The Brain Machine Interface:

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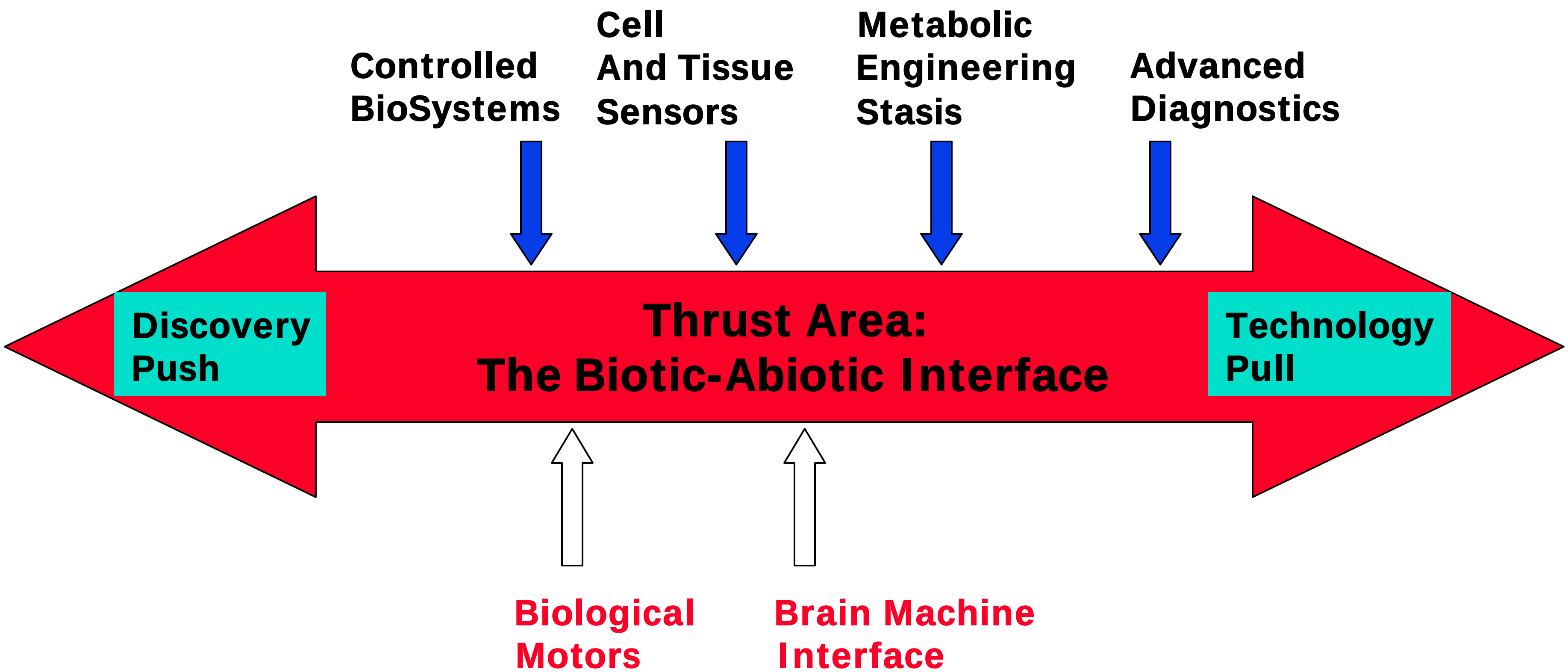
DEC 2001

