Electrical Impedance Tomography: *advances in Image Reconstruction*

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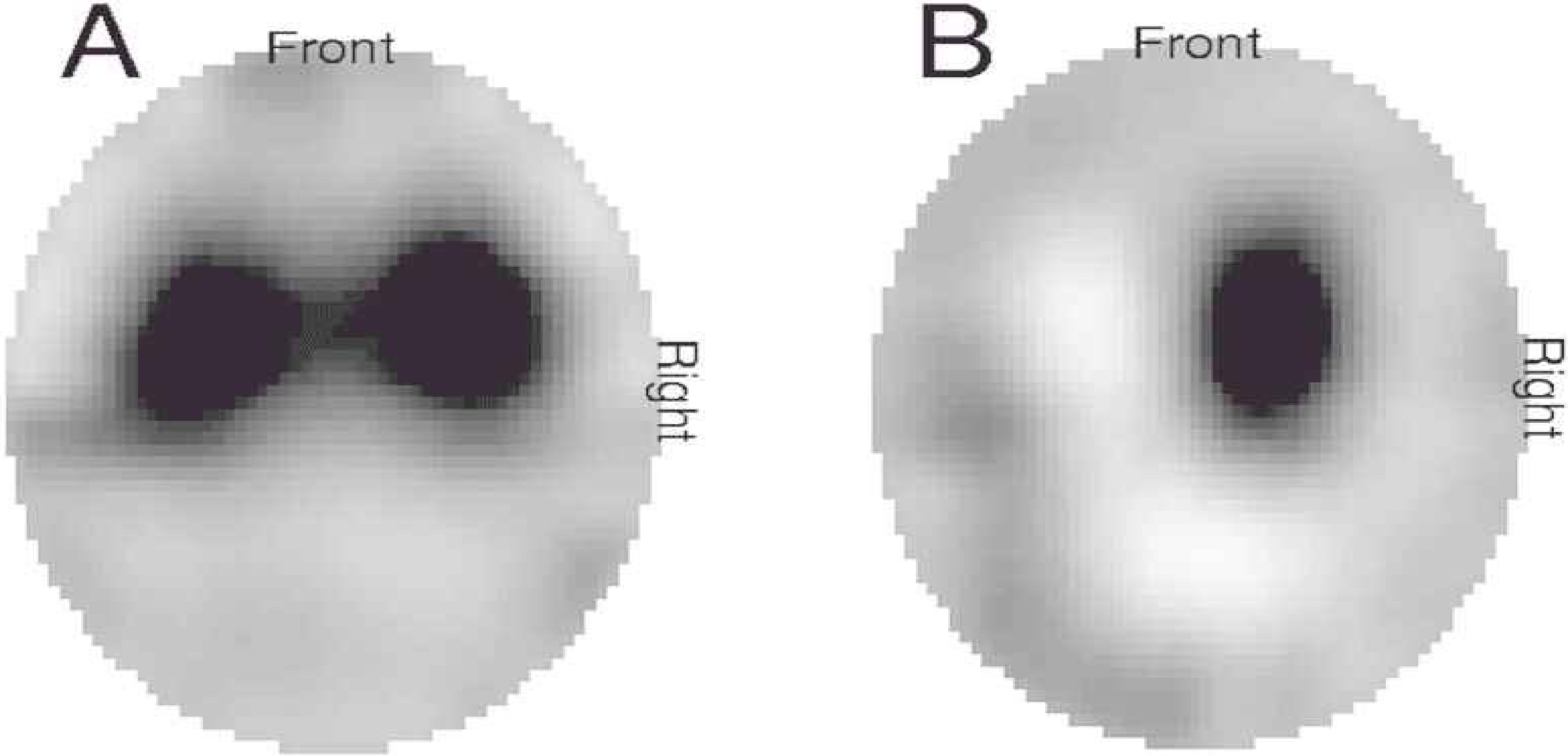
Outline

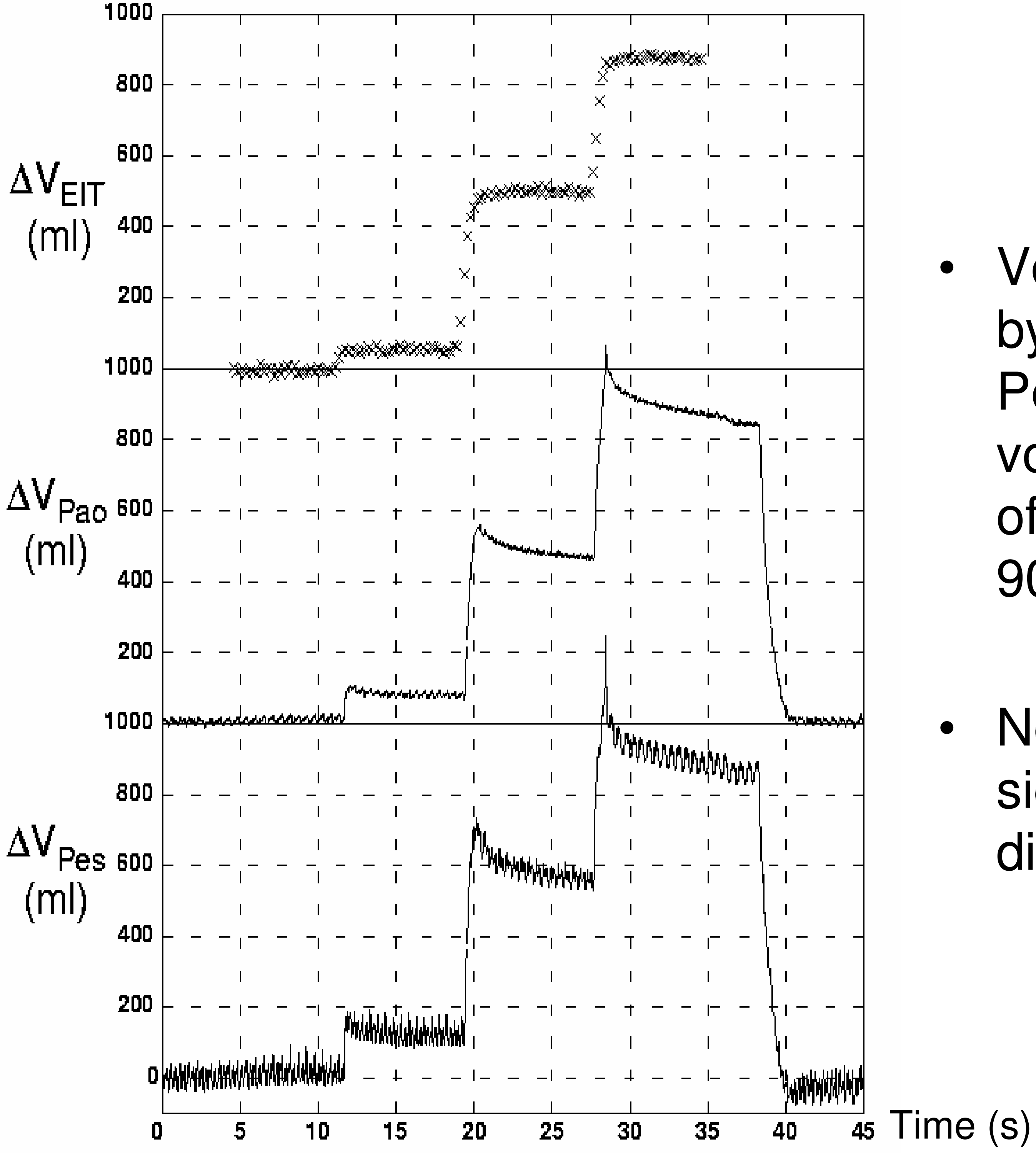
- Electrical Impedance Tomography
  - Imaging the lungs
- Measurement Difficulties and solutions
  - Electrode Errors
  - Electrode Movement
  - 3D Imaging / Electrode Placement
  - Temporal Filtering
- EIDORS Project

Lung images



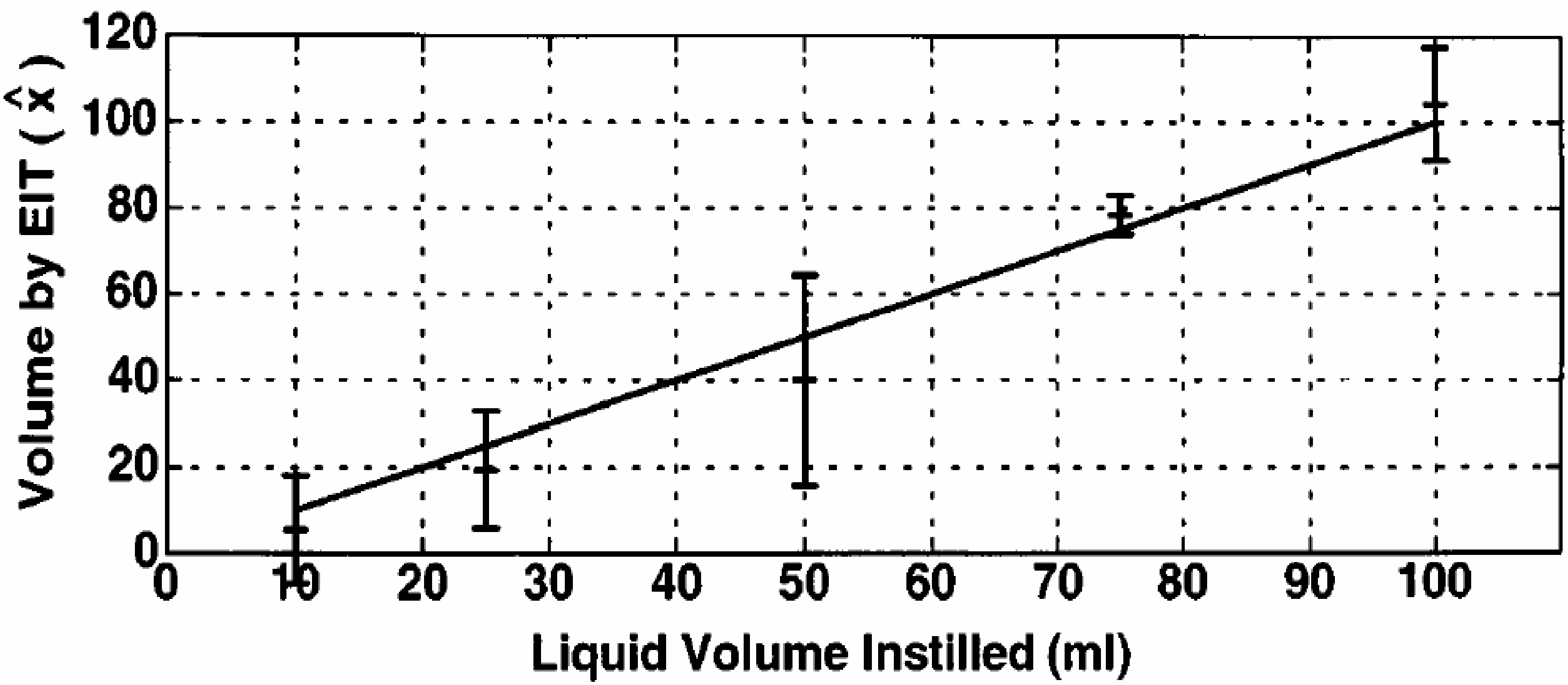
A: image of section thorax due to ΔVL 800 ml

B: image due to a ΔVL 400 where left main stem bronchus was plugged.



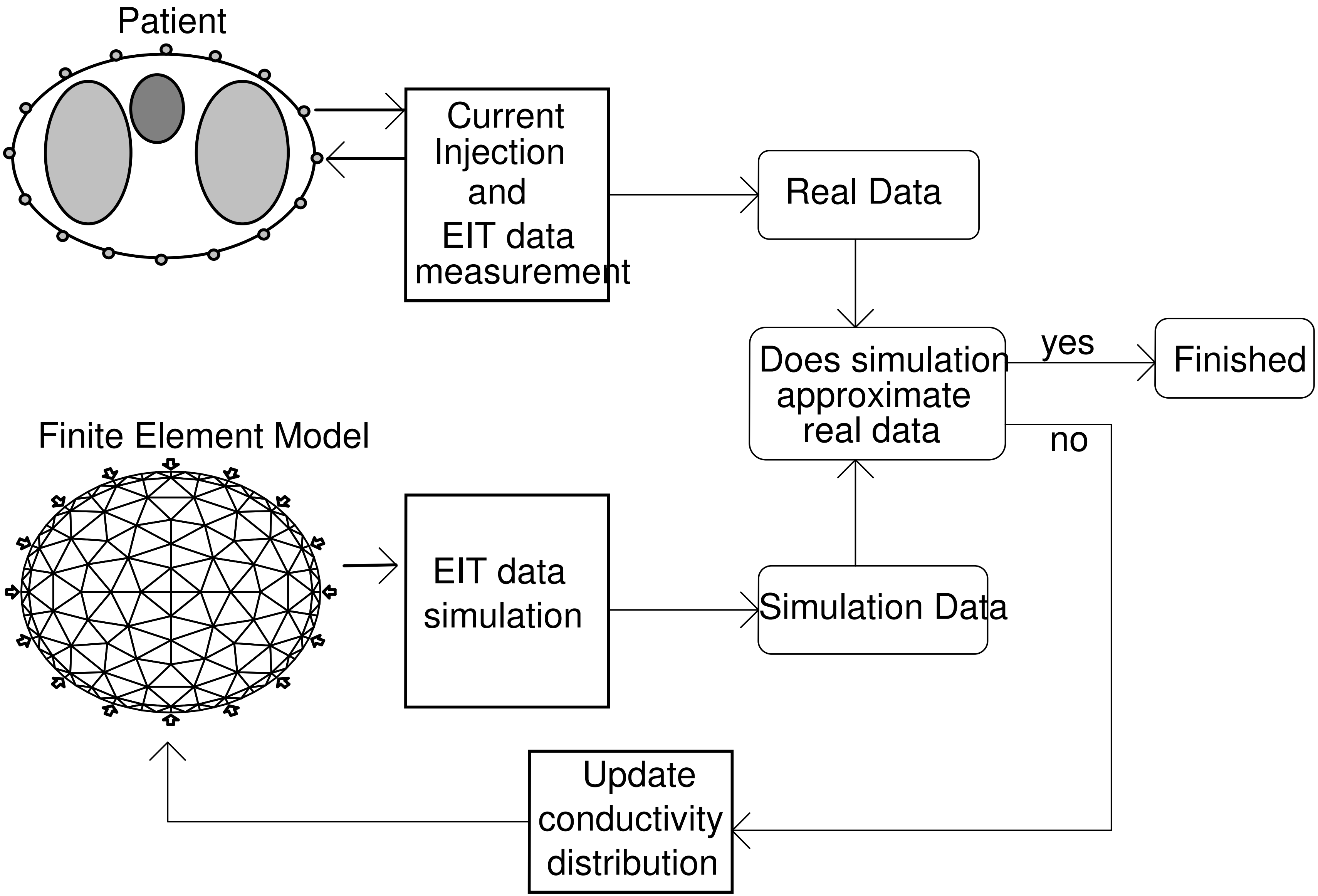
- Volume estimates by EIT, Pao and Pes, after step volume increases of 100ml, 500ml, 900ml.
- Note that EIT signal does not display overshoot

