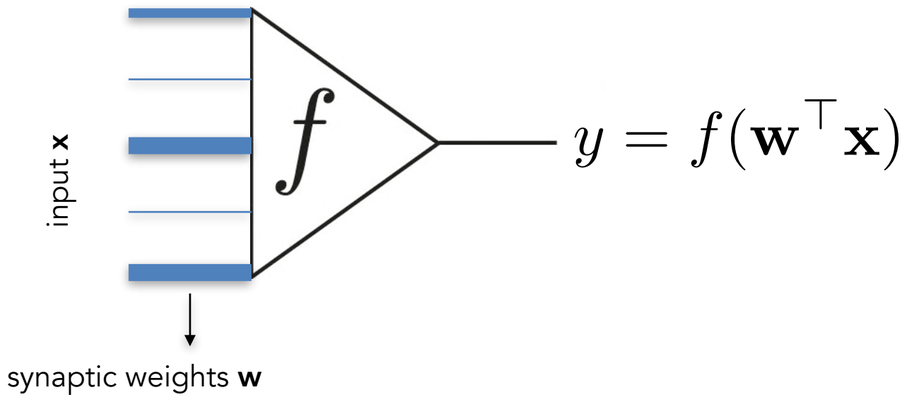




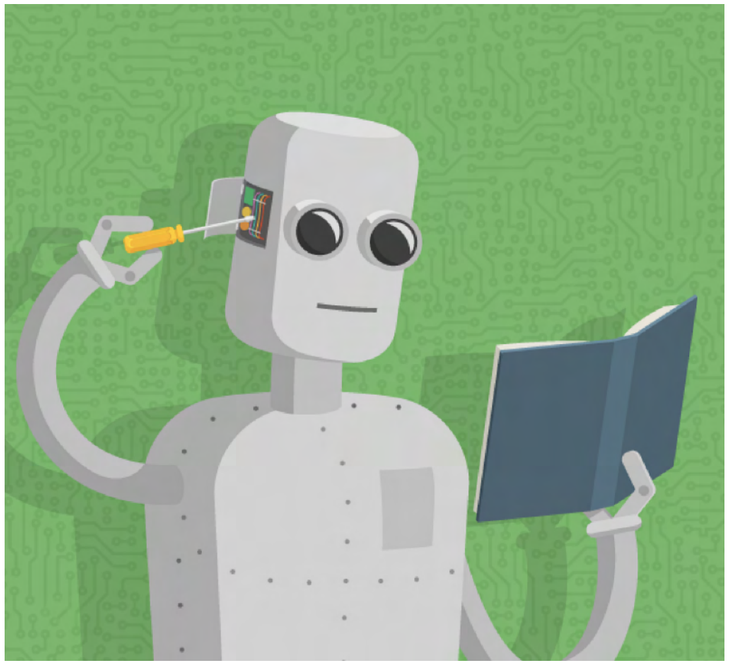
Warren McCulloch and Walter Pitts, A Logical Calculus of Ideas Immanent in Nervous Activity, 1943, *Bulletin of Mathematical Biophysics* 5:115–133.

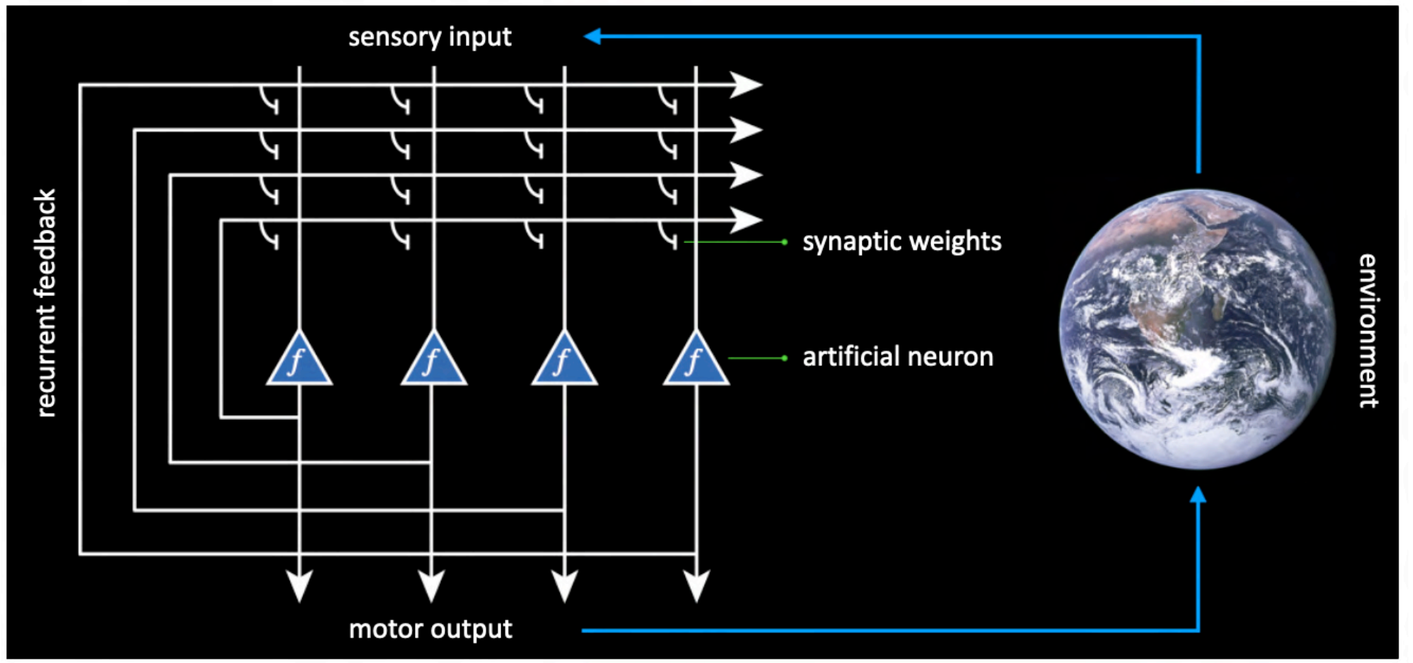
ROOTED IN BIOLOGY





SELF-LEARNING SYSTEMS





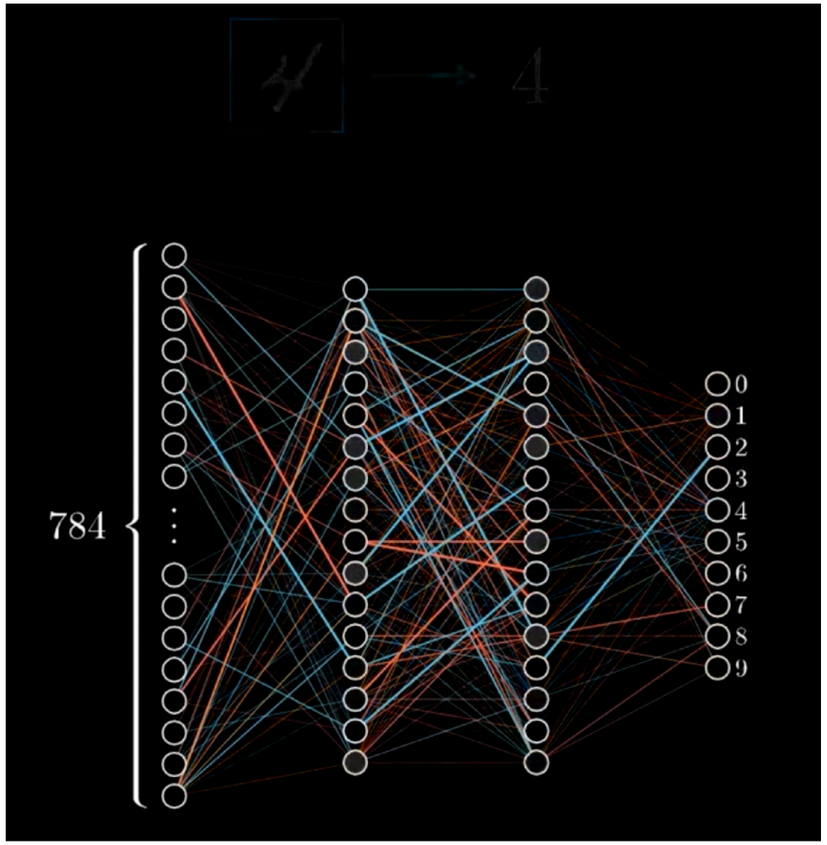
Three kinds of learning:

- Unsupervised learning: minimise surprise
- Supervised learning: teacher signal
- Reinforcement learning: reward signal

How to set the weights of a neural network such as to maximise network performance?

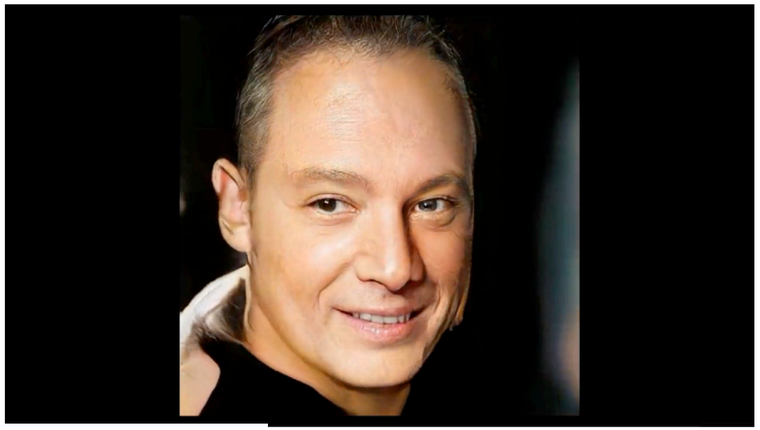
LEARNING VIA ERROR BACKPROPAGATION

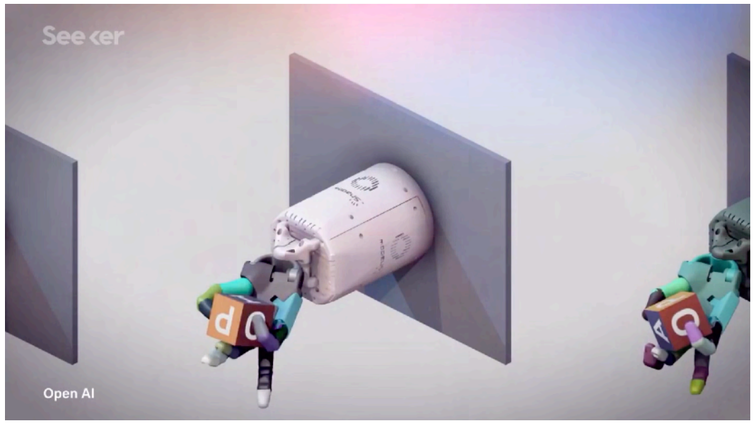
- Key algorithm for neural network training
- Developed by Linnainmaa in 1970 and applied to neural networks by Werbos in 1982
- Popularised in the 80's by Hinton, LeCun, Rumelhart, McClelland
- Minimizes the error in network output using stochastic gradient descent: $W_l \leftarrow W_l - \eta \mathbb{E}\left[\nabla_{W_l} \ell\right]$

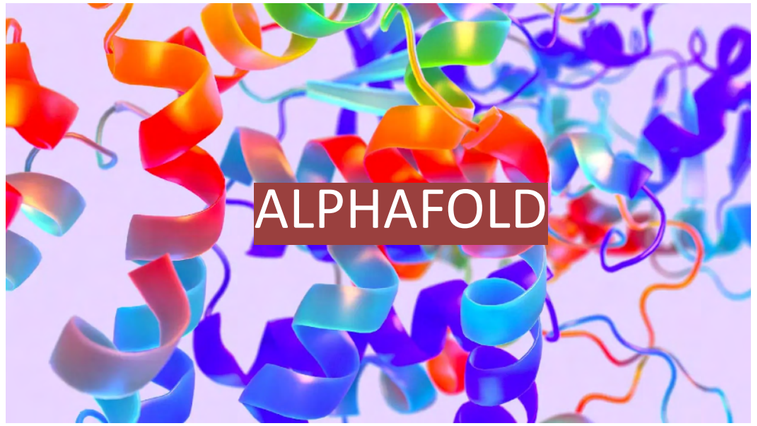


Source: 3blue1brown

THE AI REVOLUTION





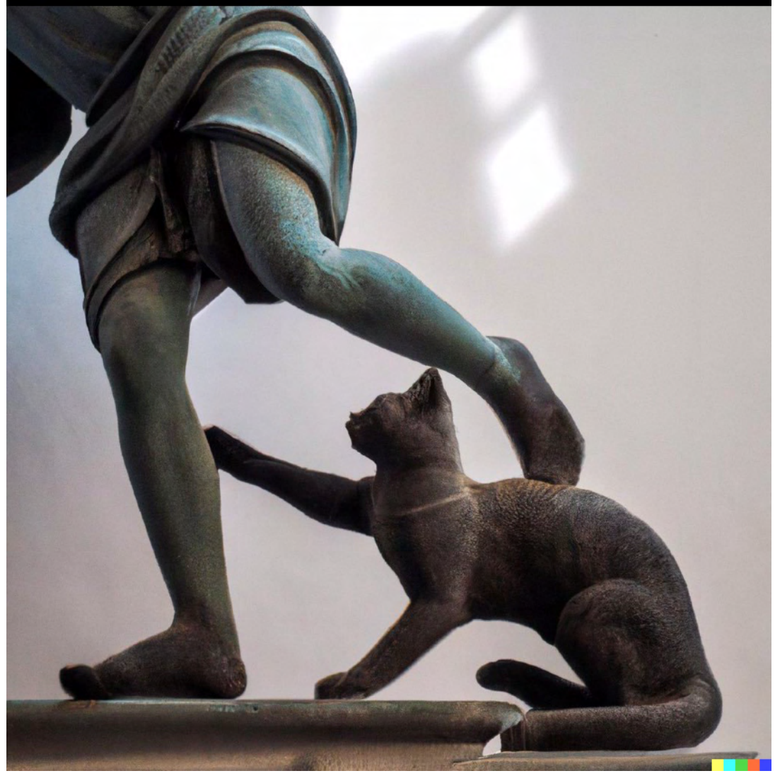


THE AI REVOLUTION?

DALL·E 2

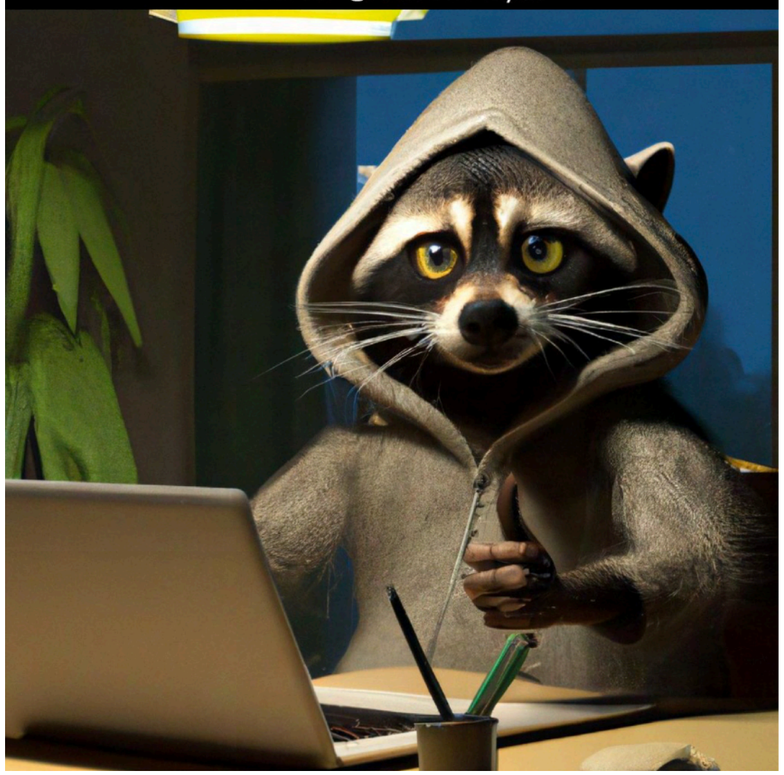
DALL·E 2 is a new AI system that can create realistic images and art from a description in natural language.

