Frontiers in Electrical Brain Imaging: stroke, epilepsy and real-time functional activity

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CMIP 2018
Como

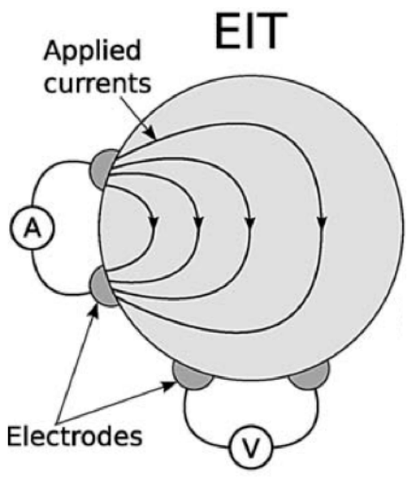
Electrical Brain Imaging

Electrical brain imaging refers to the set of techniques that exploit **electrical signals** to generate an **image** of the structure or functional activity of the brain.

- Quick setup
- Portability
- Low cost
- High temporal resolution [ms]

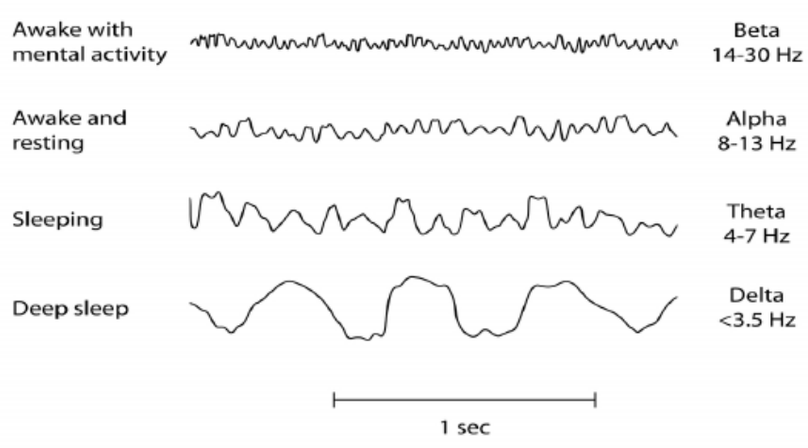
- High computational requirements
- Low spatial resolution [cm]

Electrical Impedance Tomography (**EIT**)



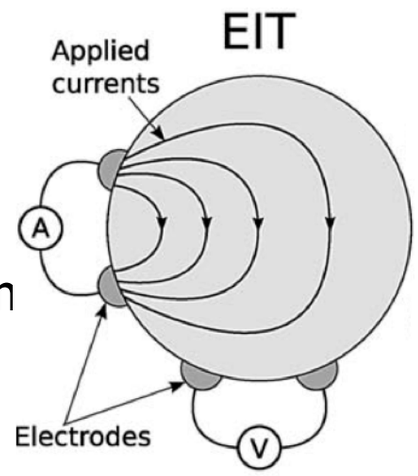
An **impedance map** of the region of interest is reconstructed from **measured electric potentials** generated by **current injections**

ElectroEncephaloGraphy (**EEG**)

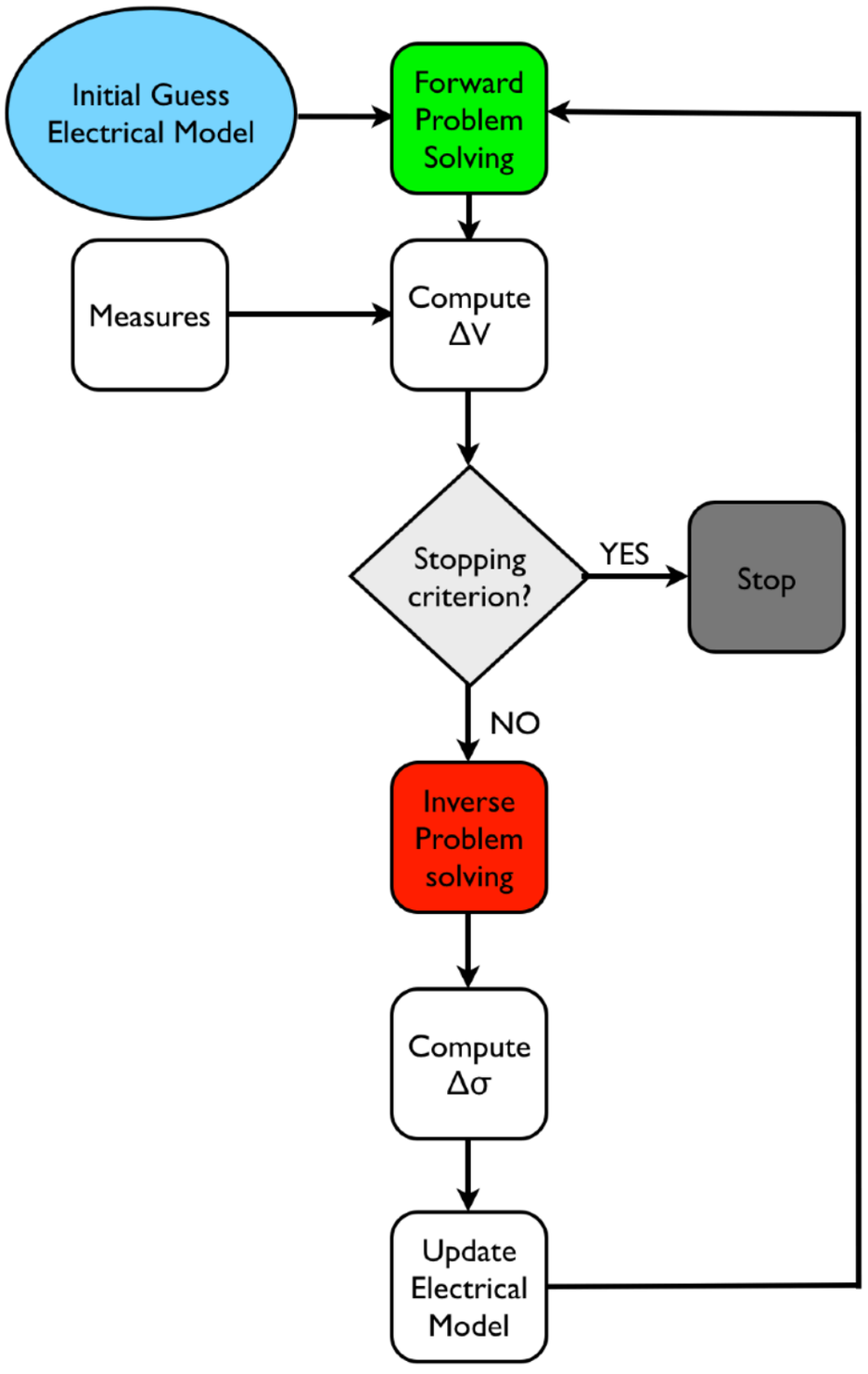


Electric potentials generated by neurons are recorded. Waveforms at **different frequencies** are associated to **different mental states**

