Imaging with Impedance: Can We Guide Lung Ventilation?

Andy Adler

Systems and Computer Engineering,

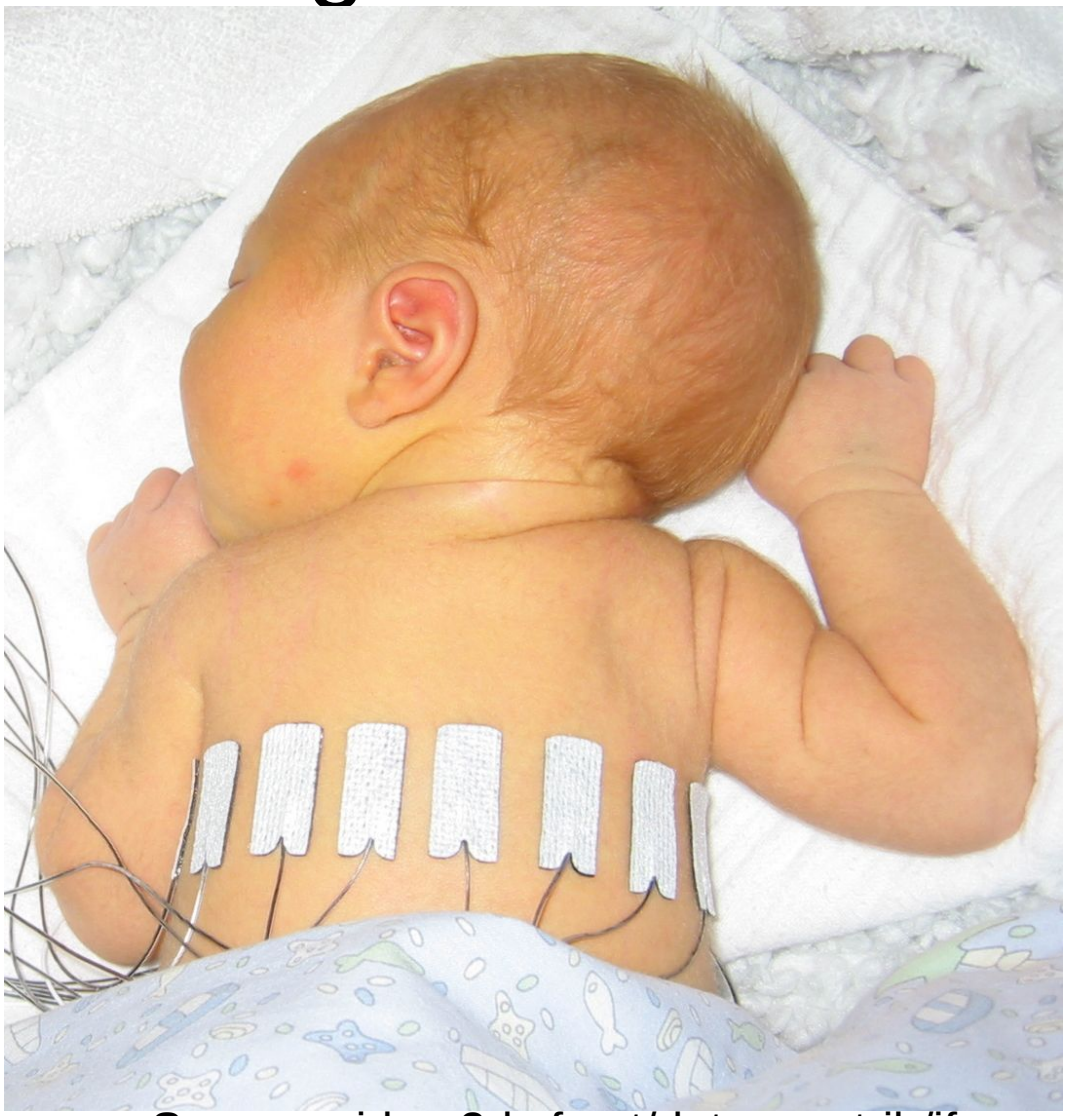
Carleton University,

Ottawa, Canada

Outline

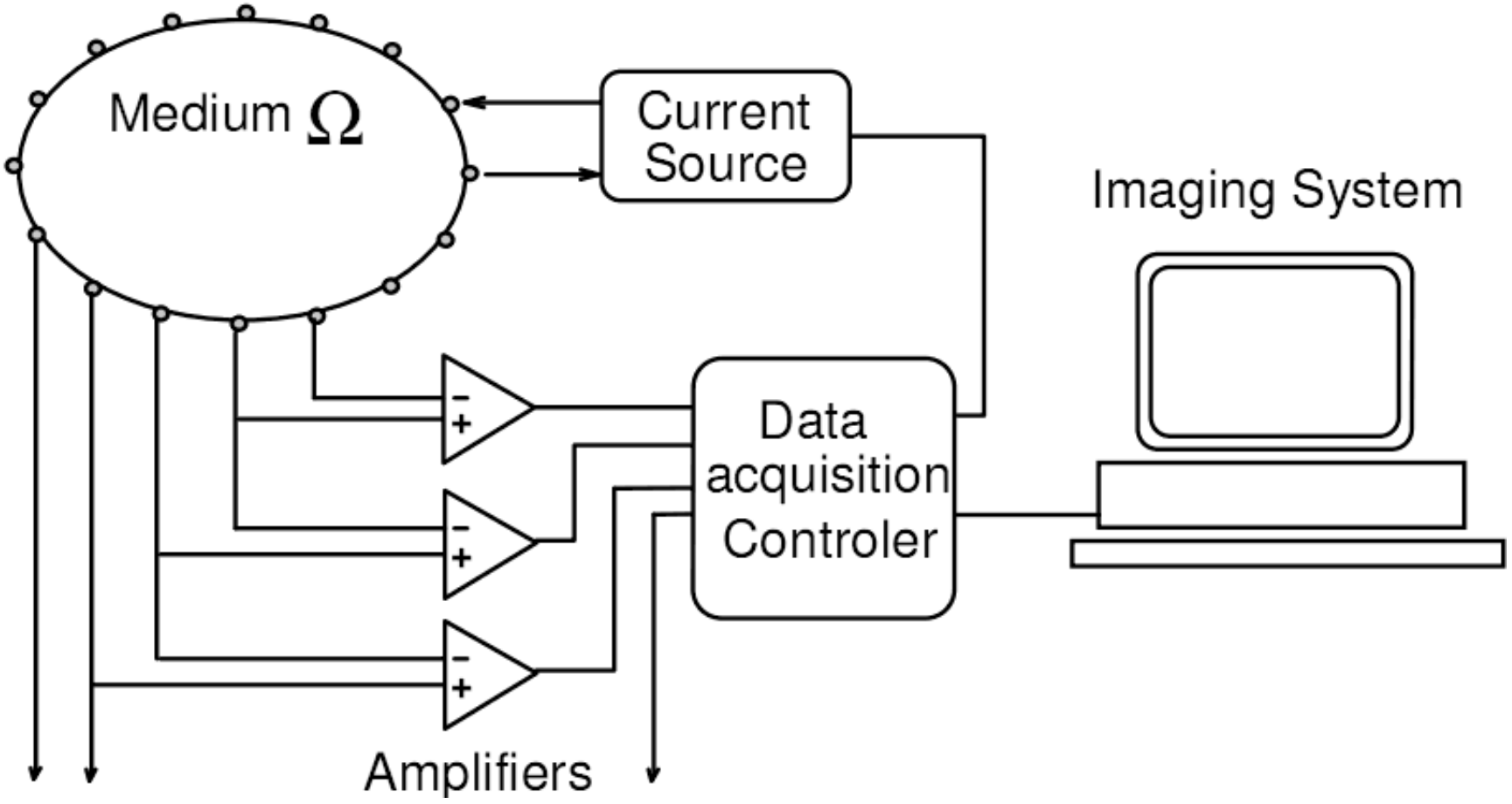
- Imaging with Impedance
  - Electrical Impedance Tomography
- Lung monitoring
- Reconstruction of images
  - Data artefacts
  - Movement compensation
  - Total Variation
- EIDORS + Open Source Software

Electrode placement to monitor the lungs and heart

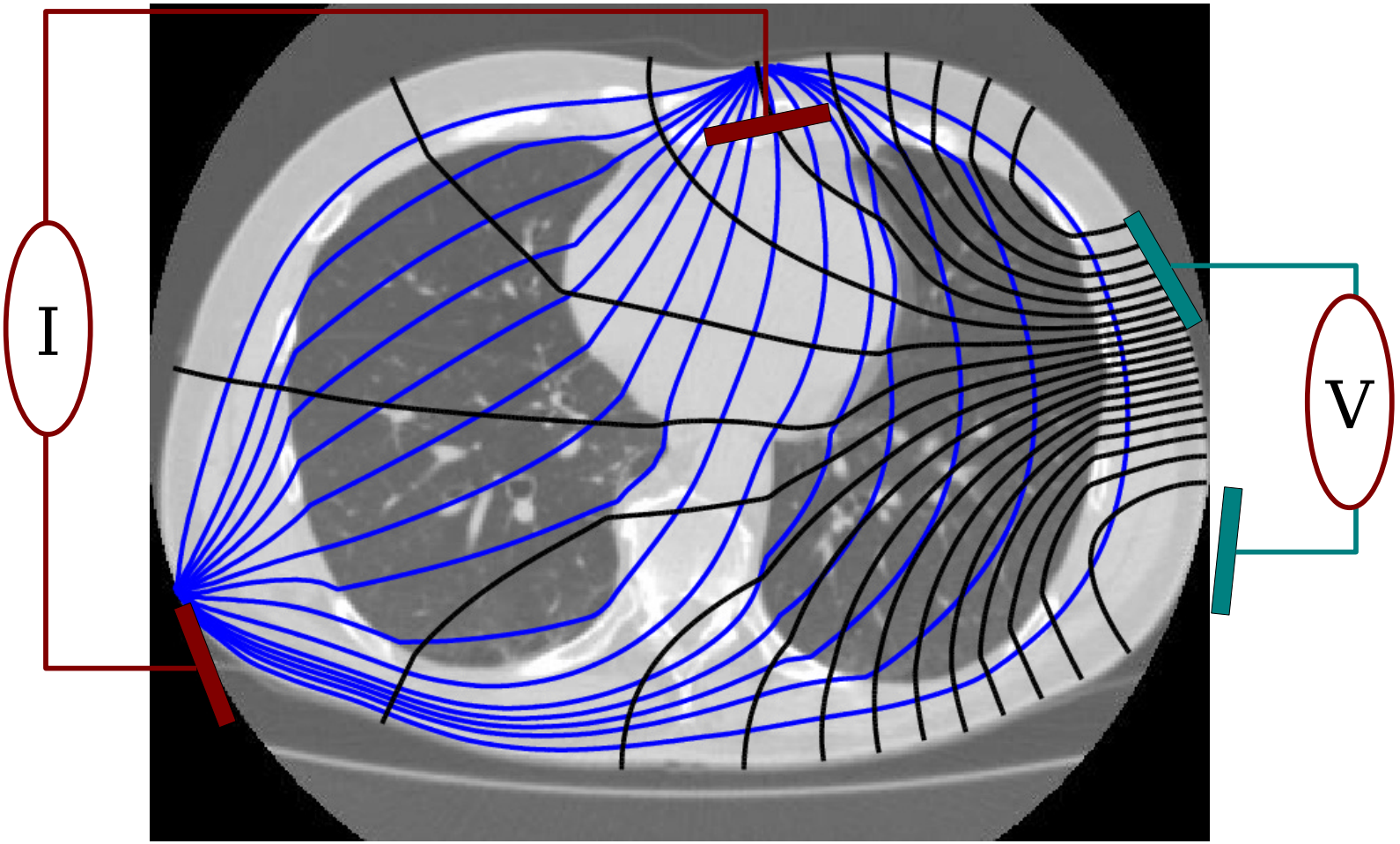


Source: eidors3d.sf.net/data_contrib/if-neonate-spontaneous

EIT: Block Diagram

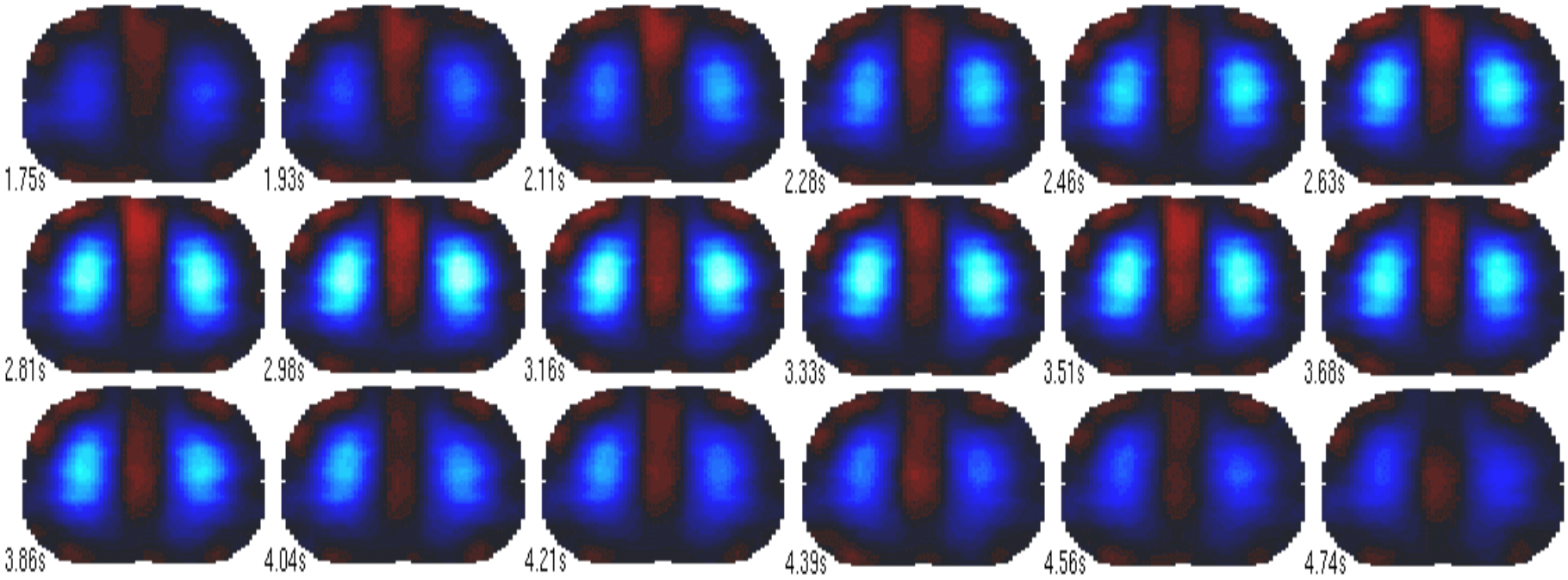


Current streamlines and voltage equipotentials



Source: eidors3d.sf.net/tutorial/netgen/extrusion/thoraxmdl.shtml

Application: Breathing

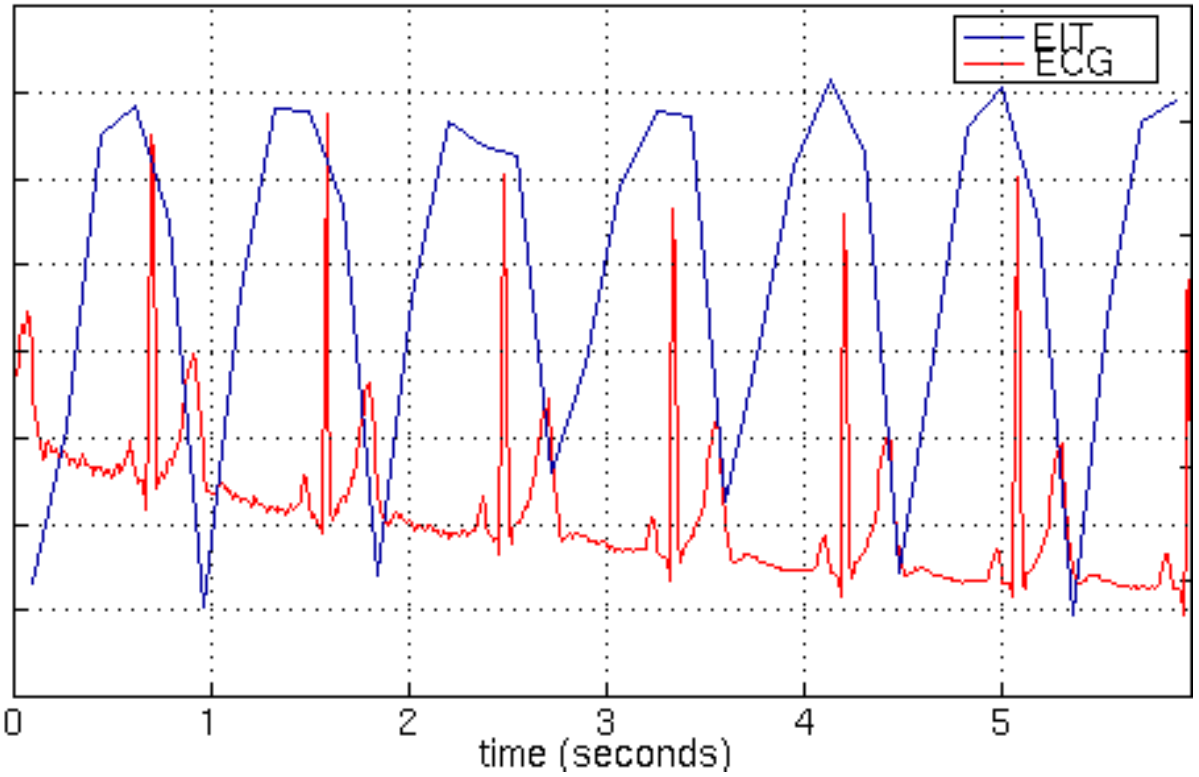


Chest images of tidal breathing in healthy adult

(7 frames / second)

(*me, when I was young, and healthy - 1994)*

Application: Heart Beat



EIT signal in ROI around heart and ECG

Why image lungs?
Respiratory Failure

Inadequate gas exchange by the respiratory system.

