Brain-Machine Interfaces

Towards a Deep Learning based Cortical Visual Prosthesis

Antonio Lozano

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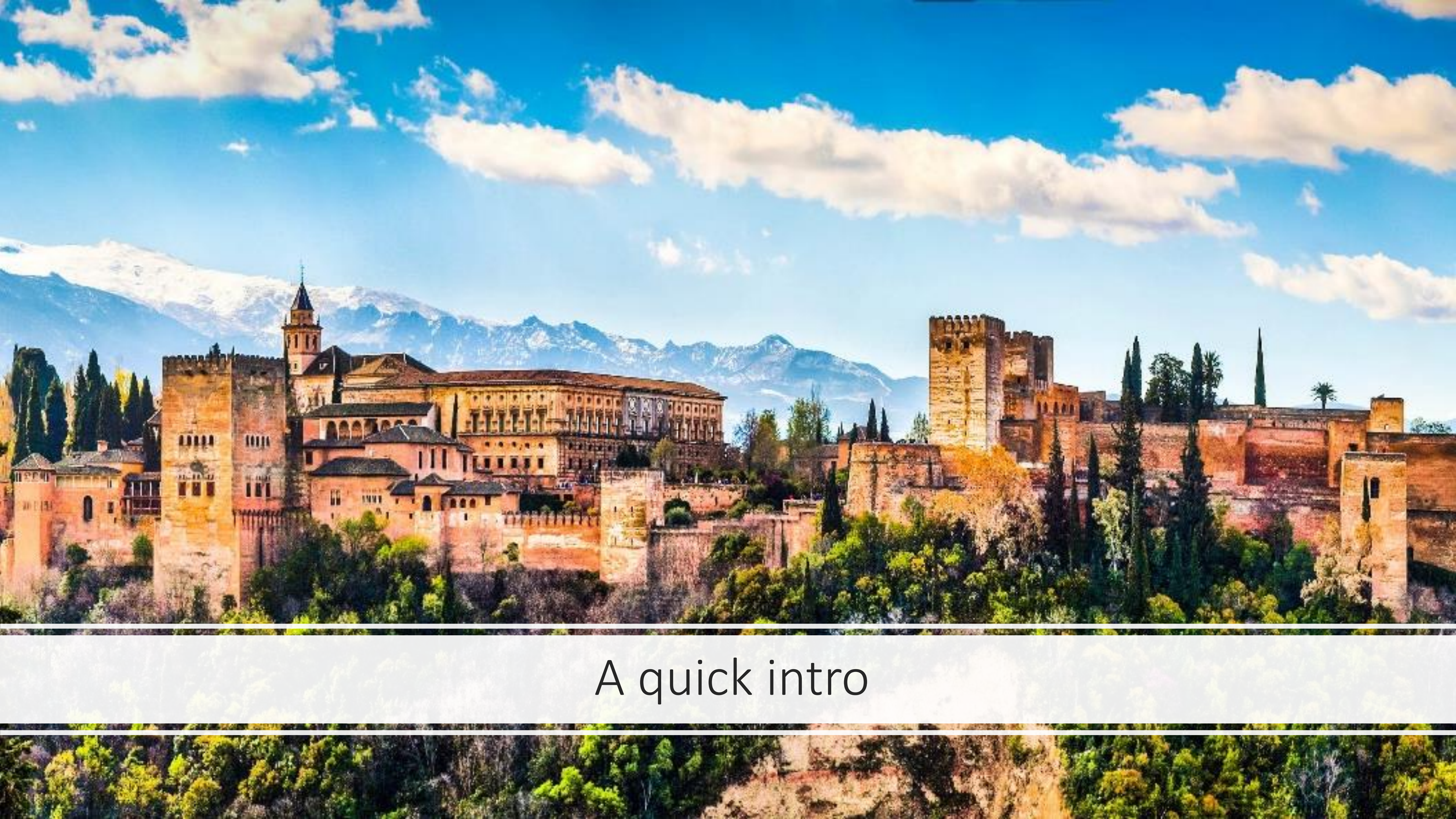
Thank you

- Machine Learning Tokyo
- Earth-Life Science Institute / Tokyo Institute of Technology
- NBIO & UPCT team
- Blind volunteer

schedule

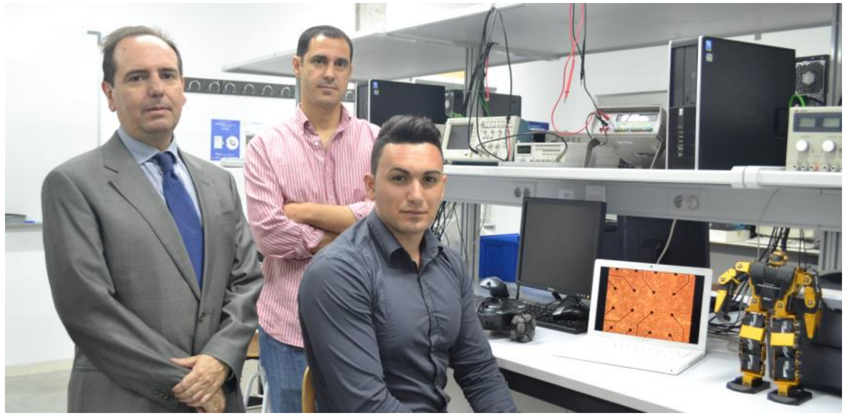
- intro
- neural engineering
- neuroprosthetics + the role of AI
- cortical neuroprosthetics for the blind (CORTIVIS)/Neurolight alpha
- neuralink and the future
- Q&A



A quick intro

A quick intro

Industrial Engineering (B.D., M.D) at **Technical University of Cartagena**, with J.M. Ferrández, Javier Garrigós and Javier Martínez from the Computer Architecture department as a thesis tutors on machine learning retina models



Universidad
Politécnica
de Cartagena

A quick intro

I learned about Neuroengineering, Bioengineering of neurosensory systems and ML/DL at **Politecnico di Milano**, Italy -and I made some japanese friends there!-

POLITECNICO
MILANO 1863

Riccardo Barbieri: Bioengineering of neurosensory systems
Cerveri Pietro: neuroengineering
Alessandra Pedrocchi: neurorehabilitation robotics

https://www.deib.polimi.it/eng/people/details/139286
https://www.deib.polimi.it/eng/people/details/992020
https://www.deib.polimi.it/eng/people/details/308234

A quick intro

PhD in *Information and Communication Technologies* at UPCT, with the Electronic Design and Signal Processing group and NBIO group at UMH.

Researching at Universidad Miguel Hernández, Elche, in a colaboration project at the Biomedical Neuroengineering Research Group with **Eduardo Fernández** as PI and mentor/thesis director

https://nbio.umh.es/

A quick intro

Im glad to be at **Tokyo Institute of Technology** for some months!
Deep Learning models of neural encoding/decoding on biological vision systems
Prof. Daniel Berrar, Data Science laboratory

https://sites.google.com/view/data-science-lab

Data Science Laboratory

Neural Engineering

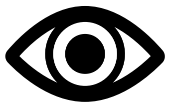
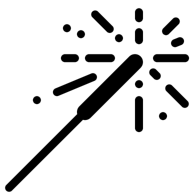
"Any (hu)man* could, if he were so inclined, be the sculptor of his own brain."

Advice for a Young Investigator (1897), p. xv

Don Santiago Ramón y Cajal

**I introduced (hu)*

Neural Engineering

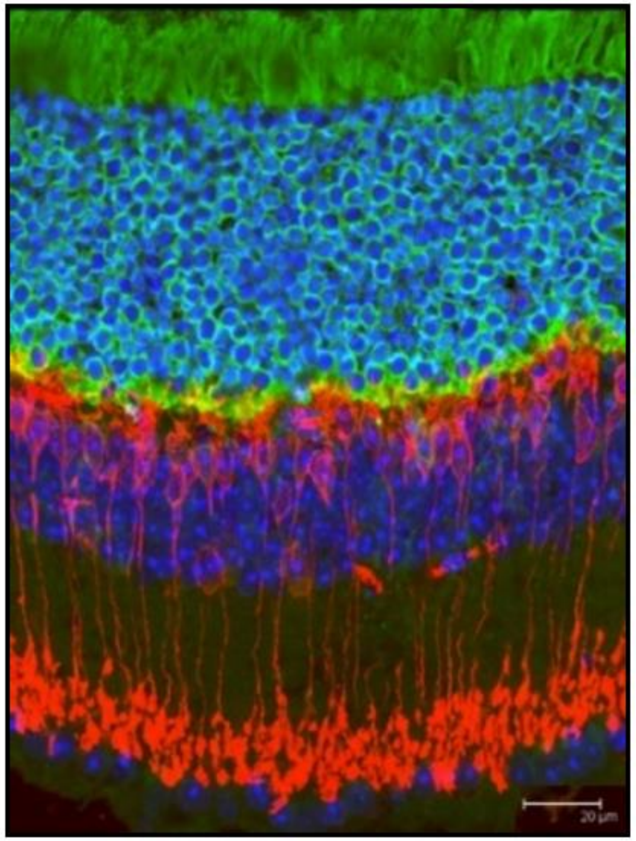
- Understanding the brain (neuroscience) 
- Mimicking the brain (Bioinspired HW/SW) 
- Brain Reading/writing: BCI and neuroprosthetics 

@SaberaTalukder

https://saberatalukder.com/what_is_neuroengineering.html

Neural Engineering

- Understanding the brain (neuroscience)



Retina image courtesy of Gema Martínez Navarrete, NBIO research group

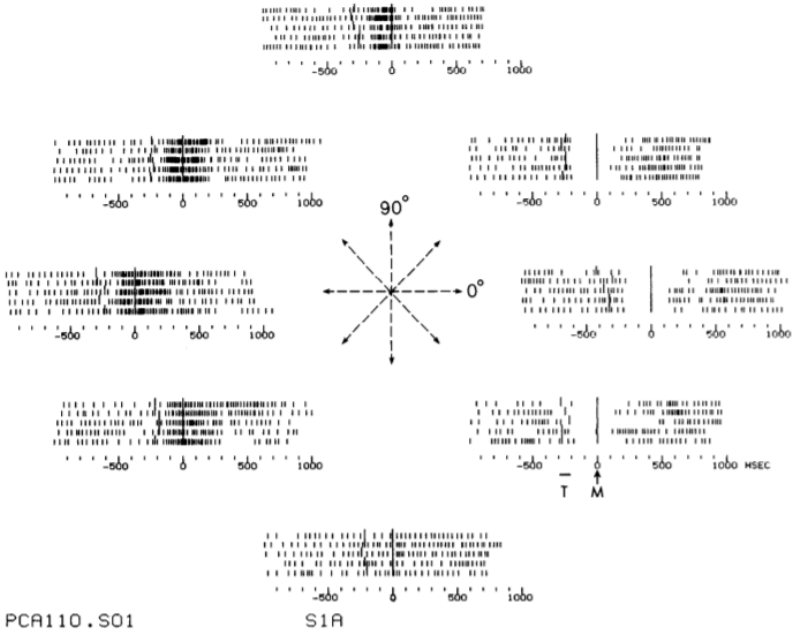
DOI: https://doi.org/10.1523/JNEUROSCI.02-11-01527.1982

ON THE RELATIONS BETWEEN THE DIRECTION OF TWO-DIMENSIONAL ARM MOVEMENTS AND CELL DISCHARGE IN PRIMATE MOTOR CORTEX[1]

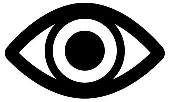
APOSTOLOS P. GEORGOPOULOS,[2] JOHN F. KALASKA,[3] ROBERTO CAMINITI,[4] AND JOE T. MASSEY[5]

Departments of Physiology and Neuroscience, The Johns Hopkins University School of Medicine, Baltimore, Maryland 21205

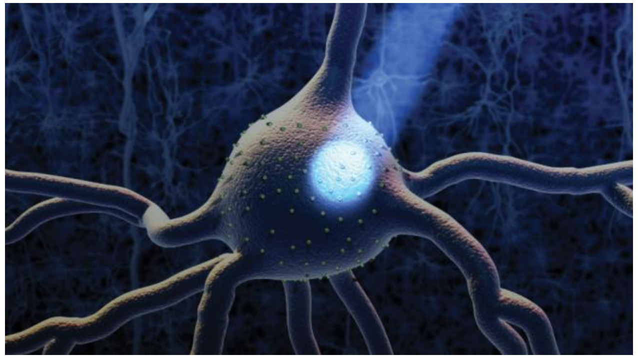
Received October 30, 1981; Revised April 30, 1982; Accepted May 21, 1982

