Jet Propulsion Laboratory
California Institute of Technology

MOBILE IN VIVO BRAIN SCAN SYSTEMS

PREPARED FOR ADVANCED BRAIN TECHNOLOGIES CONFERENCE JUNE 2005

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50 YEAR HISTORY

OF

BRAIN RESEARCH

AT

CALTECH

50 YEARS AGO

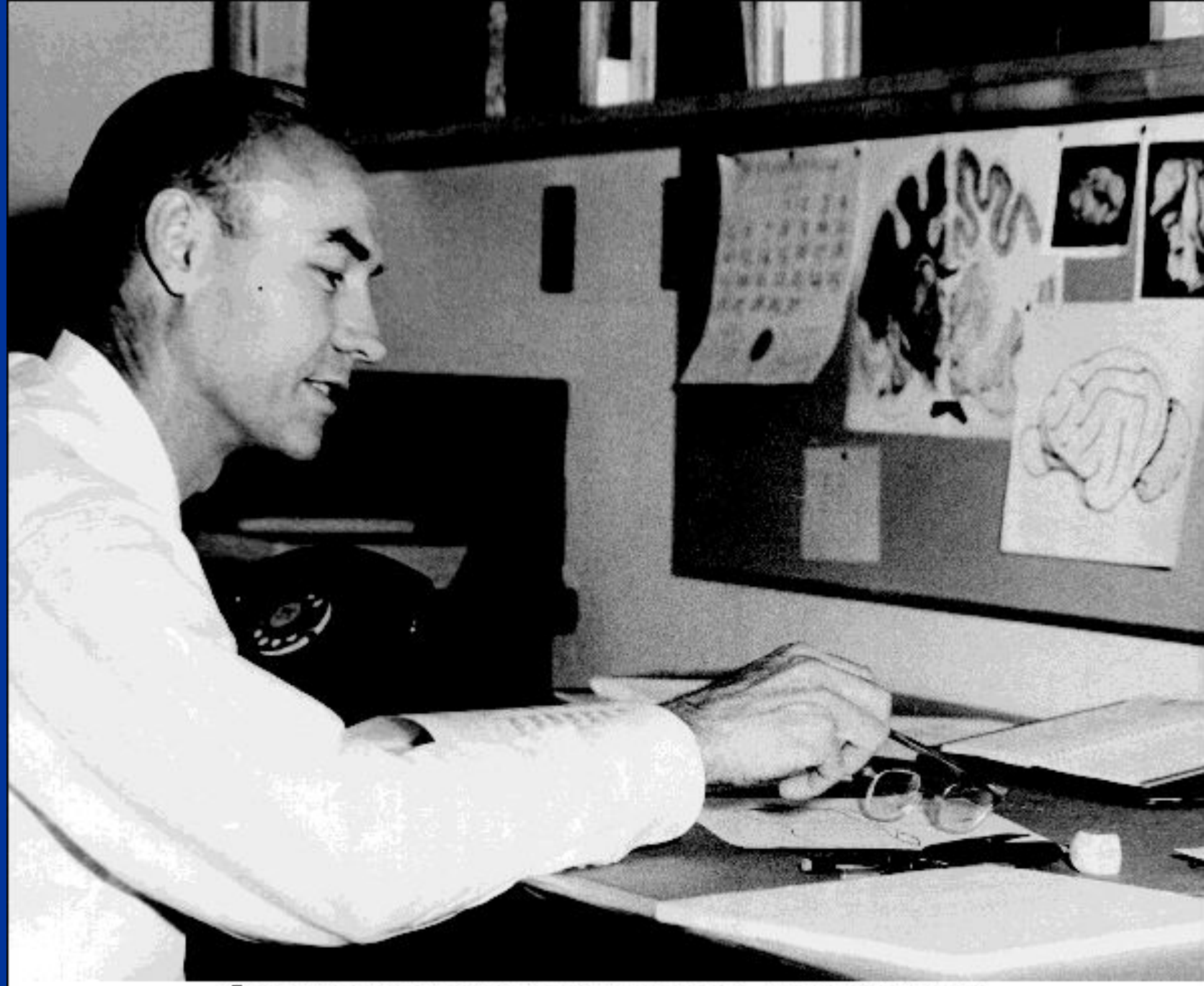
BIOLOGY IN 1954 AT CALTECH

" Approximately a hundred academic staff members were responsible for the research, teaching, and other activities of the Division of Biology in its twenty-seventh year of existence.

Research problems ranged all the way from the chemistry of Los Angeles smog to investigations of the integrative mechanisms of the cerebrum….

An important addition to the faculty of the Division was made in the appointment of Dr. Roger Sperry as Professor of Psychobiology…. "

From the Division of Biology 1954 Annual Report



October 1954

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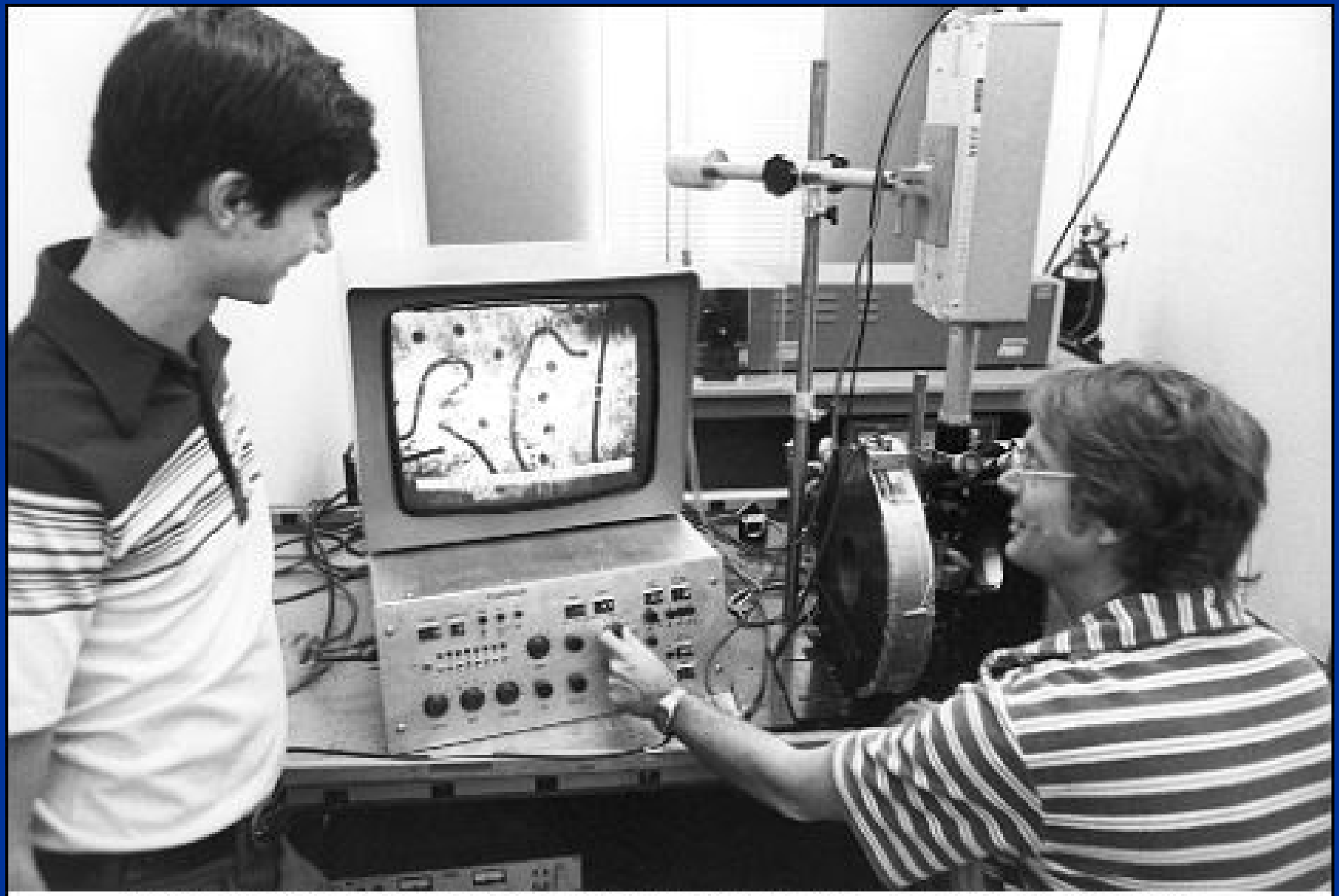