DSO

Explore Thrust Areas in Biology to Capture New Paradigm Shifts



CBS Successes
Future Opportunities

Defense Sciences Office

Current CBS Program Areas

Emerging Program Areas

Biomimetics

Biohybrids

Vivi Systems

Fault tolerant mobility

Compatible biointerfaces & Information coding

Animal control

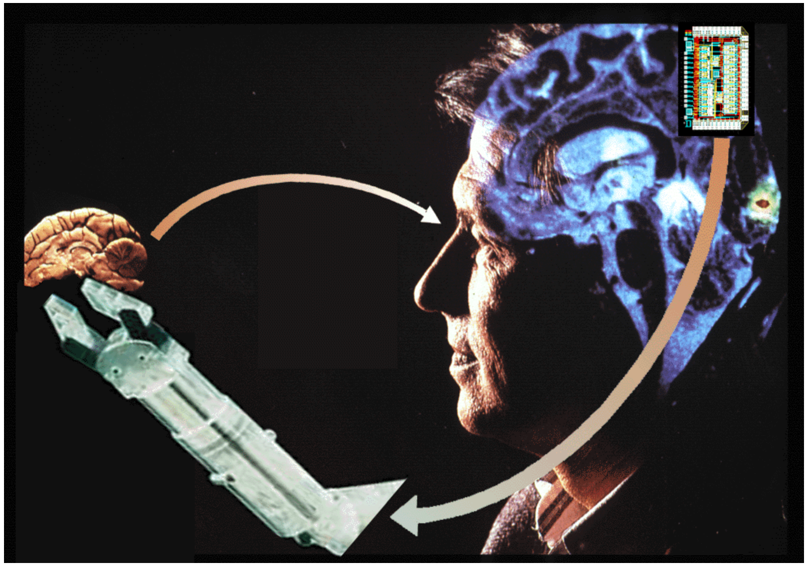
Biorobotics

Brain Machine Interfaces: "Neuromics"

Animal agents

The Dream: Brain C^3

- To use brain activity to do work; to command, control, actuate and communicate with the world directly through brain integration with peripheral Devices and Systems



DARPA

What if We Could Do This?

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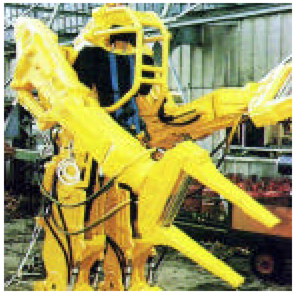


- Brain signals could take I/O from DoD devices and systems (e.g. joystick controls to C^3 of a battle space), Two conceptual modes:

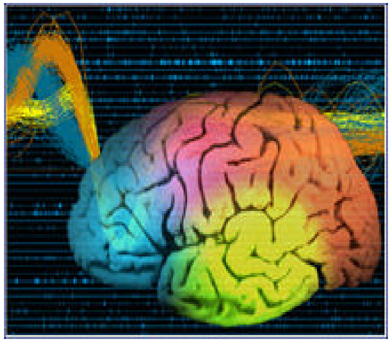
  - Use brain activity to control an existing machine (ie. control the joystick)

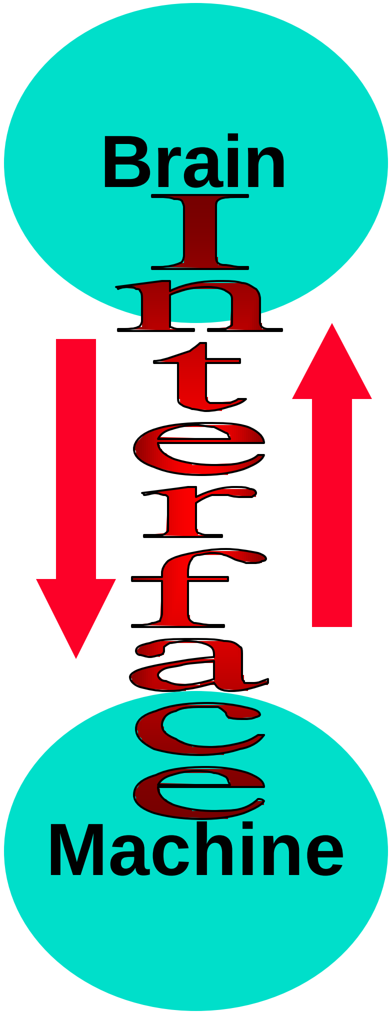
  - Use brain activity to control a system (ie. control the airplane)

- Neural ms transmission speed enables signals to effect devices/systems at 21,000 km