Hypoxemia $PaO_2 < 60$ mmHg or Hyercapnia $PaCO_2 > 45$ mmHg

Causes

- Pulmonary dysfunction
  - Asthma ,Emphysema , Chronic obstructive airway disease, Pneumonia , Pneumothorax, Hemothorax, Acute Respiratory Distress Syndrome (ARDS), Cystic Fibrosis
- Cardiac dysfunction
  - Pulmonary edema, Arrhythmia, Congestive heart failure, Valve pathology

Treatment

- Emergency treatment: cardiopulmonary resuscitation.
- Treatment of the underlying cause
- Mechanical ventilation

Ref: Wikipedia.org

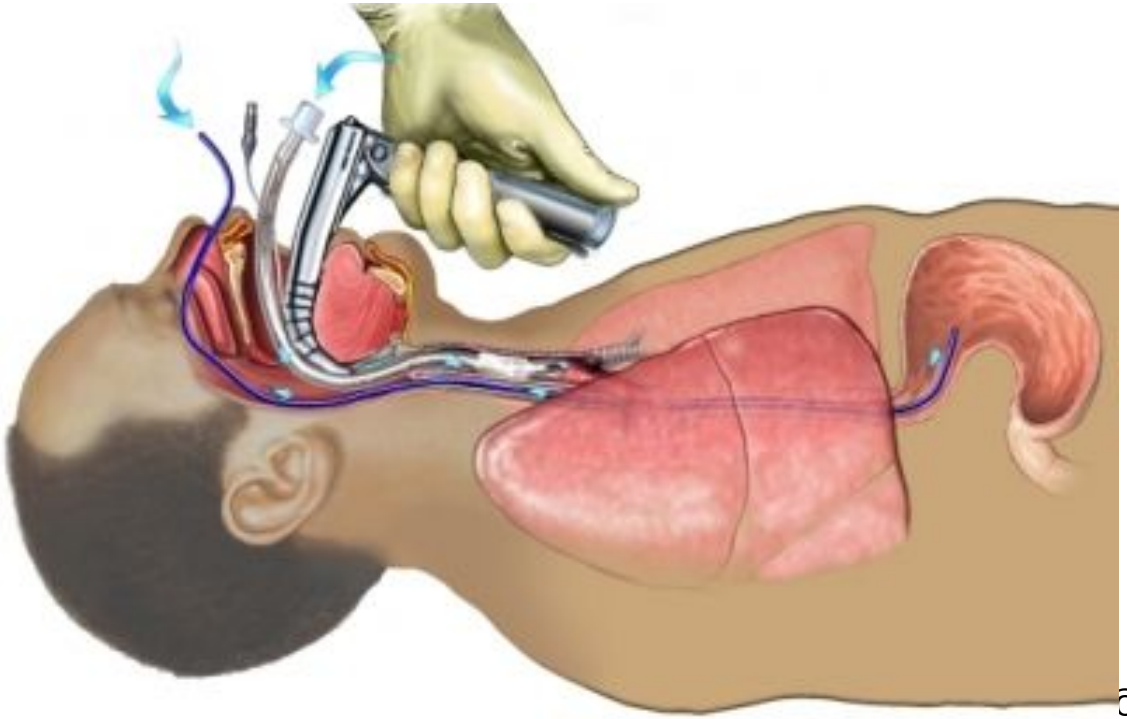
Mechanical Ventilation

used in acute settings (ICU). Often a life-saving technique, but has many complications

- pneumothorax,
- airway injury,
- alveolar damage,

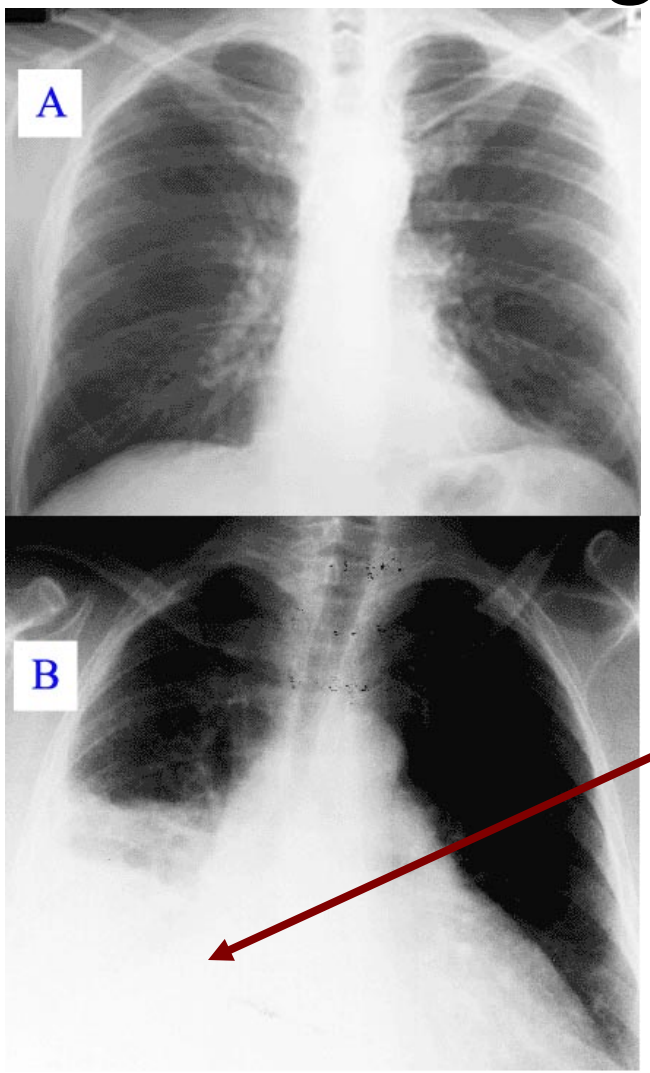
Accordingly it is generally weaned off or to minimal settings as soon as possible.

Ref: Wikipedia.org



Ref: healthlibrary.epnet.com/

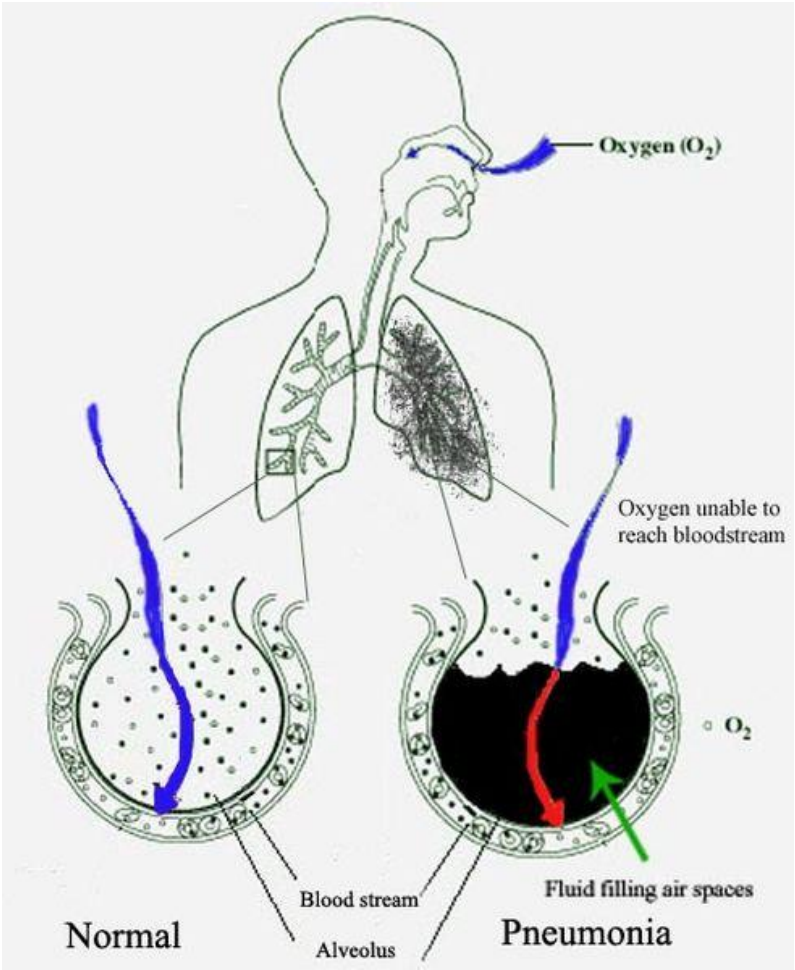
Why image lungs?
eg. Pneumonia



A: Normal chest x-ray

B: Abnormal chest x-ray

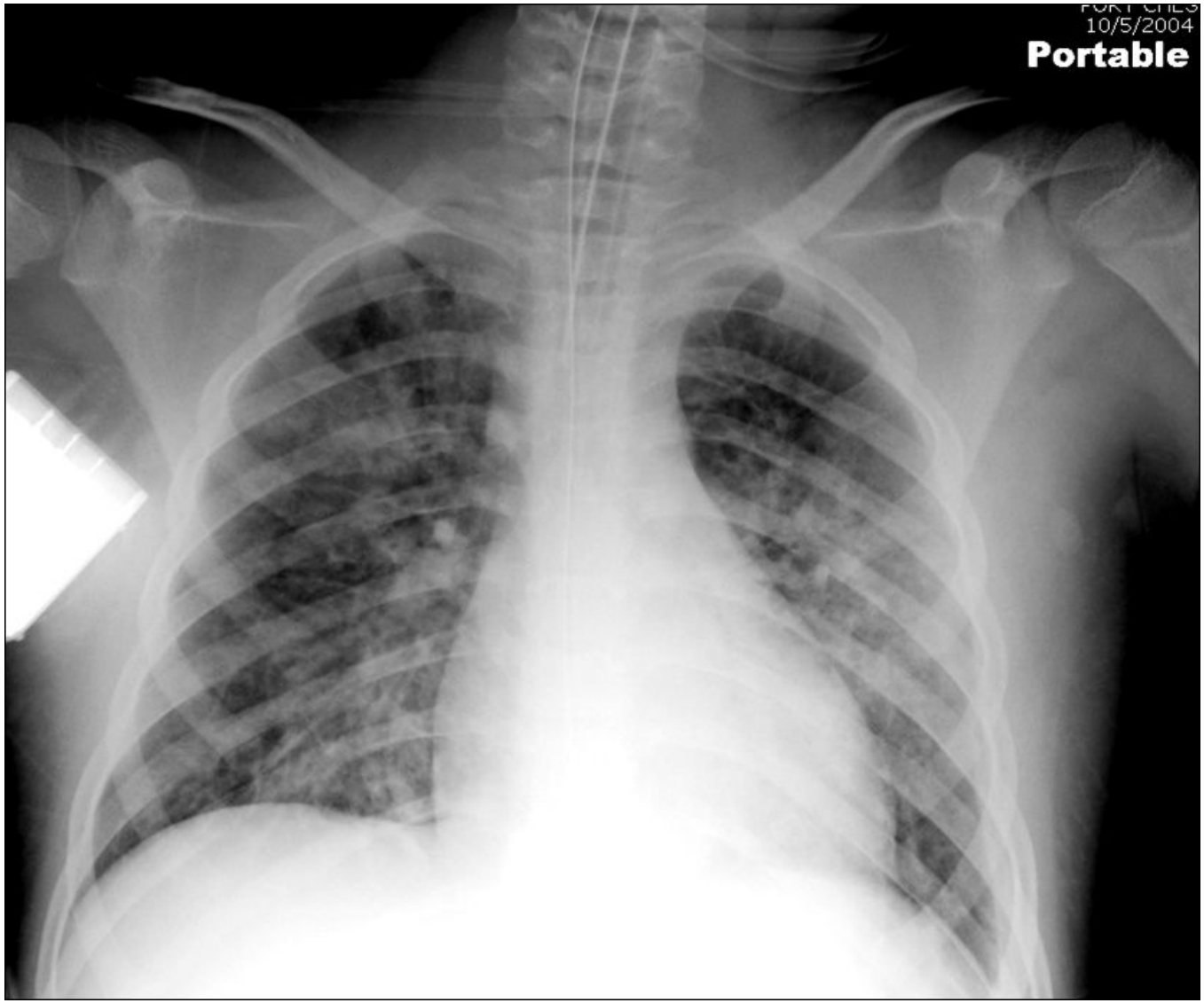
shadowing from pneumonia in the right lung



Ref: Wikipedia.org

Acute Respiratory Distress Syndrome (ARDS)

Chest X-ray of pediatric patient



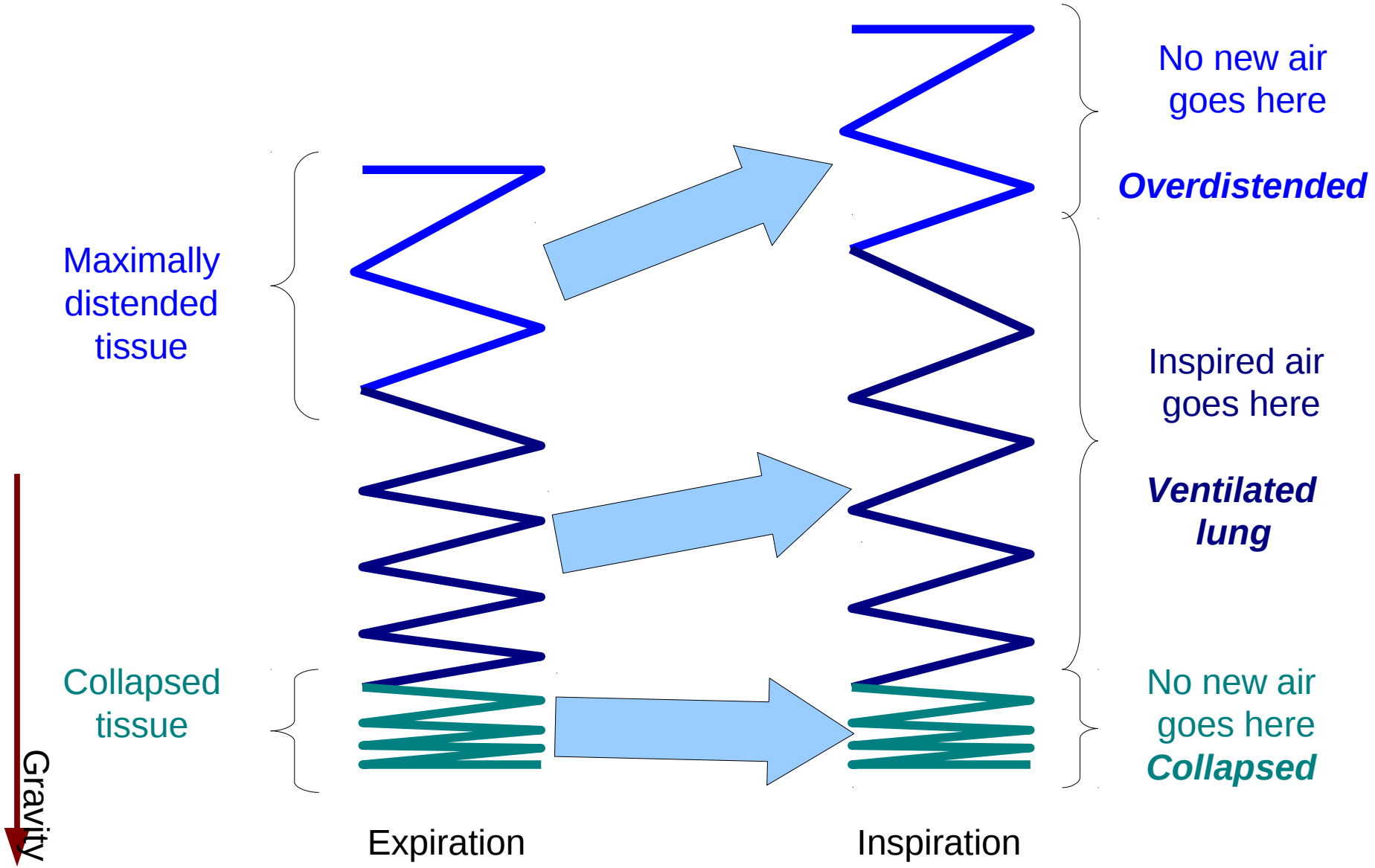
Wolf GK, Arnold JH in: Yearbook of Intensive Care and Emergency Medicine. Springer, 2005

Acute Respiratory Distress Syndrome (ARDS)

Chest CT of pediatric patient

Wolf GK, Arnold JH in: Yearbook of Intensive Care and Emergency Medicine. Springer, 2005

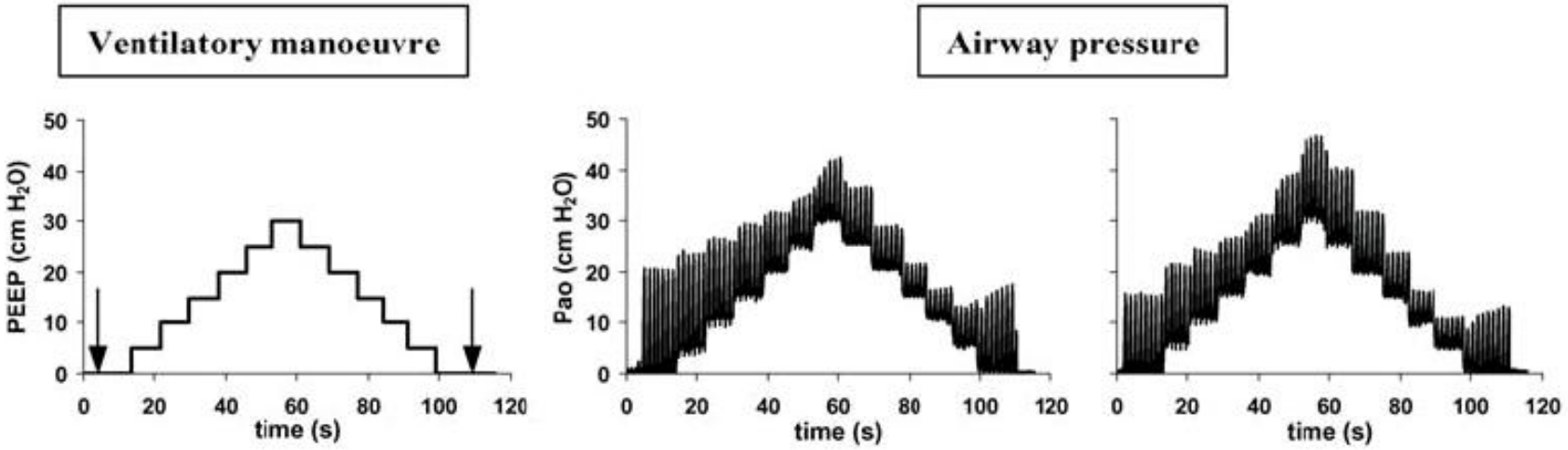
"*Slinky* Model of breathing"

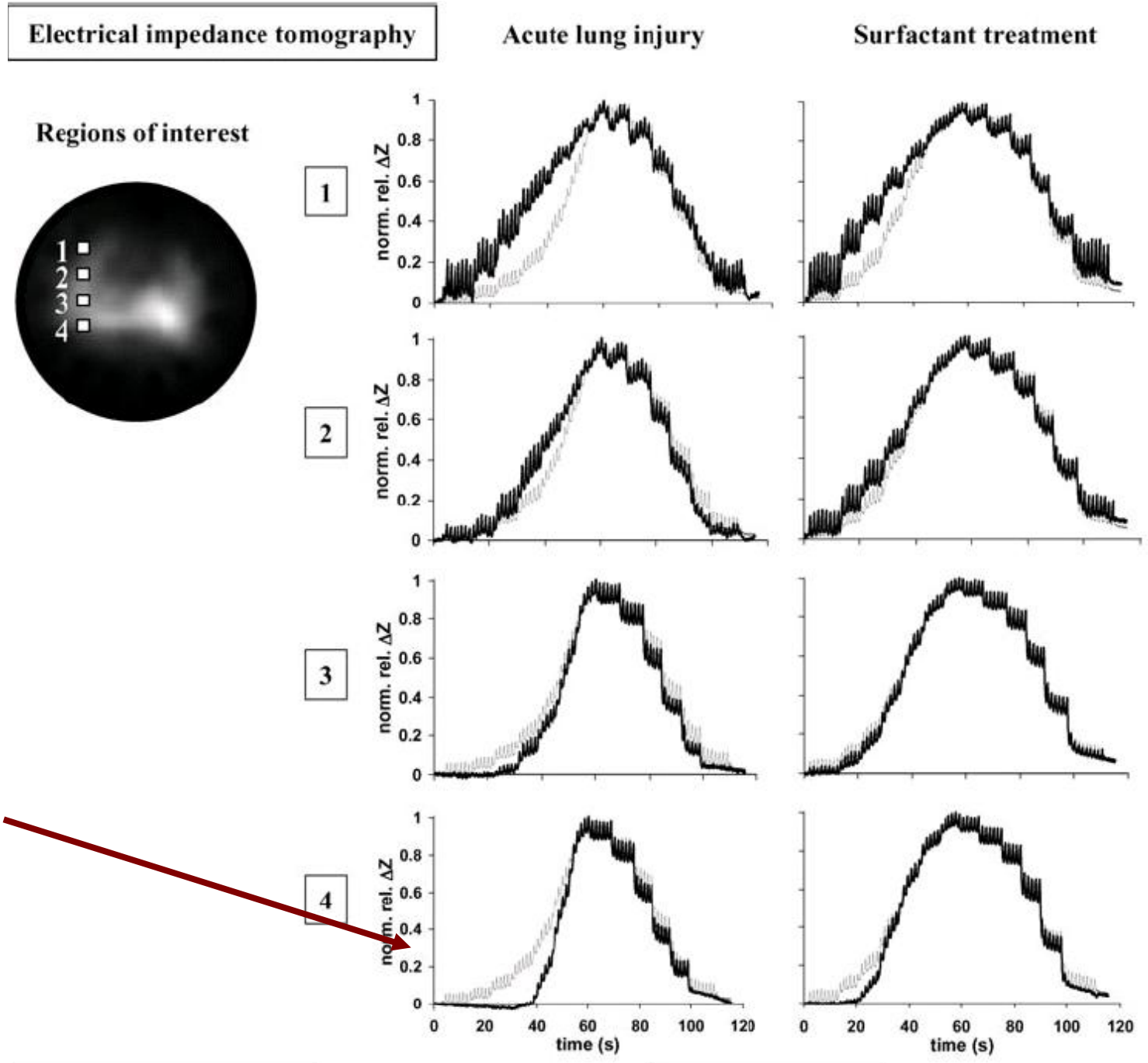


Regional ventilation

Images from Frerichs *et al* (2003) *Intensive Care Med.*.