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MOBILE IN VIVO BRAIN SCAN SYSTEMS PHASE I, II, & III

A RESEARCH PROJECT

AT THE

Jet Propulsion Laboratory

OF THE

California Institute of Technology

SPONSORED BY

Advanced Brain Technologies

and

Some Government Agency

TASK PLANS OUTLINES

PHASE I (FUNDED BY ABT)

- LITERATURE SEARCH
- FORM TECHNICAL WORKING GROUP
- INITIAL SYSTEMS ENGINEERING (EEG / IR Probes and RDBMS)
- WRITE REPORT

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PHASE II – EEG ($ 425 K PROPOSED – FY 2006 – NIH)

- CONTINUE LITERATURE SEARCH
- CONTINUE SYSTEMS ENGINEERING
- INVESTIGATE MOBILE IN VIVO EEG
- PROOF OF CONCEPT DEMO (Lab Bench)
- ENGINEERING DESIGN (If POC is success)
- WRITE A REPORT

PHASE III- IR ($ 450 K PROPOSED FY 2006-7 NIH)

- CONTINUE LITERATURE SEARCH
- CONTINUE SYSTEMS ENGINEERING
- INVESTIGATE MOBILE IN VIVO IR
- PROOF OF CONCEPT DEMO (Lab Bench)
- ENGINEERING DESIGN (If POC is success)
- WRITE A REPORT

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THE GOOD – THE BAD – THE UGLY

(OR.. WHAT CAN GO VERY WRONG OR VERY RIGHT)

FUNDING – FUNDING – FUNDING

TECHNOLOGY READINESS

PROJECT PRIORITIES

MINIMUM/MAXIMUM STRATEGIES

↓

FUNDING – FUNDING – FUNDING

MAJOR RESEARCH MILESTONES

- CHARACTERIZE AND MODEL THE BRAIN
- CHARACTERIZE AND MATHEMATICALLY MODEL THE BRAIN'S EVOKED POTENTIALS
  (Magnetic – Electrical – Spectral)
- CHARACTERIZE AND MATHEMATICALLY MODEL CONDUCTION AND DIFFUSION CHARACTERISTICS
- CHARACTERIZE AND MATHEMATICALLY MODEL EXISTING AND NEW SENSOR SYSTEMS TO DETECT EVOKED POTENTIALS
- PUBLISH AND PATENT TECHNOLOGIES

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MAJOR RESEARCH MILESTONES

- CHARACTERIZE AND MODEL THE BRAIN
- CHARACTERIZE AND MATHEMATICALLY MODEL THE CONDUCTION AND DIFFUSION
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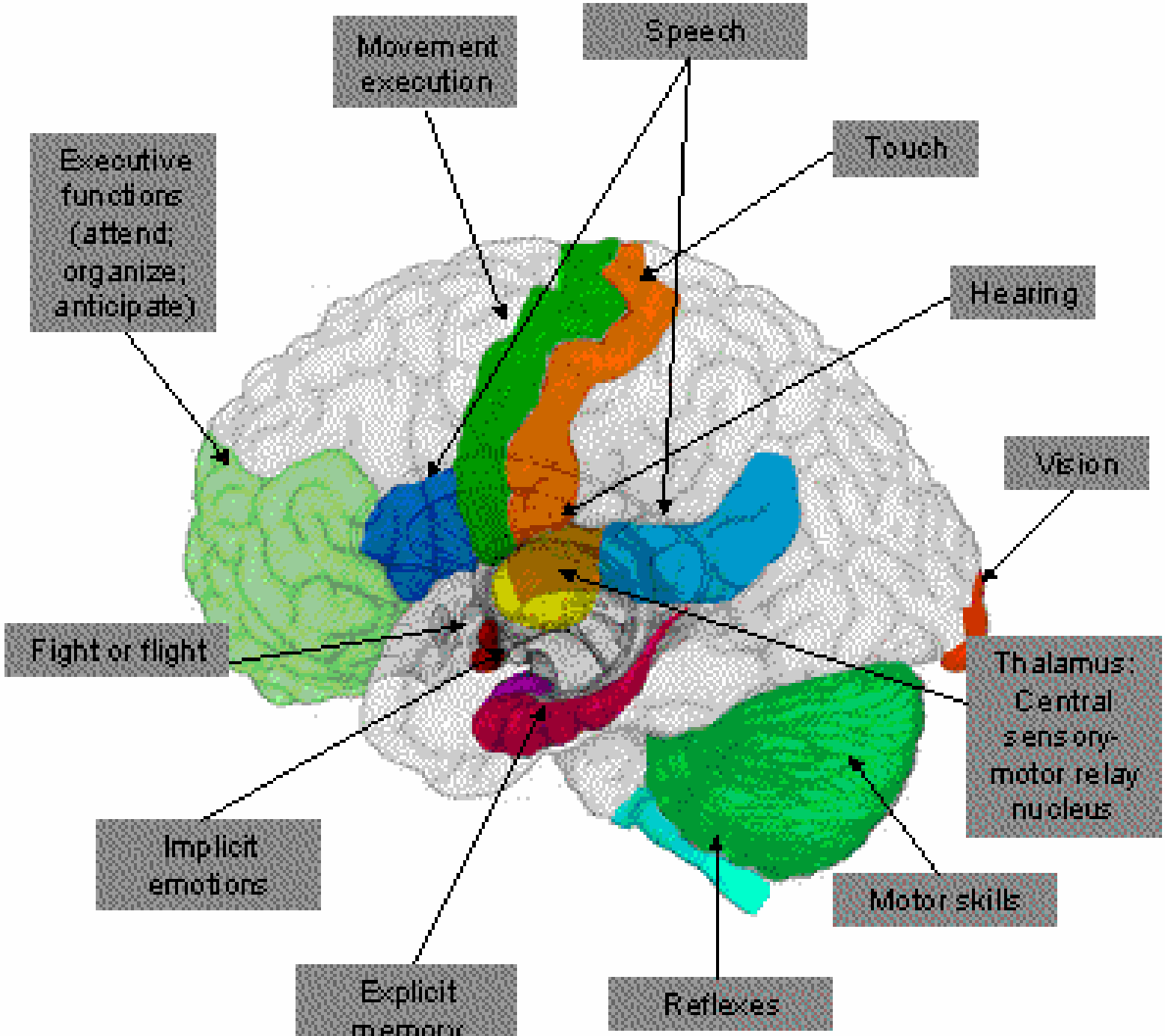
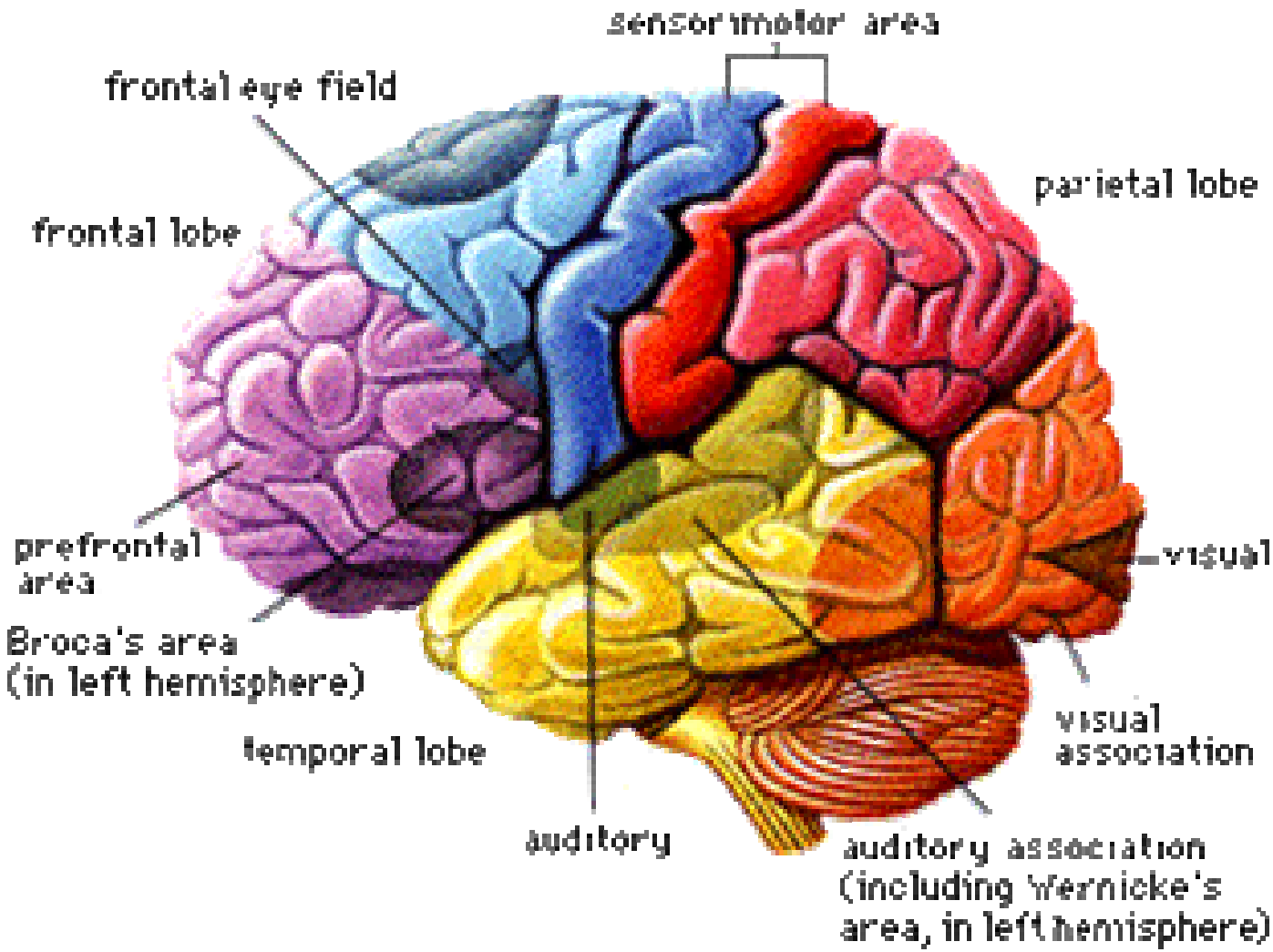
- CHARACTERIZE AND MATHEMATICALLY MODEL NEW SENSOR SYSTEMS TO DETECT EVOKED EEG AND IR POTENTIALS
- PUBLISH AND PATENT TECHNOLOGIES