Electrical Impedance Tomography

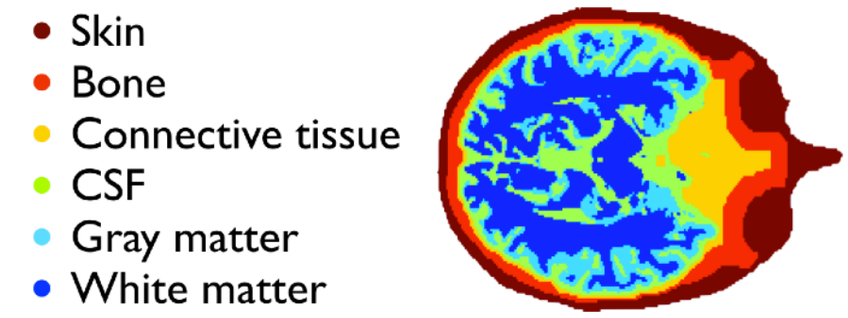


The reconstruction is an underdetermined and ill-posed inverse problem



Three main components are generally required:

- **Electrical Model**: describes the domain



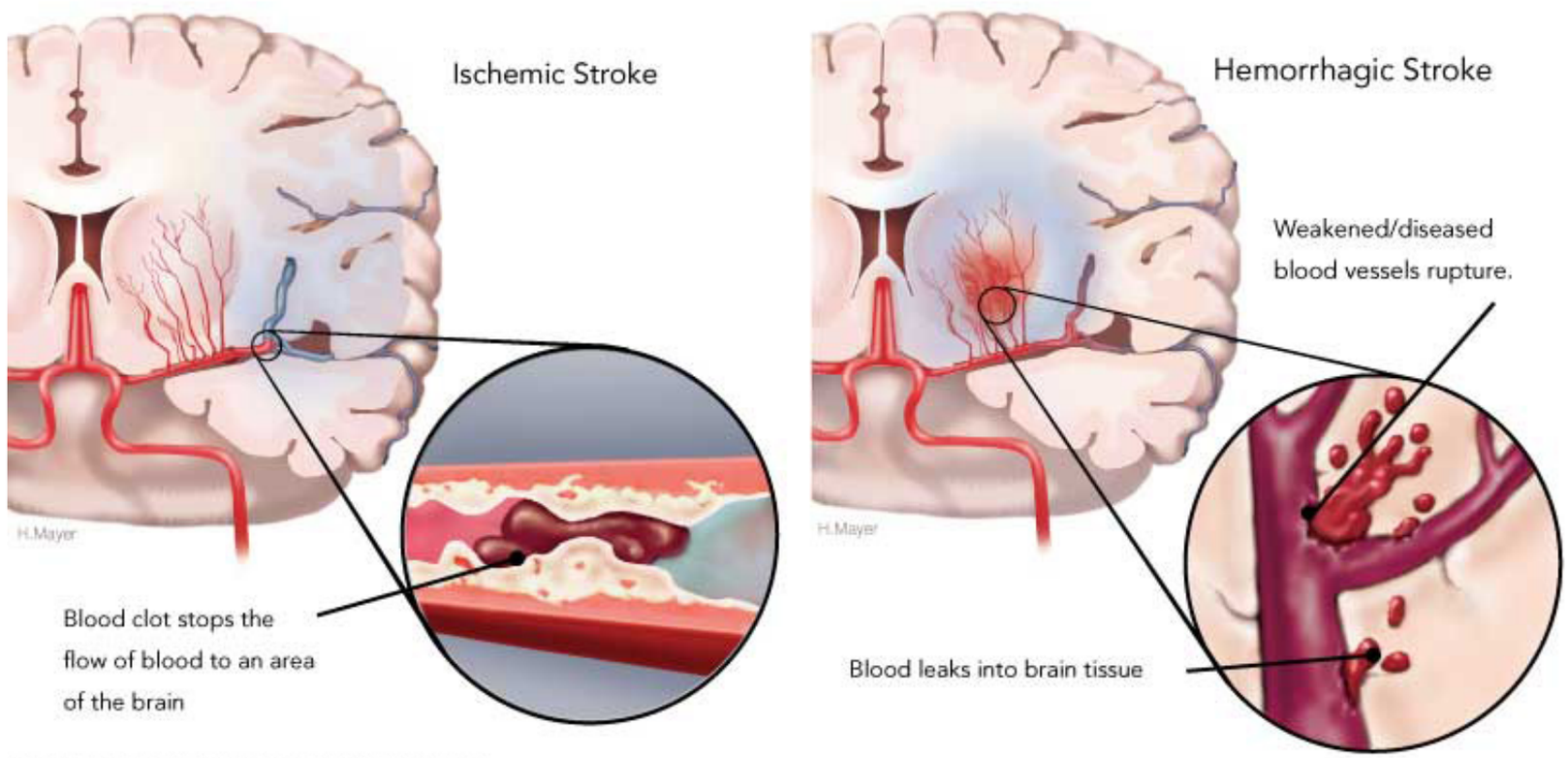
- **Forward Problem Solver**: computes the voltage distribution in the domain given the applied current injections and the electrical model

- **Inverse Problem Solver**: Makes use of the forward problem solver to provide an estimate of the physical properties of the volume, given the stimulation pattern and the set of measurements.

Stroke Overview

Life-threatening medical condition characterized by **loss of brain function** due to **disruption of blood perfusion**.

- **Ischemic**: the blood supply to a brain region is reduced or completely cut off
- **Hemorrhagic**: blood floods the region adjacent to the leakage of a vessel



Early recognition and correct discrimination are crucial for effective therapy (4.5 h tPA limit).

EIT of Strokes

Well defined electrical properties:

- **Ischemic** strokes **increase the impedance** of the affected region
- **Hemorrhagic** strokes **decrease the impedance** of the affected region

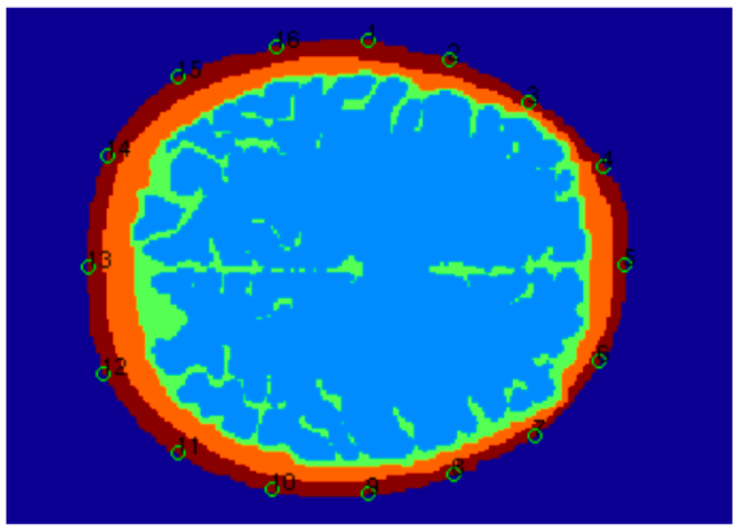
Potential EIT use case:

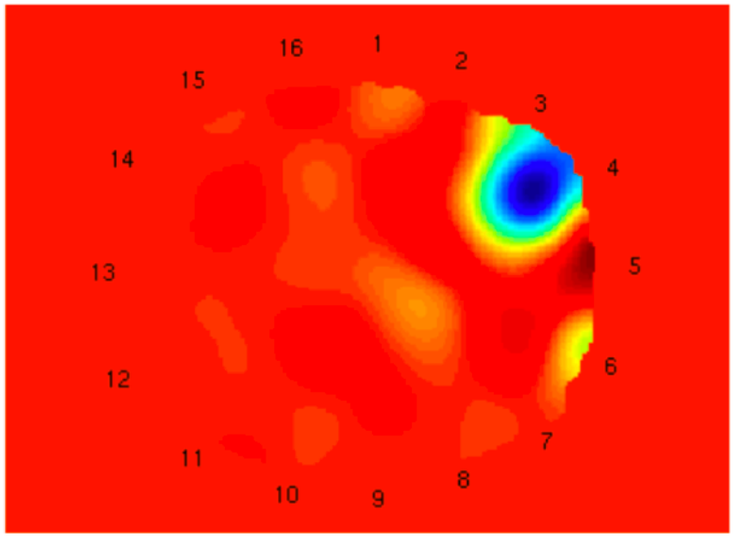
- Data acquisition with a portable EIT system is performed on site by a trained operator
- Measured data (few KB) is sent offsite for image reconstruction and stroke detection and classification
- The correct therapy is initiated as soon as possible

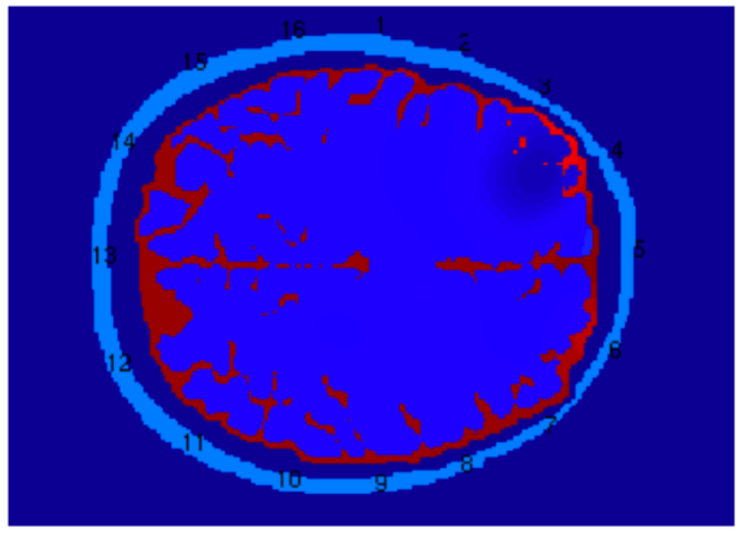
“State of the art” in applications

Tikhonov regularized reconstruction

Starting from an **initial guess** conductivity distribution, the conductivity of each voxel of the discretized domain is updated and a **conductivity map** of the region of interest is generated.







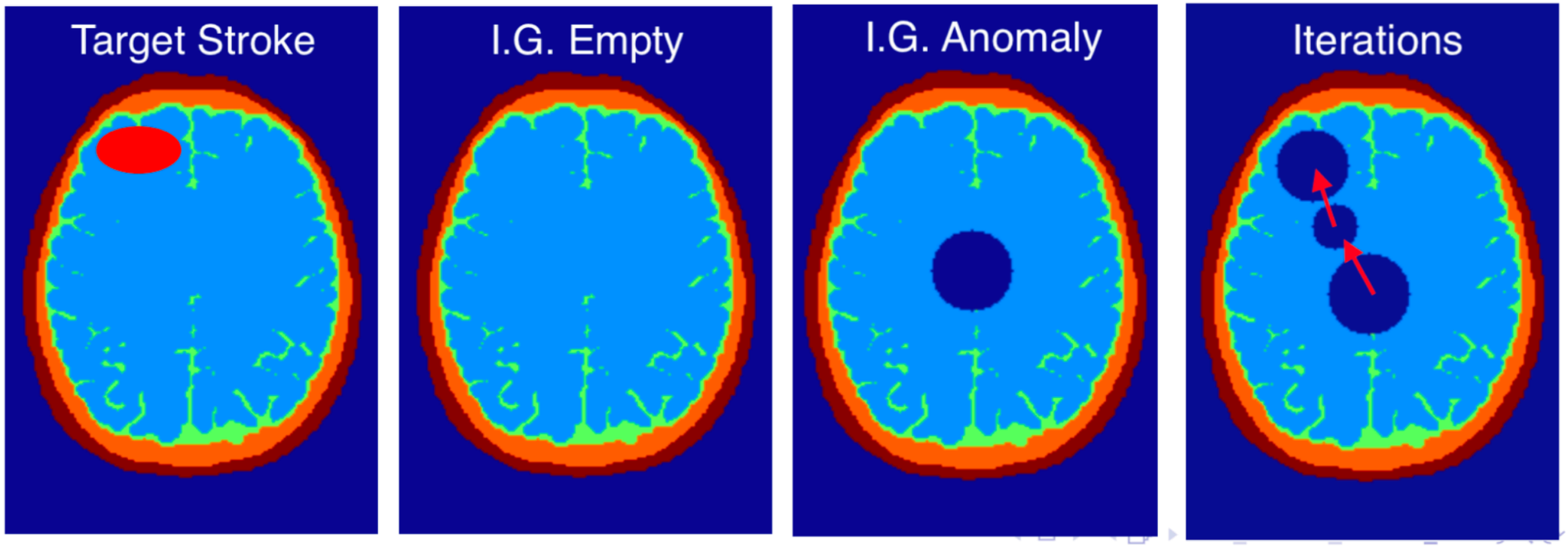
General purpose algorithm
Provides shape approximation

Computationally expensive
Regularization parameter optimization is critical

Alternative Approach

parametric reconstruction

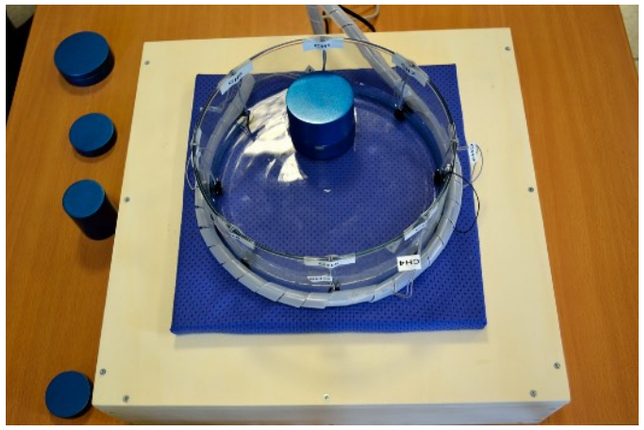
- Each segmented head tissue is assigned a value according to literature data.
- Compact conductivity anomaly is placed at an initial guess position.
- Position and size of the anomaly and conductivity of the tissues are iteratively updated till convergence or disappearance of the moving anomaly.

