Advances toward substrate-independent minds

Neural Interfaces, Neural Prostheses and Whole Brain Emulation

Randal A. Koene
carboncopies.org

Self-directed evolution to SIM

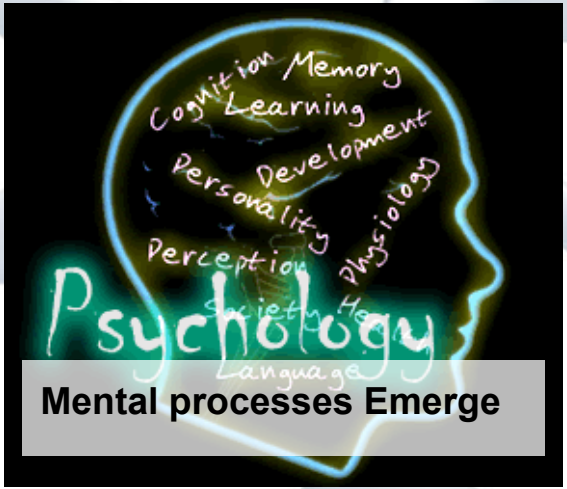
via Whole Brain Emulation, neural prostheses & neural interfaces

methodology at carboncopies.org

most significant development: a true Neural Interfacing Platform for BMI, cognitive neural prostheses and WBE

What and Why

See: http://koene.carboncopies.org



Mental processes Emerge

Objective:
Substrate-Independent Mind (SIM)

Feasible method:
Whole Brain Emulation (WBE)

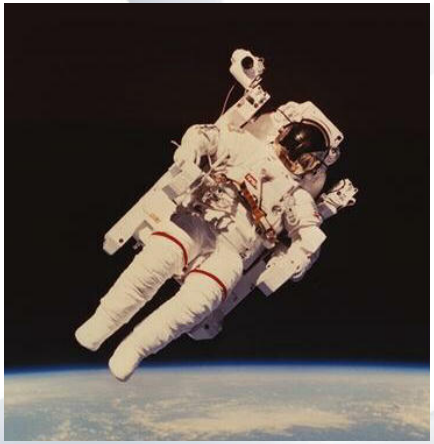
Bio to WBE transfer:
"Mind Uploading"

Like PC on Mac

Generate in other substrate:

Supporting evidence from neuro-prosthetic development

Mind independent of substrate (or platform)

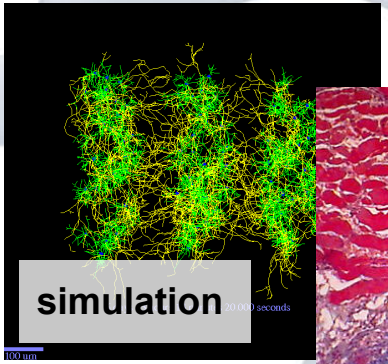


Exceeding personal limitations

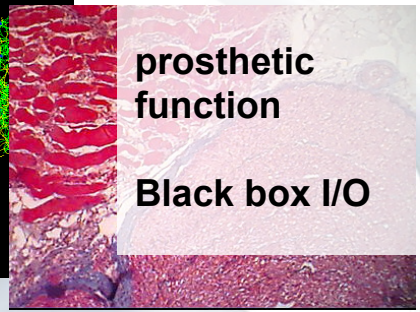
A most Adaptable Species beyond this tiny sliver of Space & Time

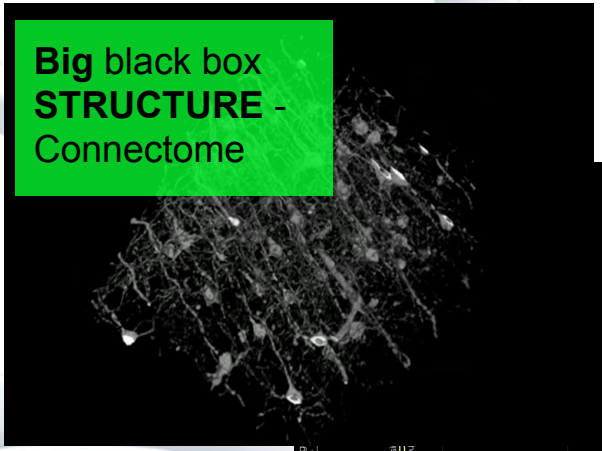
Whole Brain Emulation (WBE): Reverse Engineering of an Individual's Mind

