Imaging the body using impedance measurements

Andy Adler

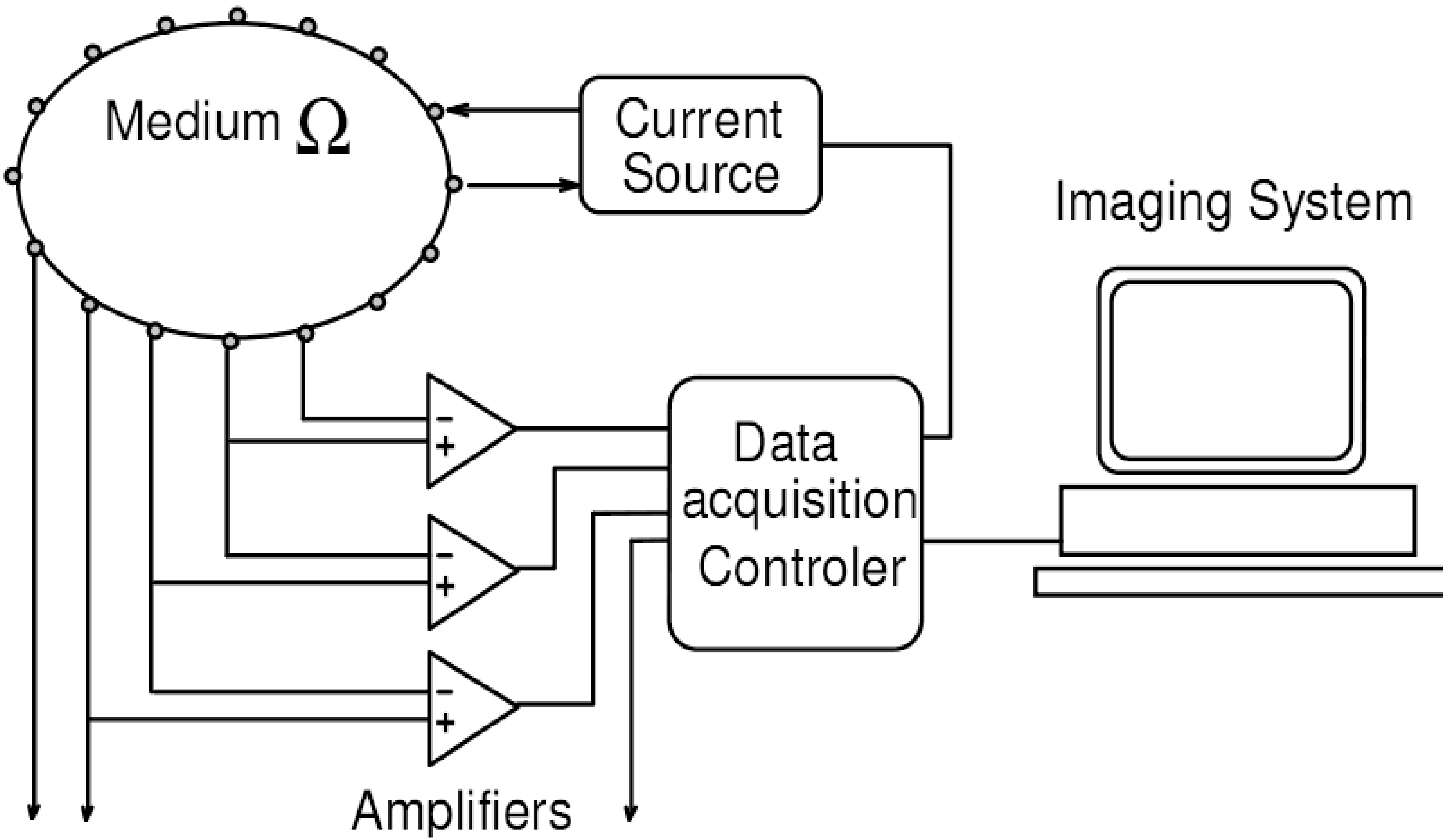
Systems and Computer Engineering, Carleton U,

Ottawa, Canada

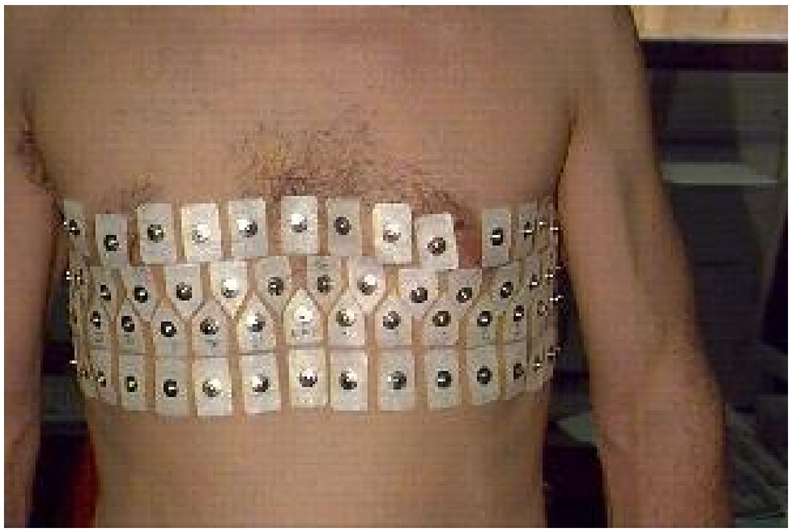
Outline

- Electrical Impedance Tomography
- Lung imaging with EIT
- Reconstruction of images
  - Data artefacts
  - Movement compensation
  - Total Variation
  - GREIT
- EIDORS

EIT: Block Diagram



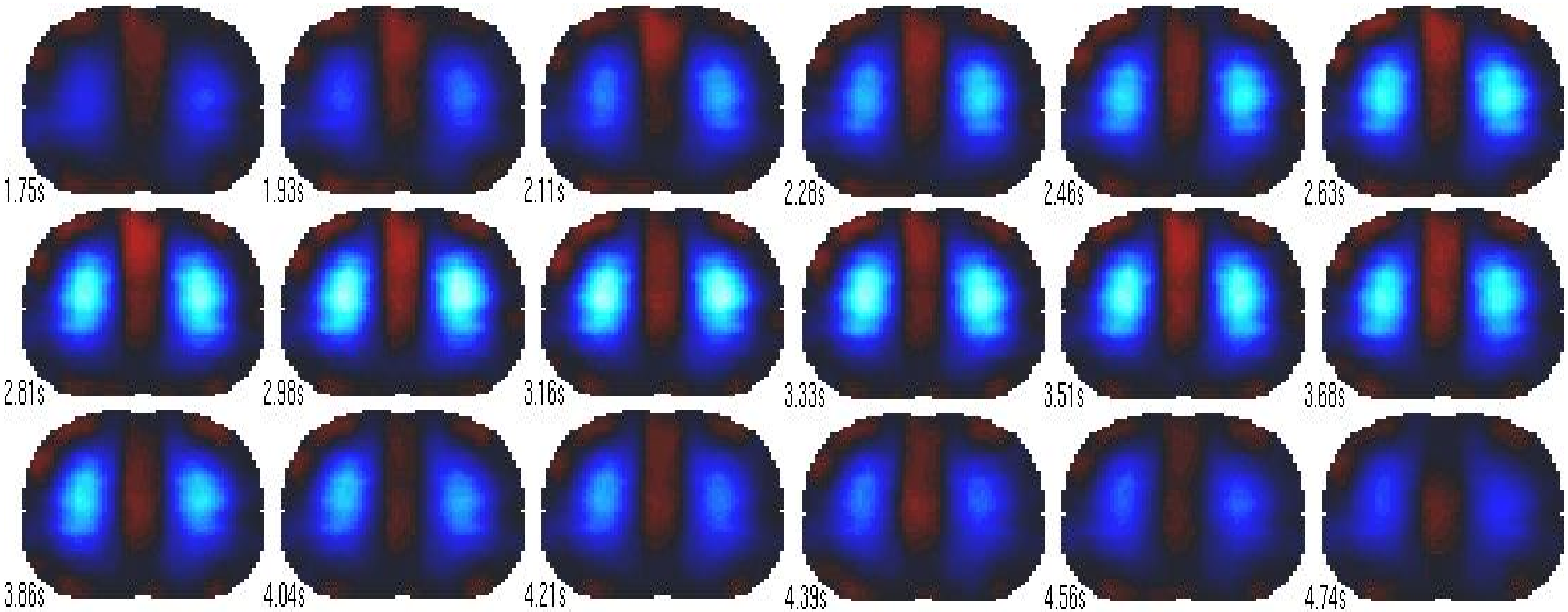
Electrode placement to monitor the lungs and heart



Adult

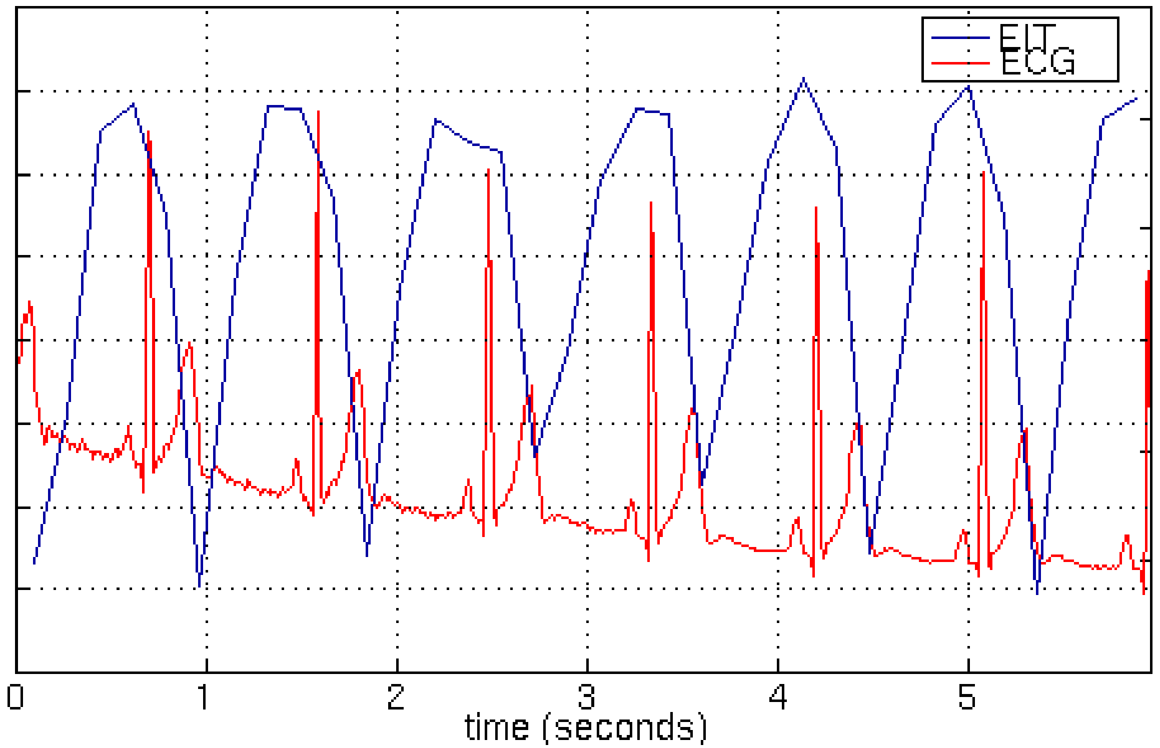
Preterm infant

Application: Breathing



Chest images of tidal breathing in normal

Application: Heart Beat



EIT signal in ROI around heart and ECG

Applications: Brain

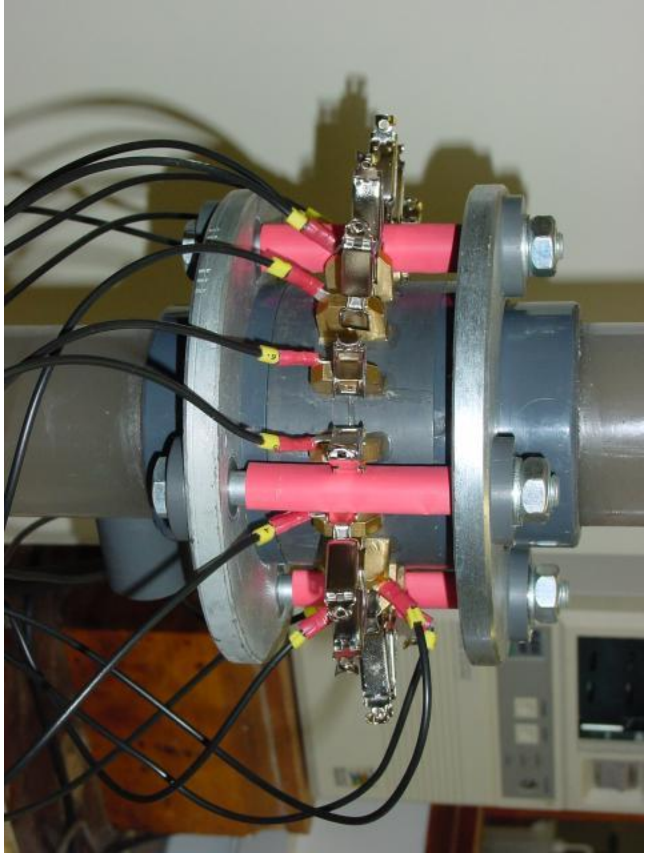
Newborn with EIT electrode cap on head

Applications

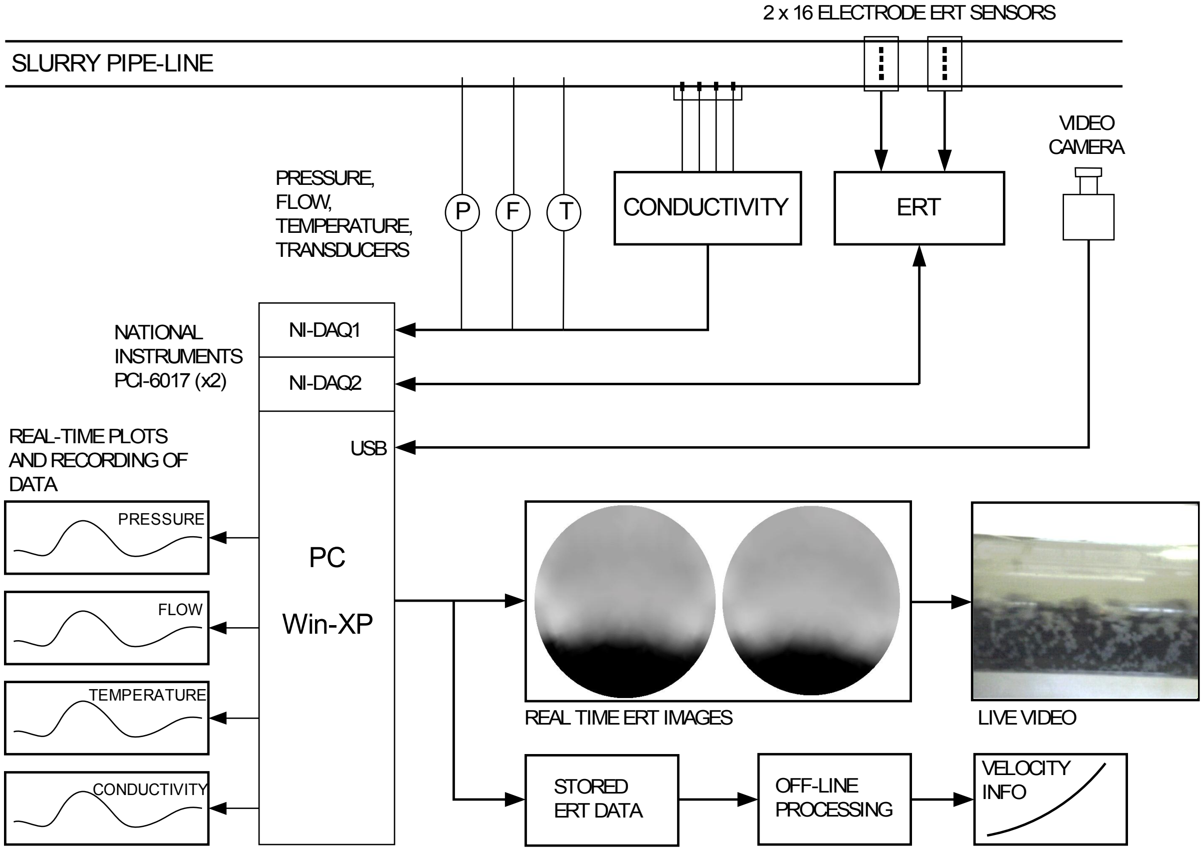
- Hemorrhage
- Localization of epileptic foci

Geophysics

Industrial Flow



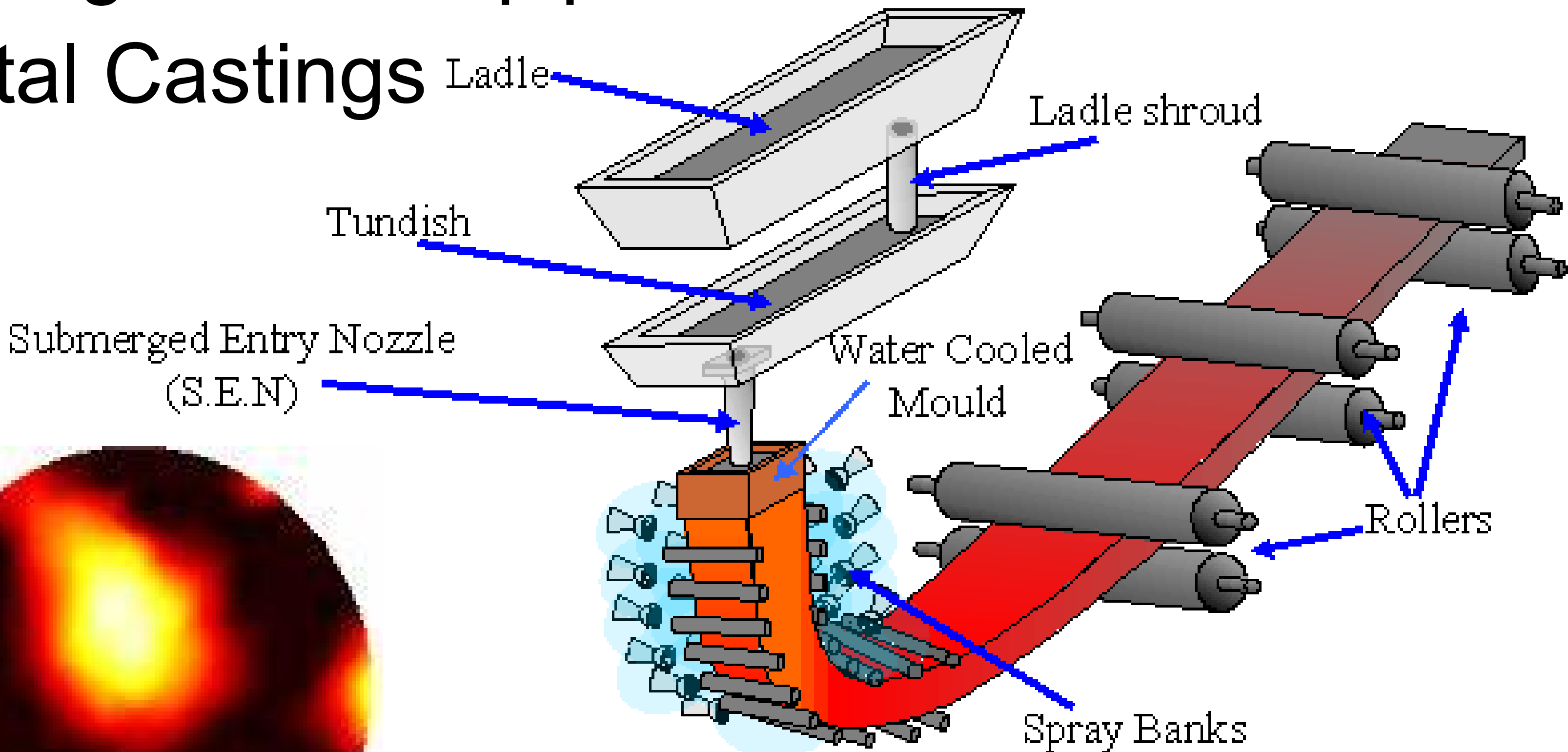
60mm diameter pipeline electrode system

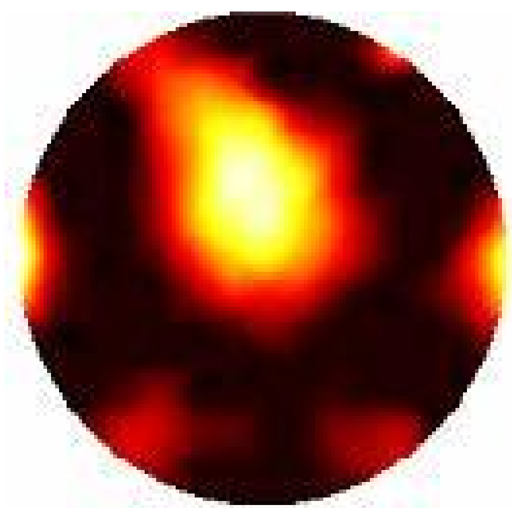


Industrial Applications

Process Tomography

- Fluid/gas flow in pipes
- Metal Castings





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 is required.
- Mechanical ventilation may be required.