Greek statue of a man tripping over a cat
Source: @LapineDeLaTerre

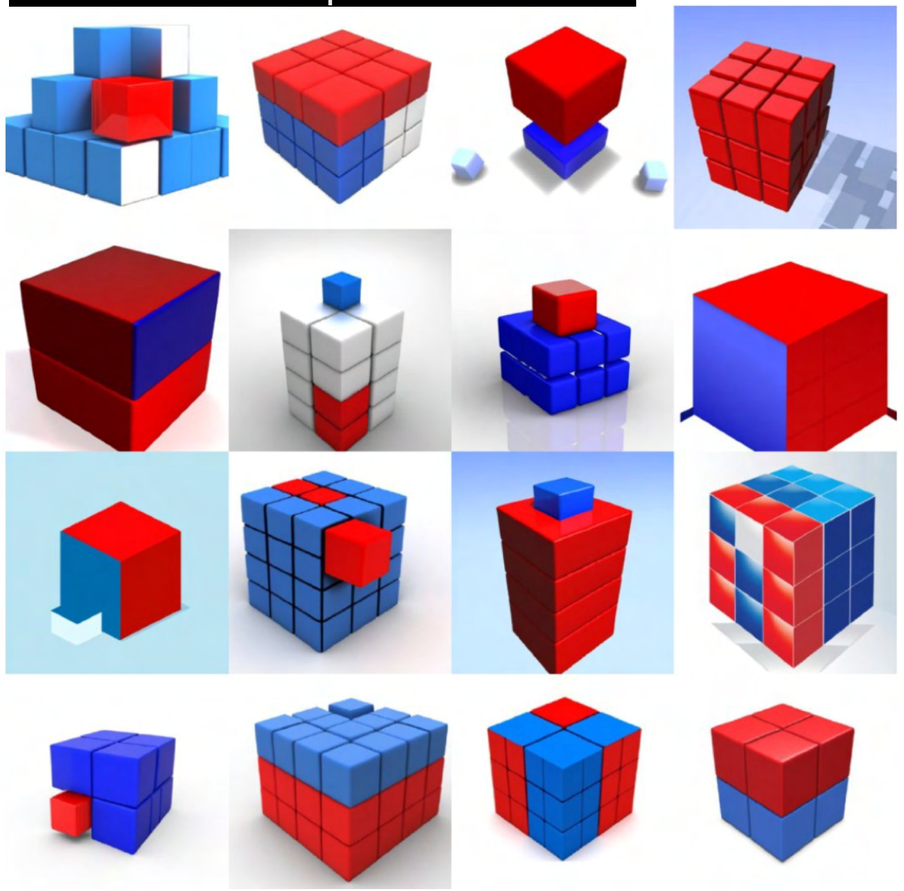


A raccoon wearing a hoodie working on his laptop late into the night in los angeles making a 'yes' as he realizes his latest book is an Audible best seller

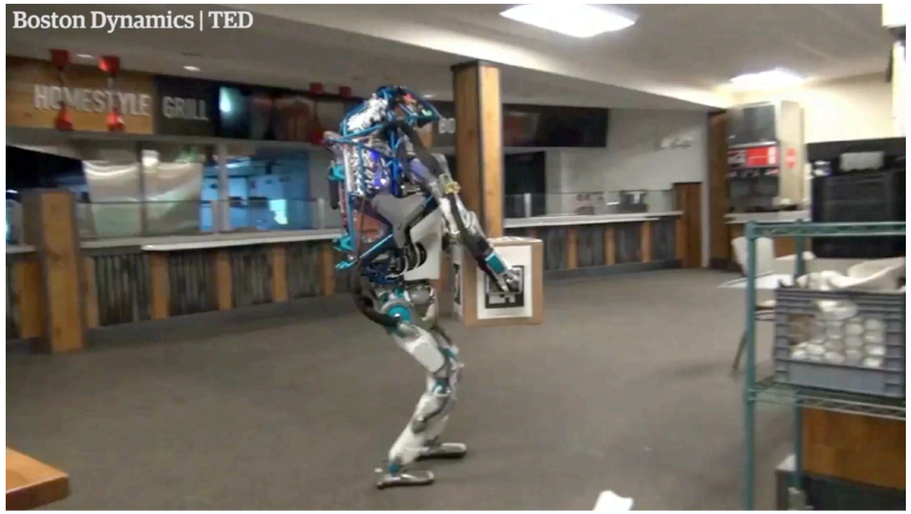
Source: @AndrewMayne



"A red cube on top of a blue cube"



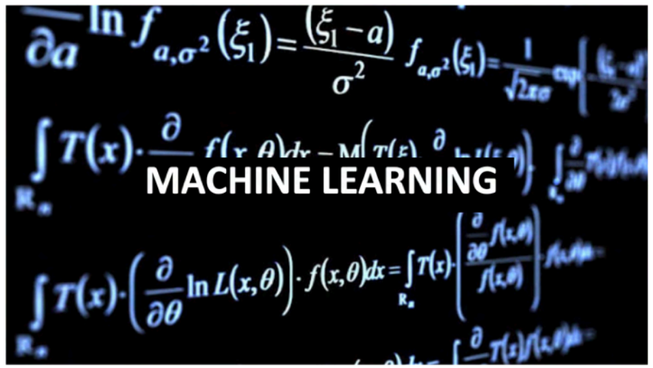
THE AI REVOLUTION?



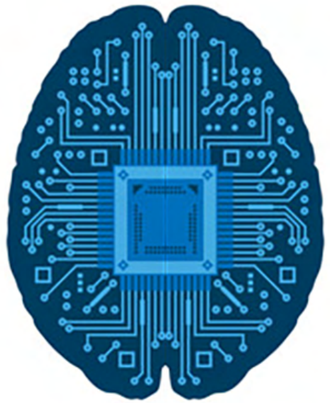
a woman riding a horse on a dirt road

a group of people standing on top of a beach

BRAIN-INSPIRED COMPUTING

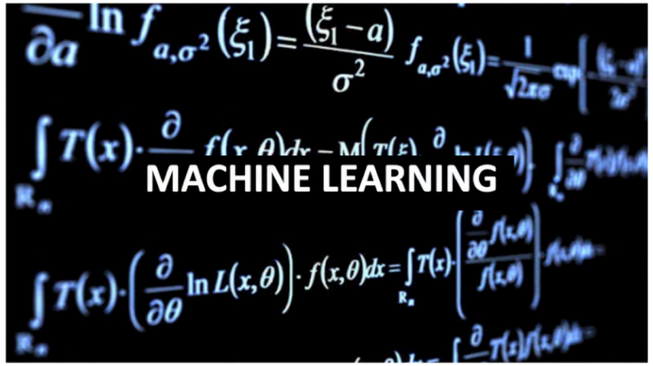


theoretical insights

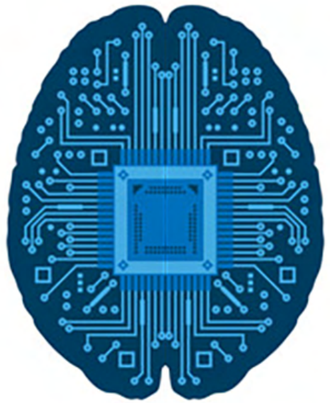


empirical insights

BRAIN-INSPIRED COMPUTING



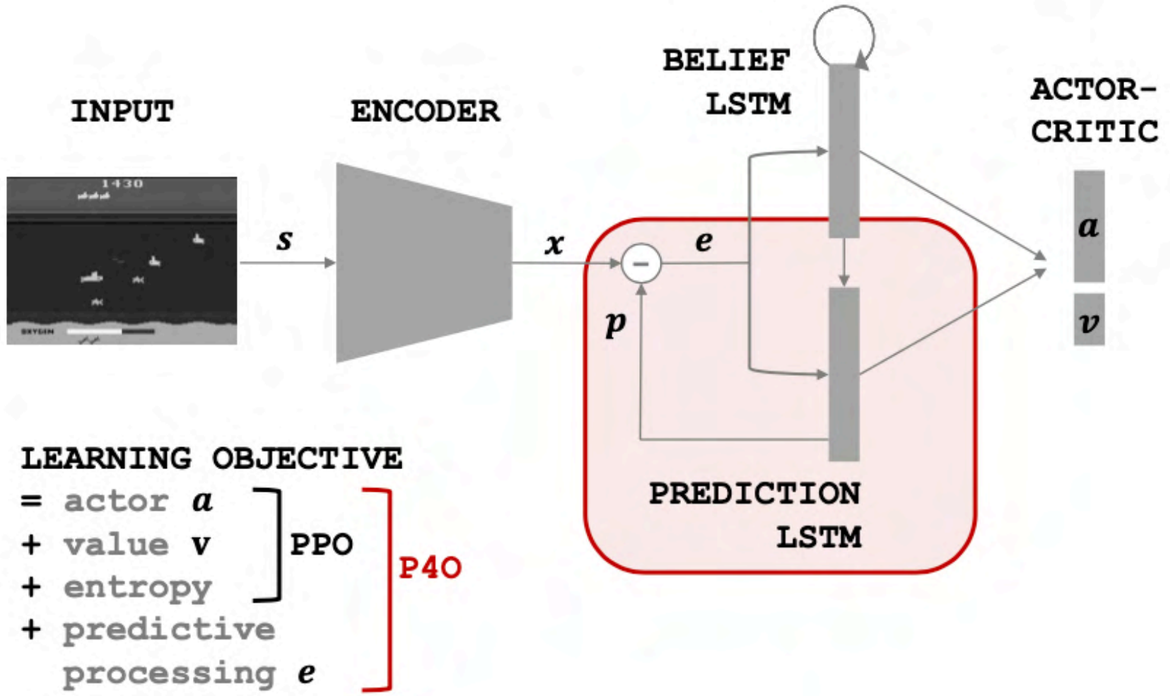
theoretical insights



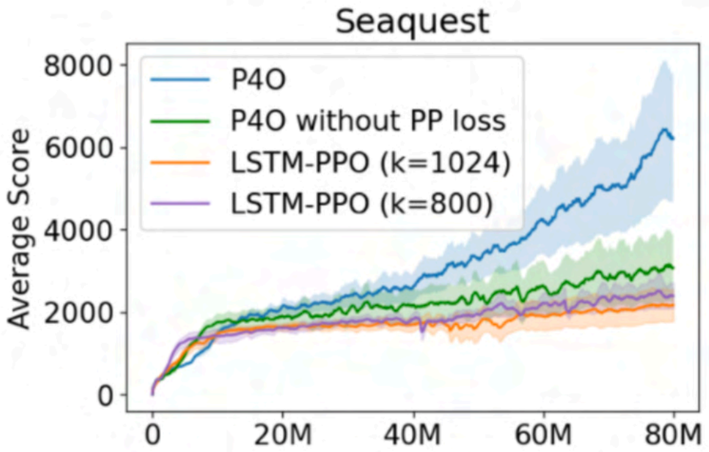
empirical insights

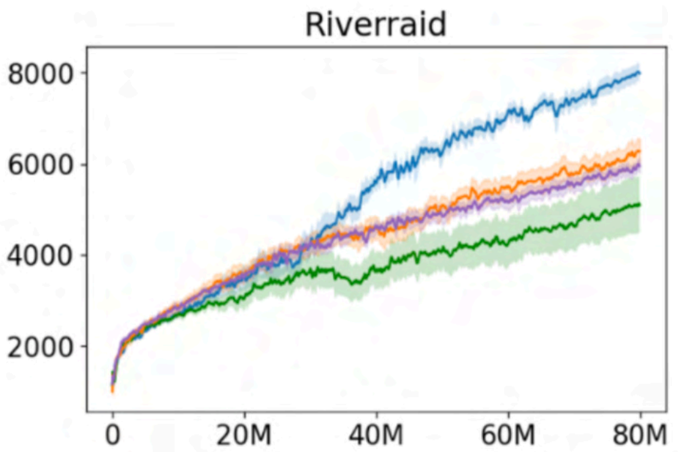
- Artificial neural networks are inspired by biological neural networks
- But…
  - Learning through backpropagation highly inefficient (and implausible)
  - Resulting systems have limited capabilities
- How can the human brain solve complex tasks so efficiently?
- Can we achieve the same in machines?

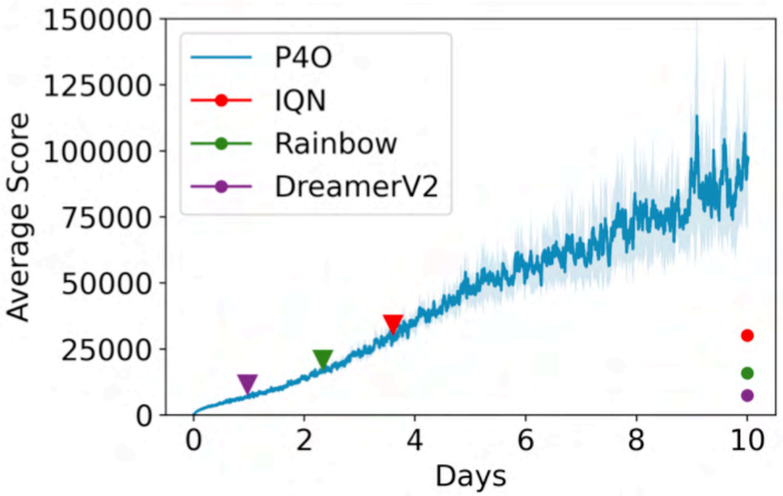
IMPROVING REINFORCEMENT LEARNING VIA PREDICTIVE PROCESSING



- Reinforcement learning sample inefficient
- Complex methods yield SOTA performance
- We use a simple approach which predicts next action as well as its own sensory input
- Large performance gains can be achieved using this predictive processing approach