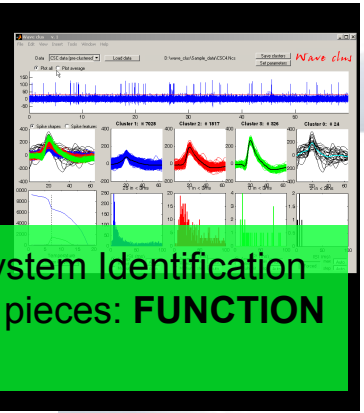
See: http://koene.carboncopies.org

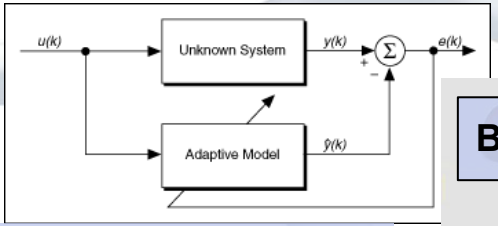


emulation

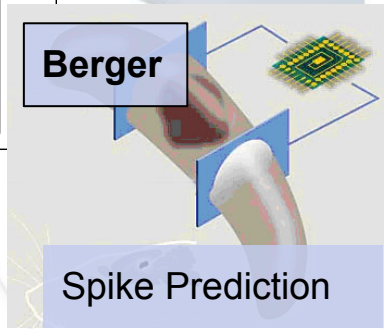








system identification

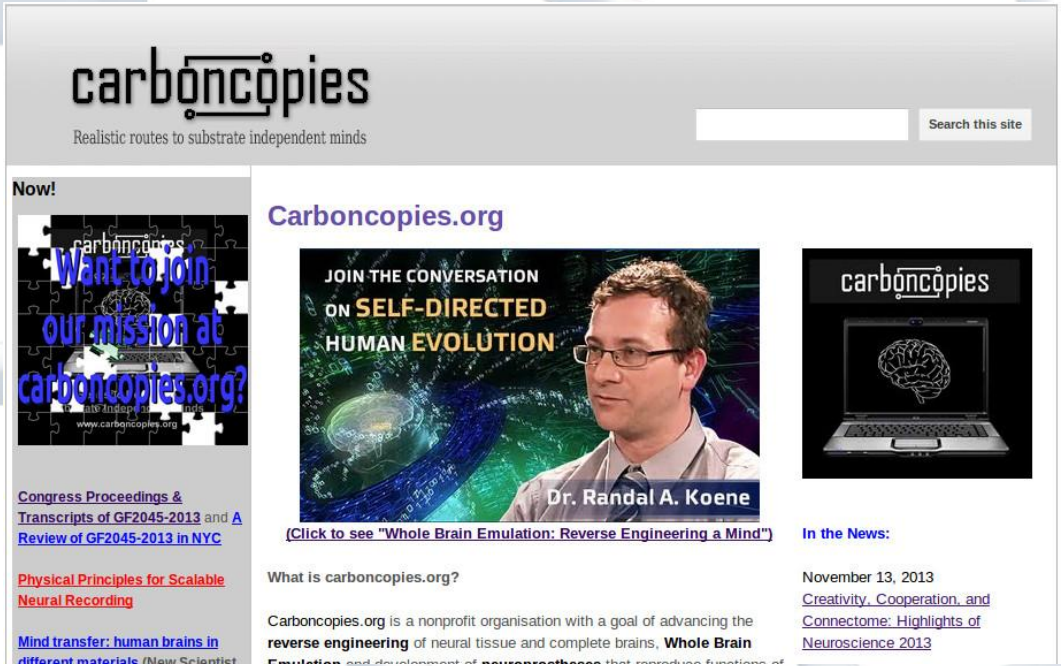


Representations & Platforms: **EMULATE**

Test & Improve: **ITERATE**

ROADMAP

My work through Carboncopies.org

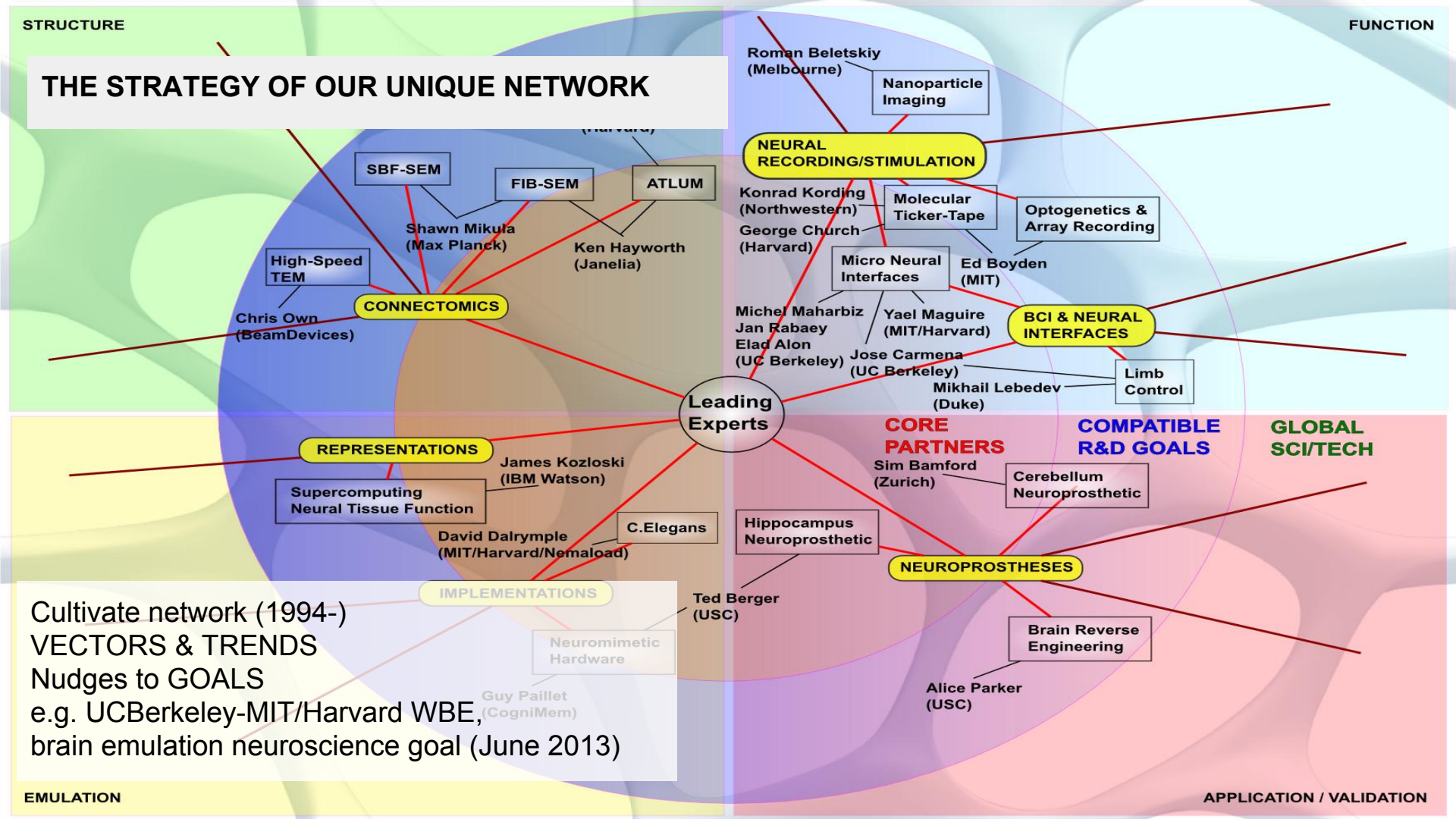


Maintain & Update ROADMAP

Publish & Inform about ROADMAP

<u>Main purpose:</u>
Whatever the Trends,
insure the Goal of SIM is achieved

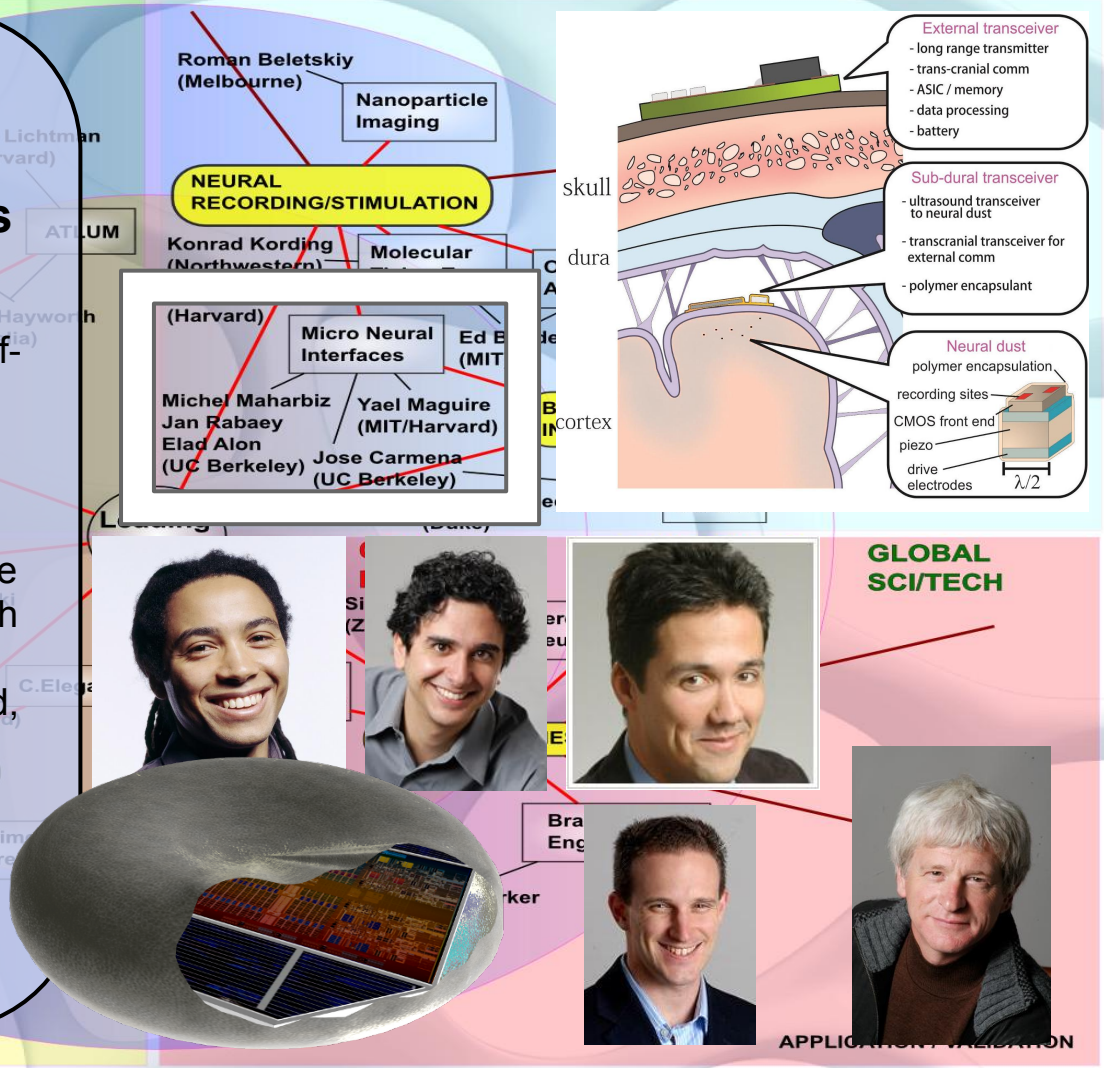
- developments **Bottom-Up** combined Feasibly & Robustly for Solutions to **Top-Down** problems
- Encourage solution that **Meet Requirements**
- Identify and Fill **Gaps**
- Involve **Experts**, find Common Interests, create New **Collaborations**, find **People** & **Resources** for projects



Cultivate network (1994-)
VECTORS & TRENDS
Nudges to GOALS
e.g. UCBerkeley-MIT/Harvard WBE,
brain emulation neuroscience goal (June 2013)

2013 Key Focus on FUNCTION:
Wireless Micro Neural Interfaces

- **Safe & Effective**: biocompatible (self-contained), no surgery, too small to break tissue
- **Cellular scale & Many regions**: wireless, 1-100um devices, anywhere (tens, thousands,...) = high bandwidth
- **Predictable development**: IC-based, mature industry & talent, integrated on-chip (one piece), Moore's Law