Ref: Wikipedia.org

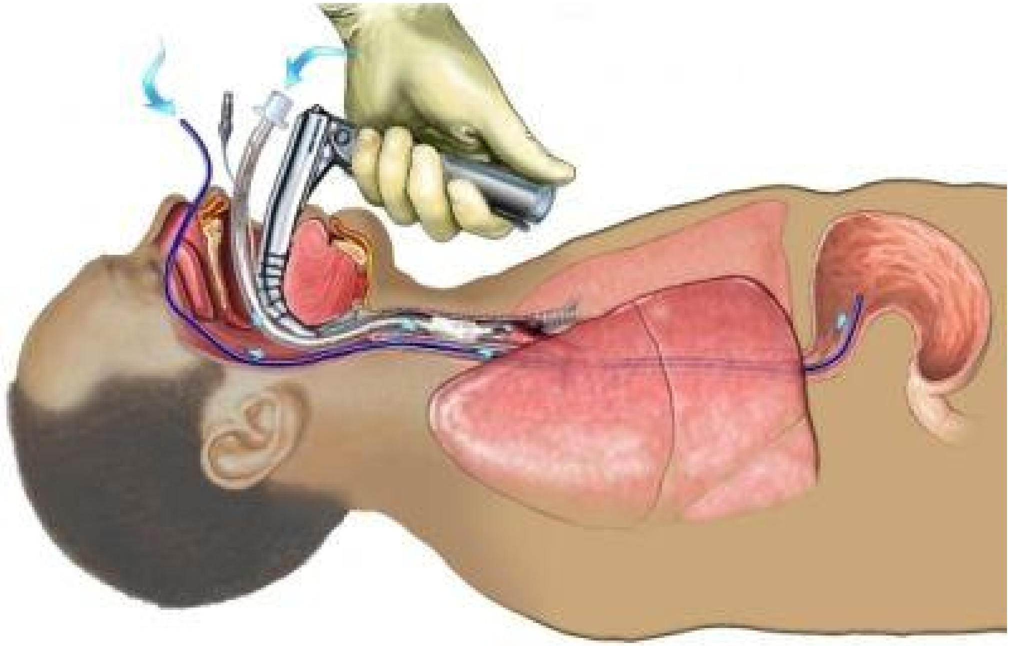
Mechanical Ventilation

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

- pneumothorax,
- airway injury,
- alveolar damage,

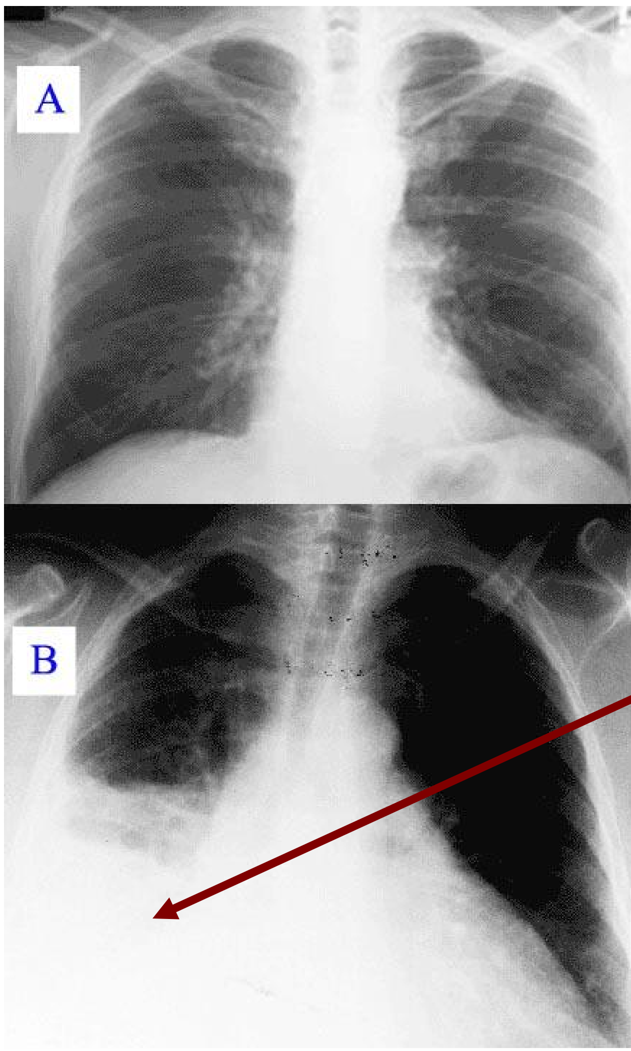
Accordingly it is generally weaned off or to minimal settings as soon as possible.

Ref: Wikipedia.org



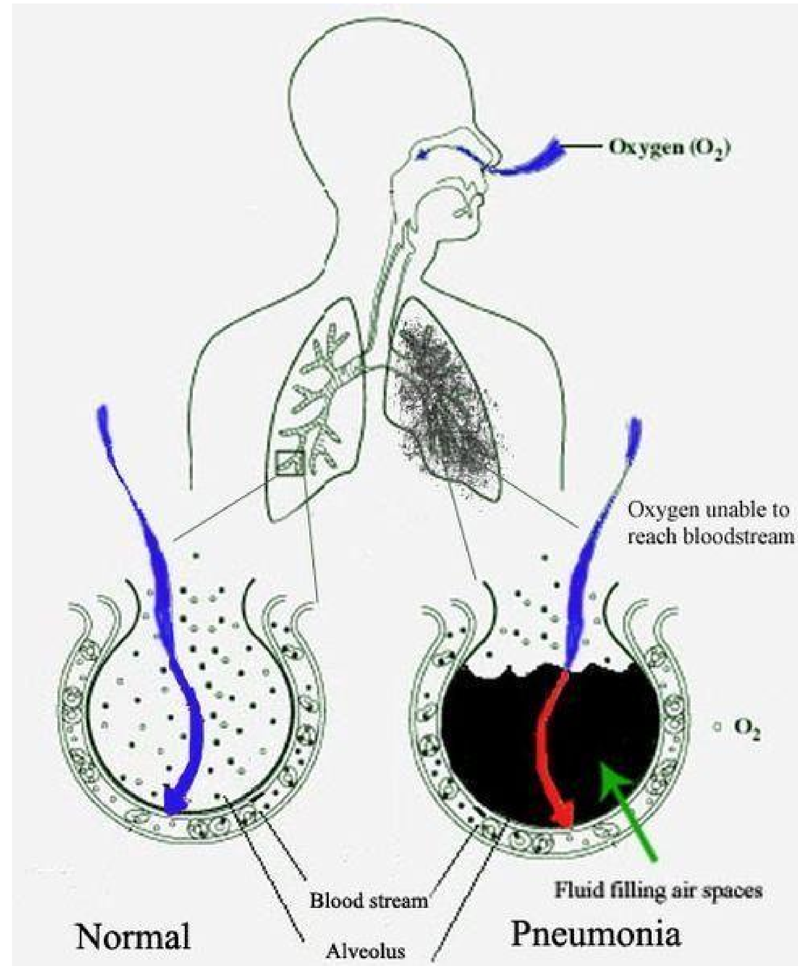
Ref: healthlibrary.epnet.com/

Why image lungs? eg. Pneumonia



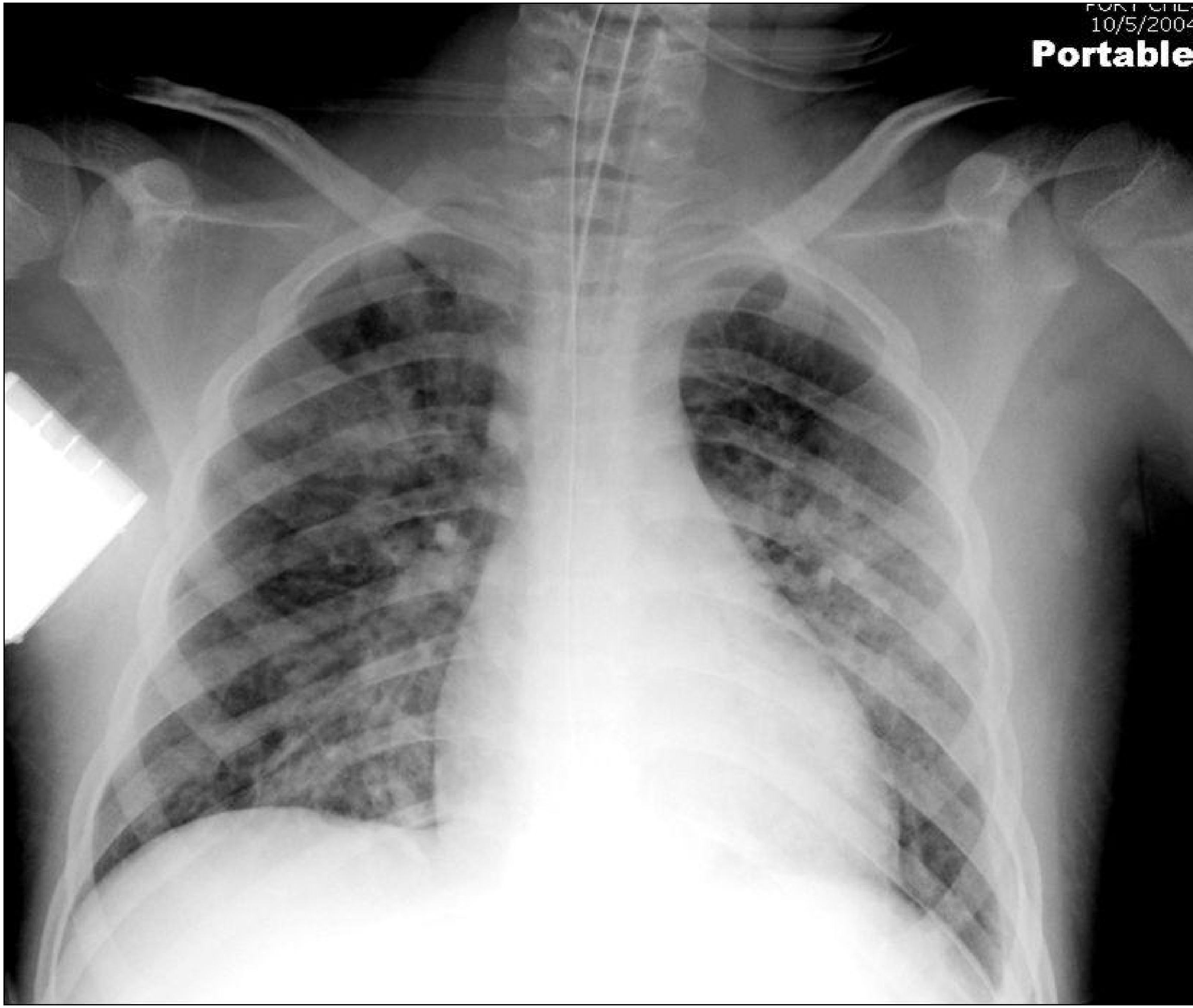
A: Normal chest x-ray
B: Abnormal chest x-ray

shadowing from pneumonia in the right lung



Ref: Wikipedia.org

Acute Respiratory Distress Syndrome (ARDS)



Chest X-ray of pediatric patient

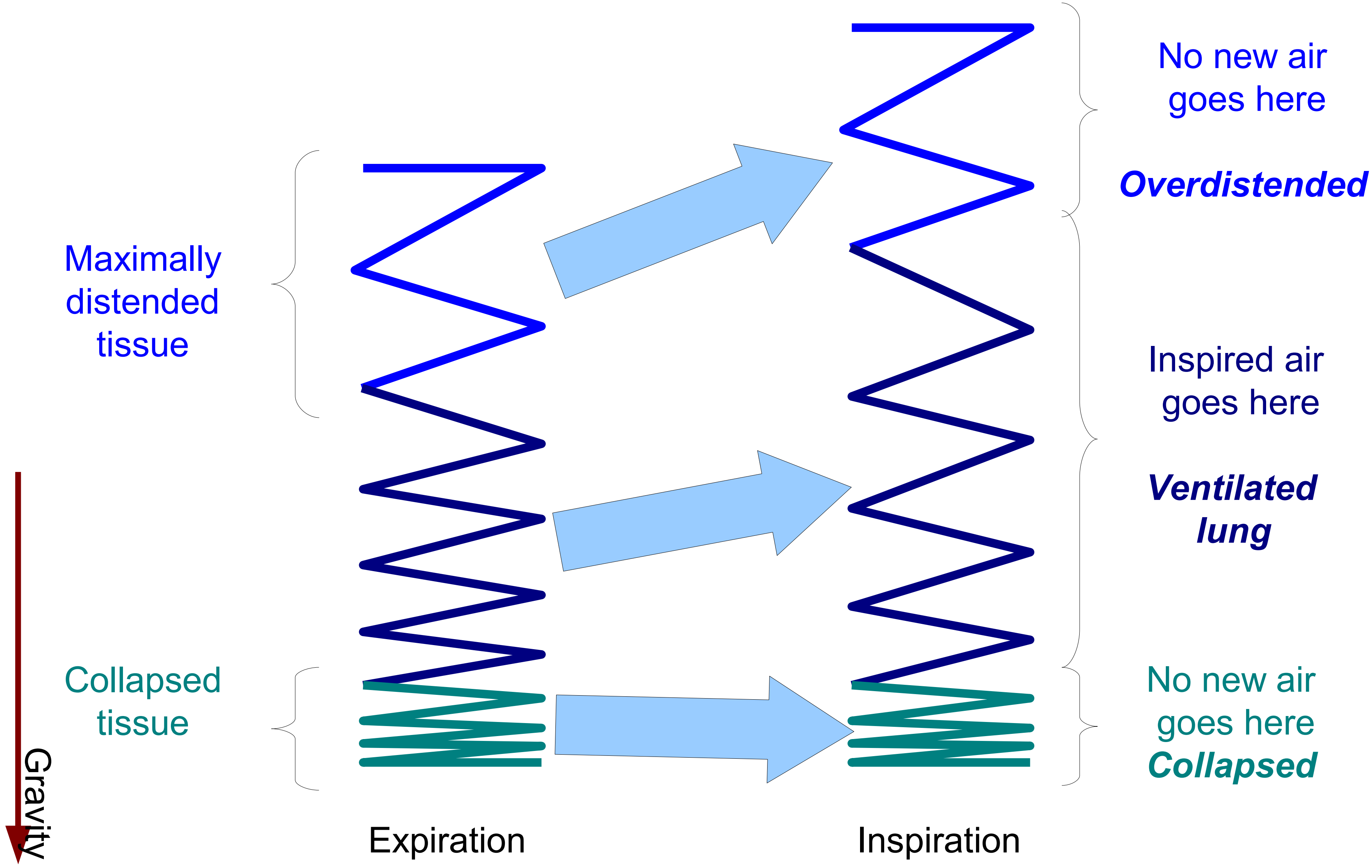
Wolf GK, Arnold JH in: Yearbook of Intensive Care and Emergency Medicine. Springer, 2005

Acute Respiratory Distress Syndrome (ARDS)

Chest CT of pediatric patient

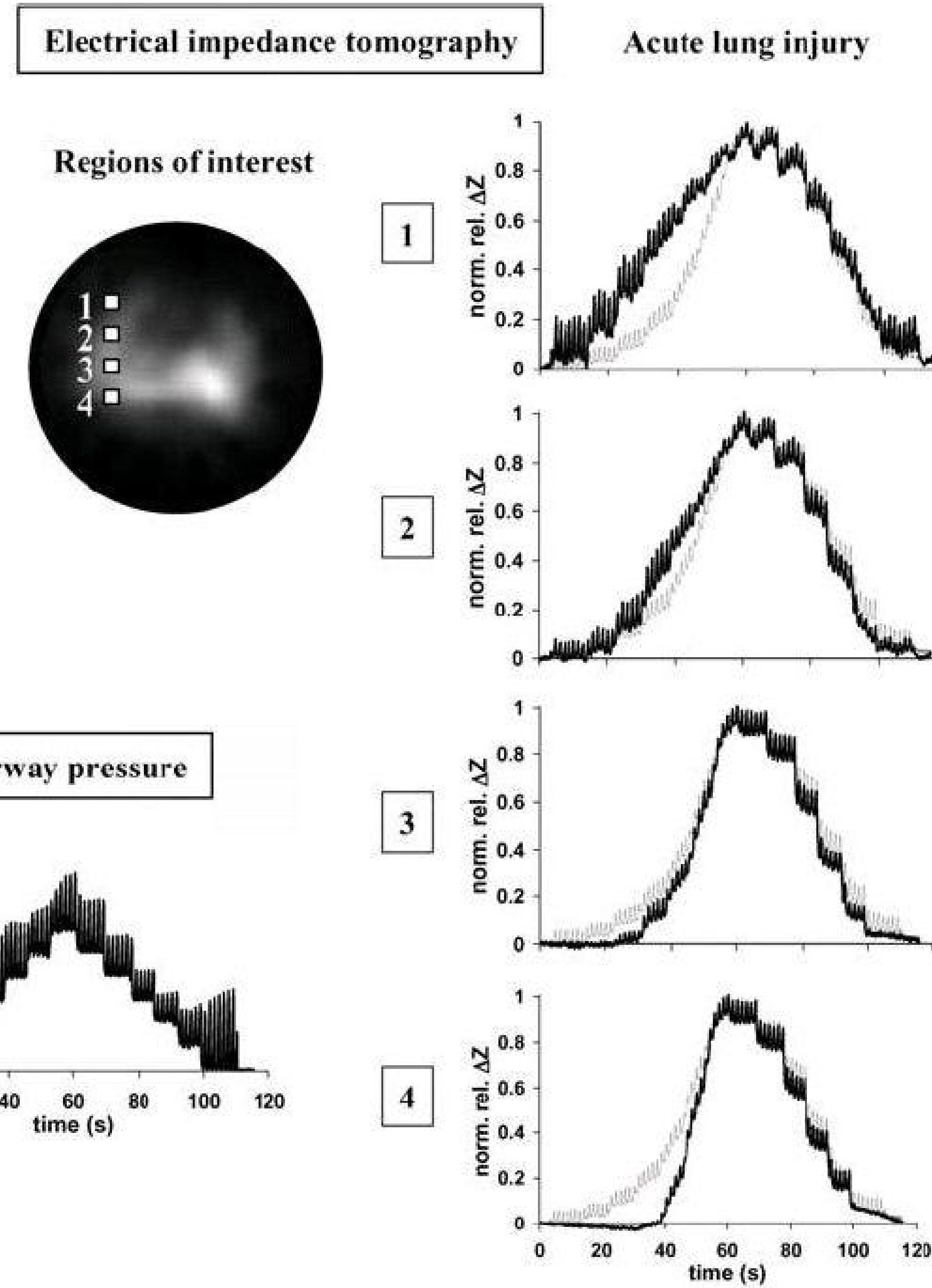
Wolf GK, Arnold JH in: Yearbook of Intensive Care and Emergency Medicine. Springer, 2005