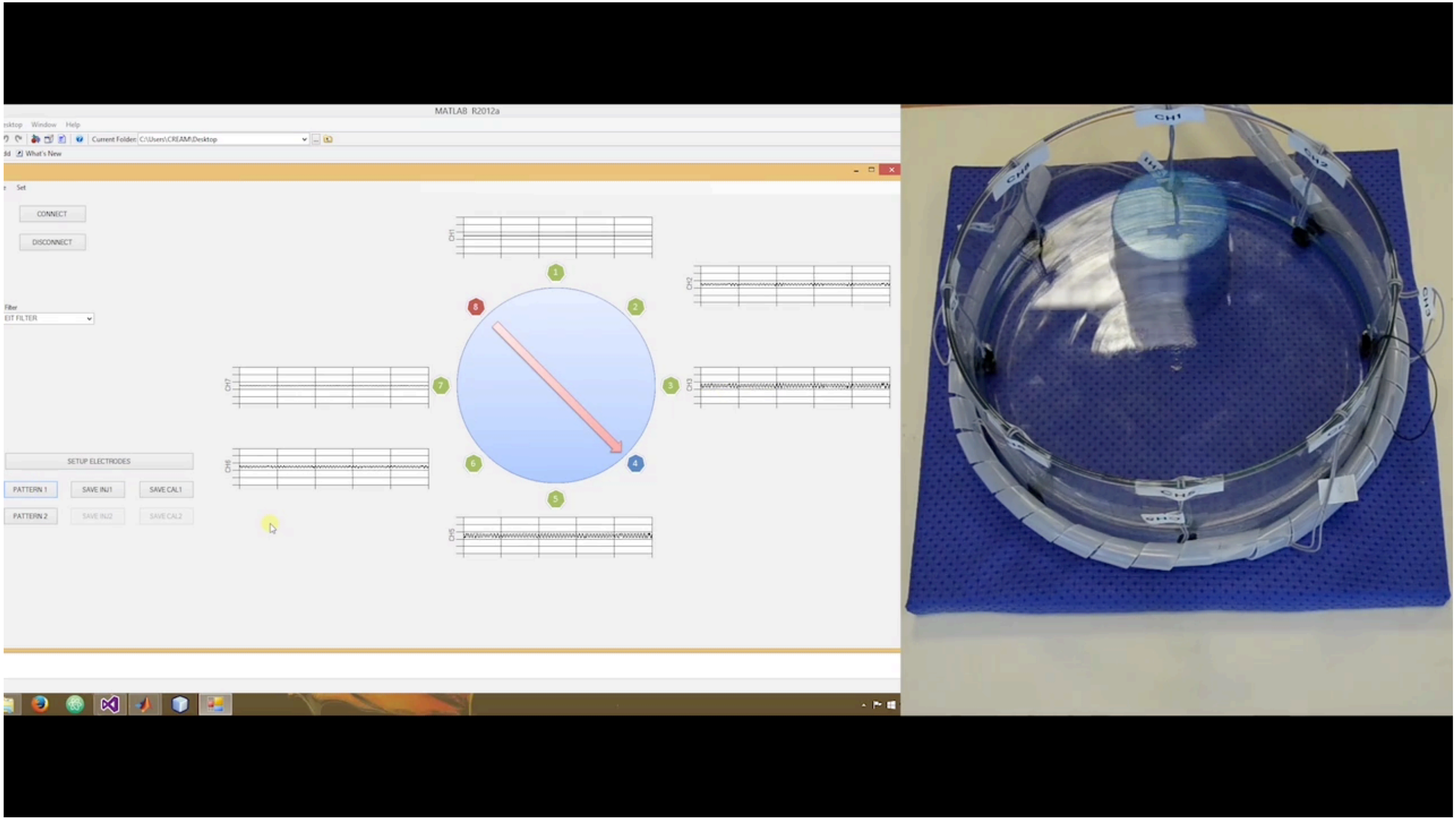


Faster and more accurate than Tikhonov

Special purpose algorithm

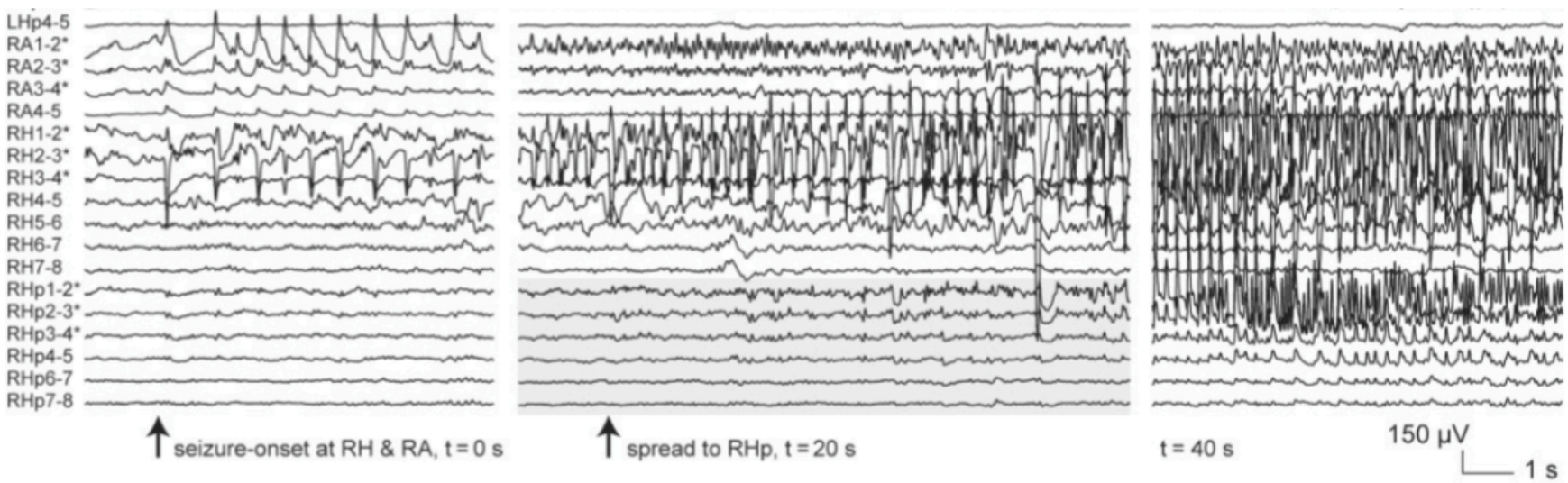
Phantom Example





Focal Epilepsy Overview

A limited part of the brain, the epileptogenic focus, initiates an abnormal activity which can spread to other brain regions.