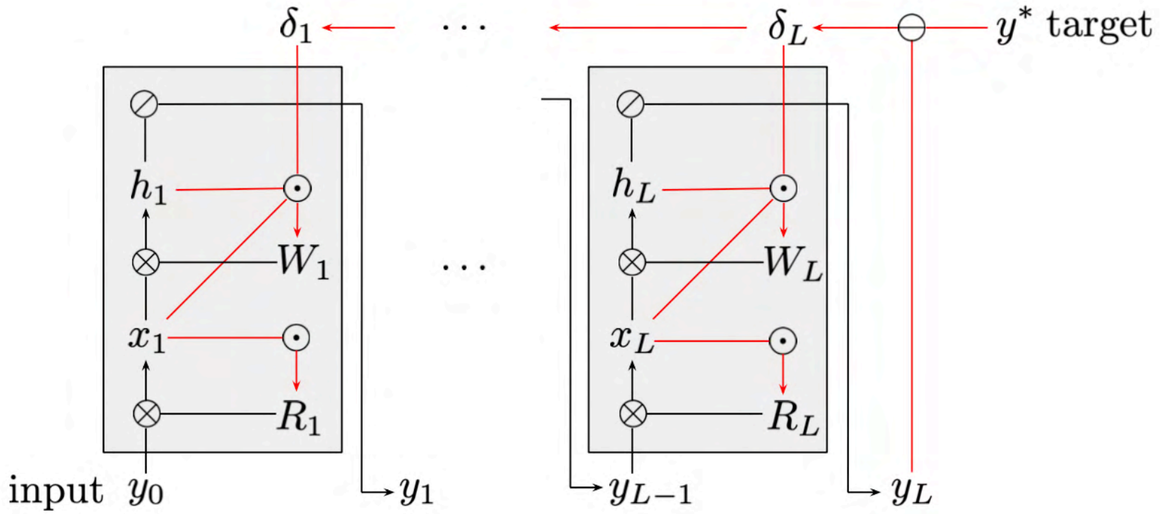






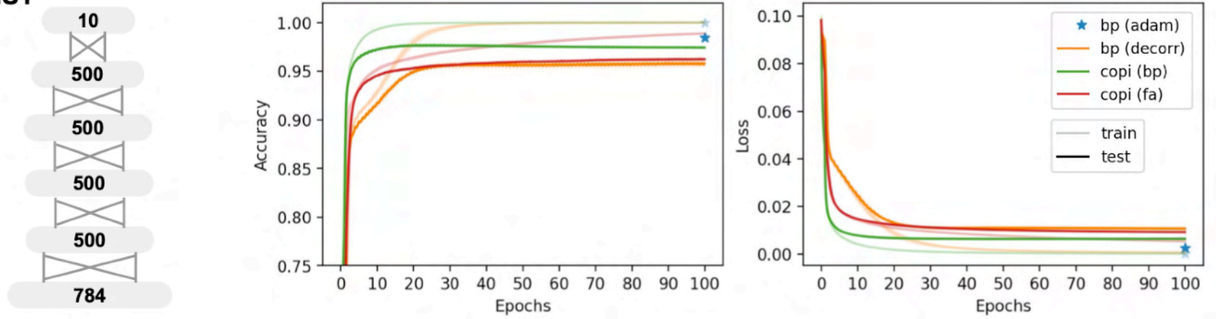
https://openreview.net/forum?id=zz_qjE6N1OF

EFFICIENT DEEP LEARNING WITH CONSTRAINED PARAMETER INFERENCE

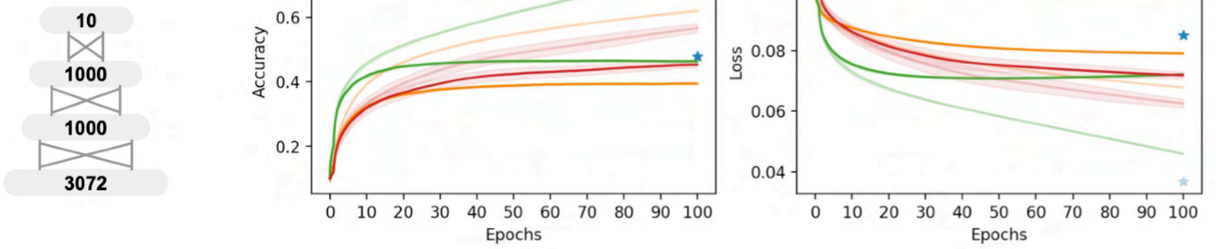


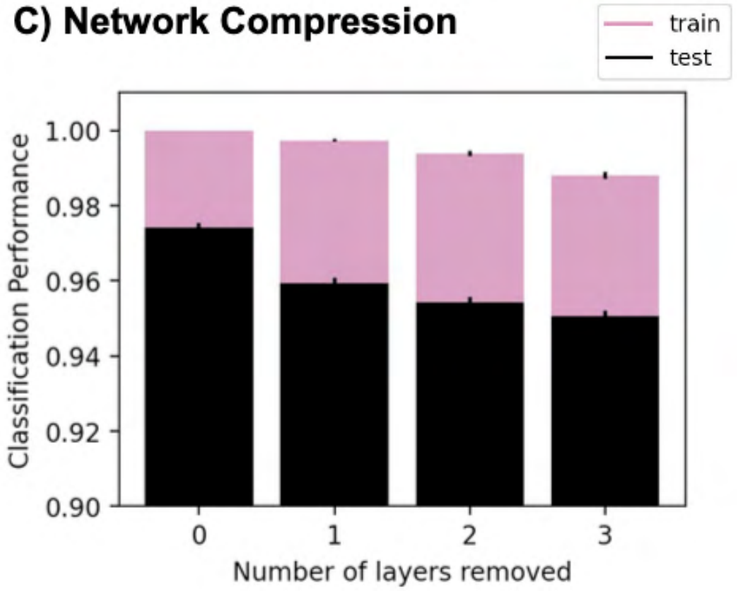
- New learning algorithm
- Achieves local learning by relying on input decorrelation
- More biologically plausible, faster convergence, same or better performance than backpropagation
- Allows for easy network compression

MNIST



CIFAR-10

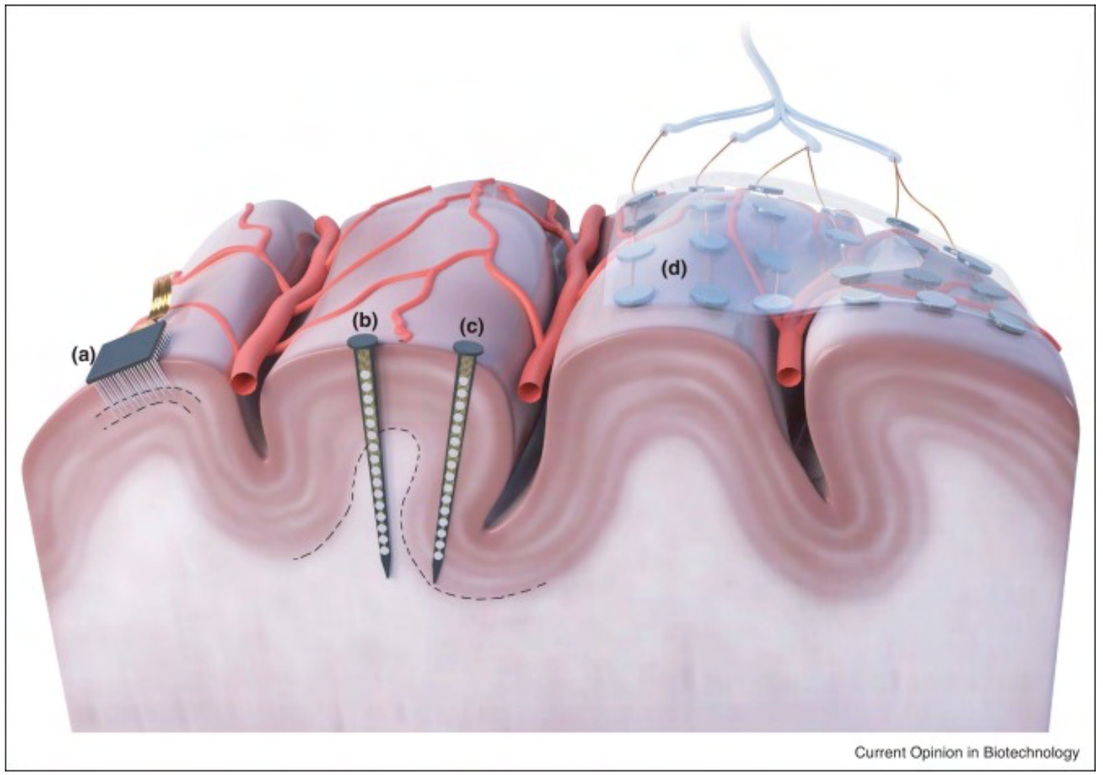




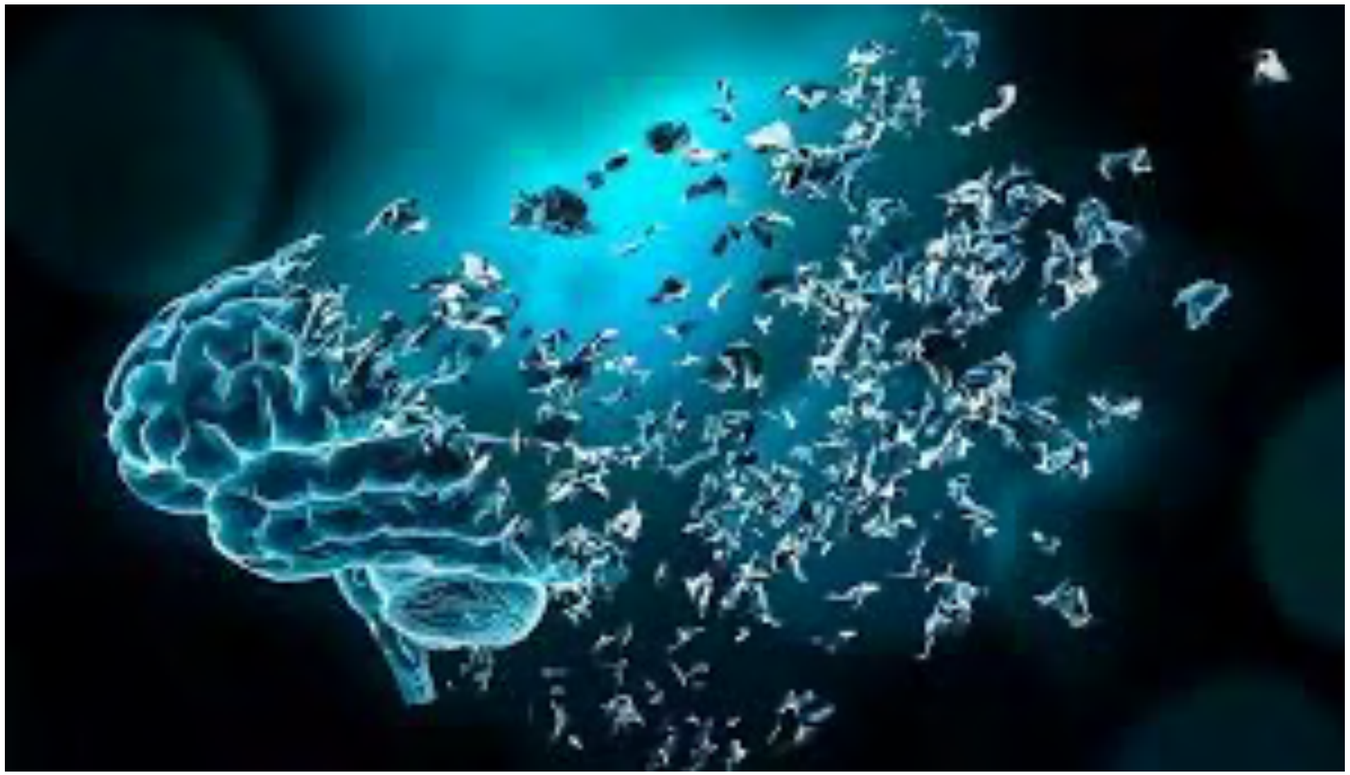
https://arxiv.org/abs/2203.13203

USE CASE: NEUROTECHNOLOGY

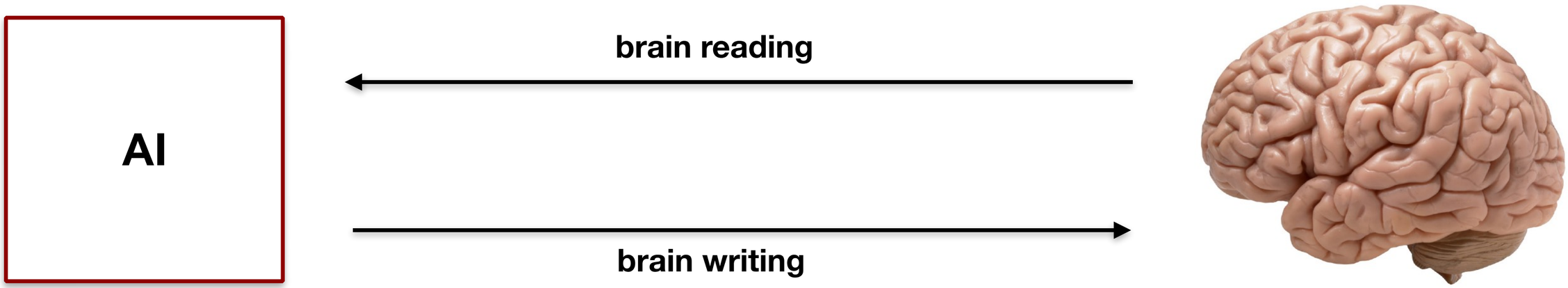
New neurotechnologies allow for simultaneous measurement and stimulation of the brain



Allows restoration of function in patients that suffer from brain disorders (blindness, deafness, paralysis, epilepsy, etc.)



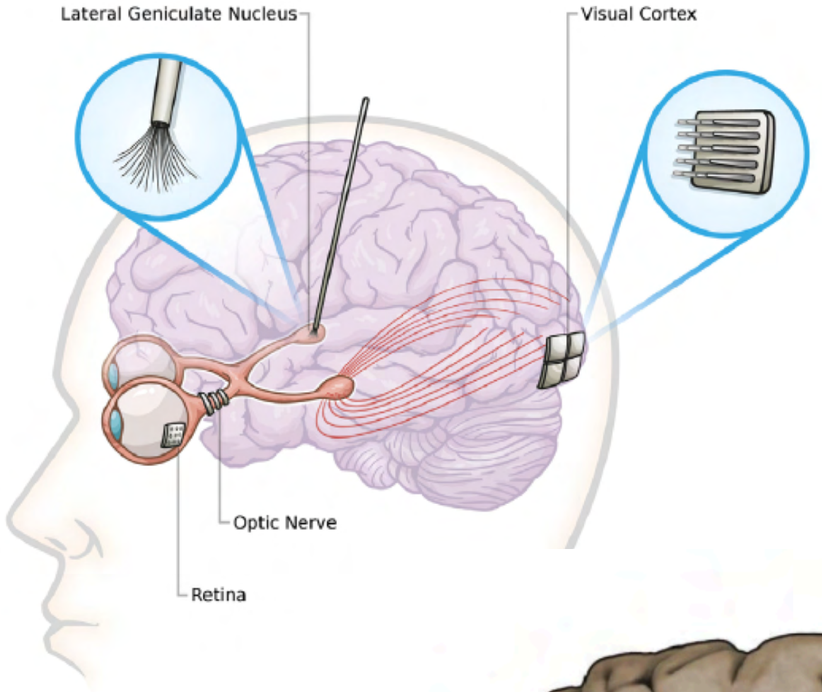
AI FOR NEUROTECHNOLOGY

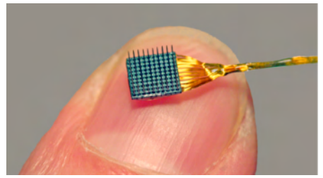


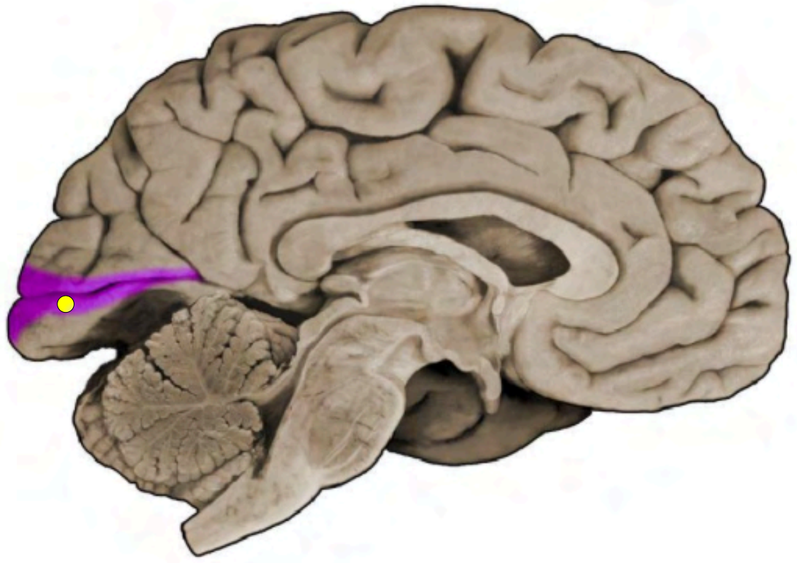
Brain reading: optimal readout of neural activity

