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Image Reconstruction in EIT Using Advanced Regularization Frameworks

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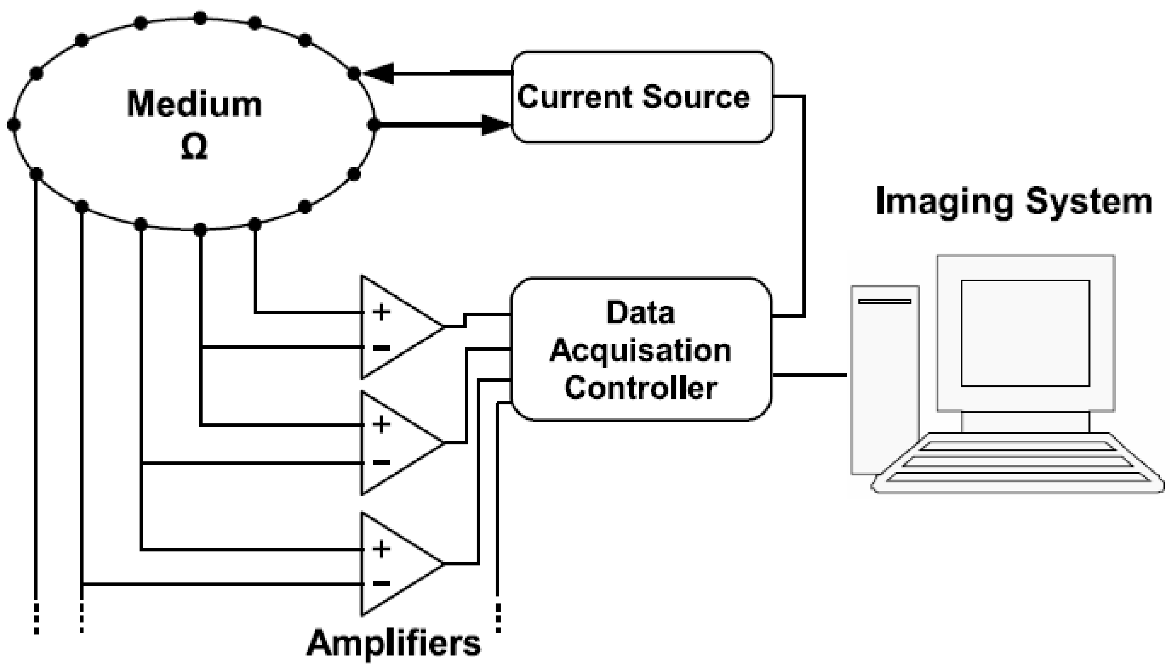
EIT System


Medium
Ω
Current Source
Data
Acquisation
Controller
Imaging System
+
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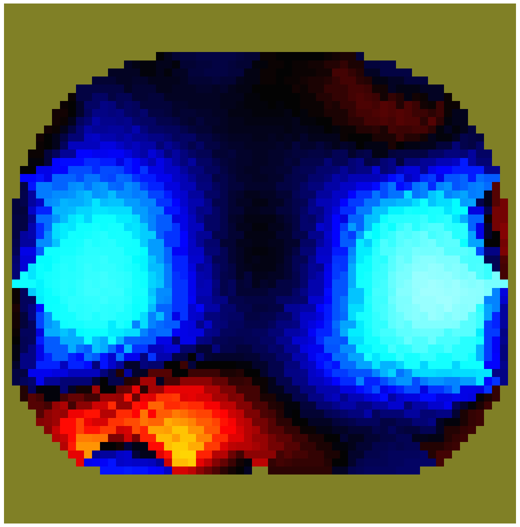
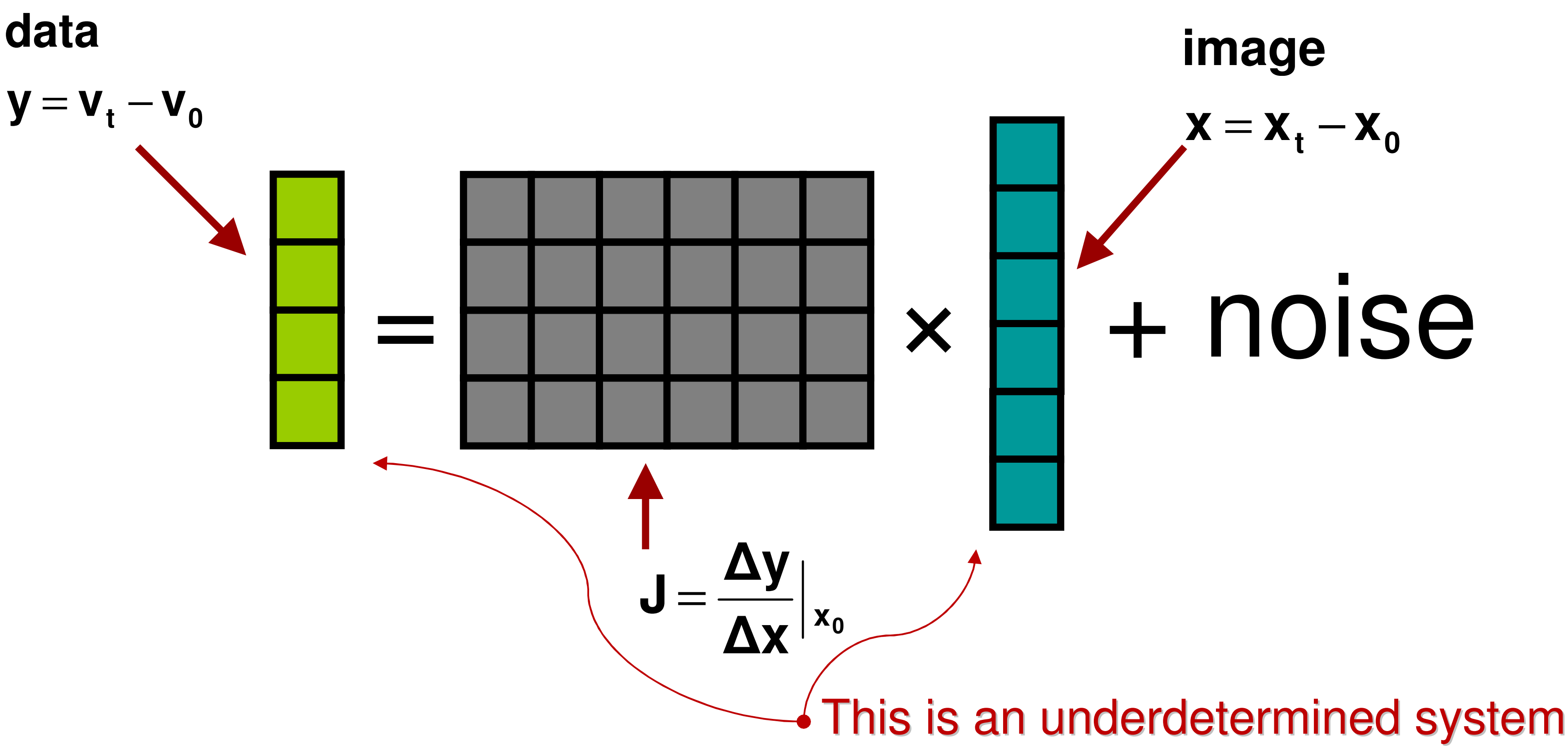
Amplifiers



Forward Model (linearized)

$$\mathbf{y} = \mathbf{J}\mathbf{x} + \mathbf{n}$$



Inverse Model (linearized)

The image X is the unknowns to be calculated:

$$\hat{\mathbf{x}} = \mathbf{J}^{-1}\mathbf{y}$$ ← **NOT realizable!**

$$\hat{\mathbf{x}} = (\mathbf{J}^{T}\mathbf{J})^{-1}\mathbf{J}^{T}\mathbf{y}$$ ← **Naïve Solution, NOT stable!**