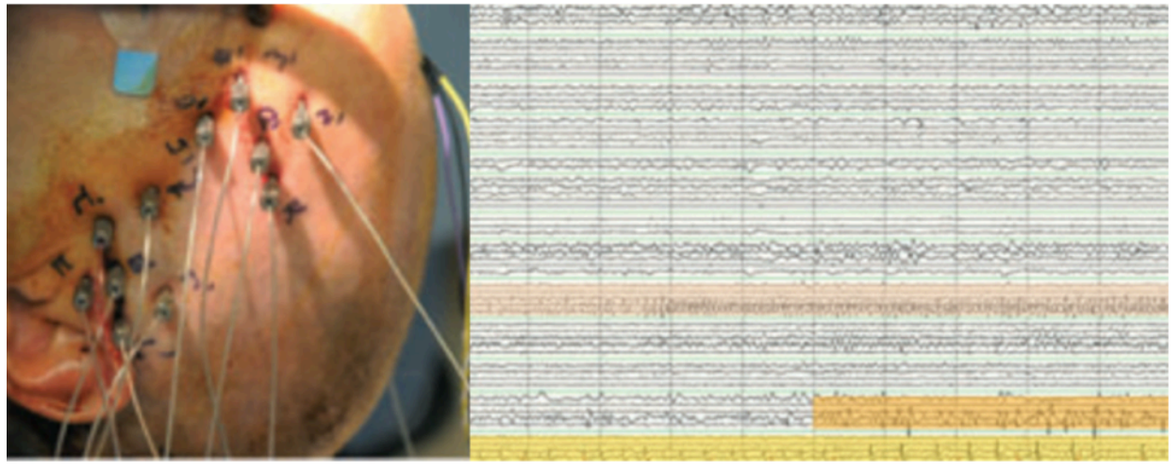


If pharmacoresistant, then treatment consists in **surgical resection** of the epileptogenic focus.

- Various noninvasive imaging techniques can be used for localization both from a structural (MRI) and a functional (PET, SPECT, (video)EEG,..) perspective

- If no definitive conclusion, invasive EEG measurements can be performed (SEEG)

Standard analysis consists in **looking at raw data** to locate the initiating focus.

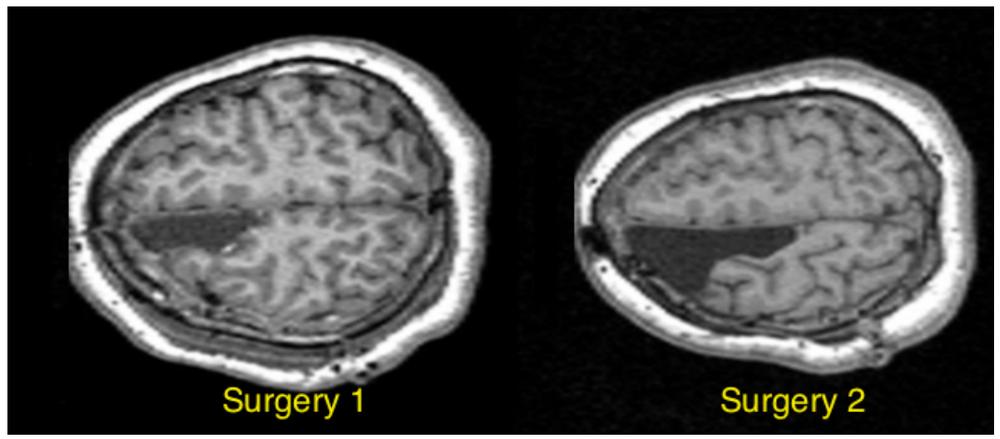


Surgical Resection

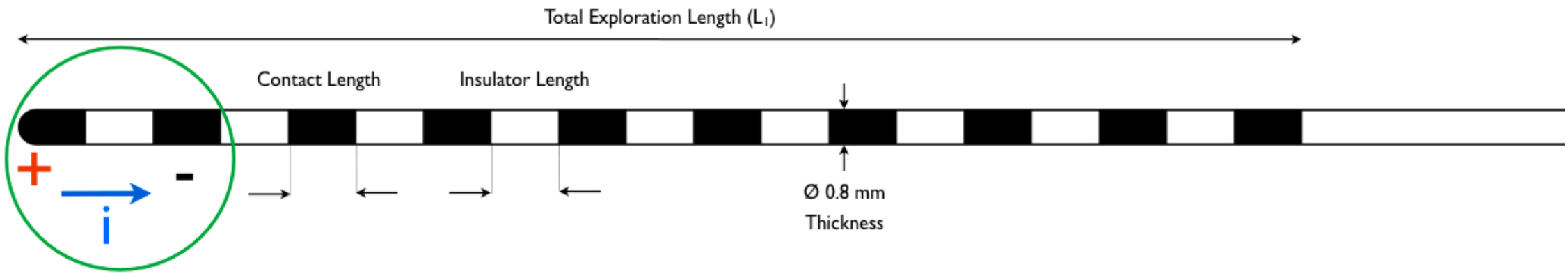
After localization, first surgery alleviates or **remove symptoms only in about 60%** of the cases. Patient may have to return for **second surgery.**

- Multiple foci
- Insufficient resection

There is room for improvement!

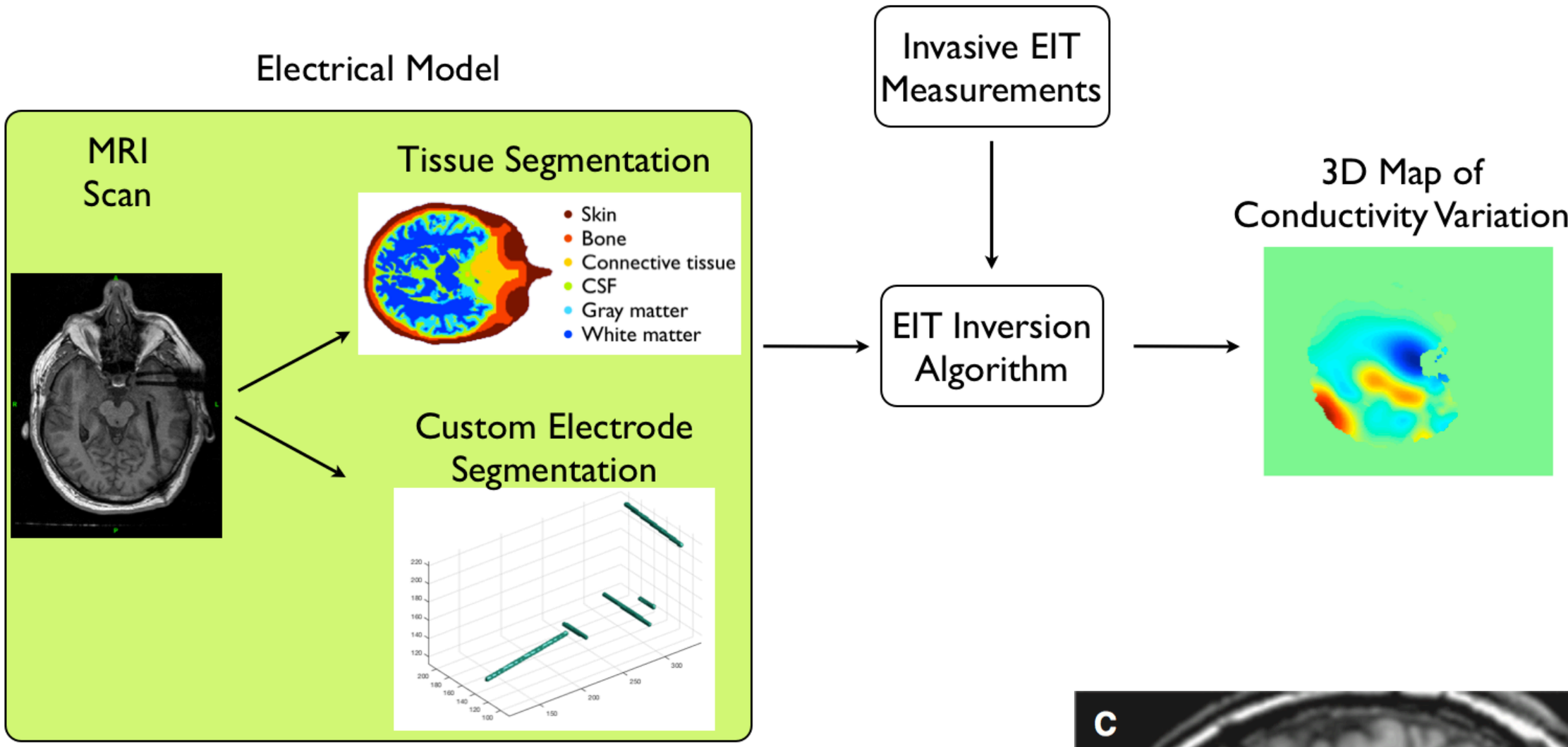


- SEEG electrodes can be used to both **measure potentials** (EEG) or **inject currents** (cortical mapping)
- Recent research highlights a 10% difference in conductivity between epileptic and non-epileptic cortex