- <u>REALLY HARD PROBLEM</u> that will require:
- biology (neuroscience, biomechanics)
- Mathematics
- Control and information theory
- material science and engineering

The Big Challenges

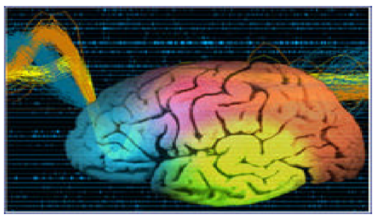




- Getting the right brain activity codes out for the desired action
- Getting the appropriate feedback in (sensory, force, visual, vestibular, acoustic, olfactory)
- Deriving algorithms that represent interaction of codes out and feedback in
- Accessing the codes non-invasively
- Optimizing the signal to noise over the spatiotemporal scale
- Determining interface biocompatibility
- Integrating new processes, form, function and materials (actuators, sensors) in devices which can be optimally controlled by the brain
- Exploiting dynamic plasticity of brain and machine to optimally perform work and control actuation

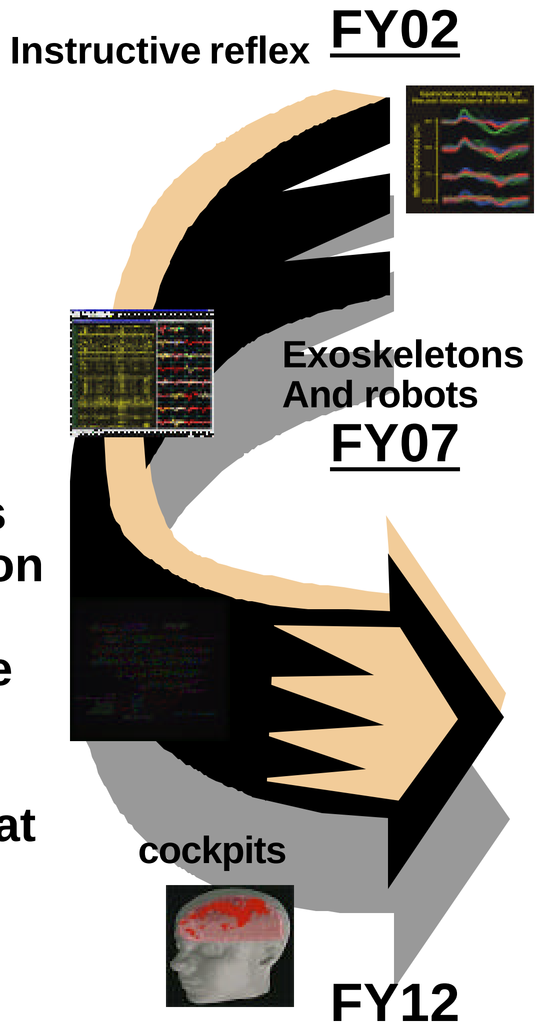
Addressing the Challenges: Getting There from Here

•The Brain



The Challenges:

- Getting the right codes out for the desired action
- Getting the appropriate feedback in
- Deriving algorithms that represent closed loop dynamic systems

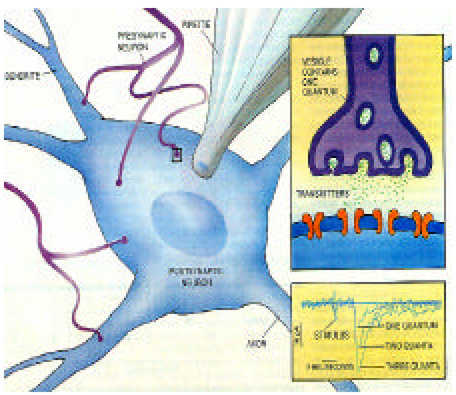


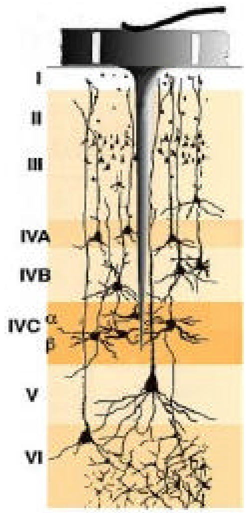
- Explore codes for non-linear transforms of brain activity for controlling a peripheral device
- Determine optimal input and output functions for coding activity in the brain
- Develop and test algorithms for optimal control of a peripheral device
- Demonstrate robust control of a peripheral device