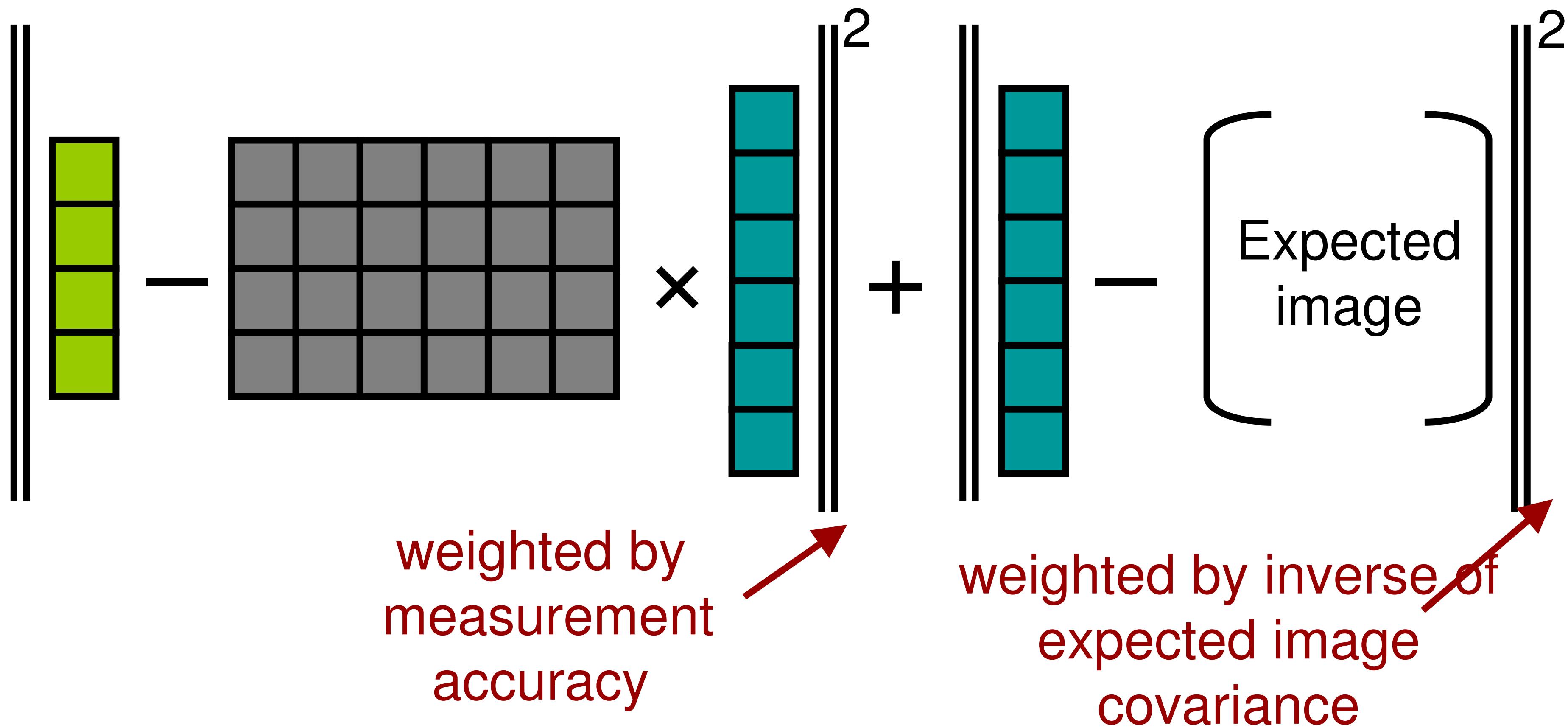
Hadamard Criteria

1. *solution existence.*
2. *solution uniqueness.*
3. *solution stability.*

Solution stabilization --Regularization →

Regularization- Tikhonov

$$\hat{\mathbf{x}} = \underset{\mathbf{x}}{\operatorname{argmin}} \left\| \mathbf{y} - \mathbf{J}\mathbf{x} \right\|^2_{\Sigma_n^{-1}} + \left\| \mathbf{x} - \mathbf{x_0} \right\|^2_{\Sigma_x^{-1}}$$



Problems

- Image quality of EIT is poor.
  - Low spatial resolution
  - High noise level
  - Large artefacts
- EIT is sensitive to system and measurement errors
  - Model error
  - Electrode movement
  - Electrode malfunction

Objectives

- General objective:

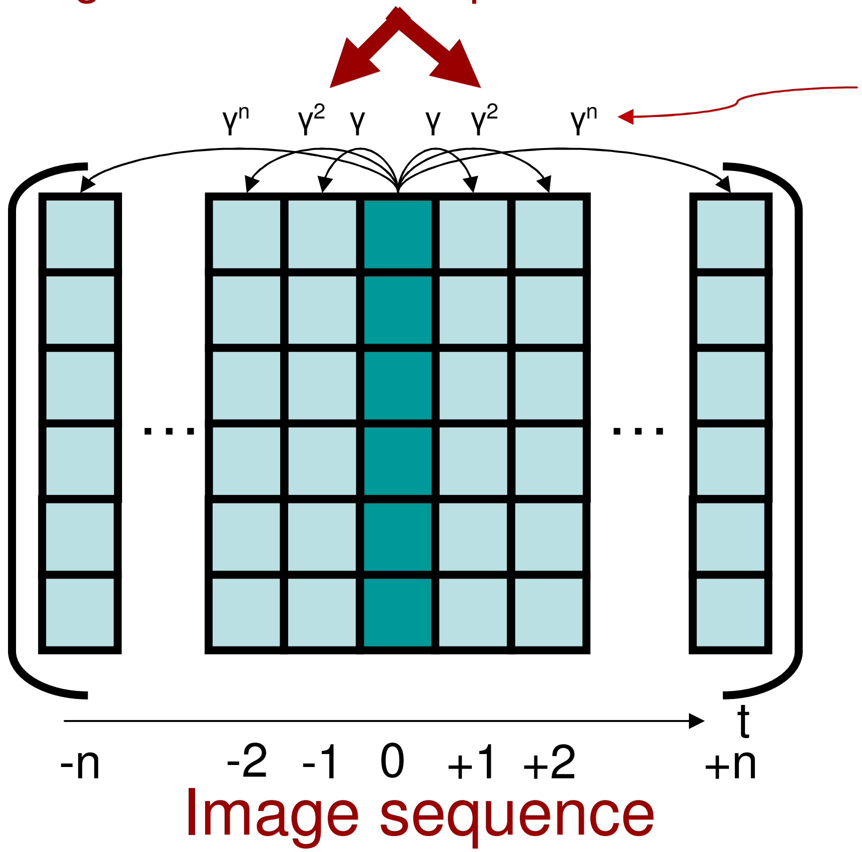
  Develop algorithms to improve EIT image reconstruction performance