Brain writing: optimal control of neural activity

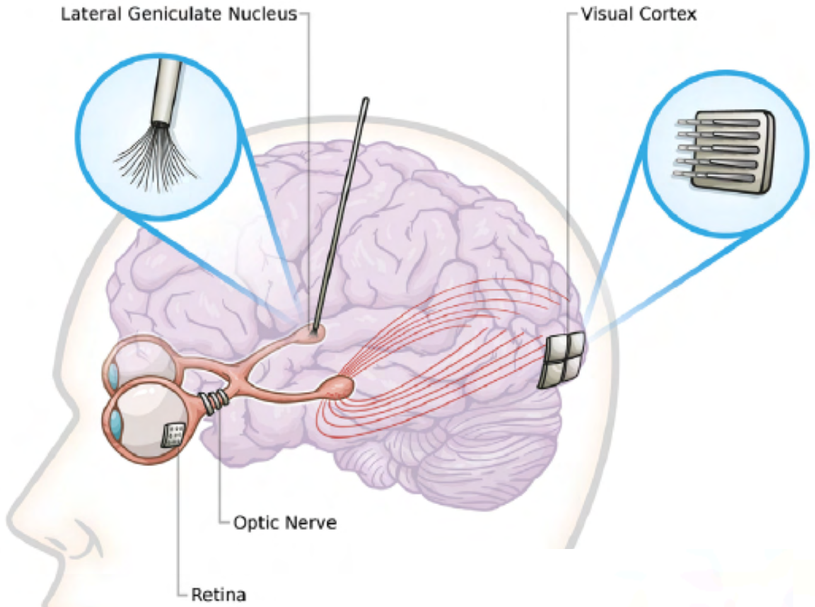
RESTORING VISUAL EXPERIENCE IN THE BLIND

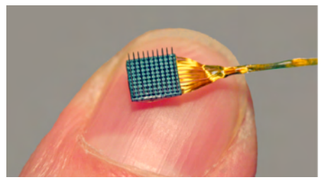


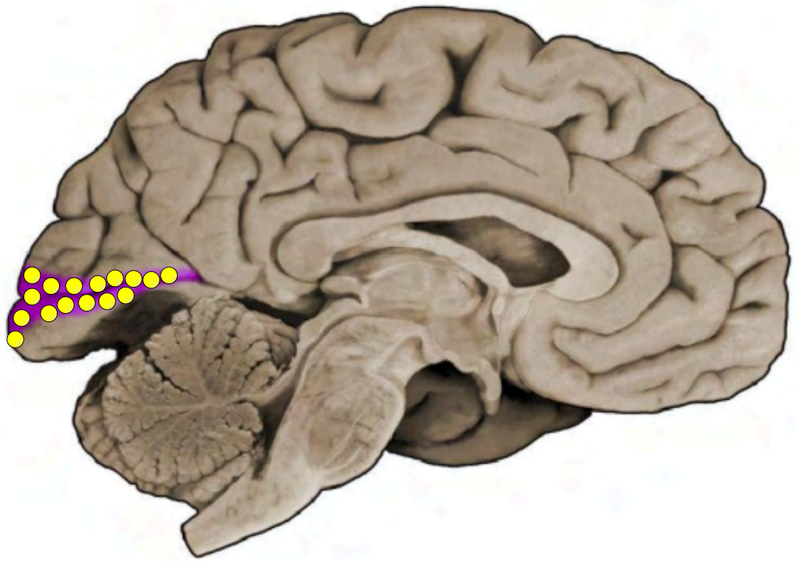


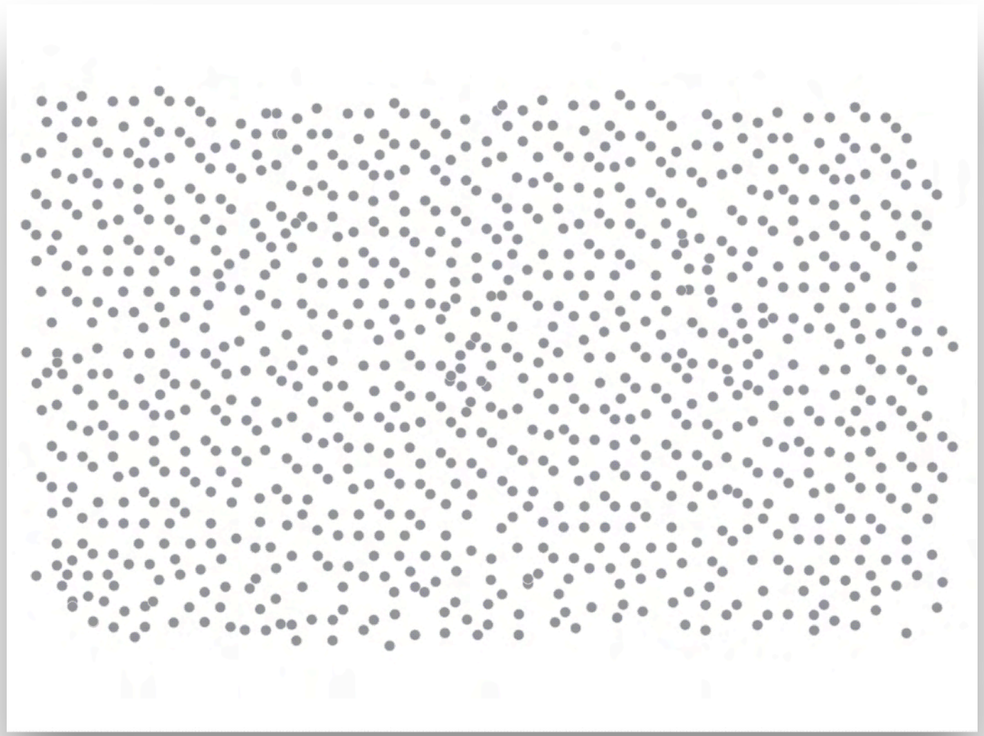


RESTORING VISUAL EXPERIENCE IN THE BLIND









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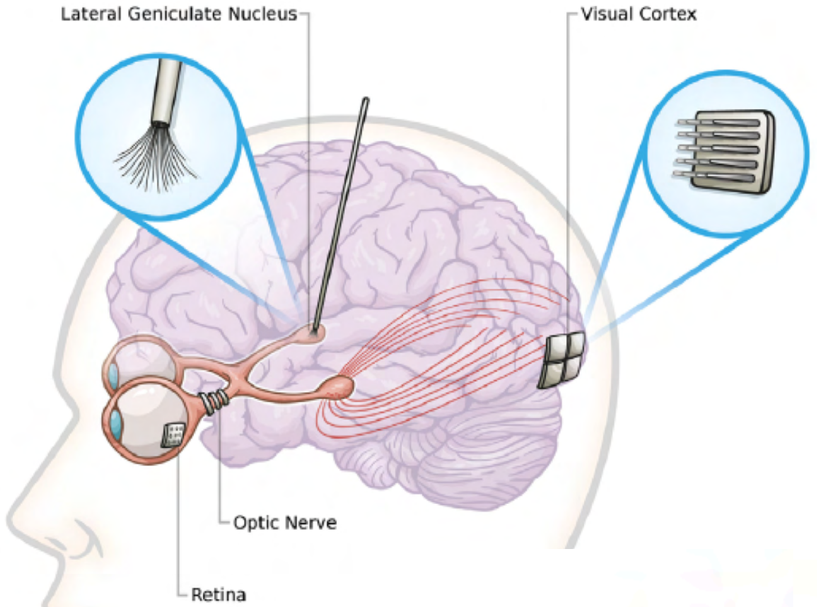
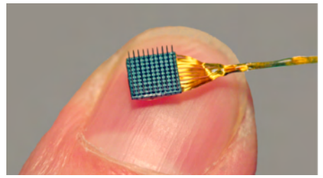
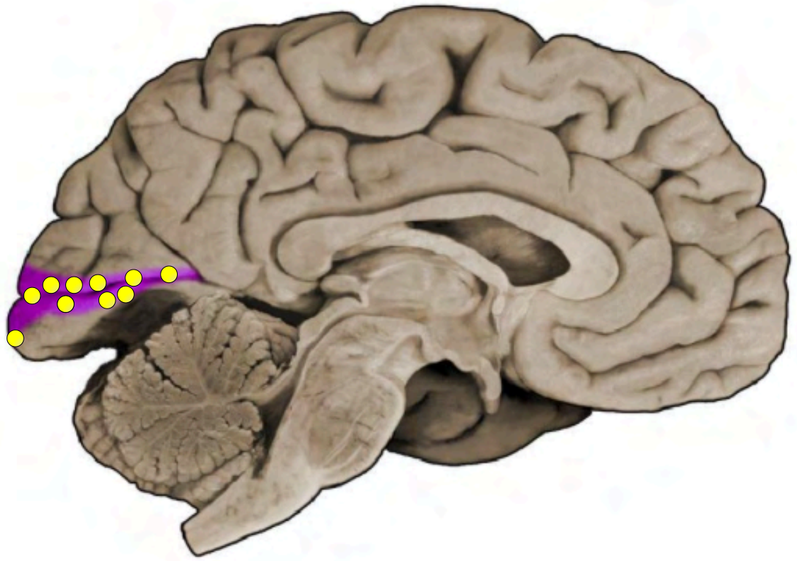
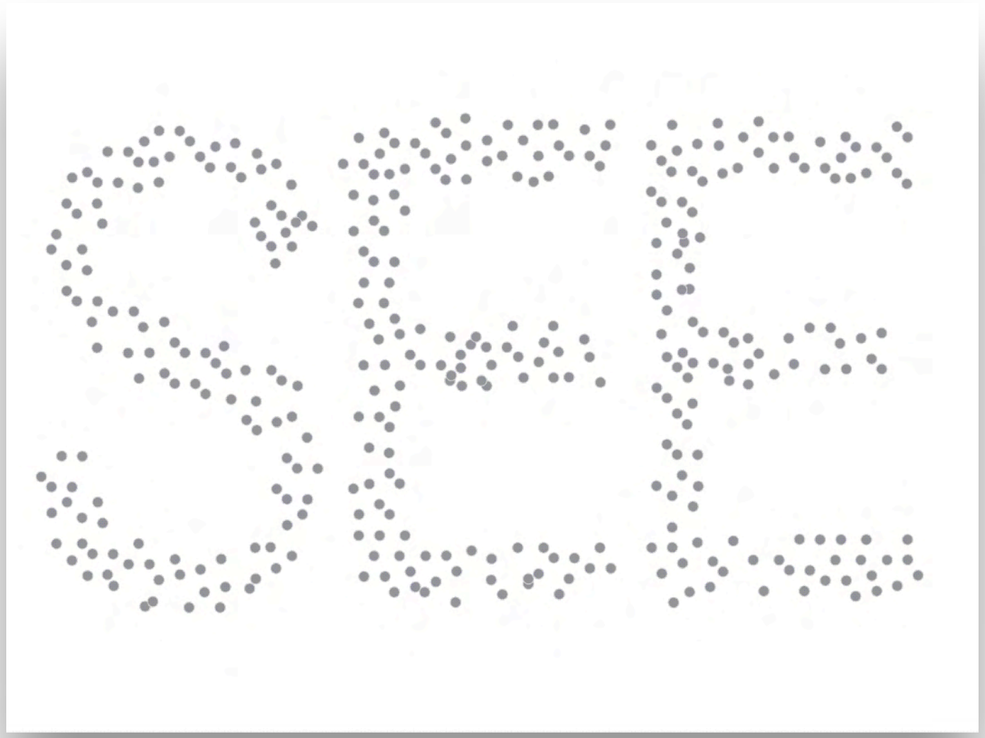
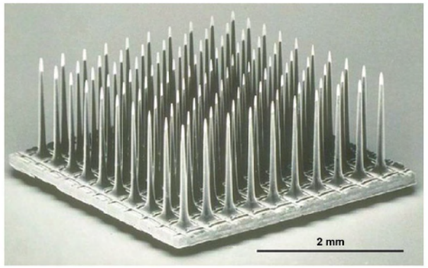