PEEP manoeuvre in four regions of interest in the right lung (*left top*) before and after surfactant treatment. An increase in local aeration is accompanied by an increase in electrical impedance; the small fluctuations in the impedance signal represent the individual breaths. For better comparison and identification of instantaneous changes of end-expirato-





No change in lower lungs until pressure gets really big

EIT vs CT in ARDS

Data from pig study of EIT and CT

Victorino JA et al (2004), *Am J Respir Crit Care Med*

Show video

EIT in ARDS

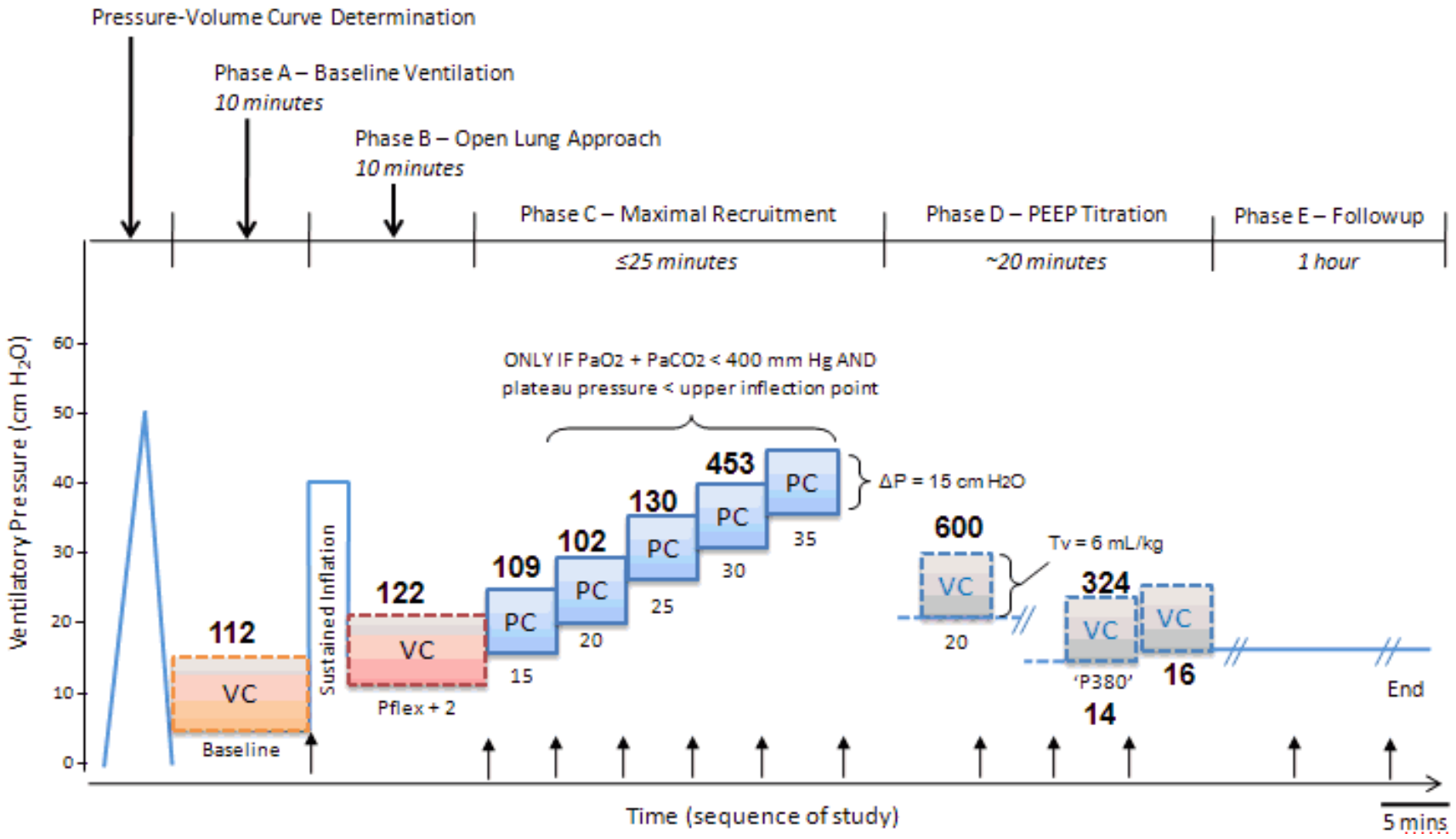
Data from Gender: F, Age: 5.9 years, Weight: 20kg, Condition: Primary ARDS triggered by parainfluenza pneumonia.

GK Wolf, C Gómez-Laberge, JN Kheir, D Zurakowski, BK Walsh, A Adler, JH Arnold. Reversal of Dependent Lung Collapse Predicts Response to Lung Recruitment in Children with Early Acute Lung Injury Pediatr Crit Care Med, In Press 2012

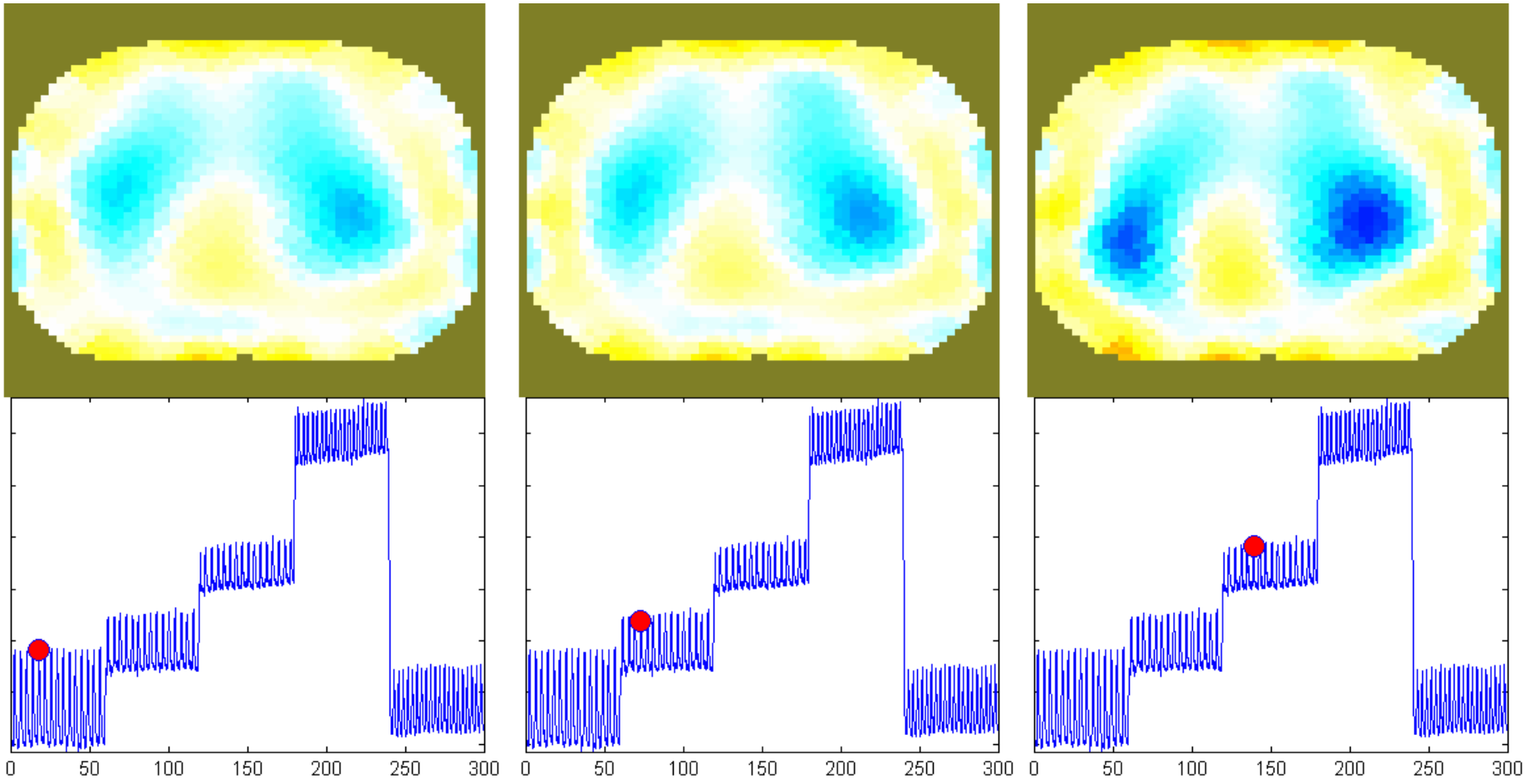
Source: eidors3d.sf.net/data_contrib/cg-2012-ards-recruitment/

Ventilation Protocol

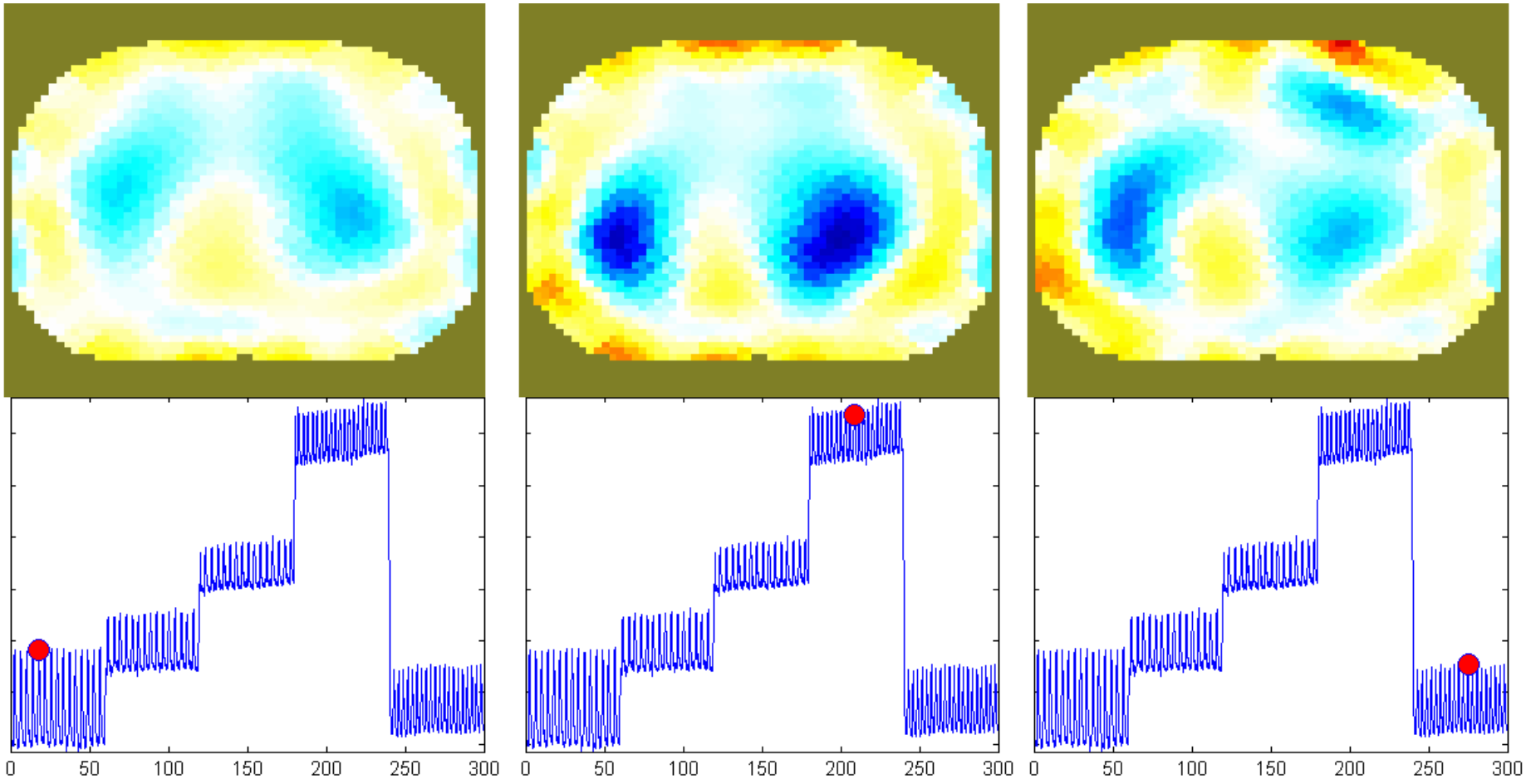
Patient 1 – PaO_2 + $PaCO_2$



Patient #1: Lung opening and “optimal ventilation” images



Patient #1: Lung opening and “optimal ventilation” images



What can EIT tell us that is *clinically* useful?

EIT shows regional ventilation

- Can a patient can be recruited?
- Have we opened up the lungs?

EIT shows changes earlier than blood gas

- PaO_2 responds slowly (LPF of blood)
- PaO_2 responds only at high shunt fraction
- Can we control ventilation better with EIT?

Image Reconstruction

Linear difference imaging with pictures

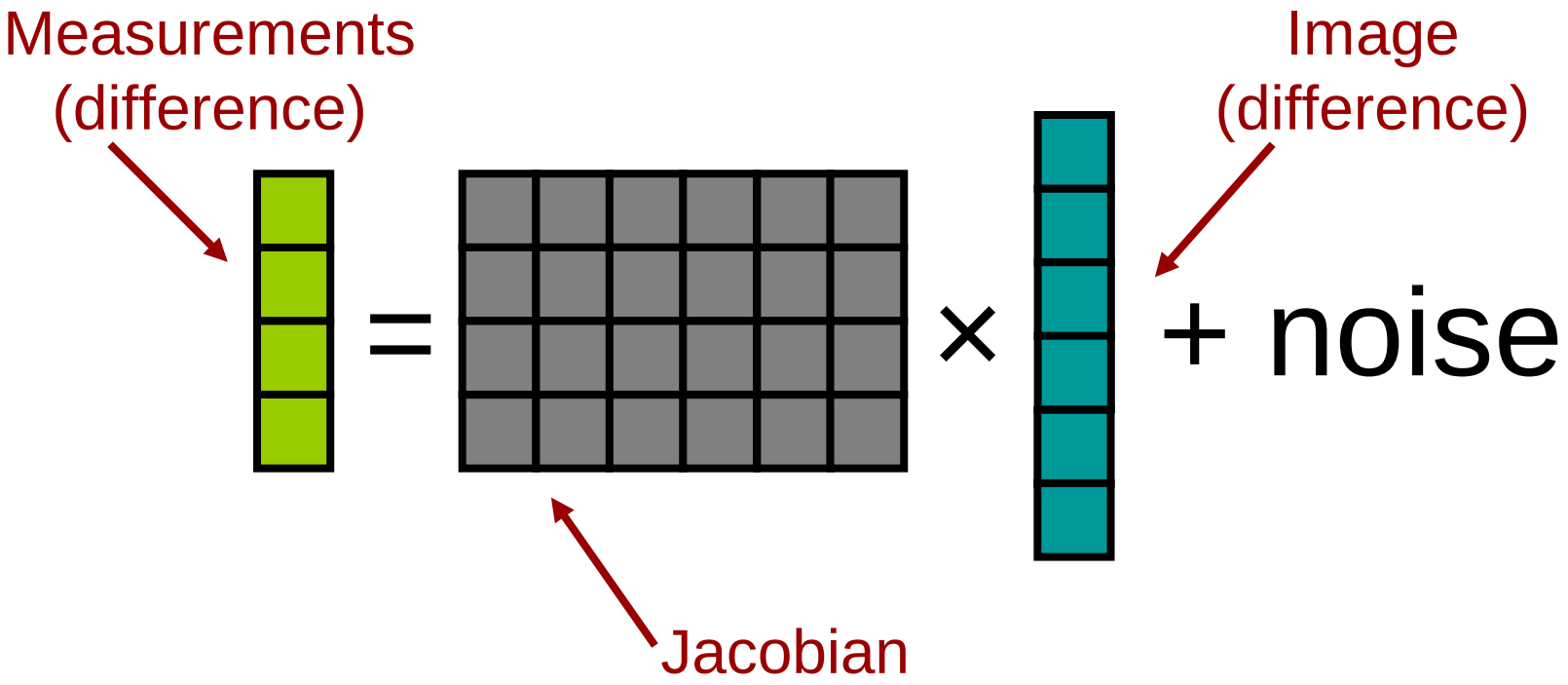
- Total Variation
- Electrode Errors
- Electrode Movement
- Temporal Filtering
- GREIT

Other applications of EIT

- Geophysics
  - First application (by Conrad Schlumberger was in 1912)
  - Mineral prospecting (ore is conductive)
  - Rock damage monitoring
  - Waste site monitoring
- Medical
  - Breast cancer
  - Brain (epilepsy, stroke)
- Process tomography
  - Pipe flow
  - Mixing tanks

Image Reconstruction

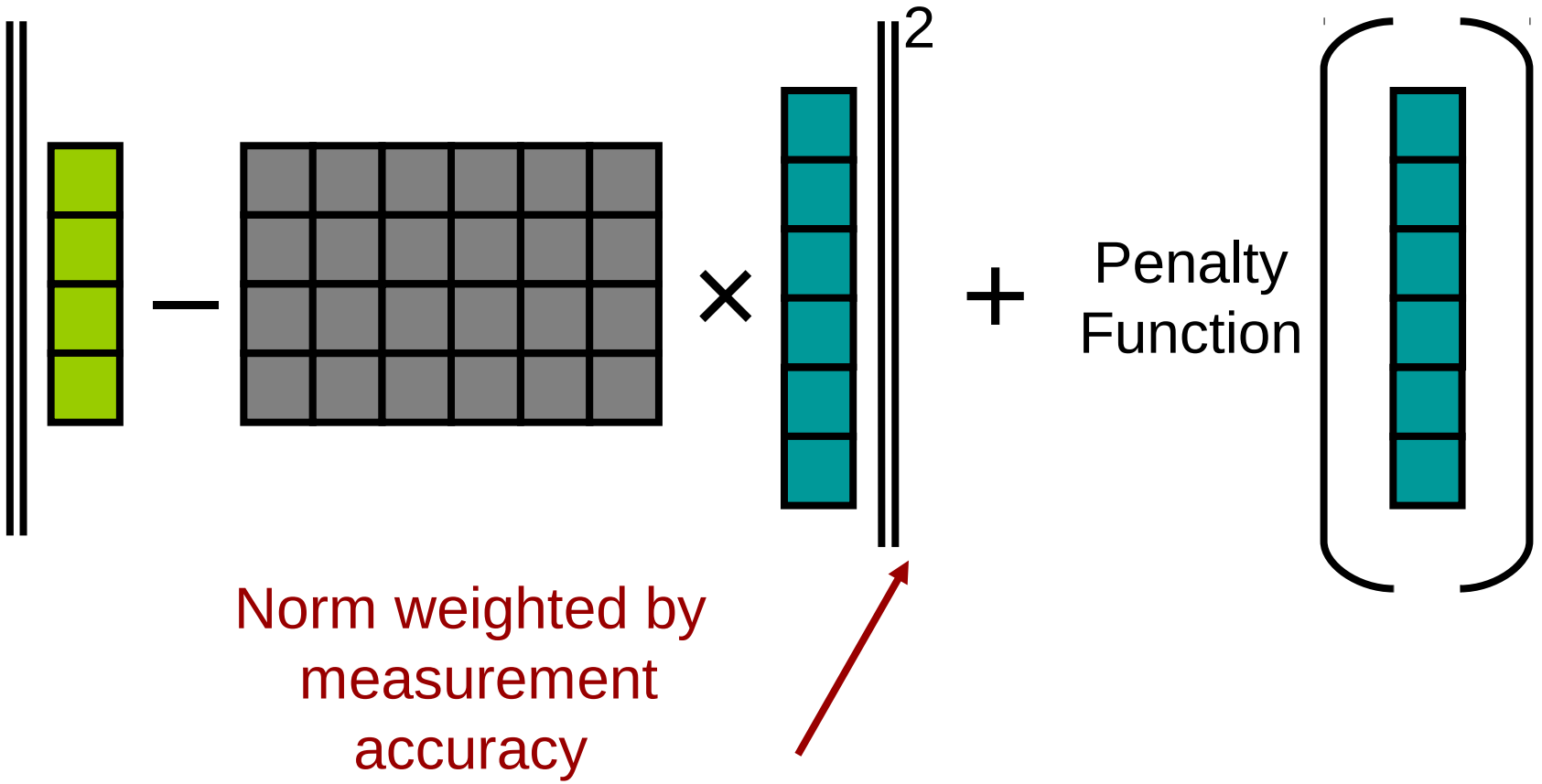
- Forward Model (linearized)