  – Object 1: improve image quality

  – Object 2: improve robustness against system and measurement errors

M1: Temporal Regularization

Current image is correlated to past and future images



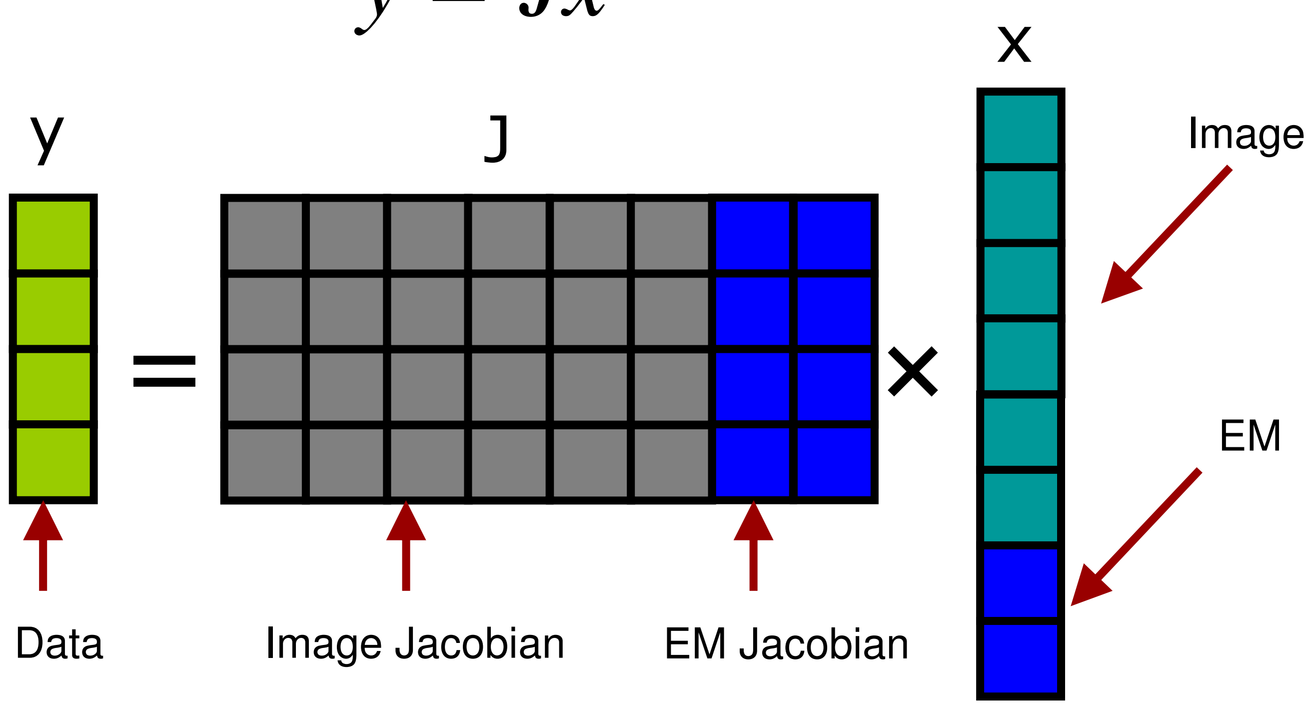
γ^n is the interframe correlation between two images with delay n

- "Temporal image reconstruction in electrical impedance tomography", A. Adler, **T. Dai**, W. R.B. Lionheart, *Physiol. Meas.* 28 S1-S11, 2007.
- "Application of a single step temporal imaging of magnetic induction tomography for metal flow visualization", M. Soleimani, A. Adler, **T. Dai**, A. J. Peyton, *J. British Institute of Non-Destructive Testing*, 50(1):25-29, 2008.

M1 Application: Temporal Regularization on electrode Motion Analysis

- **Temporal reconstruction of conductivity changes and electrode movements simultaneously**

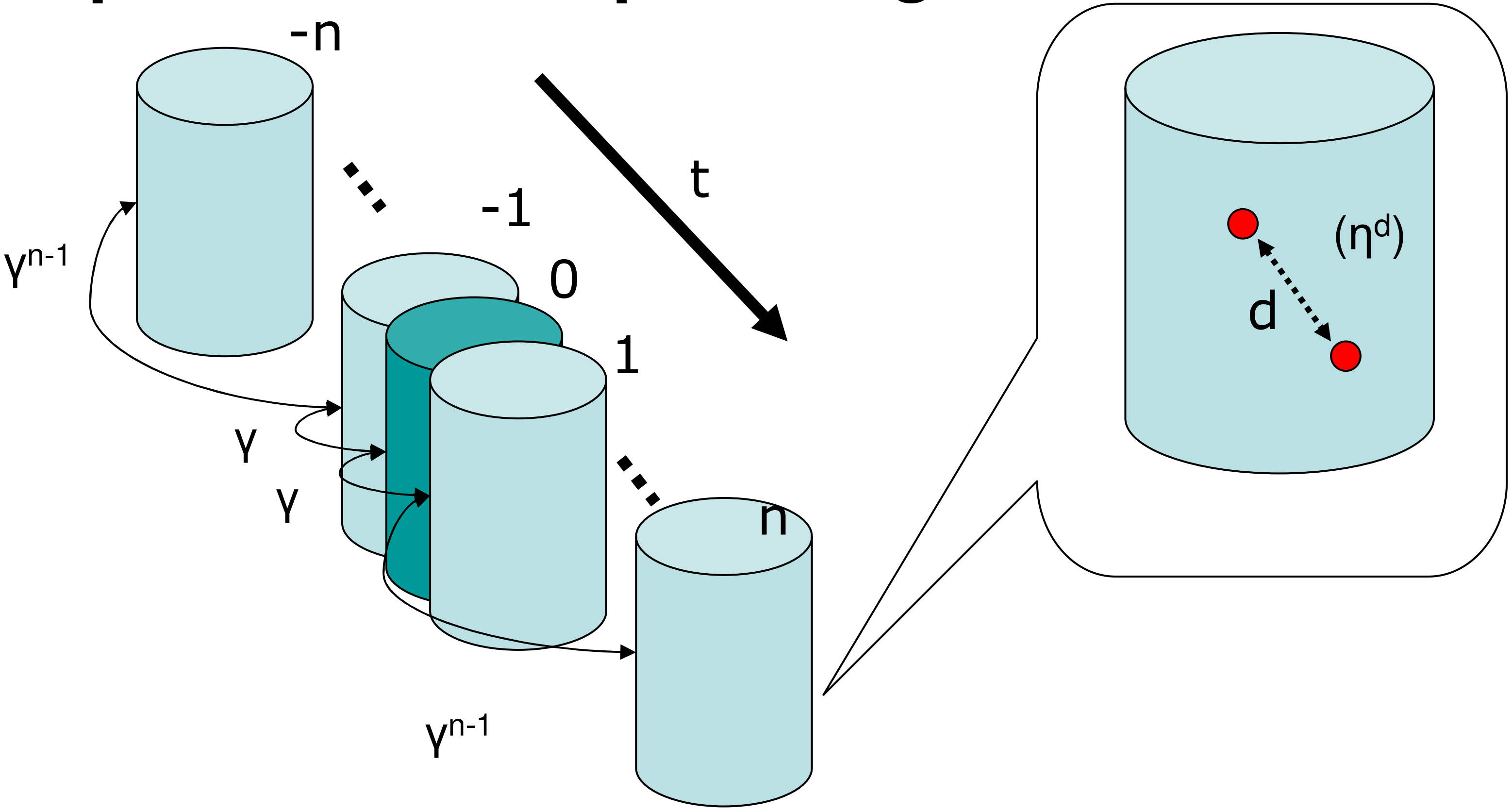
$$y = Jx$$



- "Reconstruction of conductivity changes and electrode movements based on EIT temporal sequences", **T. Dai**, C. Gomez-Laberge and A. Adler, *Physiol. Meas*, **29**, S77-S88, 2008.