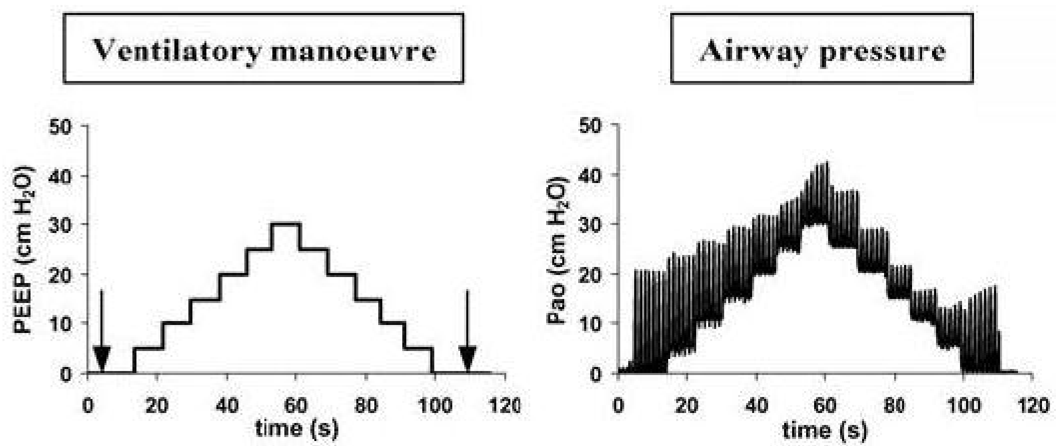
"*Slinky* Model of breathing"



Regional ventilation

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





EIT vs CT in ARDS

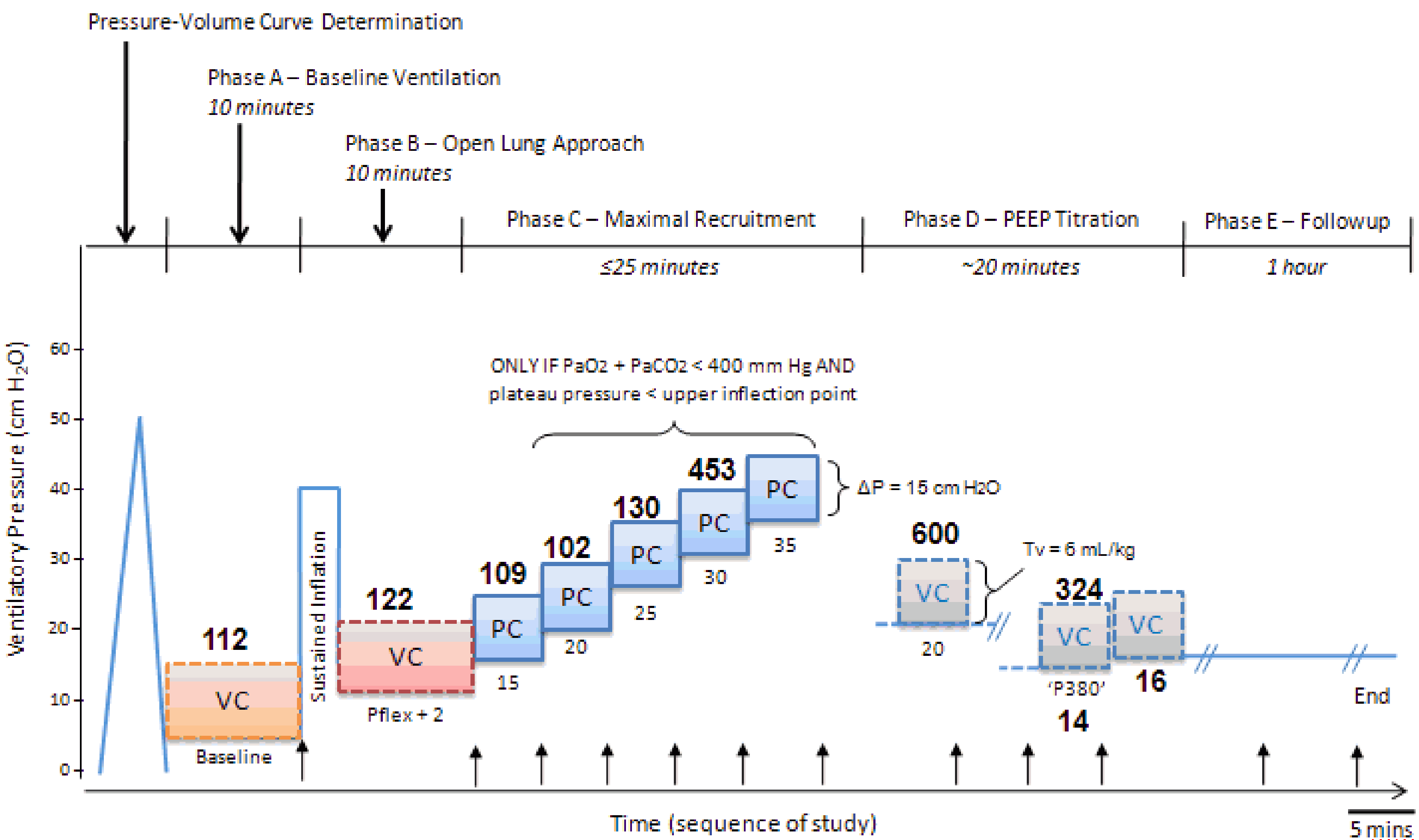
Data from pig study of EIT and CT

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

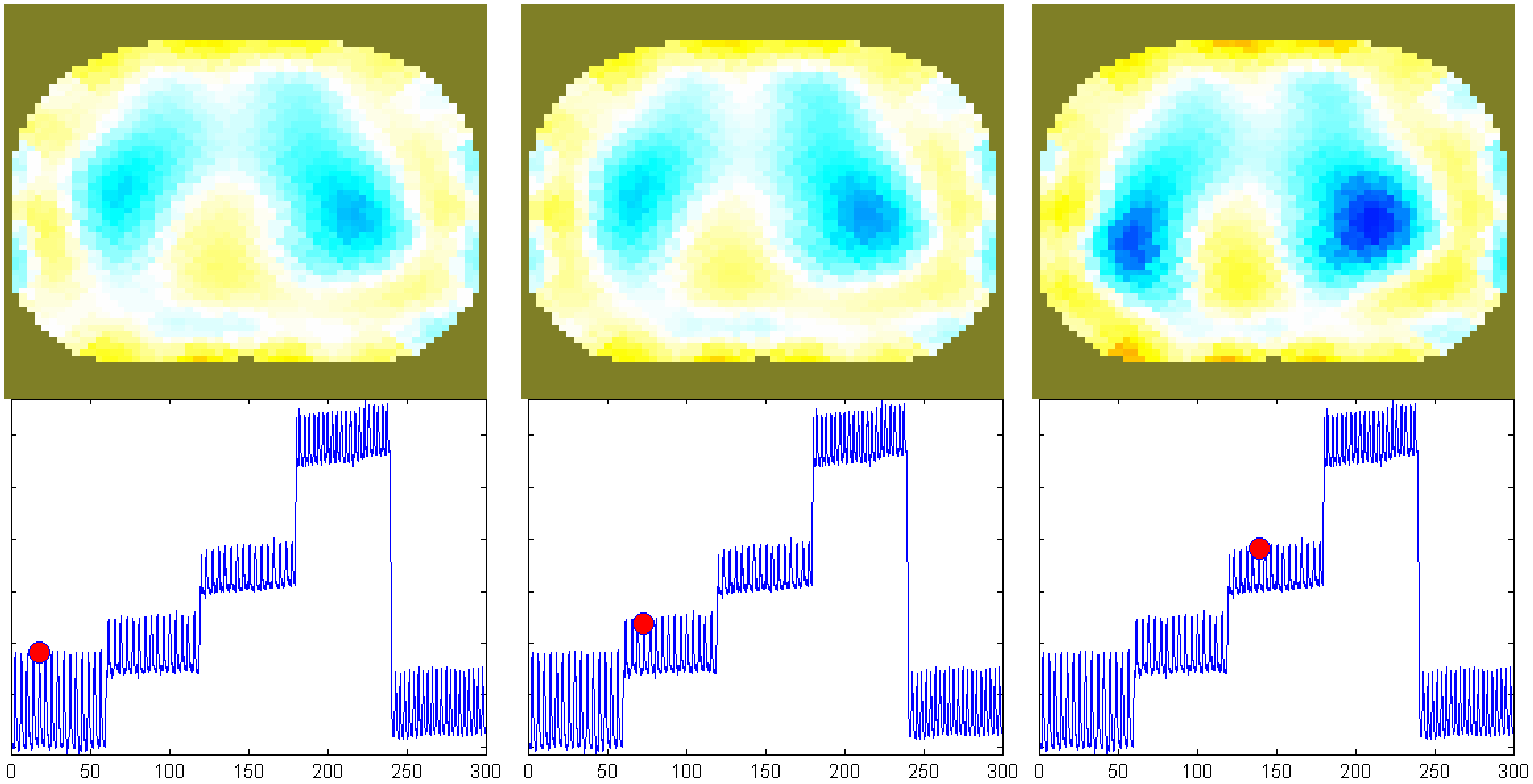
Show video

Recruitment of lungs
(Wolf, Arnold)

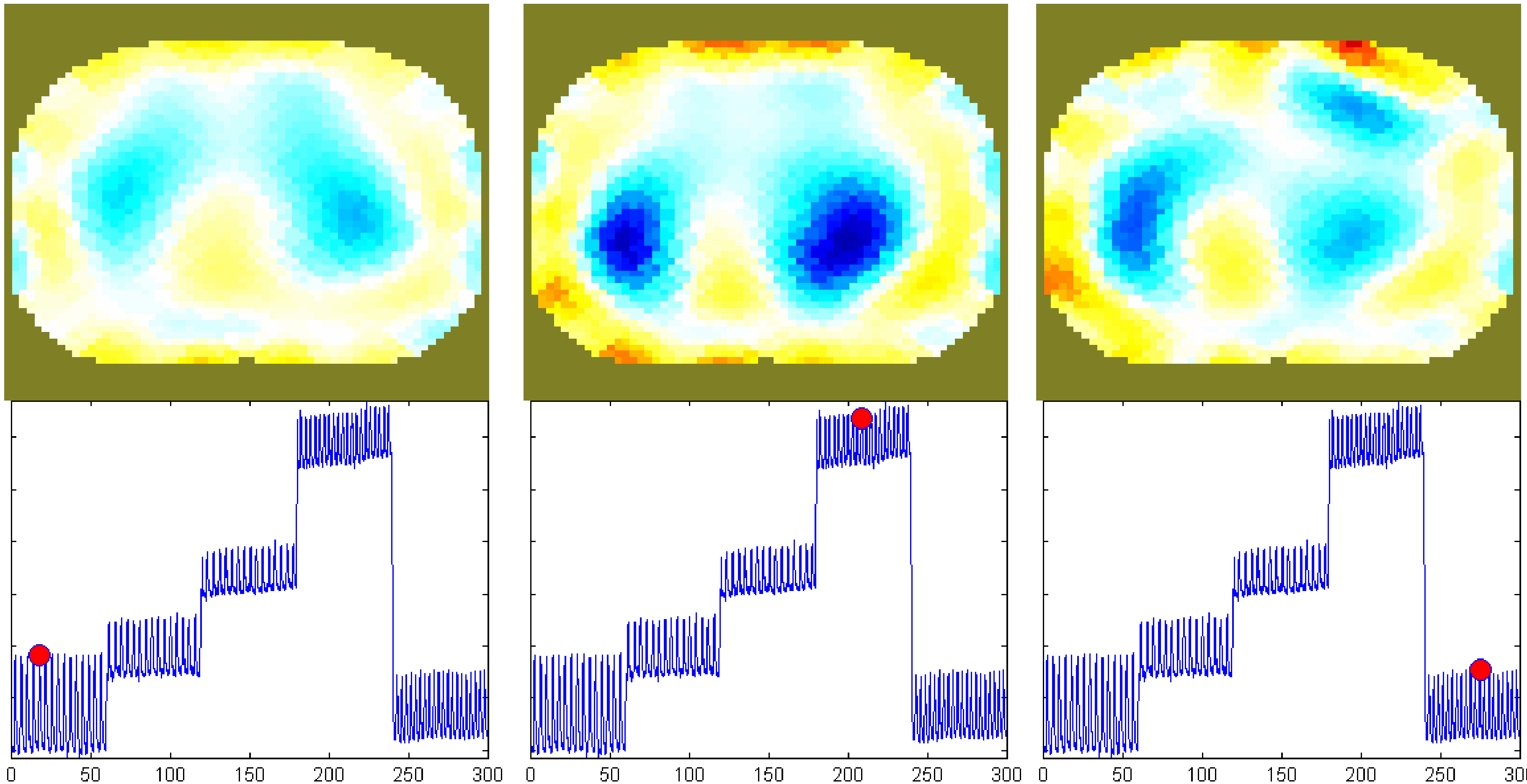
Patient 1 – PaO_2 + $PaCO_2$



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?

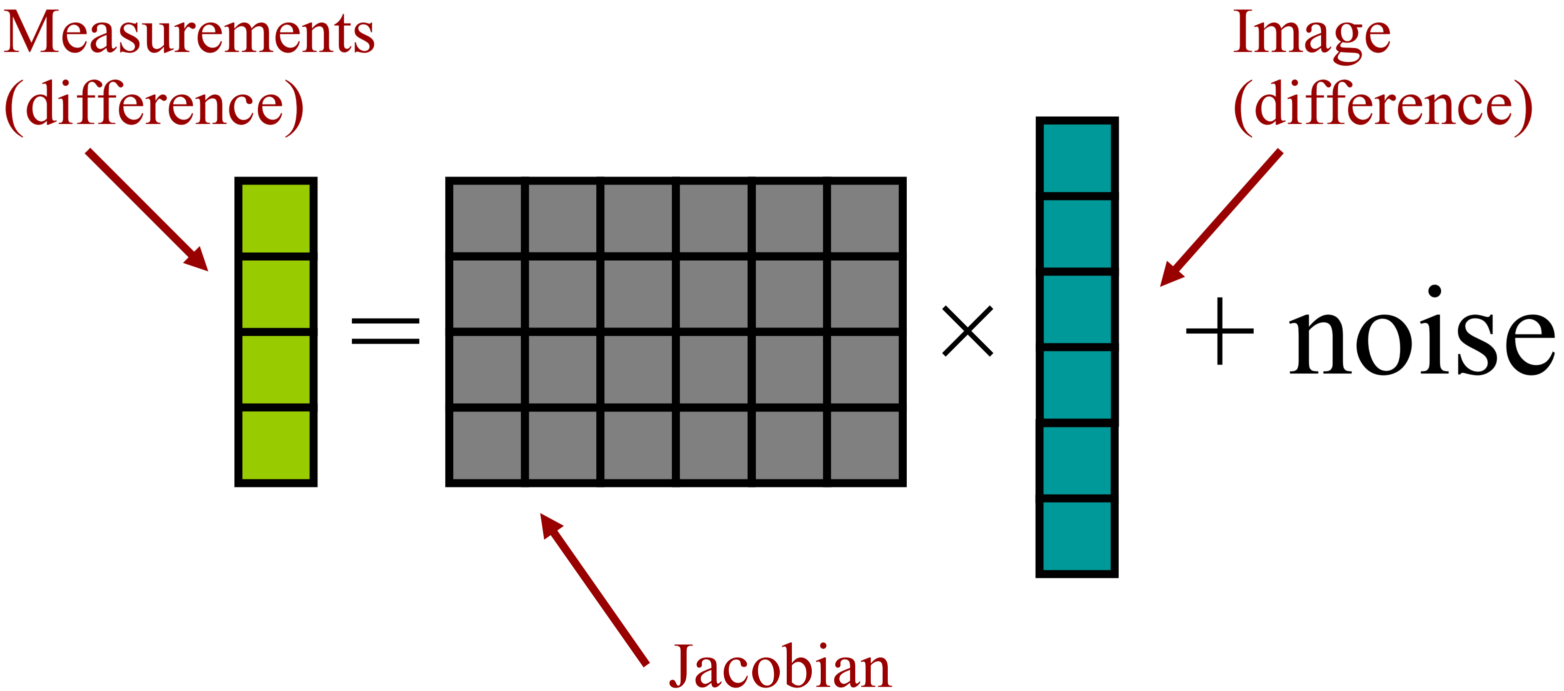
Image Reconstruction

Linear difference imaging with pictures

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

Image Reconstruction

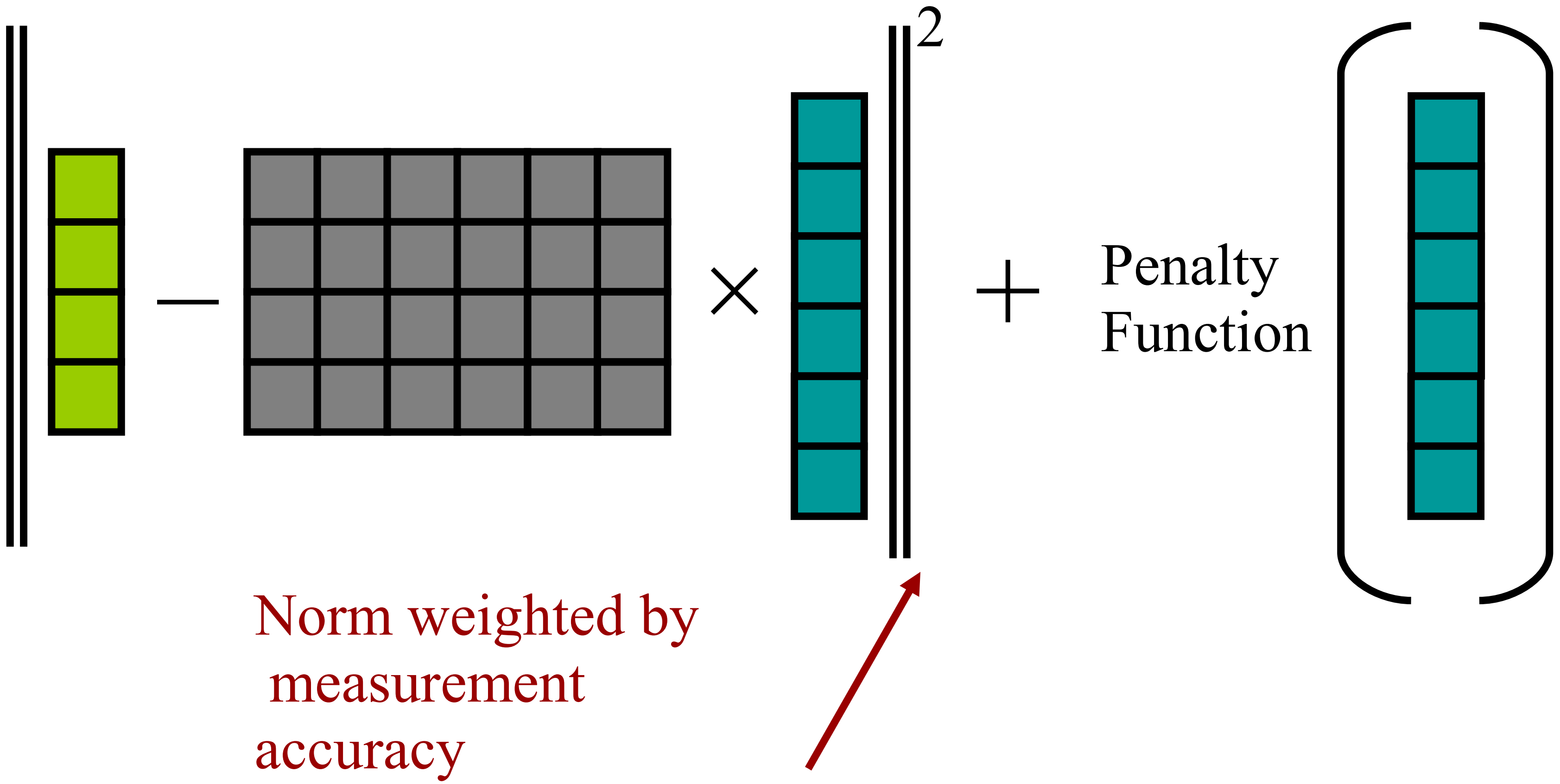
- Forward Model (linearized)