System is underdetermined

Image Reconstruction

Regularized linear Inverse Model



Measurement Norm

Penalize measurements by the SNR of each channel (ie 1/noise variance)

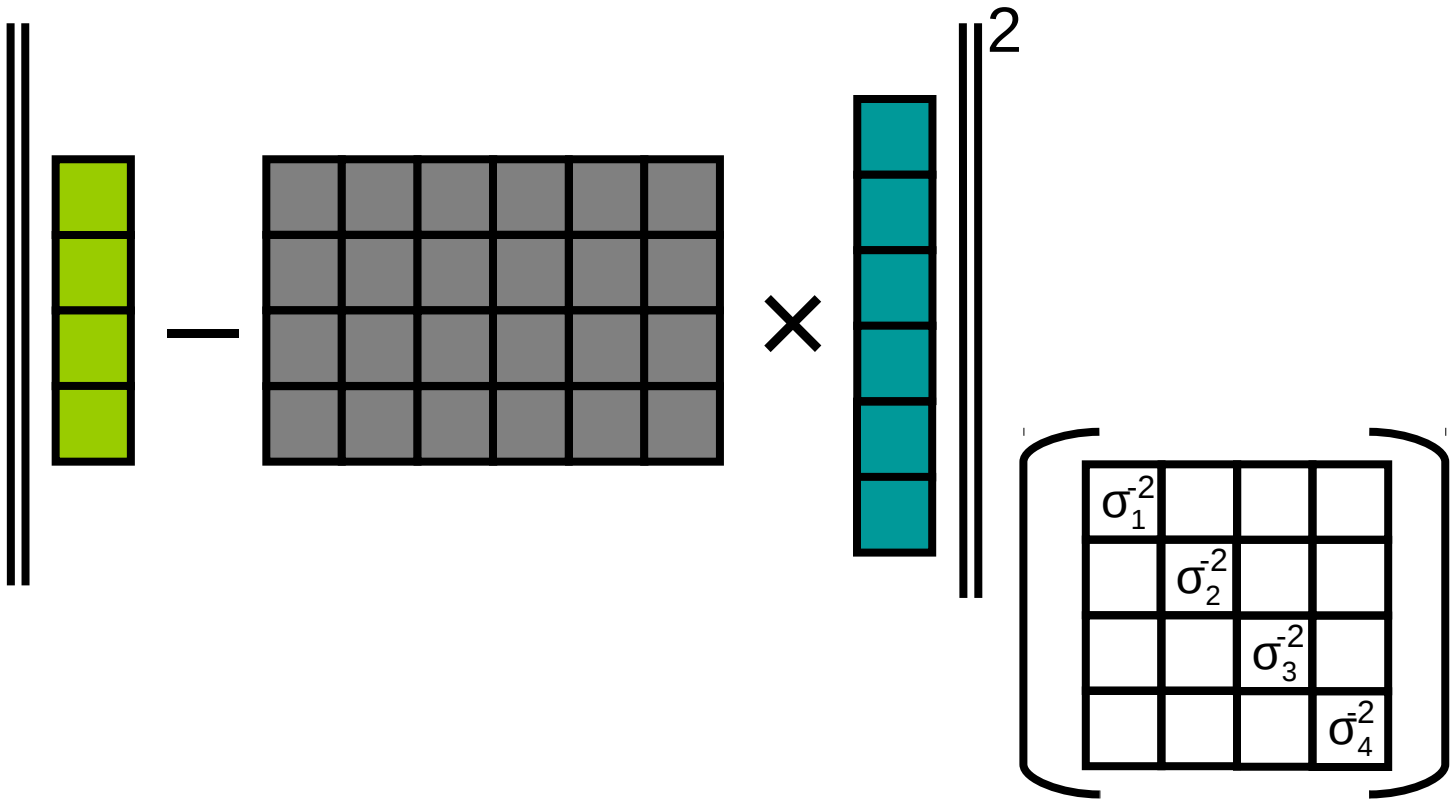


Image Reconstruction

Image Penalty Function

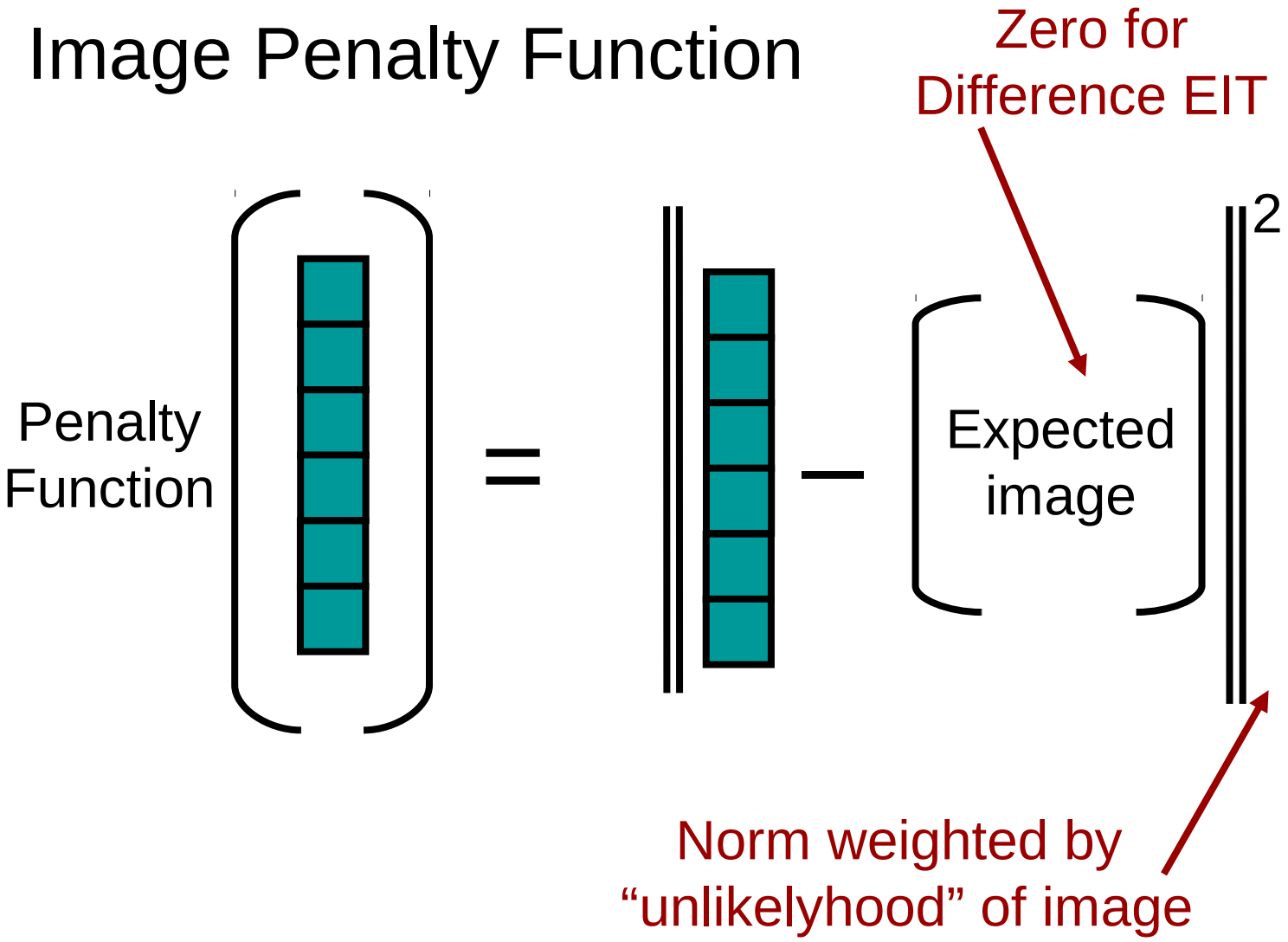


Image Reconstruction

- Penalty functions: Image Amplitude

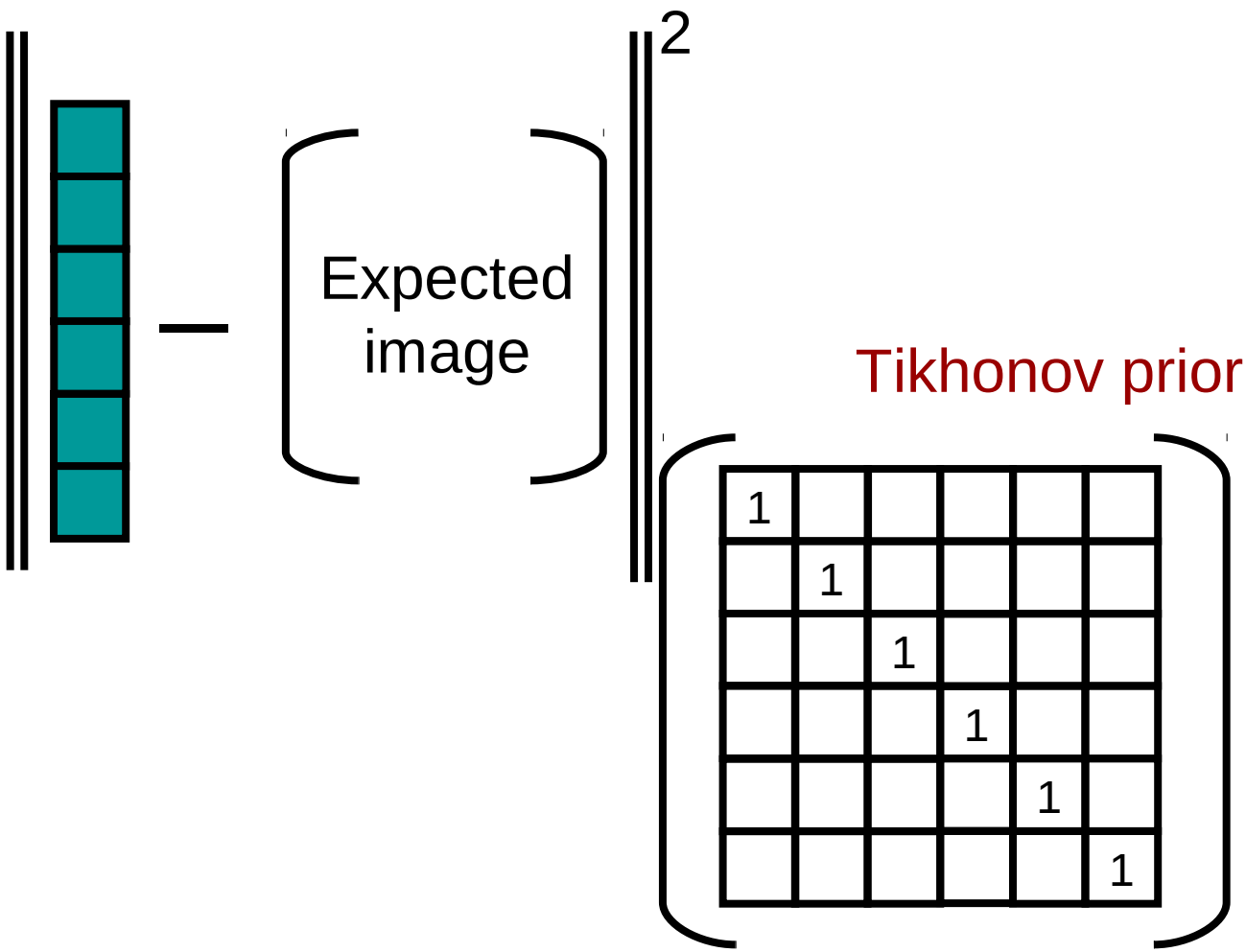
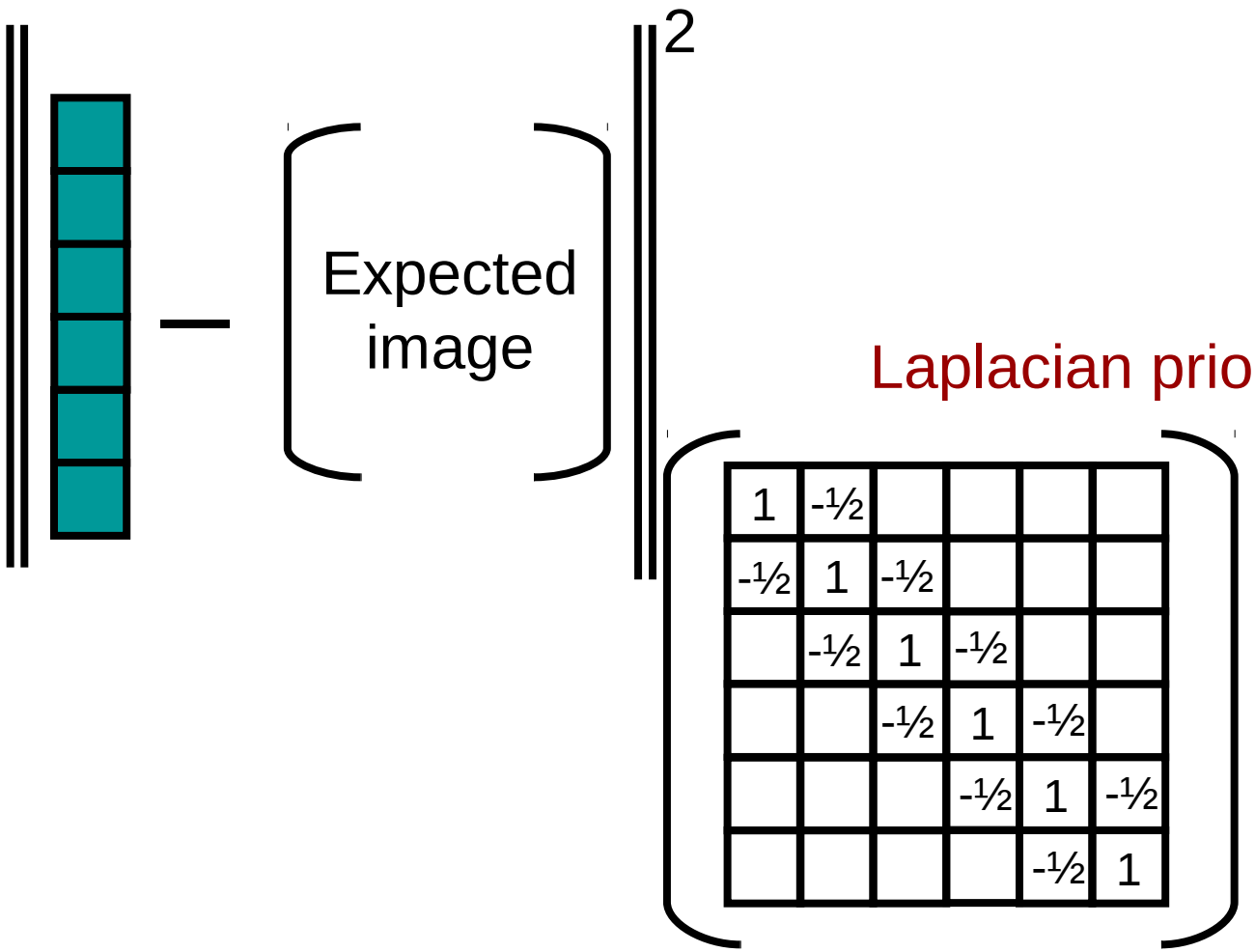


Image Reconstruction

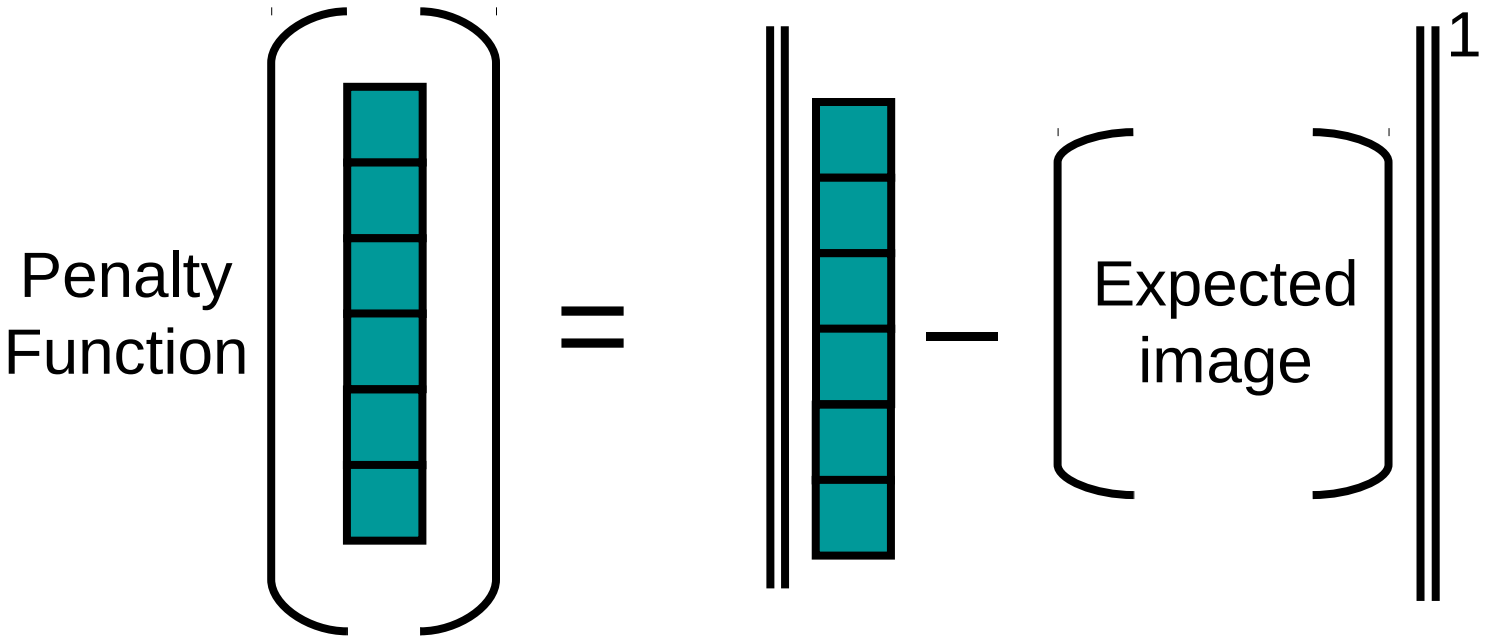
- Penalty functions: Image Smoothness



Total Variation

Image Penalty Function

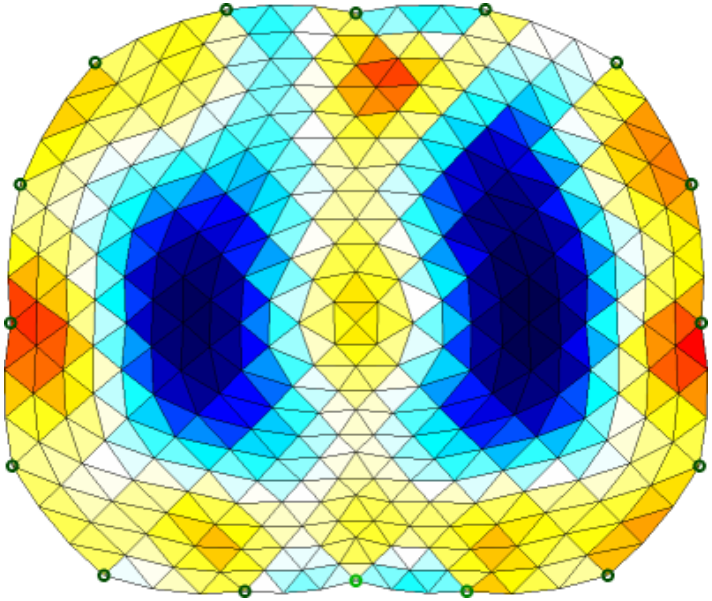
Use 1-norm
Sum(abs(.))