M2: 4-D regularization

- **Temporal and 3-D spatial regularization**



- "EIT image reconstruction with four dimensional regularization",

T. Dai, M. Soleimani and A. Adler, *Medical & Biological Engineering & Computing. In press*, 2008.

M3: Iterative Solution for L1 Norm Minimization

$$\hat{\mathbf{x}} = \underset{\mathbf{x}}{\mathbf{argmin}} \left\| \mathbf{y} - \mathbf{J}\mathbf{x} \right\|_2^2 + \left\| \mathbf{x} - \mathbf{x}_0 \right\|_2^2$$

Linearizable as fast one-step reconstruction

$$\hat{\mathbf{x}} = \underset{\mathbf{x}}{\mathbf{argmin}} \left\| \mathbf{y} - \mathbf{J}\mathbf{x} \right\|_1 + \left\| \mathbf{x} - \mathbf{x}_0 \right\|_1$$

Robust against measurement errors

Edge preservation, less artefacts

- "Electrical impedance tomography reconstruction using l1 norm on data and image terms"

T. Dai and A. Adler, 30th Annual International Conference of the IEEE EMBC, Vancouver, Canada, August, 2008.

Miscellaneous contributions

- **A scheme of in vivo blood characterization using bioimpedance spectroscopy**

  To develop a novel *in vivo* measurement technique to calculate bioelectrical properties of blood

  - Bioimpedance spectroscopy
  - Cole-Cole model
  - Nonlinear curve fitting

- "*In vivo* blood characterization from bioimpedance spectroscopy of blood pooling",
  T. Dai, A. Adler, *IEEE Transaction on Medical Instrumentation & Measurement*, Accepted, 2008.

Miscellaneous contributions

- **Variable step size affine projection algorithm with a weighted and regularized projection matrix**
  - This is part of iterative system identification research
  - Temporal weights in the projection matrix
  - Tracking the latest behaviour of error signal.

• "Variable step-size affine projection algorithm with a weighted projection matrix",
T. Dai, A. Adler and B. Shahrrava, *International Journal of Signal Processing*, submitted, 2008.

- Any Questions?
- Thank you very much!!!

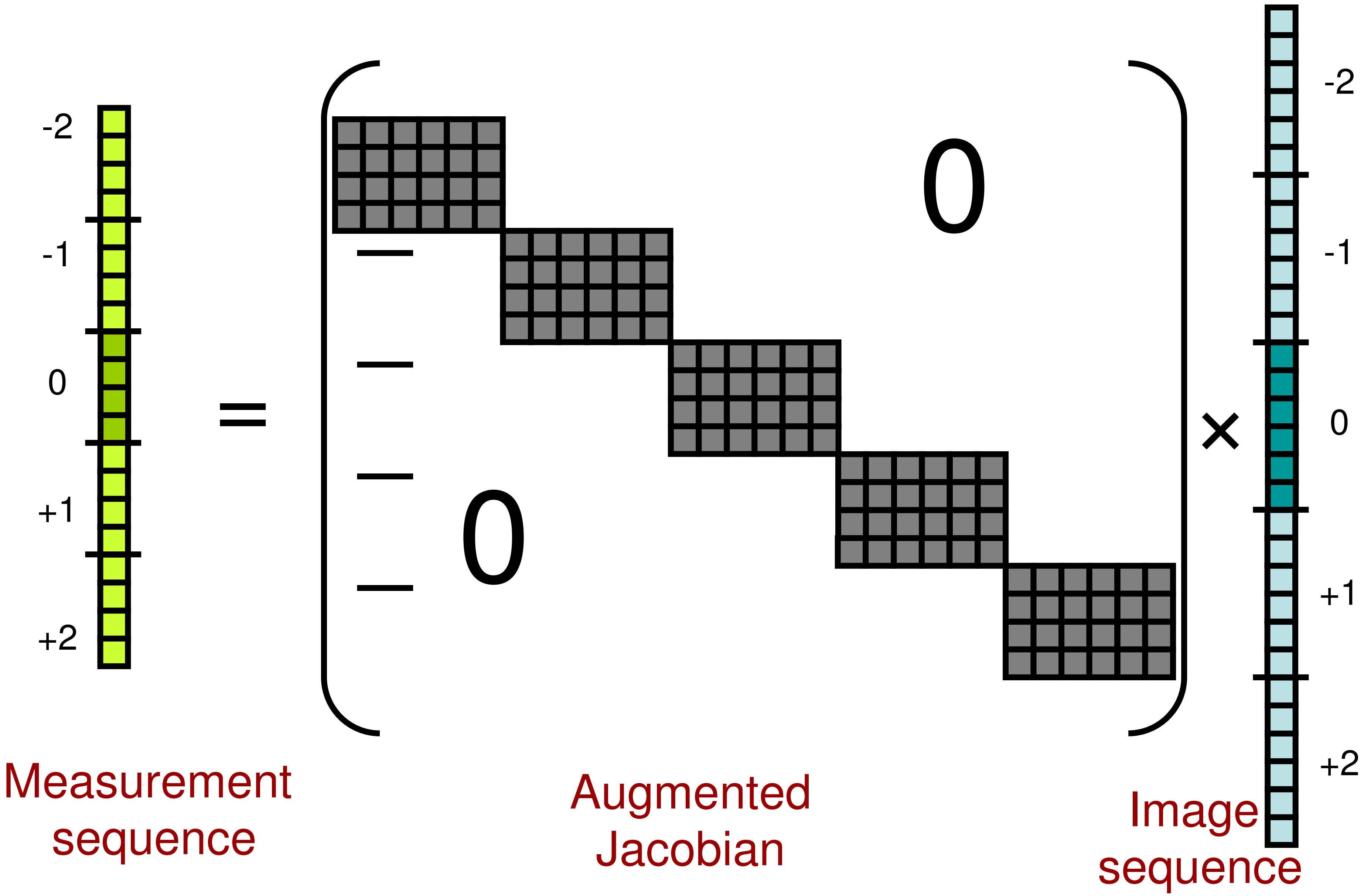
Publications: Peer-Reviewed Journals

1. "*In vivo* blood characterization from bioimpedance spectroscopy of blood pooling", T. Dai, A. Adler, *IEEE Transaction on Medical Instrumentation & Measurement*, accepted, 2008.
2. "EIT image reconstruction with four dimensional regularization", T. Dai, M. Soleimani and A. Adler, *Medical & Biological Engineering & Computing. In press*, 2008.
3. "Reconstruction of conductivity changes and electrode movements based on EIT temporal sequences", T. Dai, C. Gomez-Laberge and A. Adler, *Physiol. Meas*, **29**, S77-S88, 2008.
4. "Application of a single step temporal imaging of magnetic induction tomography for metal flow visualization", M. Soleimani, A. Adler, T. Dai, A. J. Peyton, *J. British Institute of Non-Destructive Testing*, **50**(1):25-29, 2008.
5. "Temporal image reconstruction in electrical impedance tomography", A. Adler, T. Dai, W. R.B. Lionheart, *Physiol. Meas*. **28** S1-S11, 2007.