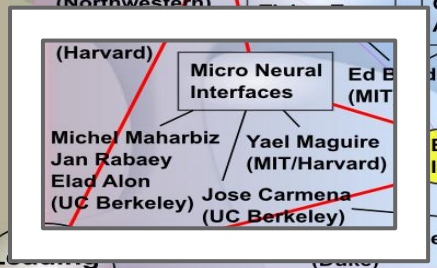


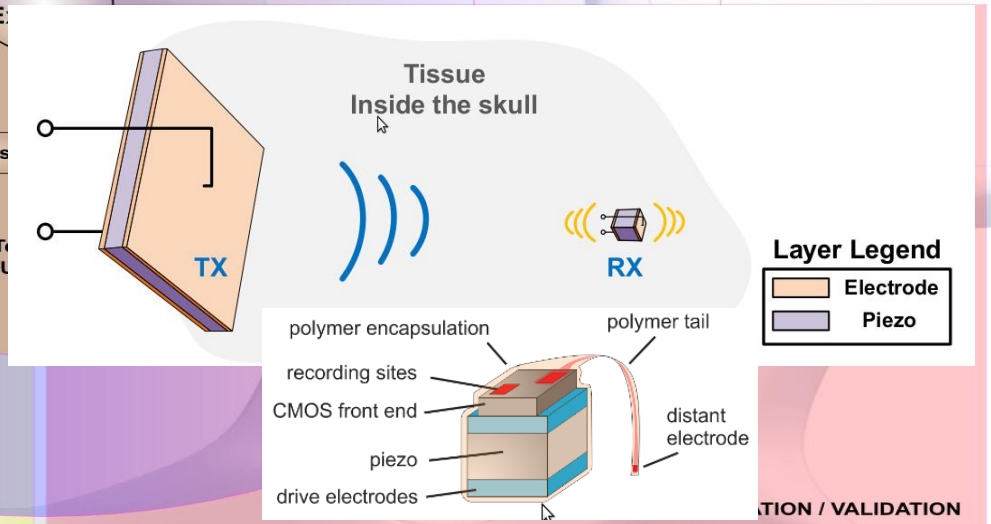
In the Lab Today

- ➔ 100um “Neural Dust” (UC Berkeley): ultrasound
- ➔ next: adding 1-5um sensor “tail”
- ➔ 1000um wireless data hub (collect, compress, transmit)
- ➔ Infrared “RFID” microprobe (MIT/Harvard), testing sensing & power

“This project is moving faster than any before, experimental reality is much like we assumed.”
- Prof. Maharbiz

Animal trials June 2014!



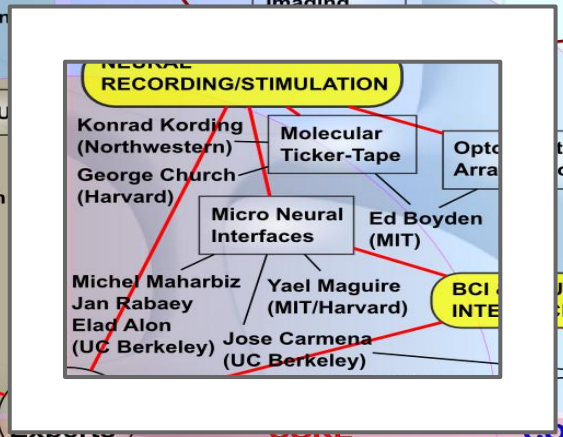


Revolutionary Brain Machine Interfaces, A New Network

A NeuraLink PLATFORM

- ➔ backbone of the next network revolution (“routers of Internet”)
- ➔ become the standard at that point in neurotechnology stack
- ➔ first-mover benefit inside demand & development feedback cycle
- ➔ at <10um micro neuro interfaces meet requirement for Whole Brain Emulation

Same tech. req. as WBE!
Need Platform for wide use & rapid iteration



ProBAM consortium goals: 1ms sample rate record/stimulate at every neuron (Marblestone et al. white papers, 2013)

Cornell Library
arXiv.org > q-bio > arXiv:1306.5709

Quantitative Biology > Neurons and Cognition

Physical Principles for Scalable Neural Recording

Adam H. Marblestone, Bradley M. Zamft, Yael G. Maguire, Mikhail G. Shapiro, Thaddeus R. Cybulski, Joshua I. Glaser, Ben Stranges, Reza Kalhor, David A. Dalrymple, Dongjin Seo, Elad Alon, Michel M. Maharbiz, Jose Carmena, Jan Rabaey, Edward S. Boyden, George M. Church, Konrad P. Kording

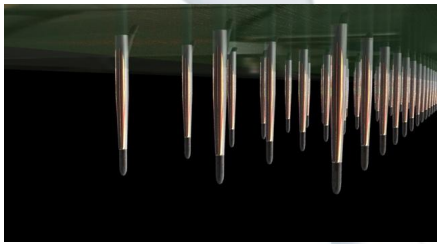
(Submitted on 24 Jun 2013 (v1), last revised 25 Jun 2013 (this version, v2))

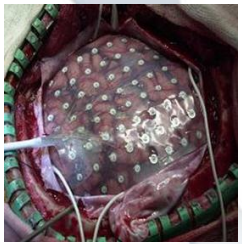
Simultaneously measuring the activities of all neurons in a mammalian brain at millisecond resolution is a challenge beyond the limits of existing techniques in neuroscience. Entirely new approaches may be required, motivating an analysis of the fundamental physical constraints on the problem. We outline the physical principles governing brain activity mapping using optical, electrical,magnetic resonance, and molecular modalities of neural recording. Focusing on the mouse brain, we analyze the scalability of each method, concentrating on the limitations imposed by spatiotemporal resolution, energy dissipation, and volume displacement. We also study the physics of powering and communicating with microscale devices embedded in brain tissue.