System is underdetermined

Image Reconstruction

Regularized linear Inverse Model



Measurement Norm

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

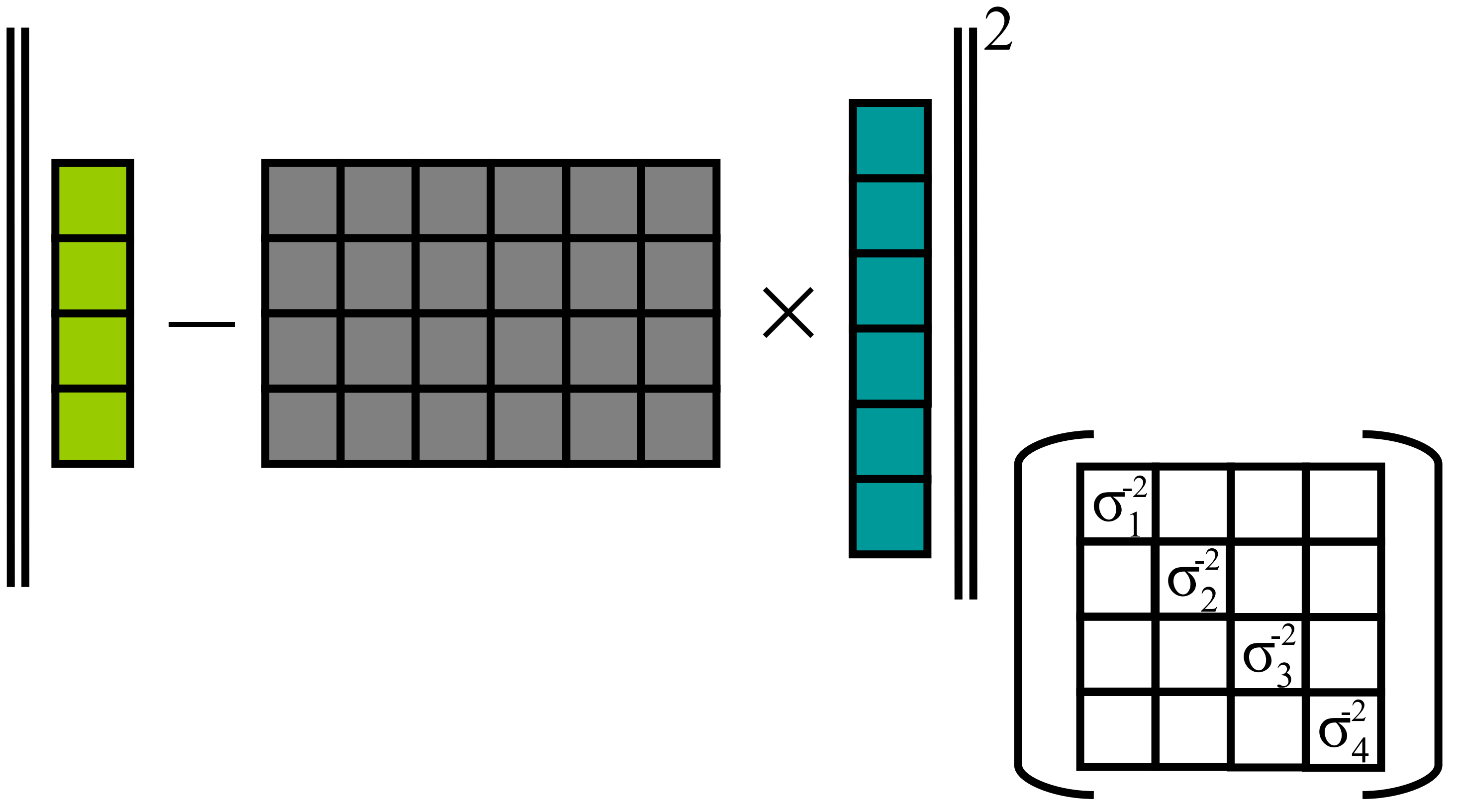


Image Reconstruction

Image Penalty Function

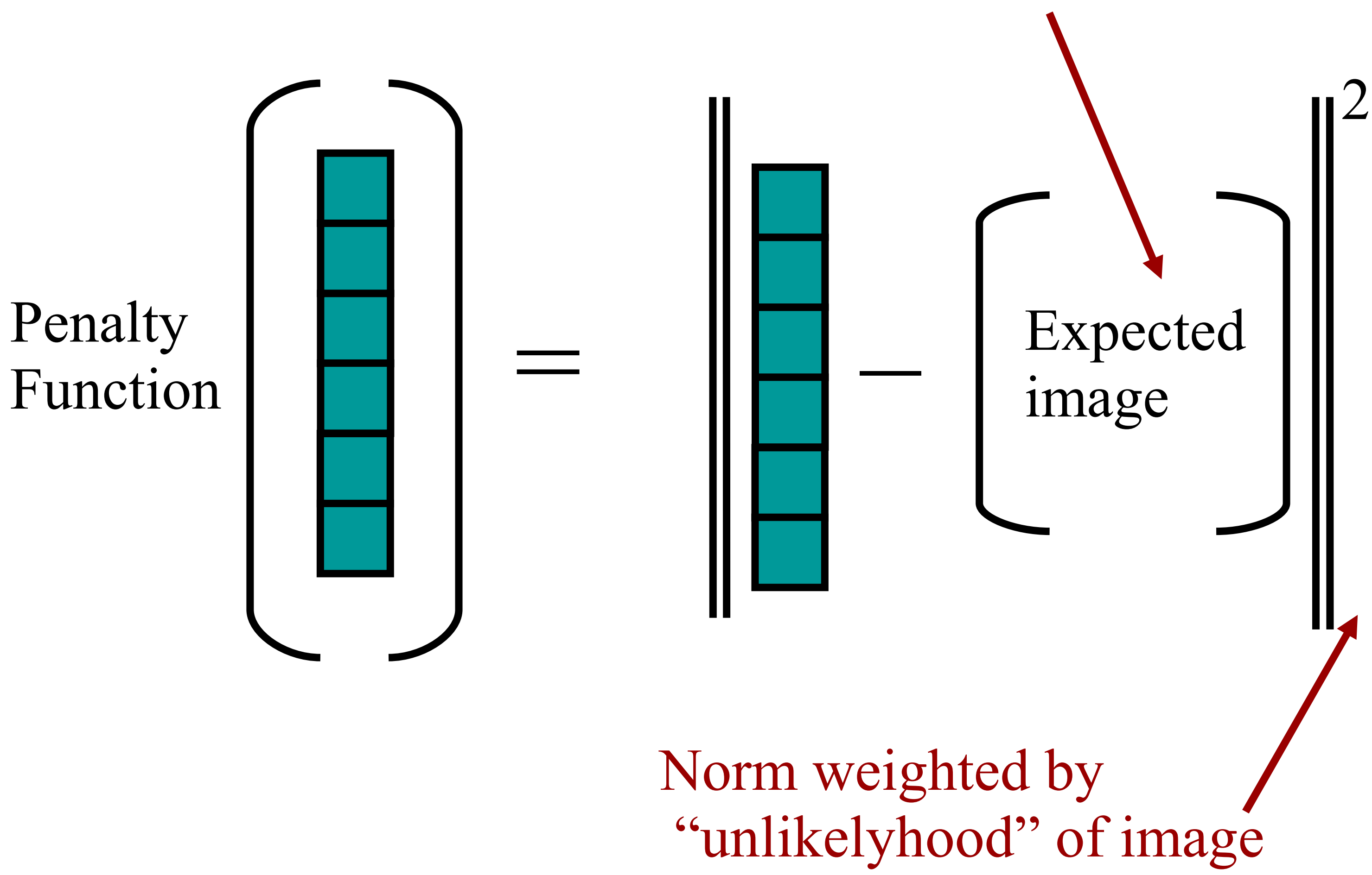


Image Reconstruction

- Penalty functions: Image Amplitude

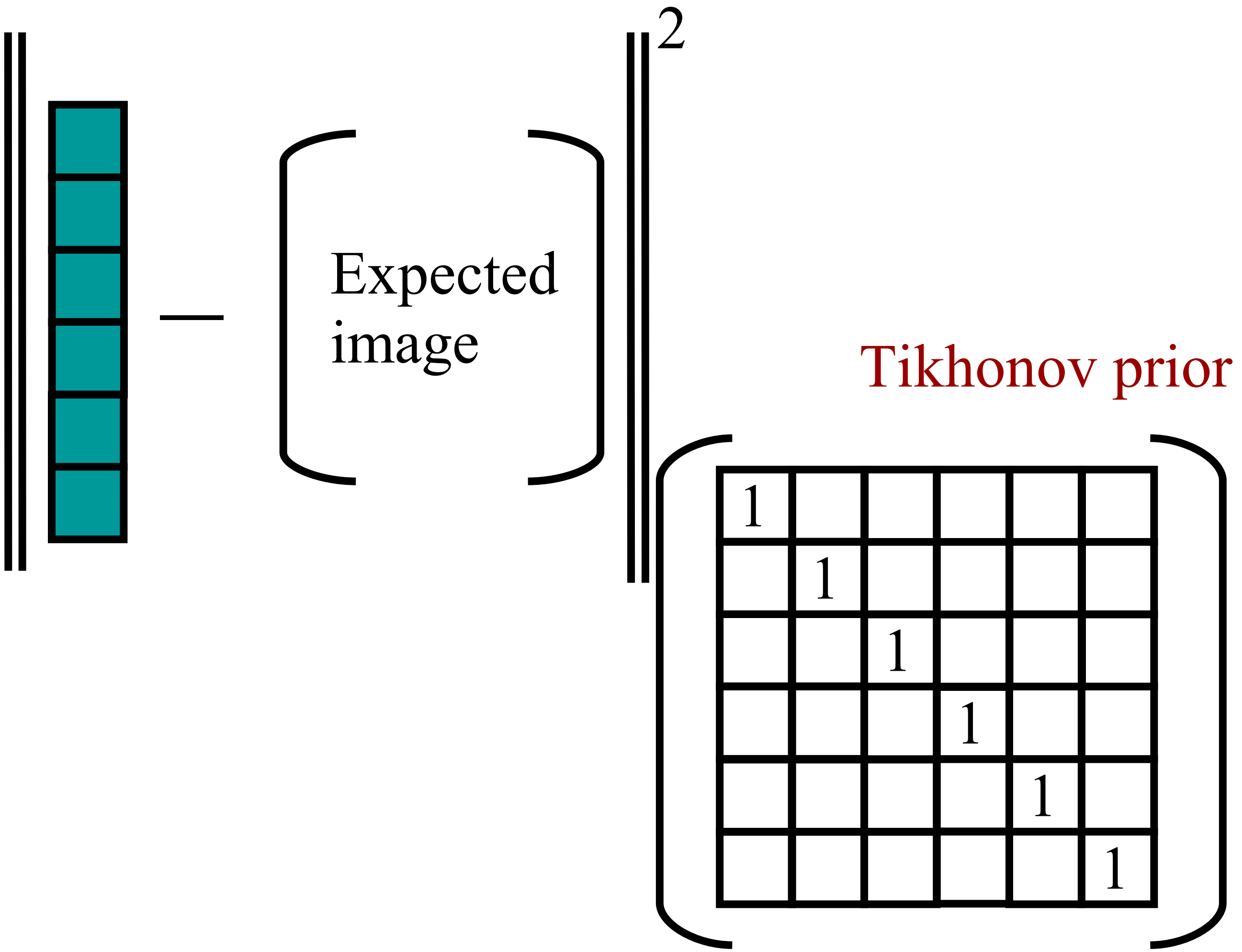
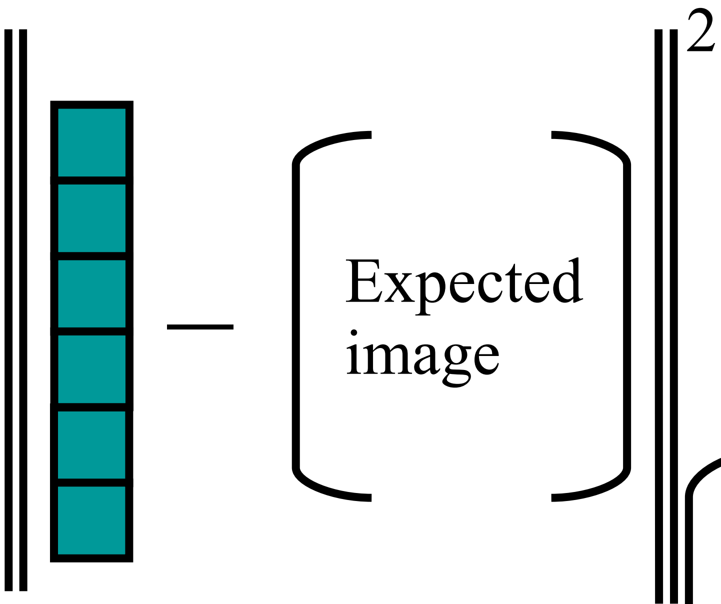


Image Reconstruction

- Penalty functions: Image Smoothness



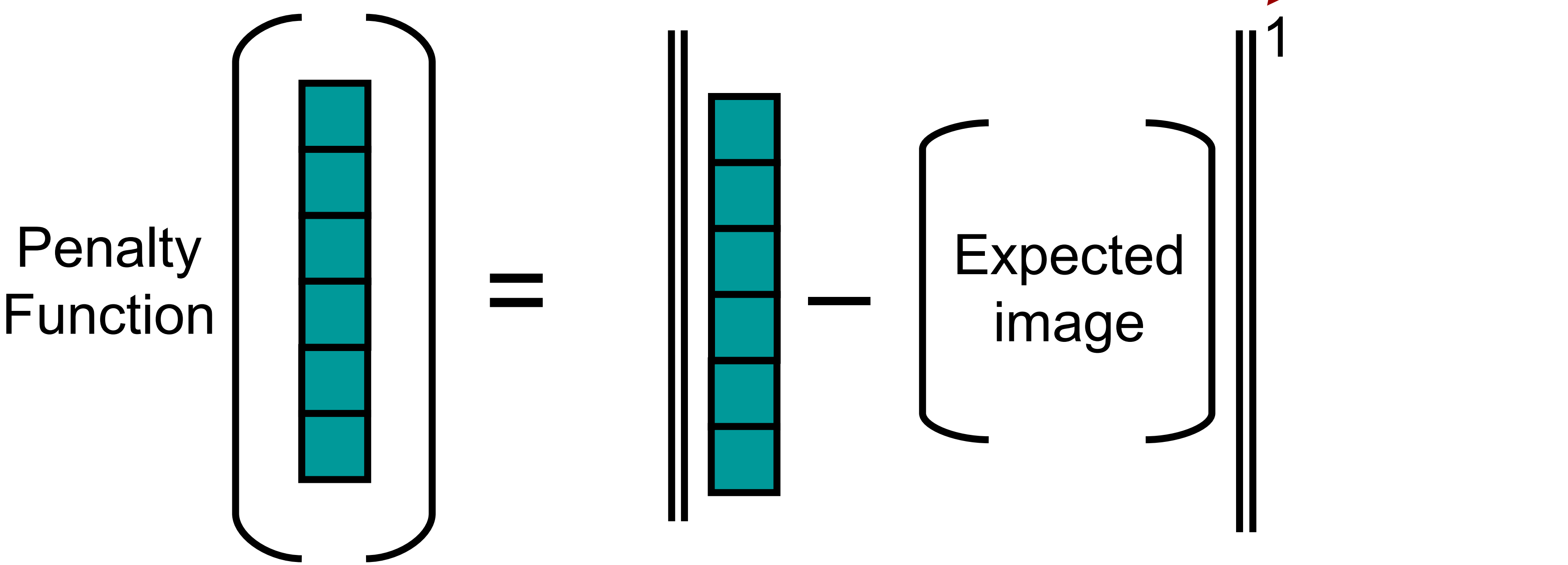
Laplacian prior

1	-½				
-½	1	-½			
	-½	1	-½		
		-½	1	-½	
			-½	1	-½
				-½	1

Total Variation

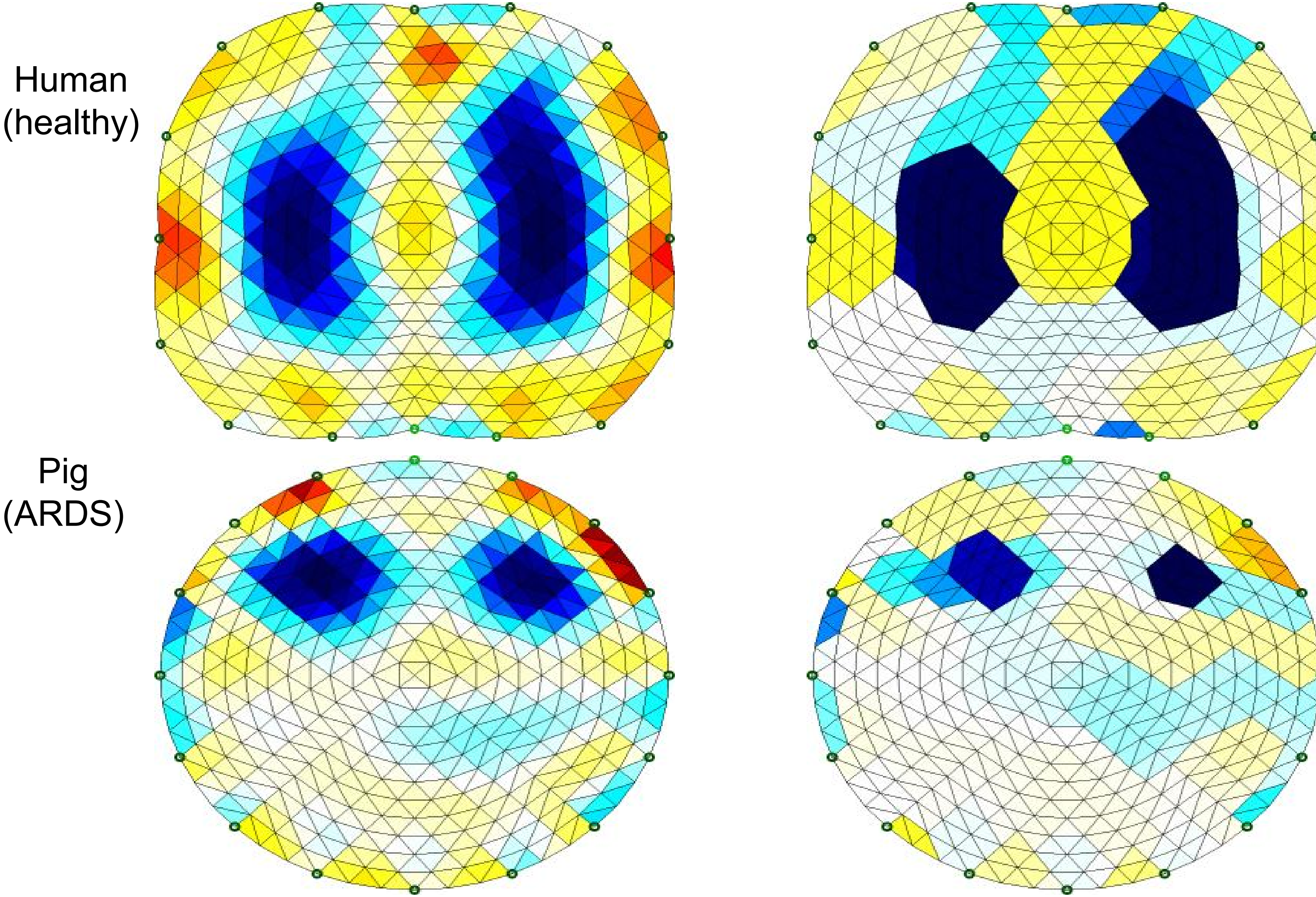
Use 1-norm
Sum(abs(.))