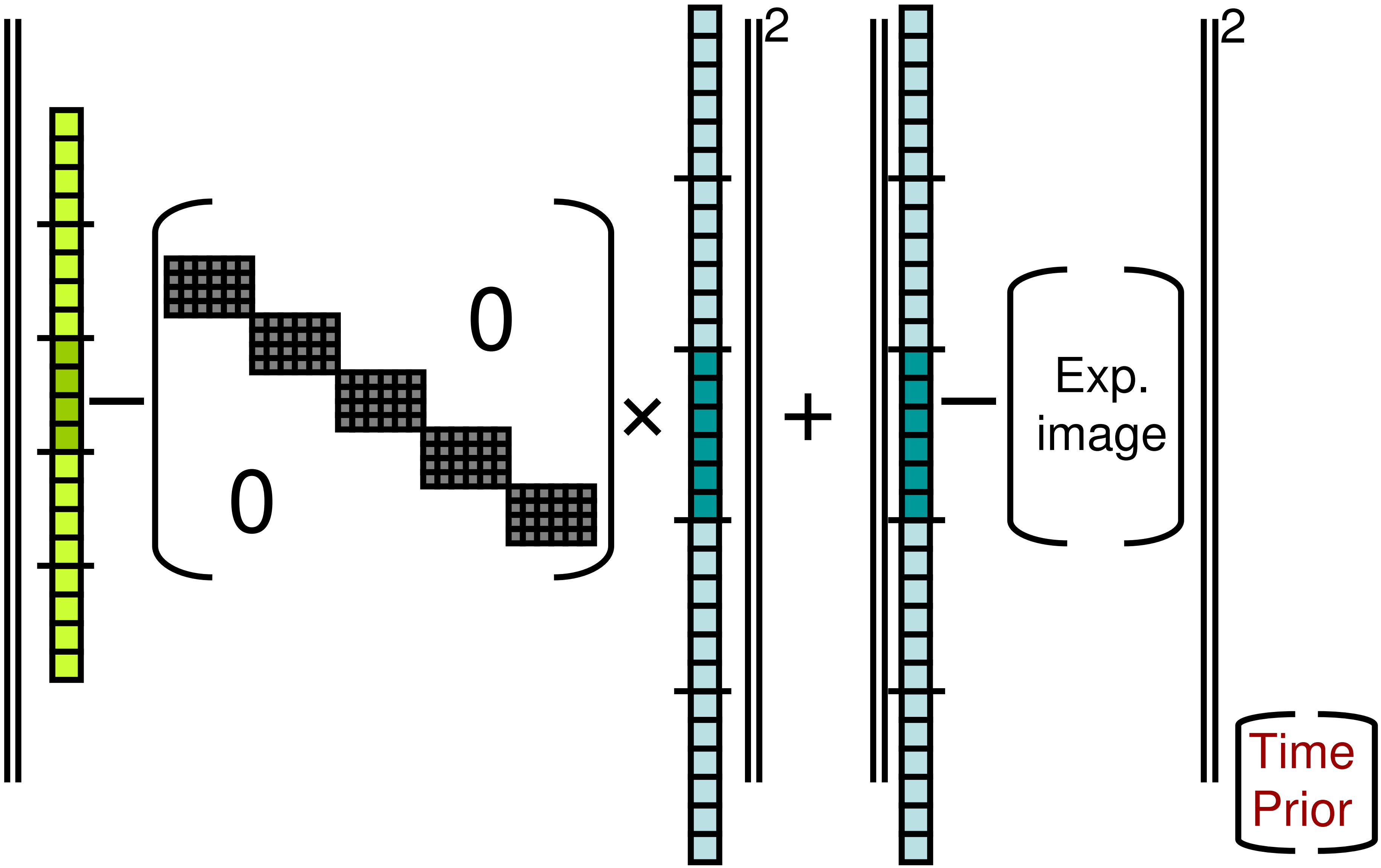
Publications: conferences

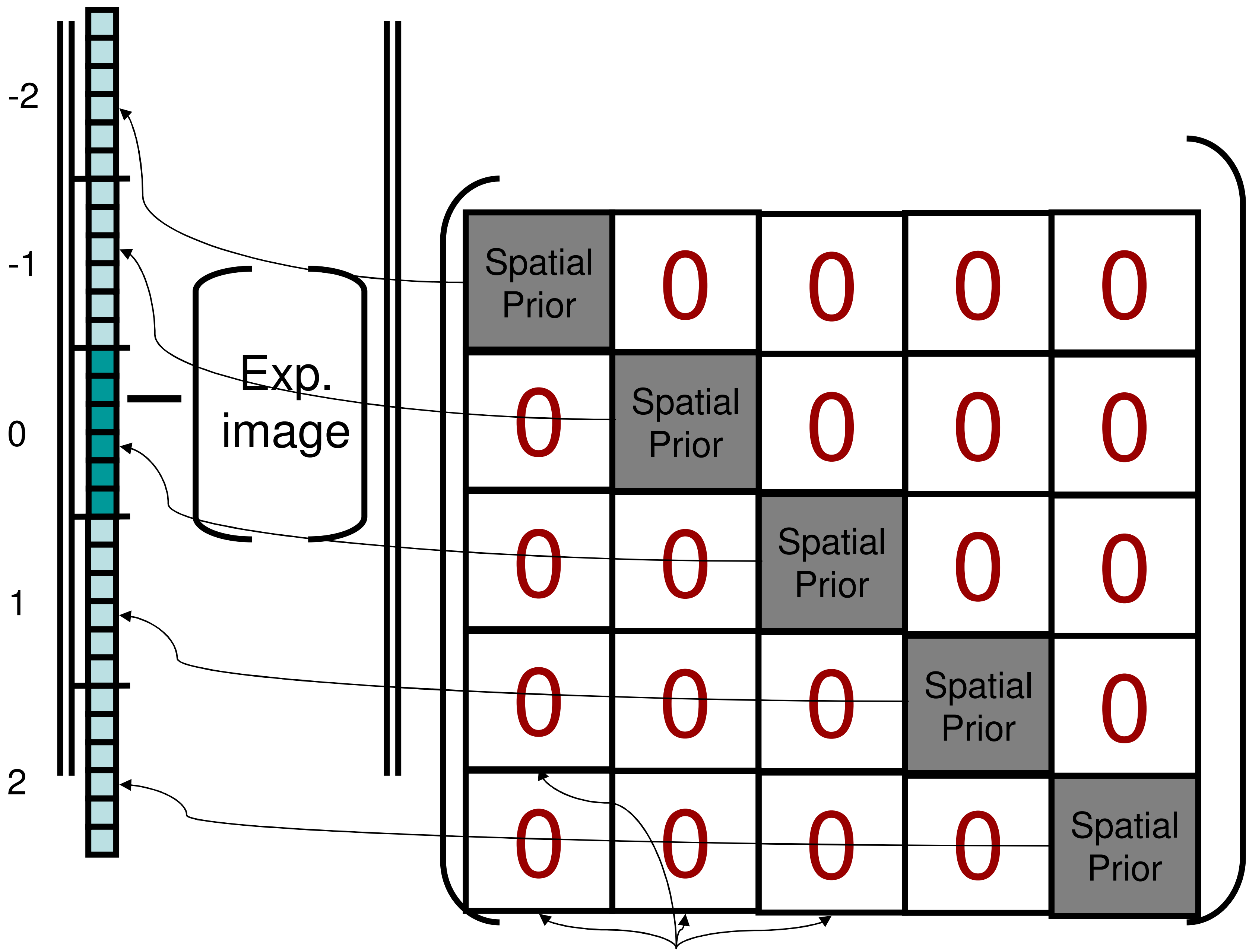
1. "Electrical impedance tomography reconstruction using l1 norm on data and image terms" T. Dai and A. Adler 30th Annual International Conference of the IEEE EMBC, Vancouver, Canada, August, 2008.
2. "Robust 4D electrical capacitance tomography imaging using experimental data", M Soleimani, CN Mitchell, R Wajman, R Banasiak, T Dai, A Adler, ProcTom, 2008
3. "Four dimensional regularization for electrical impedance tomography imaging", T. Dai, M. Soleimani, A. Adler,VIII Conf Electrical Impedance Tomography, Graz, Austria, 2007
4. "Blood characterization from pulsatile bioimpedance spectroscopy", T. Dai, A. Adler, 30th Conf Canadian Medical and Biomedical Engineering Society, Toronto, Canada June 18-20, 2007
5. "Variable step-size affine projection algorithm with a weighted and regularized projection Matrix", T. Dai, A. Adler, B. Shahrrava, IEEE Can. Conf. Computer Elec. Eng. (CCECE), Ottawa, Canada, May 7-10, 2006.
6. "Blood impedance characterization from pulsatile measurements", T. Dai, A. Adler, IEEE Can. Conf. Computer Elec. Eng. (CCECE), Ottawa, Canada, May 7-10, 2006.