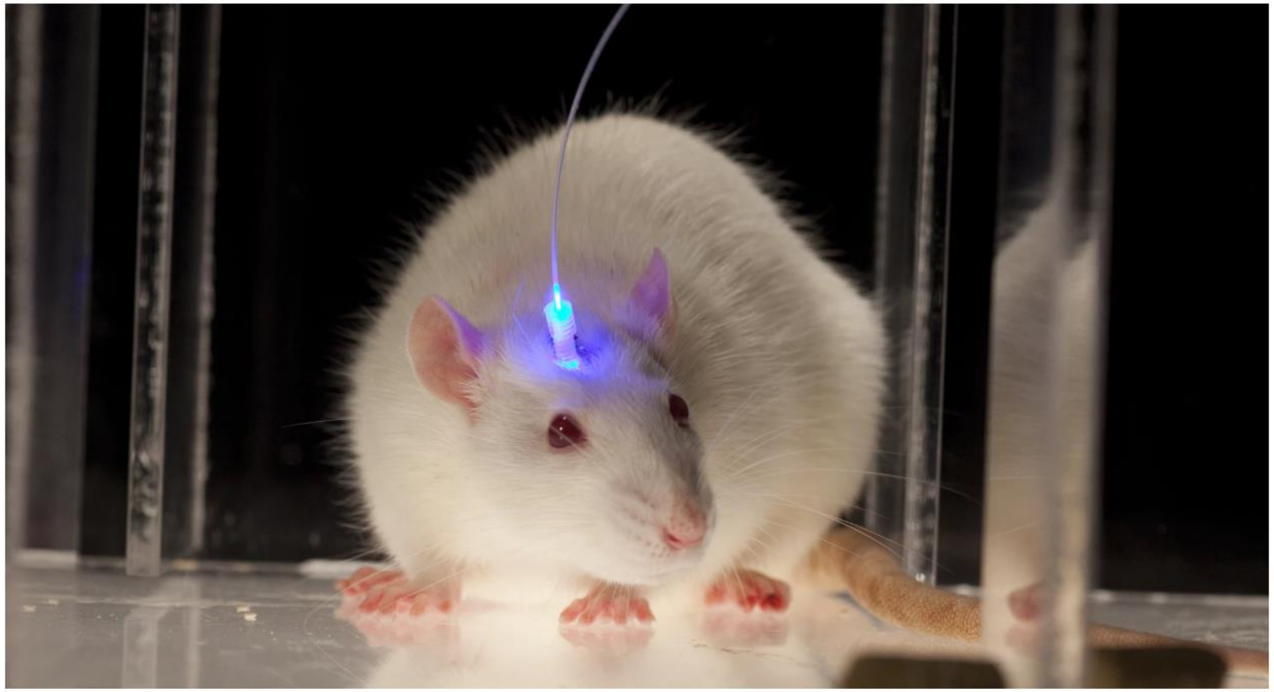


Neural Engineering

- Understanding the brain (neuroscience) 

Optogenetics





Laser brain: optogenetics lets scientists use light to stimulate specific neurons and see the results.
CREDIT: JOHN B. CARNETT / GETTY

Neural Engineering

- Mimicking the brain (Bioinspired HW/SW)

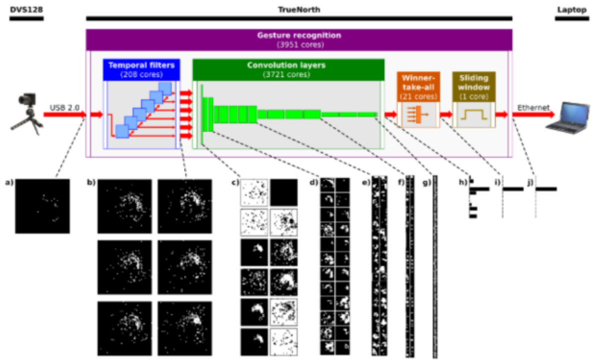
A million spiking-neuron integrated circuit with a scalable communication network and interface

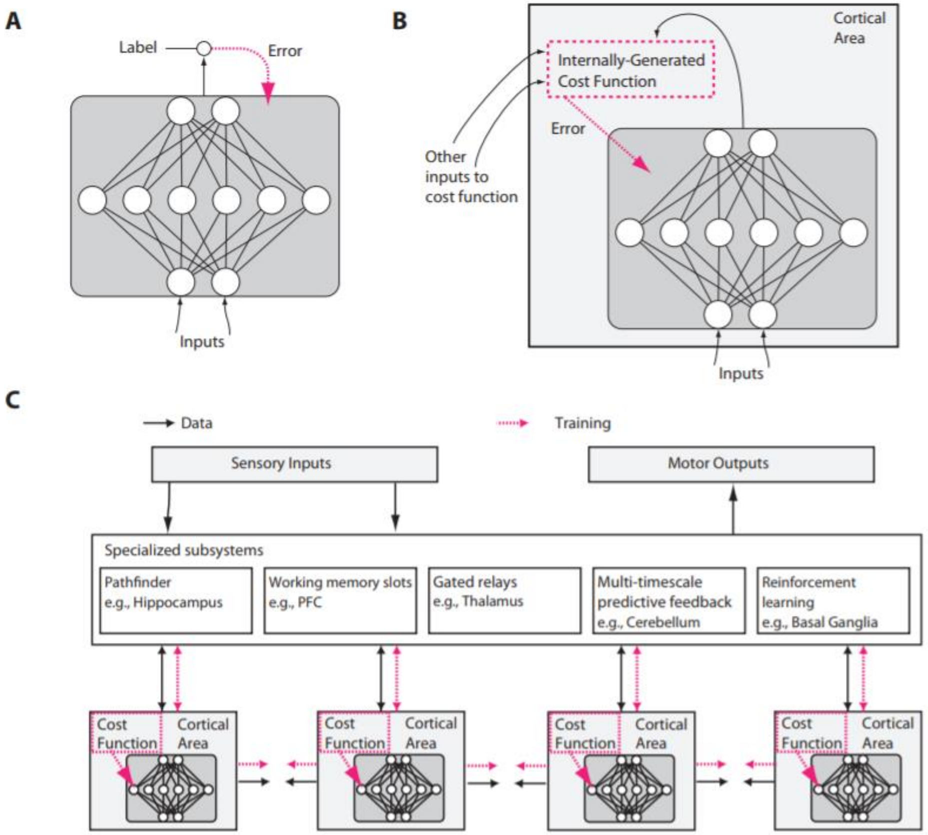
Paul A. Merolla[1,*], John V. Arthur[1,*], Rodrigo Alvarez-Icaza[1,*], Andrew S. Cassidy[1,*], Jun Sawada[2,*], Filipp Akopyan[1,*], Bryan L. Jackson[1,*], Nabil Imam[3], Chen Guo[4], Yutaka Nakamura[5], Bernard Brezzo[6], Ivan Vo[2], Steven K. Esser[1], Rathinakumar Appuswamy[1], Brian Taba[1], Arnon Amir[1], Myron D. Flickner[1], William P. Risk[1], Rajit Manohar[7], Dharmendra S. Modha[1,†]

[1]IBM Research–Almaden, 650 Harry Road, San Jose, CA 95120, USA.
[2]IBM Research–Austin, 11501 Burnet Road, Austin, TX 78758, USA.
[3]Cornell University, 358 Upson Hall, Ithaca, NY 14853 USA.
[4]IBM Engineering and Technology Services, San Jose Design Center, 650 Harry Road, San Jose, CA 95120, USA.
[5]IBM Research–Tokyo, Nippon Building Fund Toyosu Canal Front Building, 5-6-52 Toyosu, Koto-ku Tokyo 135-8511, Japan.
[6]IBM T. J. Watson Research Center, 101 Kitchawan Road, Yorktown Heights, NY 10598, USA.
[7]Cornell Tech, 111 Eighth Avenue No. 302, New York, NY 10011, USA.
↵†Corresponding author. E-mail: dmodha@us.ibm.com
↵* These authors contributed equally to this work.
- Hide authors and affiliations

Science 08 Aug 2014:
Vol. 345, Issue 6197, pp. 668-673
DOI: 10.1126/science.1254642

IBM's TrueNorth



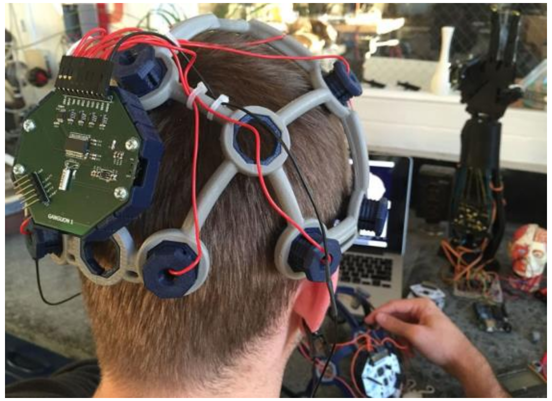


Towards an integration of deep learning and neuroscience
[Adam Marblestone](), [Greg Wayne](), [Konrad Kording]()
arXiv:1606.03813

Neural Engineering

- Brain Reading/writing: BCI and neuroprosthetics

FIRST REAL TIME EMOTION ESTIMATION WITH THIS TECH! :D



Ultracortex Mark III being worn by Conor Russomanno
https://en.wikipedia.org/wiki/OpenBCI#/media/File:UCM3.jpg

Optimization of real-time EEG artifact removal and emotion estimation for human-robot interaction applications

M. Val-Calvo [1,2,*], **J. R. Álvarez-Sánchez** [2,*], **J. M. Ferrández-Vicente** [1], **E. Fernández** [3,4]

[1] *Dpto. Electrónica, Tecnología de Computadoras y Proyectos, Univ. Politécnica de Cartagena, Cartagena, Spain*
[2] *Dpto. de Inteligencia Artificial, UNED, Madrid, Spain*
[3] *CIBER-BBN, Spain*
[4] *Instituto de Bioingeniería, Univ. Miguel Hernández, Alicante, Spain*

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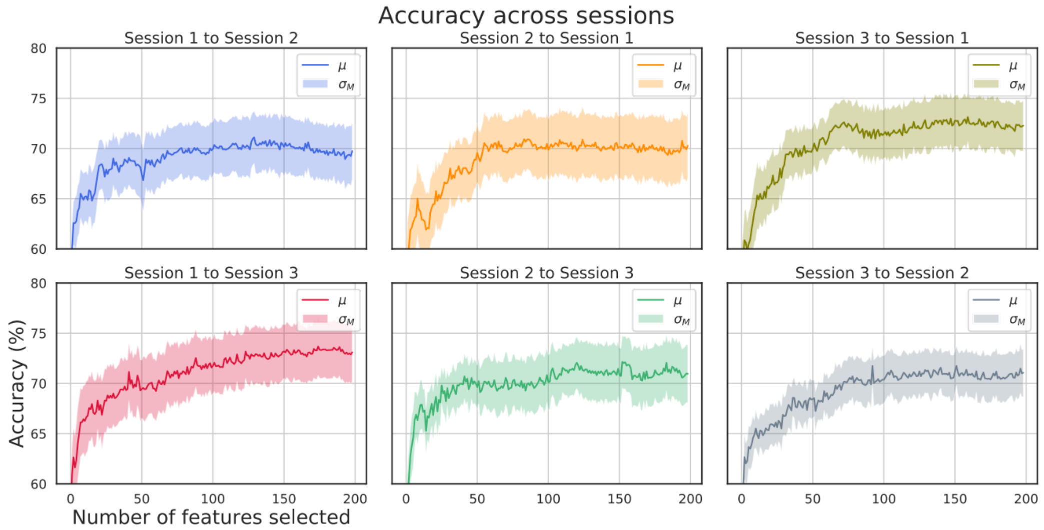
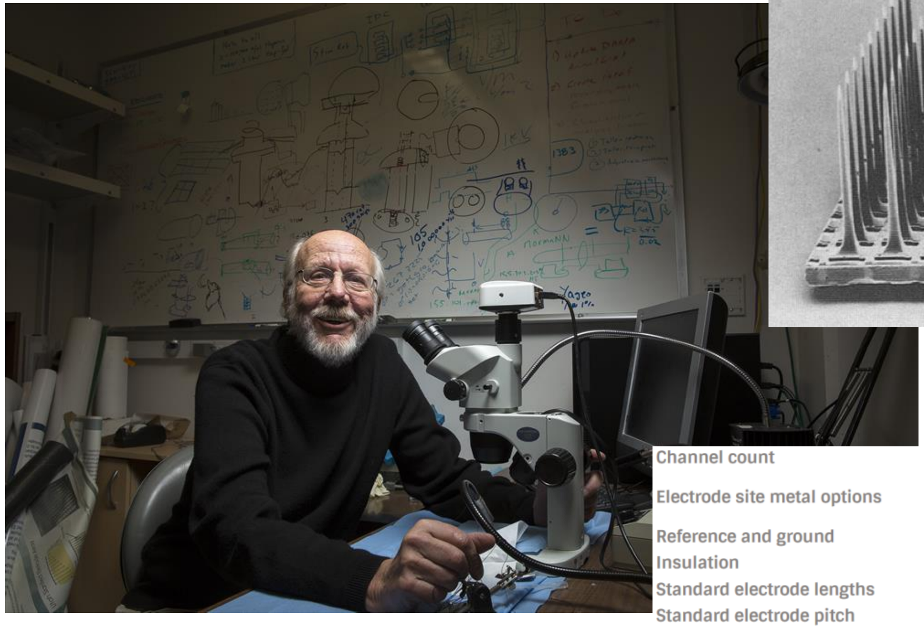