Image Penalty Function



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

Lung images with TV



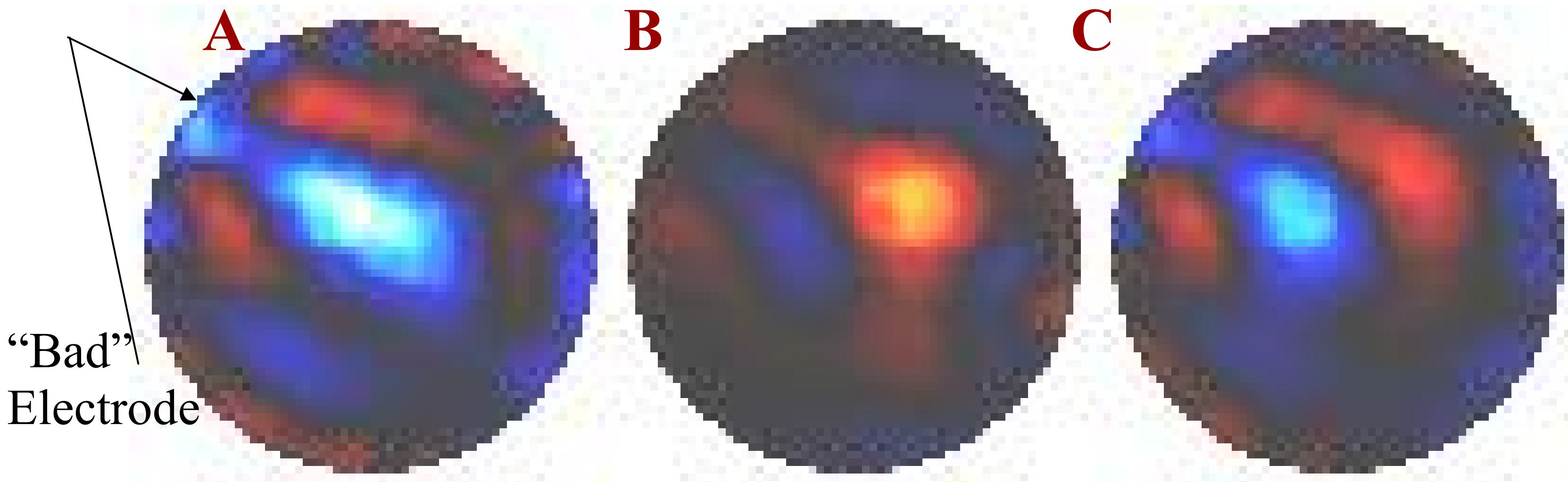
Electrode Measurement Errors

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

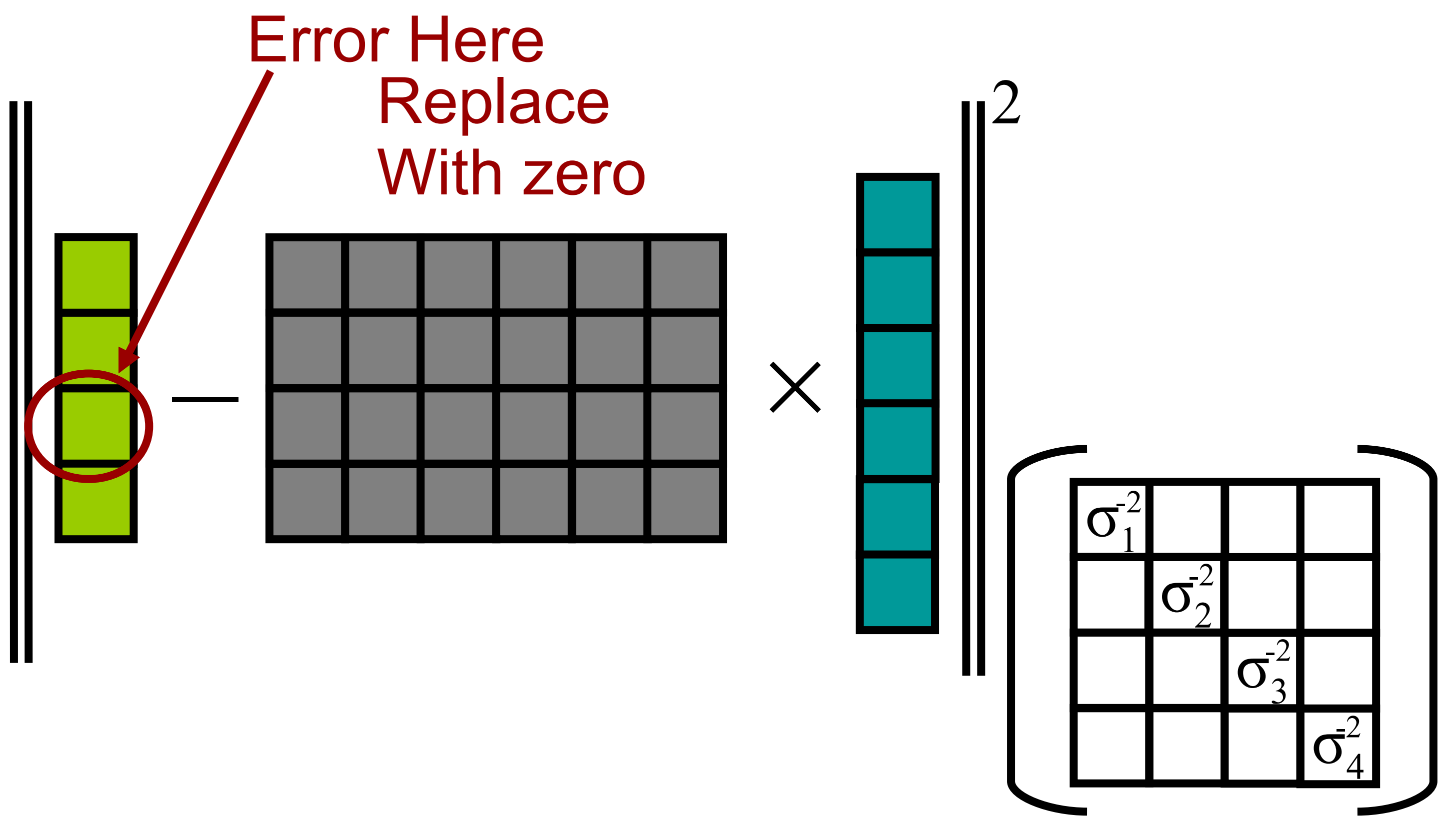


Images measured in anaesthetised, ventilated dog

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

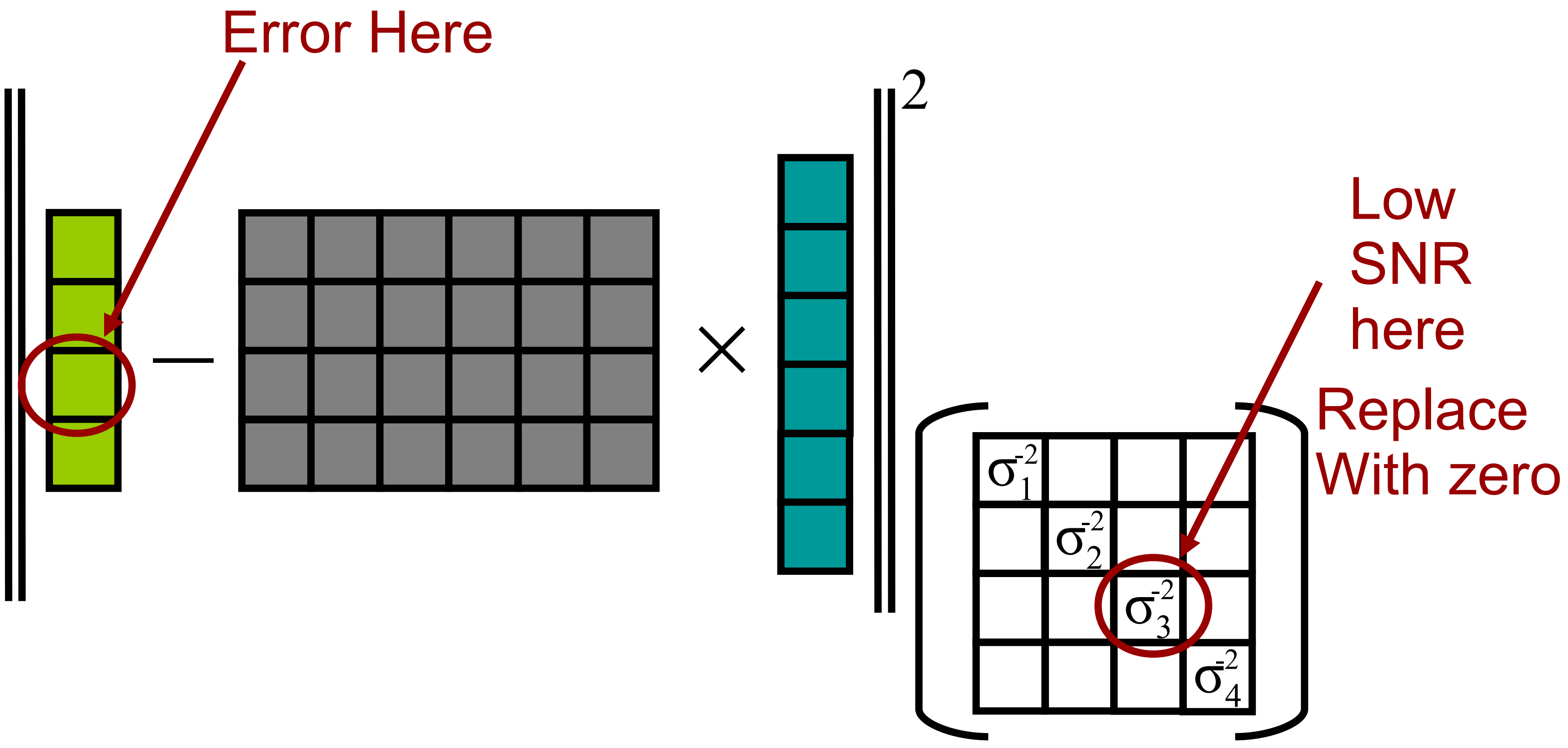
"Zero bad data" solution

"Traditional solution" (in the sense that I've done this)

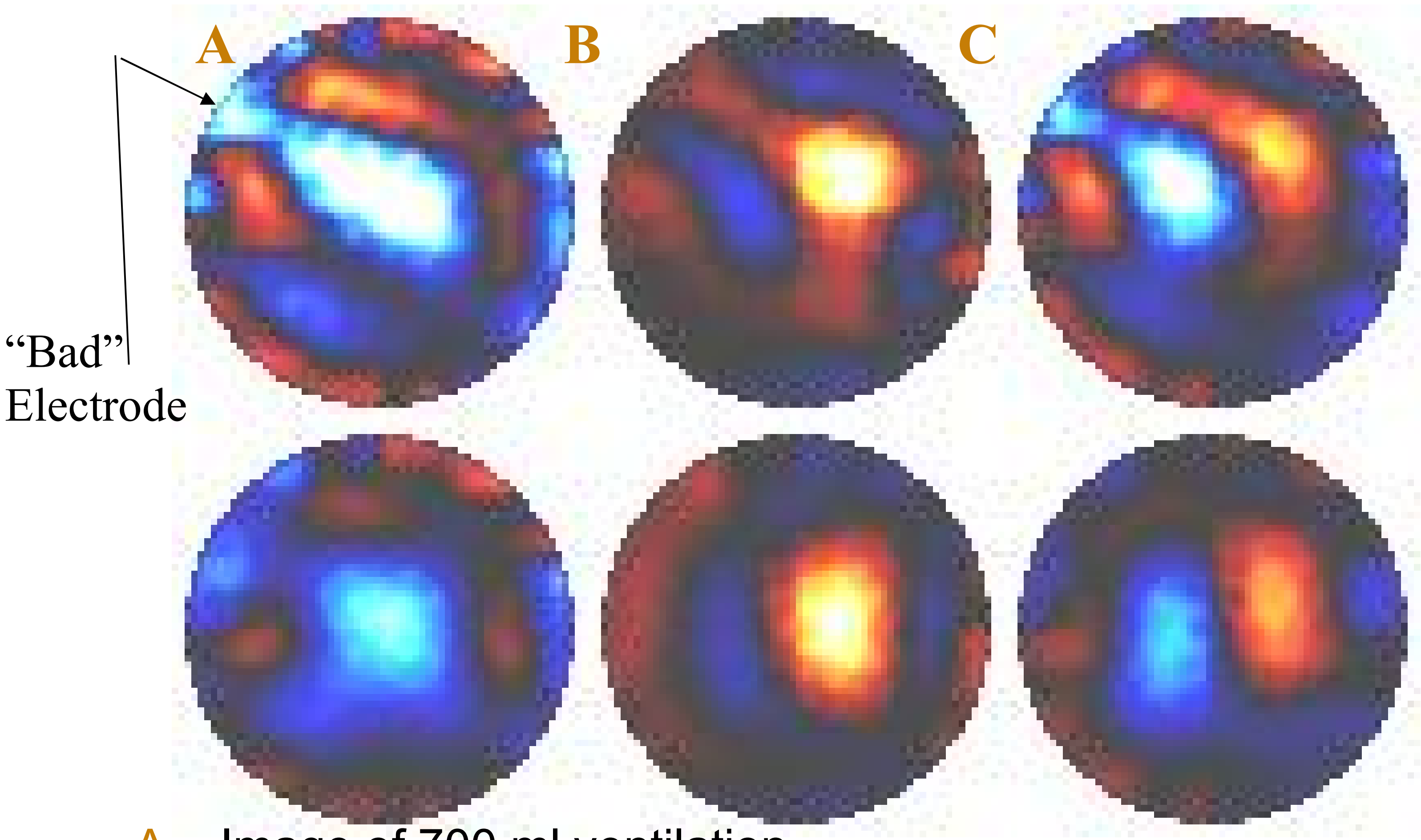


Regularized imaging solution

Electrode errors are large measurement noise on affected electrode



Correcting for errors. Results



A. Image of 700 ml ventilation
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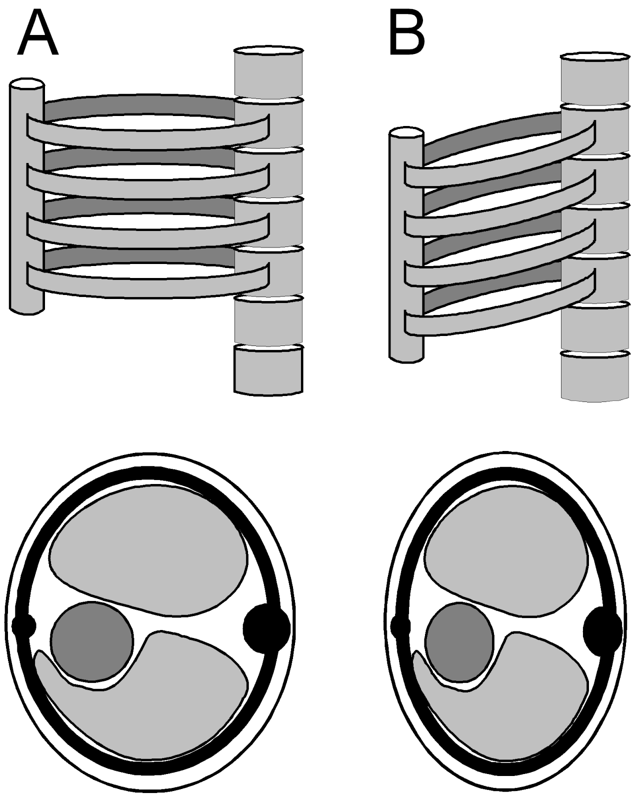
Electrode Movement