Pulmonary Oedema: model using fluid instillation



- Change in lung liquid volume by EIT vs liquid volume instilled

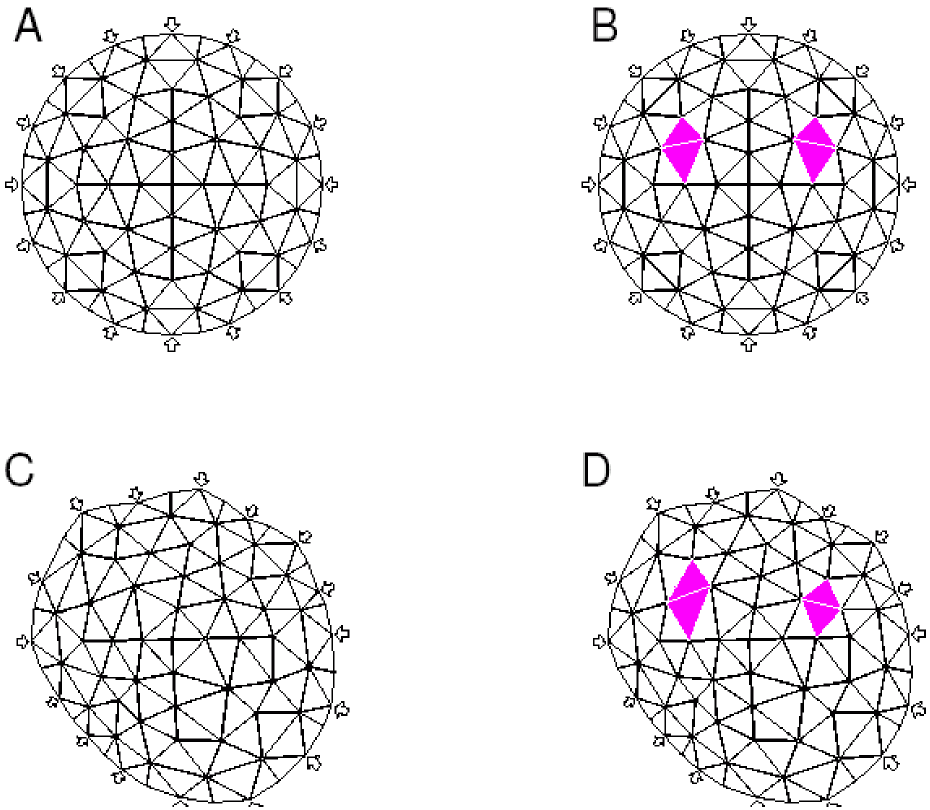
Iterative (Absolute) Image Reconstruction

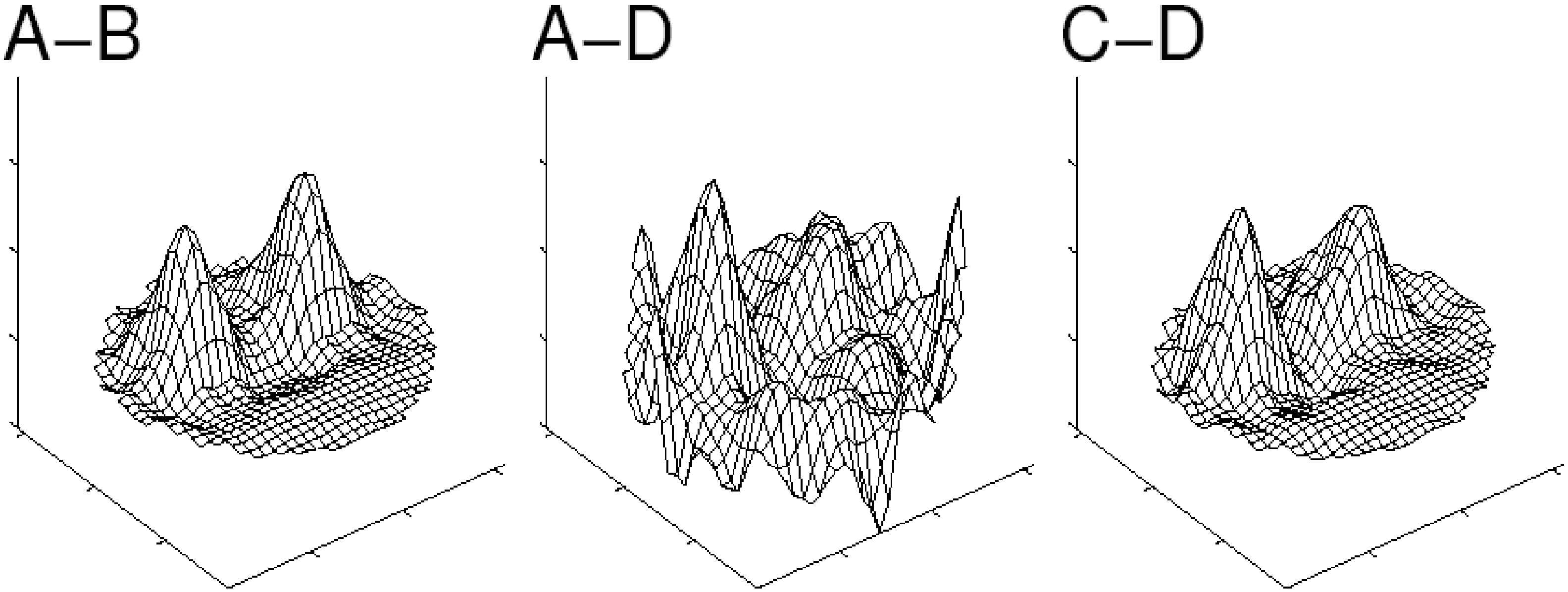


Absolute Imaging Difficulties

- Extremely sensitive to uncertainties in electrode position
  - Need to know where electrodes are to and electrode shape to 1mm
  - "Absolutely" must do 3D
- Numerical instability
- Slow reconstructions
- Is muscle in chest isotropic?

Difference Imaging: Example





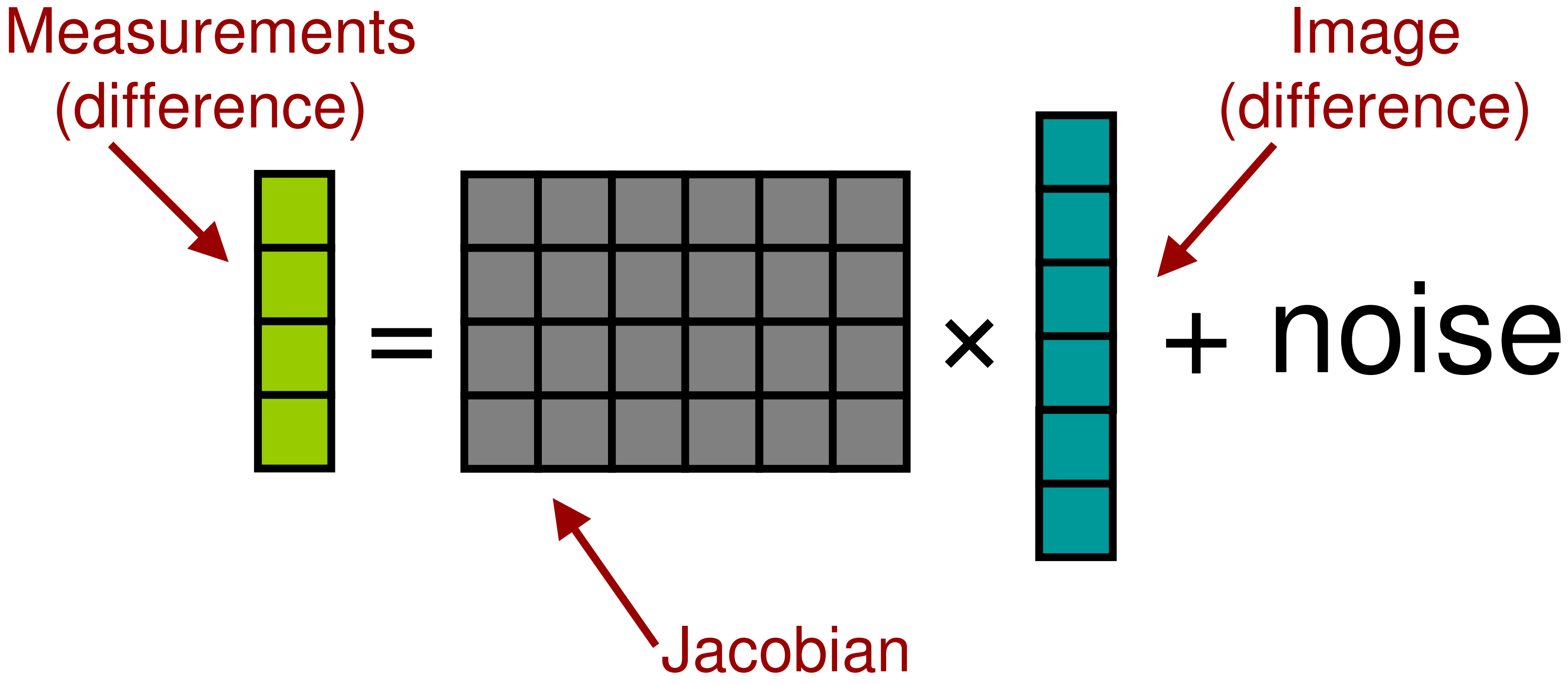
Difference Imaging

- Calculate Δ conductivity
  from Δ measurements

- Inverse problem *linearized*
- reduced sensitivity to electrode and hardware errors.
- Suitable for physiological imaging: lung, heart, GI

Image Reconstruction

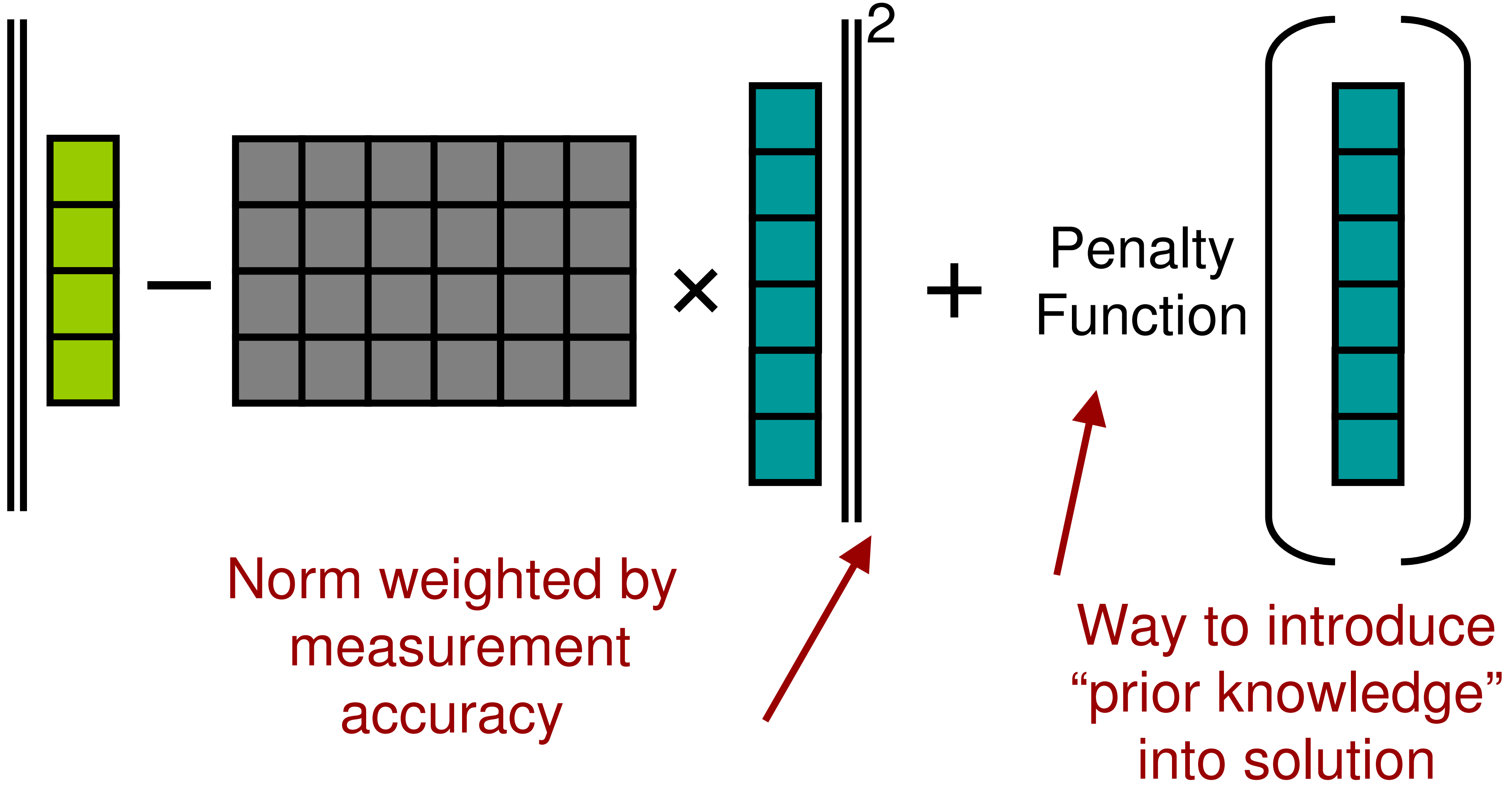
- Forward Model (linearized)



System is underdetermined

Image Reconstruction

Regularized linear Inverse Model



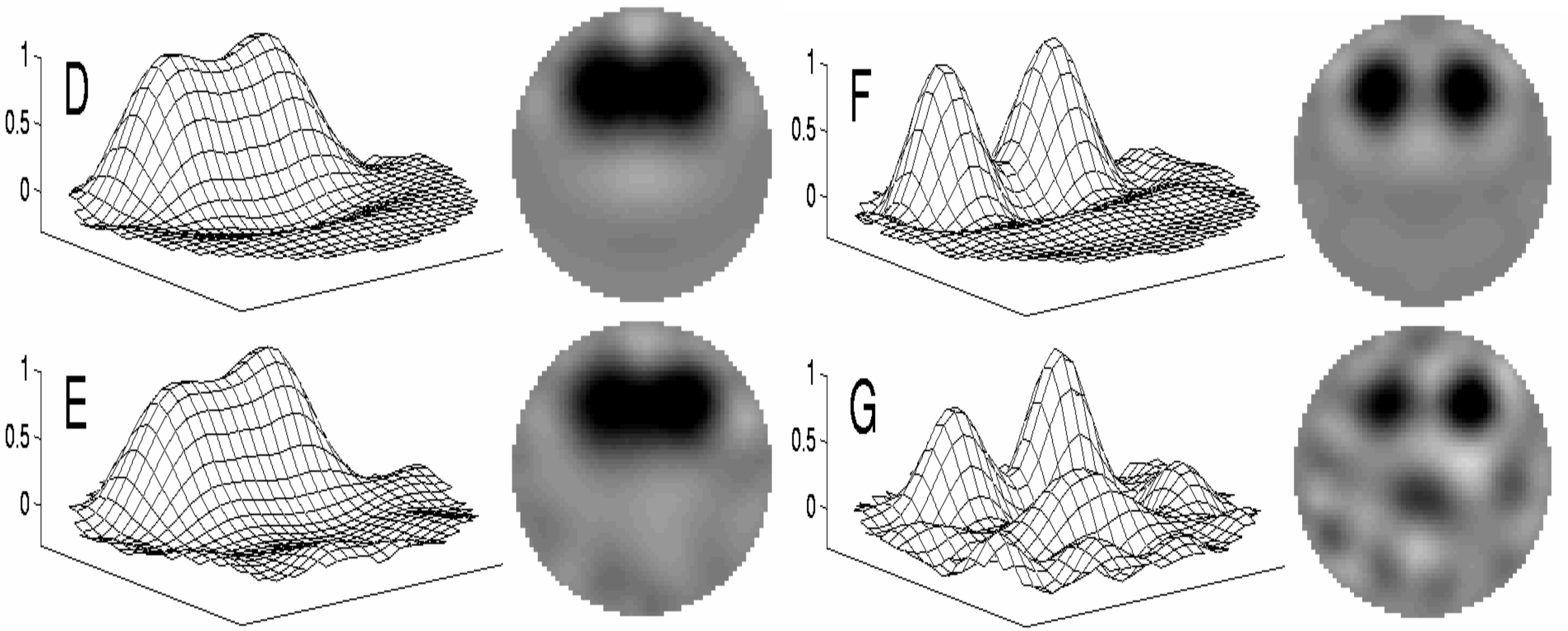
Noise – Resolution Tradeoff

Lots of Regularization (large penalty)

Little Regularization (small penalty)