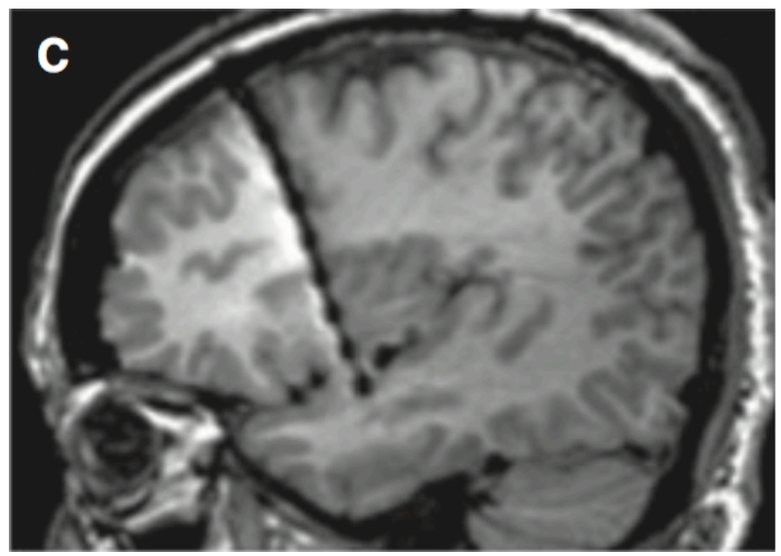


- Possible to attempt time difference EIT imaging
- EIT may provide a direct, independent measurement of epileptic activity

Epilepsy Imaging Workflow

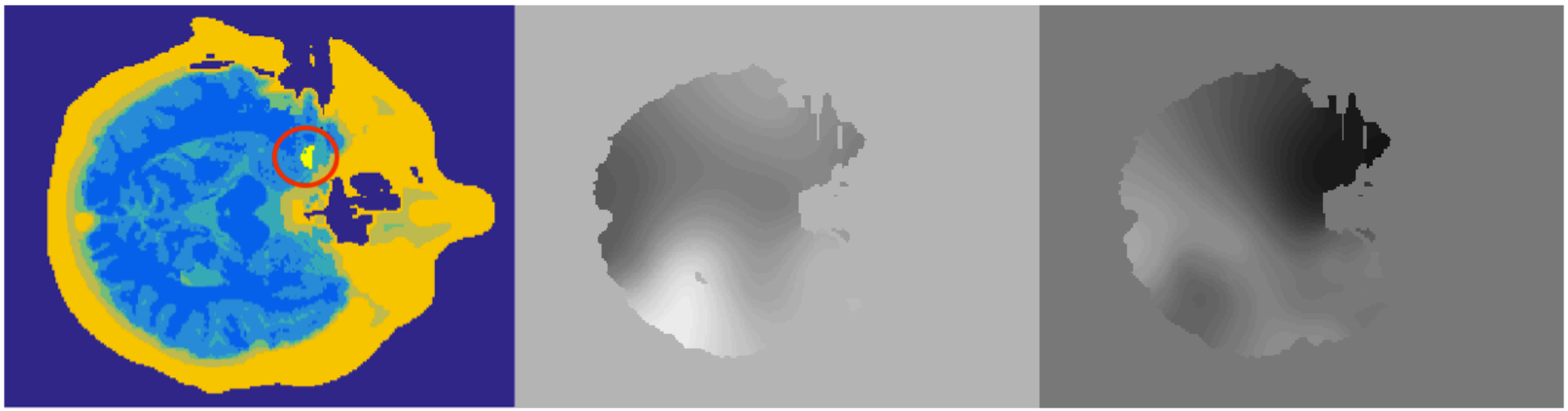


Tikhonov algorithm preferred to parametric approach due to the highly inhomogeneous background (SEEG electrodes).



Simulation Experiments

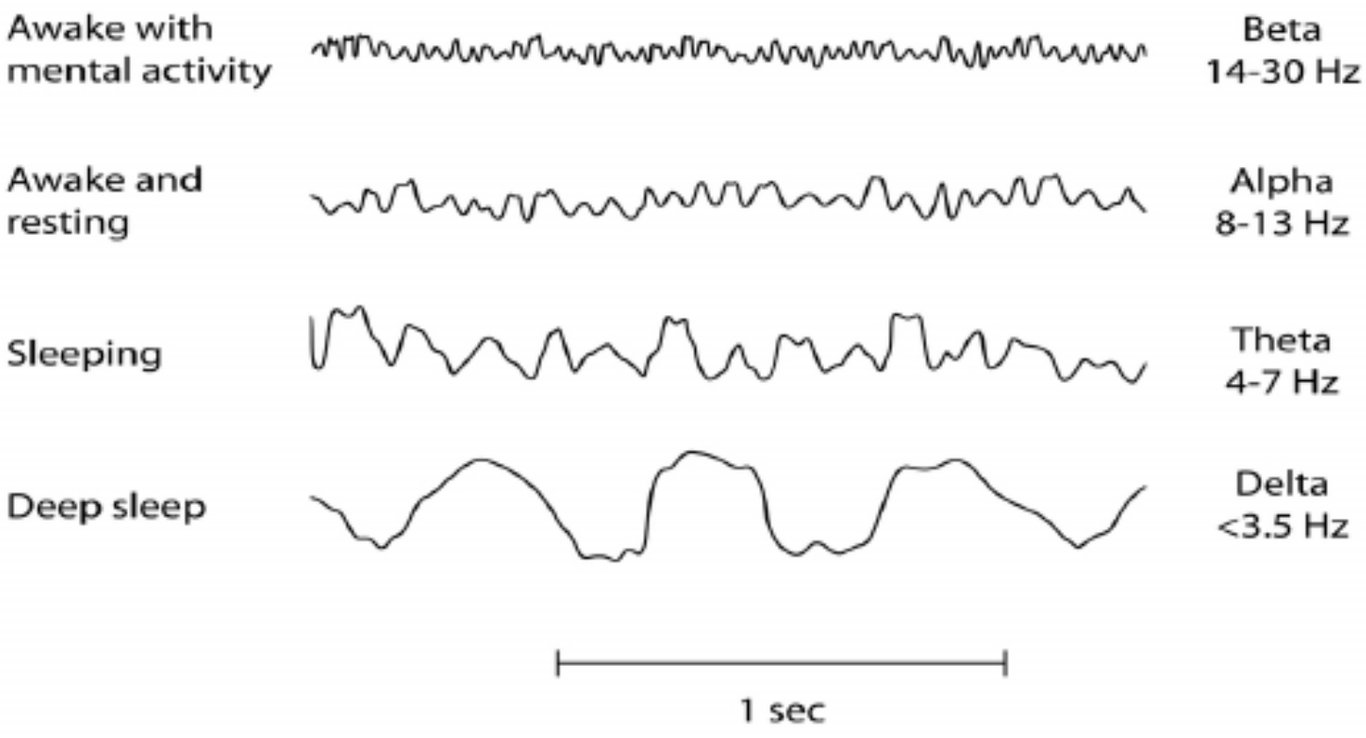
Epileptic Focus | 6 Adjacent | 6 Non-Adjacent