Movement execution
Speech
Executive functions (attend; organize; anticipate)
Touch
Hearing
Vision
Fight or flight
Thalamus: Central sensory-motor relay nucleus
Implicit emotions
Motor skills
Explicit memory
Reflexes


sensorimotor area
frontal eye field
parietal lobe
frontal lobe
prefrontal area
visual
Broca's area (in left hemisphere)
visual association
temporal lobe
auditory
auditory association (including Wernicke's area, in left hemisphere)

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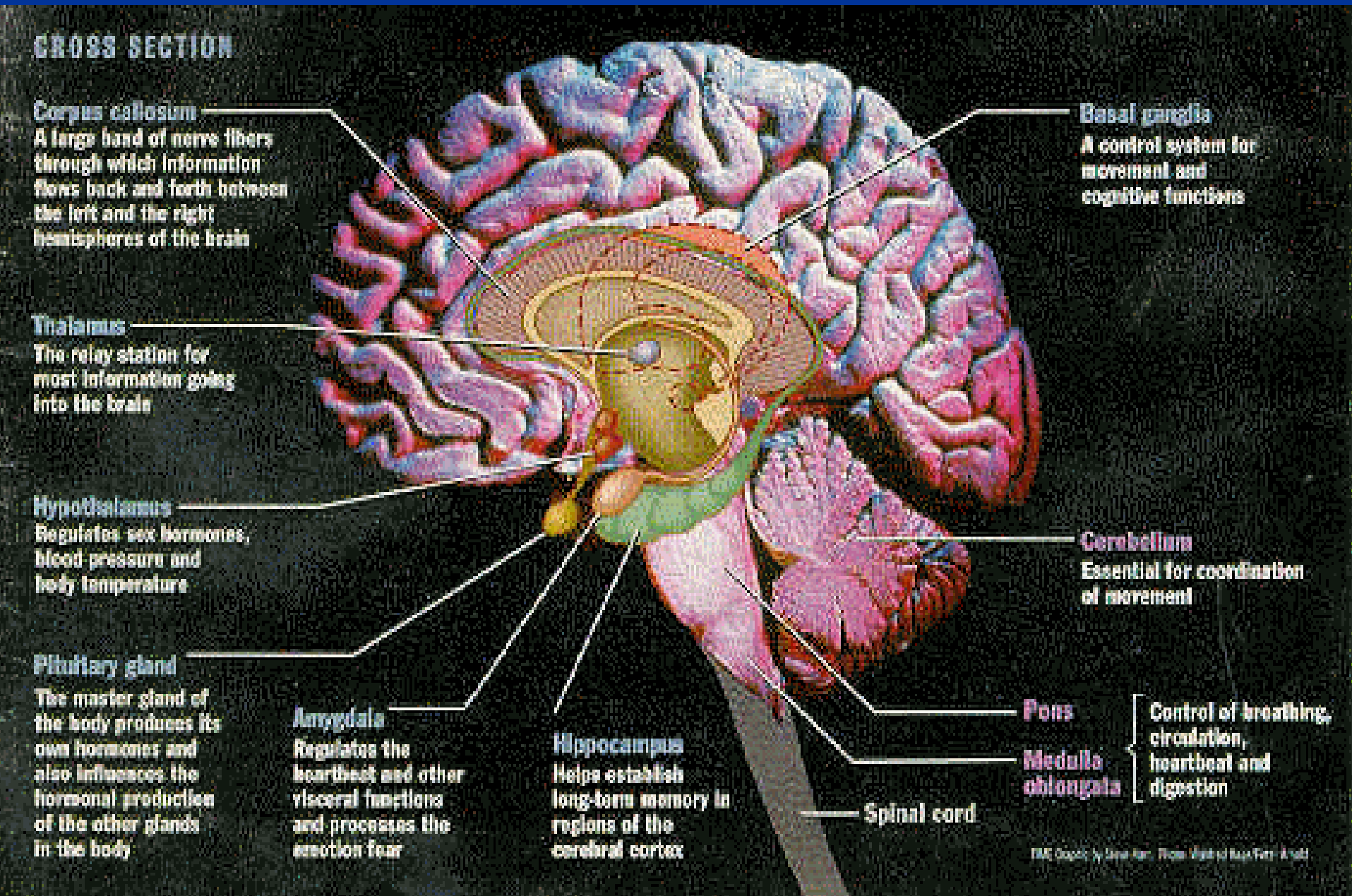
CROSS SECTION
Corpus callosum
A large band of nerve fibers through which information flows back and forth between the left and the right hemispheres of the brain
Thalamus
The relay station for most information going into the brain
Hypothalamus
Regulates sex hormones, blood pressure and body temperature
Pituitary gland
The master gland of the body produces its own hormones and also influences the hormonal production of the other glands in the body
Amygdala
Regulates the heartbeat and other visceral functions and processes the emotion fear
Hippocampus
Helps establish long-term memory in regions of the cerebral cortex
Basal ganglia
A control system for movement and cognitive functions
Cerebellum
Essential for coordination of movement
Pons
Medulla oblongata
Control of breathing, circulation, heartbeat and digestion
Spinal cord