No Noise

-3dB SNR



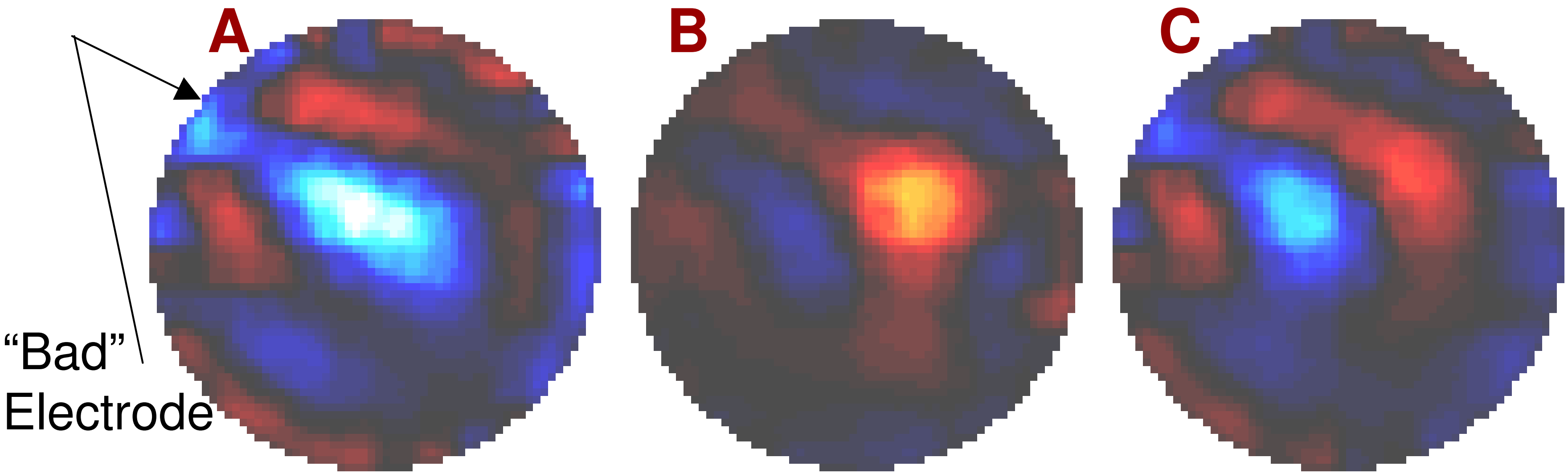
Applications …

- Electrode Errors
- Electrode Movement
- 3D Imaging / Electrode Placement
- Temporal Filtering

Electrode Measurement Errors

- Experimental measurements with EIT quite often show large errors from one electrode
- Causes aren't always clear
  - Electrode Detaching
  - Skin movement
  - Sweat changes contact impedance
  - Electronics Drift?

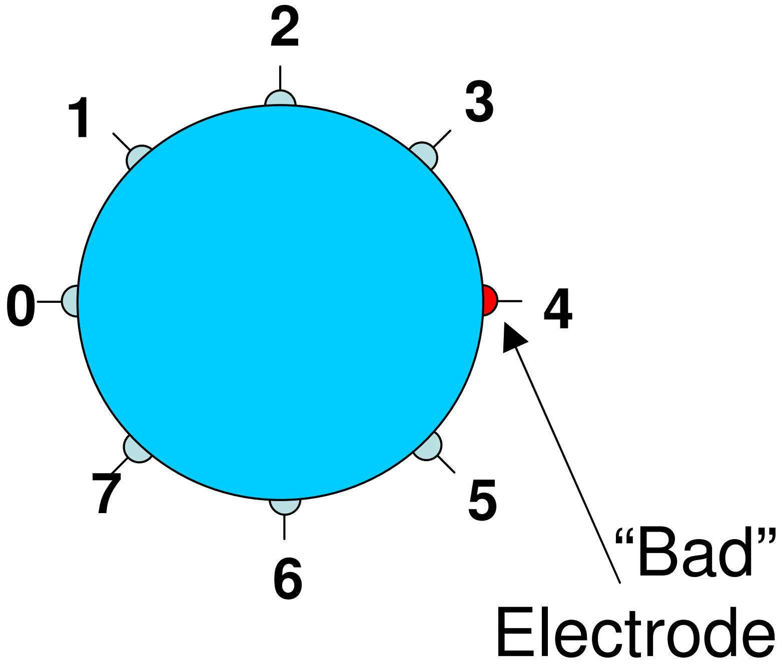
Example of electrode errors



Images measured in anaesthetised, ventilated dog

A. Image of 700 ml ventilation
B. Image of 100 ml saline instillation in right lung
C. Image of 700 ml ventilation and 100 ml saline

Measurements with “bad” electrode



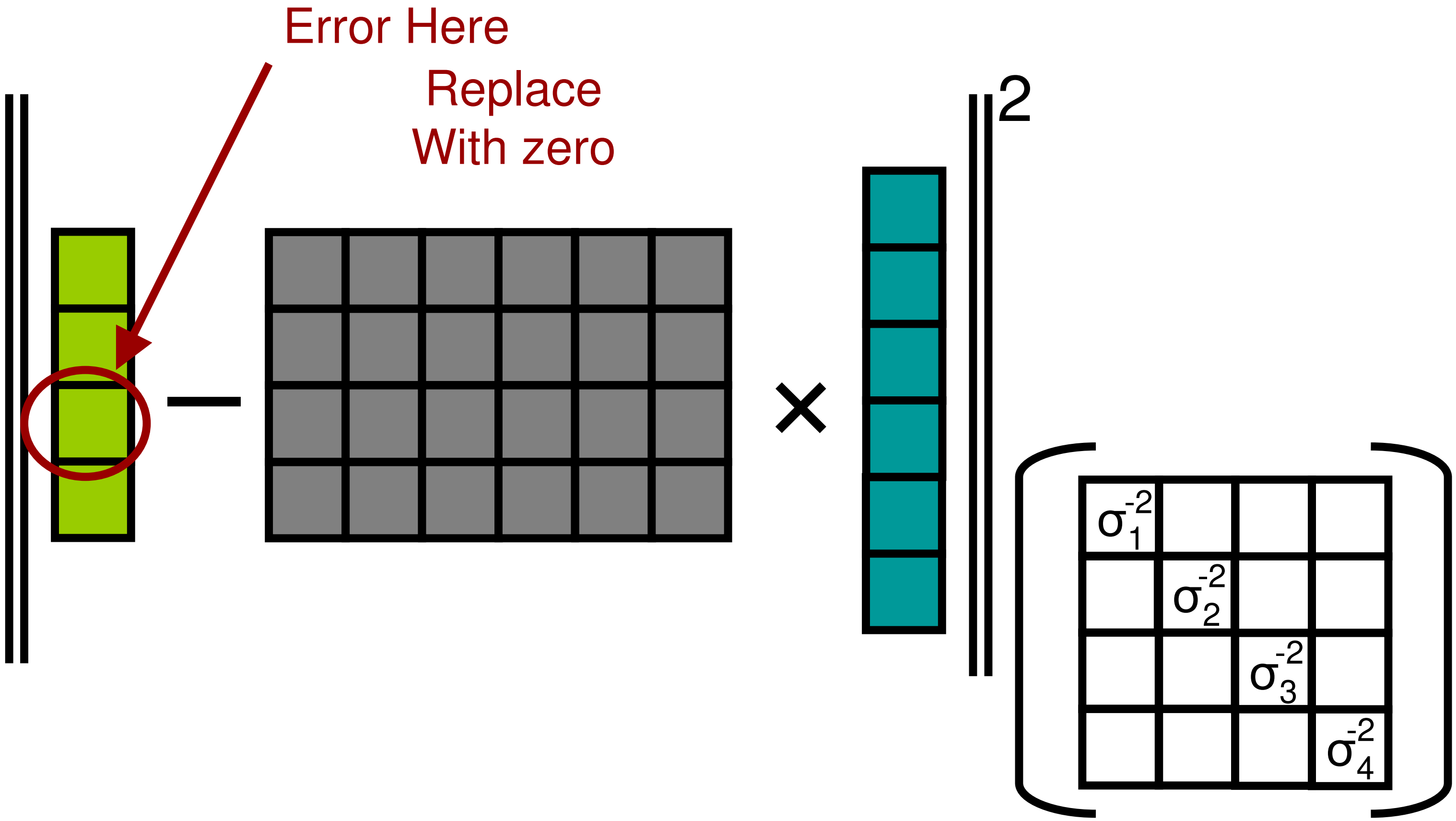
	01	12	23	34	45	56	67	70
01	X	X		*	*			X
12	X	X	X	*	*			
23		X	X	X	*			
34	*	*	X	X	X	*	*	*
45	*	*	*	X	X	X	*	*
56				*	X	X	X	
67				*	*	X	X	X
70	X			*	*		X	X

* “bad” measurement

X measurement at current injection

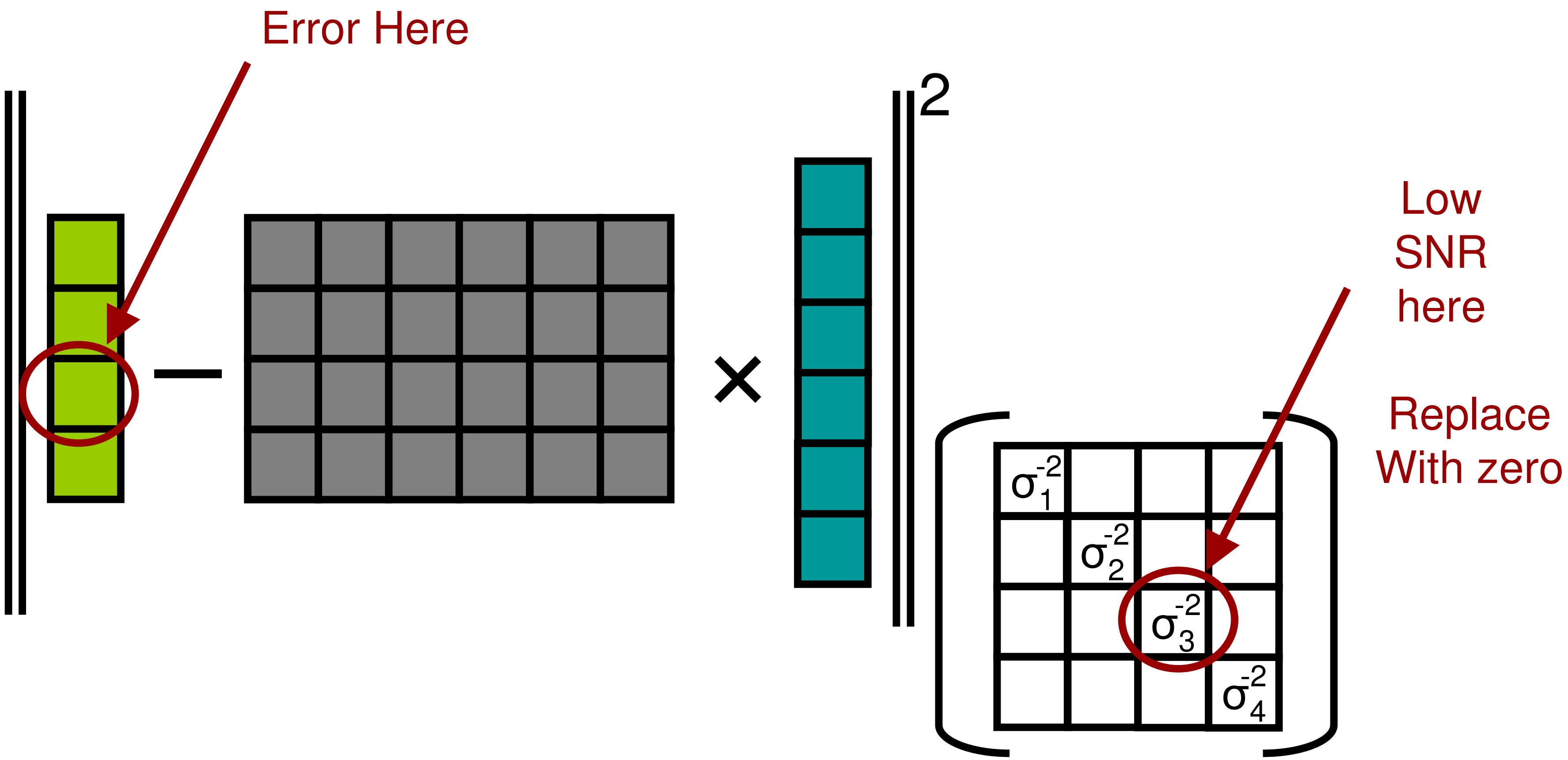
“Zero bad data” solution

“Traditional solution” (in the sense that I’ve done this)