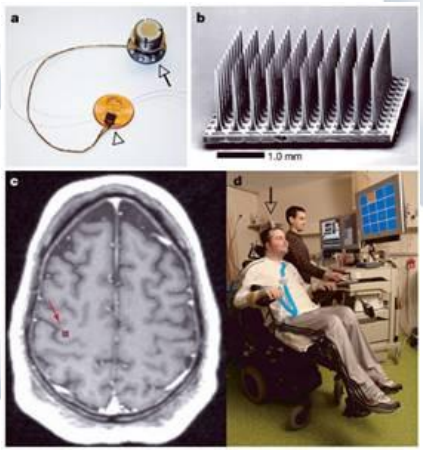
Micro neural interfaces development program

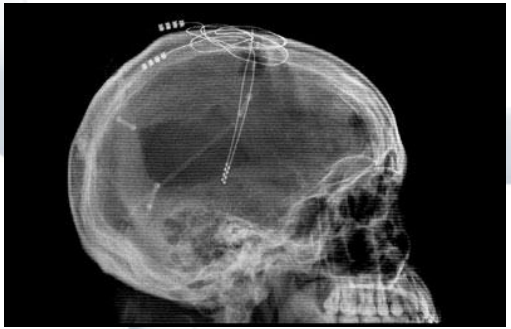
Platform is component in existing tool stack

- ➔ above: data stream handling, analysis software, results target (DBS, sensory prosthetic, diagnostic monitor, communication for locked-in/ALS, prosthetic limb control, BCI, smart drugs)
- ➔ same level: micro wireless, (opto-) electrical arrays (e.g. BrainGate), deep electrodes (e.g. DBS), ECog/uECog
- ➔ lower stack: signal choice/detection









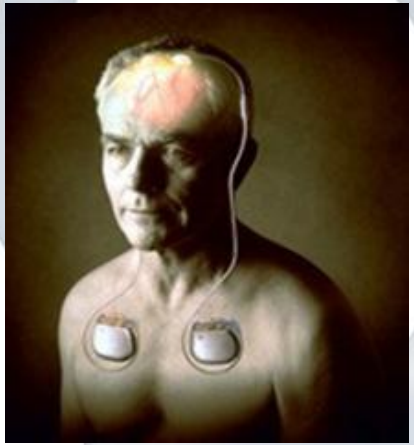
First-stage program (first year)

- ➔ v1.0 based on existing 100um prototype, built with lab infrastructure
- ➔ platform for research market - partners become 1st users/customers
- ➔ encourage use in similar labs

Micro neural interfaces development program

Second-stage program (third year)

- ➔ shrink to 10-20um
- ➔ combine with infrared high-bandwidth hub
- ➔ active delivery system
- ➔ redesigned for IC industry standard high volume production

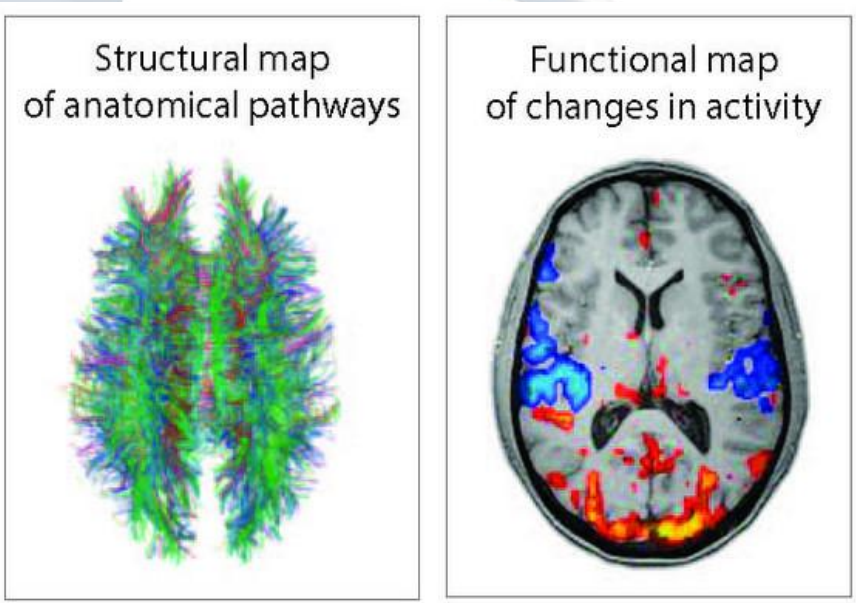


New markets

- ➔ demo applications explore horizontal & vertical tool-stack expansion of efforts
- ➔ translational approach to clinical market:
  - ◆ product-companies (e.g. DBS, cochlear implants) replace component of tool-stack with micro neural interfaces
  - ◆ they do the heavy lifting with existing motivation, experience & resources in FDA markets

Significance from Brain PROCESS Perspective

- **Long-term** operational interfaces
- To a very **large number of neurons**
- **Without harm** to the brain



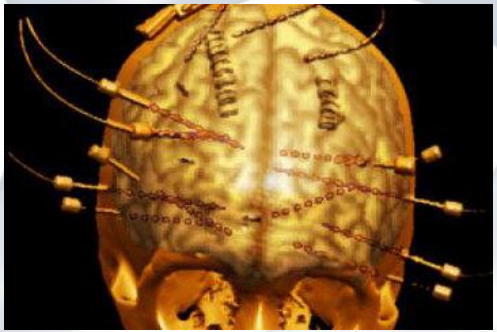
MRI, EEG, etc. impractical

low resolution

cannot distinguish events

unable to see single cell activity

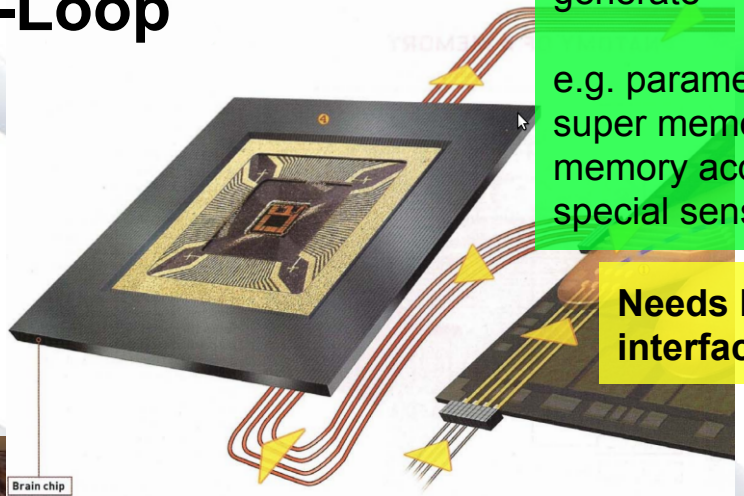
BCI electrodes access few neurons
Electrodes break down, inflammation & infection