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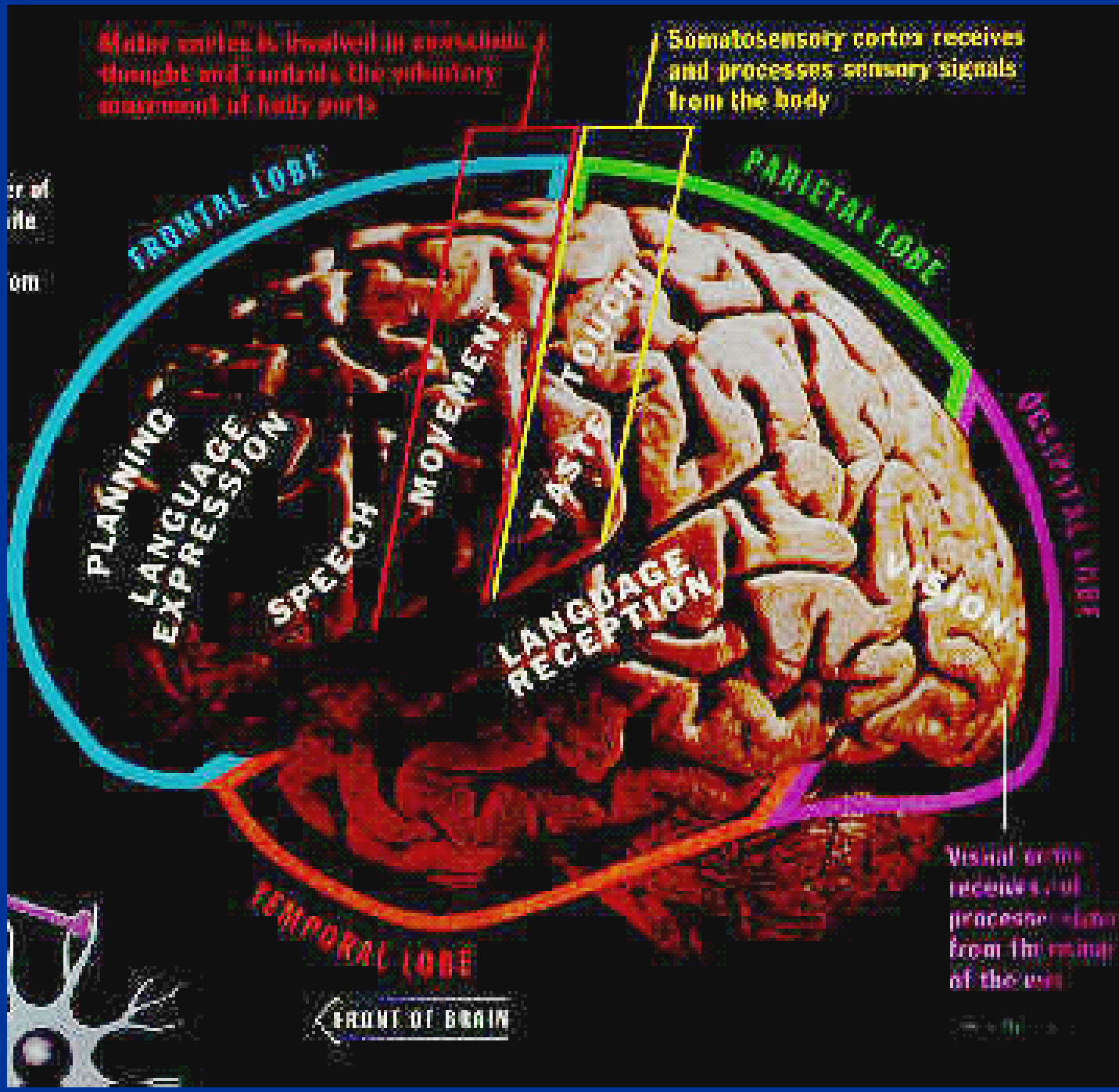
Somatosensory cortex receives and processes sensory signals from the body
FRONTAL LOBE
PARIETAL LOBE
PLANNING
LANGUAGE EXPRESSION
SPEECH
MOVEMENT
TOUCH
LANGUAGE RECEPTION
TEMPORAL LOBE
FRONT OF BRAIN

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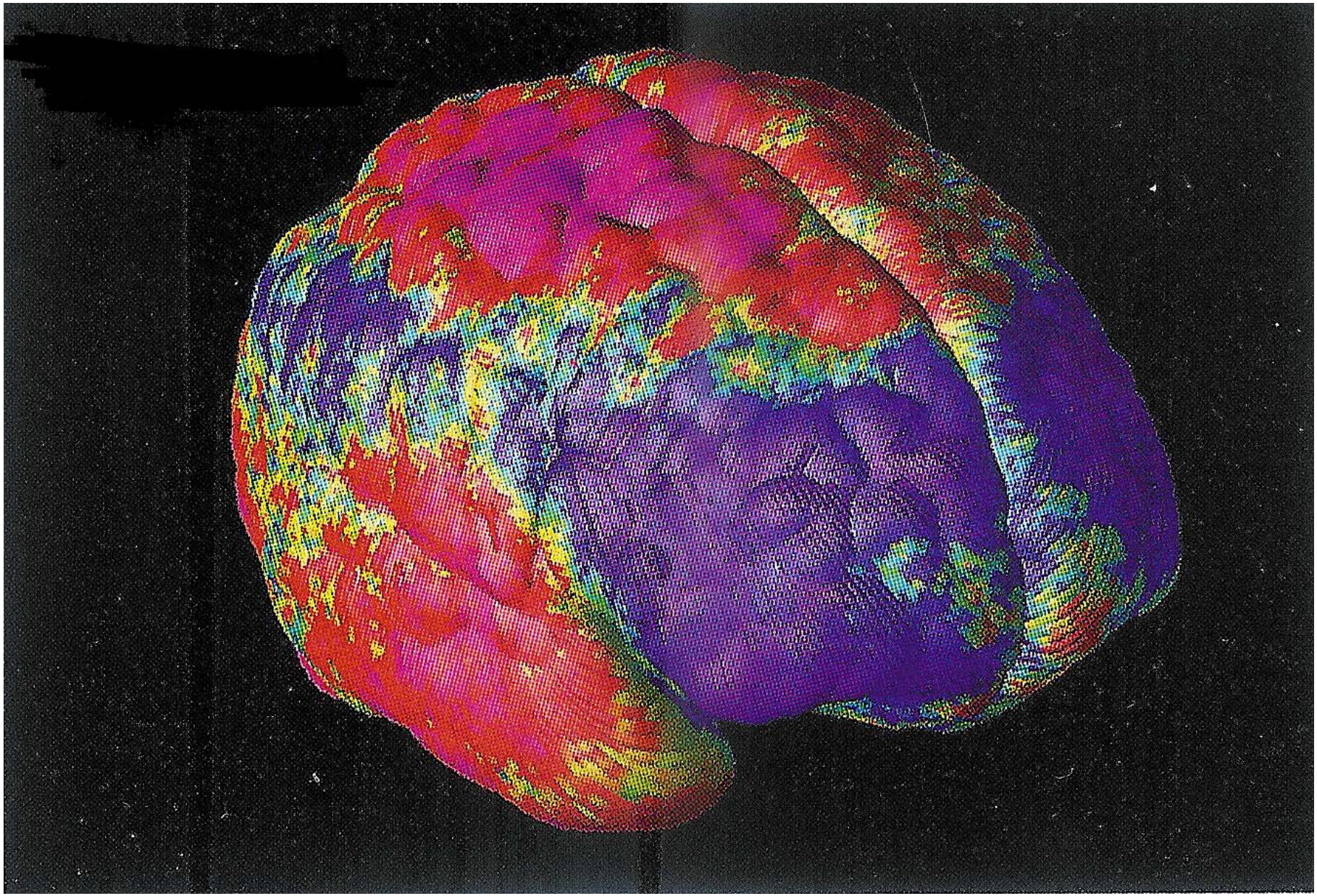