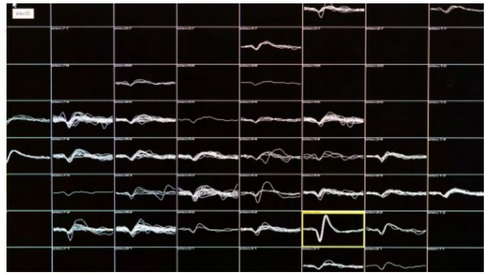


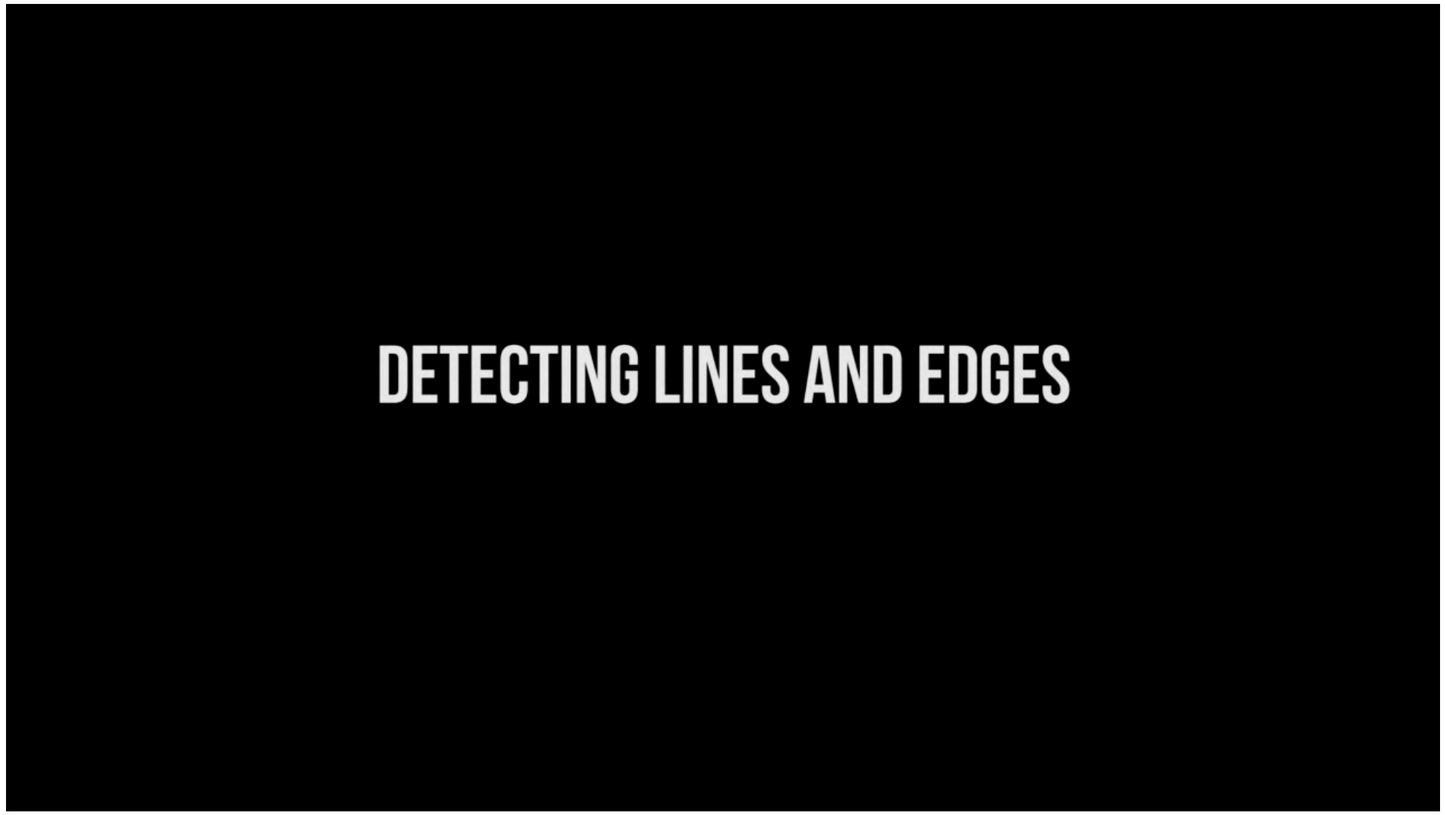




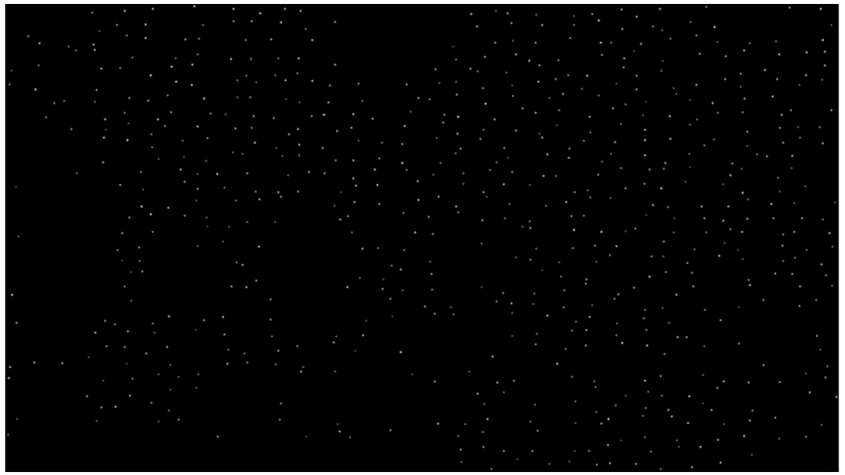
BRAIN WRITING: VISUAL CORTICAL PROSTHESIS



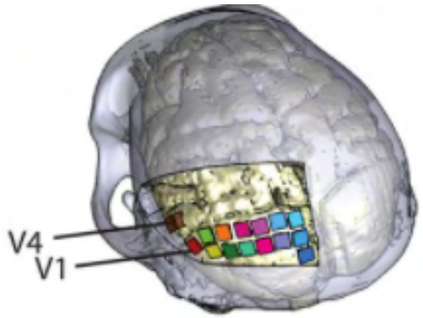


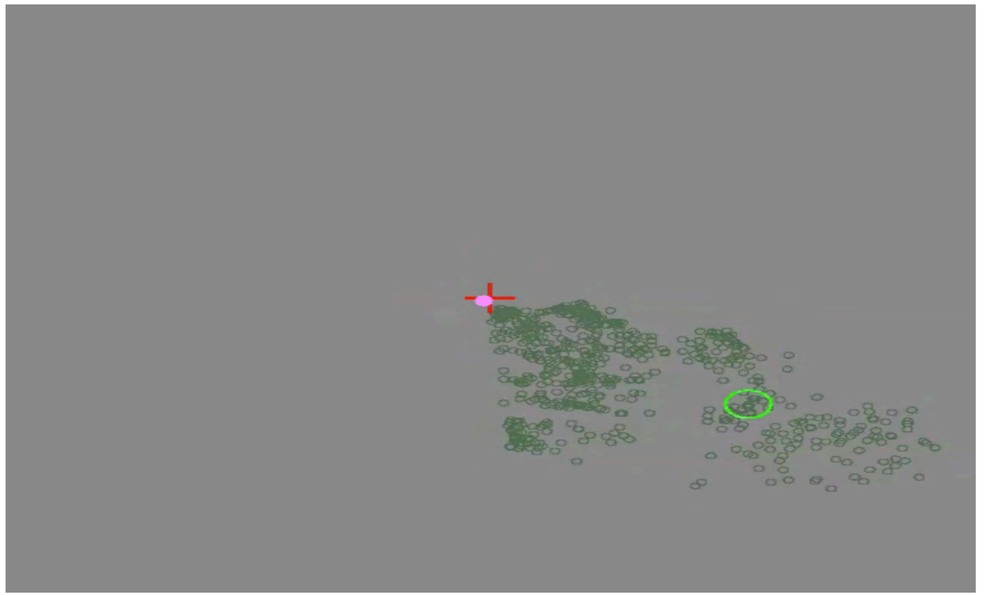


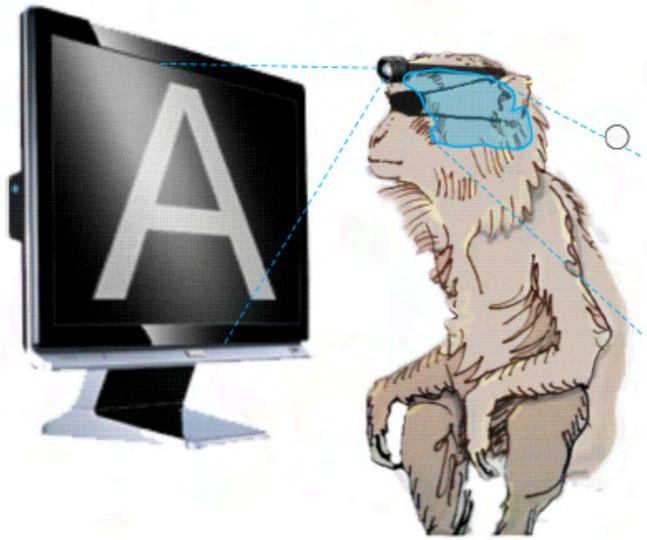
CHALLENGE: PHOSPHENE VISION IN NATURALISTIC ENVIRONMENTS

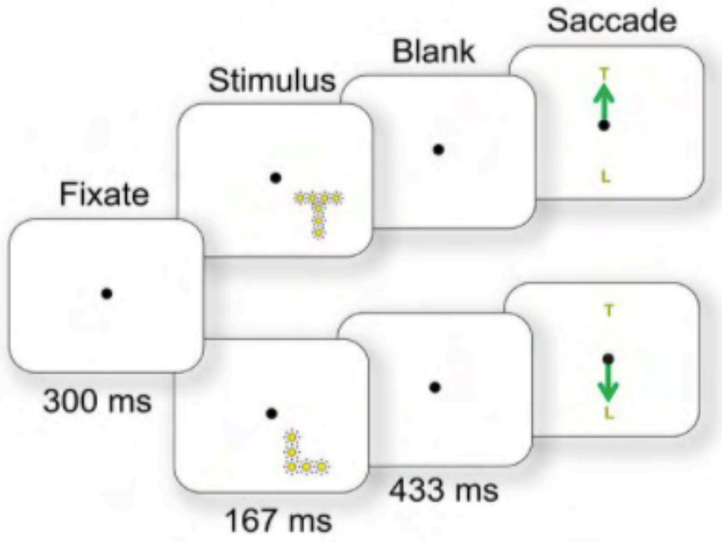


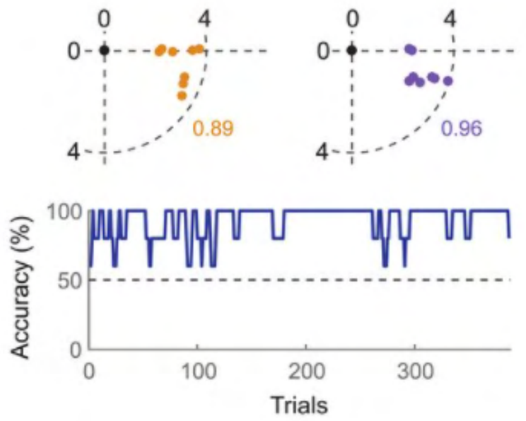
IN VIVO TESTING





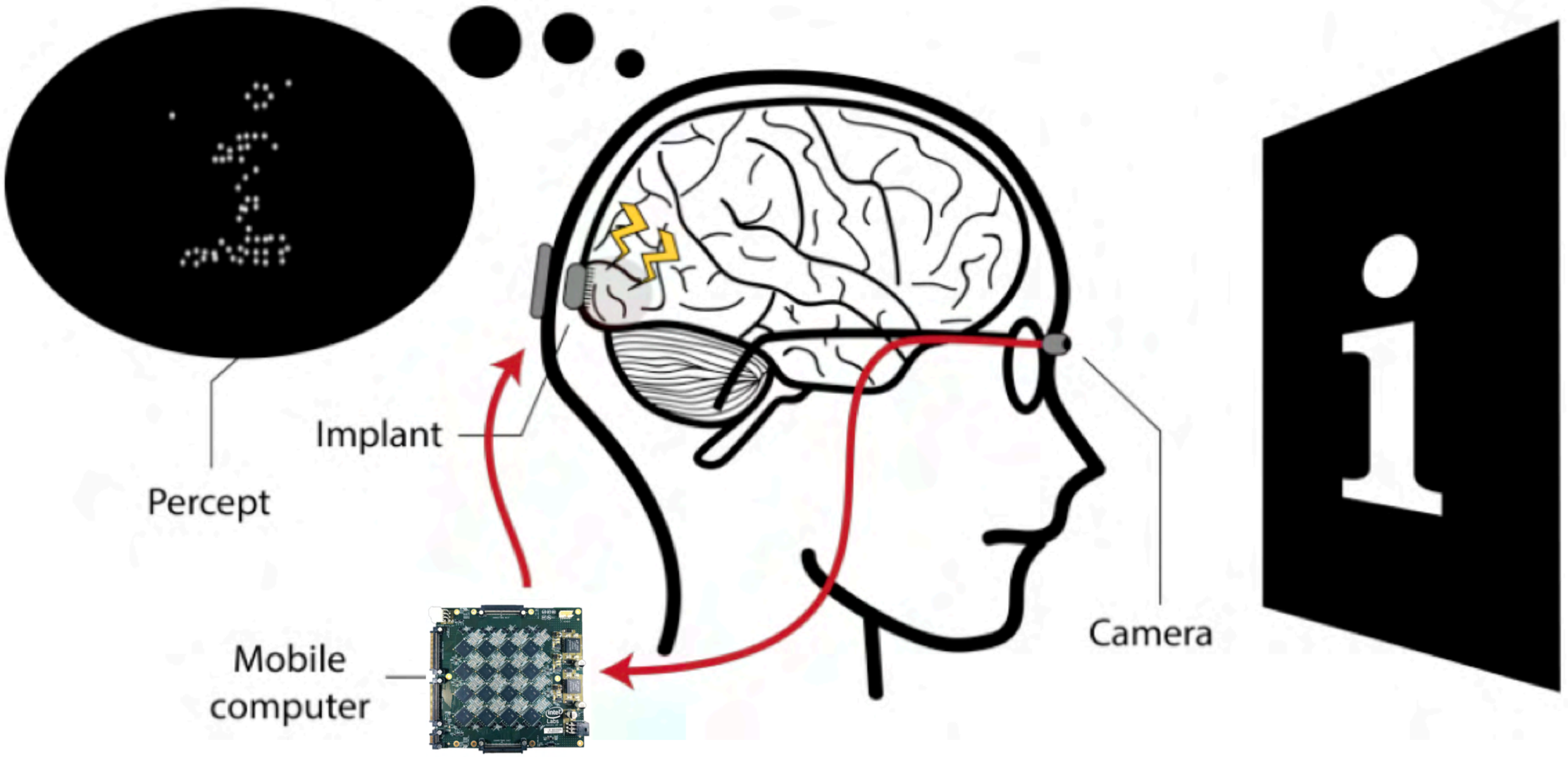






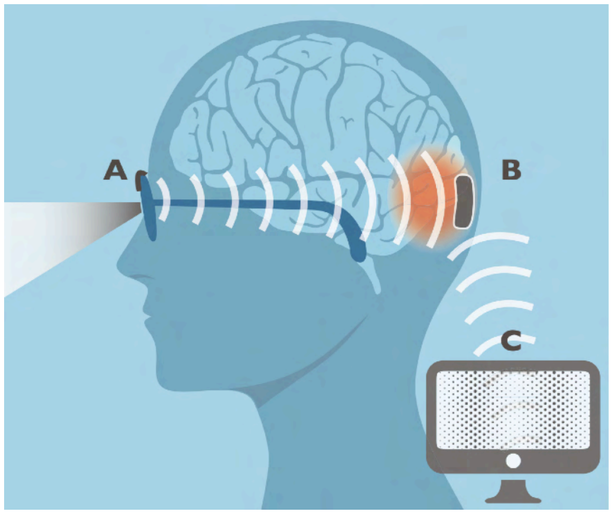
Chen *et al* 2020

BRAIN WRITING: VISUAL CORTICAL PROSTHESIS



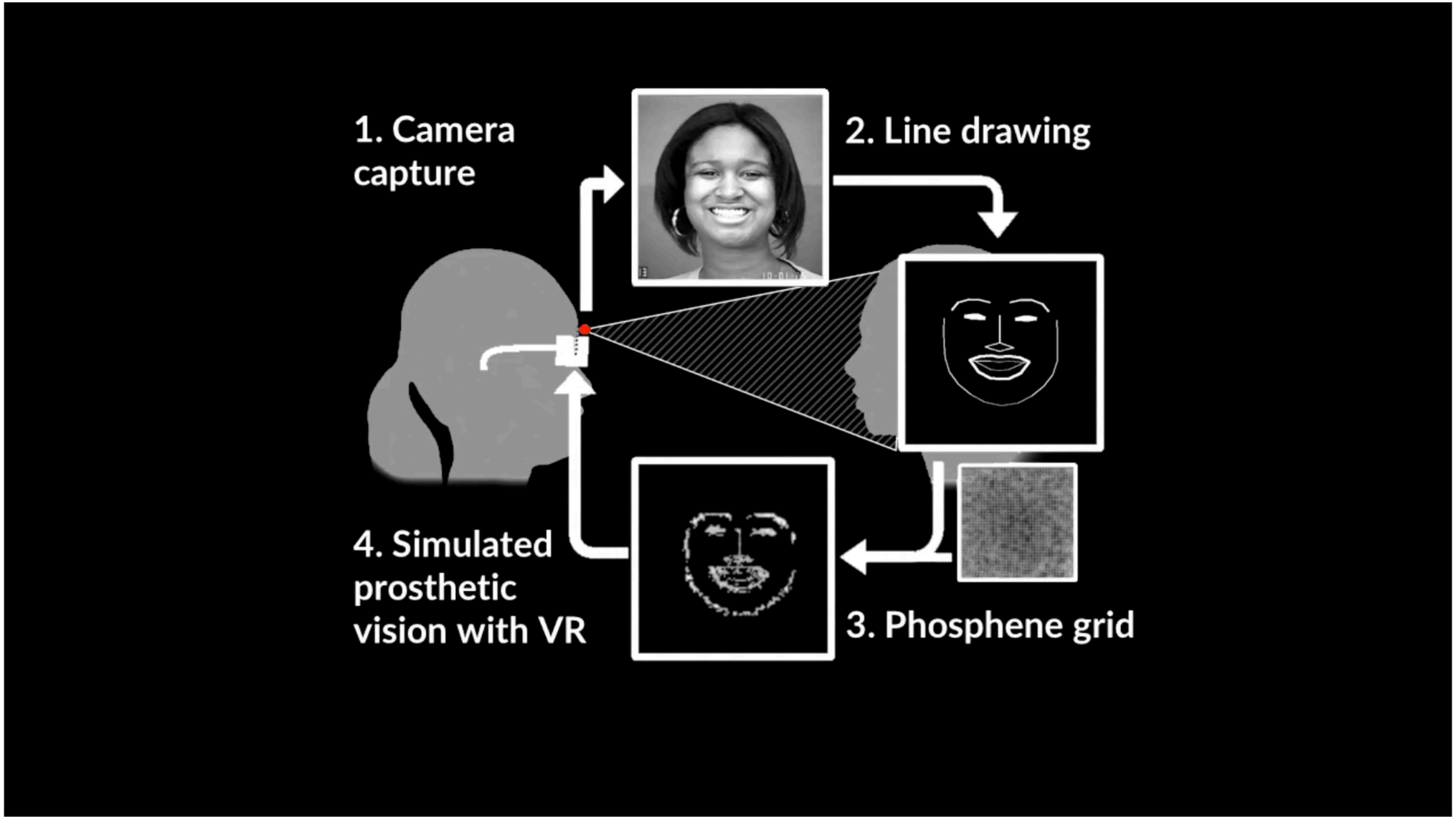
BRAIN WRITING: VISUAL CORTICAL PROSTHESIS