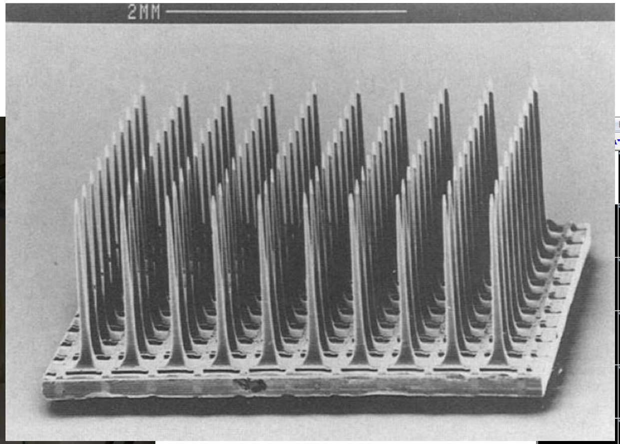
Neural Engineering

Brain Reading/writing: neuroprosthetics

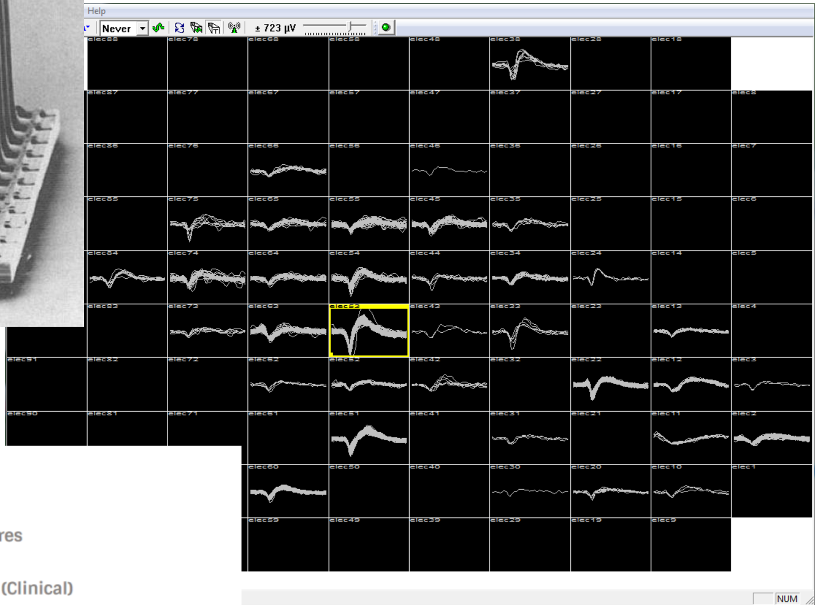
Richard Normann



The Utah array



Spikes!!!



Channel count	Up to 128 active electrode channels
Electrode site metal options	Platinum (~400 kΩ @ 1 kHz) Iridium oxide (~50 kΩ @ 1 kHz)
Reference and ground	Ground source and selectable reference wires
Insulation	Parylene-C
Standard electrode lengths	0.5 mm – 1.5 mm (Research) 1.0 – 1.5 mm (Clinical)
Standard electrode pitch	400 μm
MultiPort option	1 to 4 arrays per connector
Wire bundle	25 μm Pt/Au lead wires between electrode array and connector
Wire bundle length	20 mm to 130 mm length potted with medical-grade silicone elastomer

Neural Engineering

Brain Reading/writing: neuroprosthetics

Cortical control of a tablet computer by people with paralysis

Paul Nuyujukian[1,2,3,4,5,6], Jose Albites Sanabria[7,8], Jad Saab[7,8,9], Chethan Pandarinath[1,2,10,11], Beata Jarosiewicz[1,2,8,12], Christine H. Blabe[1], Brian Franco[13], Stephen T. Mernoff[9,14], Emad N. Eskandar[15,16], John D. Simeral[7,8,9,13], Leigh R. Hochberg[7,8,9,13,17‡], Krishna V. Shenoy[2,3,4,5,6,18,19‡], Jaimie M. Henderson[2,4,5‡*]

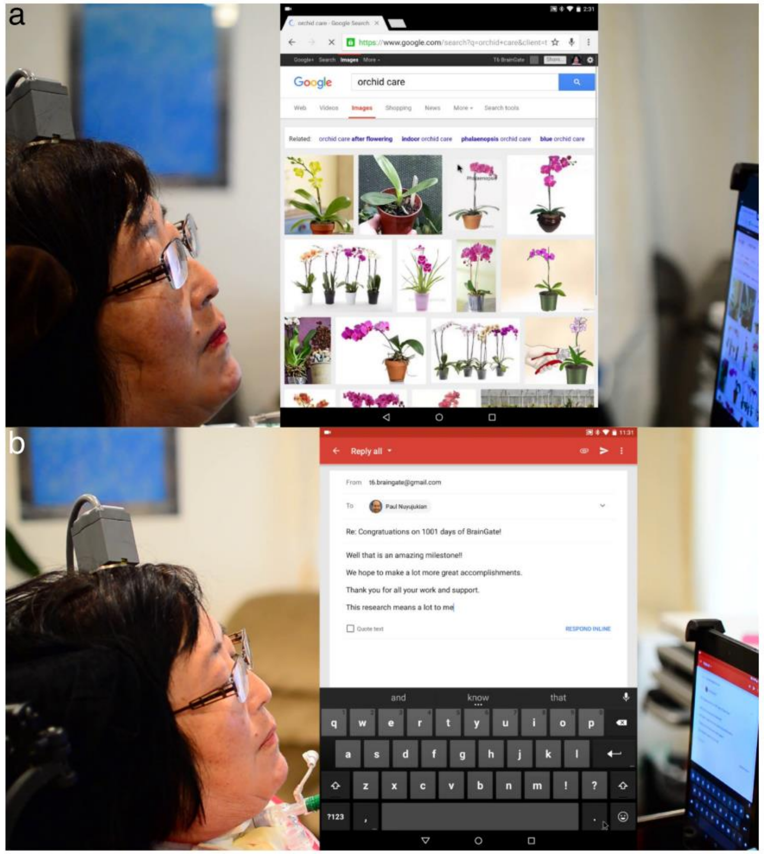


Fig 3. **a** T6 browsing the web. Overlay in center of the image is a screen capture of the tablet. **b** T6 composing an email (trial day 1001). Both images are taken from S1 Video.

https://doi.org/10.1371/journal.pone.0204566.g003

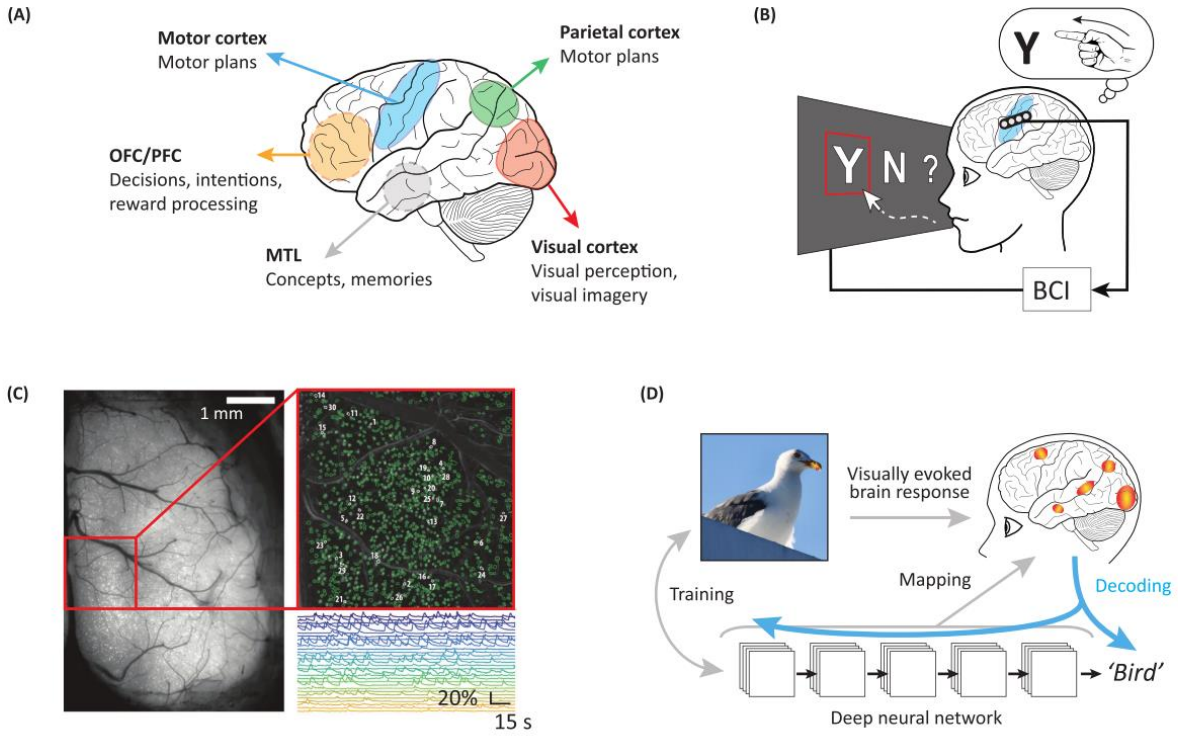
Trends in Cognitive Sciences

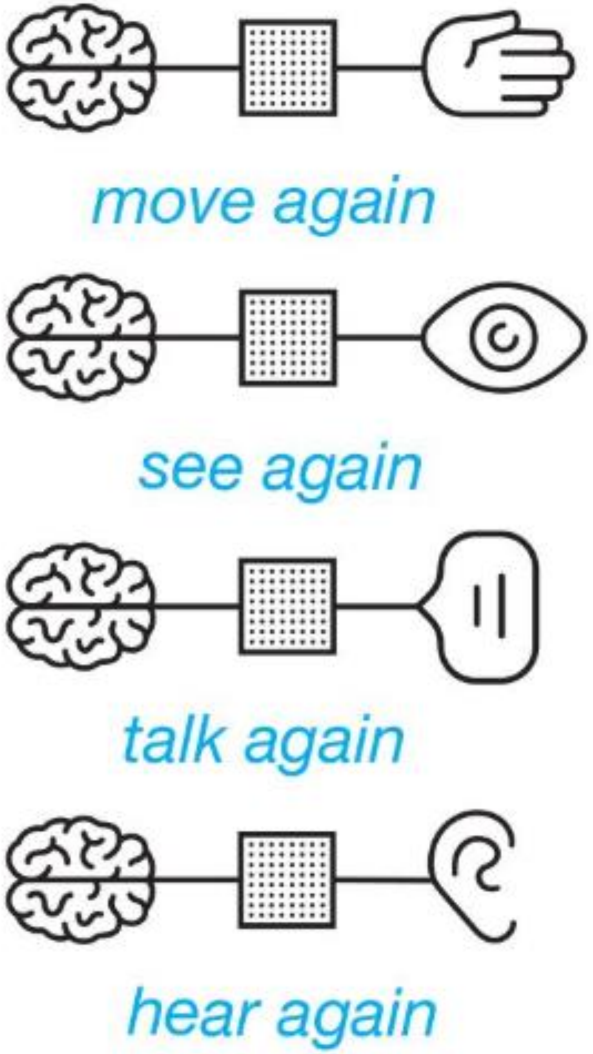
Cell Press REVIEWS

Opinion

Mind Reading and Writing: The Future of Neurotechnology

Pieter R. Roelfsema,[1,2,3,*] Damiaan Denys,[2,4] and P. Christiaan Klink[1,2,4]