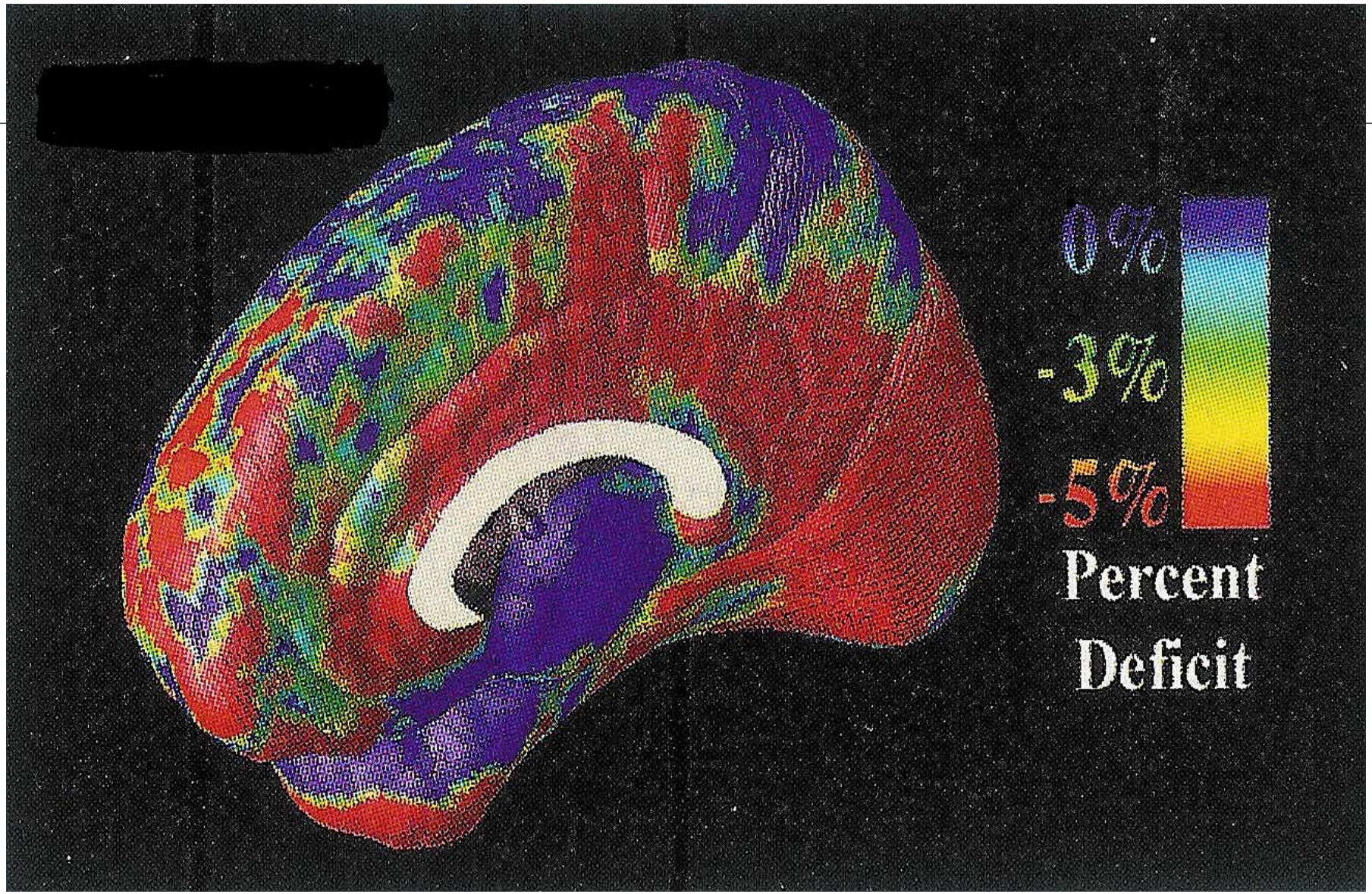
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-5%
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MAJOR MILESTONES

- CHARACTERIZE AND MODEL THE BRAIN
- CHARACTERIZE AND MATHEMATICALLY MODEL THE BRAIN'S EVOKED POTENTIALS
- CHARACTERIZE AND MATHEMATICALLY MODEL THE CONDUCTION AND DIFFUSION
- CHARACTERIZE AND MATHEMATICALLY MODEL NEW SENSOR SYSTEMS TO DETECT EVOKED POTENTIALS
- PUBLISH AND PATENT EEG AND IR TECHNOLOGIES

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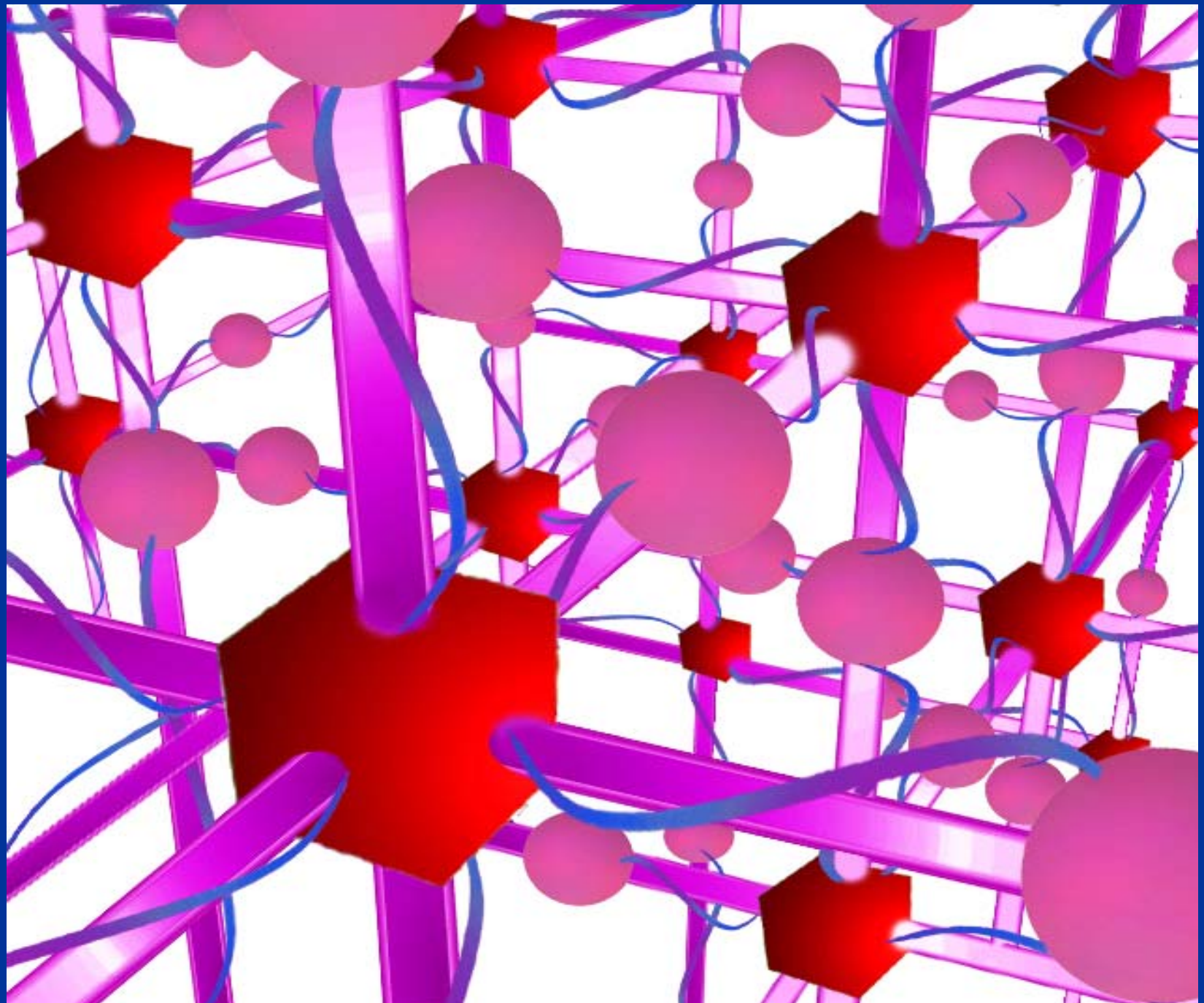

- **BRIEF COMMUNICATION**
  Robustness of Multiplicative Processes in Auditory Spatial Tuning

- **José Luis Peña and Masakazu Konishi**
- Division of Biology 216-76, California Institute of Technology, Pasadena, California 91125

- Auditory space-specific neurons in the owl's inferior colliculus selectively respond to the direction of sound propagation, which is defined by combinations of interaural time (ITD) and level (ILD) differences. Mathematical analyses show that the amplitude of postsynaptic potentials in these neurons is a product of two components that vary with either ITD or ILD. Temporal correlation in the fine structure of signals between the ears is essential for detection of ITD. By varying the degree of binaural correlation, we could accurately change the amplitude of the ITD component of postsynaptic potentials in the space-specific neurons. Multiplication worked for the entire range of postsynaptic potentials created by manipulation of ITD.