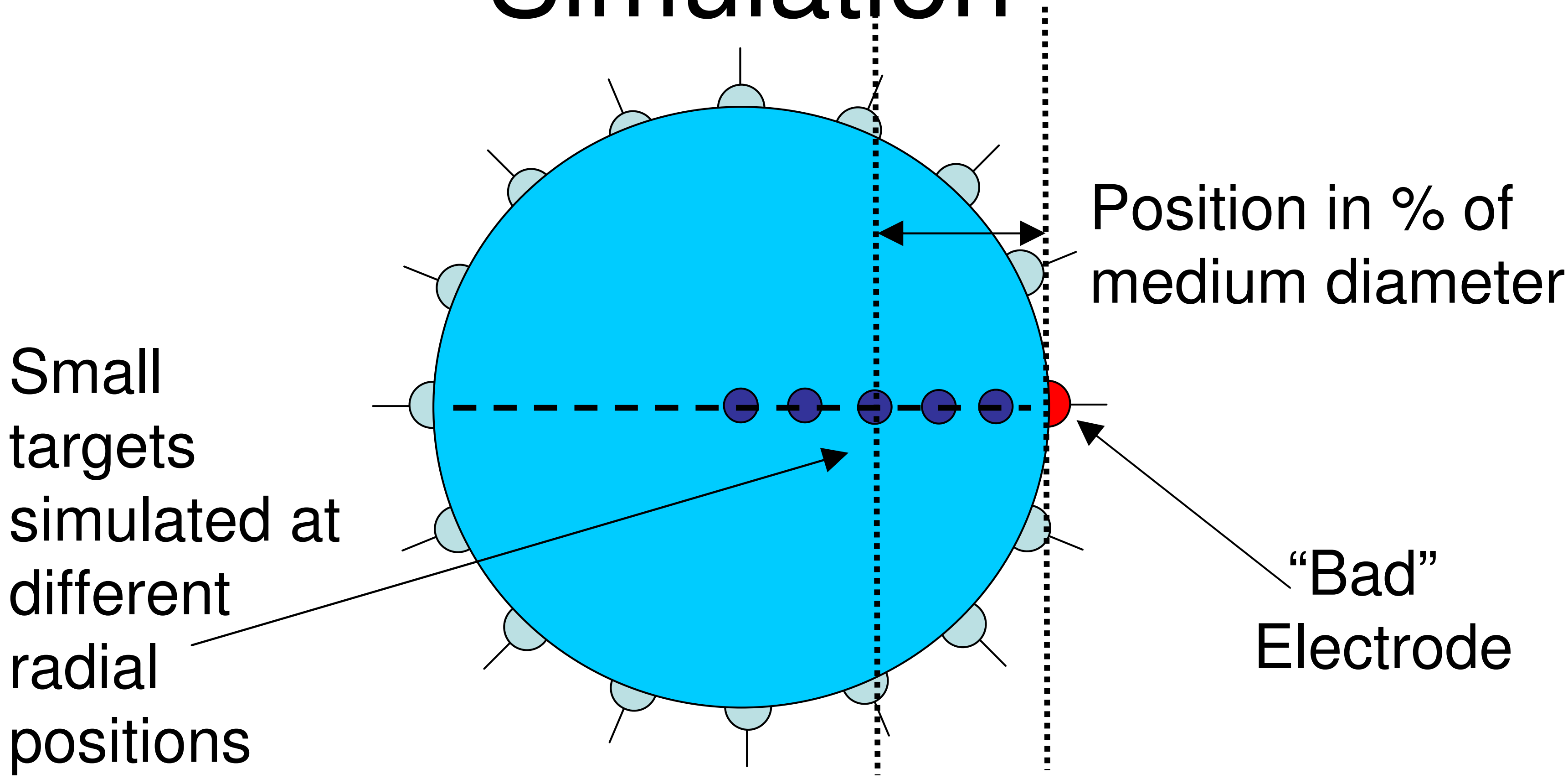


Regularized imaging solution

Electrode errors are large measurement noise on affected electrode



Simulation

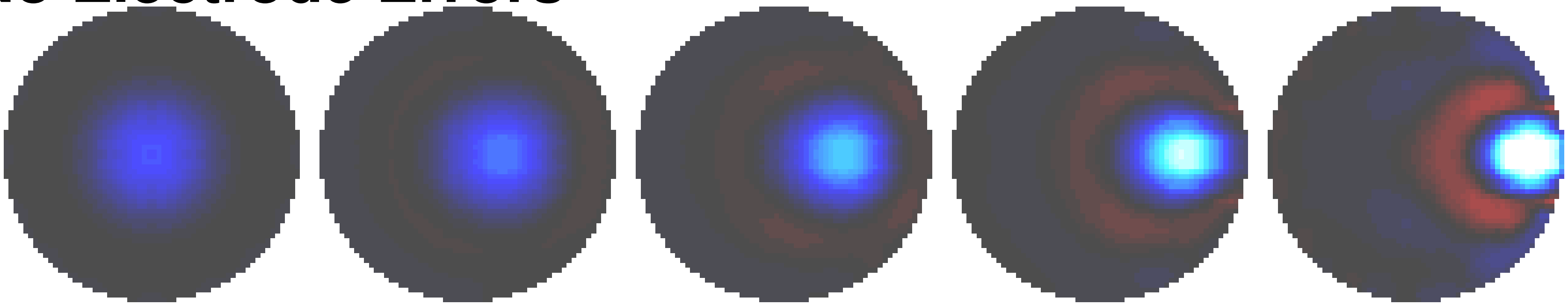


Data simulated with 2D FEM with 1024 elements

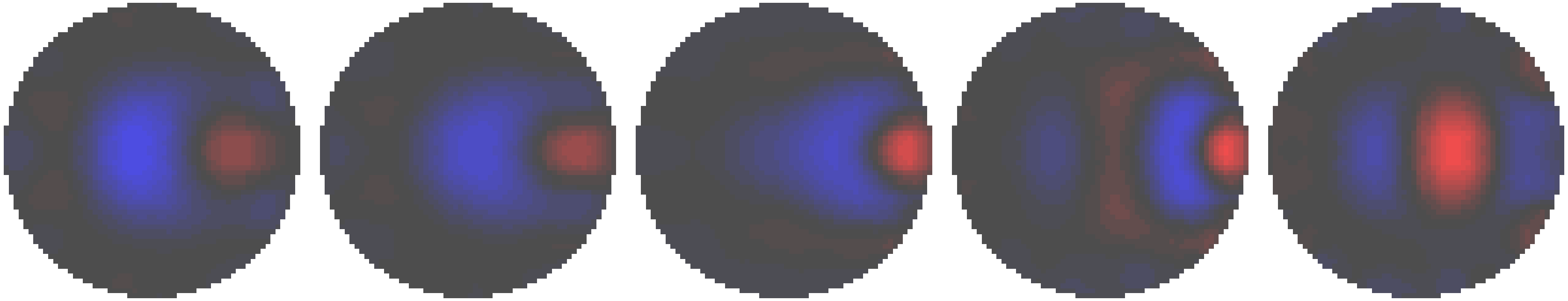
– not same as inverse model

Simulation results for opposite drive

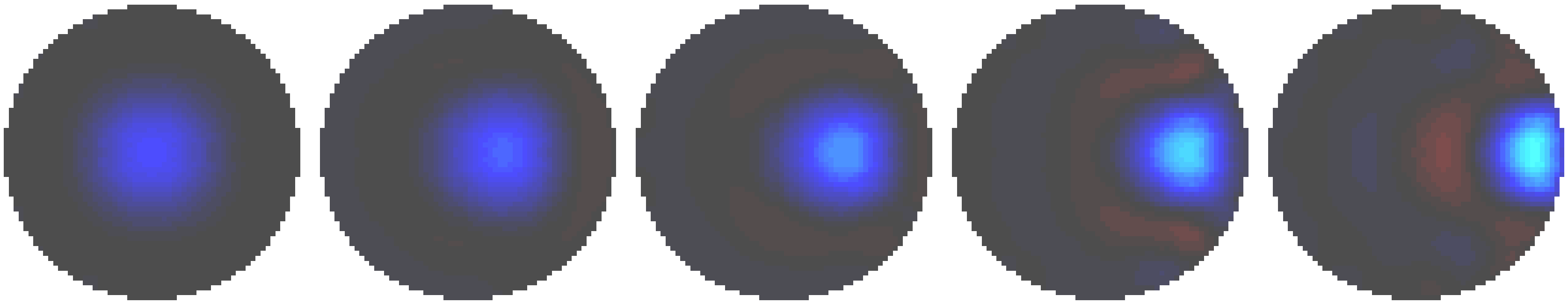
No Electrode Errors



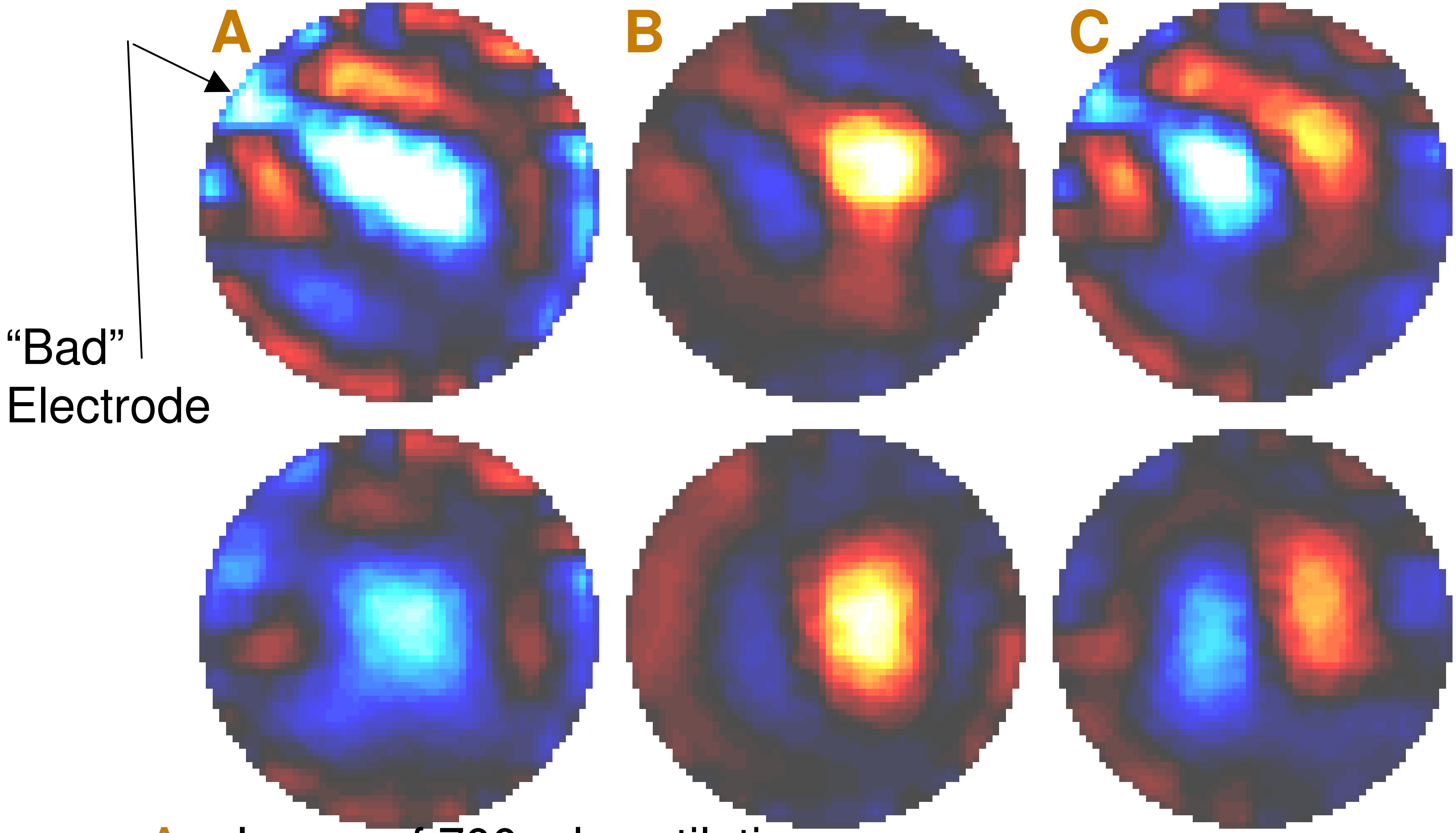
Zero Affected Measurements



Regularized Image

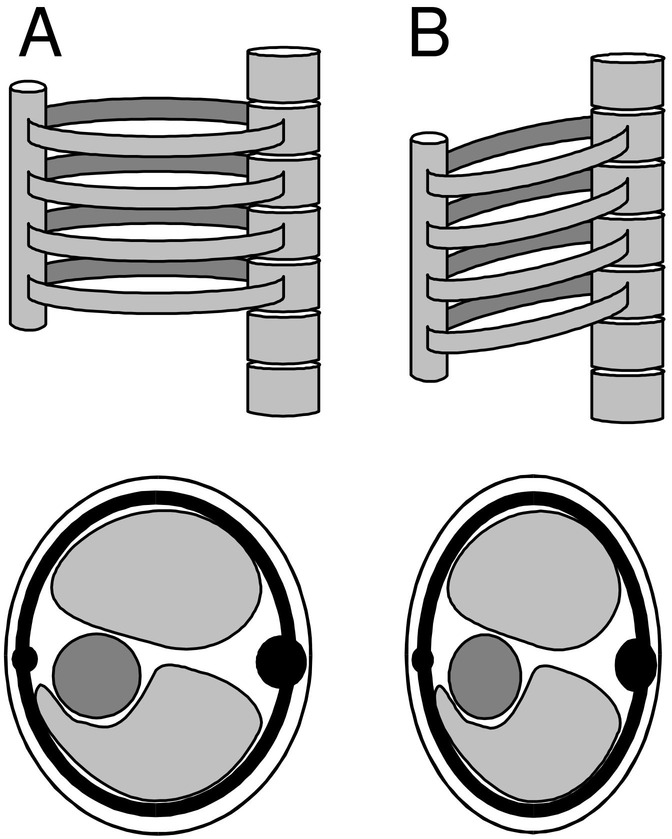


How does this work with real data?



A. Image of 700 ml ventilation
B. Image of 100 ml saline instillation in right lung
C. Image of 700 ml ventilation and 100 ml saline