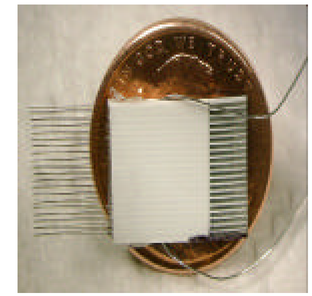
- Exploit other brain regions related to sensory activity (visual, vestibular, auditory, olfactory)
- Develop and utilize code for more complex work in more complex devices
- Determine brain plasticity in controlling new devices and machines for optimal control

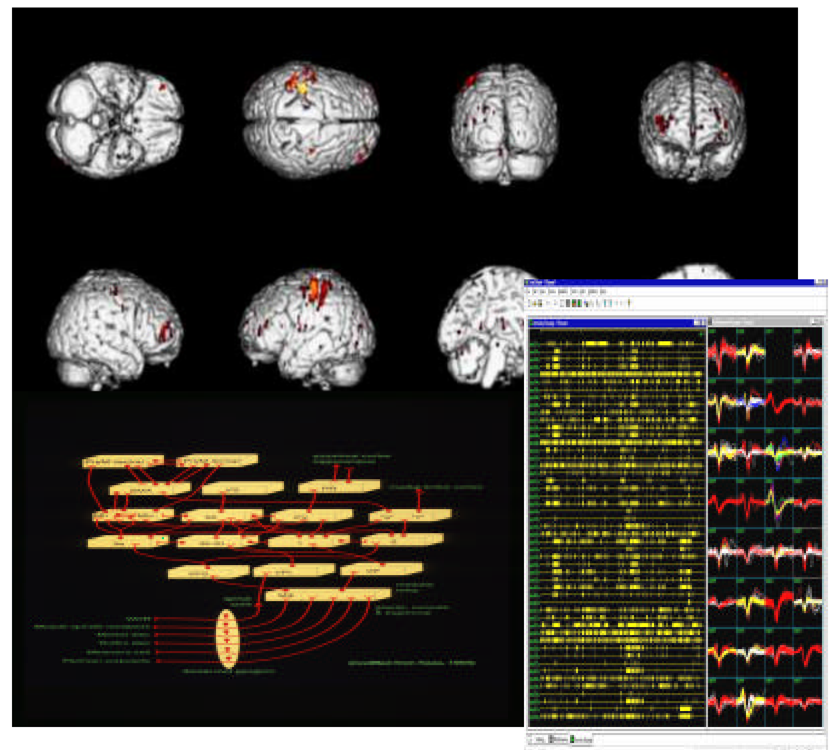
More on the Brain Challenge
Extracting of Neural Codes

- Significant data extraction and coding challenge – the brain is a massively parallel and distributed system with hiererarchal nested non-linear processes









- Will require extraction of temporal pulse train of action potentials or correlative non-invasive activity over ensemble representations (500 micron square areas) in different brain regions

A Hard Problem: Accessing the Code, Invasive or non-invasive?