- ***Key words:*** **auditory; binaural; sound localization; multiplication; barn owl; interaural correlation**
- Received July 19, 2004; revised September 1, 2004; accepted September 3, 2004.

SAMPLE RESEARCH SUMMARIES

- Neural perception - mechanisms for visual-motor integration, spatial perception and motion…
- Efficacy and adaptation in parietal local field potentials used in a brain machine interface for cursor control…
- Modeling extracellular electrical stimulation of un-myelinated axons by symmetric bipolar current pulses…
- Robustness of multiplicative processes in auditory spatial tuning..
- Dendritic spine motility: Analysis and Experiments…
- A novel approach for the identification of locally synthesized proteins in neuronal dendrites…

MAJOR MILESTONES

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- PUBLISH AND PATENT TECHNOLOGIES

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The measurement of diffusion and perfusion in biological systems using magnetic resonance imaging

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Received 12 November 1999

Abstract. The aim of this review is to describe two recent developments in the use of magnetic resonance imaging (MRI) in the study of biological systems: diffusion and perfusion MRI. Diffusion MRI measures the molecular mobility of water in tissue, while perfusion MRI measures the rate at which blood is delivered to tissue. Therefore, both these techniques measure quantities which have direct physiological relevance. It is shown that diffusion in biological systems is a complex phenomenon, influenced directly by tissue microstructure, and that its measurement can provide a large amount of information about the organization of this structure in normal and diseased tissue. Perfusion reflects the delivery of essential nutrients to tissue, and so is directly related to its status. The concepts behind the techniques are explained, and the theoretical models that are used to convert MRI data to quantitative physical parameters are outlined. Examples of current applications of diffusion and perfusion MRI are given. In particular, the use of the techniques to study the pathophysiology of cerebral ischaemia/stroke is described. It is hoped that the biophysical insights provided by this approach will help to define the mechanisms of cell damage and allow evaluation of therapies aimed at reducing this damage.

Identification of the internal sources with the aid of boundary element method

Stefan F. Filipowicz

Abstract — **Electroencephalography (EEG) is a non-invasive method of the brain activity. The principal goal of EEG is to relate measured scalp potentials to current sources generated in brain tissue. In some applications e.g. focal epilepsy, localization of the sources is desired. To solve this problem the Boundary Element Method is used to create the numerical model of the object under consideration. Using synthetic data the inverse (linear in case of EEG) problem will be solved for 2D and 3D space.**

I. Introduction

The Electroencephalography (EEG) can be used to measure scalp surface potentials. Inverse procedures in EEG are used to estimate the spatial distribution of the underlying, possibly focal, neural sources.

The equivalent current dipoles, and clusters of such dipoles, are a widely used source model for representing focal neural activity. For this model the inverse procedure must estimate the locations and amplitudes of the equivalent dipoles.

EEG problems are similar to the Electric Impedance Tomography (EIT) problems. However there is one exception. In EIT the object under investigation is excited by an external current or voltage source, when in EEG we assume that the exciting source is internal one. Consequence of this is less data which could be collected from the surface. To compare in EIT for 16 electrodes and 8 projection angles we have (16-3)*8=104 linearly independent measurements [8], but in EEG for the same number electrodes we have only 16 measurements. Assuming homogeneity of the region under consideration, the governing equation is a Poisson's equation with the Neumann boundary conditions:

$$\nabla^2 u(\vec{r}) = -b(\vec{r}) \tag{1}$$

$$q(\vec{r}) = \frac{\delta u(\vec{r})}{\delta n} = 0 \tag{2}$$

$$\begin{aligned} &\frac{1}{2}u(\vec{r}) + \int_\Gamma \frac{\partial}{\partial n} G(\vec{r},\vec{r}\,')u(\vec{r}\,')d\Gamma = \\ &= \int_\Gamma \frac{\partial u(\vec{r}\,')}{\partial n} G(\vec{r},\vec{r}\,')d\Gamma + \int_\Omega bG(\vec{r}_0,\vec{r}\,')d\Omega \end{aligned} \tag{3}$$

In BEM the dipoles are modeled by concentrated sources. They are a special case for which the function b at the internal point $\vec{r}_0$ becomes $q_0 = Q_0\delta(\vec{r}_0)$, where Q_0 is the magnitude of the source and $\delta(\vec{r}_0)$ is a Dirac delta function whose integral is equal to 1 over any volume containing the singularity point r_0 and equal to zero elsewhere. Assuming that inside of the region we have n dipoles one can write:

$$\begin{aligned} &\frac{1}{2}u(\vec{r}) + \int_\Gamma \frac{\partial}{\partial n} G(\vec{r},\vec{r}\,')u(\vec{r}\,')d\Gamma = \\ &= \int_\Gamma \frac{\partial u(\vec{r}\,')}{\partial n} G(\vec{r},\vec{r}\,')d\Gamma + \\ &+ \sum_{i=1}^{n}\left(q_{0+,i}G(\vec{r}_{0+,i},\vec{r}\,') - q_{0-,i}G(\vec{r}_{0-,i},\vec{r}\,')\right) \end{aligned} \tag{4}$$

where $\vec{r}_{0+}$ and $\vec{r}_{0-}$ are the positions of the charges $+q_0$ and $-q_0$ respectively.

In 2D space Eq.(5a) and for 3D space Eq.(5b), the fundamental solutions of the Eq.(1) are expressed by the Green's functions [2, 3]:

$$G(\vec{r},\vec{r}\,') = \frac{1}{2\pi}\ln\frac{1}{|\vec{r}-\vec{r}\,'|} \tag{5a}$$

$$G(\vec{r},\vec{r}\,') = \frac{1}{4\pi}\frac{1}{|\vec{r}-\vec{r}\,'|} \tag{5b}$$

$$|\vec{r}-\vec{r}\,'| = \sqrt{(x-x')^2 + (y-y')^2} \tag{6}$$

$$A\frac{\partial(u(\{p\})}{\partial p_i}=\frac{\partial Q(\{p\})}{\partial p_i} \qquad (18)$$

Solution of Eq.(18) will provide the values needed for direction of improvement calculation. In order to solve Eq.(18) we need to differentiate analytically the right hand side in the following way:

$$Q(\{p\})\cong\sum_{i=1}^{n}q\frac{1}{2\pi}\ln\frac{1}{\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}} \qquad (19)$$

$$\frac{\partial Q(\{p\})}{\partial p_1}=\frac{\partial Q(\{p\})}{\partial x_1}=$$

$$=q\frac{1}{2\pi}\frac{\partial}{\partial x_1}\left[\ln\frac{1}{\sqrt{(x_1-x_j)^2+(y_1-y_j)^2}}\right]= \qquad (20)$$

$$=q\frac{1}{2\pi}\frac{-(x_1-x_j)}{(x_1-x_j)^2+(y_1-y_j)^2}$$

Boundary Element method [3] as the forward problem solver, results of calculation for the starting position are presented in Fig.2.

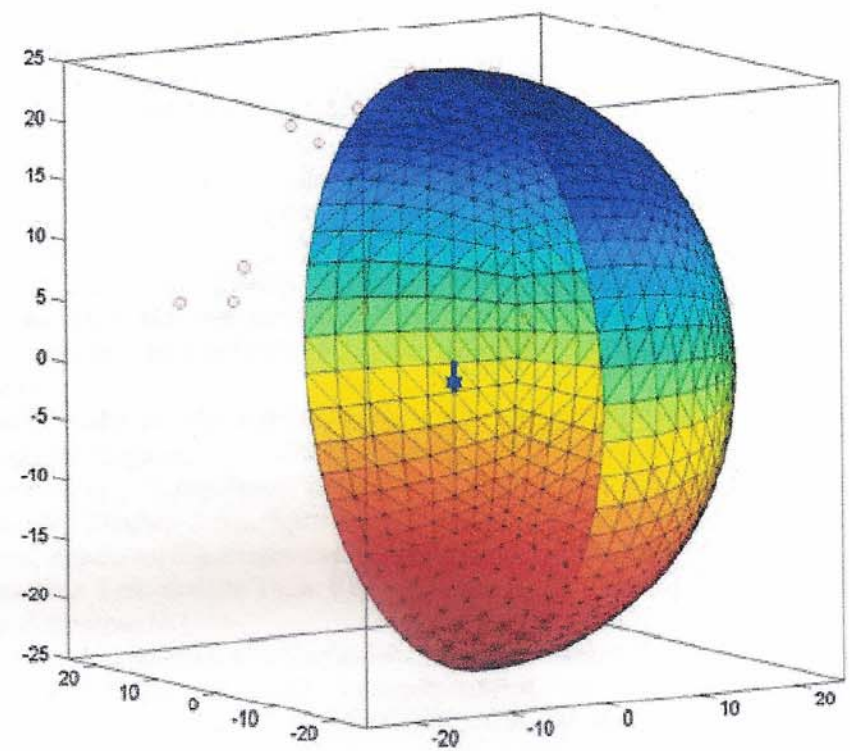

Fig. 2. Potential distribution on the sphere and one dipole starting position inside of the region.