Electrode Movement



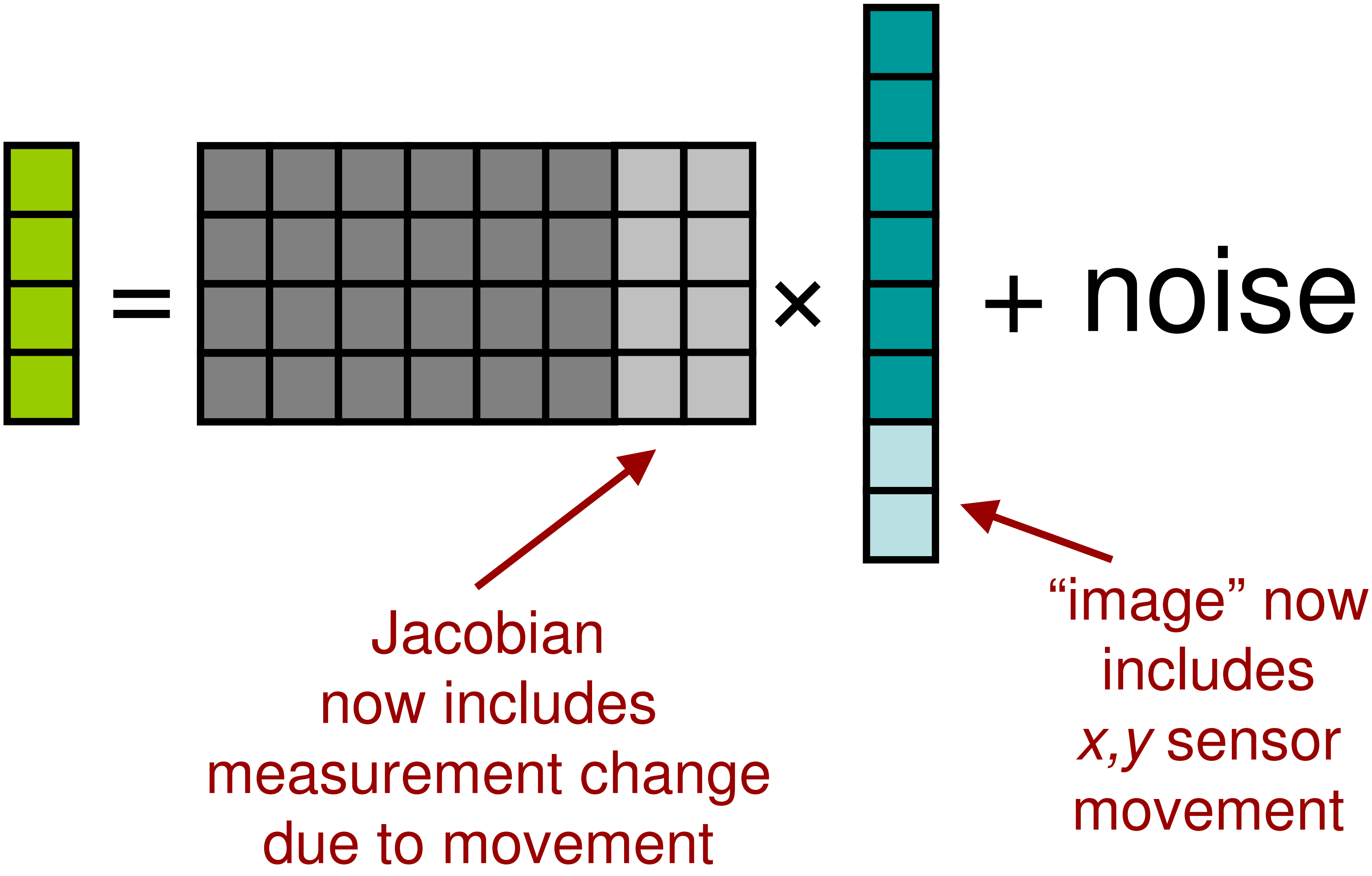
Electrodes move

- with breathing
- with posture change

Simulations show broad central artefact in images

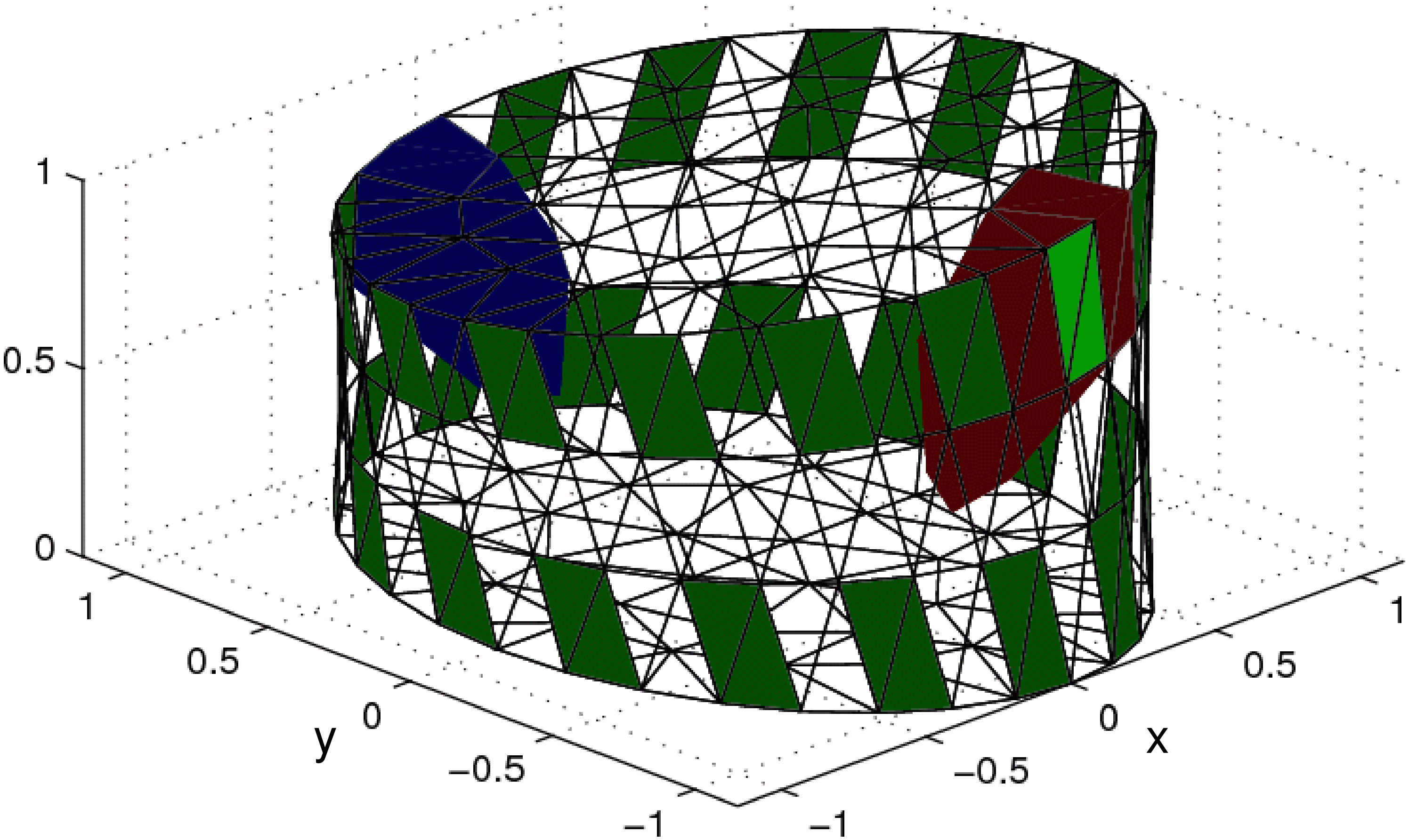
Imaging Electrode Movement

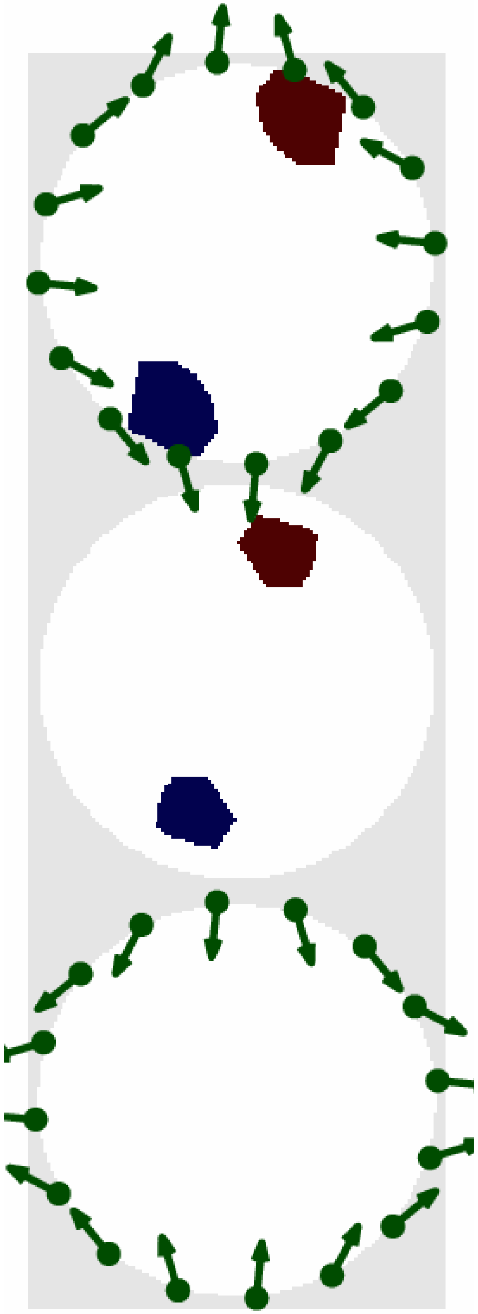
- Forward model *image* includes movement

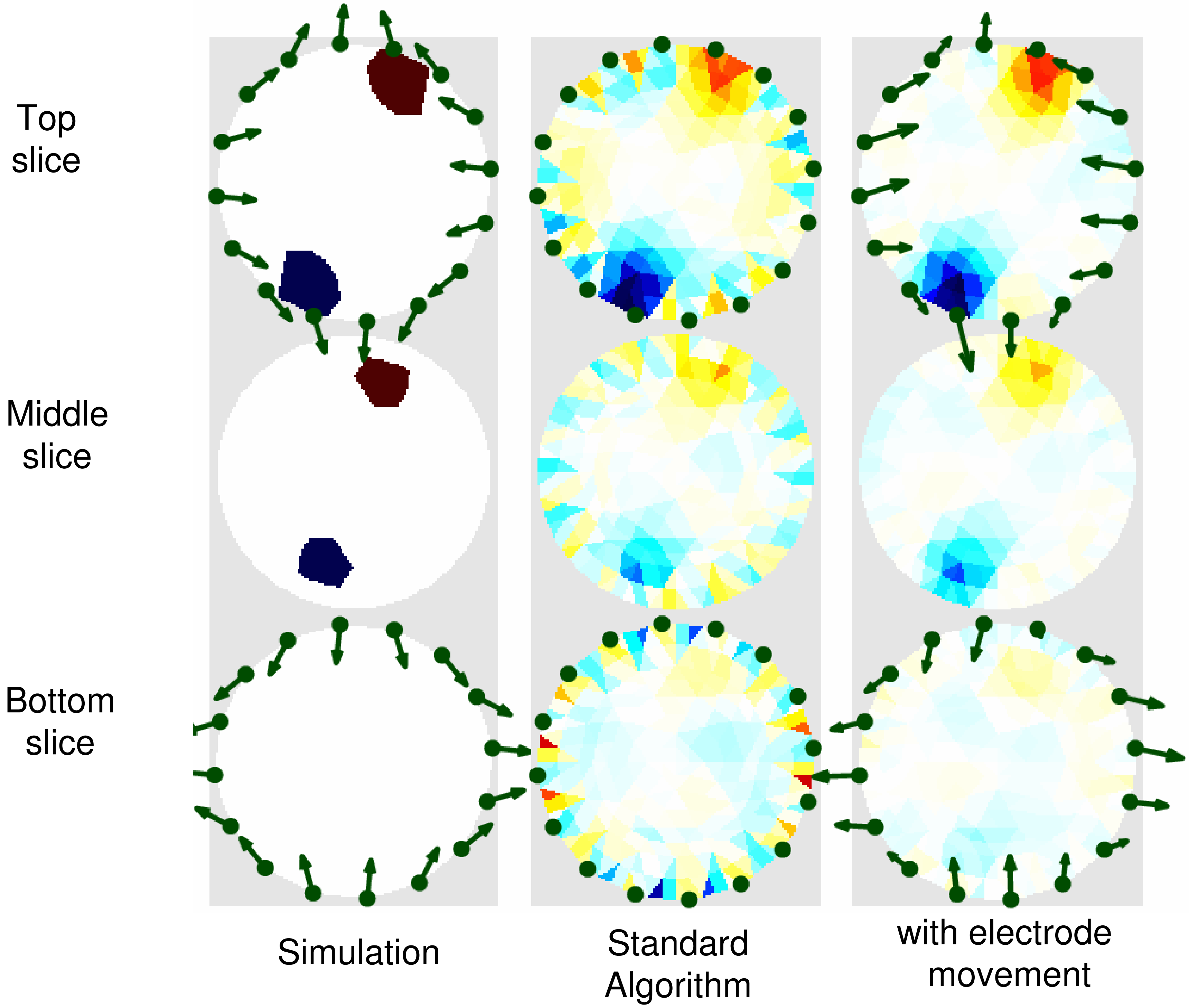


Images of electrode movement

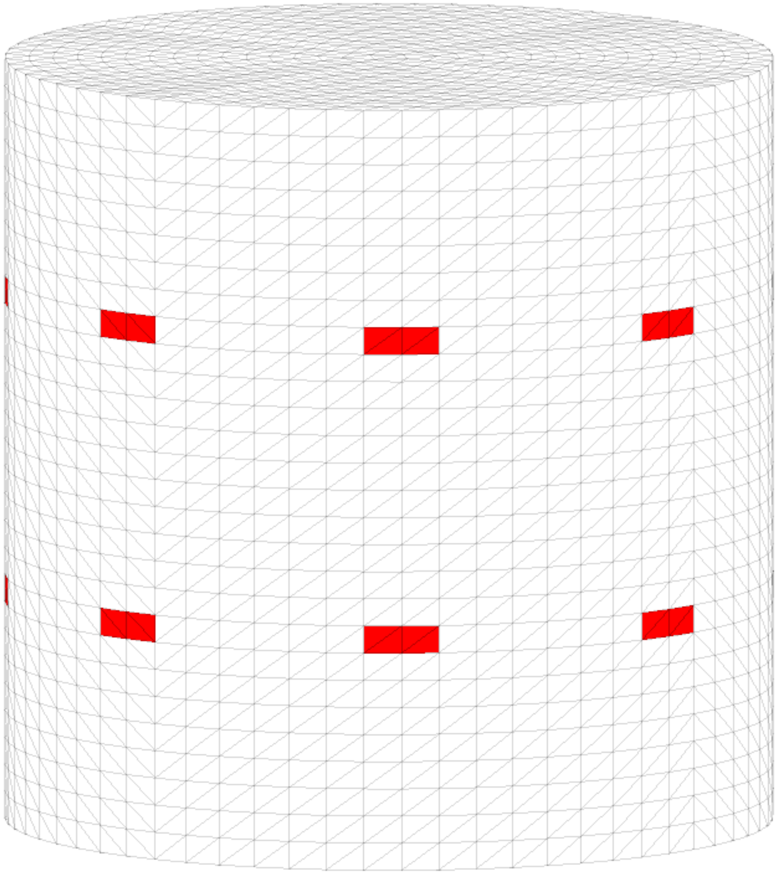
Simulation: tank twisted in 3D



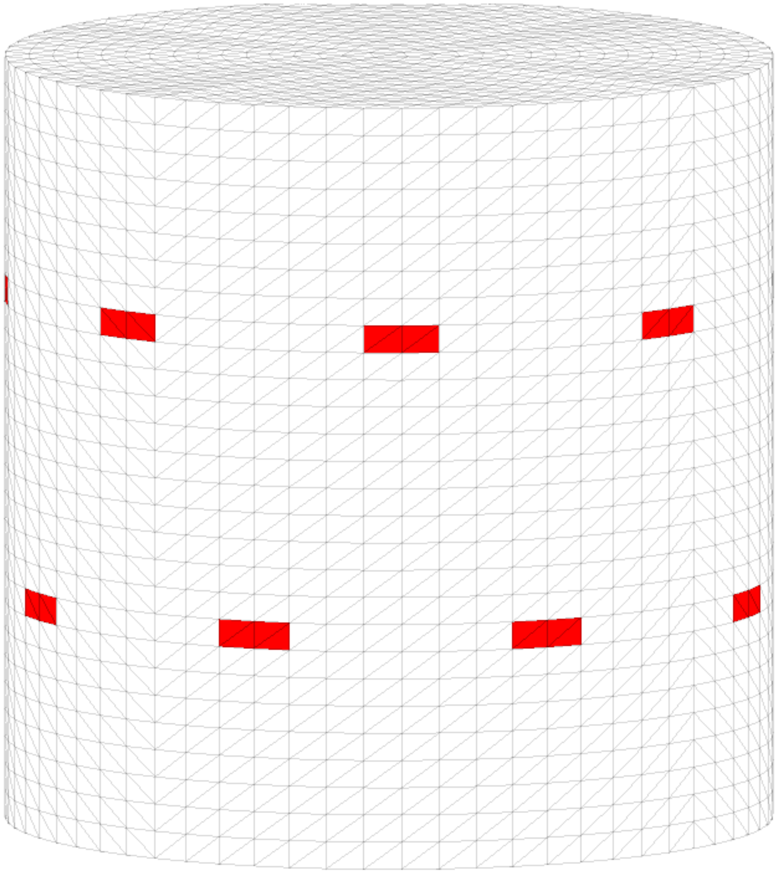



Top
slice
Middle
slice
Bottom
slice
Simulation
Standard
Algorithm
with electrode
movement