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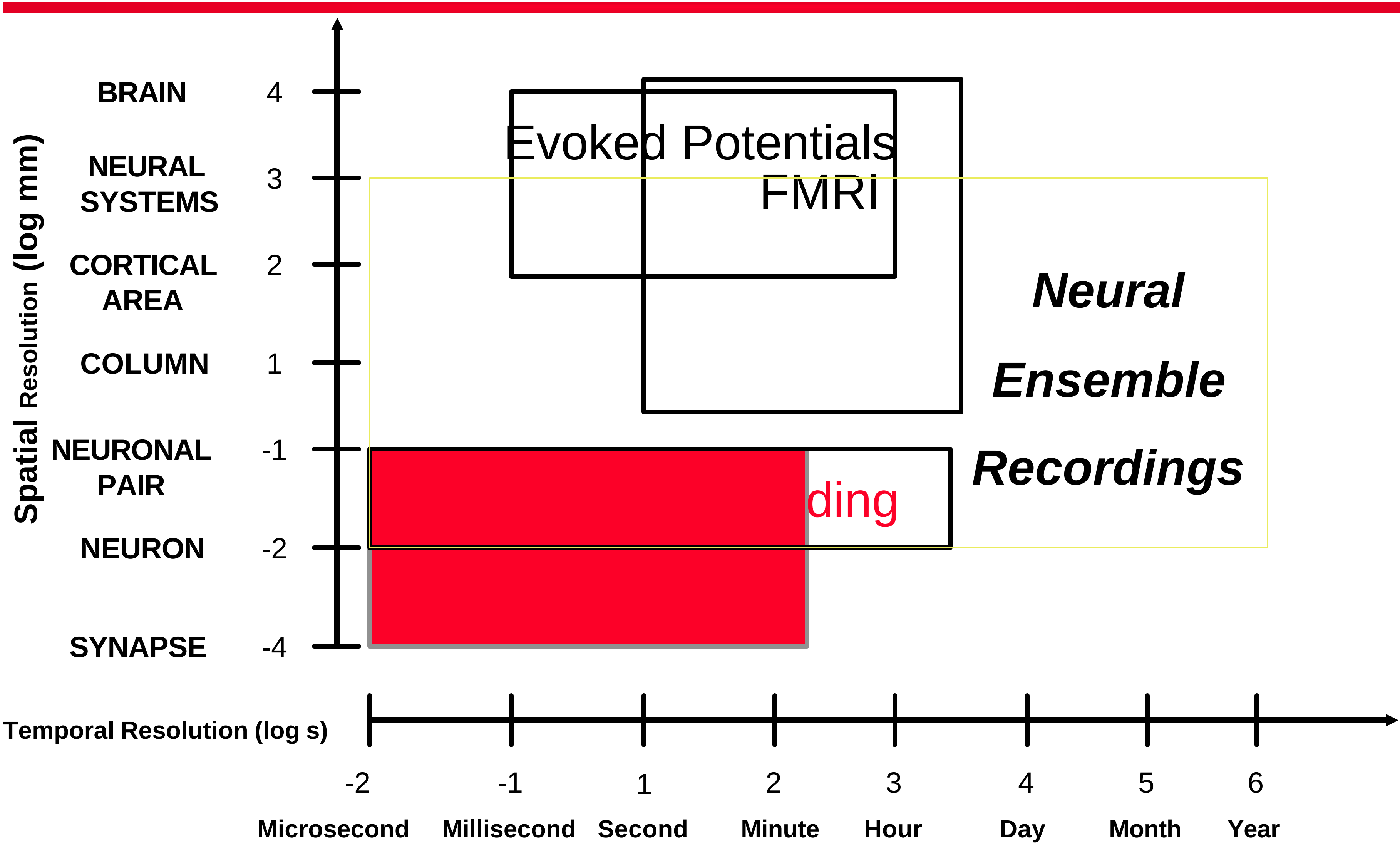
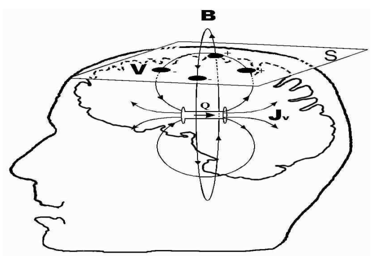
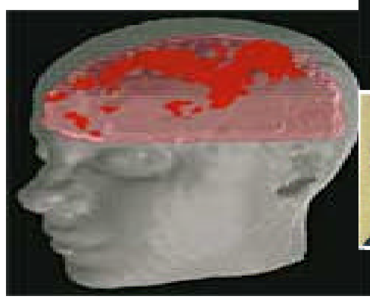
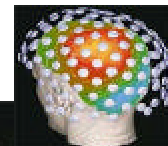
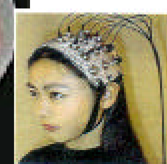
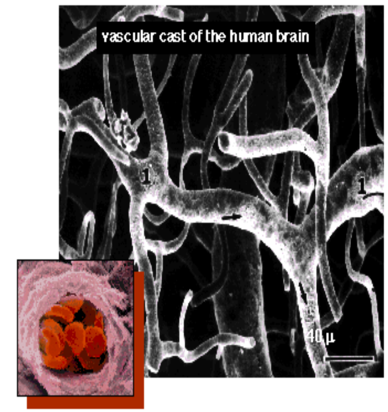