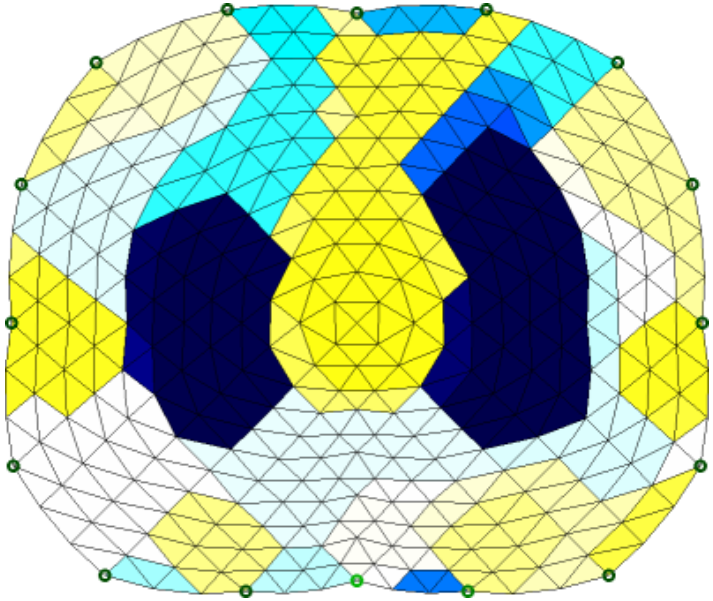


TV penalty function does not prefer smooth to “blocky” images

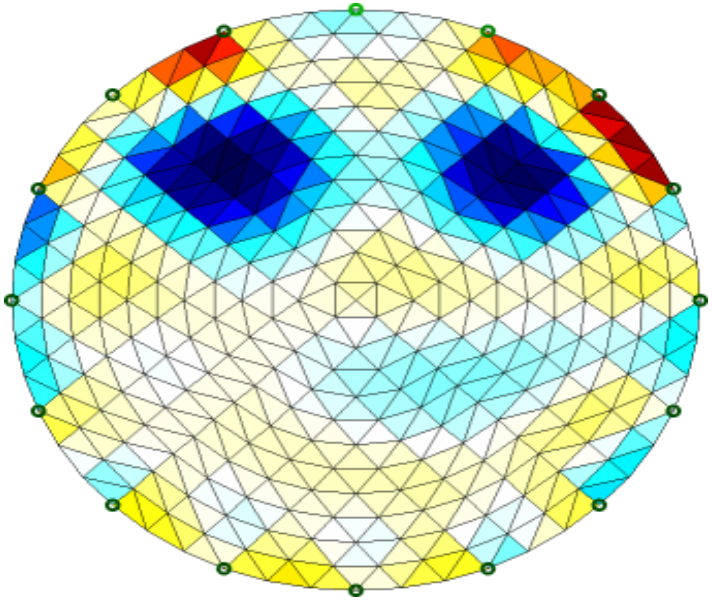
Lung images with TV

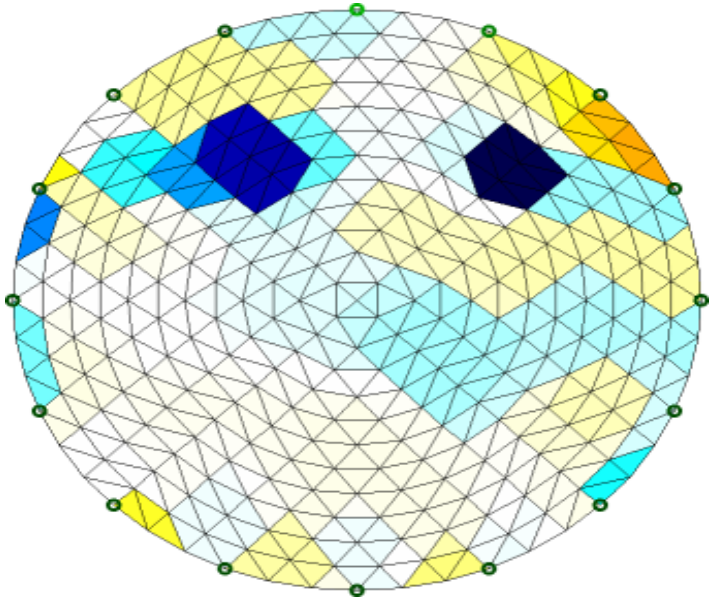
Human (healthy)



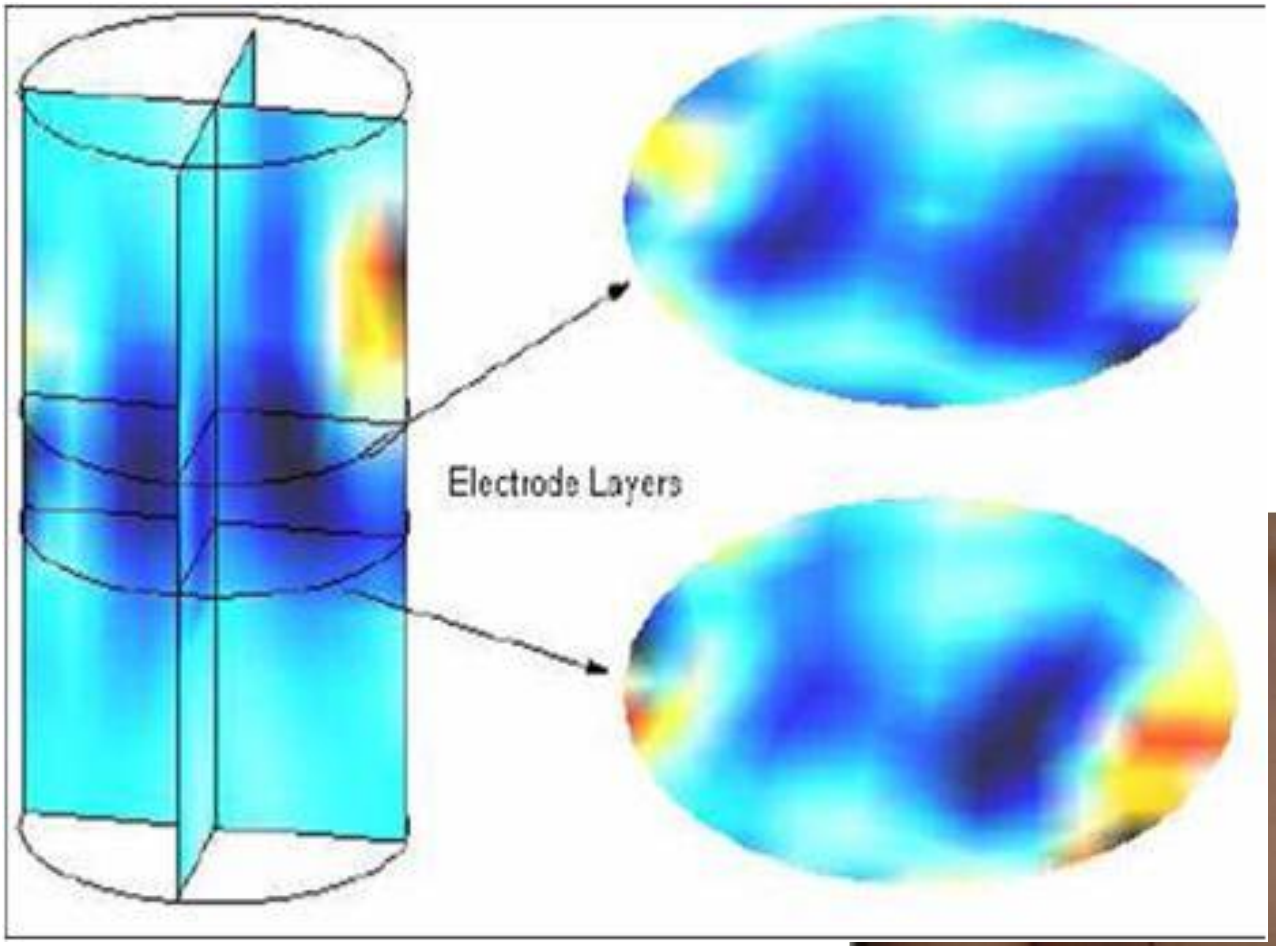


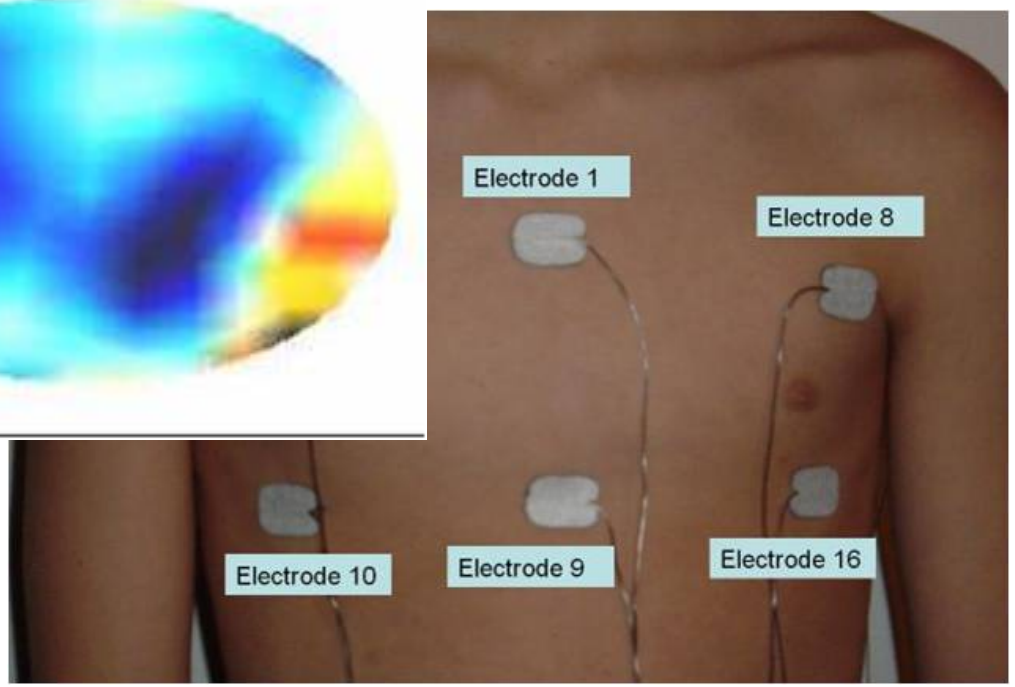
Pig (ARDS)