3D Electrode Arrangements using 16 electrodes



Aligned

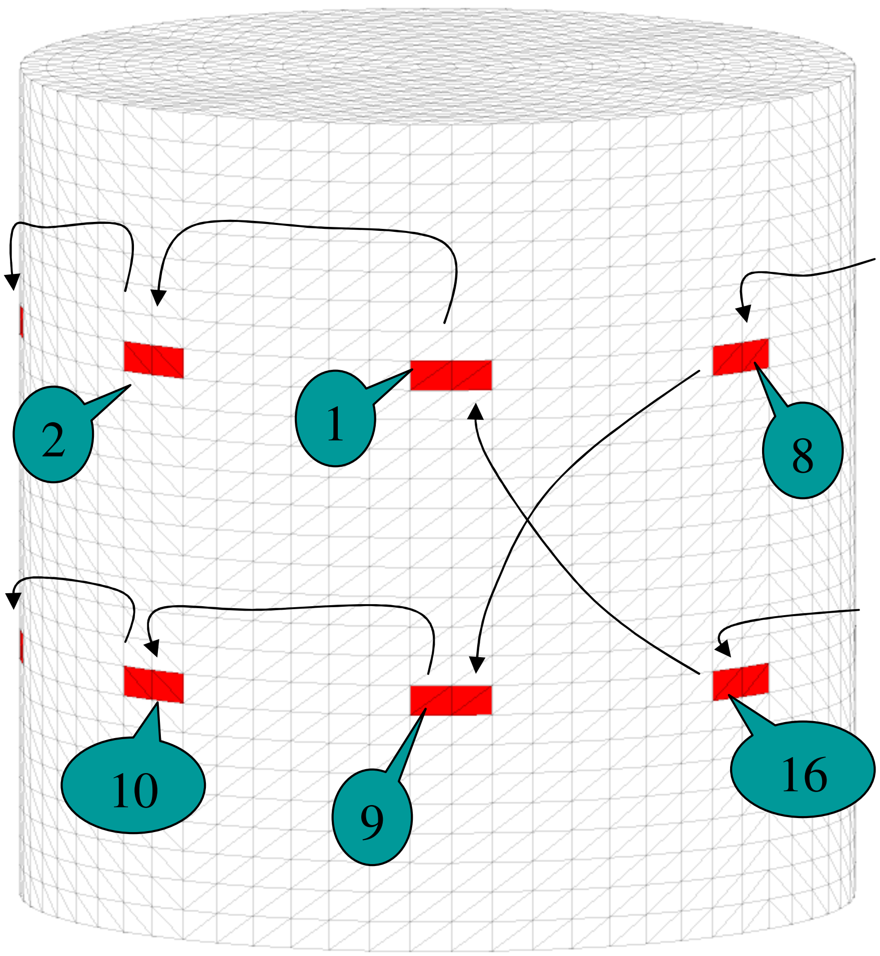


Offset

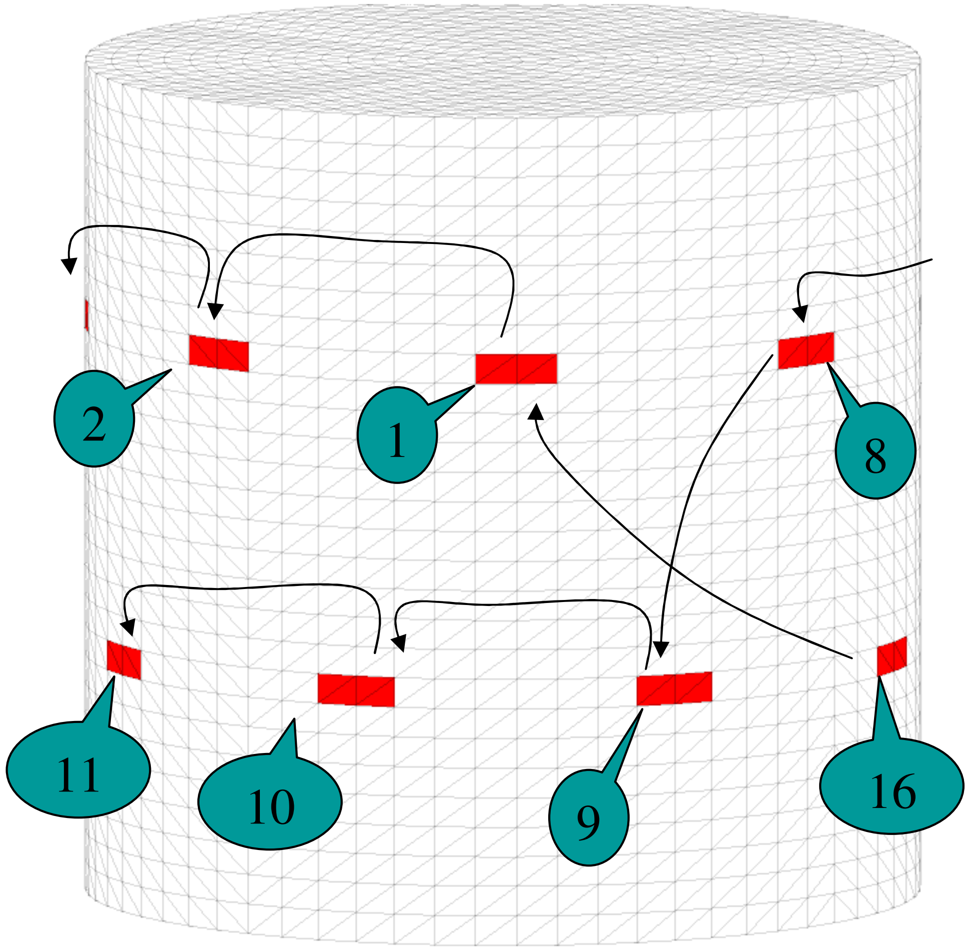
Electrode Sequencing

- Can put electrodes anywhere; algorithm knows and can interpret data
- Electrode Placement strategies to evaluate
  - Planar
  - Planar-Offset
  - Planar-Opposite
  - Zigzag
  - Zigzag-Offset
  - Zigzag-Opposite
  - Square