Electrodes move

- with breathing
- with posture change

Simulations show broad central artefact in images

Imaging Electrode Movement

- Forward model *image* includes movement

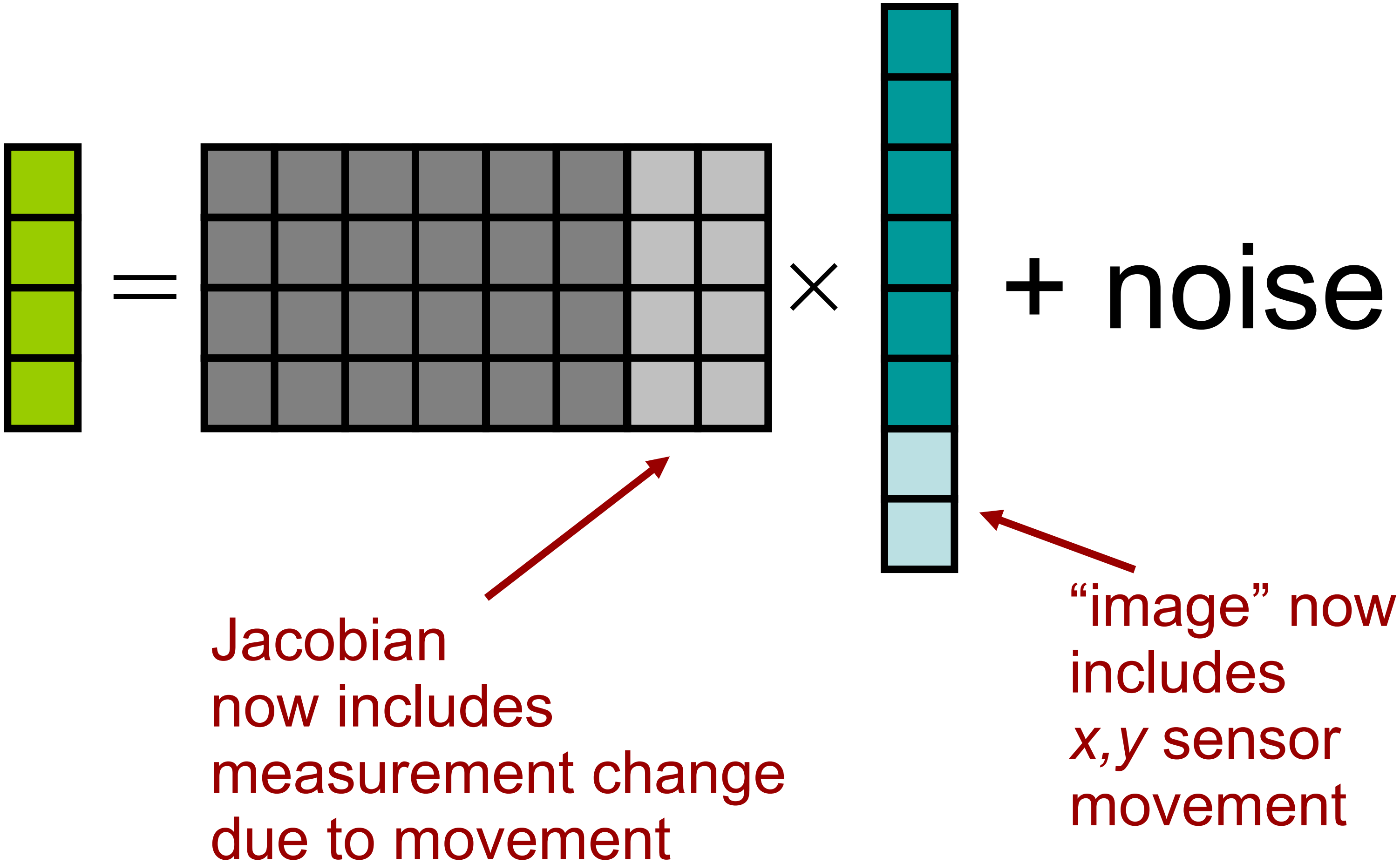
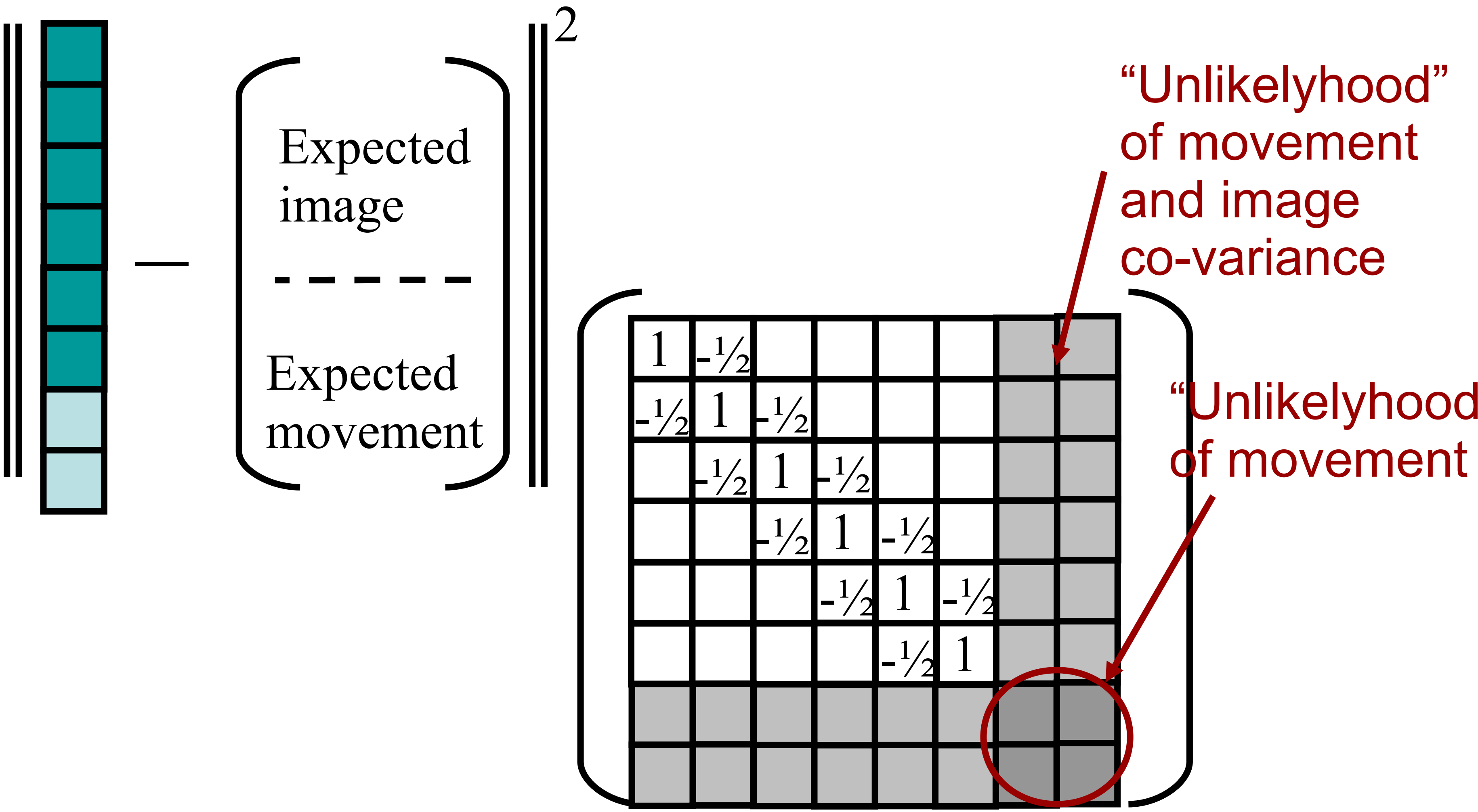


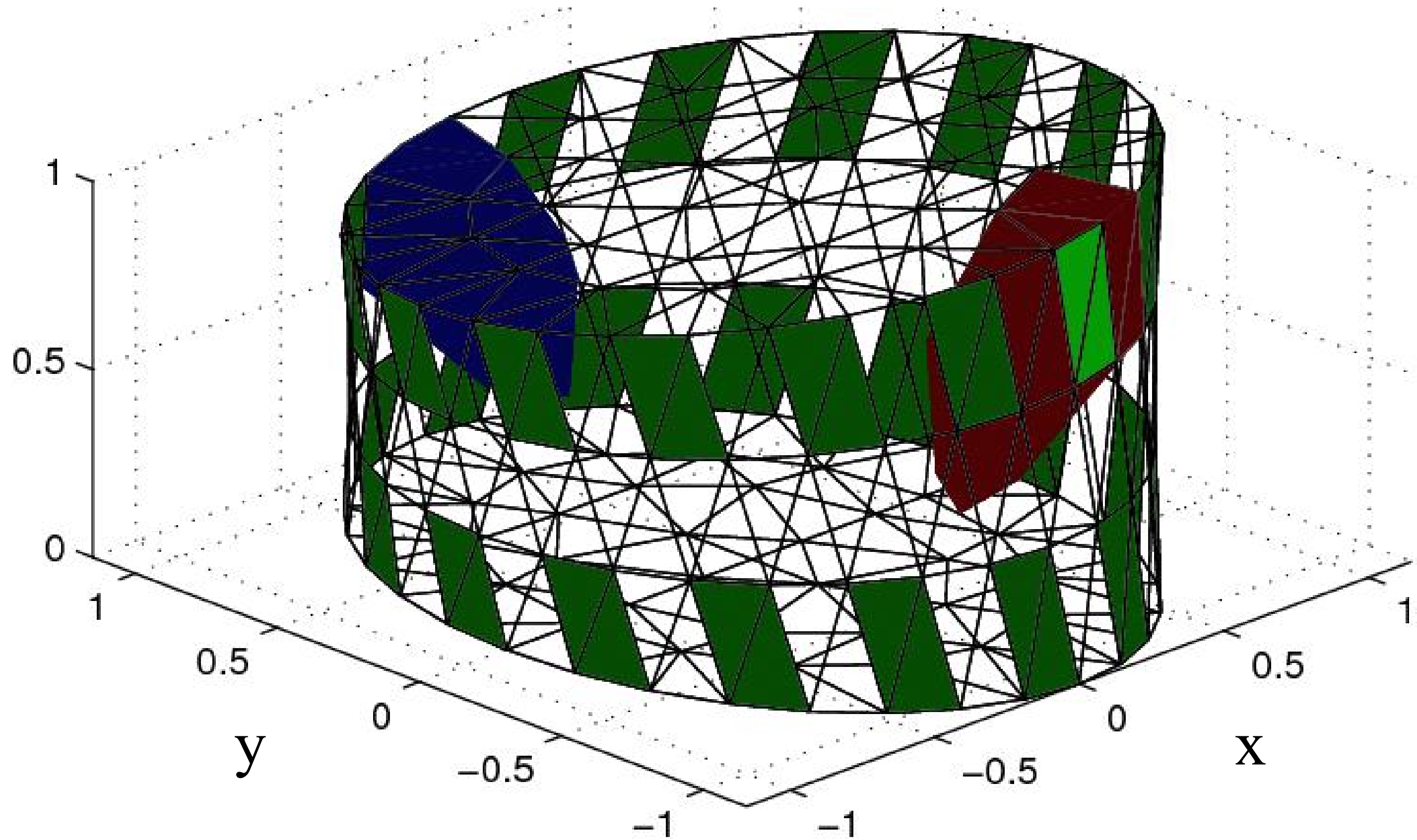
Image and movement

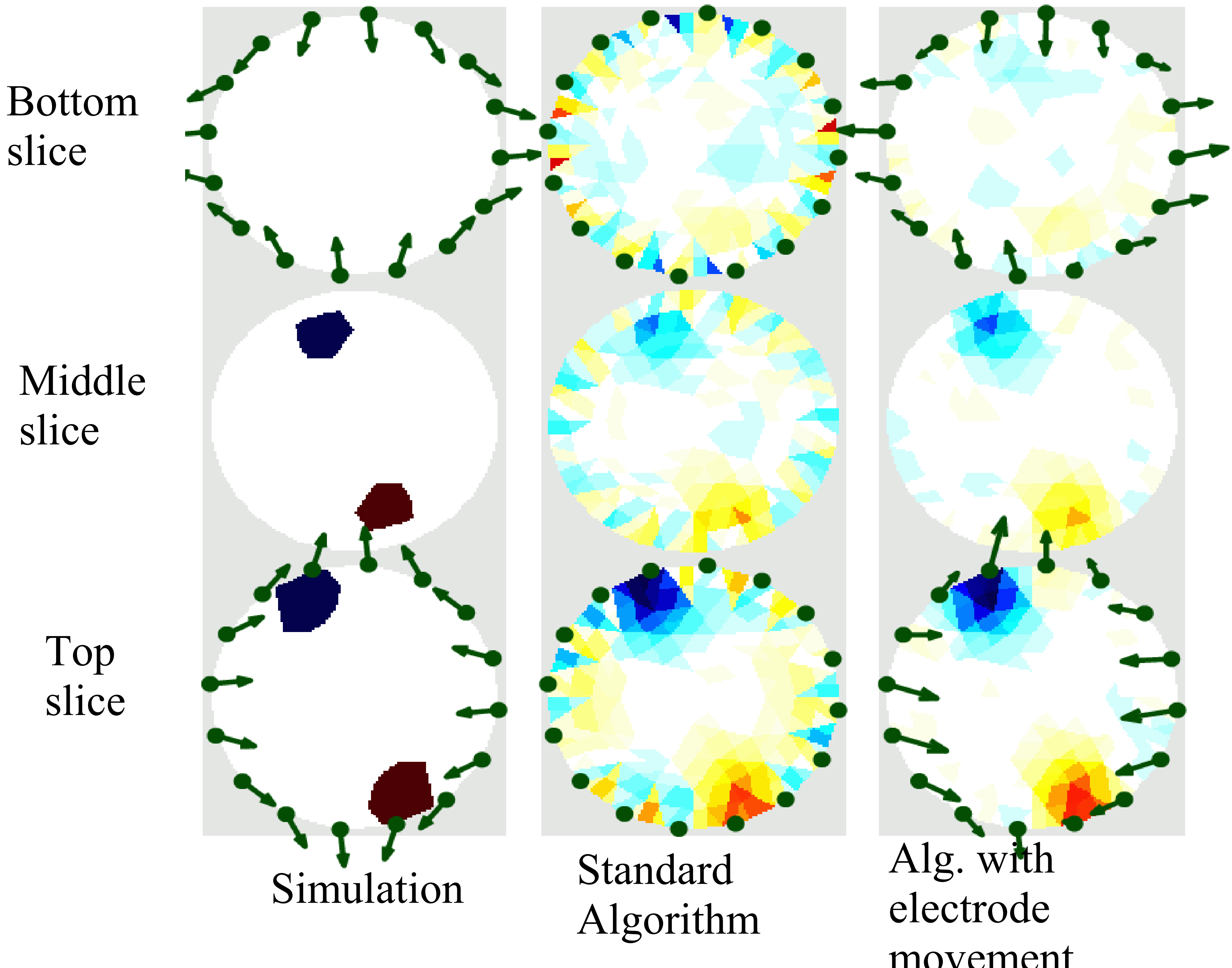
Penalty: Image and movement Smoothness



Images of electrode movement

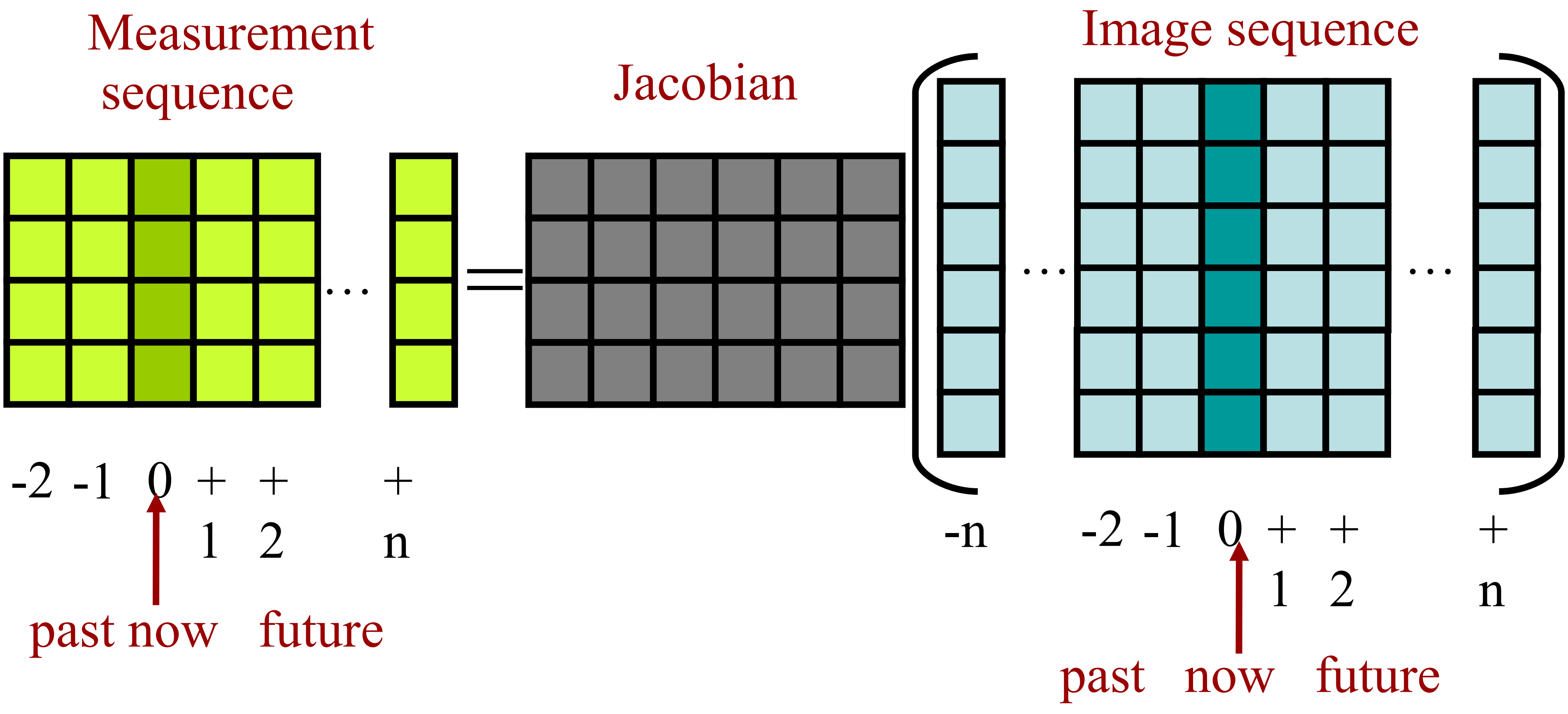
Simulation: tank twisted in 3D





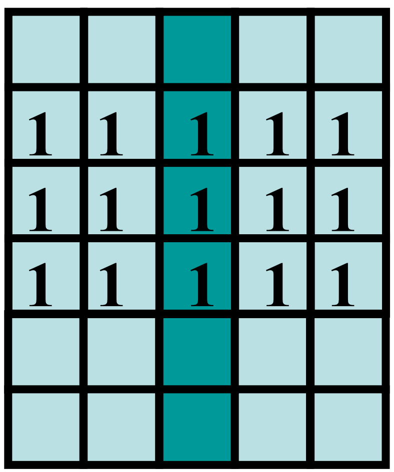
Bottom slice
Middle slice
Top slice
Simulation
Standard Algorithm
Alg. with electrode movement

EIT makes fast measurements. Can we use this fact?