3D EIT


Electrode Layers


Electrode 1
Electrode 8
Electrode 10
Electrode 9
Electrode 16

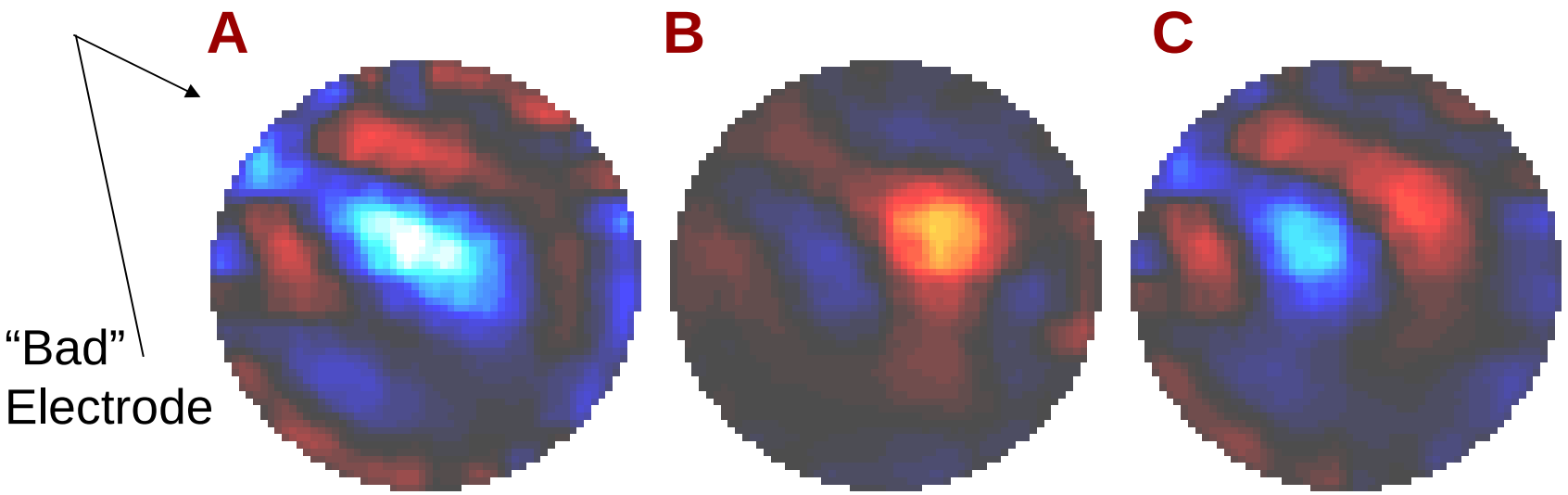
Electrode Measurement Errors

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

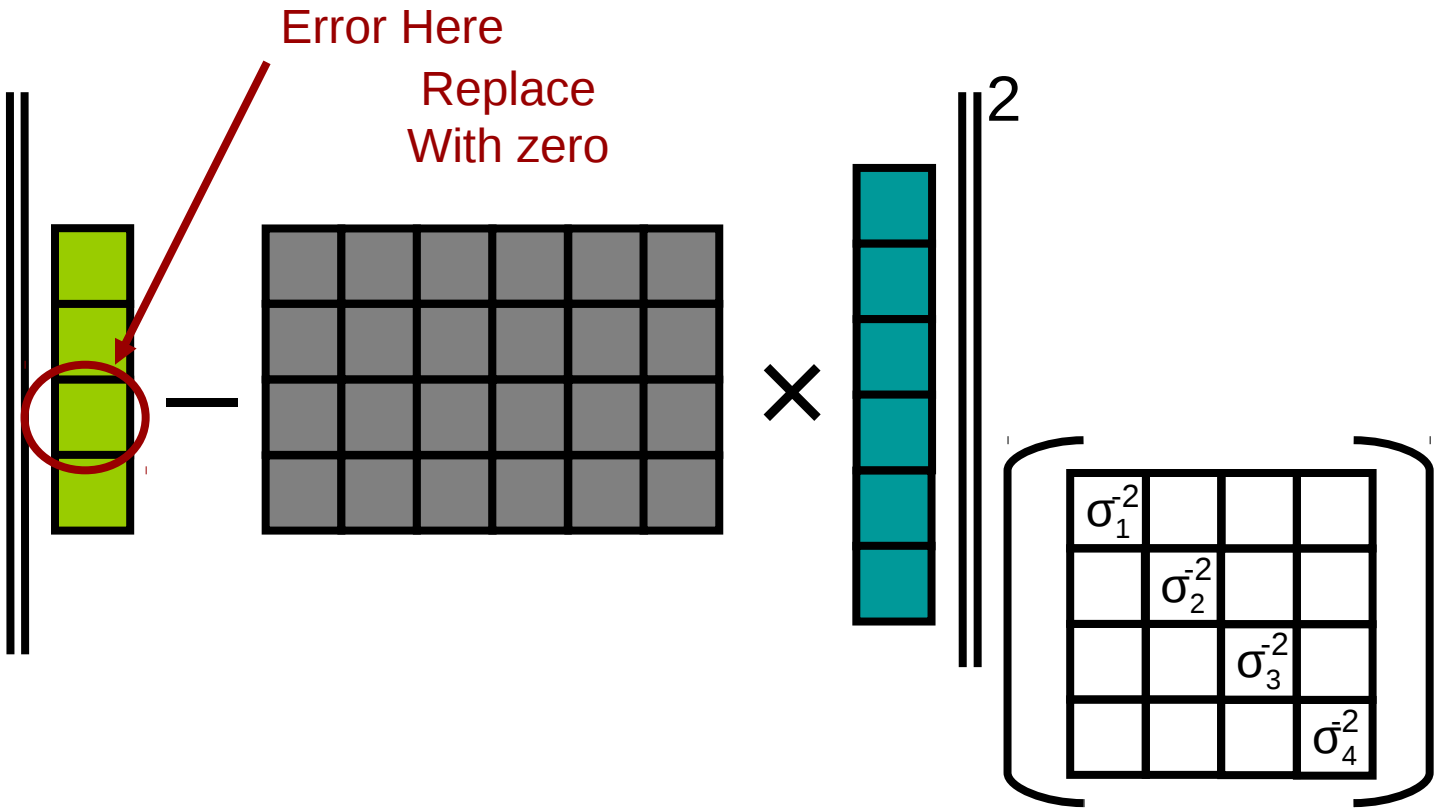


Images measured in anaesthetised, ventilated dog

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

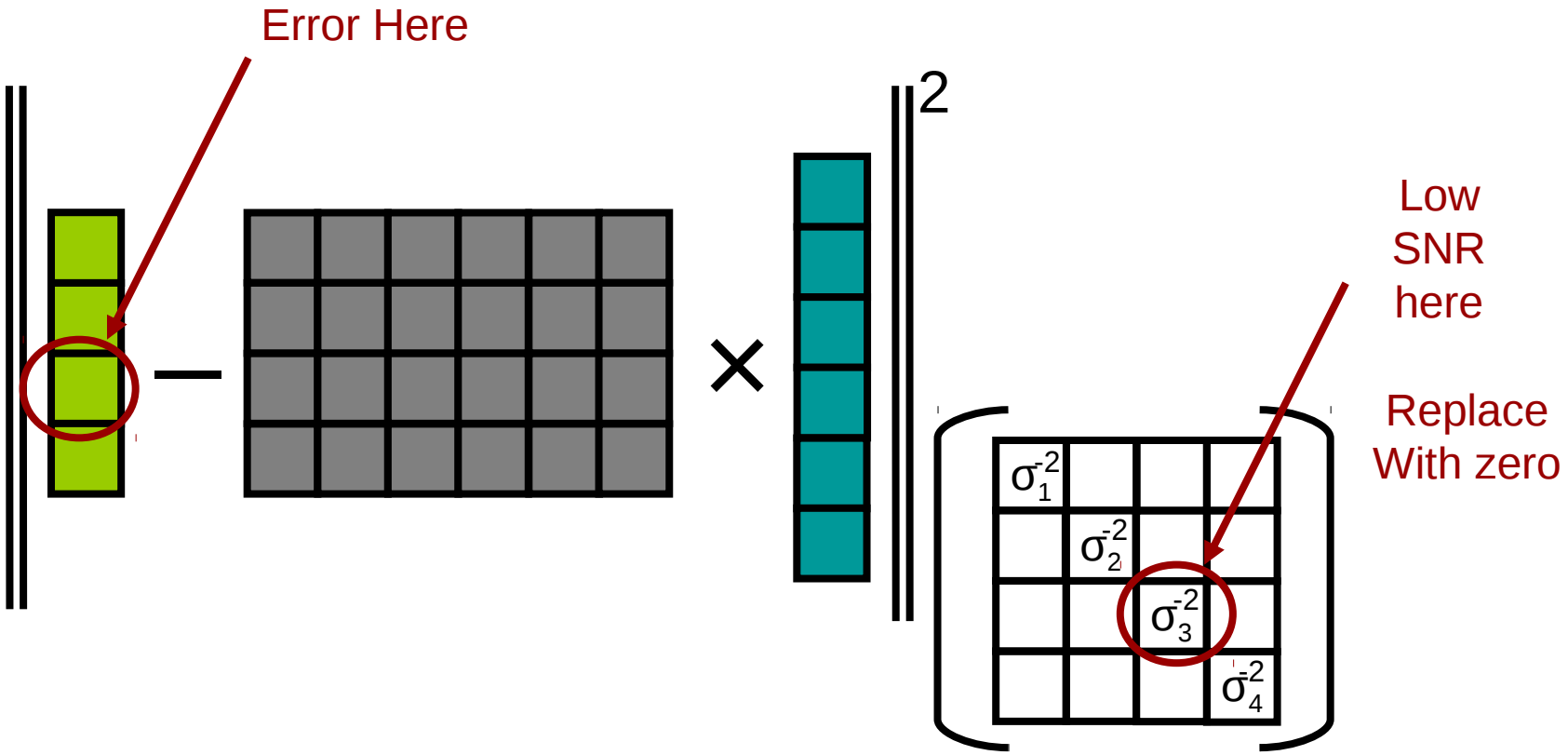
“Zero bad data” solution

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

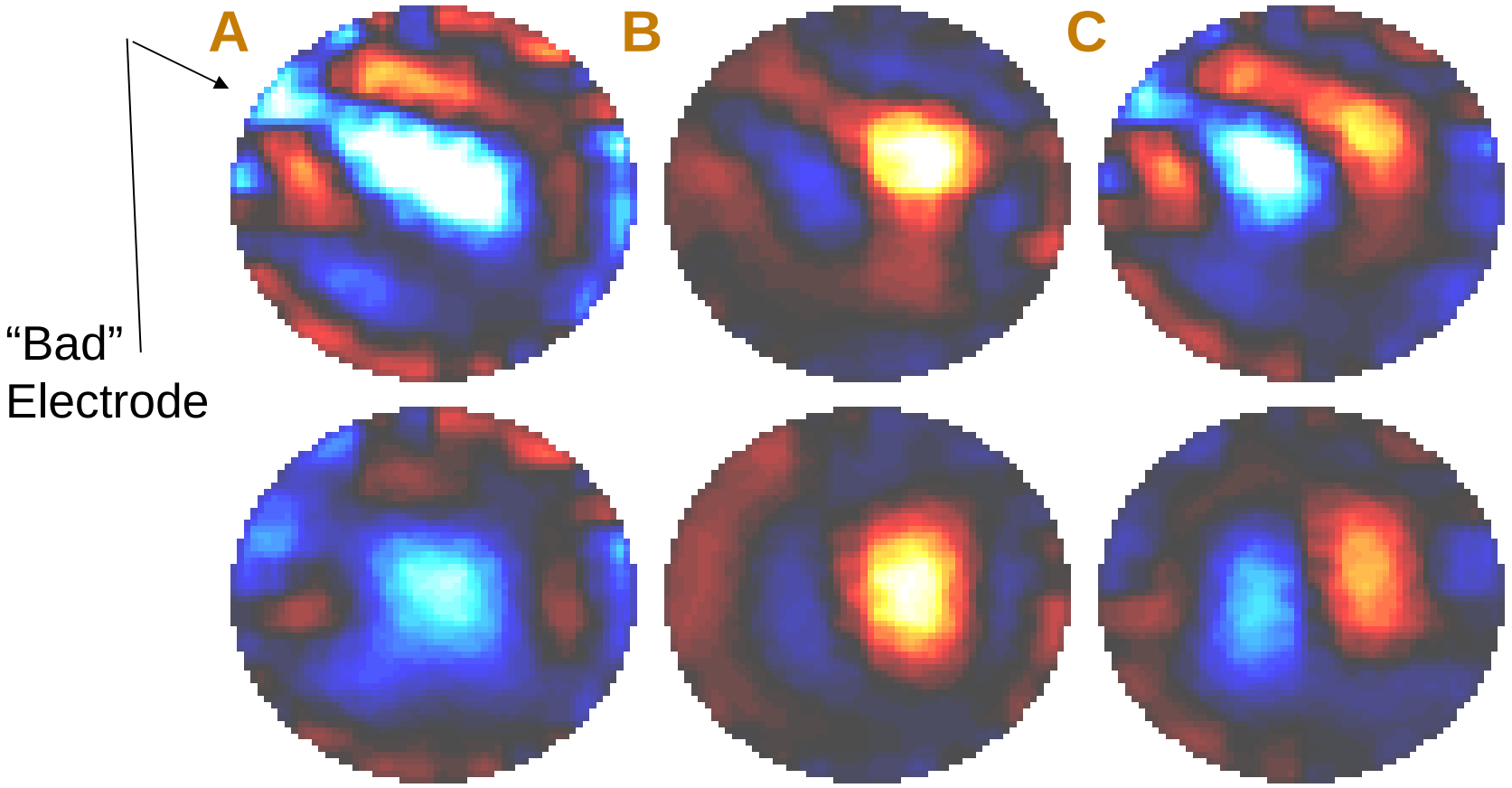


Regularized imaging solution

Electrode errors are large measurement noise on affected electrode

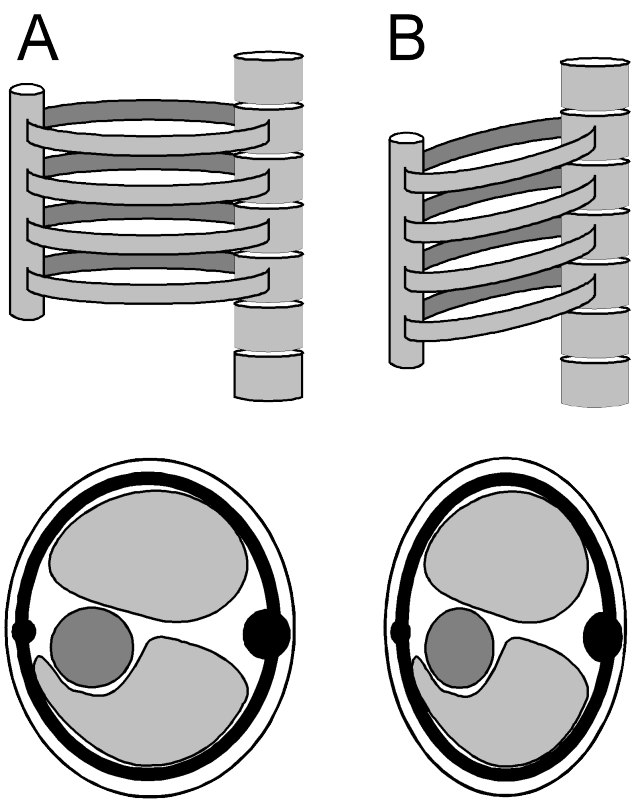


Correcting for errors. Results



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



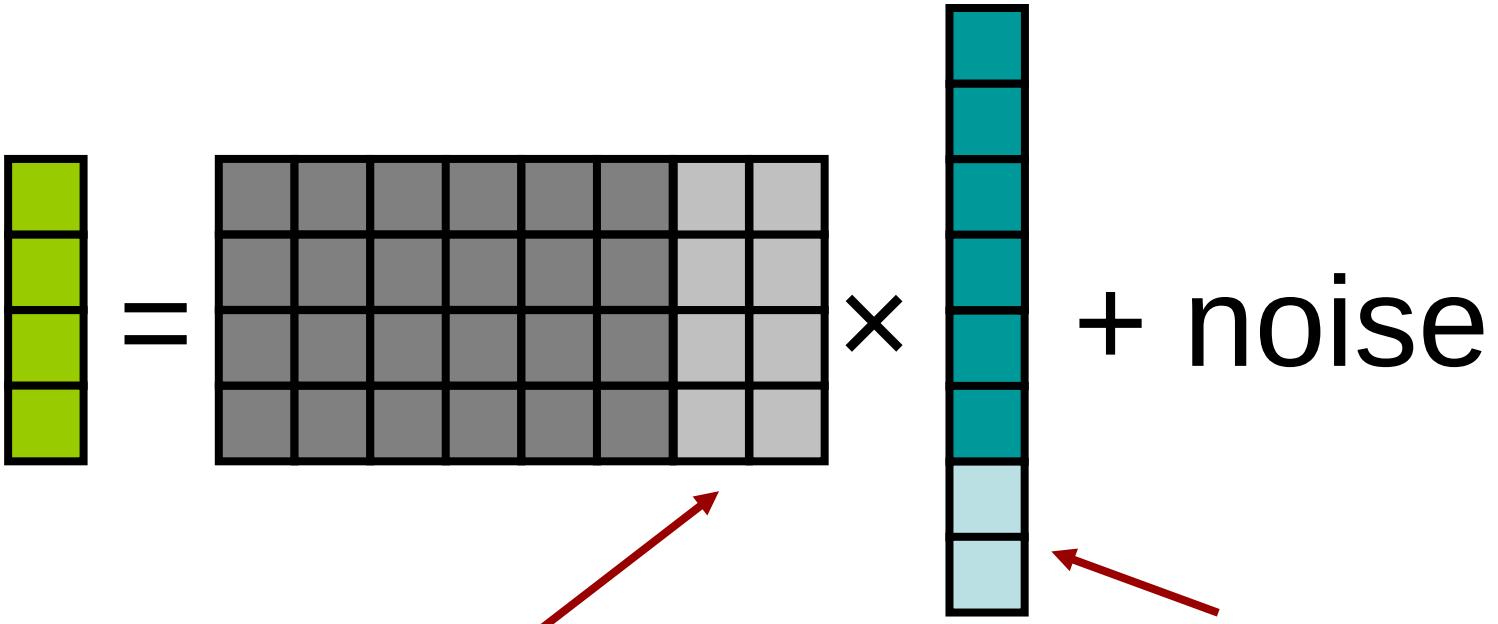
Electrodes move

- with breathing
- with posture change

Simulations show broad central artefact in images

Imaging Electrode Movement

- Forward model *image* includes movement

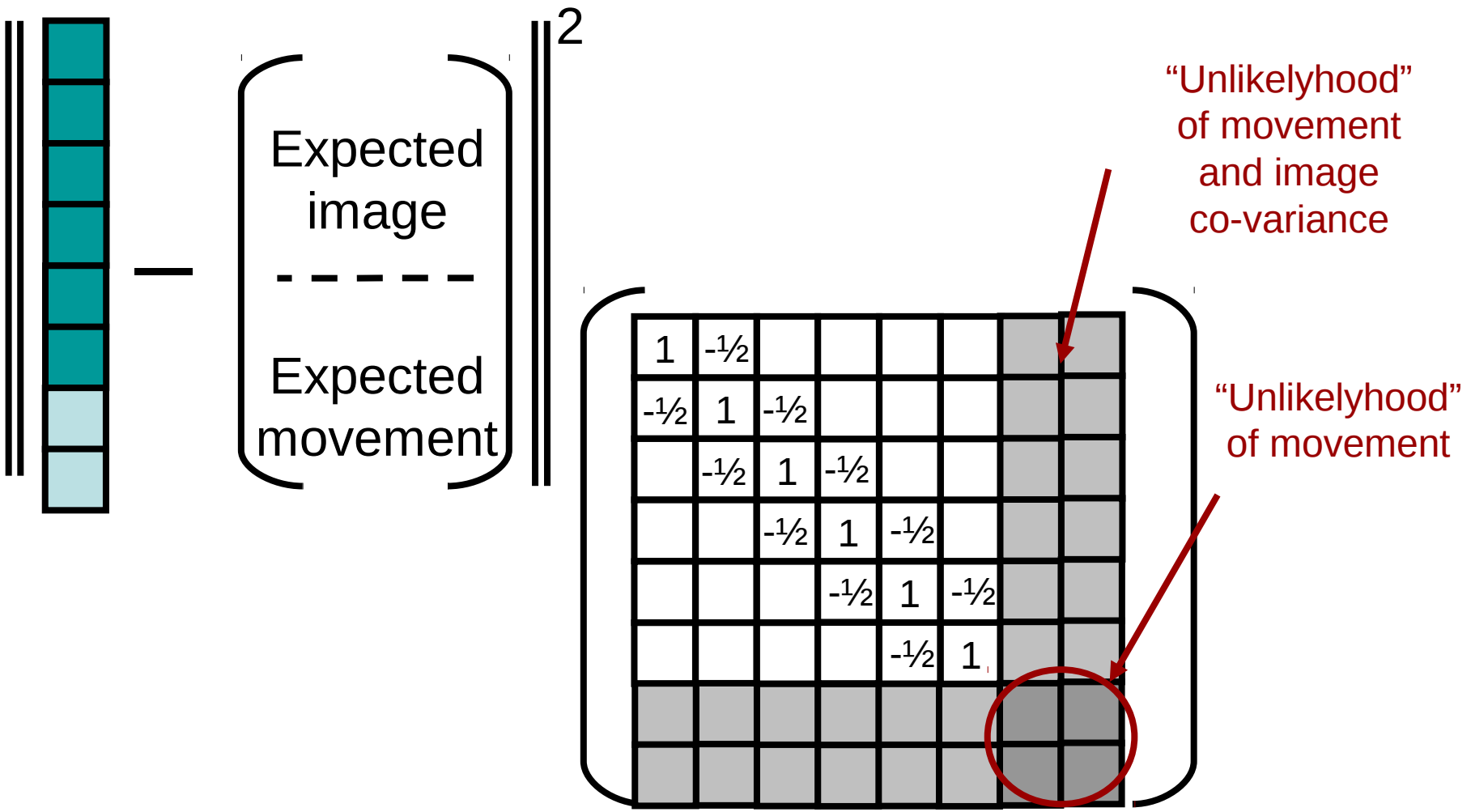


Jacobian
now includes
measurement change
due to movement

"image" now
includes
x,y sensor
movement

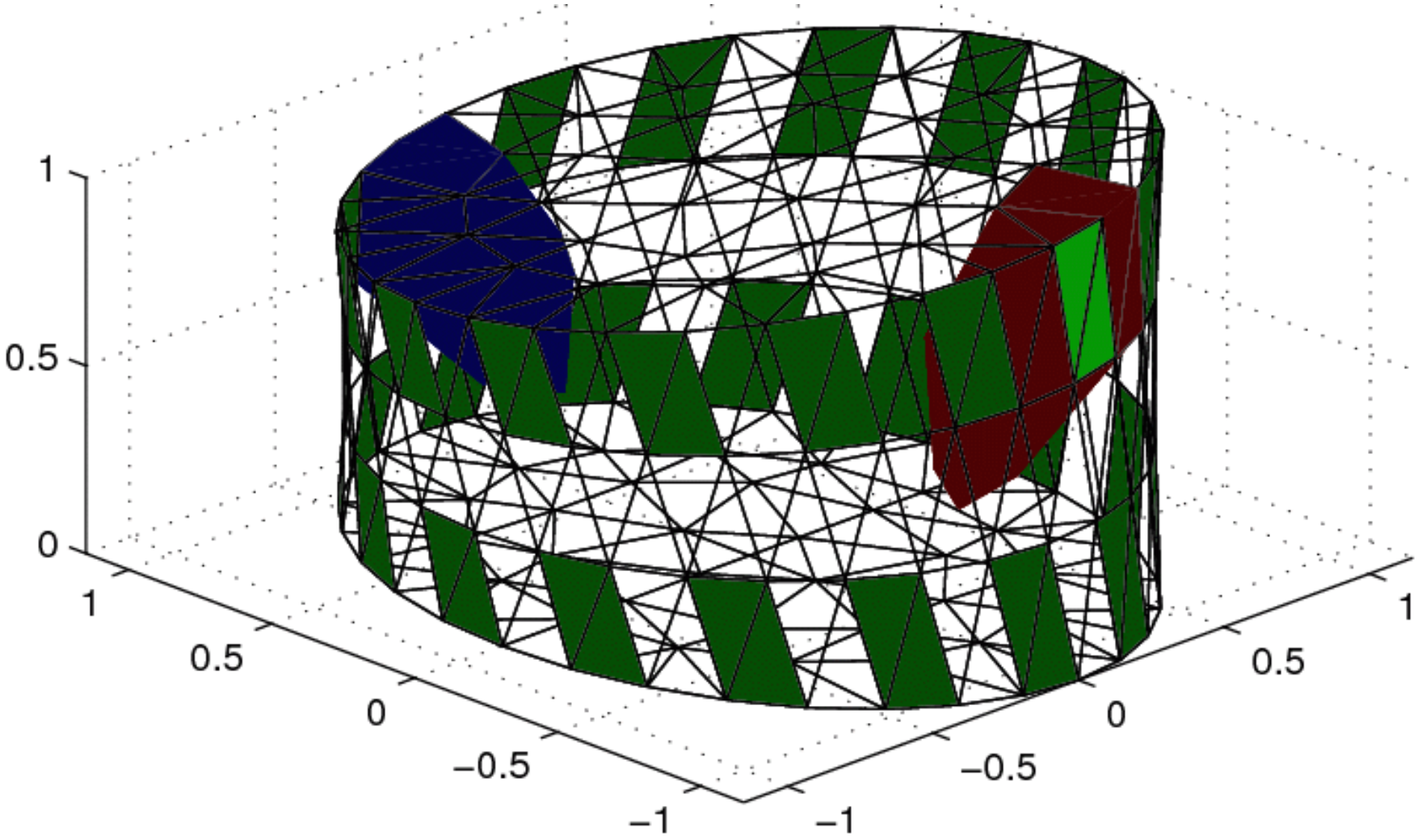
Image and movement

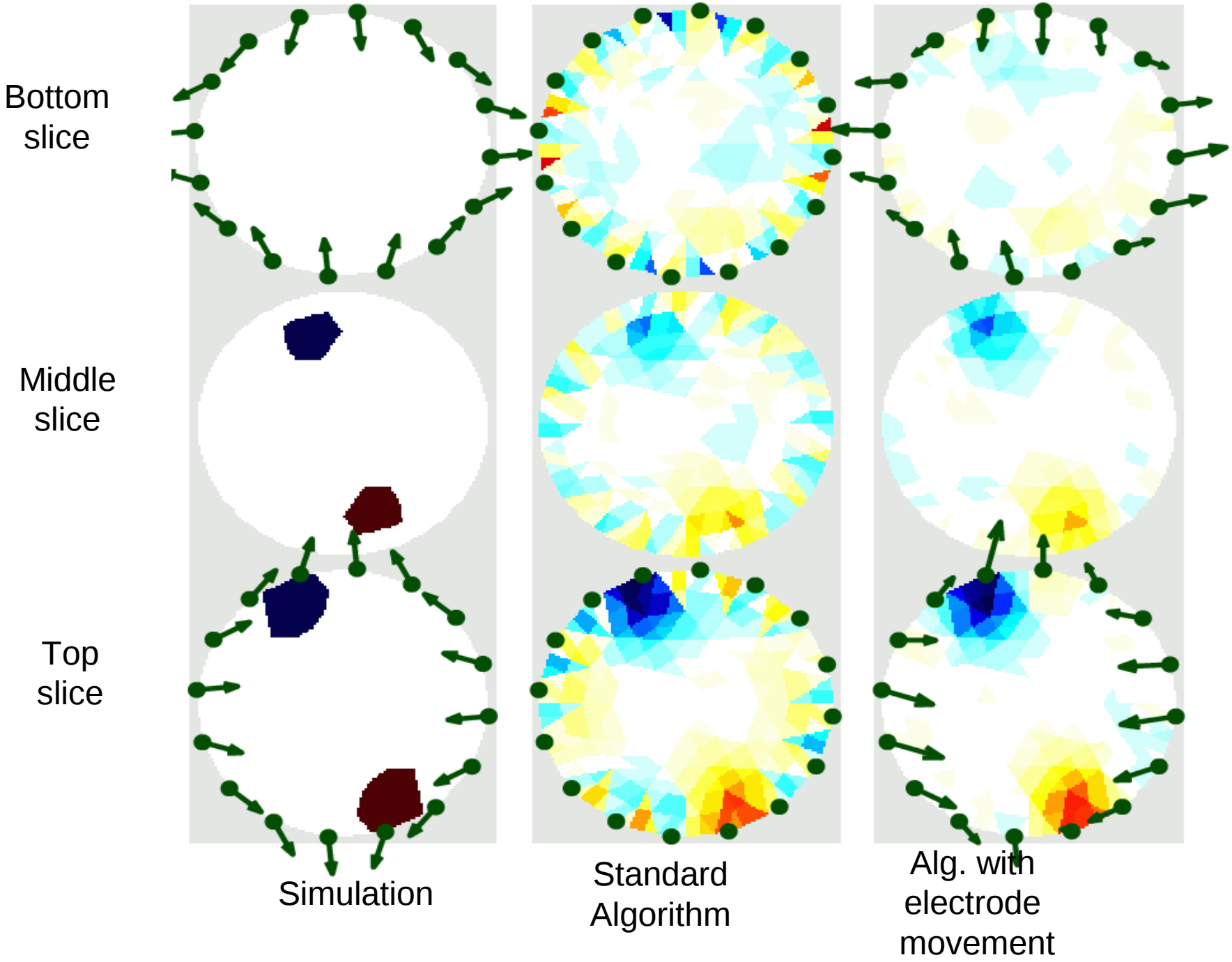
Penalty: Image and movement Smoothness