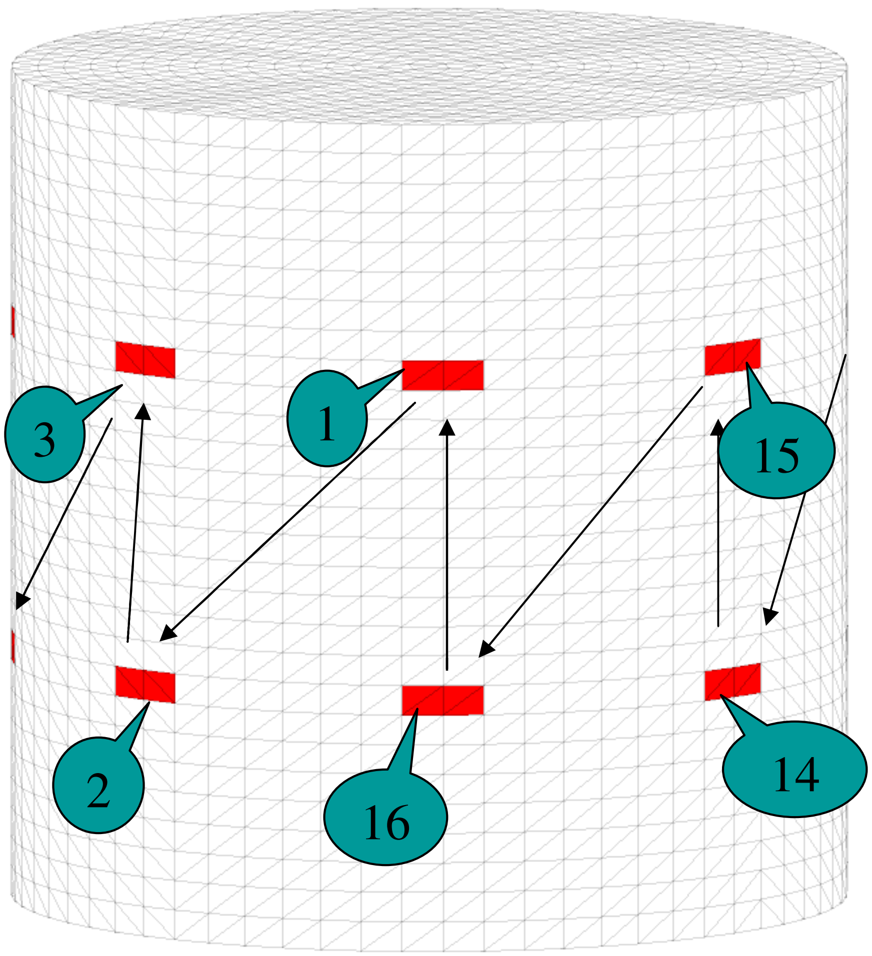
Planar



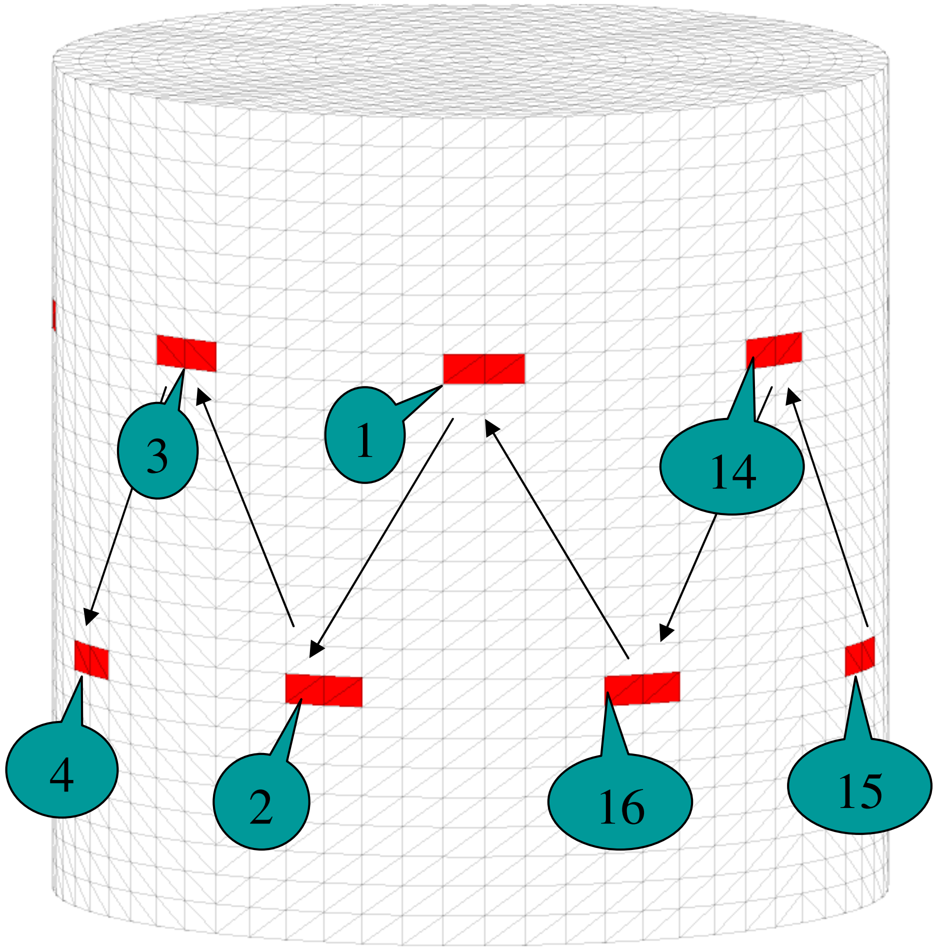
Planar-Offset



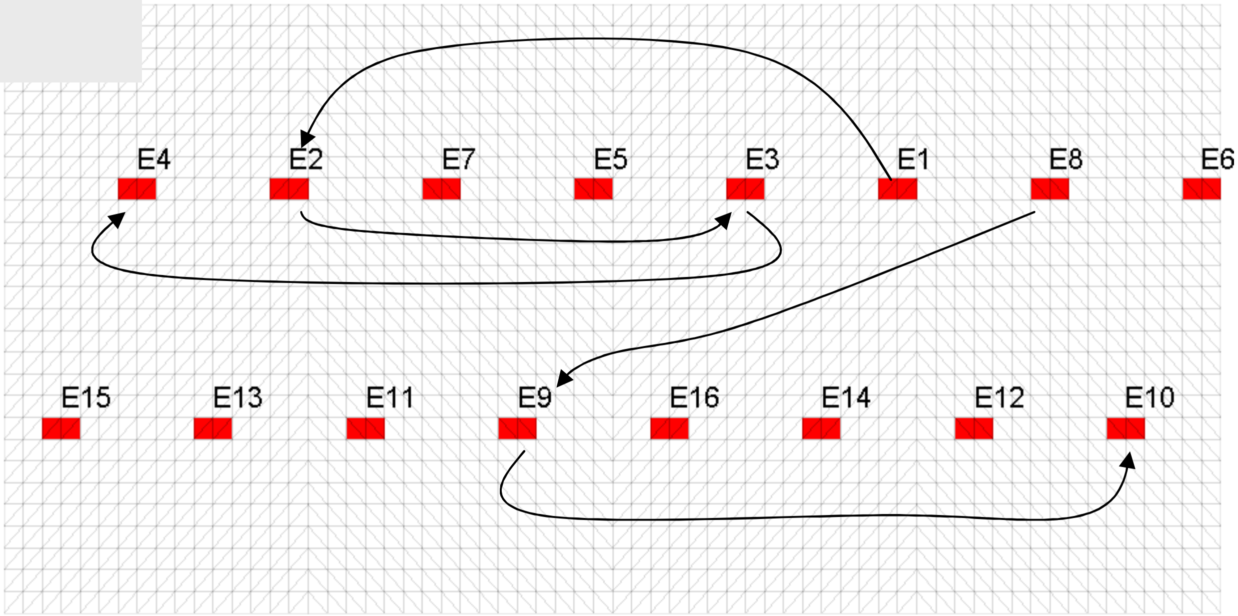
Zigzag



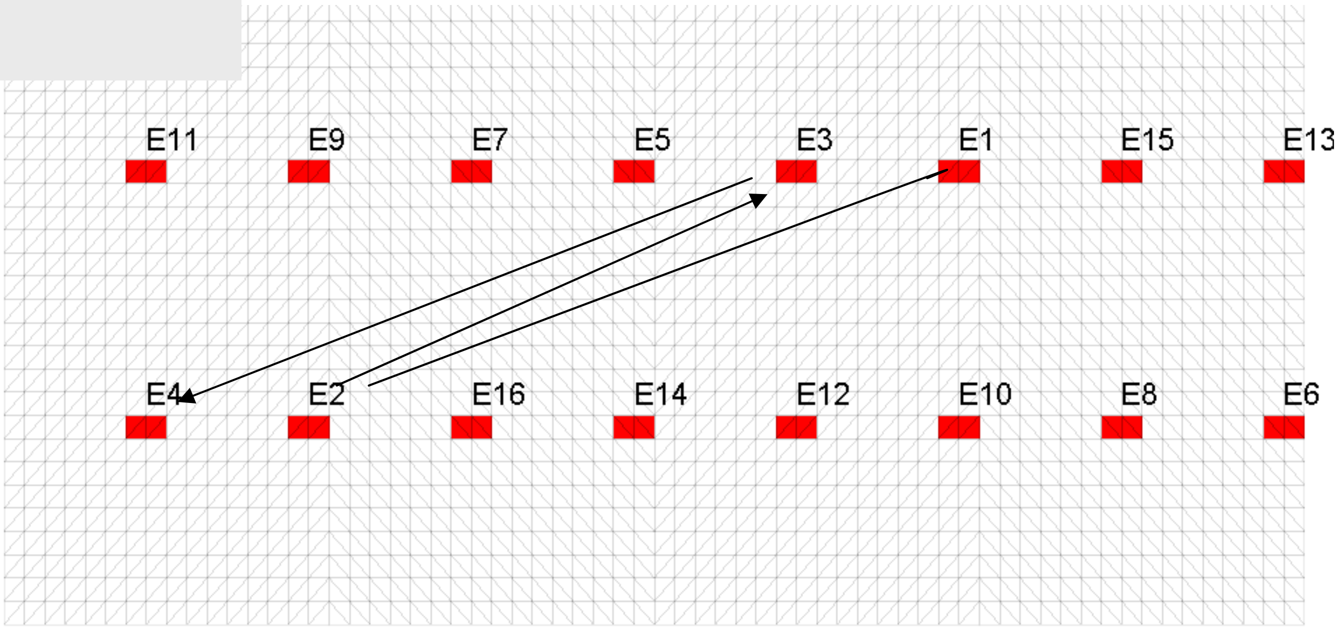
Zigzag-Offset



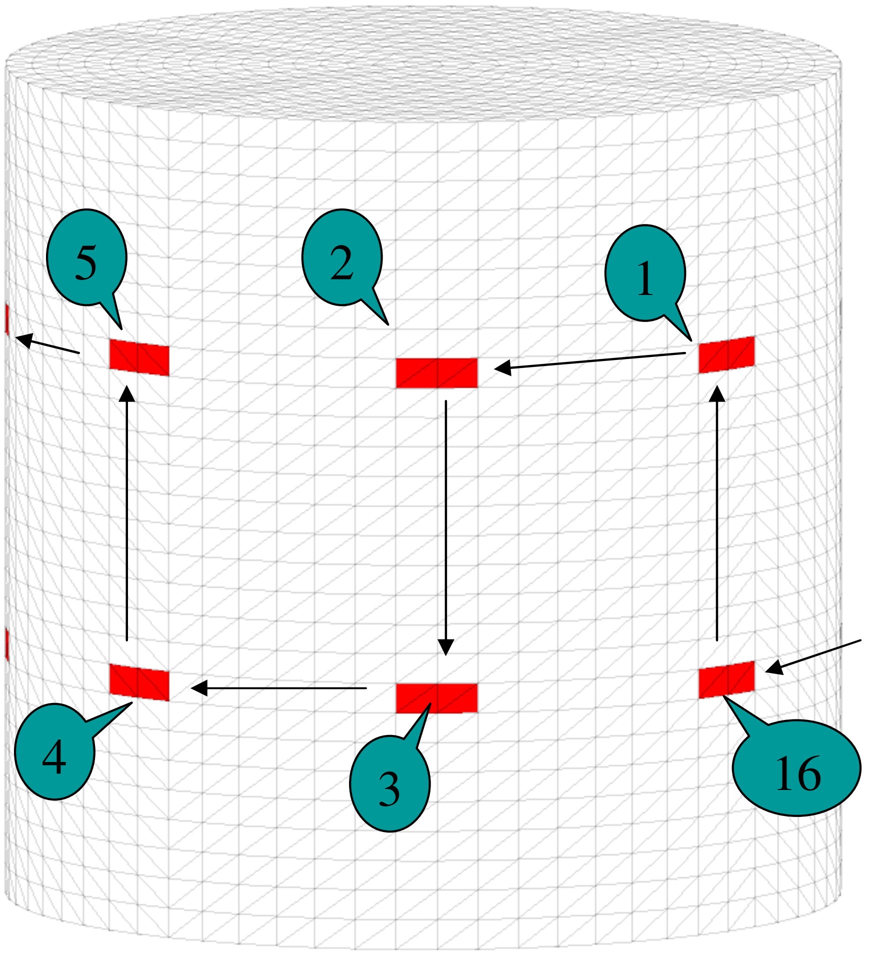
Planar-Opposite



ZigZag-Opposite



Square

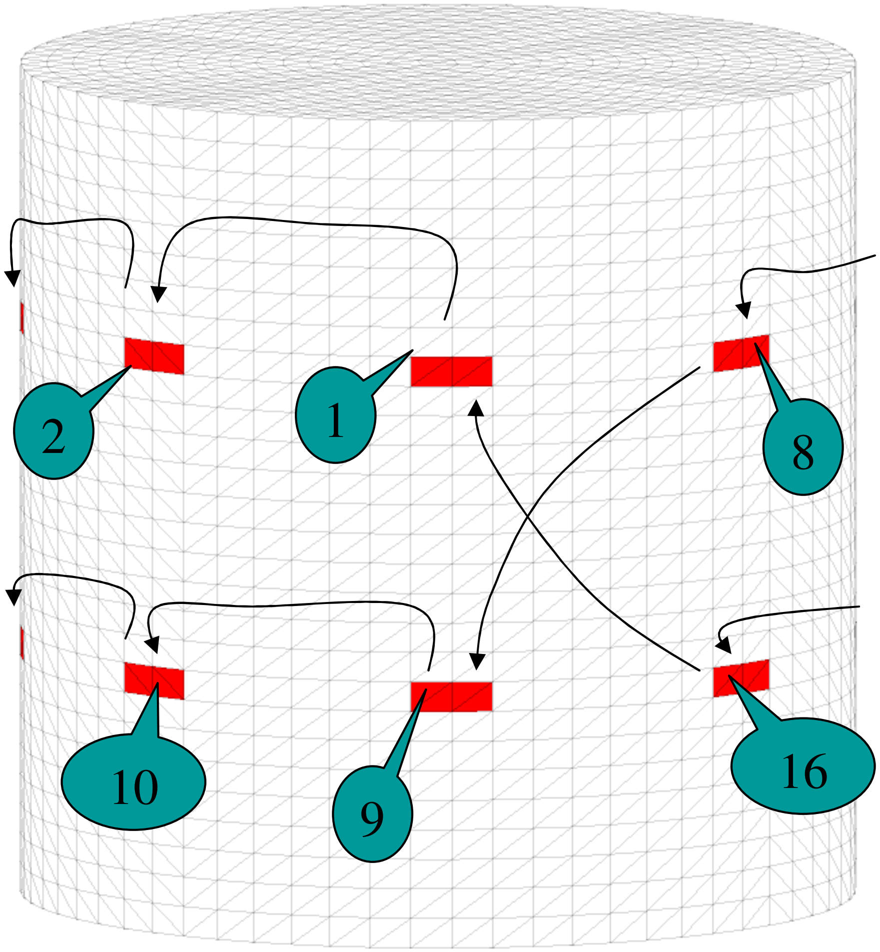


3D placement summary

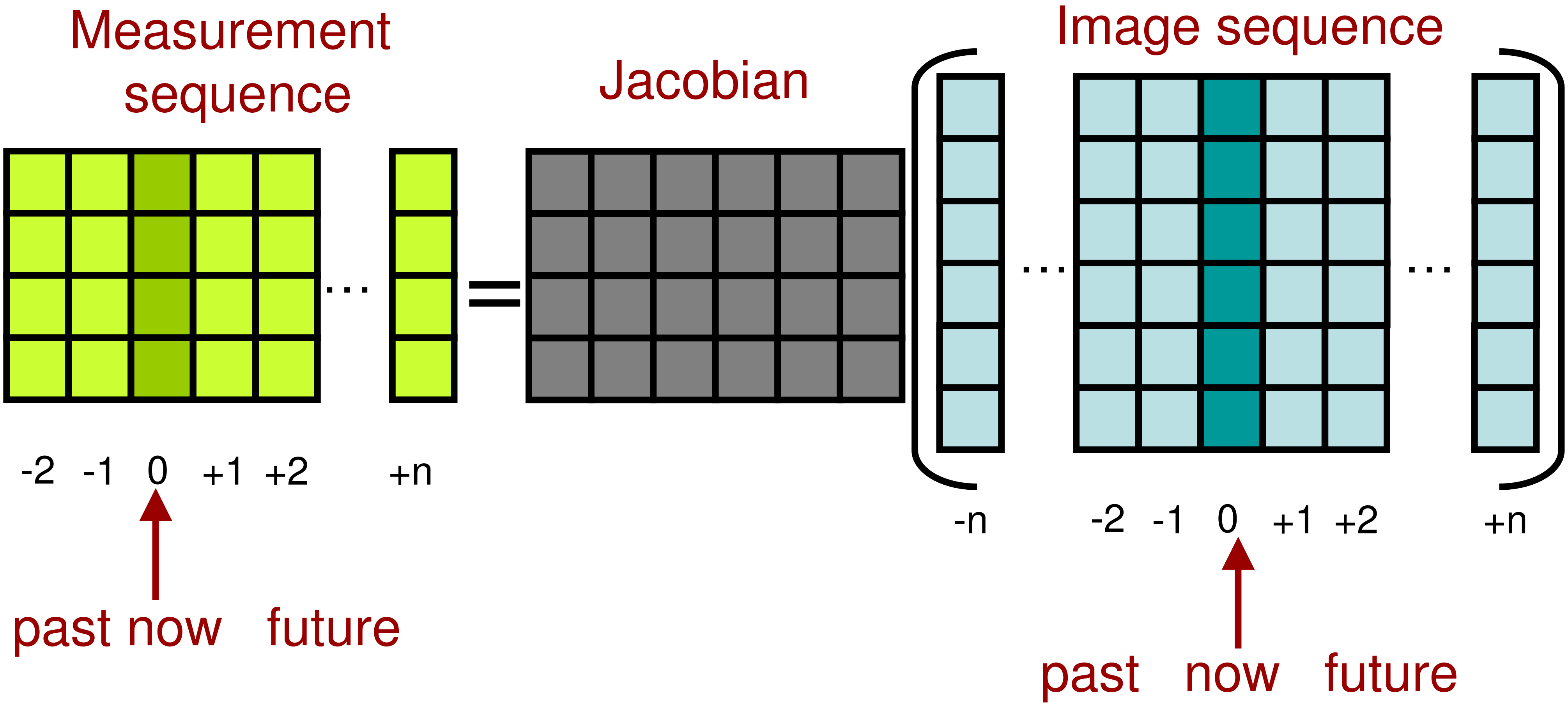
	Resolution	Vert. Posn Error	Radial Posn Error	Qualitative Image	Noise Performance	Layer Offset Error	Layer Sep Error
Planar				+	+	+	+
Planar-Offset				+	+	+	+
Planar-Opposite	-			+		--	--
Zigzag		--		-	--	+	-
Zigzag-Offset		--		--	--	-	-
Zigzag-Opposite	-			-			--
Square		--		+	-		--

Recommended 3D placement

- Planar and Planar-offset strategies are most robust.
- Planar placement is easiest

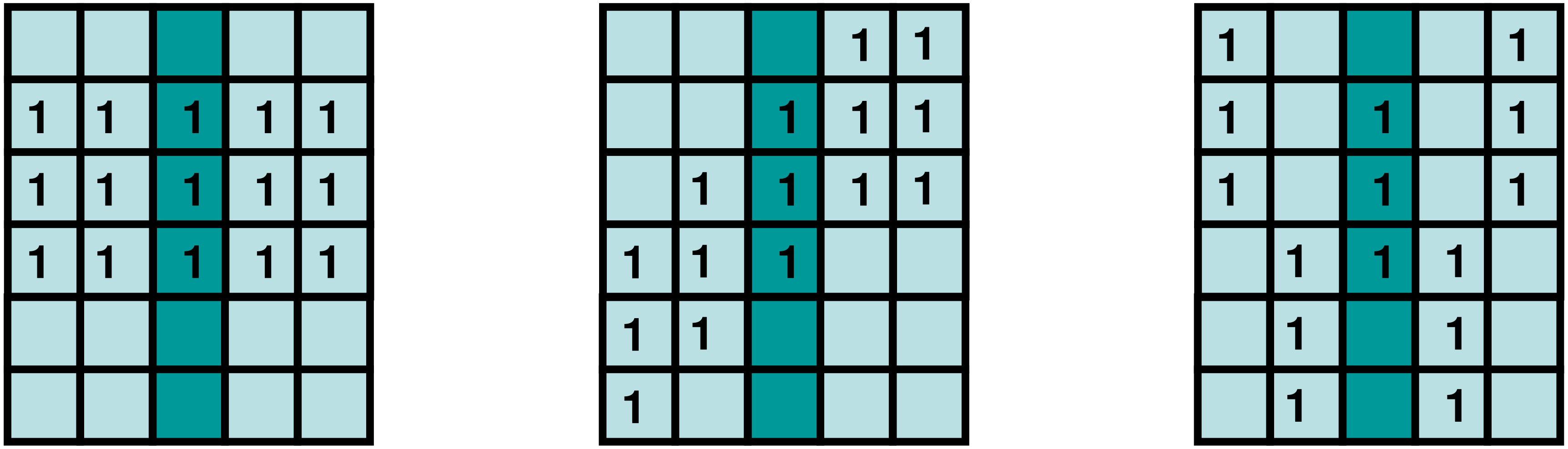


EIT makes fast measurements. Can we use this fact?



Temporal Reconstruction

Temporal Penalty Functions



likely   quite likely   unlikely

Standard EIT approaches to not take this into account

GN vs. Temporal Inverse

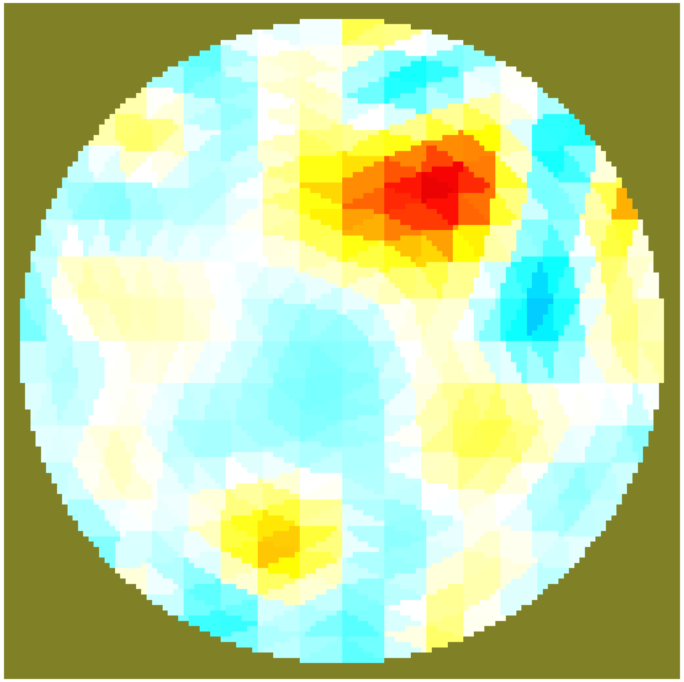
1. Noise free data (IIRC tank)
2. Data with added 6dB SNR noise

Gauss-Newton solver

Solve time = 5.33 s
(with caching) = 0.22 s

Temporal solver
(4 time steps)
Solve time = 34.81 s
(with caching) = 0.60 s

Gauss Newton vs. Temporal Inverse (6db SNR)



Gauss-Newton solver

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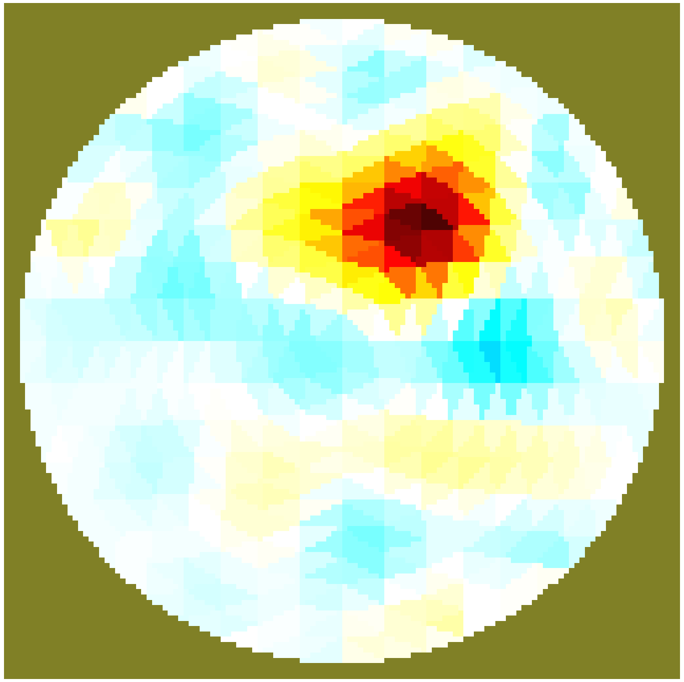


Temporal solver
(4 time steps)
Solve time = 34.81 s
(with caching) = 0.60 s

Non-blurring EIT

- Traditional EIT will dramatically blur reconstructed contrasts
- Iterative (ie slower) techniques exist to remove blur
- Problem – still low spatial resolution

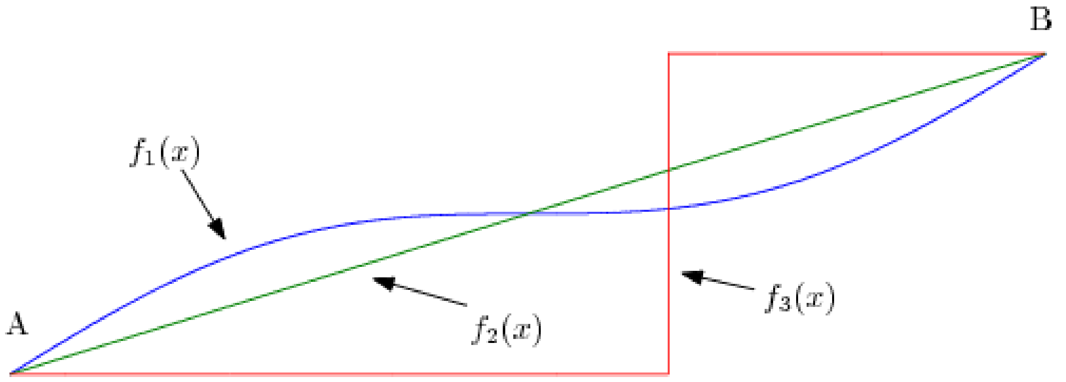
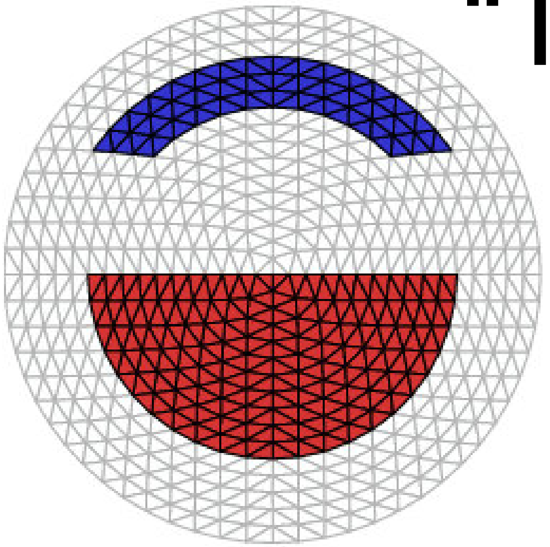
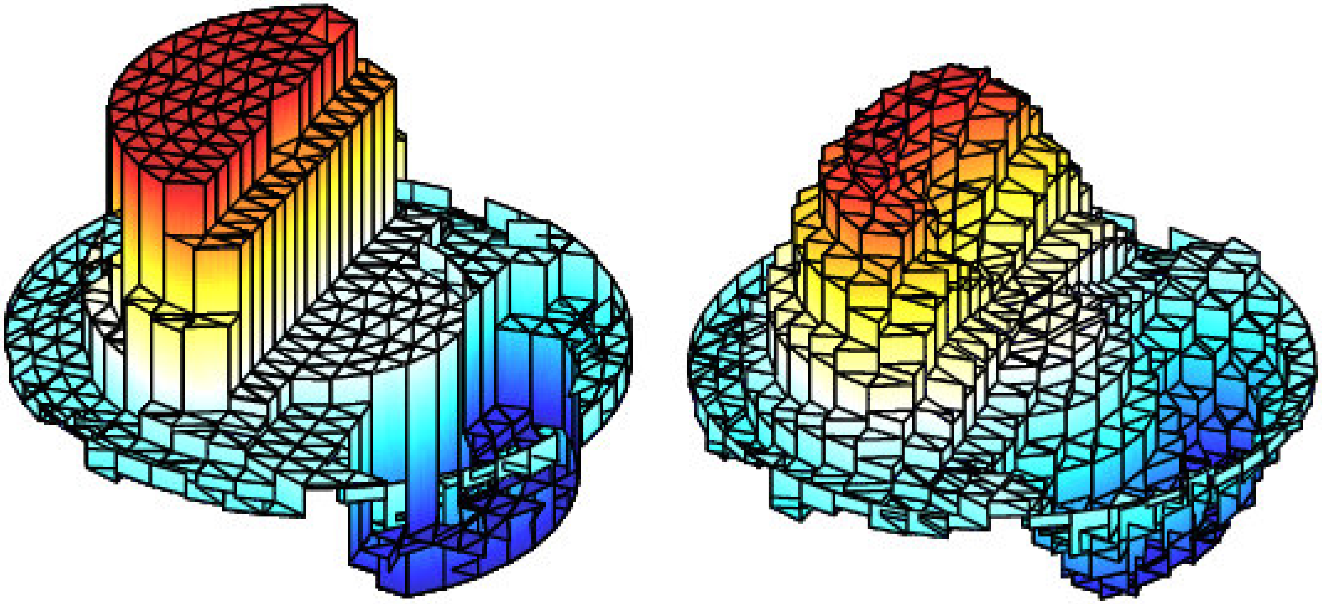


Figure 1. *Two points A and B can be connected by several paths. All of them have the same TV.*

"Total Variation" images



(b) *Phantom B*



(a) *TV solution at 8^{th} iteration* (b) *L^2 solution at 8^{th} iteration*

Figure 10. *Reconstructions of Phantom B with 2.5% AWGN.*

EIDORS: community-based extensible software for EIT

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[1]Systems and Computer Engineering, Carleton University, Ottawa, Canada

[2]School of Mathematics, University of Manchester, U.K.