Two kind of numerical simulation were carried out: for 2D region (circle) and for 3D one (sphere).

In case of 2D space the three dipoles localization problem was solved and results are shown in Fig.1. As we can see in Fig.1, for unpolluted data - "measurements" the localization is perfect.

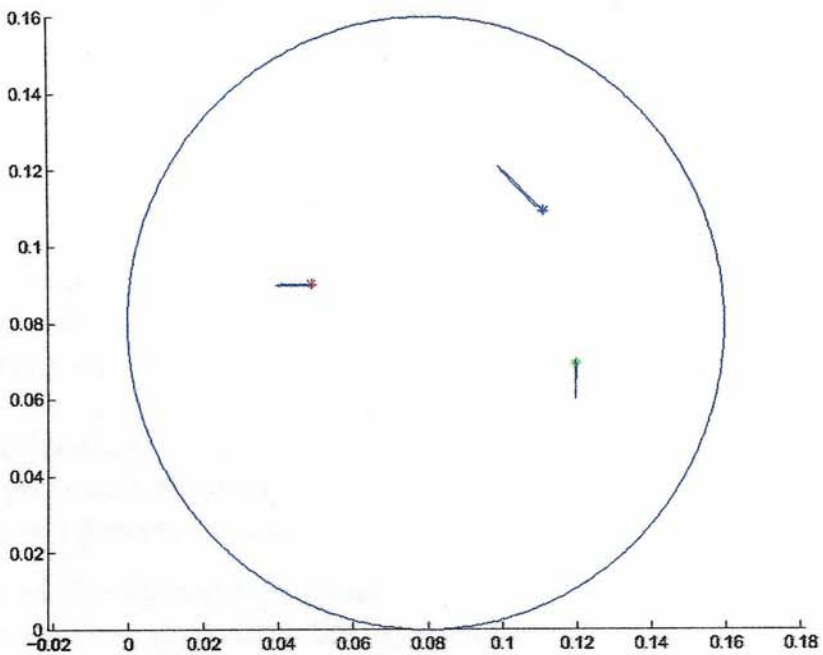

Fig. 1. Three dipoles position reconstruction in case of synthetic pollution free data

The second example for 3D space is localization of one dipole placed inside of the sphere. Using the

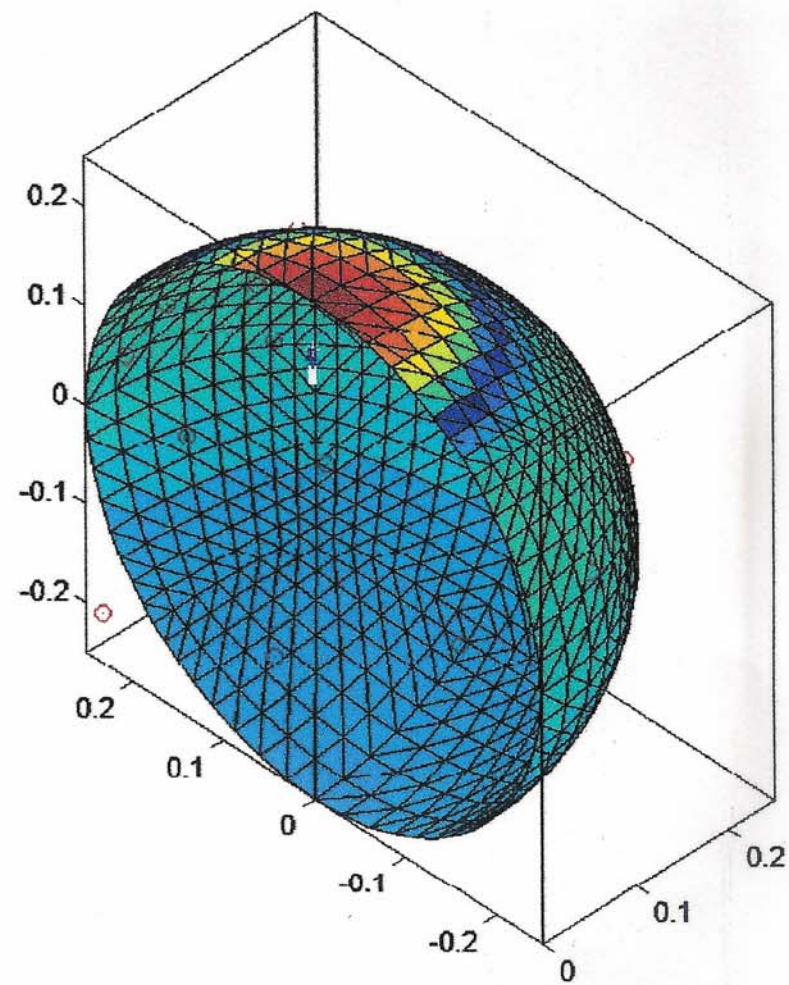

Fig. 3 Expected (black) and achieved (white) position of the dipole inside of the sphere of radius 25cm.

V. FUTURE WORK

The future work will be concentrated on the solution of the inverse problem based on the measured data collected from 2D and 3D phantoms. The bottom hemisphere of the 3D phantom with the semi-rigid coaxial cable as a model of the dipole is shown in Fig.4.

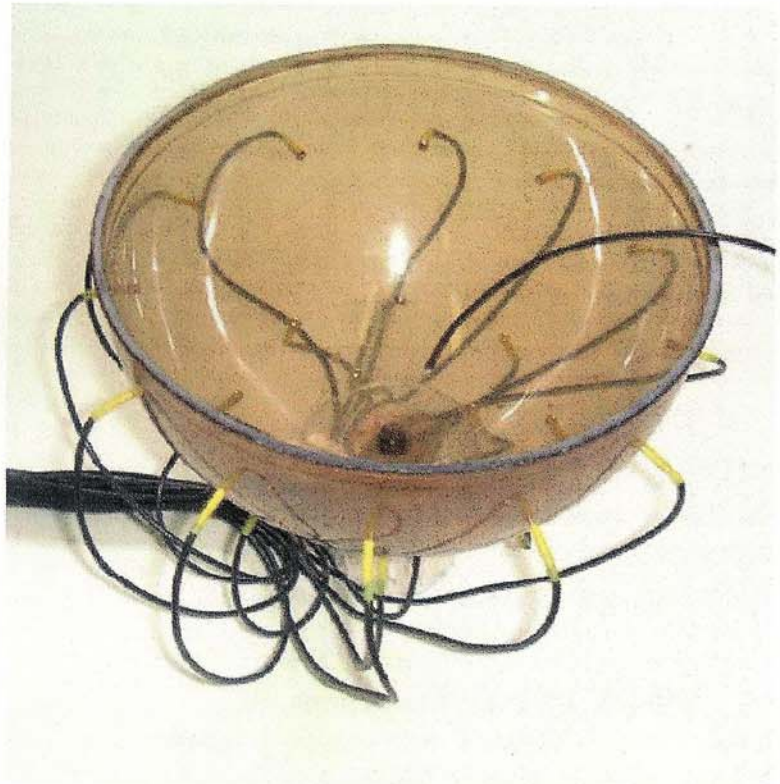

Fig. 4. Example of the 3D phantom with the set of electrodes.