More on the Interface Challenge

- One premise: Non-invasive access to brain I/O neural codes will be required for human augmentation application





- No non-invasive technique currently exists that approaches spatial resolution needed to extract neuron activity code

- Current non-invasive techniques may be insufficient to provide sensory motor codes for brain C^3

- Non-coherent energy techniques (evoke potential EEG, magnetoencephelography MEG, optical tomography) all require complex solution to inverse problem (n^3 problem)

Non-invasive Data Acquisition Methods

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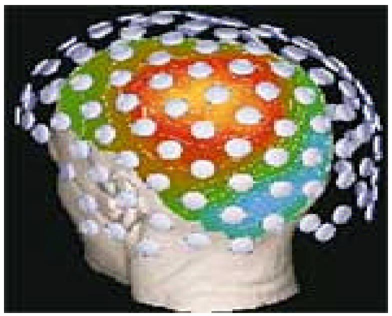
Modality	Spatial Resolution (mm)	Temporal Resolution	Energy	Information
MRI	.5 x .5 x 1	min.	RF	p^+ density in H_20
fMRI	2 x 2 x 3	min.	RF	Fe in Hb
SPECT	5 x 5 x 10	100 sec	Tc 99 → g	Metabolic
PET	5 x 5 x 10	100 sec	$e^+ + e^-$ → 2 (.511 MeV) g	Metabolic
CT	.1 x .1 x 1	2 sec	X ray	Density
EEG	8 - 10	ms	Electric current	Brain activity
MEG	2 - 4	ms	Magnetic dipole	Brain activity
IR	~ 1 x 1 x 5	200 fps	~ 750 nm g (D= .009 °C)	Blood flow (brain fxn)

Addressing the Challenges: Getting There from Here

•The Interfaces

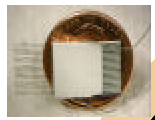


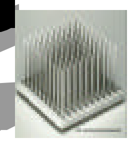
The Challenges:

- Accessing the codes non-invasively
- Optimizing the signal to noise over the spatiotemporal scale
- Biocompatibility of invasive interfaces

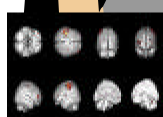
Multiunit recordings

FY02

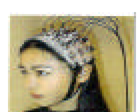




FY07



Non-invasive interface



FY12

- Exploit advances in current multiunit recordings and correlate with MEG/EEG/and optical recordings
- Determine sources of noise and optimize signals over useful spatiotemporal regions
- Develop non-invasive methods of acquiring brain activity codes sufficient to control a peripheral device
- Examine new mathematical treatments of inverse problem with non-coherent energy and brain activity
- Develop new hardware for acquiring non-invasive signals from the brain
- Demonstrate long-term compatibility of non-invasive techniques

Some Questions for the BioMagic program?

- **Could we target magnetic particles to specific brain regions that would interact with the magnetic field fluctuations introduced by neuronal activity?**

- **Could this create a local signal (e.g 500 micron, 500-1000 neurons) that would be read by a non-invasive technique?**

- **Could we use magnetic stimulation (inputs) to control ensemble neuronal system outputs in robust predictable ways? (higher resolution than TMS)**

- **Can we increase the spatial resolution of MEG by 1-2 orders magnitude to enable correlative neuronal ensemble activity and non-invasive brain activity?**