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The role of AI (by examples)

Spike sorting

Dimensionality Reduction

Neural Decoding

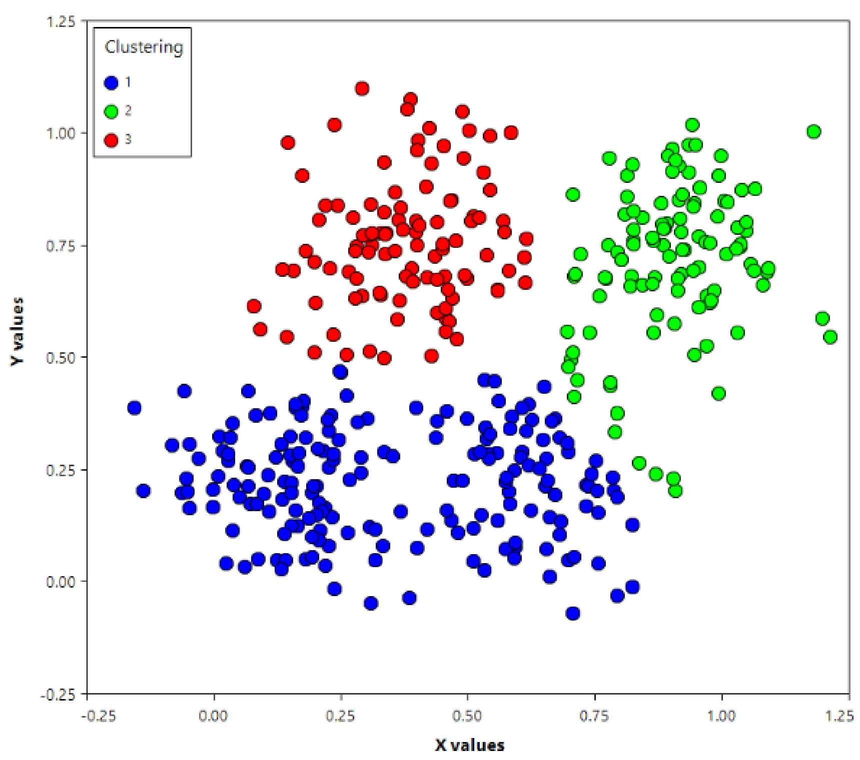
Deep Learning models of neural systems

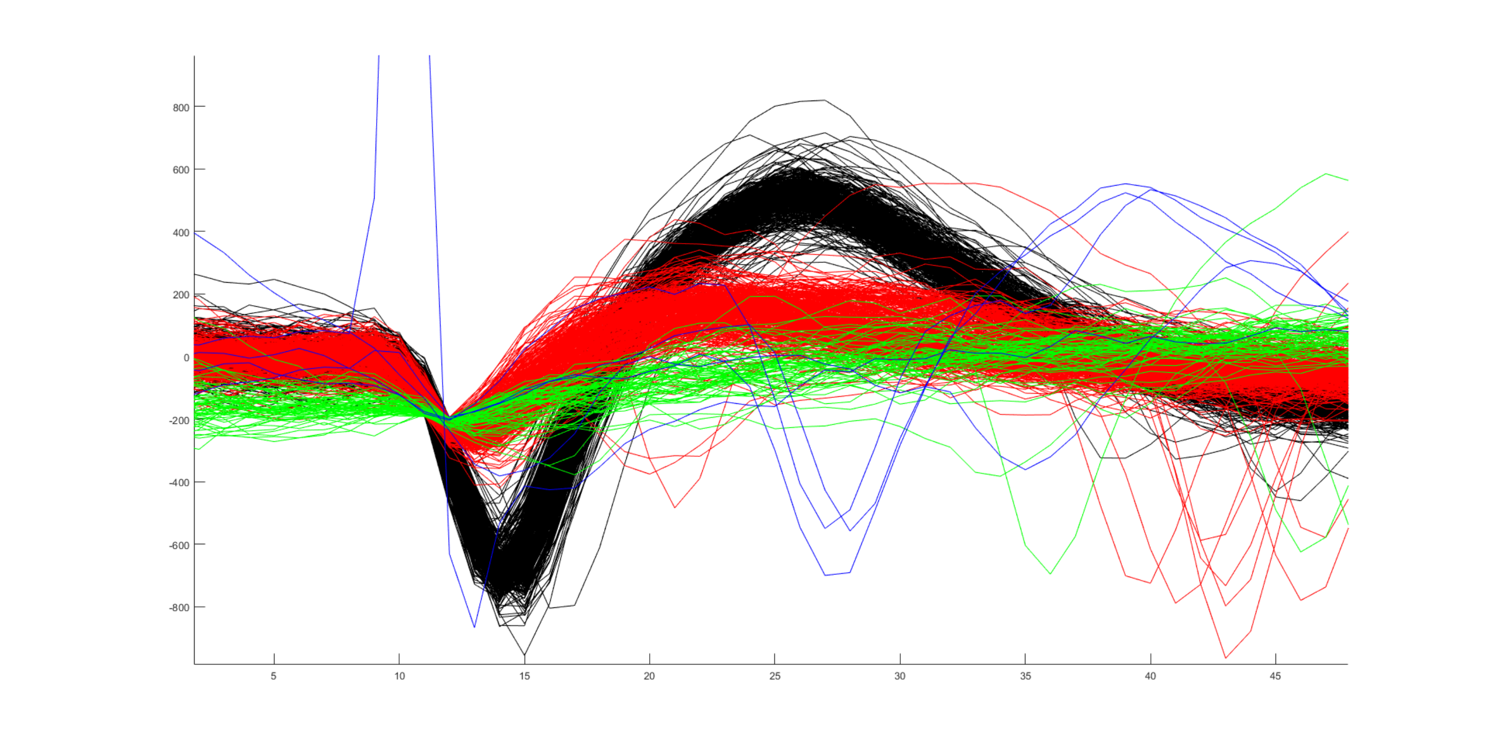
Generating highly exciting sensory inputs with Deep Learning

The role of AI
Spike sorting

WHICH WAVEFORM CORRESPONDS TO WICH NEURON?

1. PRINCIPAL COMPONENT ANALYSIS
2. CLUSTERING





Dimensionality Reduction

The role of AI

(and neural population dynamics analysis)

Noise Assisted Multivariate Empirical Mode Decomposition (NA-MEMD)

- https://doi.org/10.1371/journal.pone.0208822

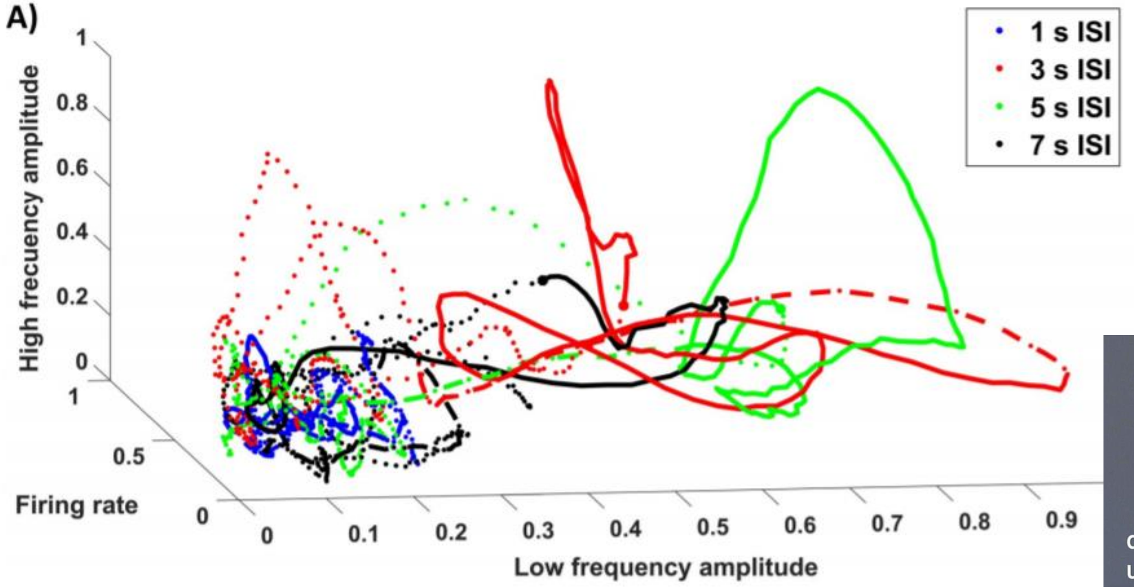
RESEARCH ARTICLE

Multiscale dynamics of interstimulus interval integration in visual cortex

J. Alegre-Cortés[1], C. Soto-Sánchez[1,2,3]*, E. Fernandez[1,2]

1 Bioengineering Institute, Miguel Hernández University (UMH), Alicante, Spain, **2** Biomedical Research Networking center in Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), Madrid, Spain, **3** Biotechnology Department, University of Alicante (AU), Alicante, Spain

* sotosanc@gmail.com

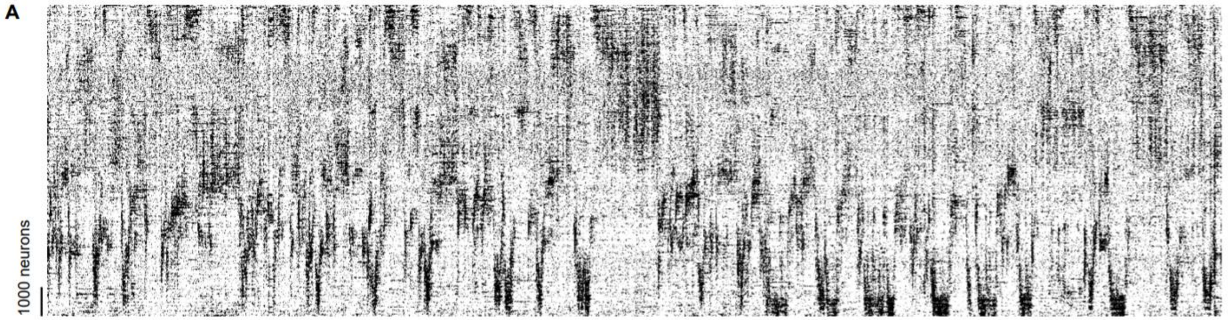


Spontaneous behaviors drive multidimensional, brain-wide neural activity

Carsen Stringer*[1,2], Marius Pachitariu*[1,3,4], Nicholas Steinmetz[5], Charu Reddy[5], Matteo Carandini†[5] and Kenneth D. Harris†[3,4]

[1] HHMI Janelia Research Campus, Ashburn, Virginia, 20147, USA. [2] Gatsby Computational Neuroscience Unit, UCL, London W1T 4JG, UK. [3] UCL Institute of Neurology, London WC1E 6DE, UK. [4] UCL Department of Neuroscience, Physiology, and Pharmacology, London WC1E 6DE, UK. [5] UCL Institute of Ophthalmology, London EC1V 9EL, UK.

* equal first authors, † equal senior authors. Correspondence to CS (stringerc@janelia.hhmi.org)

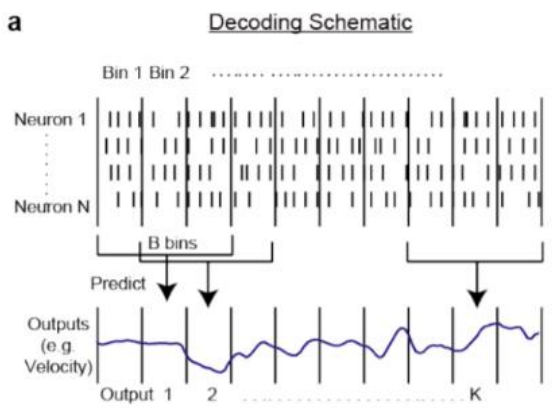


http://dx.doi.org/10.1101/306019.