REFERENCES

[1] Adby P. R., Dempster M. A. H.: Introduction to Optimization Methods, Chapman and Hall, London 1974

[2] Beer G., Programming the Boundary Element Method. An Introduction for Engineers, John Wiley & Sons Ltd., Chichester 2001

[3] Bolkowski S., Stabrowski M., Skoczyłaś J., Sroka J., Sikora J., Wincenciak S.; Komputerowe metody analizy pola elektromagnetycznego, WNT, Warszawa 1993

[4] Ermere J.J., Moher J.C., Baillet S., Leahy R.M.: Rapidly re-computable EEG forward models for realistic head shapes, Rapport Grant ROI-MH53213 Los Alamos National Laboratory

[5] Jabłoński P.: Metoda elementów brzegowych w analizie pola elektromagnetycznego, Wydawnictwo Politechniki Częstochowskiej, Częstochowa, 2003

[6] Leahy R. M, Mosher J. C., Spencer M., Huang M. L. J. D.: A study of dipole localiyationaccuracz for EEG using a human skull phantom, Los Alamos Tech. Report N° LA

[7] Numerical Recipes in C++

[8] Ollikainen J., Vauhkonen M., Karjalainen P.A., Ronkanen P.J., Kaipio J.P.: Effect of skull inhomogeneities on EEG localization accuracy, 19th IC – IEEE/EMBS Oct. 30-Nov. 2, Chicago, USA 1997

[9] Sikora J.: Algorytmy numeryczne w tomografii impedancyjnej i wiroprądowej. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2000

[10] Wróbel L.C.: The Boundary Element Method, Vol.1, John Wiley & Sons Ltd., Chichester 2002

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- PUBLISH AND PATENT TECHNOLOGIES

ON THE DESIGN OF INTRACRANIAL MULTI-SITE MICROELECTRODES FOR ELECTRO IMPEDANCE TOMOGRAPHY.

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+ Medizinische Universität zu Lübeck, Neurochirurgische Klinik, Lübeck, Germany
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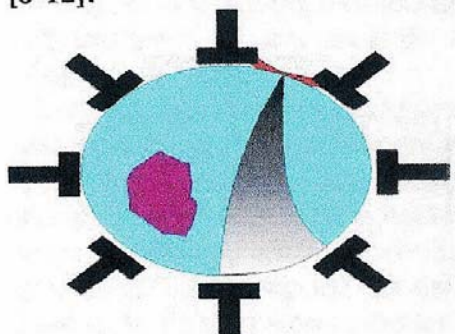
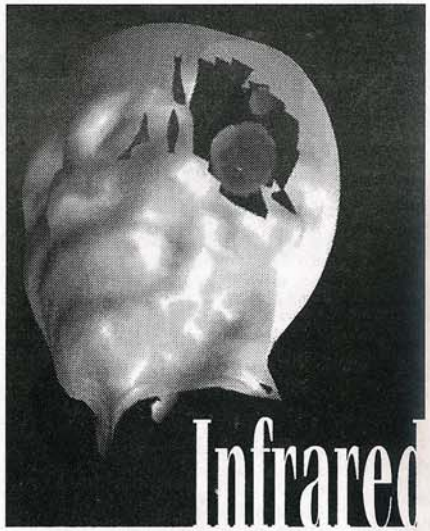
INTRODUCTION

The measurement of physiological data using harmless and painless techniques is one of the major advantages of modern monitoring techniques. One potentially interesting area for the application of these procedures lies in clinical neurosciences, where measurements are used to obtain impressions of functional changes of the human brain. In diagnostics and treatment of patients with severe head injuries, intracerebral bleeding and other space-occupying intracranial lesions, measurement of short-term changes, e.g. intracranial pressure (ICP) and cerebral perfusion pressure, are necessary to prevent secondary brain injury like brain infarction due to cerebral ischemia. The ICP is a result of a constantly changing interplay between the cerebrospinal-fluid-system, the cerebral blood volume and brain tissue. Various attempts

ELECTRICAL IMPEDANCE TOMOGRAPHY

In standard EIT, an array of electrodes is attached on the boundary of an object (Fig.1) and small sinusoidal currents are applied to the volume by two driving electrodes. The resulting voltages on the other electrodes are measured and the internal resistivity distribution map is computed based on this boundary data. Many applications of this technology are developed both for medical and industrial use [8-12].





JPL's Infrared Focal Plane Array Technology Group developed the infrared camera. From left: John Liu, Ricky Chuang, Sarath Gunapala, Don Rafol and Sumith Bandara.

Infrared camera helps surgeons map brain tumors

By Natalie Godwin

Using an infrared video camera developed by scientists at JPL, surgeons are testing thermal imaging and image processing to see if they can create useful maps of brain tumors.

Researchers want to see if the camera, which detects infrared—or heat—emissions, might help neurosurgeons better visualize tumors before they operate and also find tiny clusters of cancerous cells that might remain after surgery.

NASA scientists already use infrared technology to map Earth's surface and search for distant objects in the universe. Firefighters use it to locate people trapped in buildings, and military forces track down their targets hiding in the dark.

Physicians have used infrared technology for mapping the roots of skin cancer, but it's never been used for brain tumors until now.

Doctors at USC's Keck School of Medicine are using the JPL-developed camera and infrared imaging in a trial. They're trying to see if they can sketch tumor margins by detecting temperature changes during surgery, since tumor cells emit more heat than healthy ones. "The camera's precision allows it to map temperature differences of one-hundredth of a degree Celsius at a high resolution," said Dr. Sarath Gunapala, supervisor of the Infrared Focal Planes and Photonics Technology Group in Section 384 and lead engineer for the camera.

Currently, neurosurgeons delve carefully into the brain and remove as much of the tumor as they can see under magnification. However, they may take healthy tissue along with the cancerous cells or leave residual cells that can grow back along the tumor's margins.

"Brain tumor tissue looks the same as healthy tissue on the edges," said Babak Kateb of the Keck School of Medicine, a research fellow and lead scientist of the project. "Tumor cells use different biochemical pathways from normal cells, and when researchers use the infrared camera, they can pick up hotspots or areas of tissue warmer than normal tissue," he added.

After doctors receive infrared images of the brain, imaging-processing software marks the boundaries between tumor regions and surrounding healthy tissue. "We are refining software similar to what our group has been using for analyzing rocks on Mars and other planets," said Dr. Wolfgang Fink, JPL senior researcher.

"An advantage of thermal imaging is that it's non-invasive," said Dr. Peter Gruen, a neurological surgeon at the Keck School of Medicine. "It measures heat energy emerging from patients without exposing them to X-rays or intravenous solutions, and is performed without incisions or contact to the brain tissue," he added.

A clinical study of this proposed mapping process is underway at the Keck School of Medicine.

This is another example of the great benefits of transferring NASA-developed technology for the public good.

For more information on the USC study, log on to *http://www.usc.edu/keck.html.*

For more information on the infrared camera, visit *http://www.jpl.nasa.gov/technology/features/tech930.html.*

Portable QWIP Cameras for Brain Imaging

Sarath Gunapala

Visible light spanning the wavelength range from blue (~ 0.4 μm) to red (~ 0.7 μm) is a tiny slice of the electromagnetic spectrum. While an enormous wealth of scientific information can be and is obtained through imaging and spectroscopy of objects in visible light, the invisible portion of the spectrum can be harvested to yield both more detailed and new information. Objects that are invisible to the human eye may be visible at other wavelengths. For instance, an object at room temperature (~ 300 K) and in complete darkness may be perfectly invisible to the human eye; but its temperature will make it glow in the infrared, shining brightest at an infrared (IR) wavelength of around 8.5 μm. A camera which can see 8.5 μm light and convert an 8.5 μm image to a visible black-and-white image on a standard TV monitor or camcorder viewfinder may make the invisible scene spring to life. Temperature and emissivity variations in the dark scene translate to contrast in the gray scale of the black-and-white image, rendering objects and their motion visible. This is the basis of a IR based night-vision camera. When fitted with filters to make it blind to visible light, such a camera, on viewing a human body in daylight, produces a contrasting black-and-white image which is a thermal map of the skin surface (i.e., in this context related to the brain activities inside skull). Collapse the camera to a single detector, calibrate it to convert the IR radiation it sees to a temperature, and you have an infrared thermometer, the kind currently attached to most hospital beds.

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C O N C L U S I O N