Camera image



Percept

BRAIN WRITING: VISUAL CORTICAL PROSTHESIS



Bollen, C. J. M., Guclu, U., Van Wezel, R. J. A., Van Gerven, M. A. J., & Gucluturk, Y. (2019). Simulating neuroprosthetic vision for emotion recognition. 2019 8th International Conference on Affective Computing and Intelligent Interaction Workshops and Demos, ACIIW 2019. https://doi.org/10.1109/ACIIW.2019.8925229

END-TO-END PROSTHETIC VISION

128 x 128
Input image

de Ruyter van Steveninck, J., Güçlü, U., van Wezel, R., & van Gerven, M. (2020). End-to-end optimization of prosthetic vision. Journal of Vision, 22(20). https://doi.org/10.1101/2020.12.19.423601

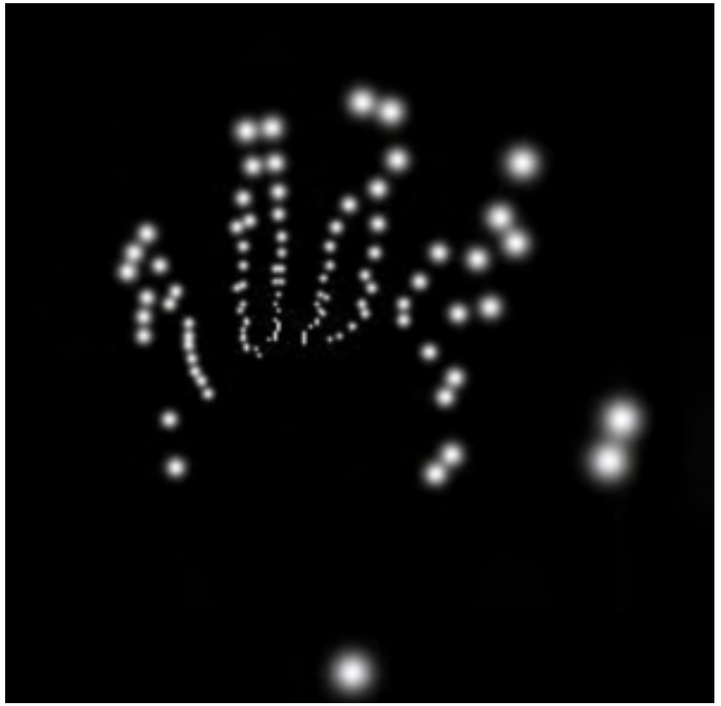
END-TO-END PROSTHETIC VISION

Task:

Image

BEHAVIOURAL VALIDATION USING AUGMENTED REALITY

A testing environment for psychophysical and behavioral experiments with healthy human participants



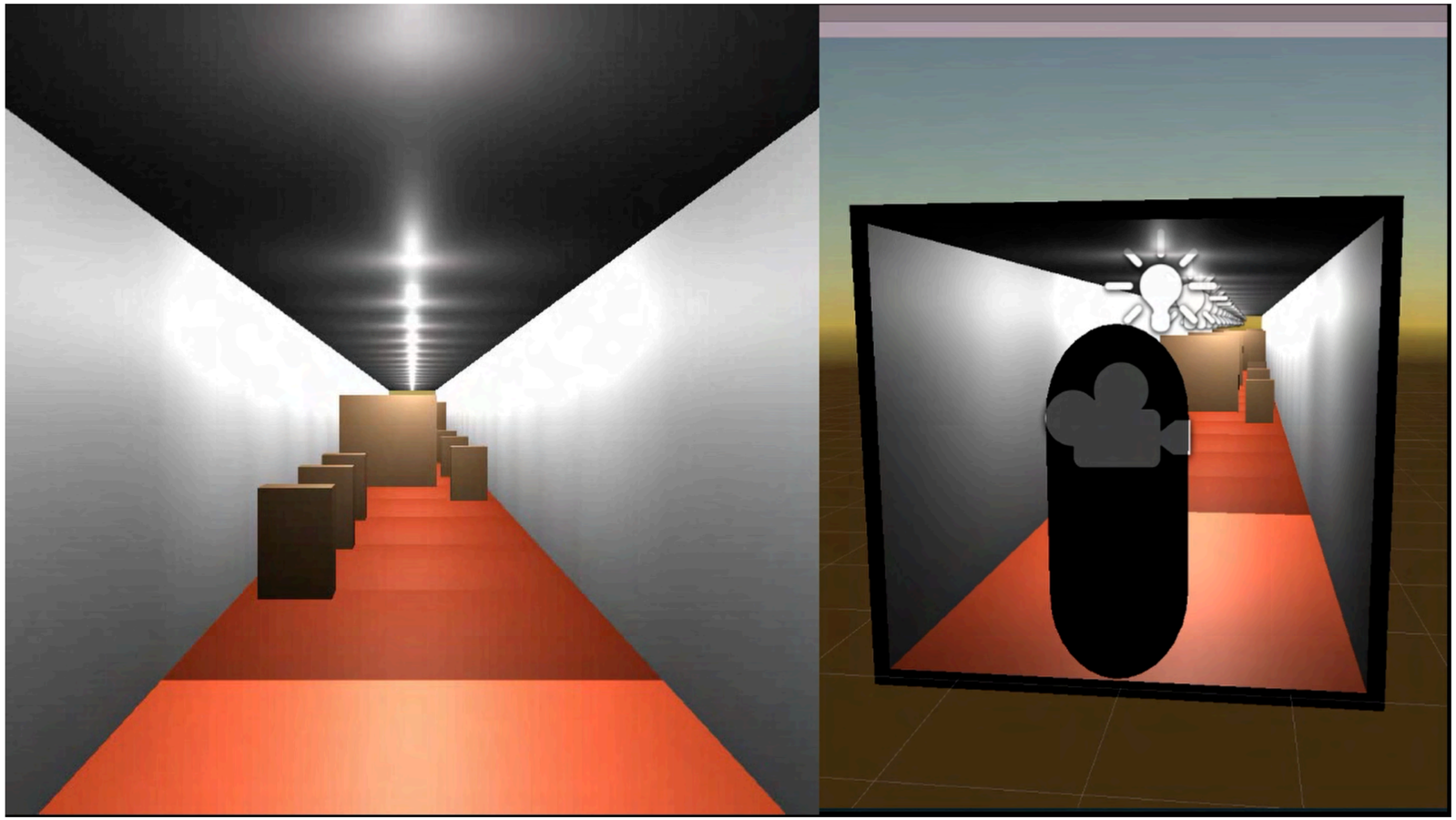
Towards meaningful personalised solutions:

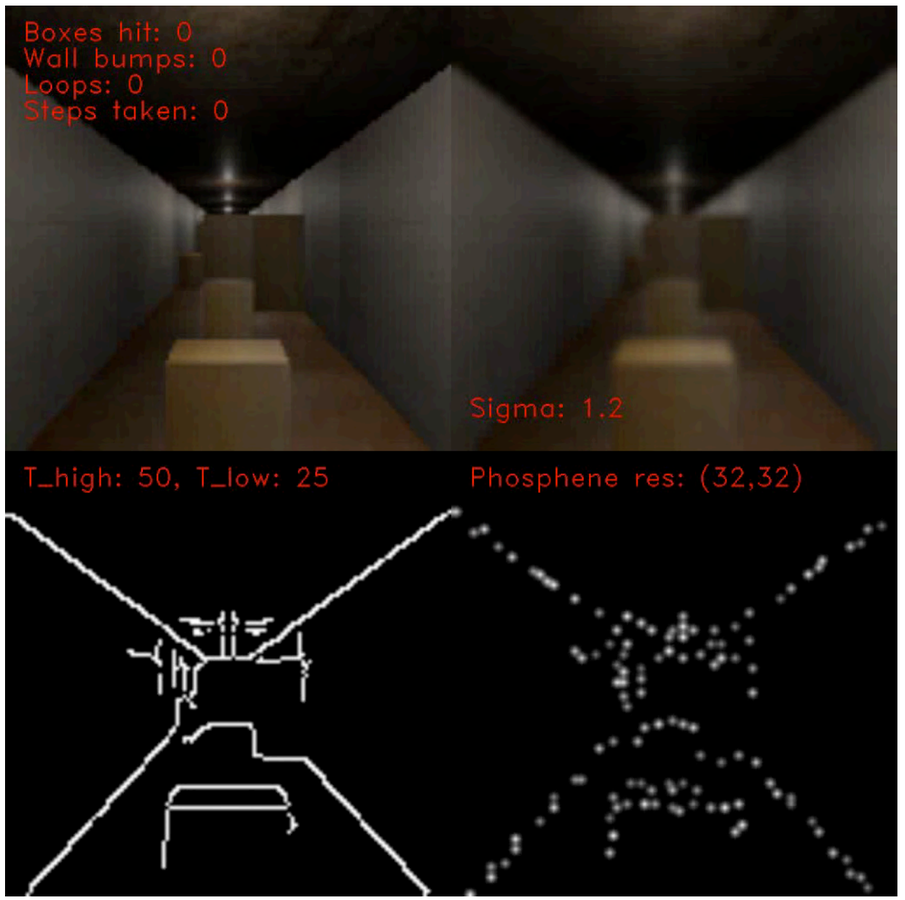
⇒ Patient characteristics (electrode placement, brain state, phosphene characteristics)

⇒ Context dependence (environment, task)