- Average resection volume: 30cm^3 → sphere with 4 cm diameter
- EIT resolution: ≈ cm
- Completely new source of information with clinical significance
- Only slight modification of the clinically used SEEG protocol is required

EEG Introduction

- Recording of electric potentials generated by the activity of neurons.
- Generally measured on the scalp.



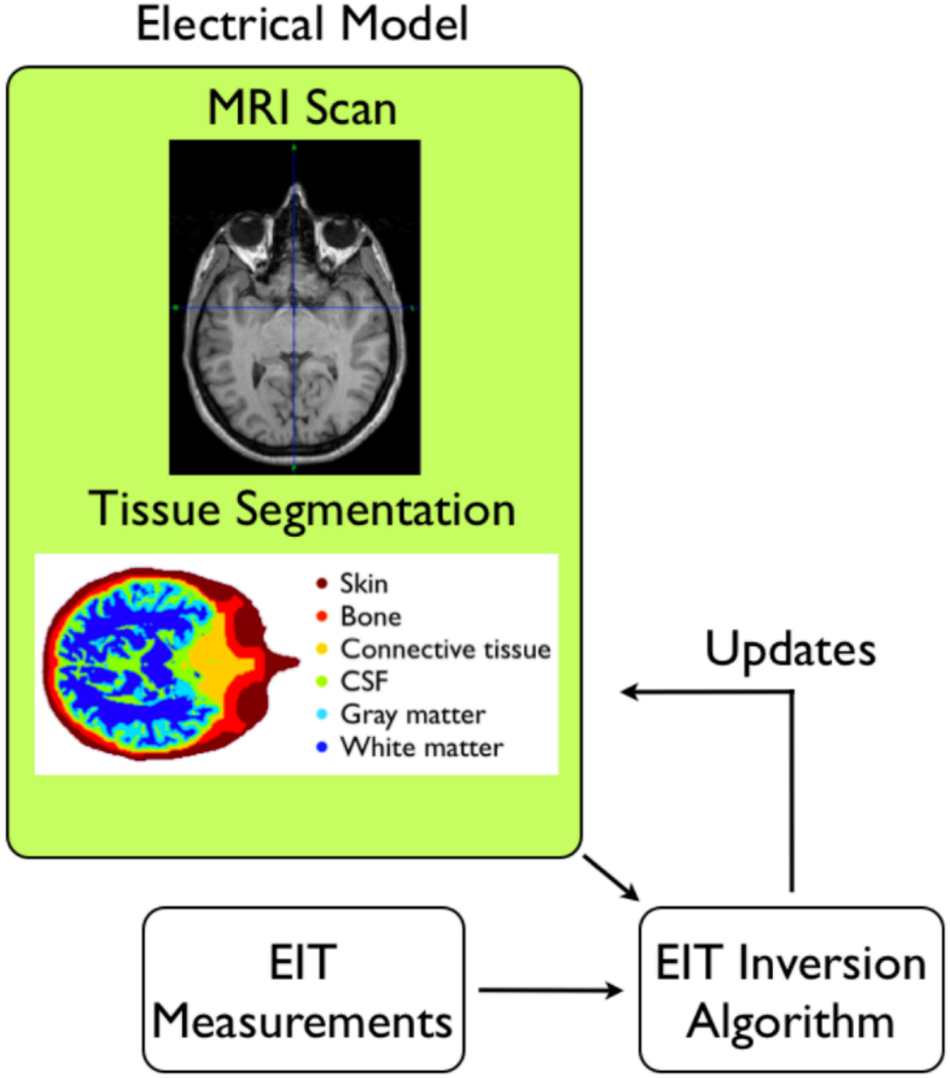
- Commonly used to diagnose brain disorders associated to its electrical activity (epilepsy, brain tumors, sleep disorders).

Brain Imaging through EEG

- Identify which region of the brain produced the electrical signal recorded on the scalp and produce a **functional map of brain activity.**
- **Inverse problem** (underdetermined and ill posed).

To attack the problem, an **electrical model** of the brain is needed.

The electrical model can be fine-tuned to the specific subject using EIT measurements.



Inverse Problem

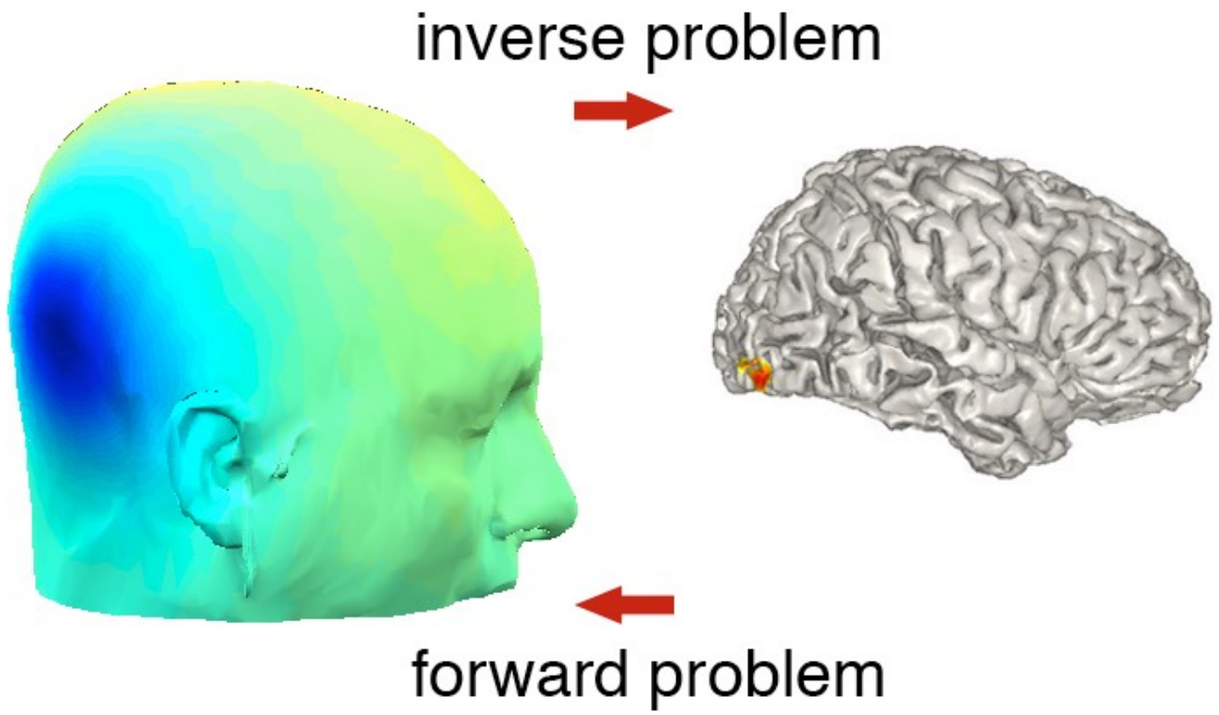
Identify the current density J in each voxel of the domain that corresponds to the electric potentials measured on the scalp Φ