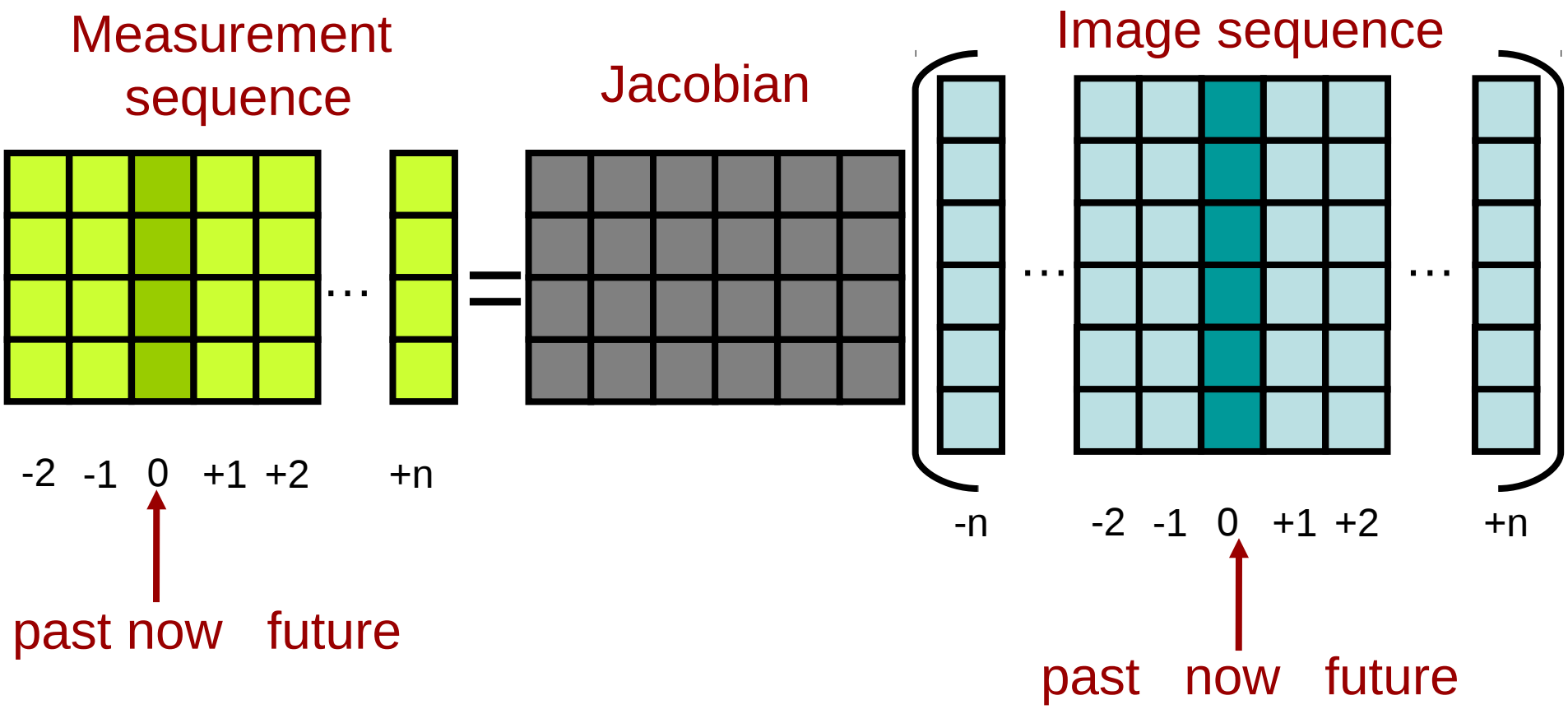
Images of electrode movement

Simulation: tank with 3D deformation



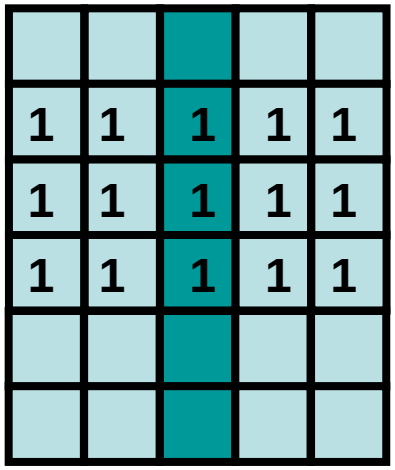

Bottom slice
Middle slice
Top slice
Simulation
Standard Algorithm
Alg. with electrode movement

EIT makes fast measurements. Can we use this fact?

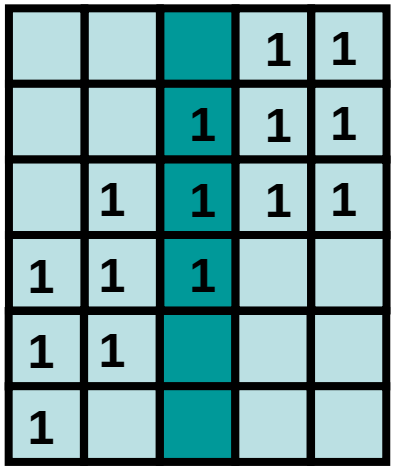


Temporal Reconstruction

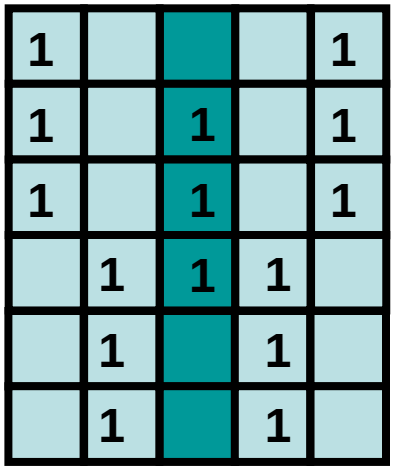
Temporal Penalty Functions



likely



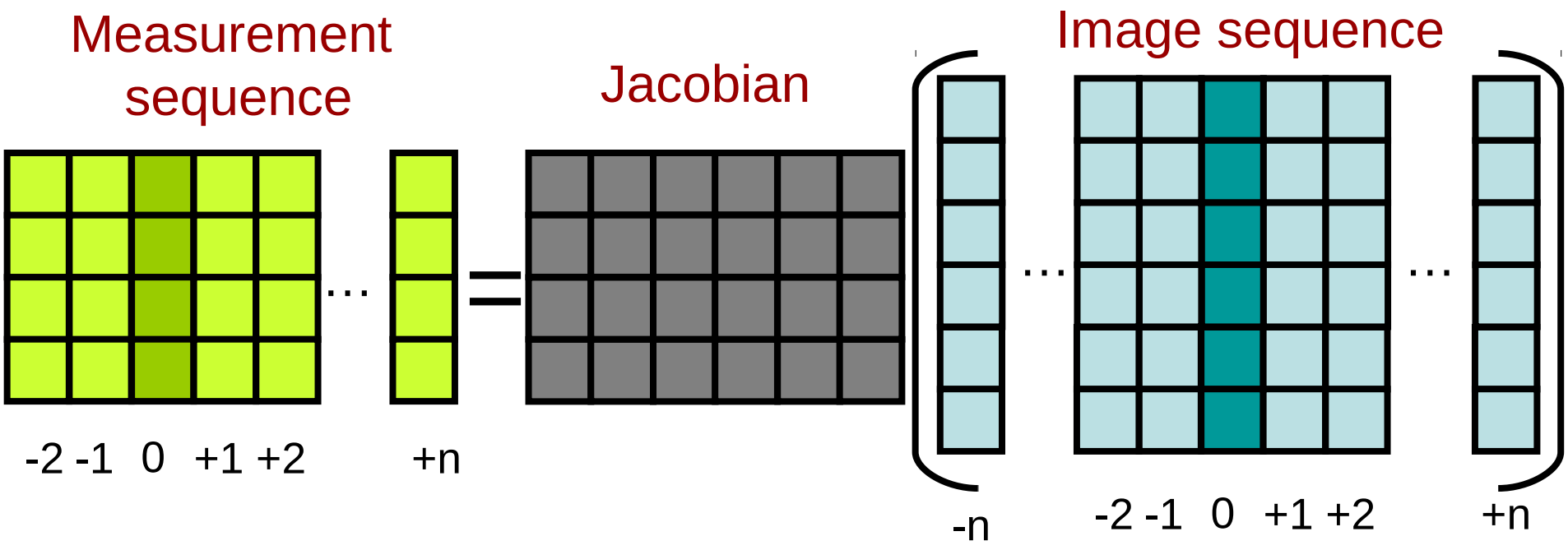
quite likely



unlikely

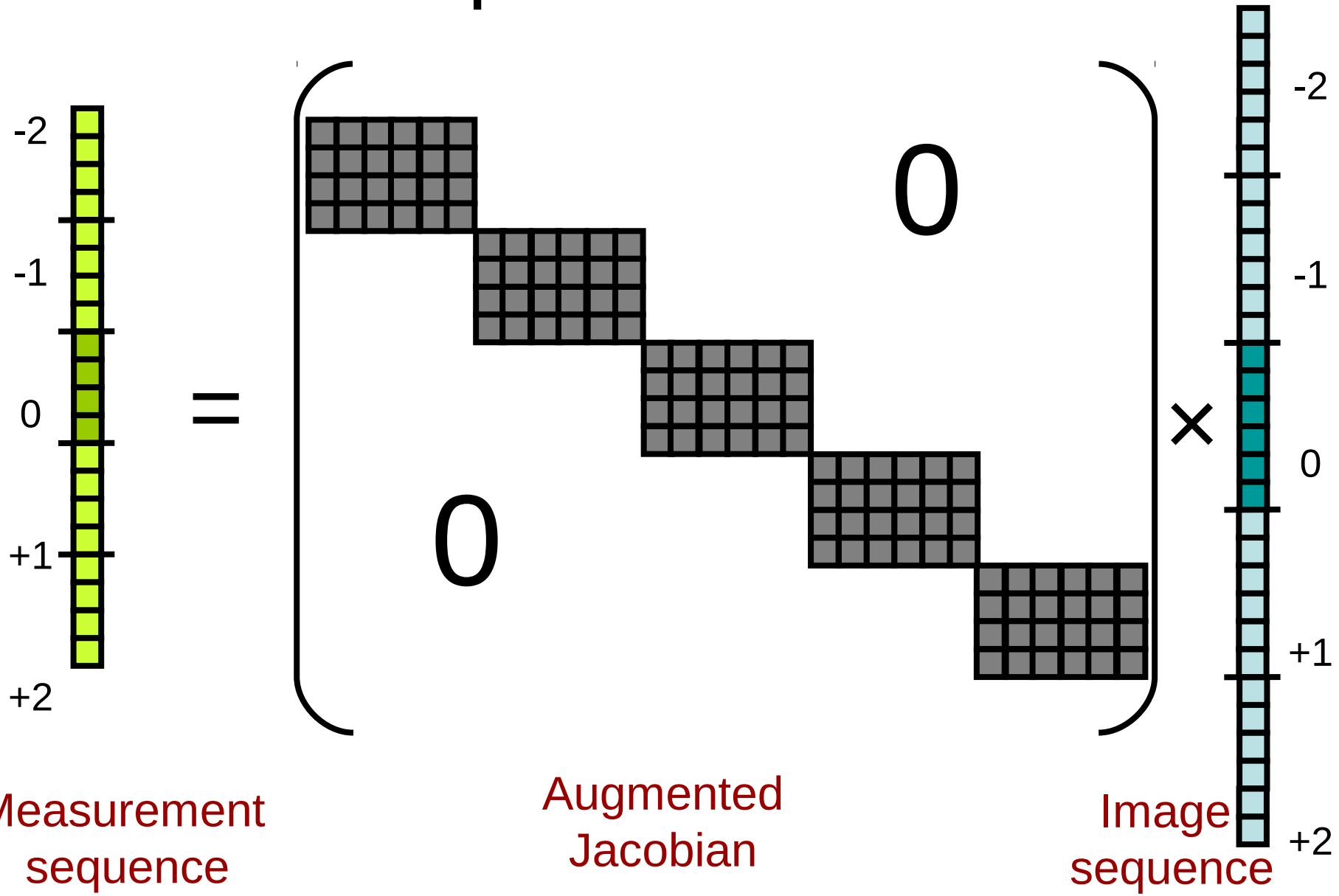
Standard EIT approaches to not take this into account

Direct temporal solver

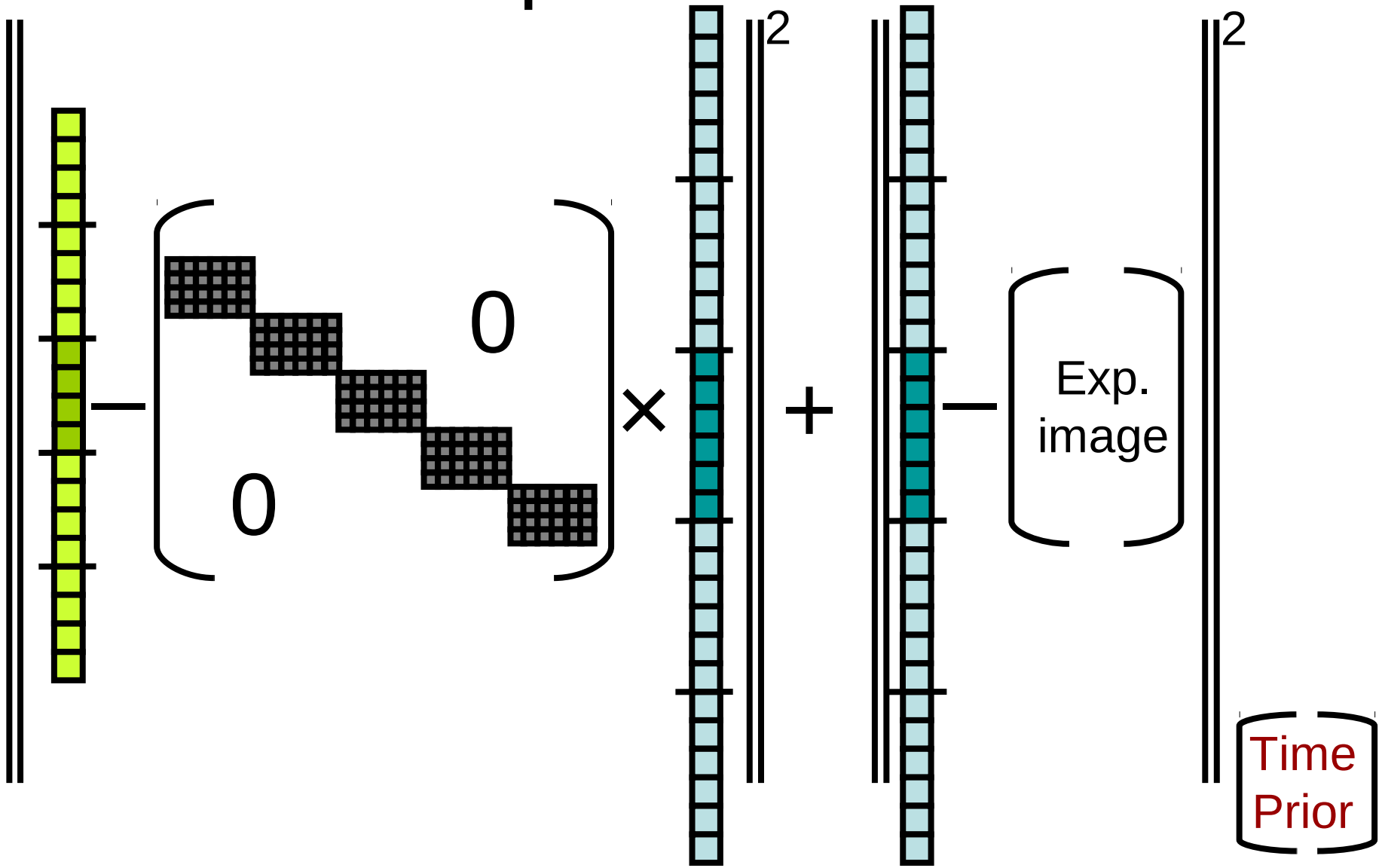


Rewrite as …

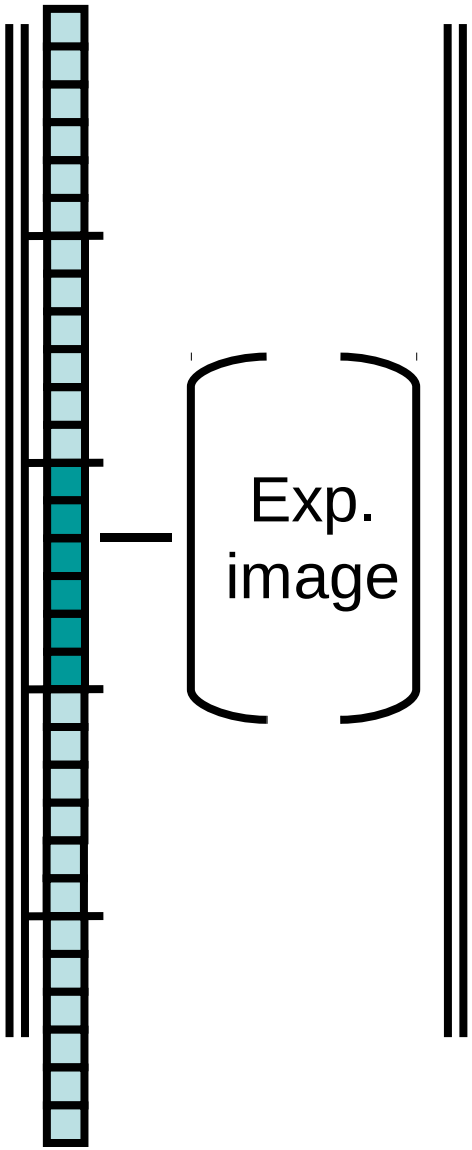
Direct temporal forward model



Direct temporal inverse model



Temporal Priors



Spatial Prior	Time Prior Δt = 1	Time Prior Δt = 2	Time Prior Δt = 3	Time Prior Δt = 4
Time Prior Δt = 1	Spatial Prior	Time Prior Δt = 1	Time Prior Δt = 2	Time Prior Δt = 3
Time Prior Δt = 2	Time Prior Δt = 1	Spatial Prior	Time Prior Δt = 1	Time Prior Δt = 2
Time Prior Δt = 3	Time Prior Δt = 2	Time Prior Δt = 1	Spatial Prior	Time Prior Δt = 1
Time Prior Δt = 4	Time Prior Δt = 3	Time Prior Δt = 2	Time Prior Δt = 1	Spatial Prior