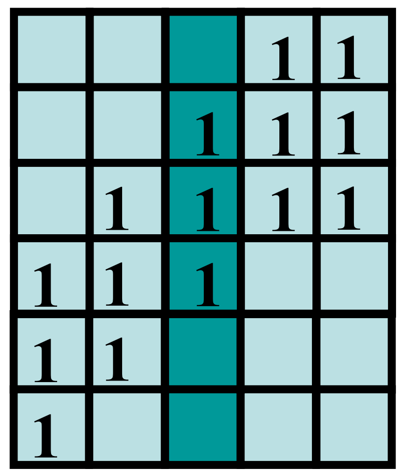


Temporal Reconstruction

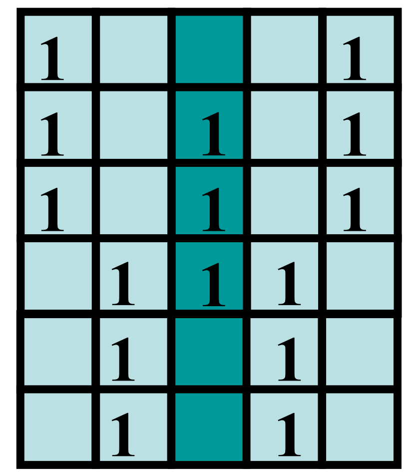
Temporal Penalty Functions



likely



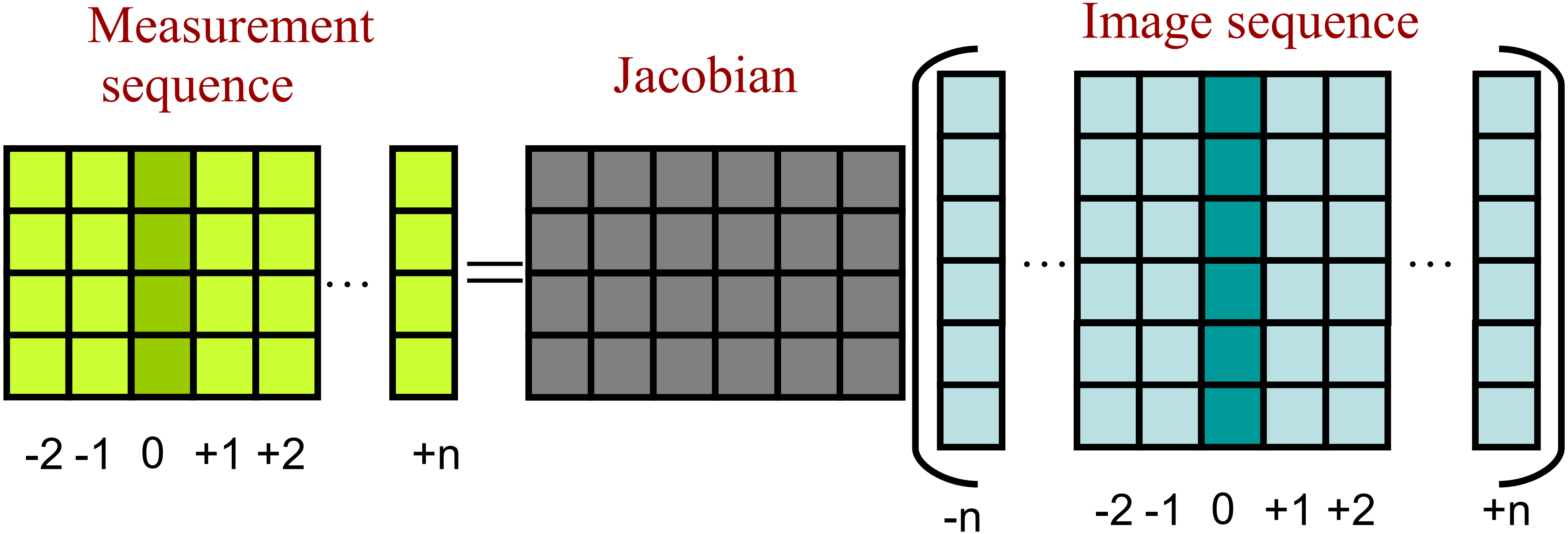
quite likely



unlikely

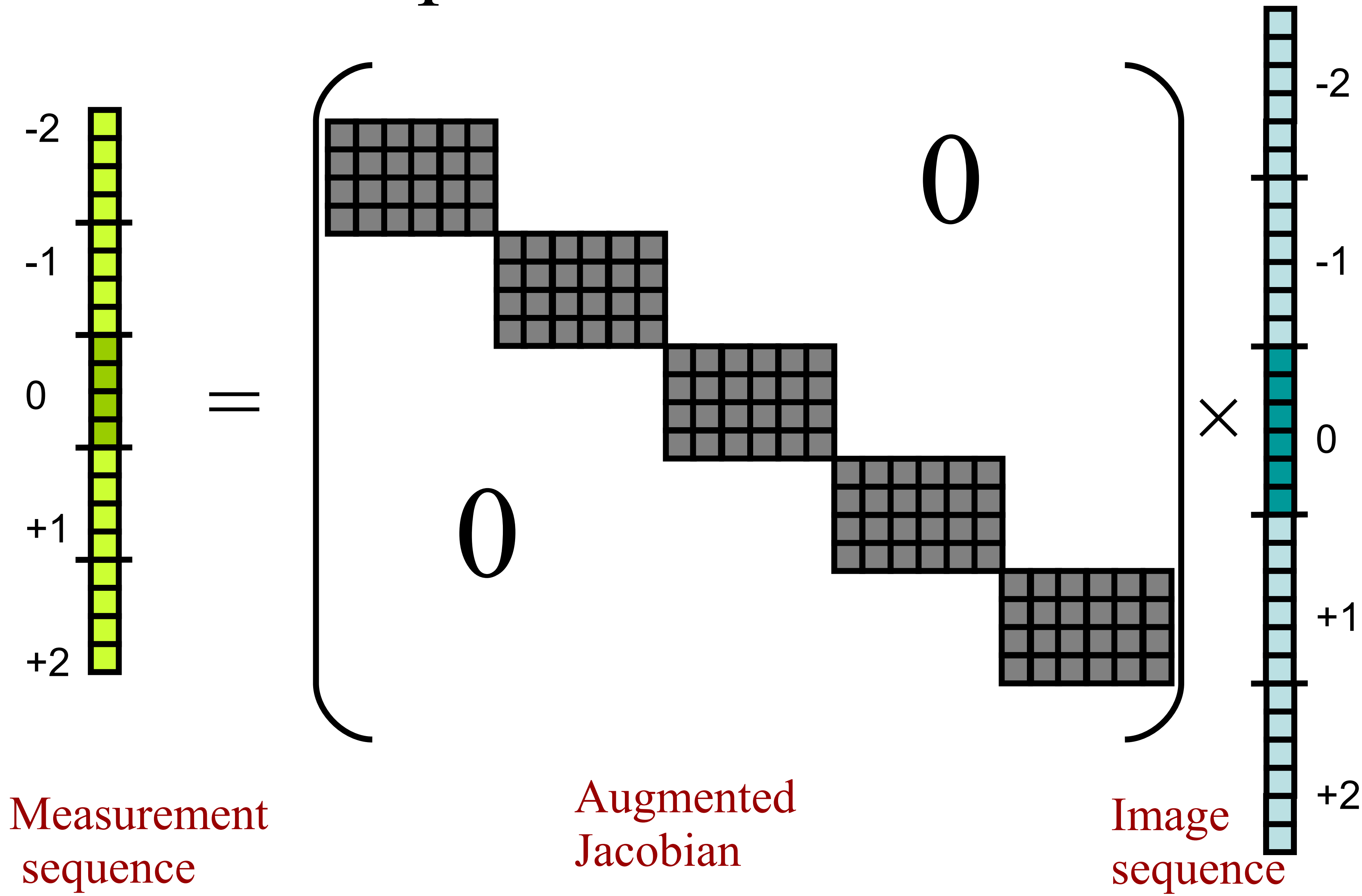
Standard EIT approaches to not take this into account

Direct temporal solver

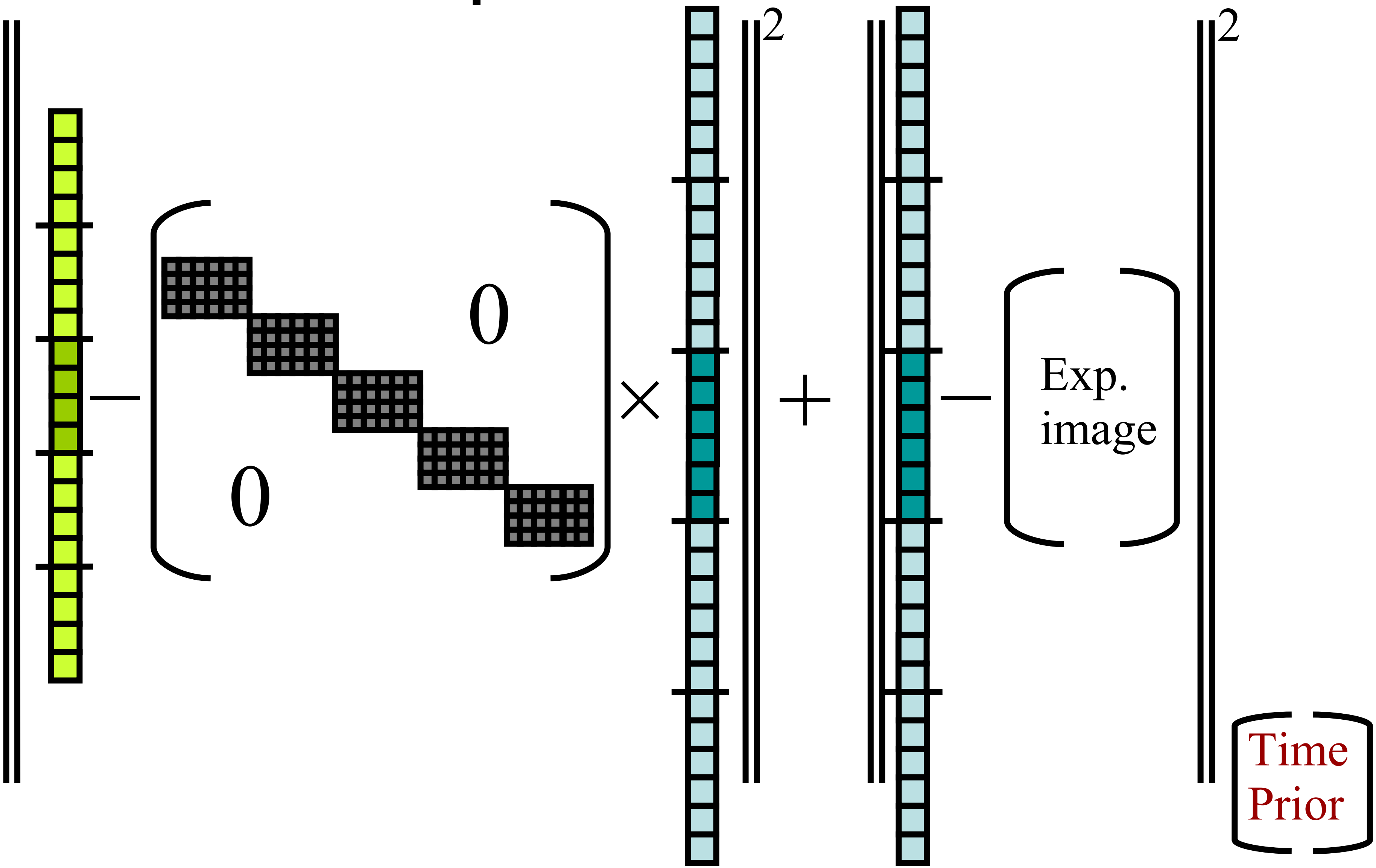


Rewrite as …

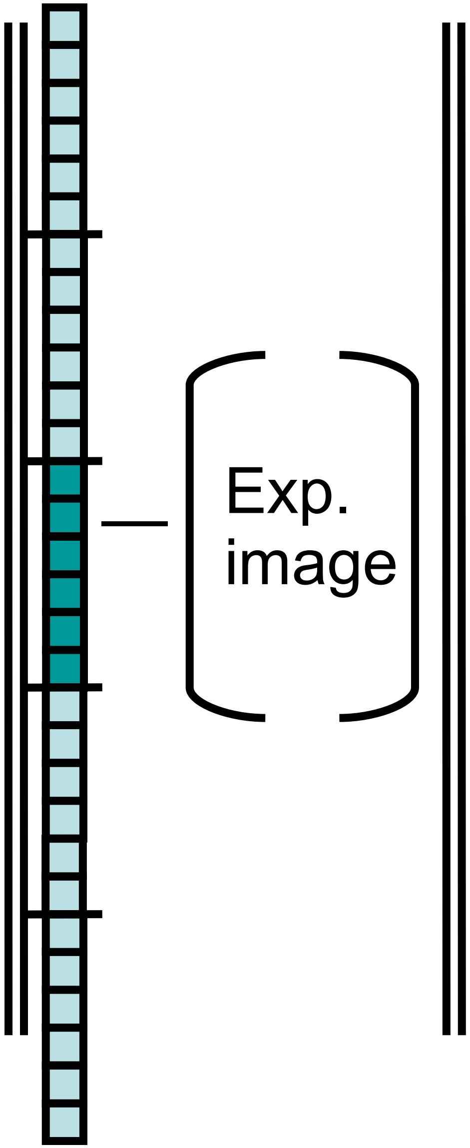
Direct temporal forward model



Direct temporal inverse model



Temporal Priors



Spatial Prior	Time Prior $\Delta t = 1$	Time Prior $\Delta t = 2$	Time Prior $\Delta t = 3$	Time Prior $\Delta t = 4$
Time Prior $\Delta t = 1$	Spatial Prior	Time Prior $\Delta t = 1$	Time Prior $\Delta t = 2$	Time Prior $\Delta t = 3$
Time Prior $\Delta t = 2$	Time Prior $\Delta t = 1$	Spatial Prior	Time Prior $\Delta t = 1$	Time Prior $\Delta t = 2$
Time Prior $\Delta t = 3$	Time Prior $\Delta t = 2$	Time Prior $\Delta t = 1$	Spatial Prior	Time Prior $\Delta t = 1$
Time Prior $\Delta t = 4$	Time Prior $\Delta t = 3$	Time Prior $\Delta t = 2$	Time Prior $\Delta t = 1$	Spatial Prior

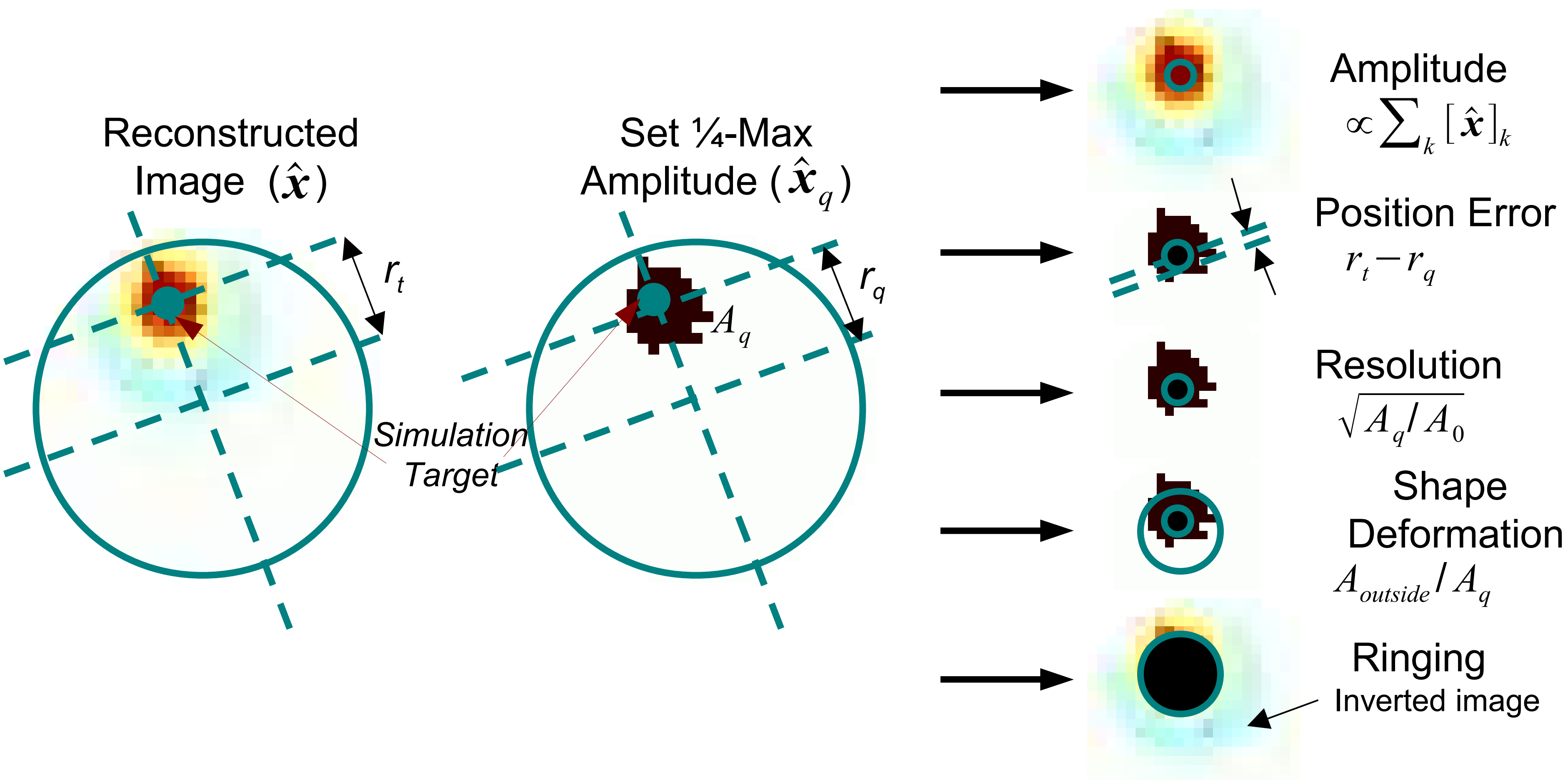
GREIT: Consensus EIT algorithm for lung images

Lots of authors! Our goal is to get people to stop using Backprojection (which was super in 1982) and use something "rational"

Andy Adler, John Arnold, Richard Bayford, Andrea Borsic, Brian Brown, Paul Dixon, Theo J.C. Faes, Inéz Frerichs, Hervé Gagnon, Yvo Gärber, Bartlomiej Grychtol, Günter Hahn, William R B Lionheart, Anjum Malik, Janet Stocks, Andrew Tizzard, Norbert Weiler, Gerhard Wolf

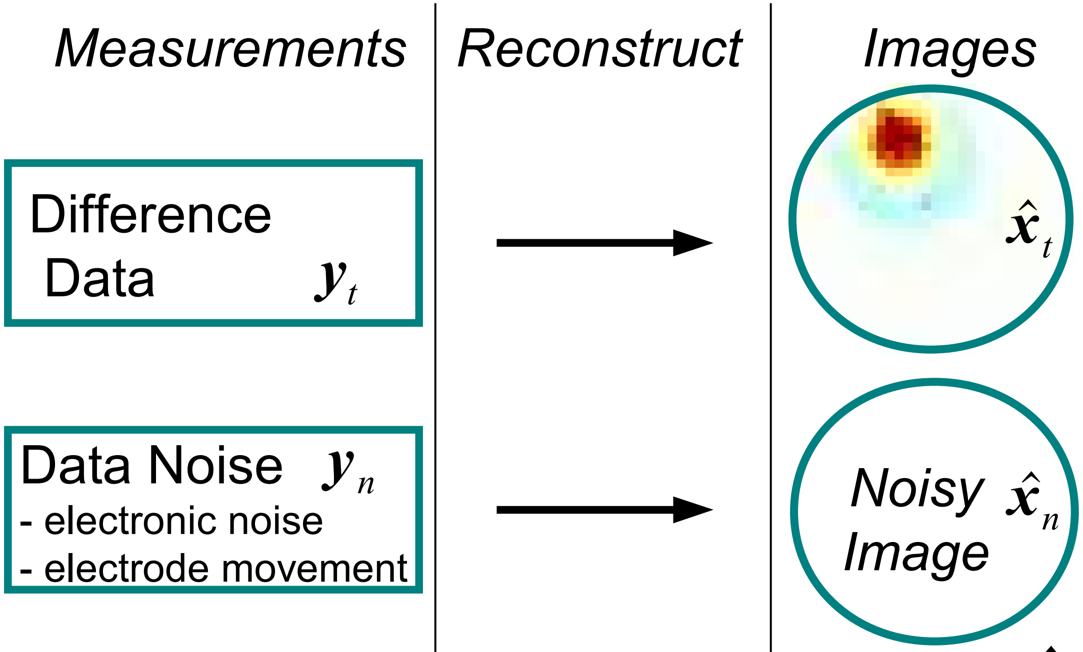
Step #1: Agree on performance parameters

In order of "consensus importance"