EIDORS Tutorial

- Introduction to EIDORS
  - Goal
  - Features
- Examples (worked together)
  - Forward solutions
  - Inverse solutions
- Examples (worked alone)
  - Based on EIDORS tutorial (with V3.1)

Goal: software community

Project: **E**lectrical
Impedance and
Diffuse
Optical
Tomography
Reconstruction
Software

Blobby the Walrus?

1. EIT images blobby objects in aqueous media; Blobby the Walrus is a fat animal that lives in water.
2. Walrus is EIDORS logo
3. Walruses are much funnier than a talk about software architecture

Images credit: www.biosbcc.net
© Genny Anderson

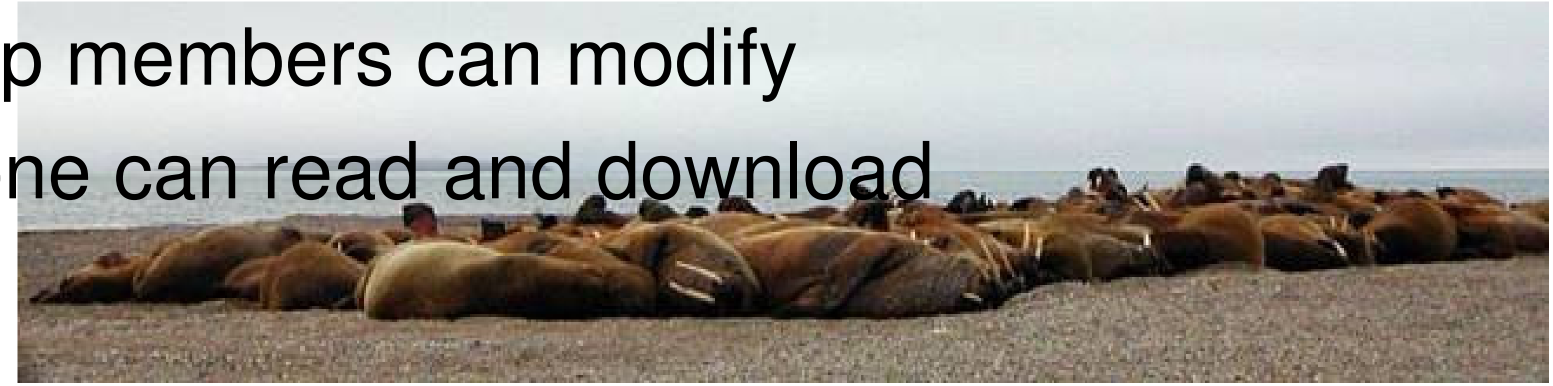
EIDORS Features

Open-source:

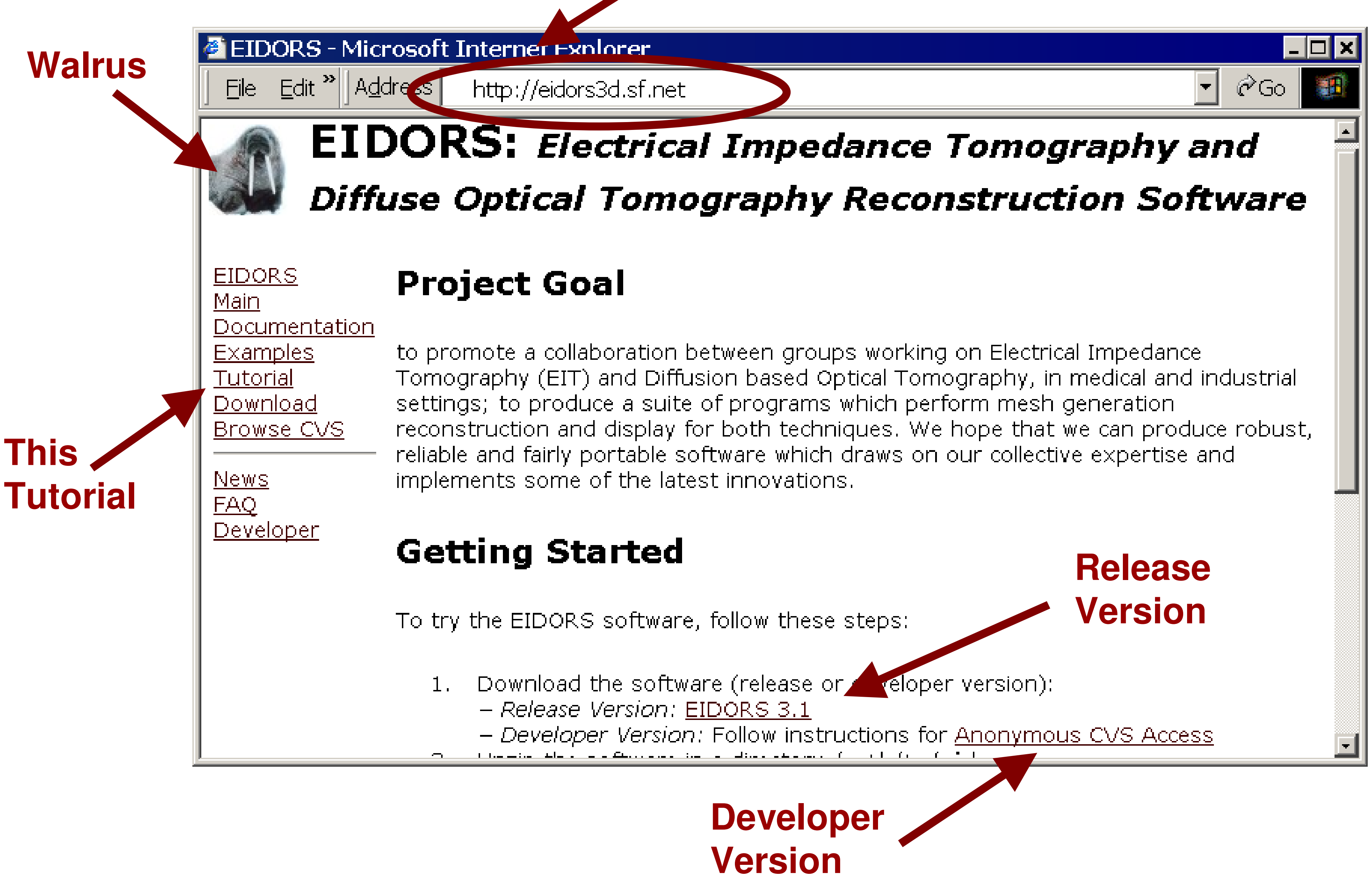
- License: GNU General Public License.
- Free to use, modify, and distribute modifications.
- May be used in a commercial product

Hosted on Sourceforge.net

- Software is available for download (version 2.0)
- CVS access to latest developer versions
- Group members can modify
- Anyone can read and download



Web Site


Walrus
This Tutorial
Release Version
Developer Version
EIDORS - Microsoft Internet Explorer
File Edit
Address http://eidors3d.sf.net
Go
EIDORS: Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software
EIDORS
Main
Documentation
Examples
Tutorial
Download
Browse CVS
News
FAQ
Developer
Project Goal
to promote a collaboration between groups working on Electrical Impedance Tomography (EIT) and Diffusion based Optical Tomography, in medical and industrial settings; to produce a suite of programs which perform mesh generation reconstruction and display for both techniques. We hope that we can produce robust, reliable and fairly portable software which draws on our collective expertise and implements some of the latest innovations.
Getting Started
To try the EIDORS software, follow these steps:
1. Download the software (release or developer version):
– Release Version: EIDORS 3.1
– Developer Version: Follow instructions for Anonymous CVS Access

Features

Language independence:

- Octave (octave.org, ver≥ 2.9)
- Matlab (version ≥ 6.0).

Usage examples:

- new software is based on demos.
- simple and more complex usage examples.

Tests:

- Software is intrinsically difficult to test.
- Numerical software is probably more difficult
- Implement of regression test scripts

Features

Pluggable code base:

- Object-oriented: *Packaging* and *Abstraction*.
- Don’t use the Matlab OO framework
- Instead, EIDORS designed as "Pluggable" software using function pointers.

Features

Automatic matrix caching:

- Save computationally expensive variables
  - ie Jacobian , Image priors.
- Caching complicates software
- Caching managed in `eidors_obj`

Features

Generalized data formats:

- EIT has a wide variety of stimulation, measurements
- general EIT data format : *fwd_model*
  - electrode positions
  - contact impedances
  - stimulation and measurement patterns.

Interface software for common EIT systems:

- Load data from some EIT systems
- Please contribute

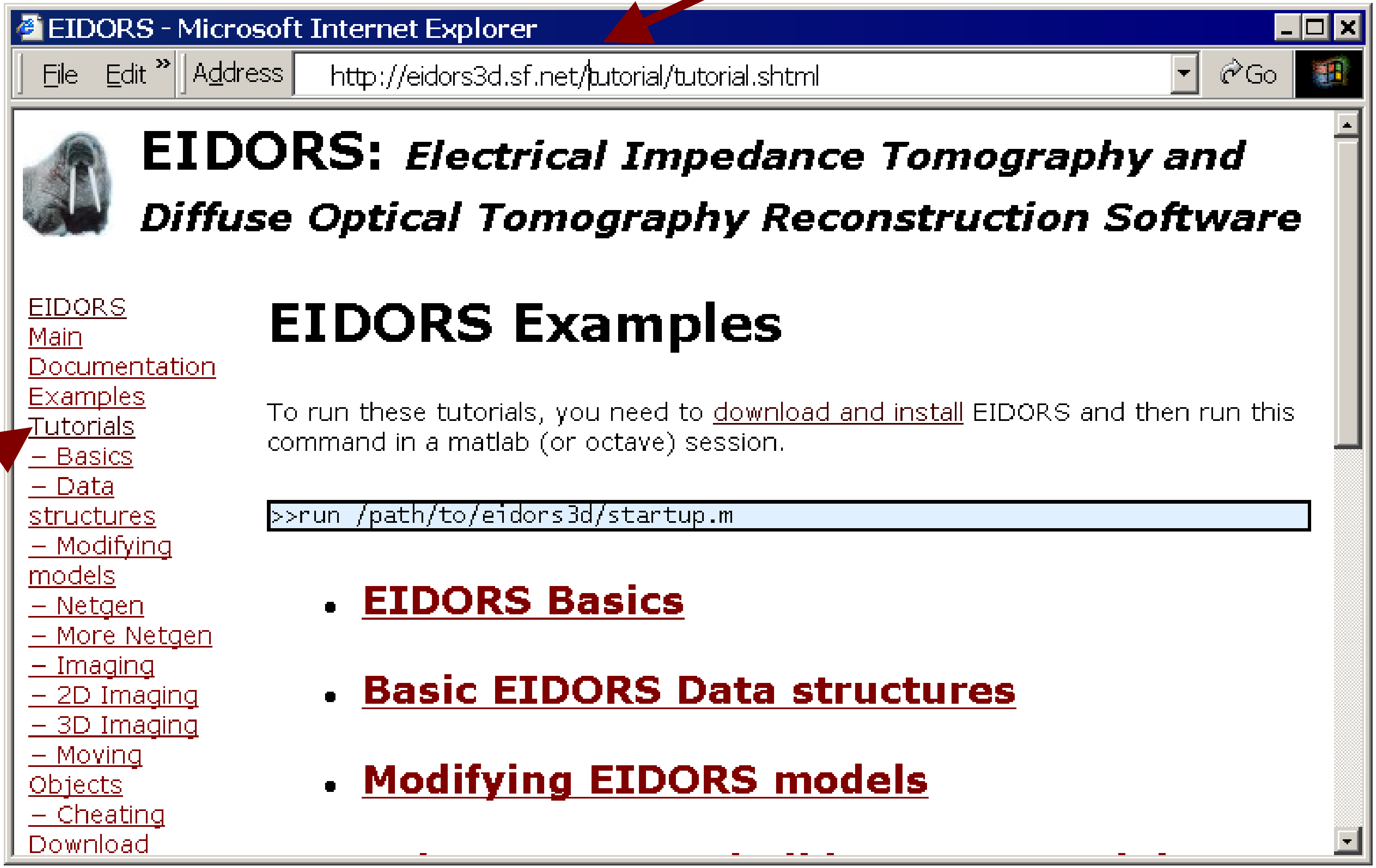
getting started

- Download
  - Run tutorial examples
- Join Mailing list

  `eidors3d@listserv.umist.ac.uk`
- Sign up as developer at:
  `sourceforge.net`
- Contribute your code

Tutorials

Also tutorial.shtml
In eidors-v3.1 distribution



Tutorials

Summary

- EIT and Image Reconstruction
  - Electrode Errors
  - Electrode Movement
  - Temporal Filtering
  - EIDORS Project
- Significant recent developments in EIT image algorithms will improve EIT's clinical applicability

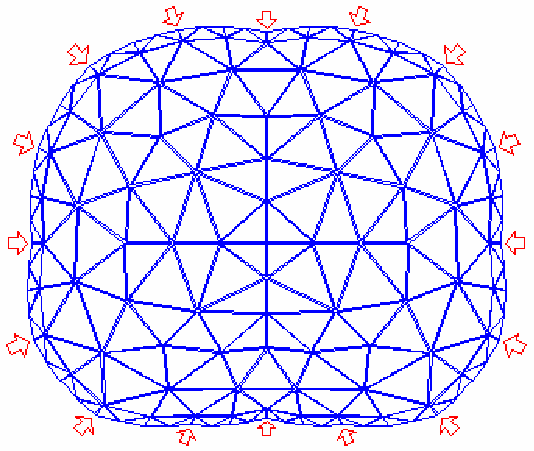
Is backprojection bad?

Yes

- No Mathematical Model – poorly understood artifacts
- Pushes objects into centre
- Can't handle arbitrary electrode placements
- No 3D
- Must be done on a circular thorax

No

- Handles position Error
- Maybe good enough for rough model



What do clinical people want from algorithm people?

- Better accuracy?
- More stable
- Automatic detection of errors

- How much more accurate data (ie. electrode placement) are clinical people prepared to make