Electric Potentials
(known)

$$\Phi = KJ + c_1$$

Lead Field
Matrix
(built with EM)

Current Density
(unknown)



sLORETA

standardized **LO**w **R**esolution brain **E**lectromagnetic **T**omogr**A**phy
can localize test point sources with zero localization error in the absence of noise

CREAM: **CR**eativity **E**nhancement through **A**dvanced brain **M**apping and stimulation

SEVENTH FRAMEWORK PROGRAMME

http://www.ict-cream.eu/project_sticky/

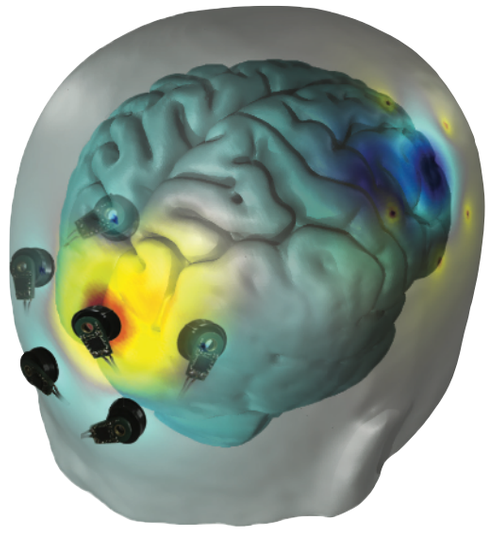
- Goal: measure functional activity of the brain and compute real-time stimuli to modulate a high-level behaviour such as creativity

- Previous studies have shown that electrical stimulation can modulate verbal associative thoughts, problem solving, insight....

- Current stimuli (tDCS, tACS,...) and visual and acustic stimuli.

- Engineering & ICT: link measurement and electrical stimulation

- Need quick reconstructions to inform stimulation in real time



- Cognitive psychology
- Neuroscience
- Engineering
- ICT

Goldsmiths UNIVERSITY OF LONDON

MEDIZINISCHE UNIVERSITÄT WIEN

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ULL Universidad de La Laguna

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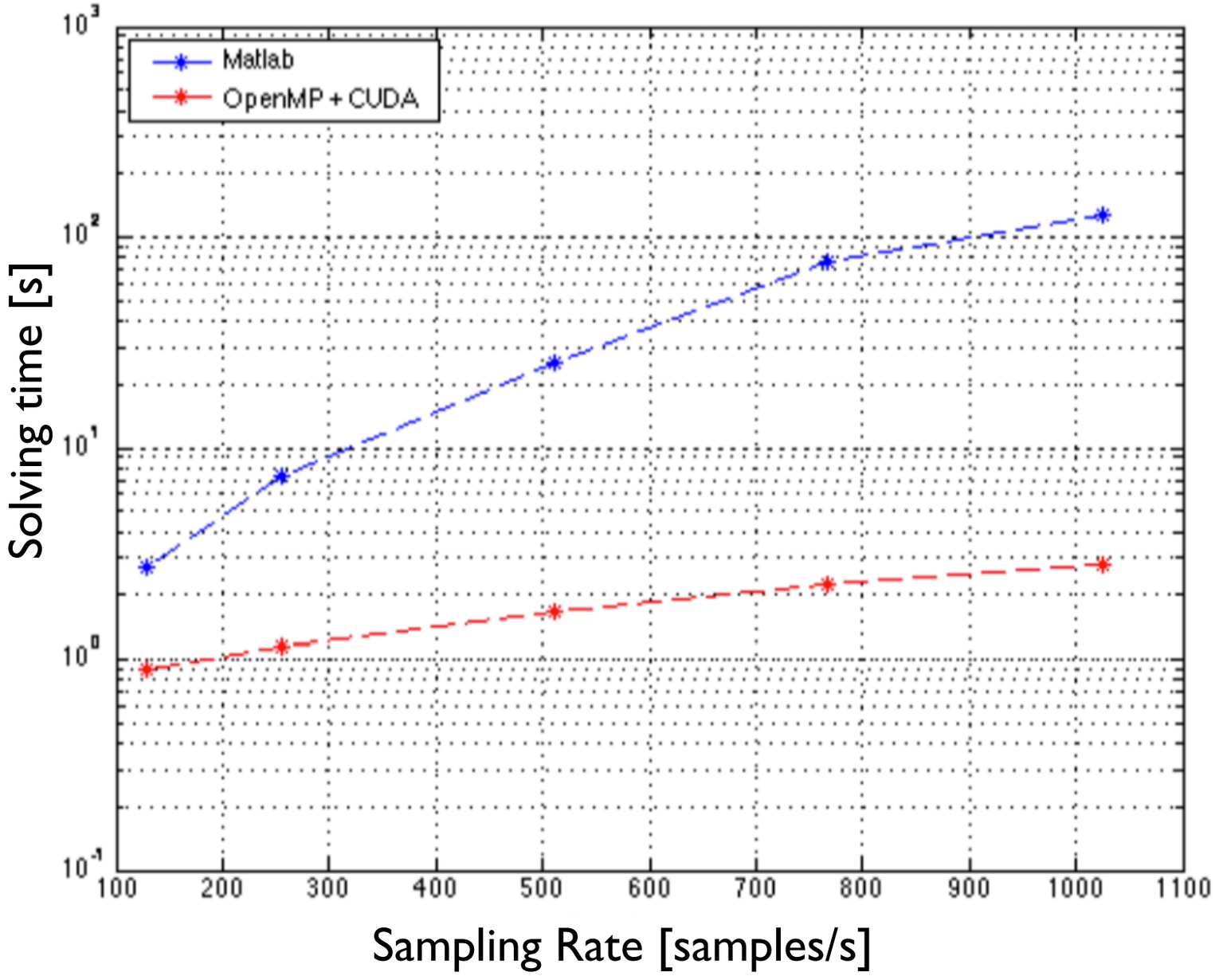
g.tec GUGER TECHNOLOGIES

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

Parallel Implementation

CPUs	2x Intel Xeon E5-2650 v2 (octa-cores HT) @2.6 GHz
GPUs	4x Geforce GTX Titan Black (4 x 6GB GDDR5 Memory)
RAM	64GB DDR3 1866MHz



128 Electrodes
90K Voxels

The openMP + CUDA implementation of sLoreta solves the inverse problem in less than a second (sampling rate 128).

- Real Time Reconstruction.
- Integration between measurement and stimulation.

Questions?