Direct temporal forward model



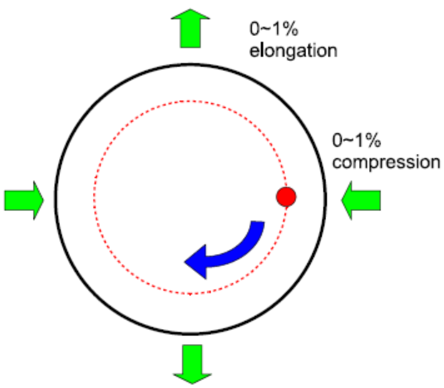
Direct temporal inverse model



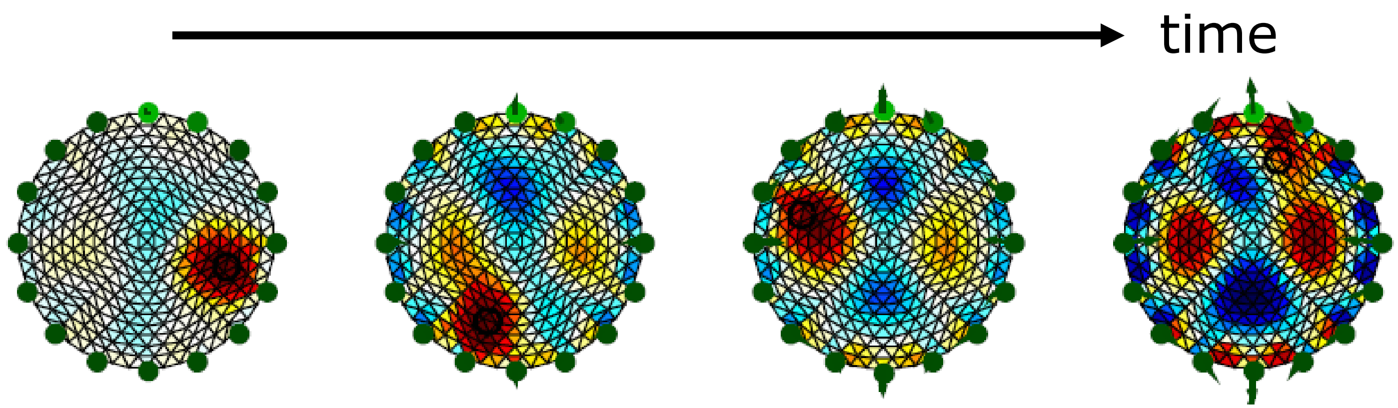


Normally, non-diagonal elements are zeros based on assumption that images are independent

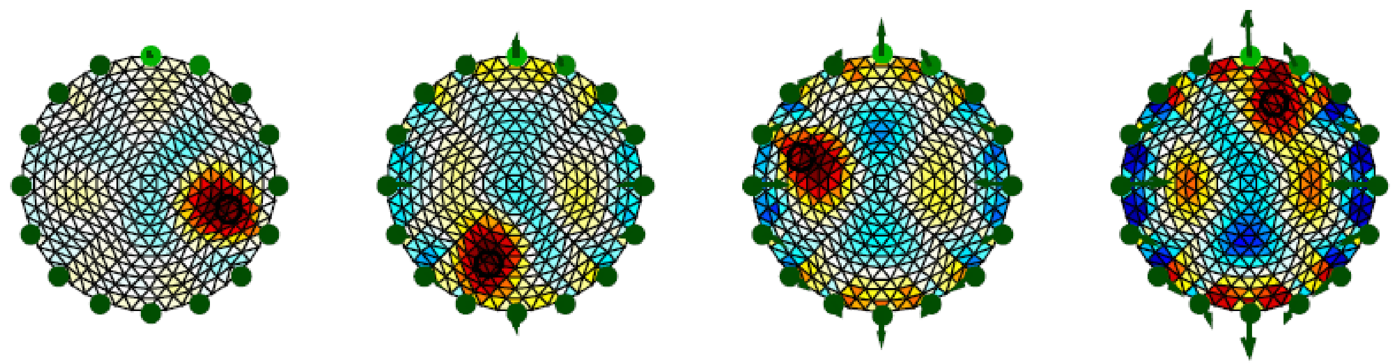
Temporal Boundary Element Motion Analysis



(a)

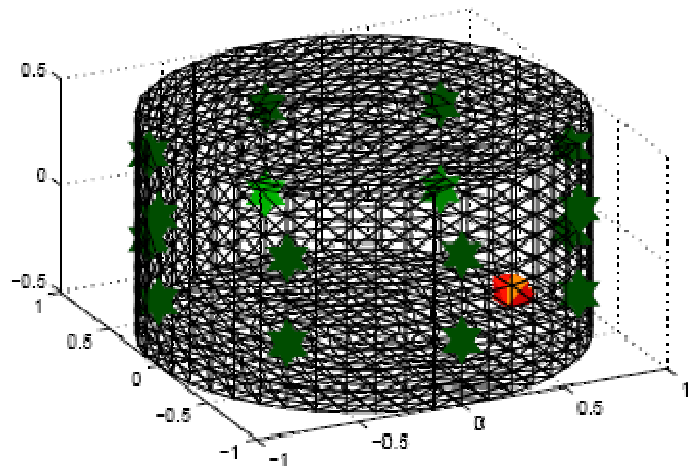


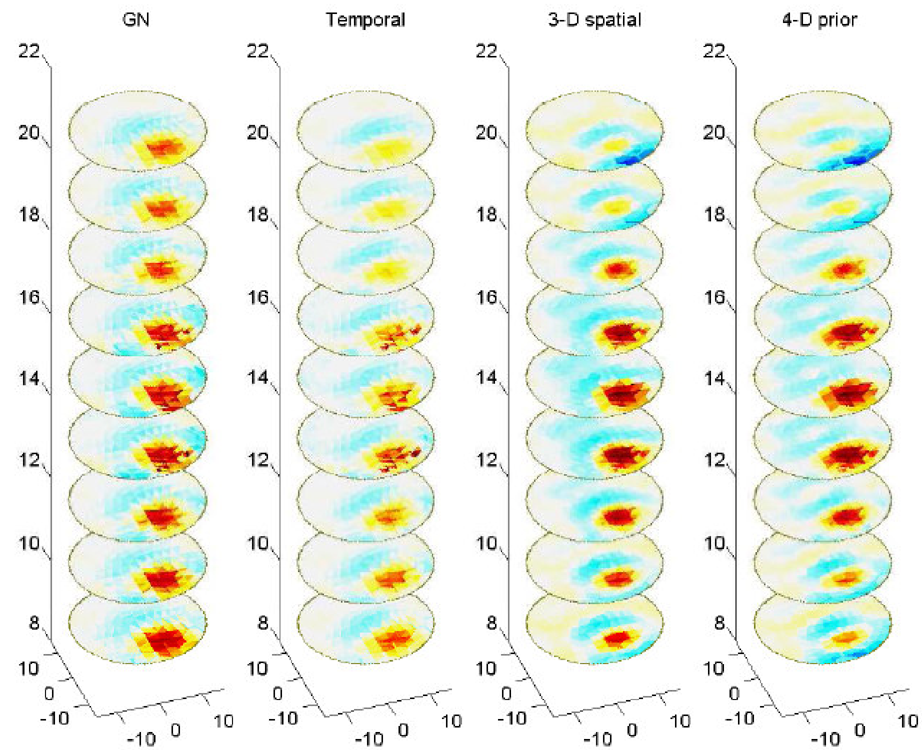
GN Method with EM calculated
(without temporal regularization)



GN Method with EM calculated
(with temporal regularization)