The role of AI

Neural Decoding

- **Neural Decoding**



Machine learning for neural decoding
Joshua I. Glaser, Raeed H. Chowdhury, Matthew G. Perich, Lee E. Miller, Konrad P. Kording, https://arxiv.org/abs/1708.00909

Letter | Published: 16 May 2012

Reach and grasp by people with tetraplegia using a neurally controlled robotic arm

Leigh R. Hochberg, Daniel Bacher, Beata Jarosiewicz, Nicolas Y. Masse, John D. Simeral, Joern Vogel, Sami Haddadin, Jie Liu, Sydney S. Cash, Patrick van der Smagt & John P. Donoghue

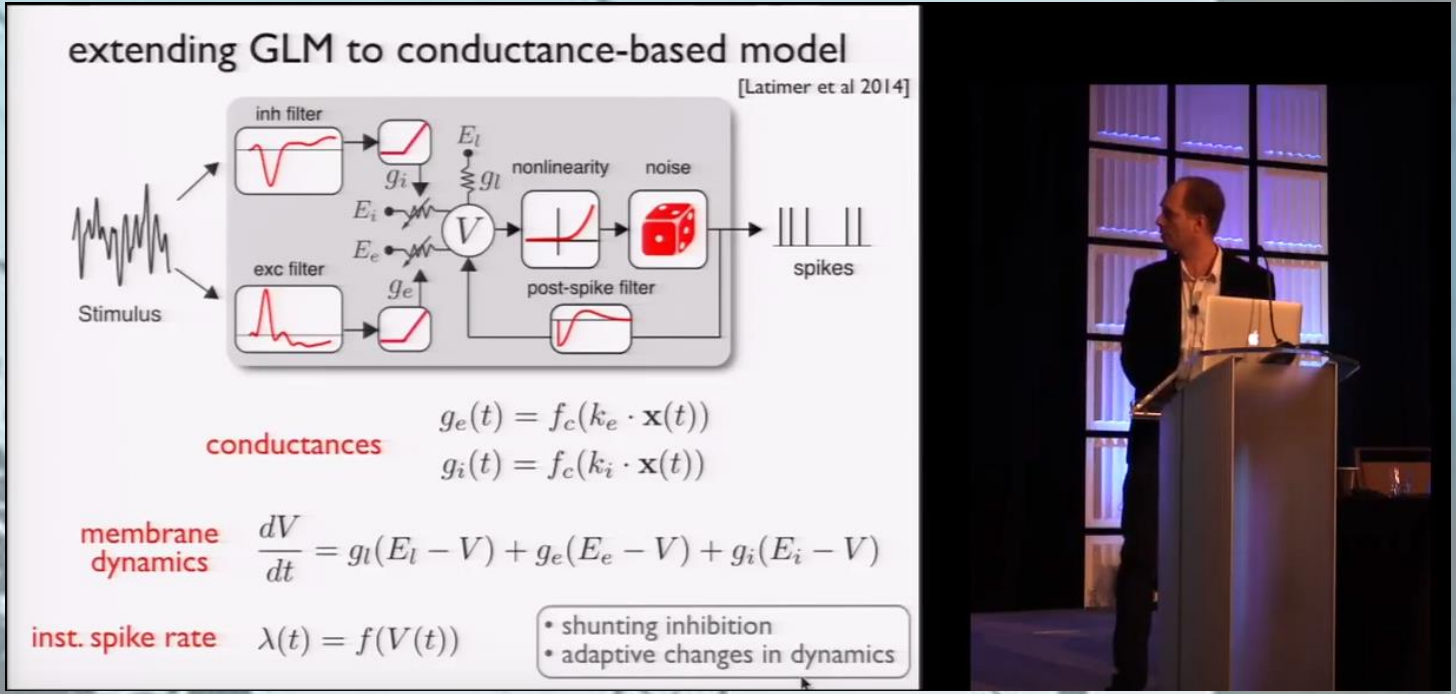
Nature **485**, 372–375 (17 May 2012) | Download Citation

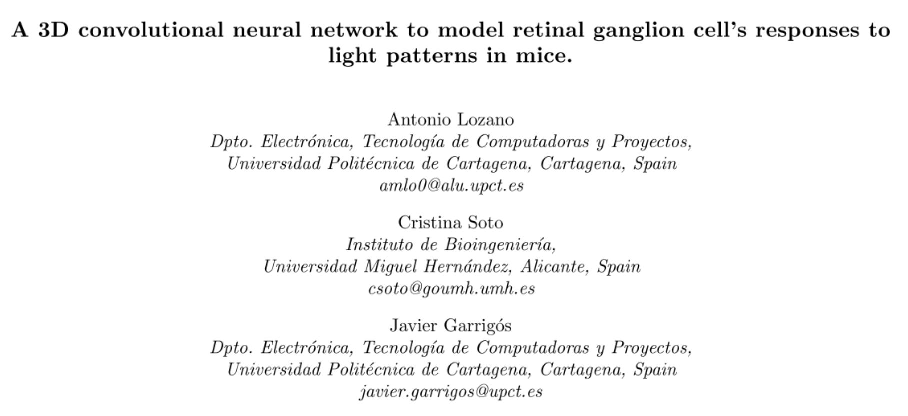
The role of AI

Deep Learning models of neural systems

Int J Neural Syst. 2018 Dec;28(10):1850043.
doi: 10.1142/S0129065718500430.

Jonathan Pillow - Tutorial: Statistical models for neural data - Part 2 (Cosyne 2018)
https://www.youtube.com/watch?v=rItGnzSHLcQ





A 3D convolutional neural network to model retinal ganglion cell's responses to light patterns in mice.

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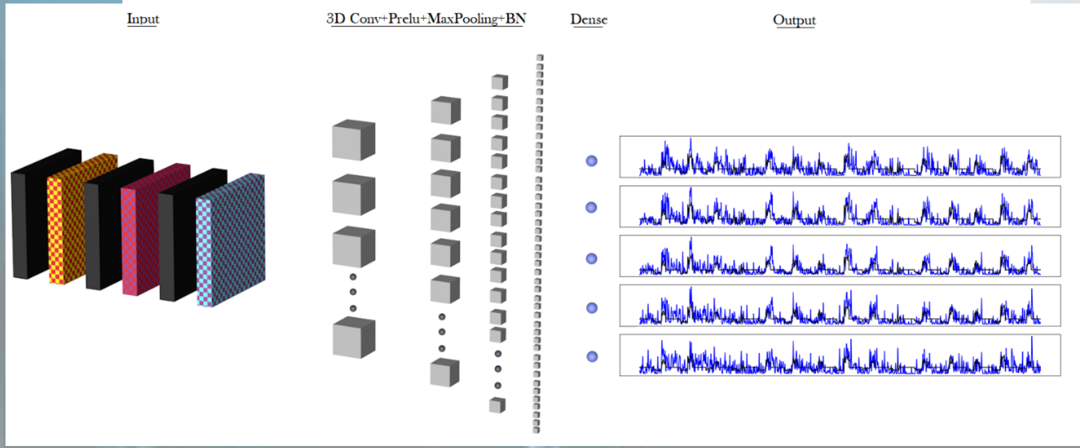

The role of AI

Generating highly exciting sensory inputs with Deep Learning

Inception in visual cortex: *in vivo-silico* loops reveal most exciting images

doi: http://dx.doi.org/10.1101/506956

Edgar Y. Walker,[1,2†*] Fabian H. Sinz,[1,2,5,7†*] Emmanouil Froudarakis,[1,2]
Paul G. Fahey,[1,2] Taliah Muhammad,[1,2] Alexander S. Ecker,[2,4–6] Erick Cobos,[1,2]
Jacob Reimer,[1,2] Xaq Pitkow,[1–3] Andreas S. Tolias[1–3*]

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[3] Department of Electrical and Computer Engineering, Rice University, Houston, TX, USA
[4] Centre for Integrative Neuroscience, University of Tübingen, Germany
[5] Bernstein Center for Computational Neuroscience, University of Tübingen, Germany
[6] Institute for Theoretical Physics, University of Tübingen, Germany
[7] Institute for Computer Science, University of Tübingen, Germany
[†] equal contribution,
*To whom correspondence should be addressed;
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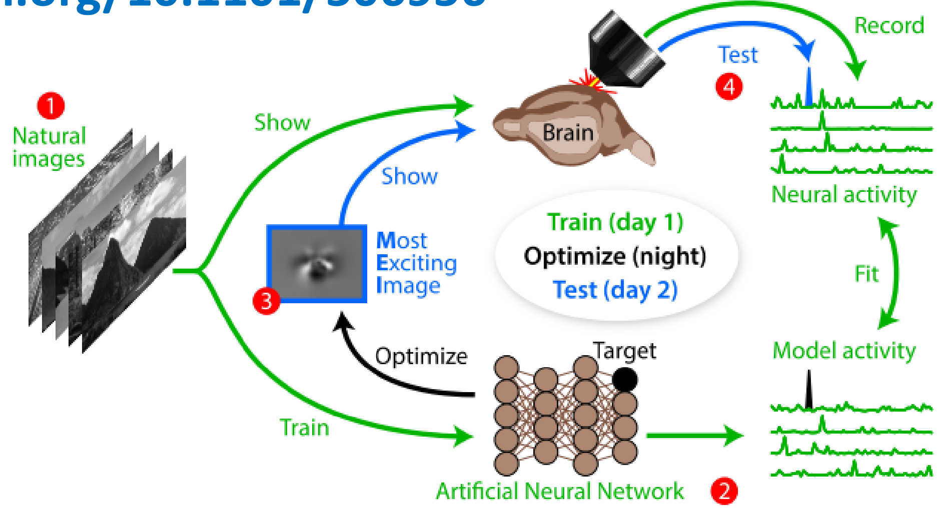


Figure 1: Schematic of the inception loop. On day 1 (green) we showed sequences of natural images to a mouse and recorded neural activity by two-photon calcium imaging. We trained artificial neural networks to reproduce those measured neural responses. Overnight (black) we generated Most Exciting Images (MEIs) for each target neuron in the neural network, as well as for a linear model. On day 2 (blue) we showed these MEIs from nonlinear and linear models back to the same neurons in the brain and compared the responses.

Our research at NBIO

cortical neuroprosthetics for the blind (CORTIVIS)

neurolight alpha

CORTICAL NEUROPROSTHETICS FOR THE BLIND (CORTIVIS)/NEUROLIGHT ALPHA

bio

Universidad Politécnica de Cartagena

Eduardo Fernández Jover, PI
Biomedical Neuroengineering Research Group, UMH, Spain

Toward the development of a cortically based visual neuroprosthesis
Richard A Normann,[1] Bradley A Greger,[1] Paul House,[2] Samuel F Romero,[3] Francisco Pelayo,[3] and Eduardo Fernandez[4]
doi: 10.1088/1741-2560/6/3/035001

CORTIVIS

is one of the main visual prostheses projects worldwide

Trial record **1 of 1** for: CORTIVIS

Previous Study | Return to List | Next Study

Development of a Cortical Visual Neuroprosthesis for the Blind (CORTIVIS)

This study is currently recruiting participants.