BEHAVIOURAL VALIDATION USING AUGMENTED REALITY

OPTIMIZATION USING REINFORCEMENT LEARNING

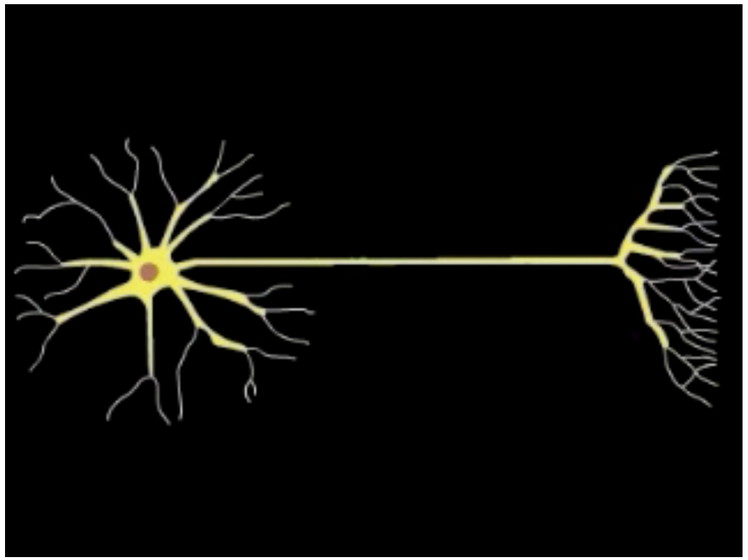


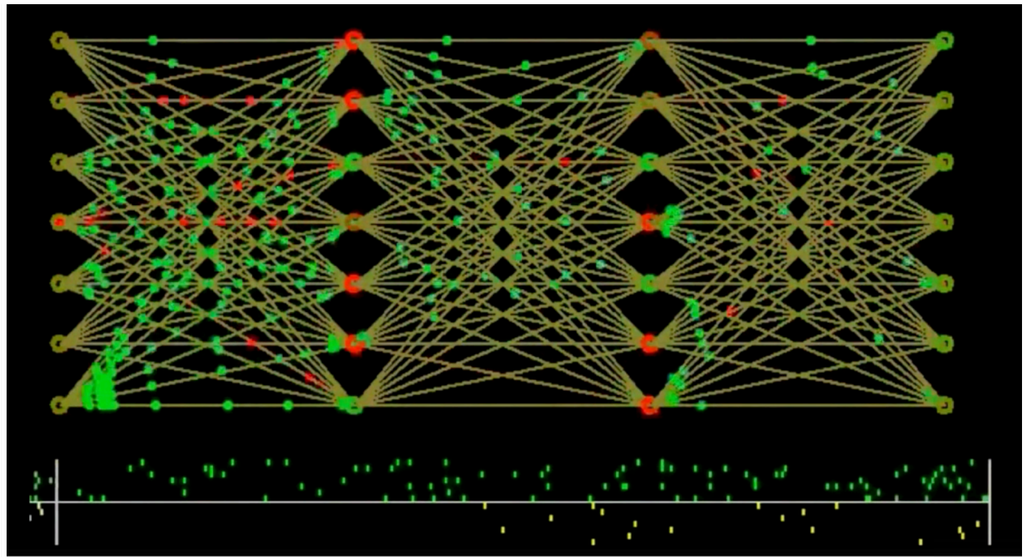


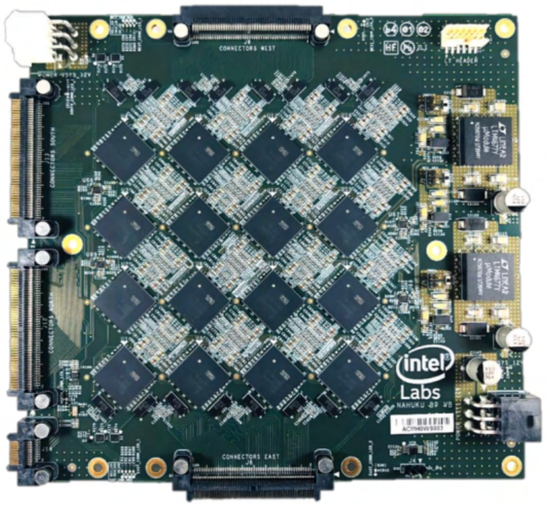
SIMULATION-BASED MACHINE LEARNING

Use ultra-realistic simulated environments to solve machine learning problems

NEUROMORPHIC COMPUTING

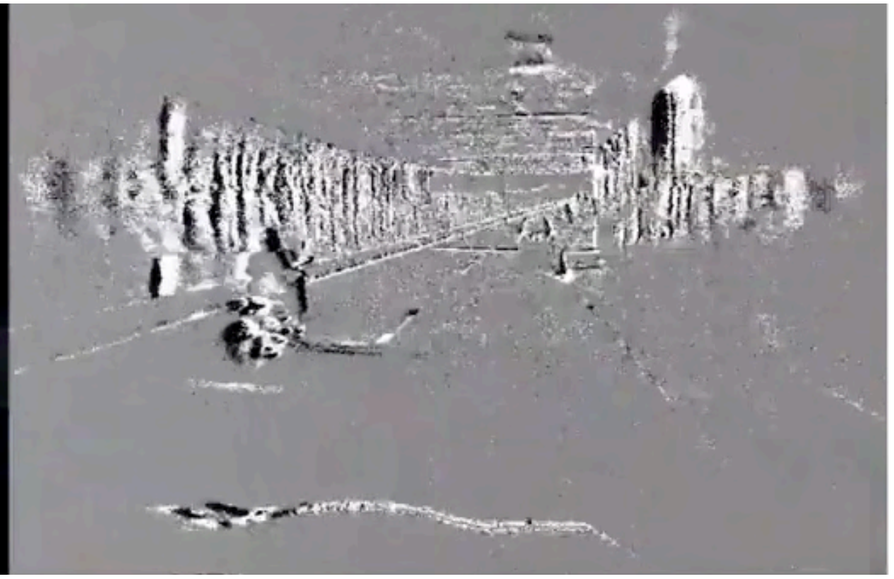




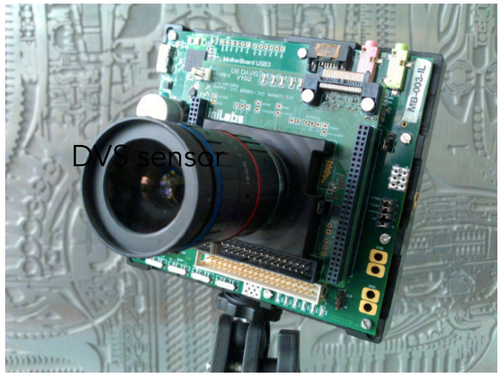


Intel Loihi chip

Frame-based sensor

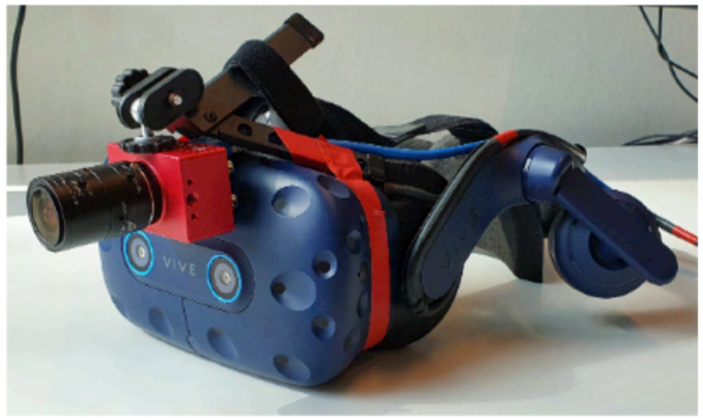


Event-based sensor

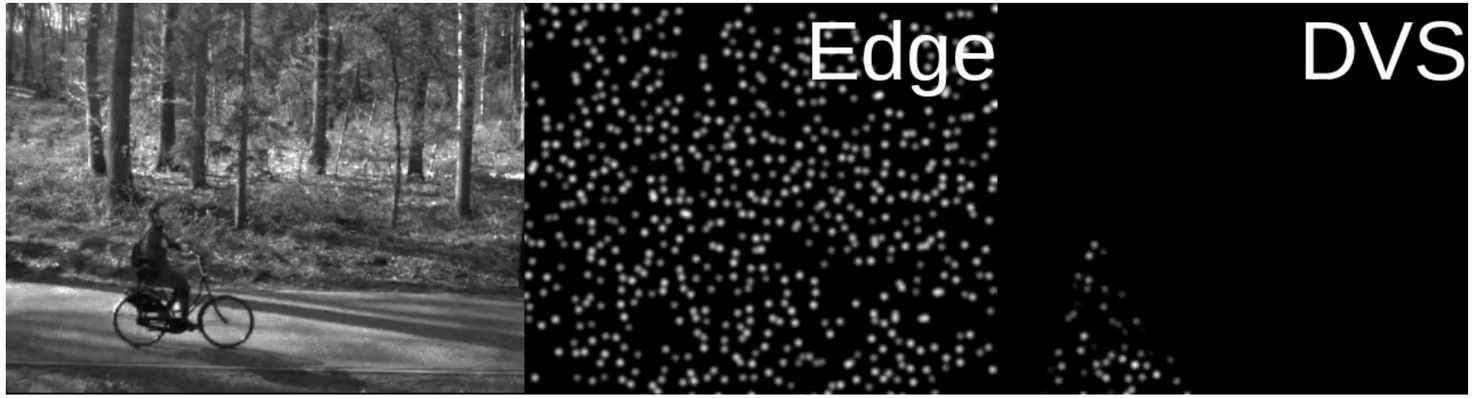


DVS sensor

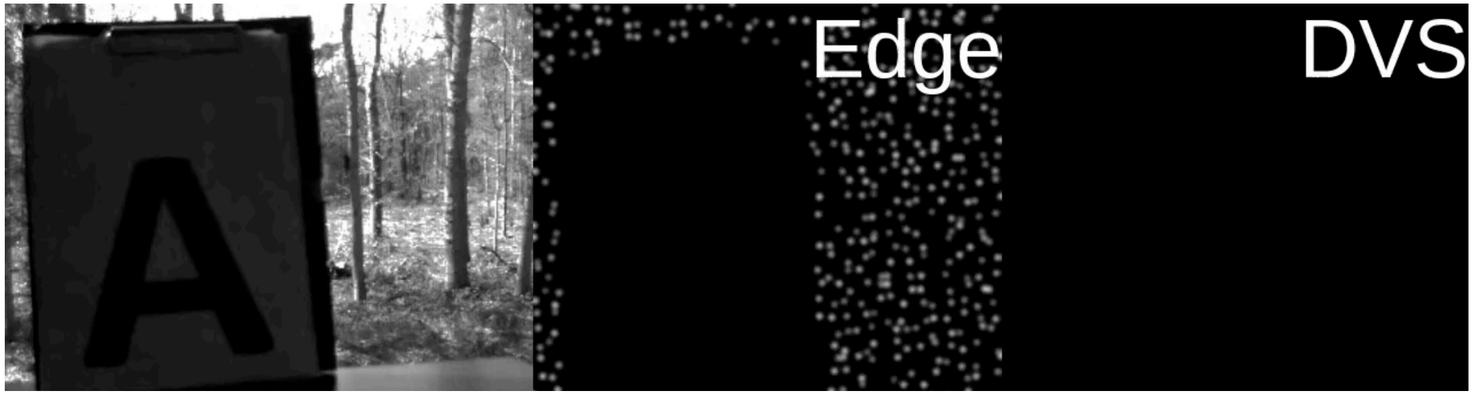
EVENT-BASED PHOSPHENE VISION



pedestrian detection



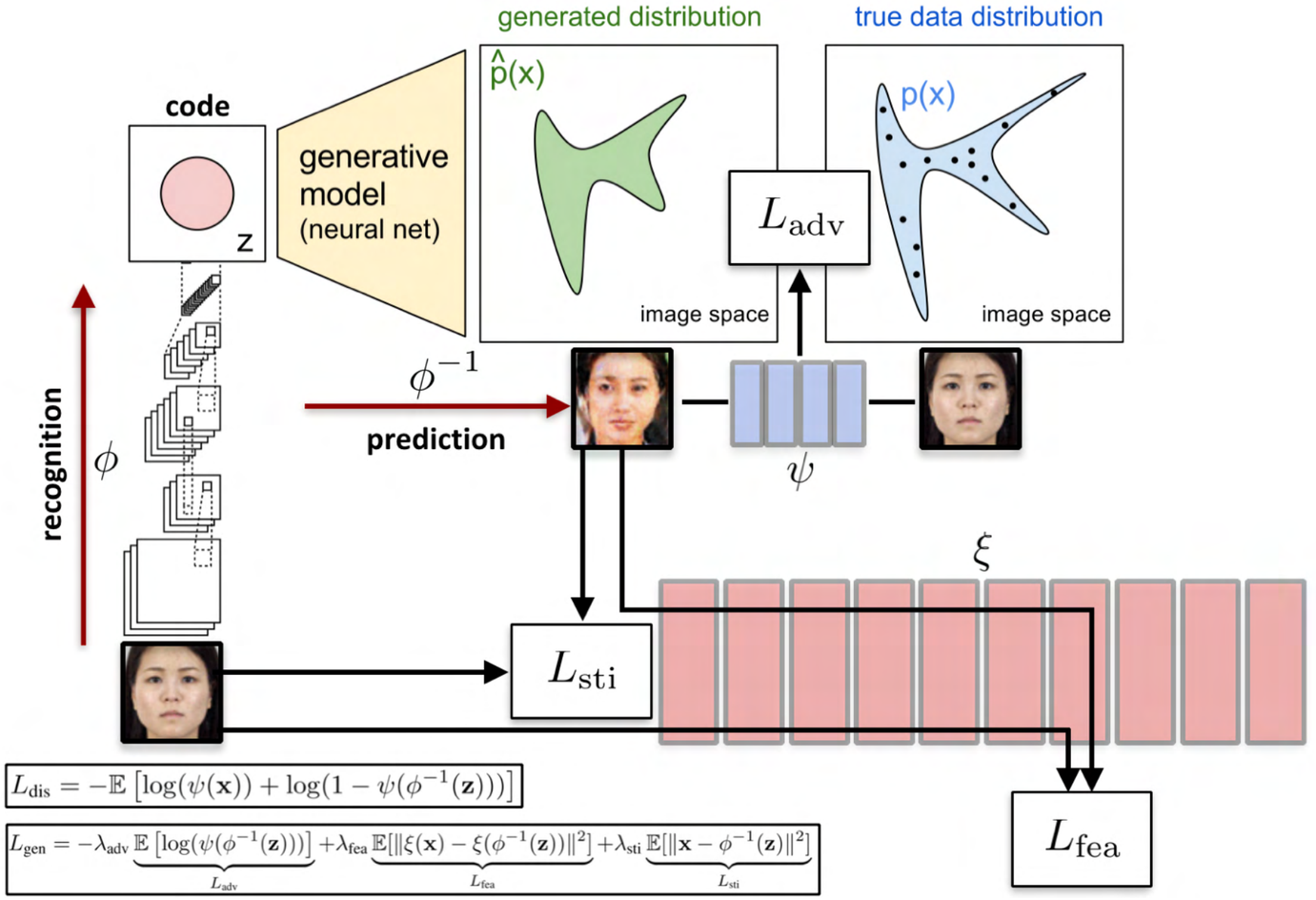
dynamic range

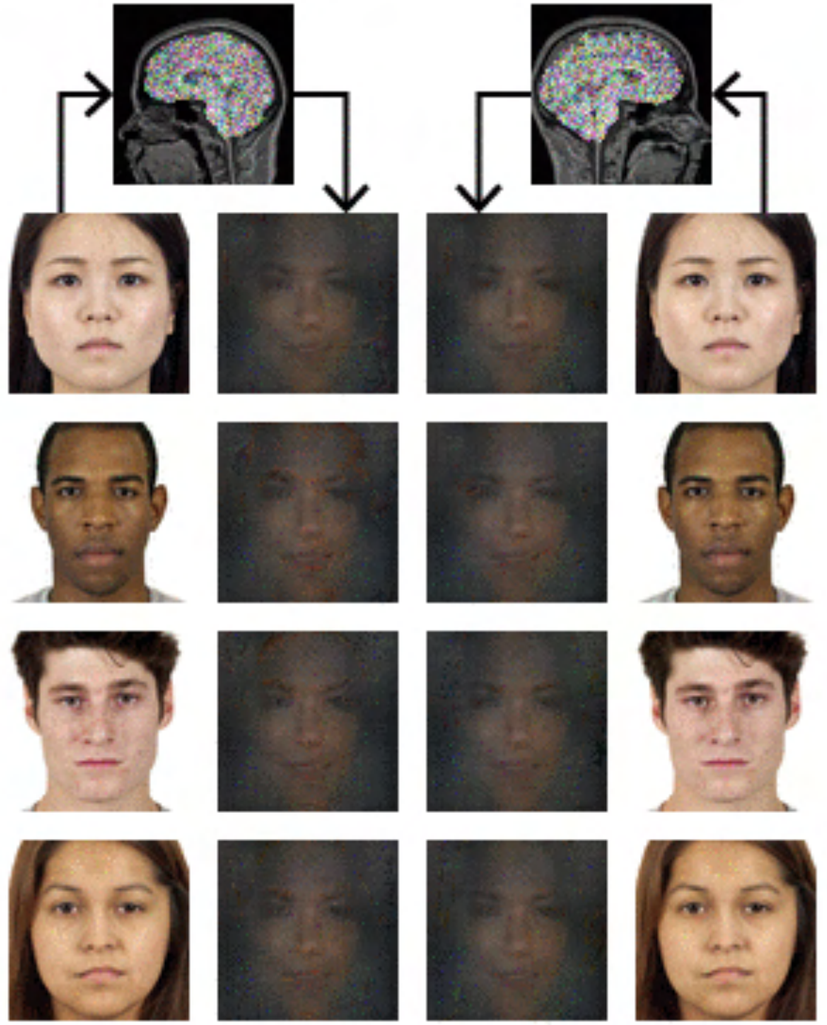


motion blur

Source: Bodo Rueckauer

BRAIN READING: RECONSTRUCTING PERCEIVED STIMULI

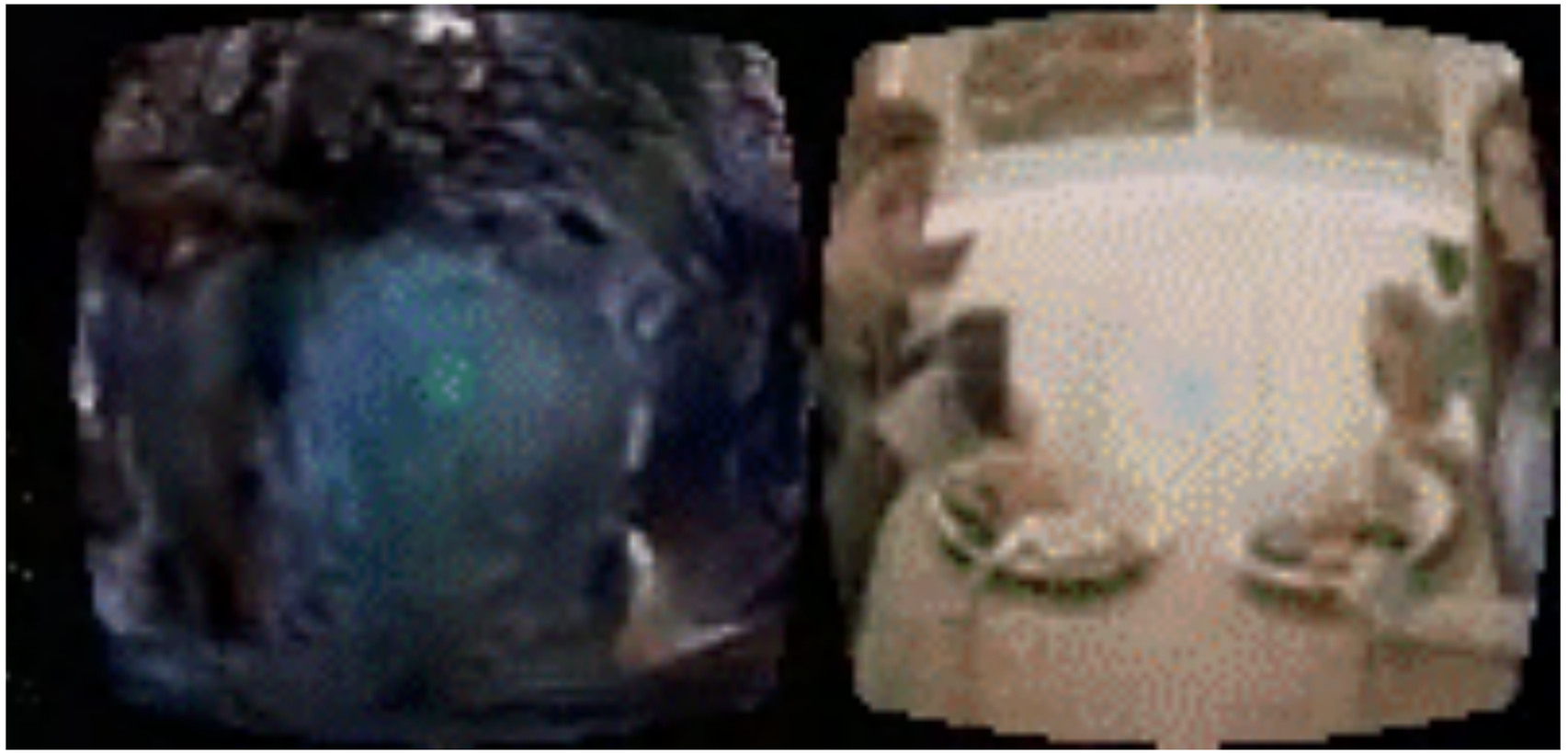




Y. Güçlütürk & U. Güçlü et al., "Deep adversarial neural decoding", arXiv, 2017.

BRAIN READING: THE DR WHO PROJECT

RECONSTRUCTION GROUND TRUTH

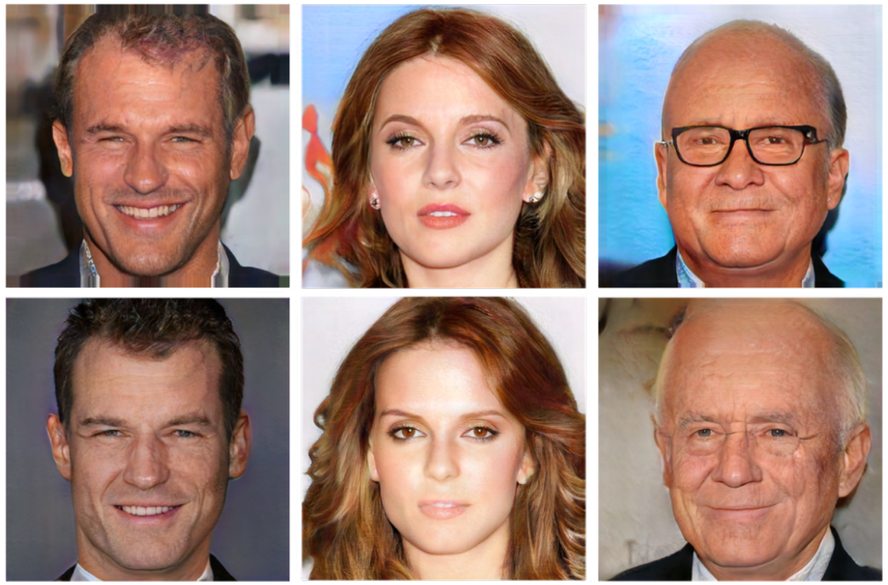


https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1008558

BRAIN READING: LATEST ADVANCES

In Humans

Stimulus



Reconstruction

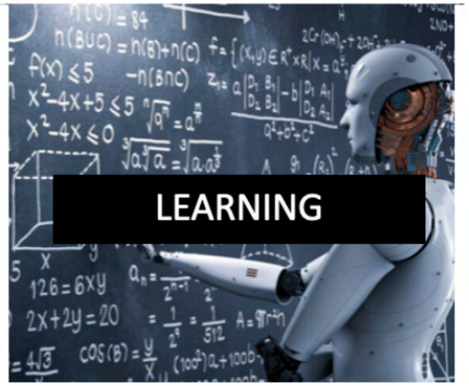
In Monkeys

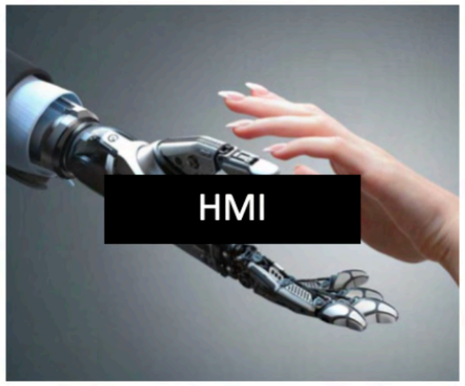
Stimulus

Reconstruction