Contributions



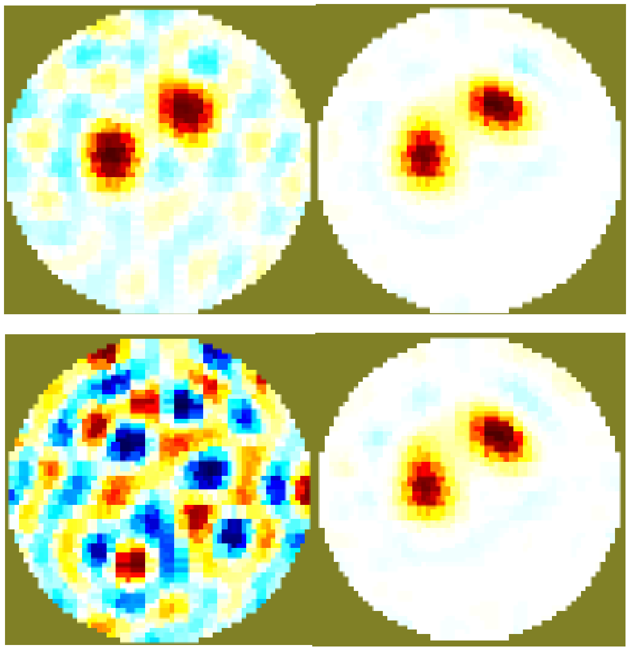


Advantages:

(a)L-2 norm solution (b)L-1 norm solution

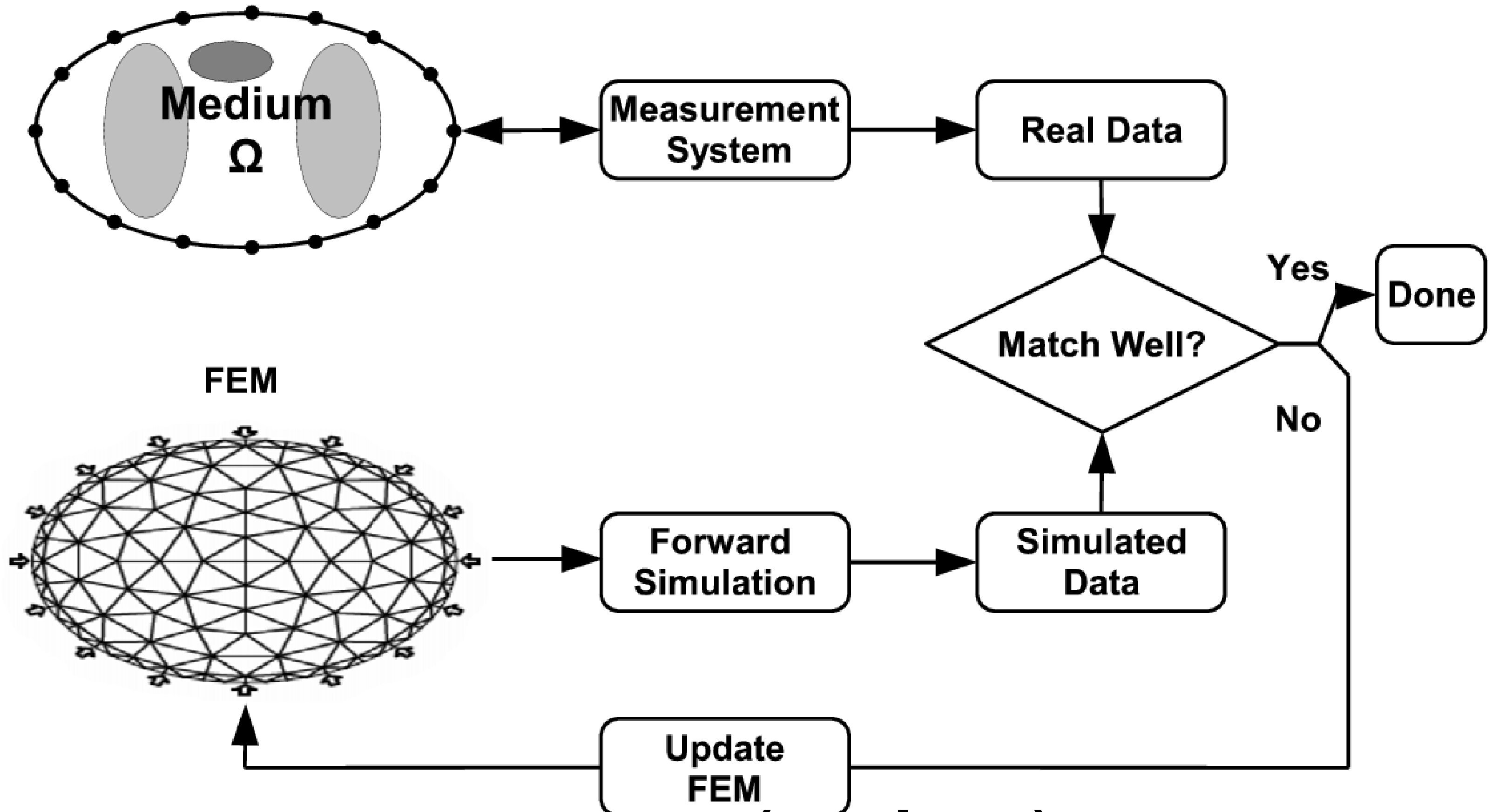
1. Edge preservation

2. Data error robustness



(a) (b)

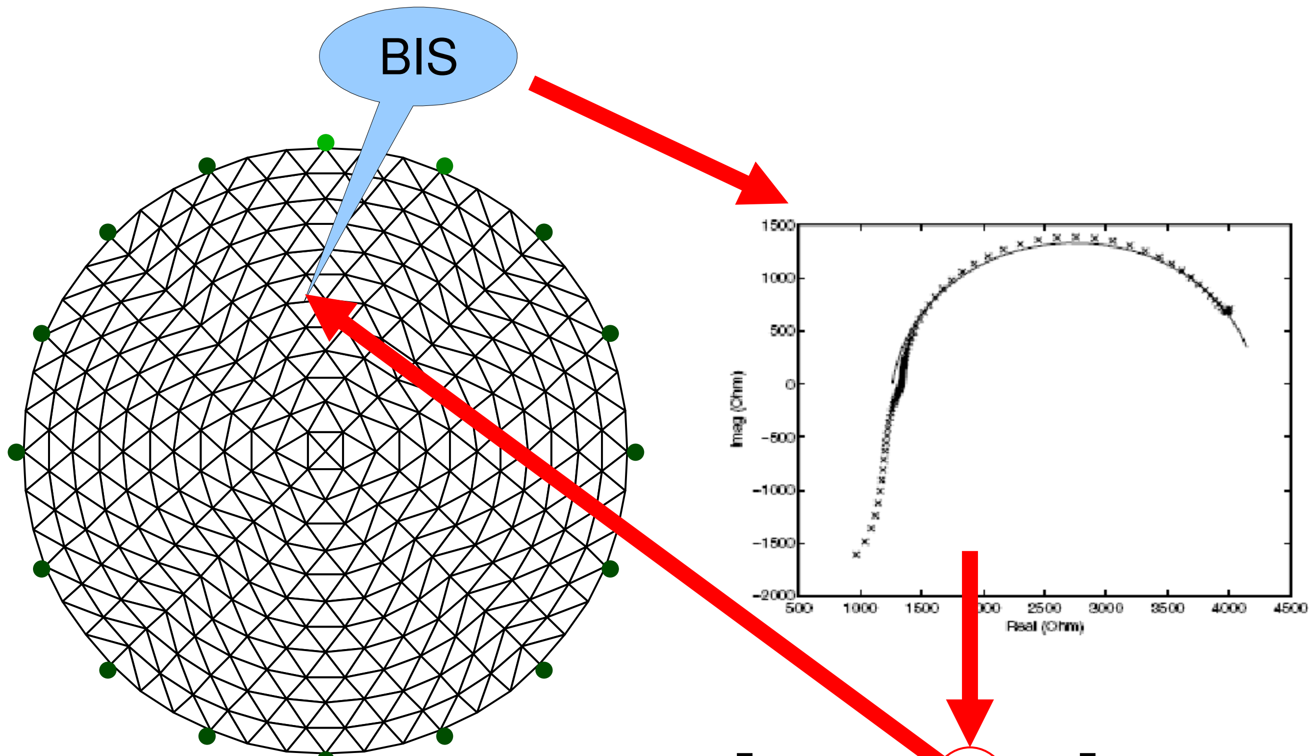
M3: Iterative Solution for L1 Norm Minimization



$$x_k = x_{k-1} + w_k(y - Jx_{k-1})$$

Parametric images for virtual biopsy:

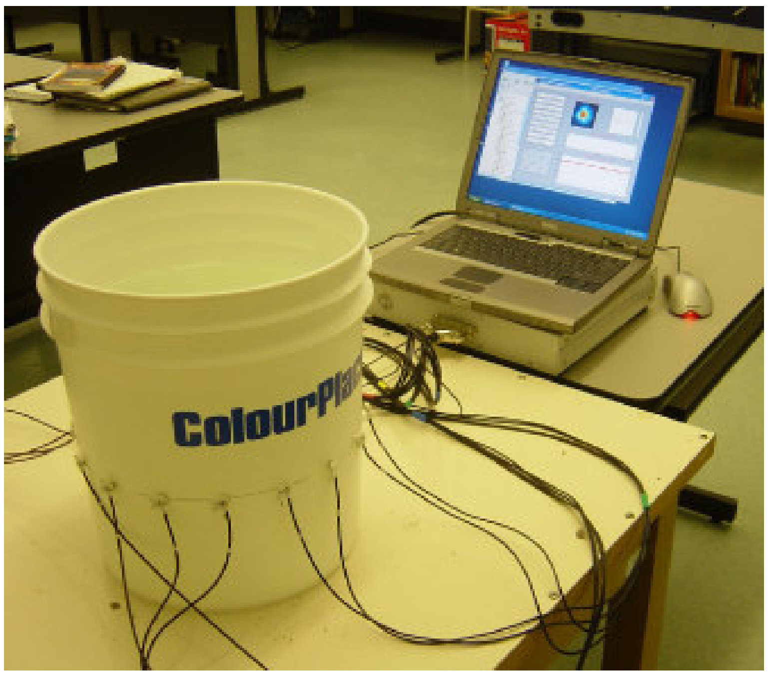
Multi-frequency EIT

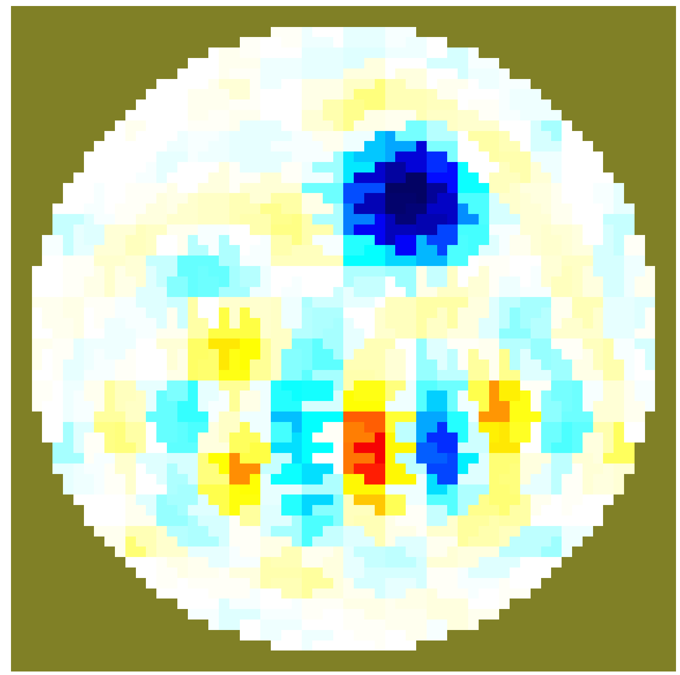


$$m = [R_0 \; R_\infty \; f_c \; \alpha]$$

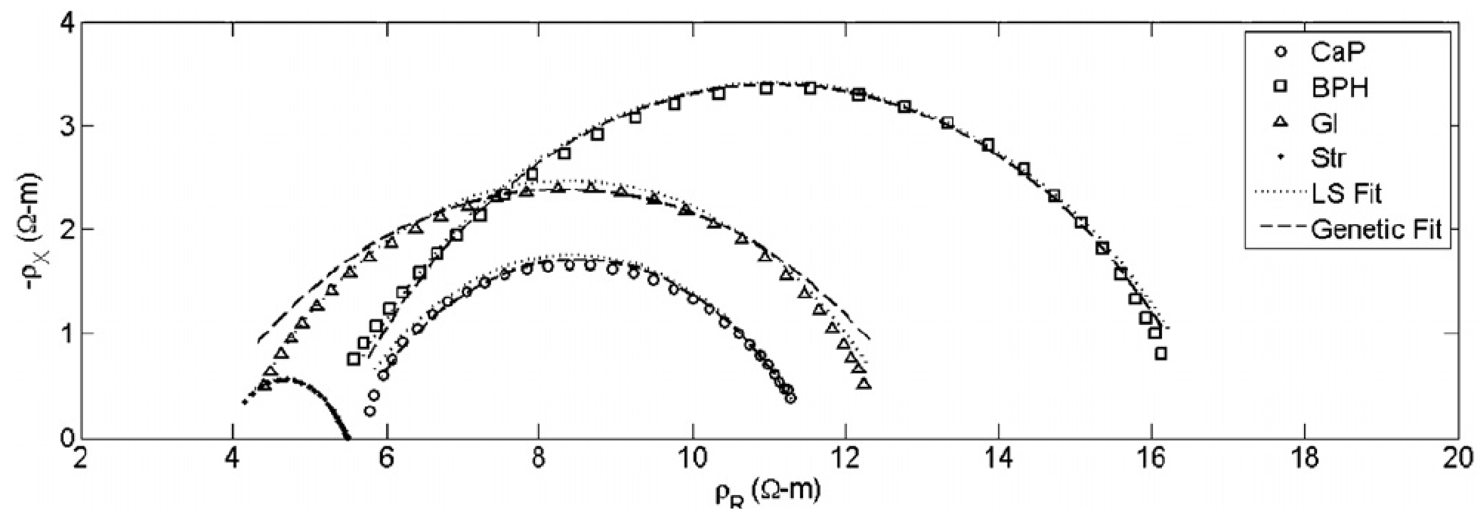
Multi-frequency EIT

EIT: A phantom experiment





BIS for prostate cancer detection (from Dartmouth College)



Parameters	Units	CaP	BPH	Gl	Str
ρ_∞	Ω m	5.79 (5.14–6.44)	5.61 (5.23–5.94)	4.72 (4.38–5.06)	4.58 (4.26–4.89)
$\Delta\rho$	Ω m	3.96 (3.17–4.76)	6.98 (6.00–7.97)	5.10 (4.41–5.79)	2.18 (1.76–2.61)
f_c	kHz	5.01 (3.86–6.16)	2.97 (2.71–3.24)	5.06 (4.37–5.76)	3.92 (3.29–4.54)
α	–	0.62 (0.59–0.66)	0.67 (0.65–0.68)	0.67 (0.66–0.69)	0.74 (0.71–0.77)

Use BIS to differentiate prostate tissues

Upper: different spectra; Lower: different parametric characteristics

***CaP**: Cancerous prostate; **BPH**: Benign Prostatic Hyperplasia*

***Gl**: Glandular tissue; **Str**: Stroma*