See Contacts and Locations

Verified December 2016 by Eduardo Fernandez, Universidad Miguel Hernandez de Elche

Sponsor:
Universidad Miguel Hernandez de Elche

Collaborator:
Hospital IMED Elche

Information provided by (Responsible Party):
Eduardo Fernandez, Universidad Miguel Hernandez de Elche

ClinicalTrials.gov Identifier:
NCT02983370

First received: September 12, 2016
Last updated: December 1, 2016
Last verified: December 2016
History of Changes

Full Text View | Tabular View | No Study Results Posted | Disclaimer | How to Read a Study Record

Purpose

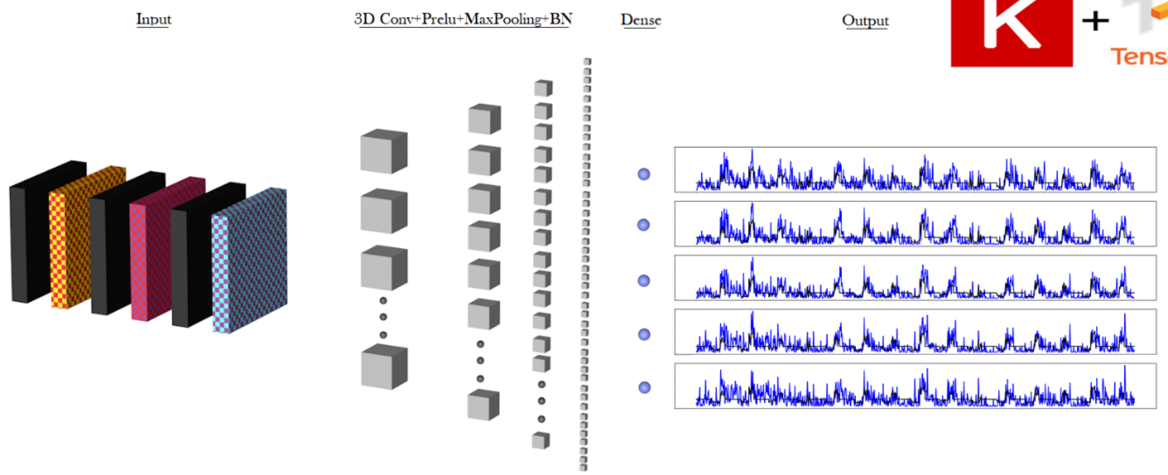
The objective of this study is to evaluate the usefulness of a cortical visual prosthesis based on intracortical microelectrodes to provide a limited but useful sense of vision to profoundly blind. This pilot study will provide important information on safety and efficacy for the development of an useful cortical visual neuroprosthesis for the blind.

- **Which are the best parameters to send useful information to the brain?**
- **How stable are phosphene thresholds and their associated features (i.e., intensity, size, spatial location) on a day-to-day basis?**
- **What is the optimum spacing of electrodes in the implanted microelectrode array?**
- **How many electrodes are required to produce a useful visual sense?**

Neurolight Alpha:

Interfacing Computational Neural Models
for Stimulus Modulation in Cortical Visual Neuroprostheses

Deep Learning retina models (previous work)



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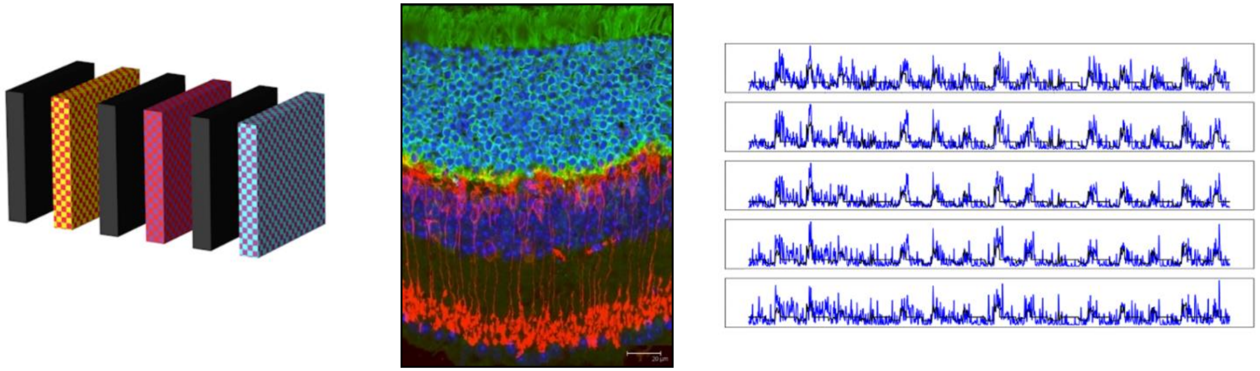

Retina image courtesy of Gema Martínez Navarrete, NBIO research group

Int J Neural Syst. 2018 Dec;28(10):1850043.
doi: 10.1142/S0129065718500430.

A 3D convolutional neural network to model retinal ganglion cell's responses to light patterns in mice.

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Universidad Miguel Hernández, Alicante, Spain
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Similar work in Stanford:

Adv Neural Inf Process Syst. Author manuscript; available in PMC 2017 Jul 18.
Published in final edited form as:
Adv Neural Inf Process Syst. 2016; 29: 1369–1377.

PMCID: PMC5515384
NIHMSID: NIHMS870072
PMID: 28729779

Deep Learning Models of the Retinal Response to Natural Scenes

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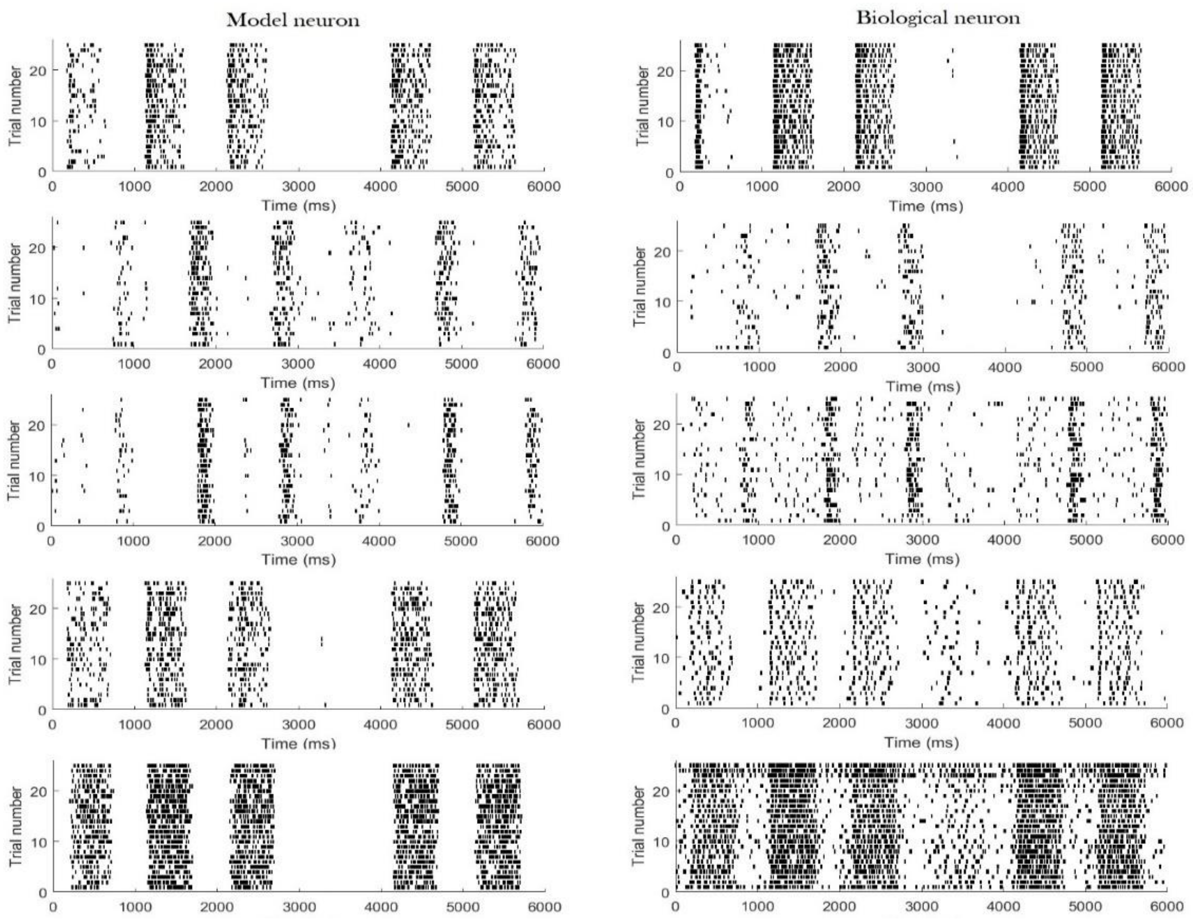
Neurolight Alpha:

Interfacing Computational Neural Models
for Stimulus Modulation in Cortical Visual Neuroprostheses

Deep Learning retina models (previous work)



A 3D convolutional neural network to model retinal ganglion cell's responses to light patterns in mice.

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CORTICAL NEUROPROSTHETICS FOR THE BLIND (CORTIVIS)/NEUROLIGHT ALPHA

Neurolight Alpha:
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DOI: 10.1007/978-3-030-19591-5_12

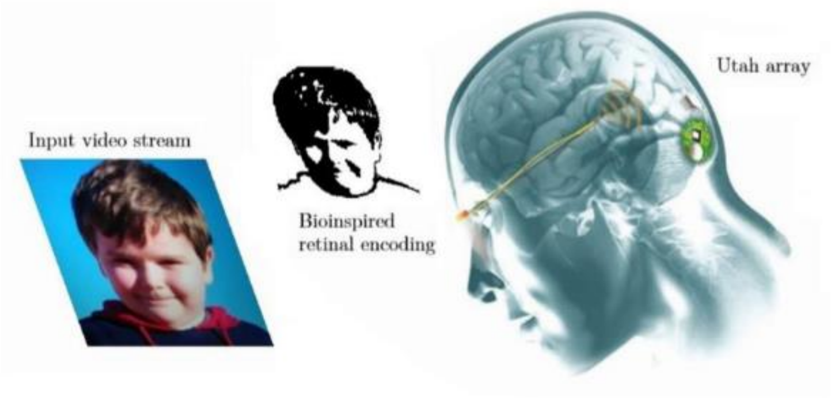
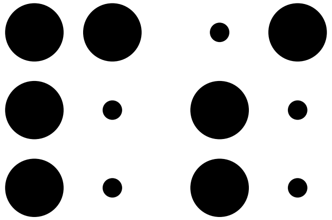


Fig. 1. A general idea of a cortical visual neuroprosthesis is composed of a camera obtaining a video stream, a encoding module and a stimulator which sends electrical pulses throughout an intracortical microelectrode interface.



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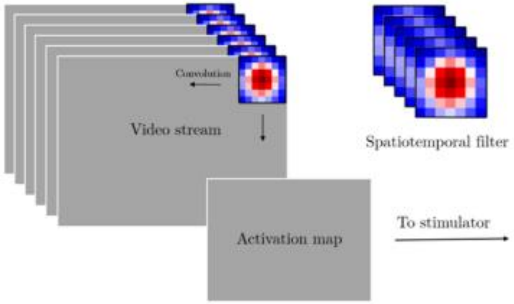
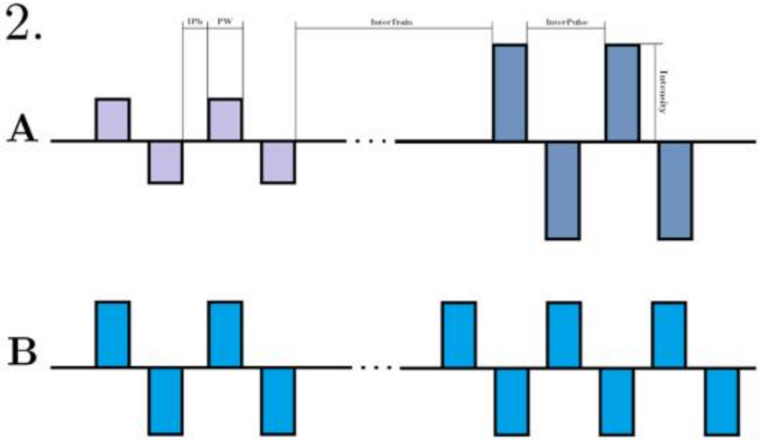
1.



Algorithm 1. Experiments module

```
Create train configurations
Select electrodes to use
Create encoding model
while processFlag do
    Obtain and process frame
    Update video buffer
    Model processing
    Stimulation command
    if exitCondition == True then
        processFlag ← True
    end if
end while
```

2.



Antonio Lozano et al.

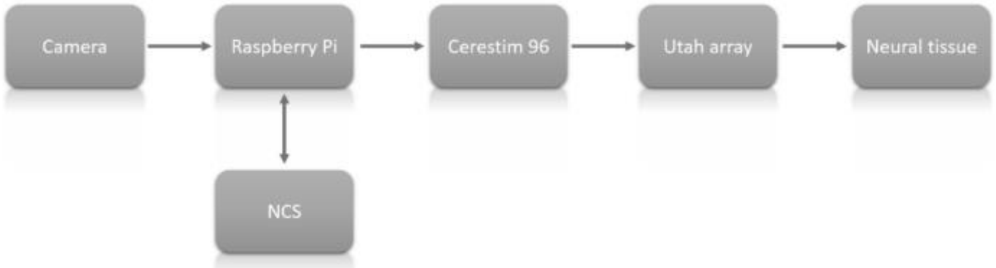


Fig. 3. Illustration of the main system's pipeline.