Dado et al. Hyperrealistic neural decoding for reconstructing faces from fMRI activations via the GAN latent space. Scientific Reports 12(141). 2022.

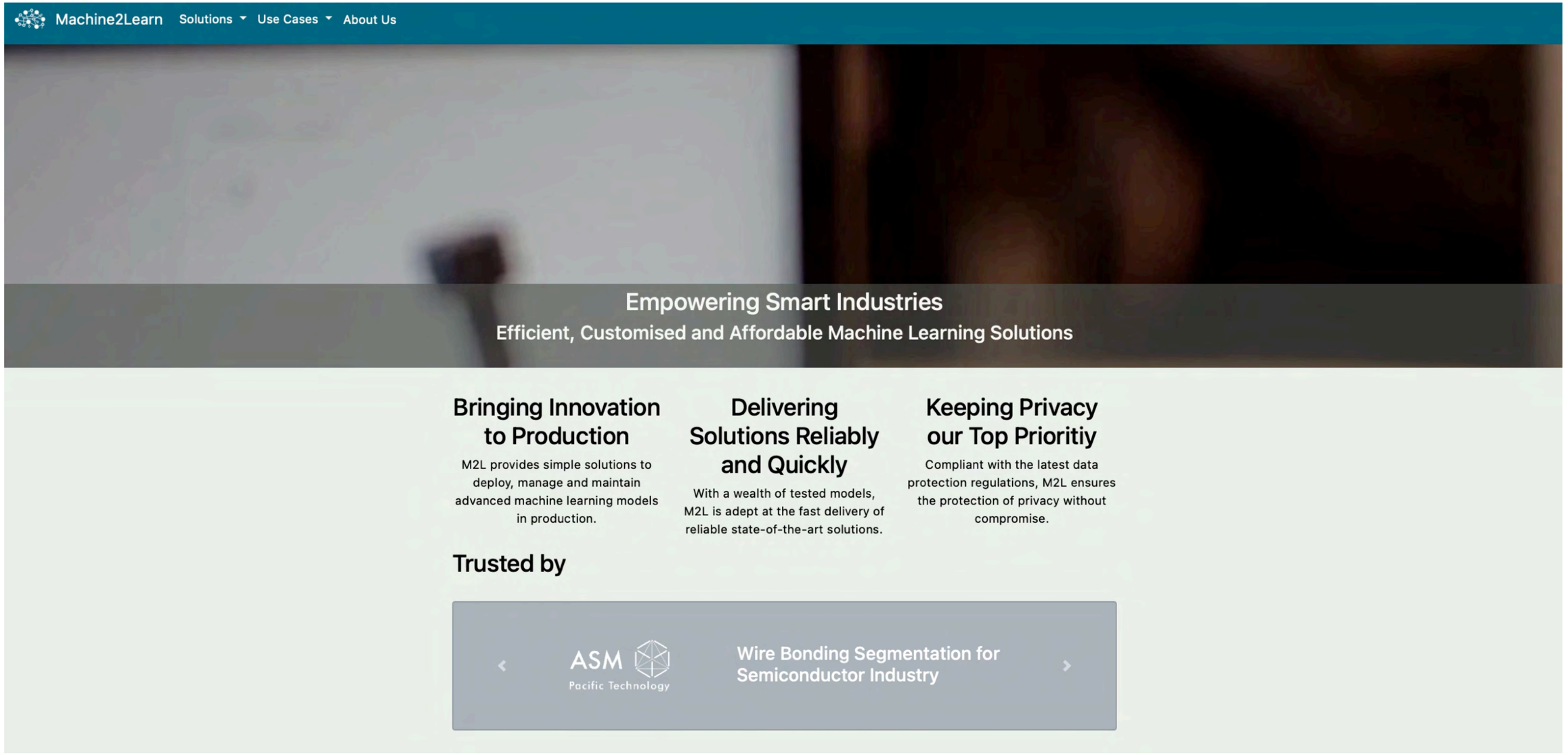
APPLIED RESEARCH



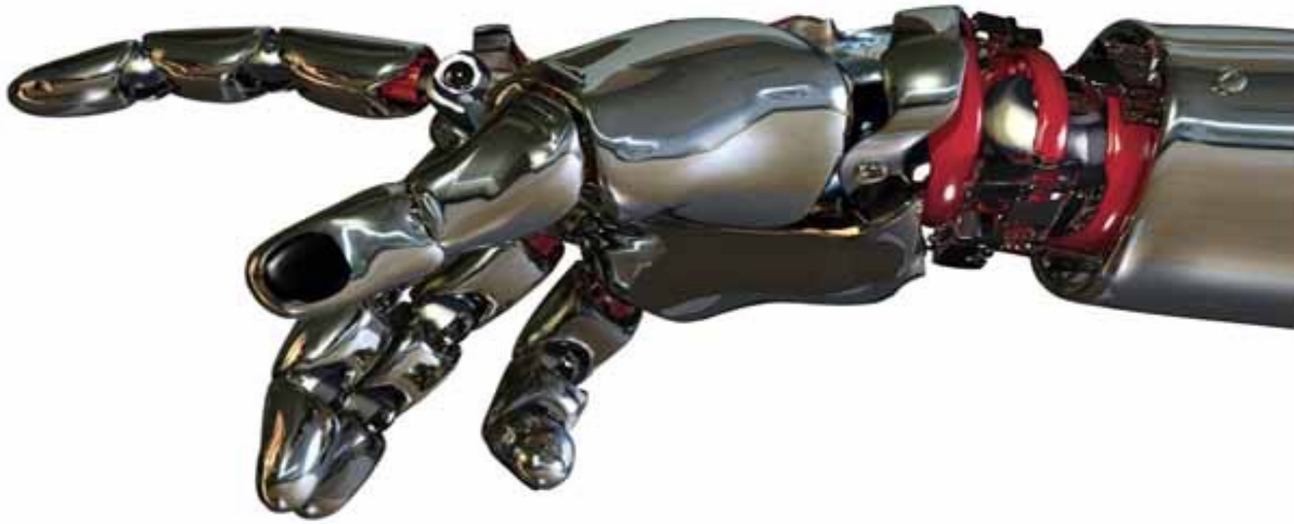


ICAI labs on Health, Neurotech, Semiconductor manufacturing, Energy grids, …

MACHINE2LEARN: FROM RESEARCH TO INDUSTRY



CONCLUSIONS



- Creation of efficient and robust AI systems by embracing principles of natural intelligence
- Focus on real-time learning, inference and control on edge devices
- Address scientific, societal and industrial problems

ACKNOWLEDGEMENTS

Thanks to:

Richard van Wezel, Pieter Roelfsema, Umut Güçlü, Burcu Küçükoğlu, Thirza Dado, Xing Cheng, Bodo Rueckauer, Michelle Appel, Yağmur Güçlütürk, Antonio Lozano, Bodo Rückauer, Paula Koenders, Sam Danen, Guus van der Ham, Tom van Gestel, Floris Vereecken, Berfu Karaca, Maureen van der Grinten, Moritz Nipshagen, …

NESTOR
Neuronal Stimulation for Recovery of Function

NWO GRANT FOR INTENSE PROJECT
INNOVATIVE NEUROTECHNOLOGY FOR SOCIETY

NeuraViPeR

Abbott

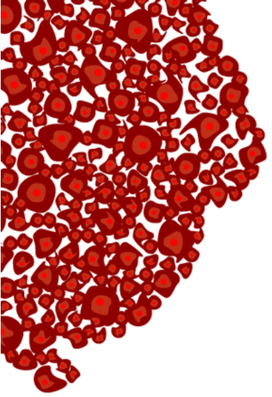
ADVANCED BIONICS
POWERFUL CONNECTIONS

Blackrock Neurotech

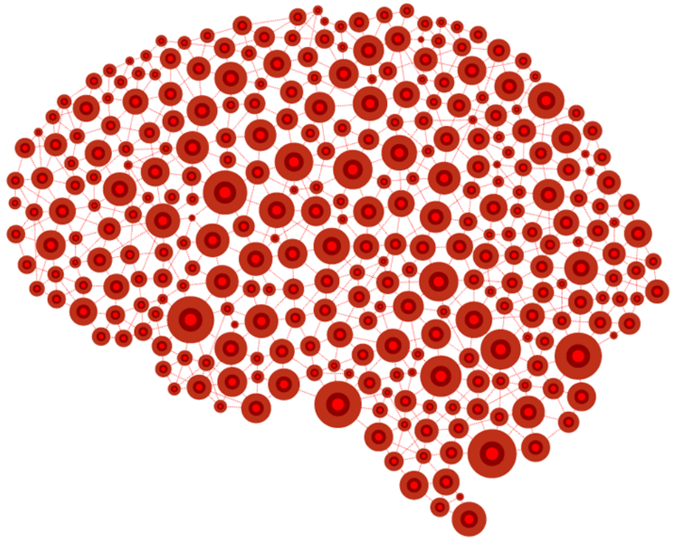
OnePlanet Research Center

NWO

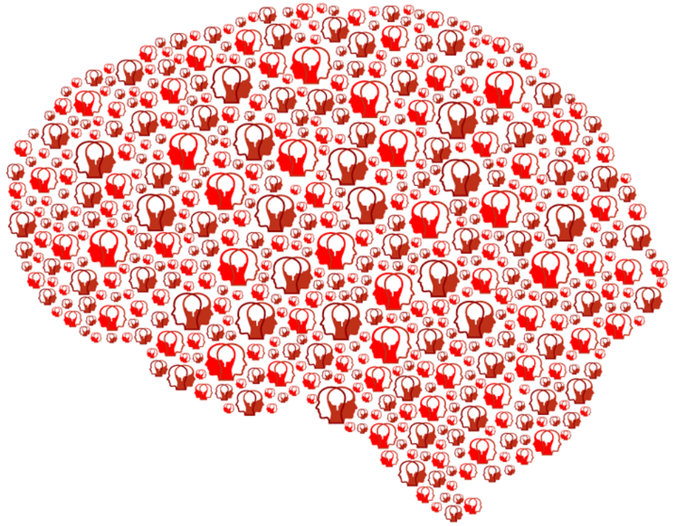
European Commission

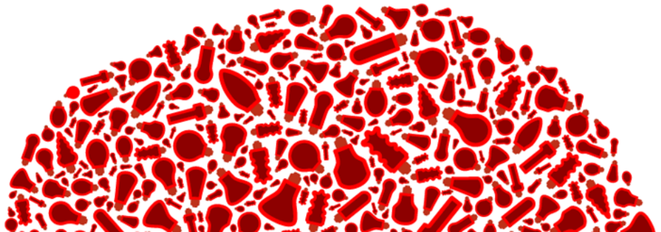


DONDERS INSTITUTE



QUESTIONS?



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