Significance from APPLICATION Perspective High Bandwidth within the Brain-Loop

Low-res BCI (locked-in patients)
behavioral training, neurofeedback

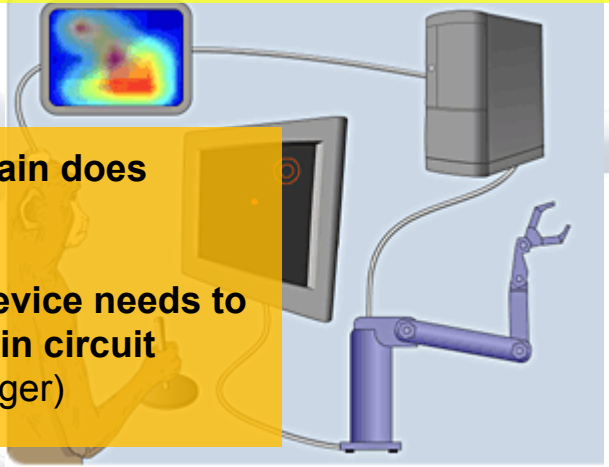
But is EEG > eye-tracking for narrow BCI?



BCI in-loop:
out: use data otherwise hard to get
in: deliver data otherwise impossible to generate

e.g. parameter fitting, super object-recognition, super memory-retrieval, selective super memory acquisition, trajectory prediction, special senses (UV, stock market)

Needs large-scale high resolution interfacing

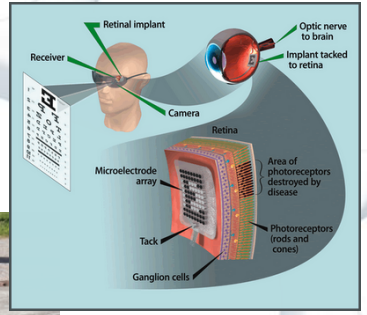


Low-res BCI: **Brain does heavy lifting**

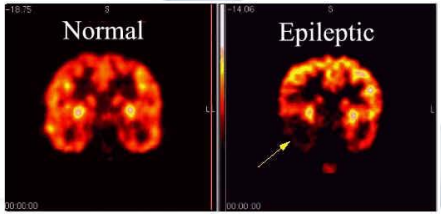
High-res BCI: **Device needs to understand brain circuit** signals (e.g. Berger)

Products & Application Areas

Small & High Bandwidth
- ➔ wireless record/stimulate at cell, ensemble, region level



Patients first
- ➔ Diagnostic
- ➔ Treatment



Non-Harmful -- Not just for Patients!

- ➔ The interfaces increase capabilities without doing harm

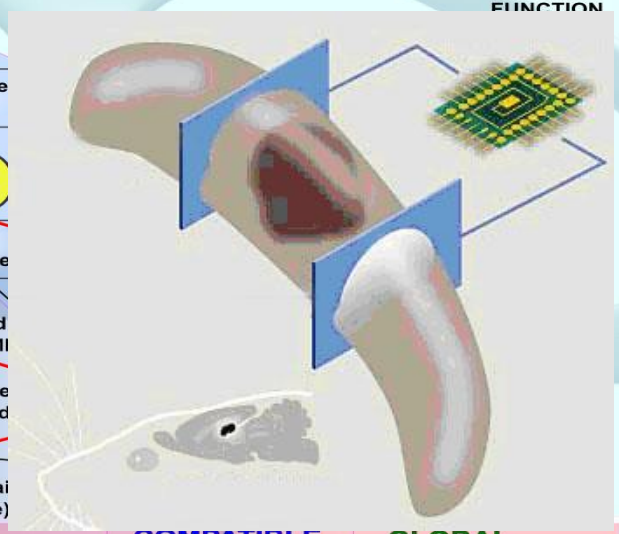
A New Network shift in the world!

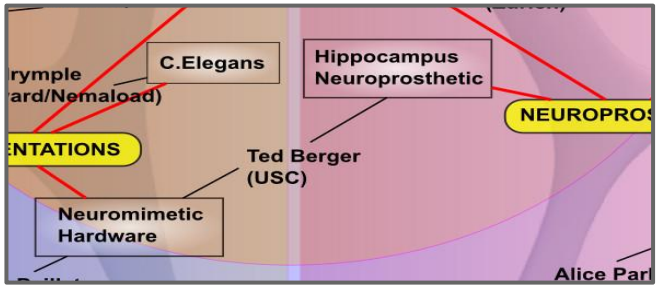
Trans-human enhancement
- ➔ emotion communication
- ➔ “telepathic” communication
- ➔ retina record/playback
- ➔ auditory record/playback
- ➔ library record/sort/stimulate of episodic memory cues (hippocampus)
- ➔ knowledge portal (Internet, Wikipedia, etc)
- ➔ BCI for full-experience
- ➔ data access & transition for whole brain emulation

(Most apps unimaginable, like Google etc was unimaginable to 1980s Internet.)

Repair with brain prostheses - Strategically Part-Wise to Whole Brain Emulation

- ➔ First cognitive neural prosthesis: biomimetic hippocampal chip (Ted Berger)
- ➔ Created via system identification (functions for “spike” input - output)
- ➔ Implemented in other substrate: biomimetic chip





Success in rats!

New results in primates!

Part-Wise to WBE is a likely route!