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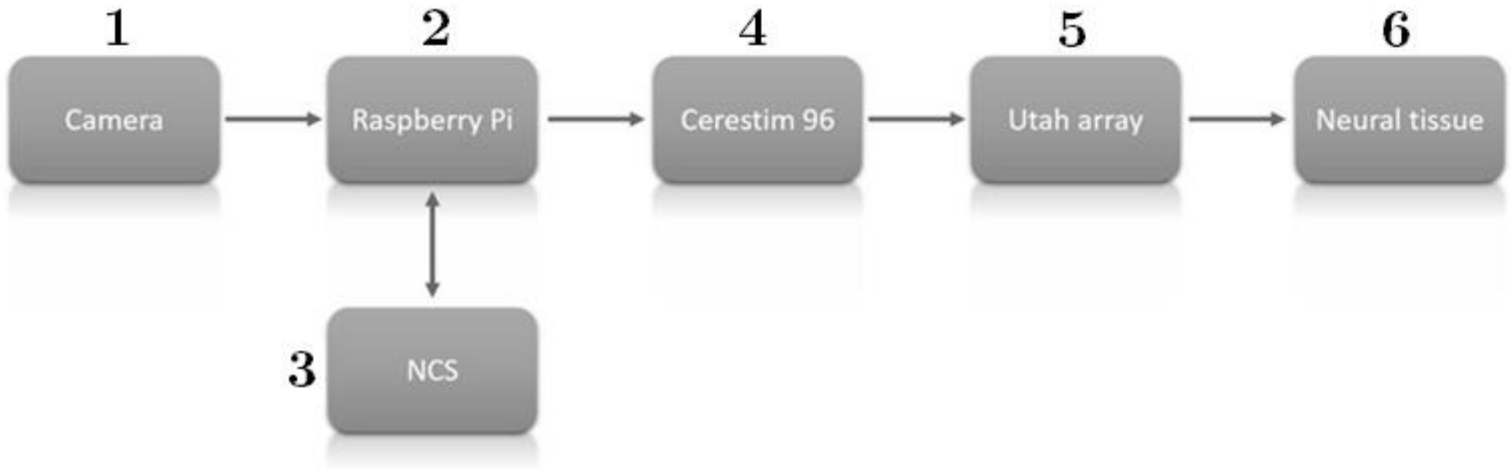
Juan Sebastián Suárez Peña

Our system's pipeline:



1. Commercial camera that retrieves a video stream
2. A lightweight, portable computer that coordinates the process (Neurolight's custom Python API)
3. Intel's Neural Compute Stick for fast DL retina model's inference of stimulation parameters (optional)
4. Black Microsystems's neurostimulator that generates the electrical pulse trains
5. An Utah electrode array, implanted into the patient's visual cortex (V1 or V2)
6. The encoded signals activates the nearby neurons, eliciting visual perceptions

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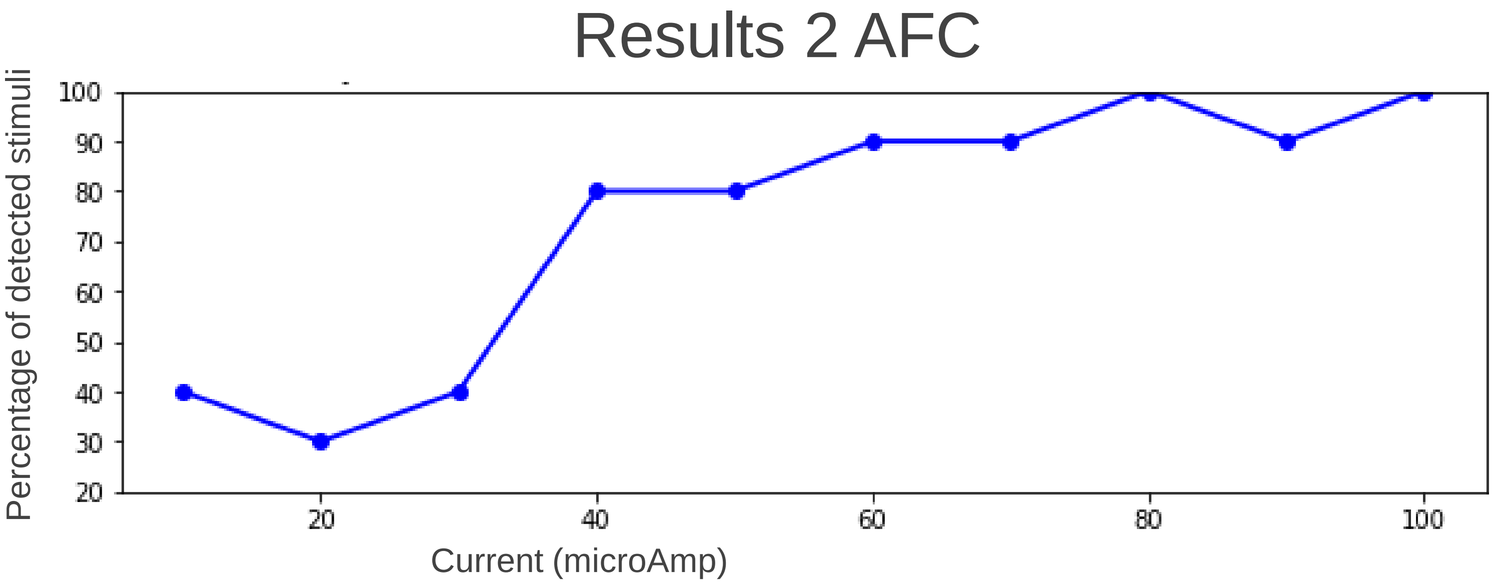
The future:

An armonious integration with psychophysics to match stimulus and visual perception in experimental setups

Psychophysics has been described as ***"the scientific study of the relation between stimulus and sensation“***

Many questions are to be answered!!



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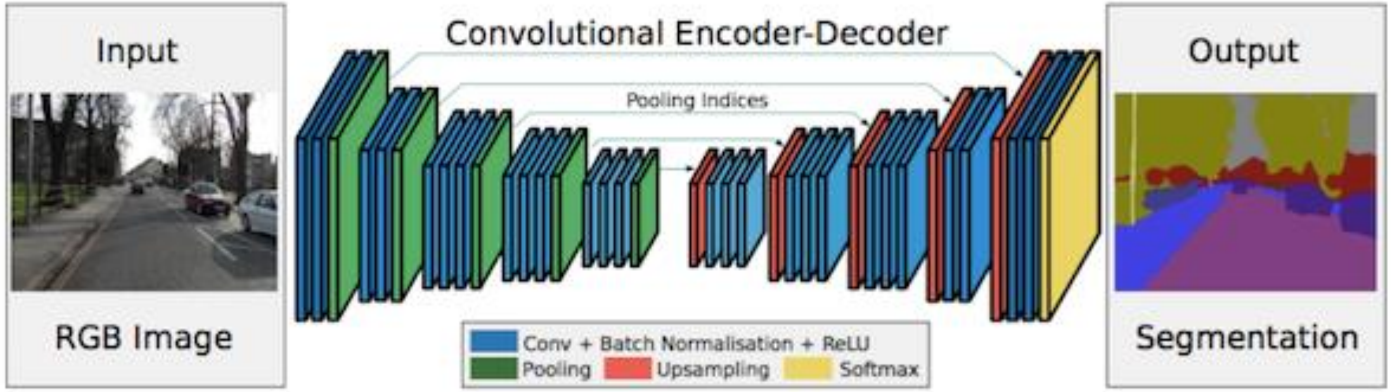
Universidad Politécnica de Cartagena

The future:

Developing alternative and hybrid strategies for image processing and electrical stimulus modulation in cortical prostheses

Image segmentation, object detection...

We will may custom, high performance hardware to run this in real time!



SegNet: A Deep Convolutional Encoder-Decoder Architecture for Image Segmentation

Vijay Badrinarayanan, Alex Kendall, Roberto Cipolla

NEURALINK

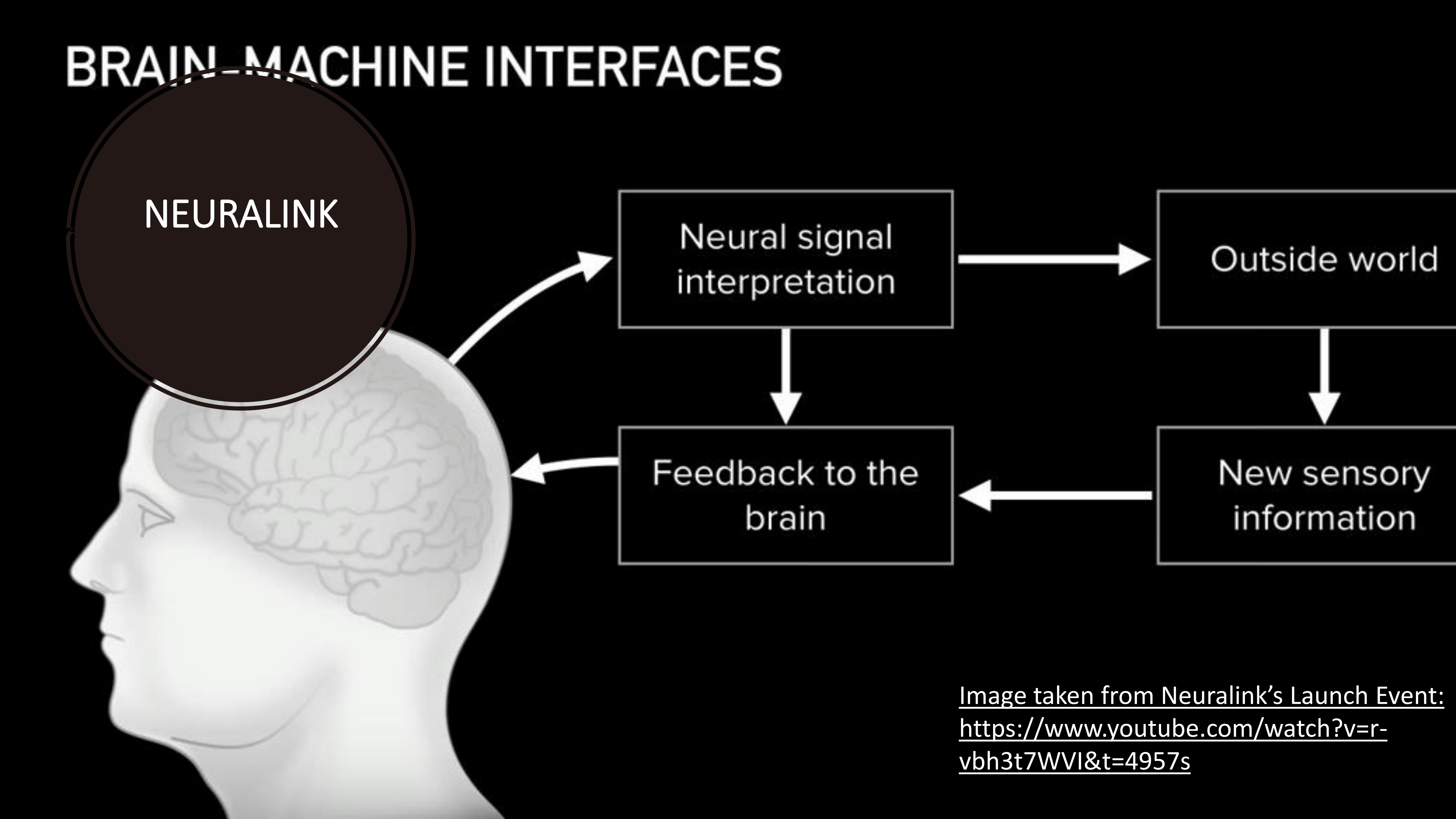


Image taken from Neuralink's Launch Event: https://www.youtube.com/watch?v=r-vbh3t7WVI&t=4957s

• Neuralink

State of the art *technological developments*

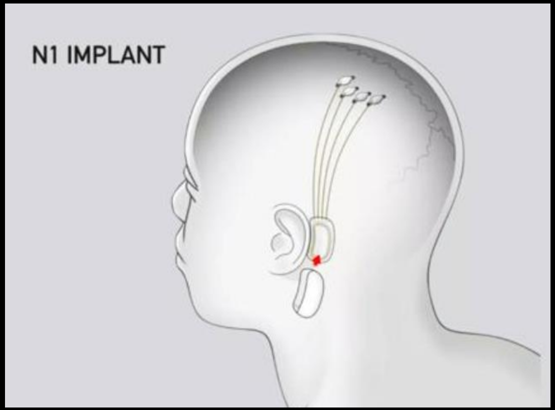
Advanced surgical robot

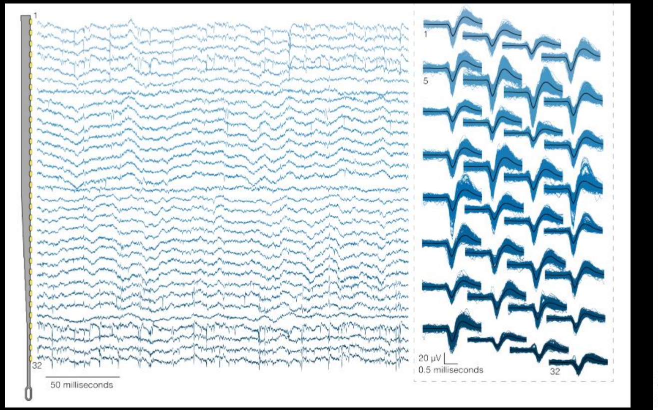
High count, flexible Electrodes

Advanced electronics: in situ spike detection,
high bandwidth neural interface

Clinical trials?