EIDORS: community-based extensible software for EIT

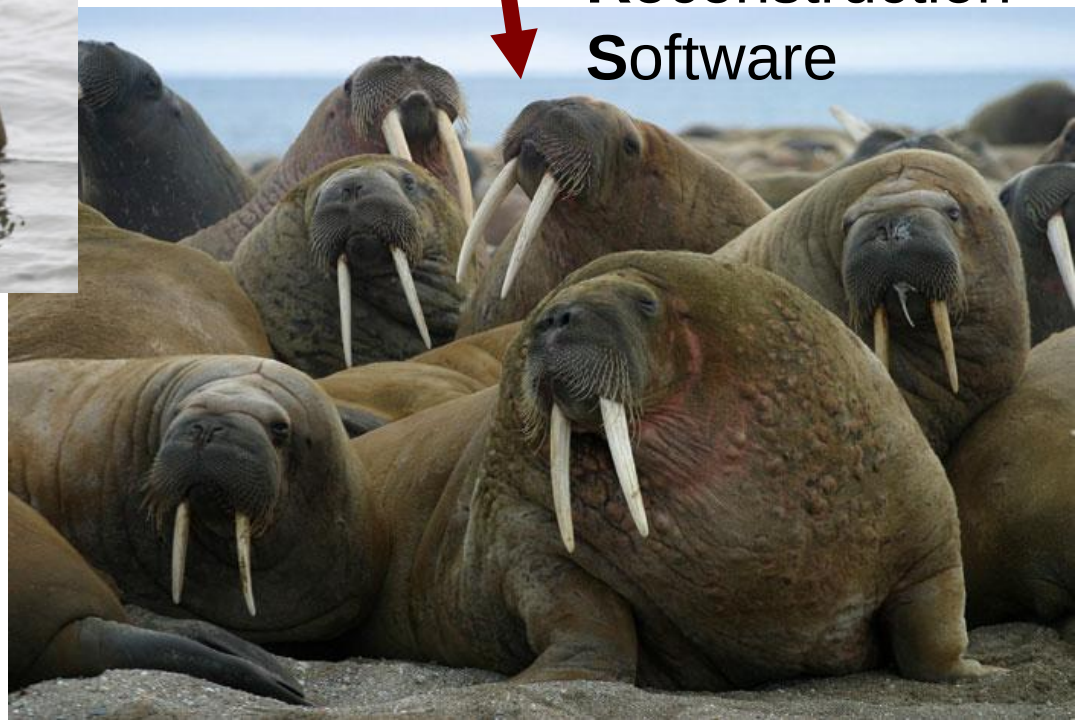
Andy Adler[1], William R.B. Lionheart[2]

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

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

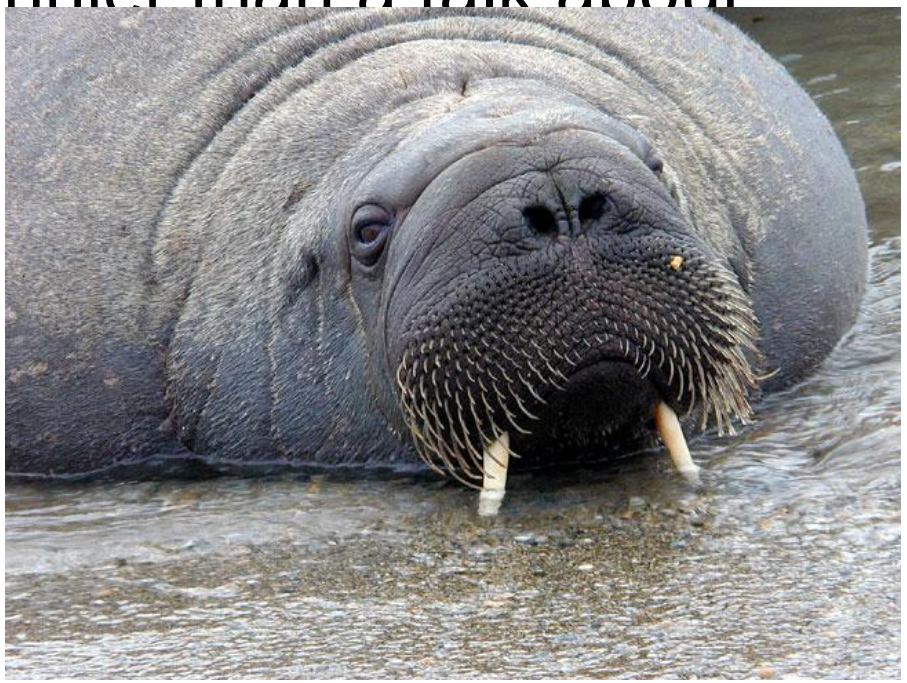
Goal: software community

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: www.biobcc.net

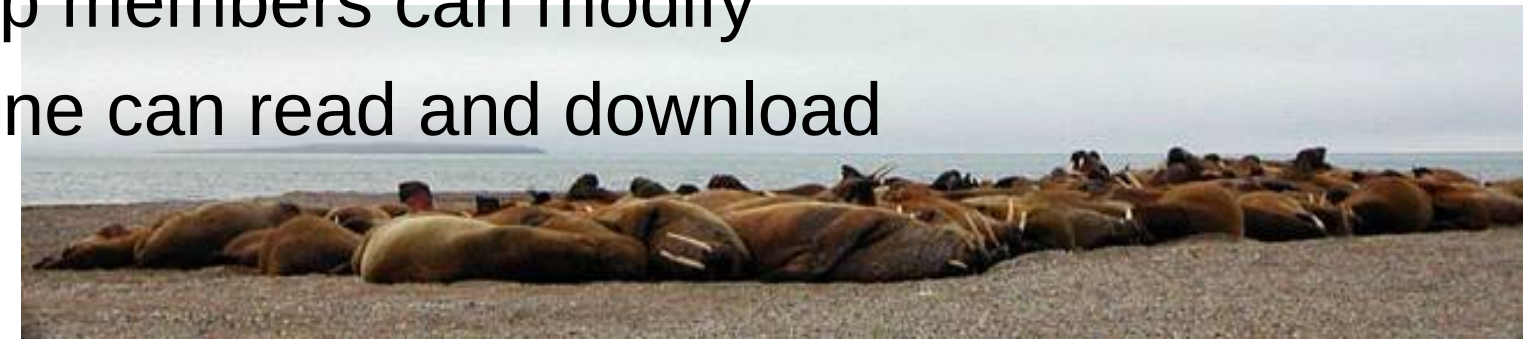
EIDORS Features

Open-source:

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

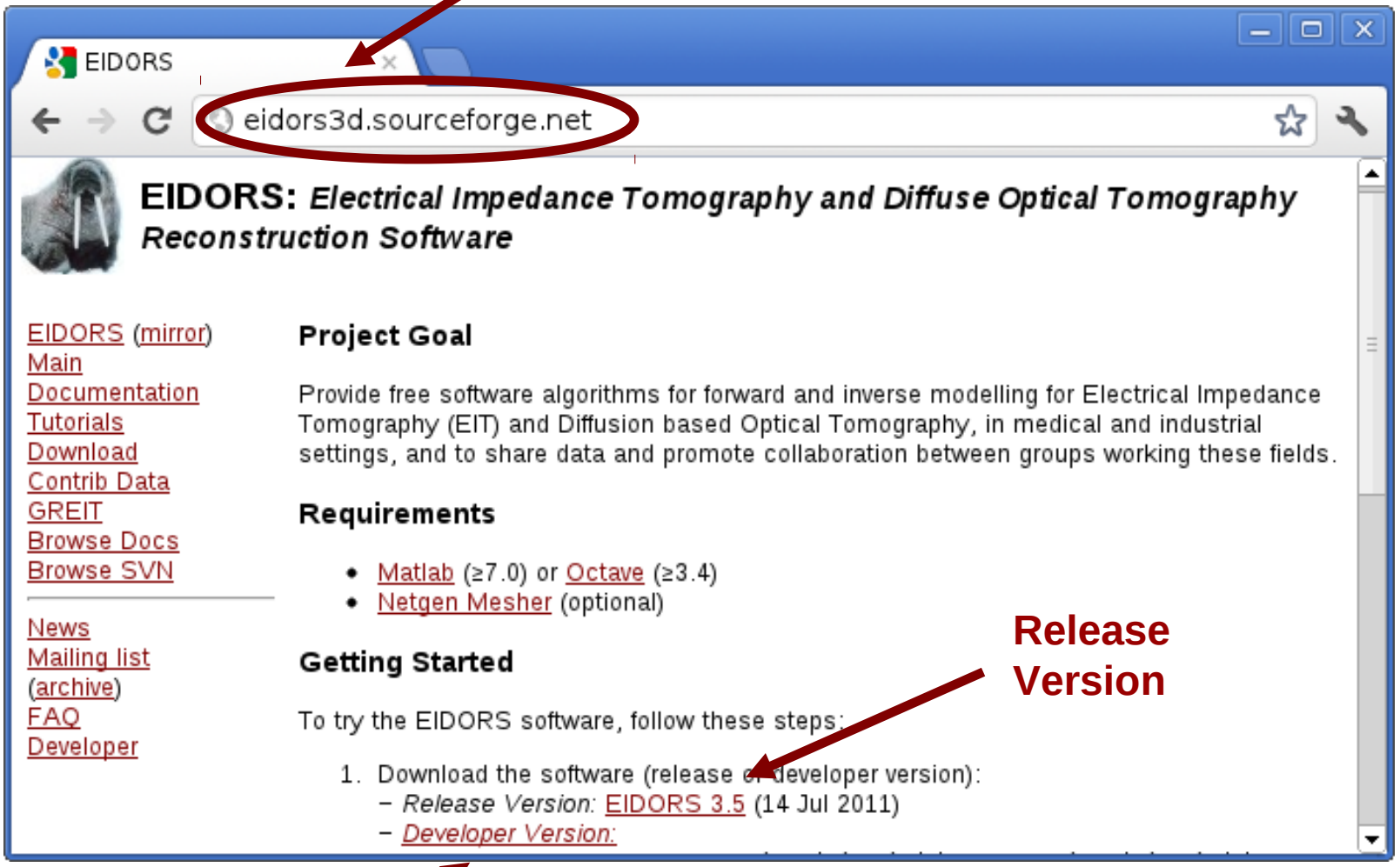
Hosted on Sourceforge.net

- 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

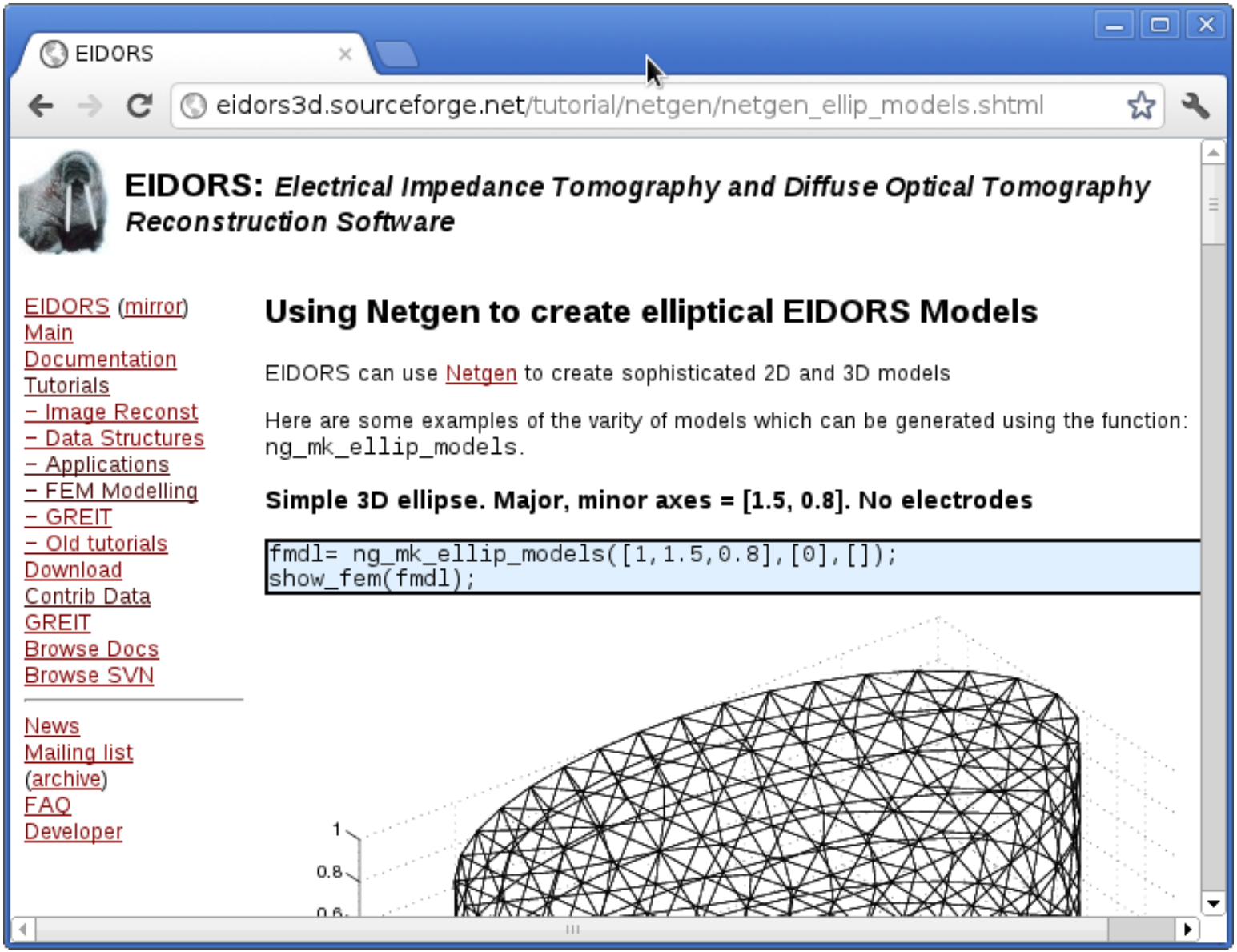
Walrus



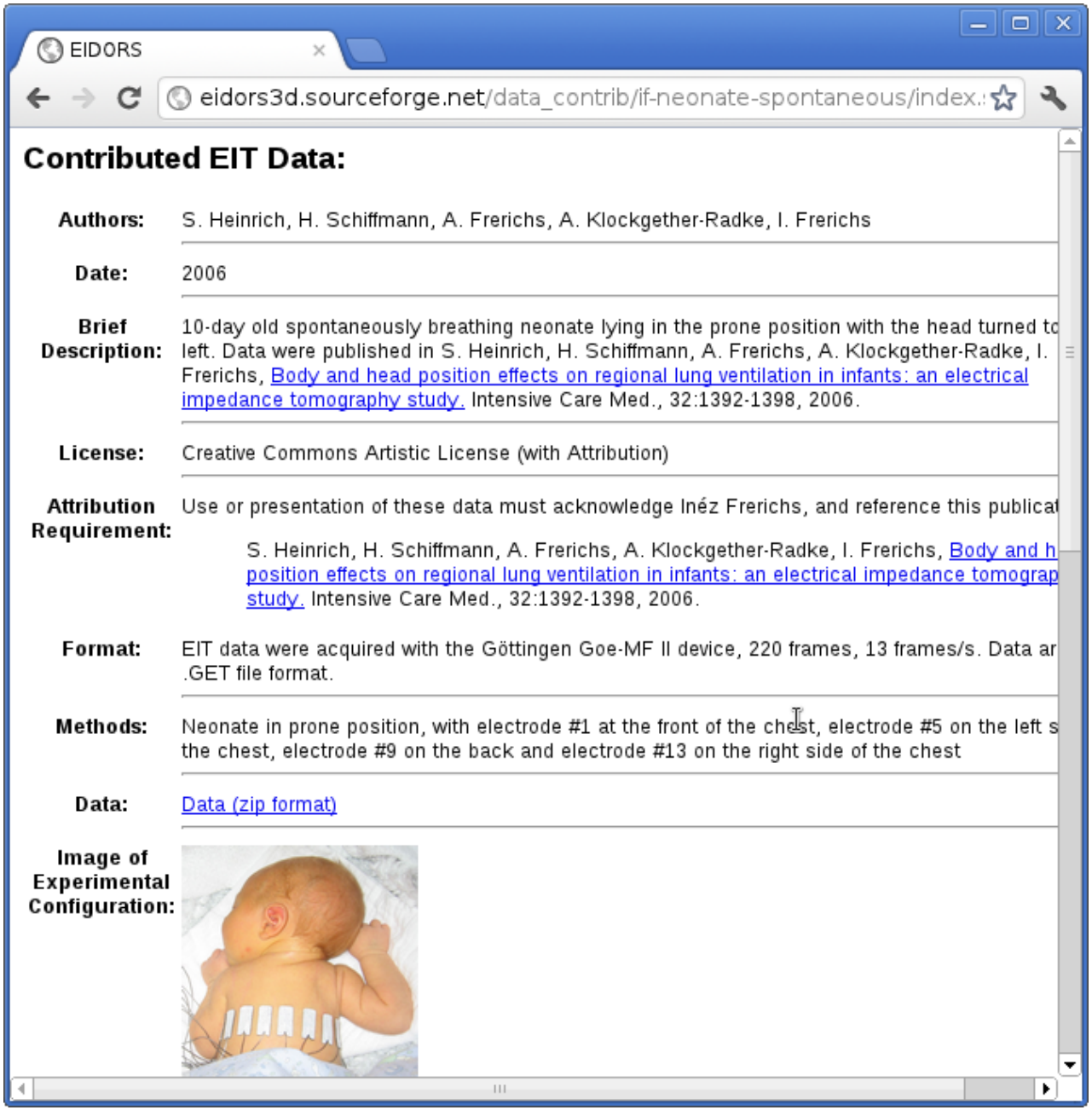
Release Version

Developer Version

Tutorials


EIDORS
eidors3d.sourceforge.net/tutorial/netgen/netgen_ellip_models.shtml
EIDORS: Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software
EIDORS (mirror)
Main
Documentation
Tutorials
– Image Reconst
– Data Structures
– Applications
– FEM Modelling
– GREIT
– Old tutorials
Download
Contrib Data
GREIT
Browse Docs
Browse SVN
News
Mailing list
(archive)
FAQ
Developer
Using Netgen to create elliptical EIDORS Models
EIDORS can use Netgen to create sophisticated 2D and 3D models
Here are some examples of the varity of models which can be generated using the function: ng_mk_ellip_models.
Simple 3D ellipse. Major, minor axes = [1.5, 0.8]. No electrodes
fmdl= ng_mk_ellip_models([1,1.5,0.8],[0],[]);
show_fem(fmdl);
1
0.8
0.6

Contributed Data



Thank you

Source: http://scm-l3.technorati.com/11/12/28/59203/Ottawa-Rideau-Canal-courtesy-city-of-ottawa.jpg

Imaging with Impedance: Can We Guide Lung Ventilation? Lecture

Abstract: Electrical Impedance Tomography (EIT) uses a set of electrodes placed around the patient's body to apply current simulation and measure the resulting potentials, from which an image of the internal conductivity distribution is calculated. EIT was invented 100 years ago by the brother's Schlumberger to prospect for conductive minerals. Since EIT is sensitive to physiological phenomena which affect the conductivity, it has been used to image the brain (to view perfusion changes due to epilepsy and stroke), the breast (to screen for cancerous regions), the abdomen (for gastric emptying) and thorax (to image the movement of blood and gas in the heart and lungs).

Patients in respiratory failure require positive pressure ventilation to ensure adequate gas exchange. While ventilation is life-saving, it imposes significant risks. To address these risks, lung EIT has the potential to be a monitoring tool to help guide and optimize lung protective ventilation individually for each patient.

EIT image reconstruction is difficult because of the way current propagates through all paths in the body; EIT image reconstruction is non-linear, spatially variant, and mathematically ill-conditioned. To solve these problems, regularized image reconstruction techniques are used, which use prior models to penalise low probability solutions. Recently, the increase in computer power has facilitated much more powerful algorithms.

This talk will review recent work in EIT image reconstruction, and its application for lung imaging.