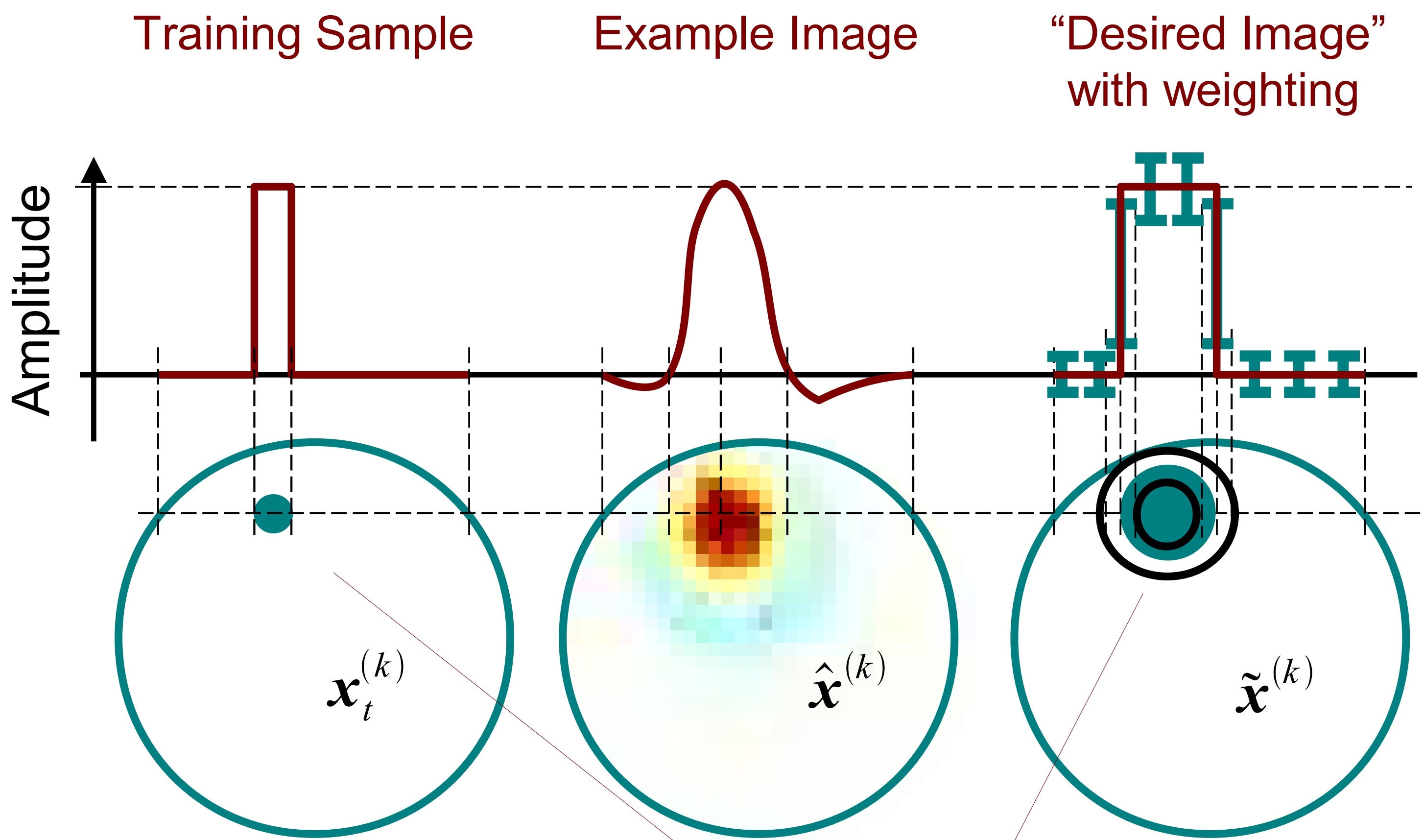
Step #1: Agree on performance parameters

Noise parameters – set equal to behaviour of backprojection



$$\mathrm{SNR}_y = \frac{\text{mean } \boldsymbol{y}_t}{\text{std } \boldsymbol{y}_n} \qquad \mathrm{SNR}_x = \frac{\text{mean } \hat{\boldsymbol{x}}_t}{\text{std } \hat{\boldsymbol{x}}_n}$$

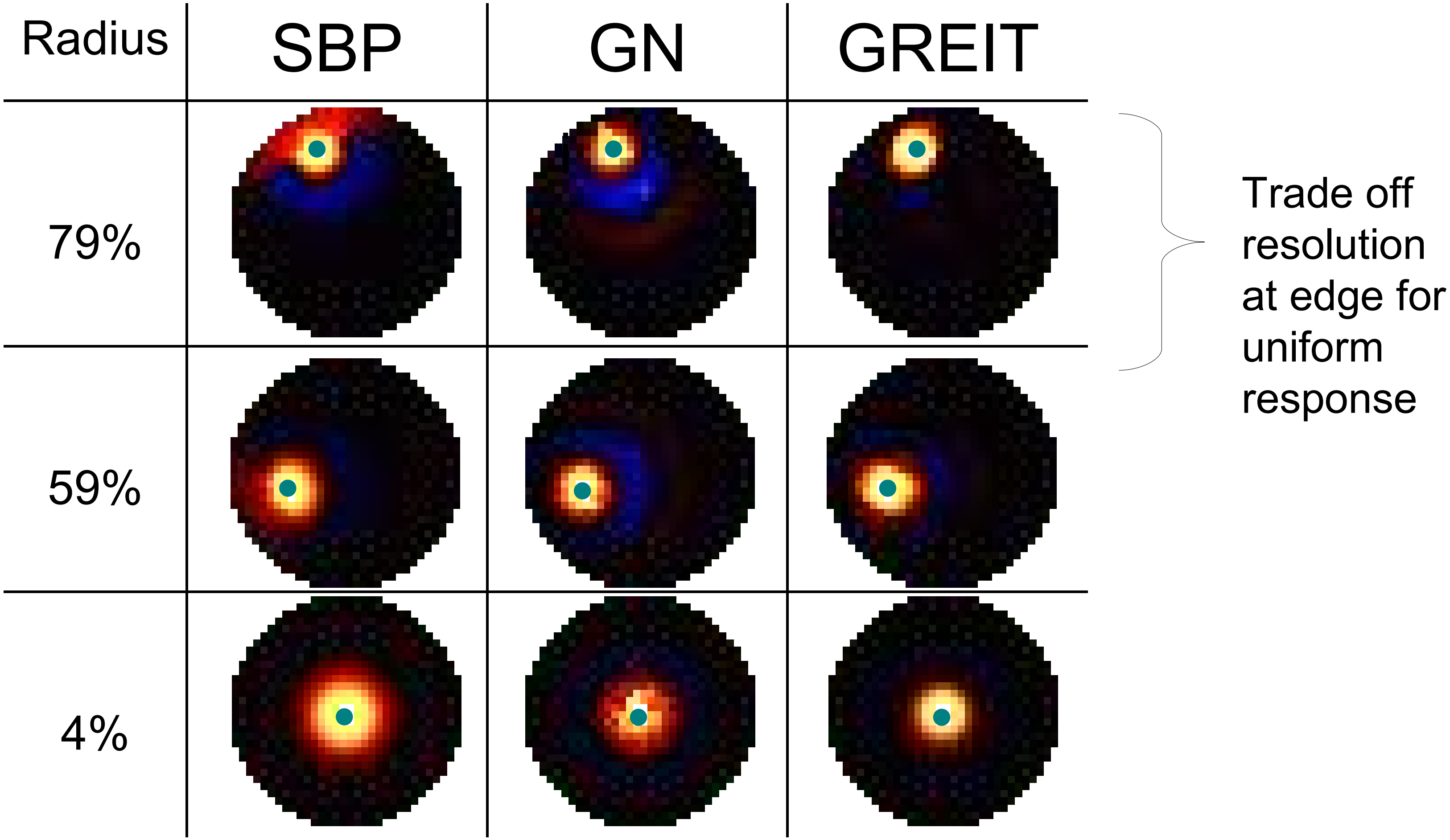
Step #2: Reconstruction matrix based on specified performance



GREIT reconstruction Matrix **R** minimizes

$$\sum_k \left\| R\, y^k - \tilde{x} \right\|_{W^k}^2$$

GREIT Reconstruction examples



EIDORS: community-based extensible software for EIT

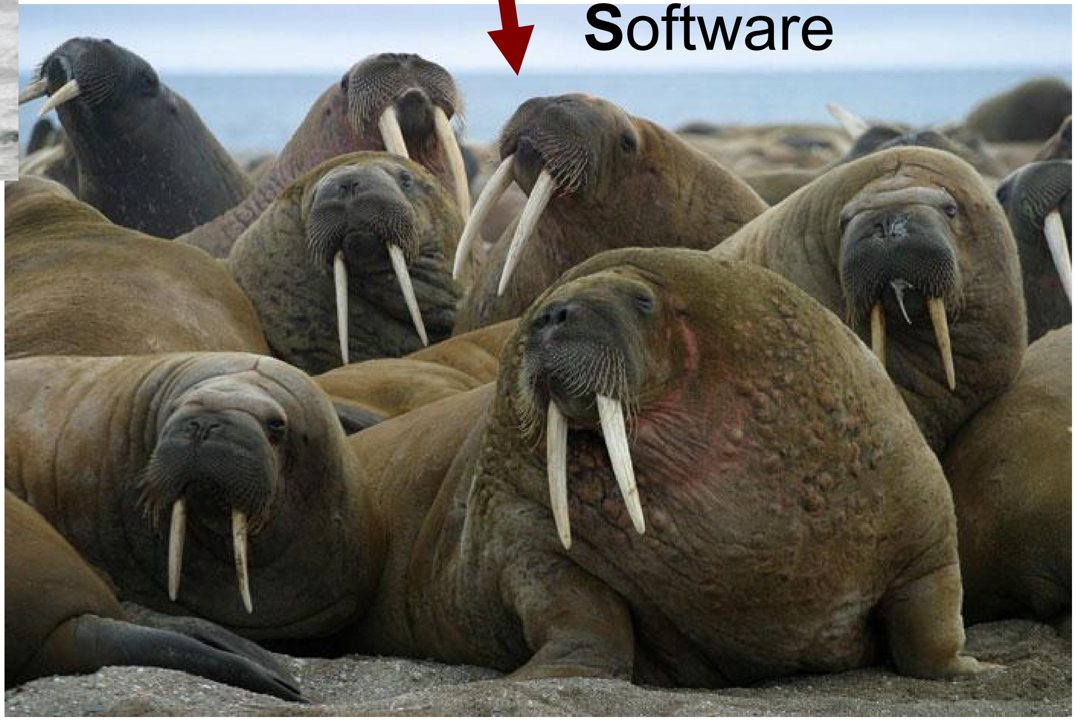
Andy Adler[1], William R.B. Lionheart[2]

[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
© Genny Anderson

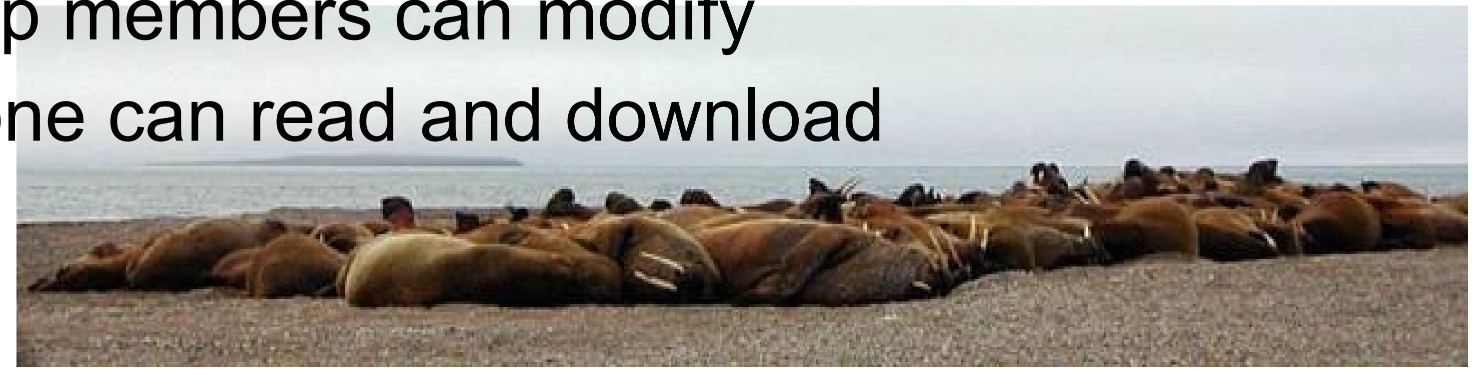
EIDORS Features

Open-source:

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

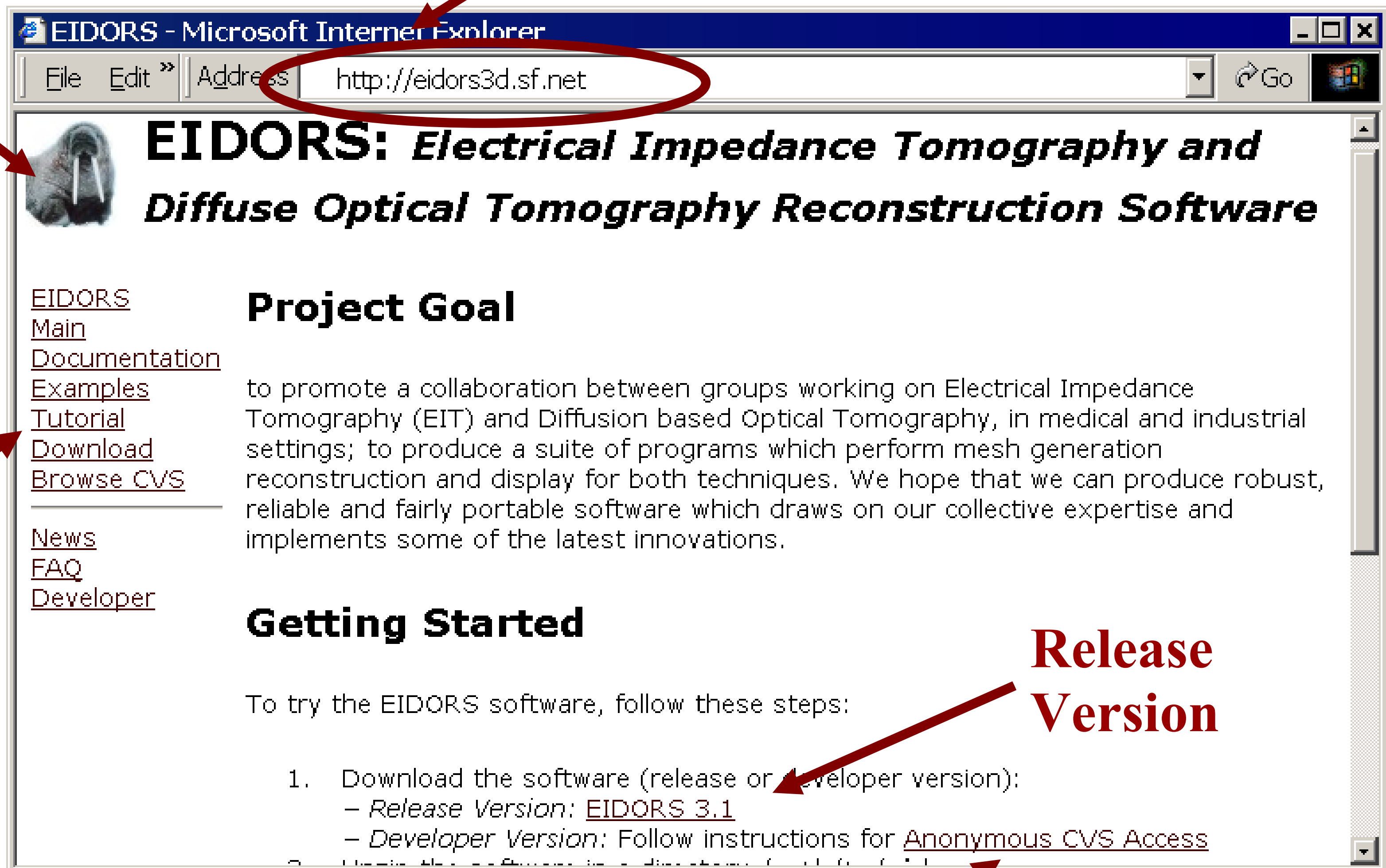
Hosted on Sourceforge.net

- 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

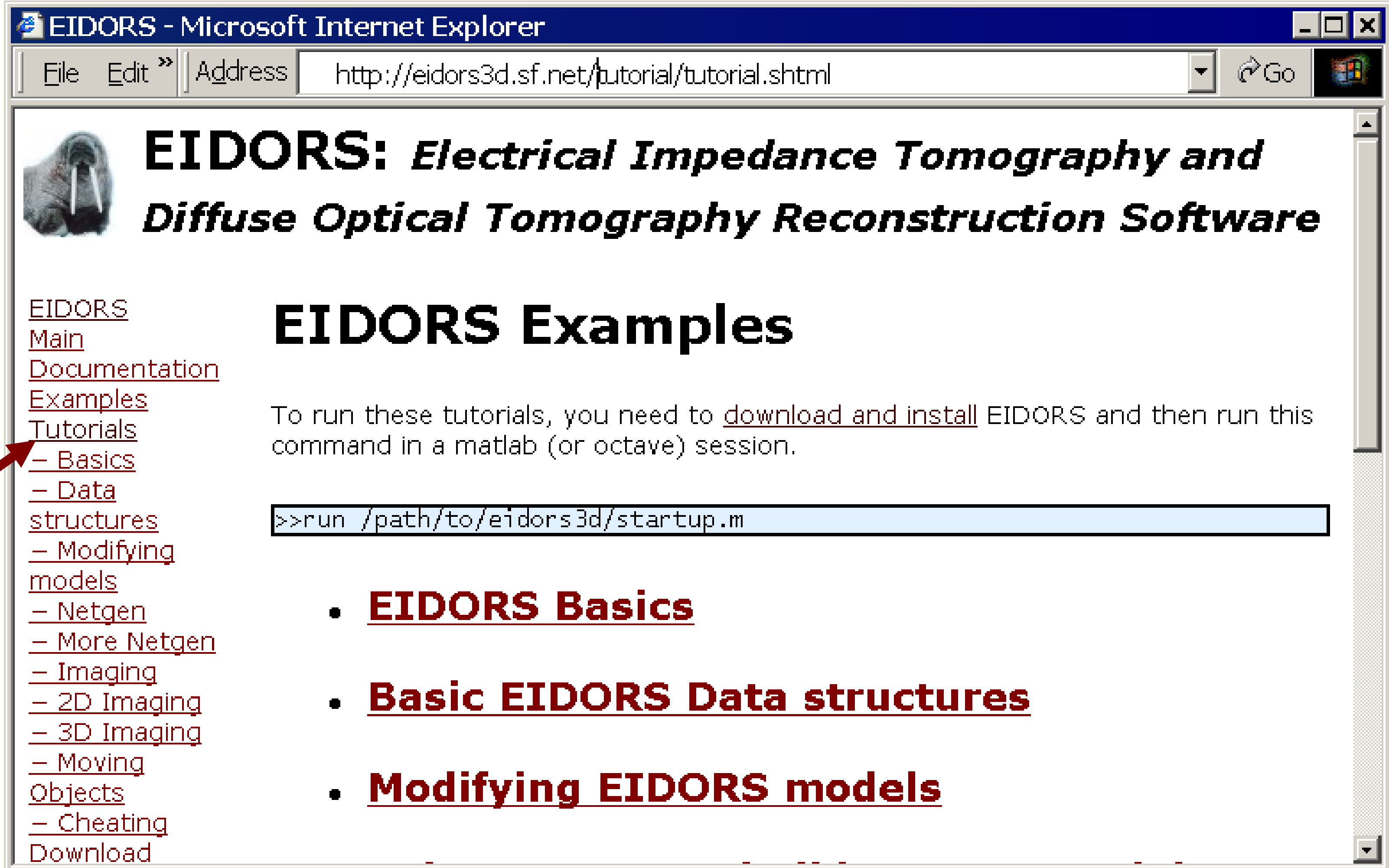


This Tutorial

Release Version

Developer Version

Tutorials



Tutorials