Images from Neuralink's White paper: "An Integrated Brain-Machine Interface Platform with thousands of channels"





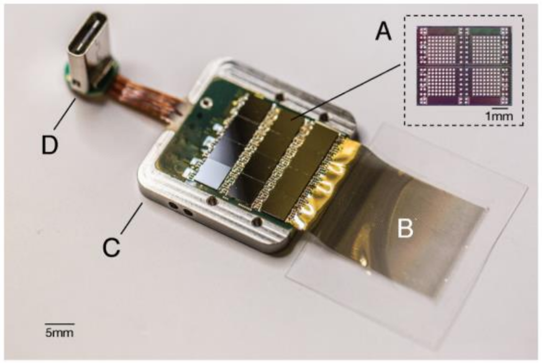
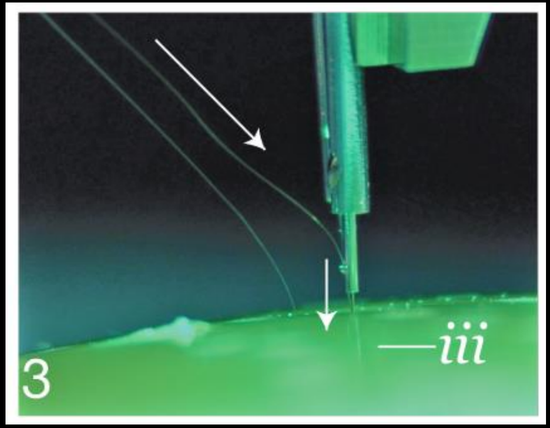


Figure 5: A packaged sensor device. **A.** individual neural processing ASIC capable of processing 256 channels of data. This particular packaged device contains 12 of these chips for a total of 3,072 channels. **B.** Polymer threads on parylene-c substrate. **C.** Titanium enclosure (lid removed). **D.** Digital USB-C connector for power and data.



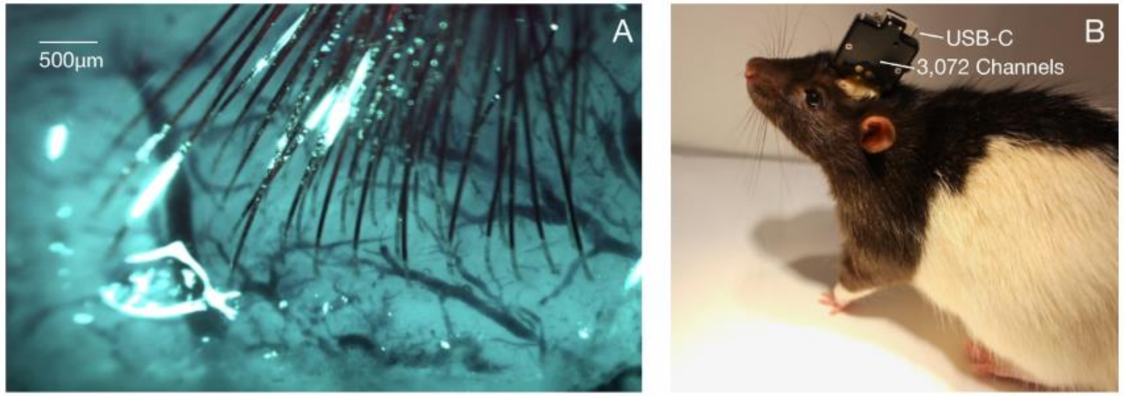


Figure 6: Thread implantation and packaging. **A.** An example peri-operative image showing the cortical surface with implanted threads and minimal bleeding. **B.** Packaged sensor device ("System B") chronically implanted in a rat.

An excellent integrative technological effort!!!

An integrated brain-machine interface platform with thousands of channels

Elon Musk & Neuralink

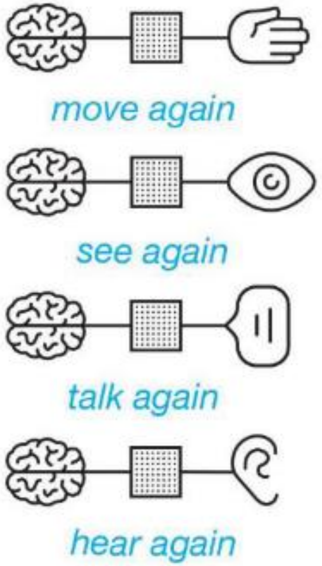
• Neuralink

Merging AI with humans?

[If possible, it looks far away into the future]

[We are just in our infancy in understanding the brain or creating anything near Artificial General Ingelligence]

Neuralink and the future of neural engineering



What are the real potential outcomes?

The neural engineering dream is “old”, and great teams are working on that all over the world

Andrew Schwartz, Motor prostheses University of Pittsburgh

Eduardo Fernández visual prostheses NBIO,Miguel Hernández University

Richard Normann, Visual/motor prostheses University of Utah

Pieter Roelfsema Visual prostheses, Netherlands Institute of Neuroscience

COGNITIVE FUNCTION

Movement
Somatosensation
Vision
Spatial maps

Speech and language
Mood
Pain
Hunger and thirst
Memory
Mathematical reasoning

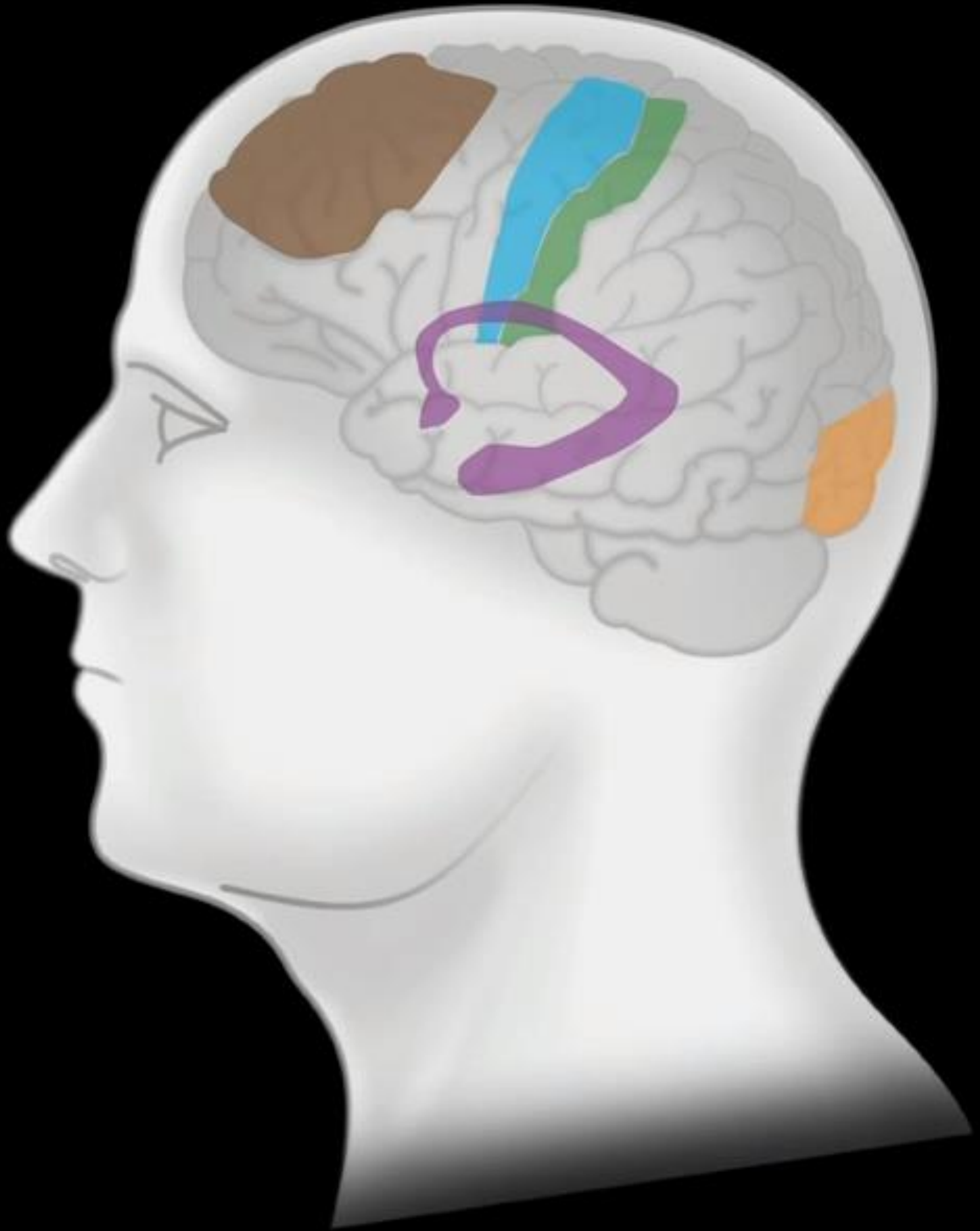
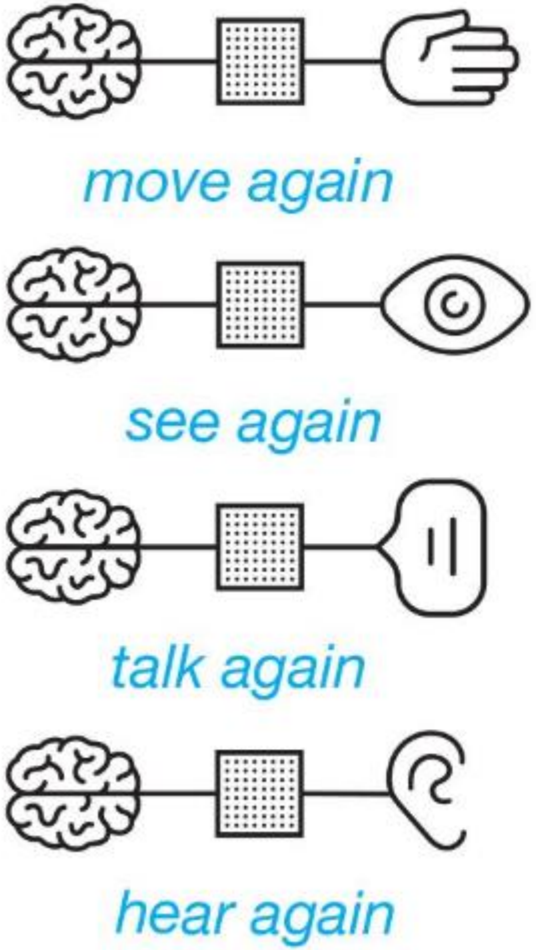


Image taken from Neuralink's Launch Event:
https://www.youtube.com/watch?v=r-vbh3t7WVI&t=4957s

Prof. Anna Wang Roe
http://www.ziint.zju.edu.cn/Anna/index.php/Index/index1.html

What's next?



BLACKROCK MICROSYSTEMS

Q&A/Discussion time!

Thank you!

I'm looking forward to hearing your questions/ideas

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