Time-Line from APPLICATION Perspective

(2-3 years) hippocampus prosthesis in Human trials - experimental treatment of stroke & neurological damage

(5-8 years) prosthesis enables “library of memory” collect/identify/tag

(5-10 years) brain circuit analyses enable machine learning products (AI, compare “deep learning”)

(8-12 years) motor control prostheses - treatments for paralysis

(10-14 years) sensory prostheses - treatments for blindness, deafness, etc (compare cochlear implants)

(10-14 years) augmented sensation via prosthetic

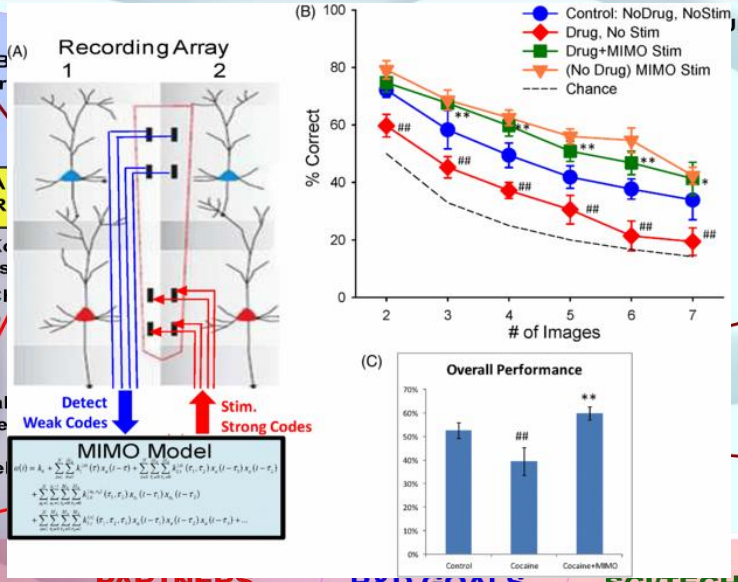
(10-20 years) mental co-processors (database-like memory, faster recognition/reflexes, etc)

(10-25 years) prosthetic treatments for deficits in many brain regions

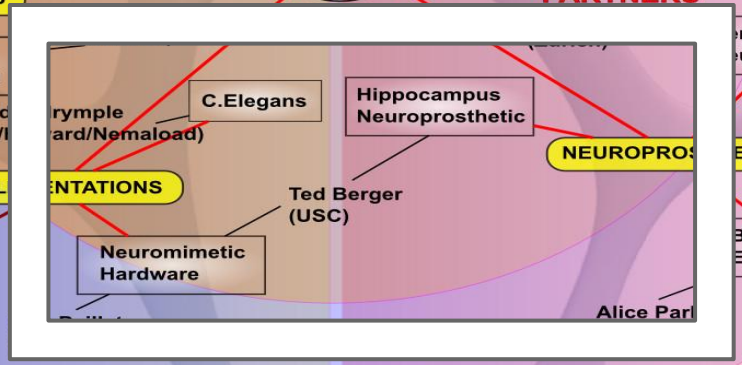
(25+ years) all parts of Whole Brain Emulation with mind transfer protocol (robust & failsafe mind, substrate-independent, long lasting)

Science Development Perspective
Step 1: Berger - The prosthetic works better than the original!

- ➔ Hippocampus prosthetic trials in humans
- ➔ In primates, extension of Berger-protocol to prefrontal cortex

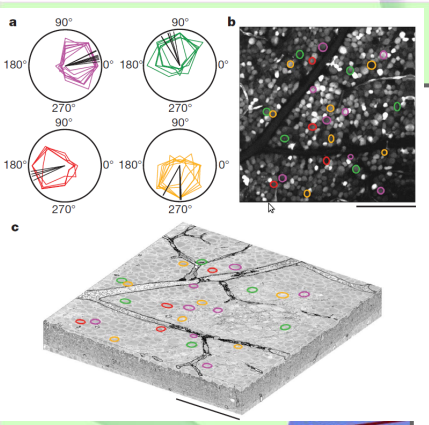


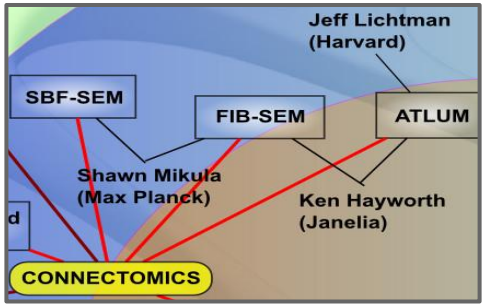
Repairs &
Improves performance!

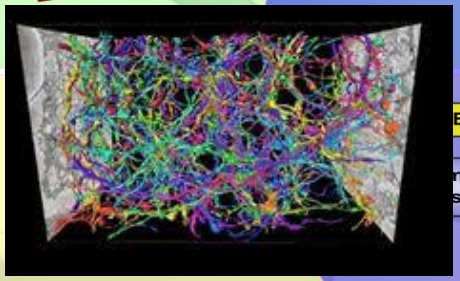


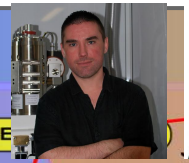
Step 2: Small whole brains & special areas of brain

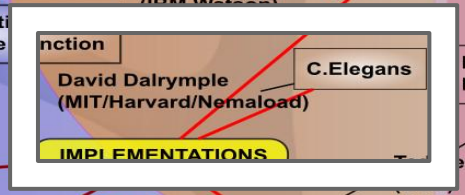
- ➔ C.Elegans (Nemaload, Openworm) & Drosophila (Janelia Farms) proofs-of-concept: structure + function in hundreds & thousands of neurons
- ➔ Retina & Cerebellum prostheses based on general connectomes & “sparse” activity recording (Hayworth, Lichtman, Mikula, Bamford): circuit analysis and principles (earlier: Briggman et al, Bock et al)

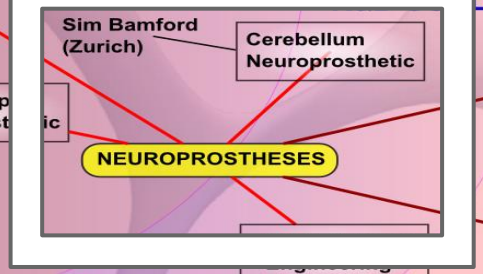


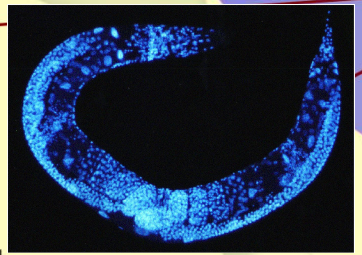










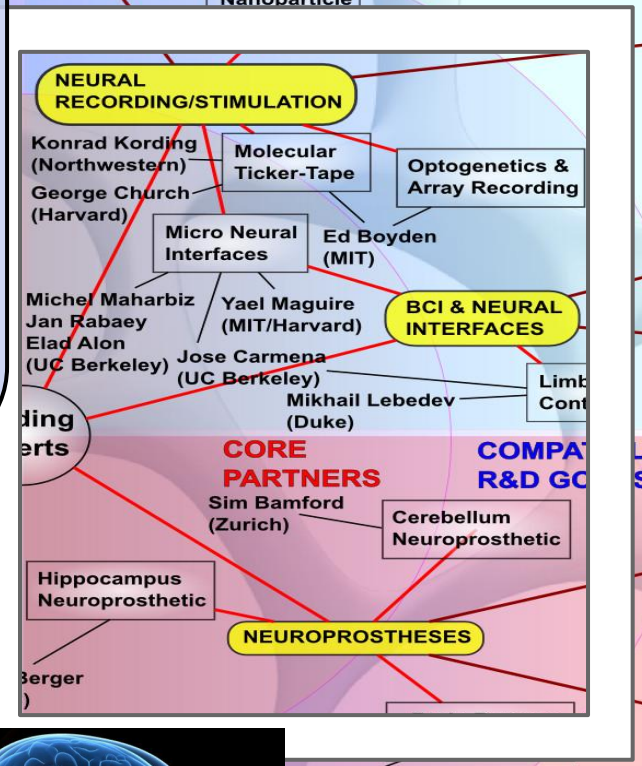


EMULATION

APPLICATION / VALIDATION

Step 3: New Interfaces make prosthesis of any part possible

- ➔ ProBAM results: new interface platform - extends prosthetic development to systems with personal memories
- ➔ Enables Extension Tech: memory capture, off-line memory sorting, sight & sound capture / stimulation



STRUCTURE

FUNCTION

Step 4: Many parts up to Whole Brain Emulation

- ➔ Generalized process:
  - structure gives interacting sub-circuits
  - function gives sub-circuit system identification
  - math. representation + implementation gives emulated function & brain prosthetic

Roman Beletskiy (Melbourne)

Nanoparticle

NEURAL RECORDING/STIMULATION

Konrad Kording (Northwestern)

Molecular Ticker-Tape

Optogenetics & Array Recording

George Church (Harvard)

Micro Neural Interfaces

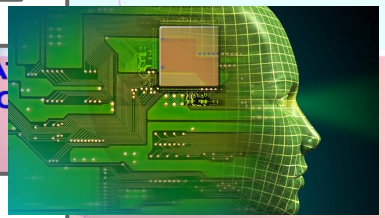
Ed Boyden (MIT)

Michel Maharbiz
Jan Rabaey
Elad Alon
(UC Berkeley)

Yael Maguire (MIT/Harvard)

BCI & NEURAL INTERFACES

Jose Carmena



Experts

CORE PARTNERS

Sim Bamford (Zurich)

Cerebellum Neuroprosthetic

REPRESENTATIONS

James Kozloski (IBM Watson)

Supercomputing Neural Tissue Function

David Dalrymple (MIT/Harvard/Nemaload)

IMPLEMENTATIONS

NEUROPROSTHESES

Ted Berger (USC)

Brain Reverse Engineering

- ➔ Piece-wise neuroprosthetic replacement (circuit by circuit / cell by cell)
- ➔ Substrate-Independent Mind

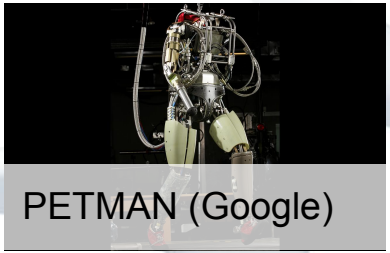
APPLICATION / VALIDATION

2014

Government, Google, Facebook: Machine learning, Robotics
Machine-centric -- not self-directed evolution

Futures: human/machine vs human&machine

SIM network: apply study of life, brain & mind to improve human condition



PETMAN (Google)

GOALS, not same as following TRENDS
- ➔ where are we in 20, 40, 60 years?
- ➔ carboncopies.org & partners: Ensure Goals of SIM

Probability of Success for Complex Long-Term Objective - **Monitor & Nurture explicitly**
- ➔ grass-roots among scientists
- ➔ awareness of concrete roadmap WBE to public
- ➔ bring together experts around common interest in WBE (they didn't even know they shared)
- ➔ repurpose a chip foundry to shrink neural interfaces on fab

- ★ 10 years ago: WBE in academia, unmentionable (now accepted goal)
- ★ 6 years ago: Connectomics starts (now proof-of-principle + ramping up)
- ★ 3 years ago: Activity recording Gap! (now ProBAM & BRAIN)
- ★ proto.neural prosthesis
- ★ proto.high-res interface

2014 milestones:
- ➔ WBE Coffee Table Book
- ➔ Roadmap Iteration & Visualization + add people
- ➔ High-res Interface PLATFORM (NeuraLink)
- ➔ No single point of failure - Robust financial support

YOU CAN HELP!