Electrical Impedance Tomography for Deformable Media

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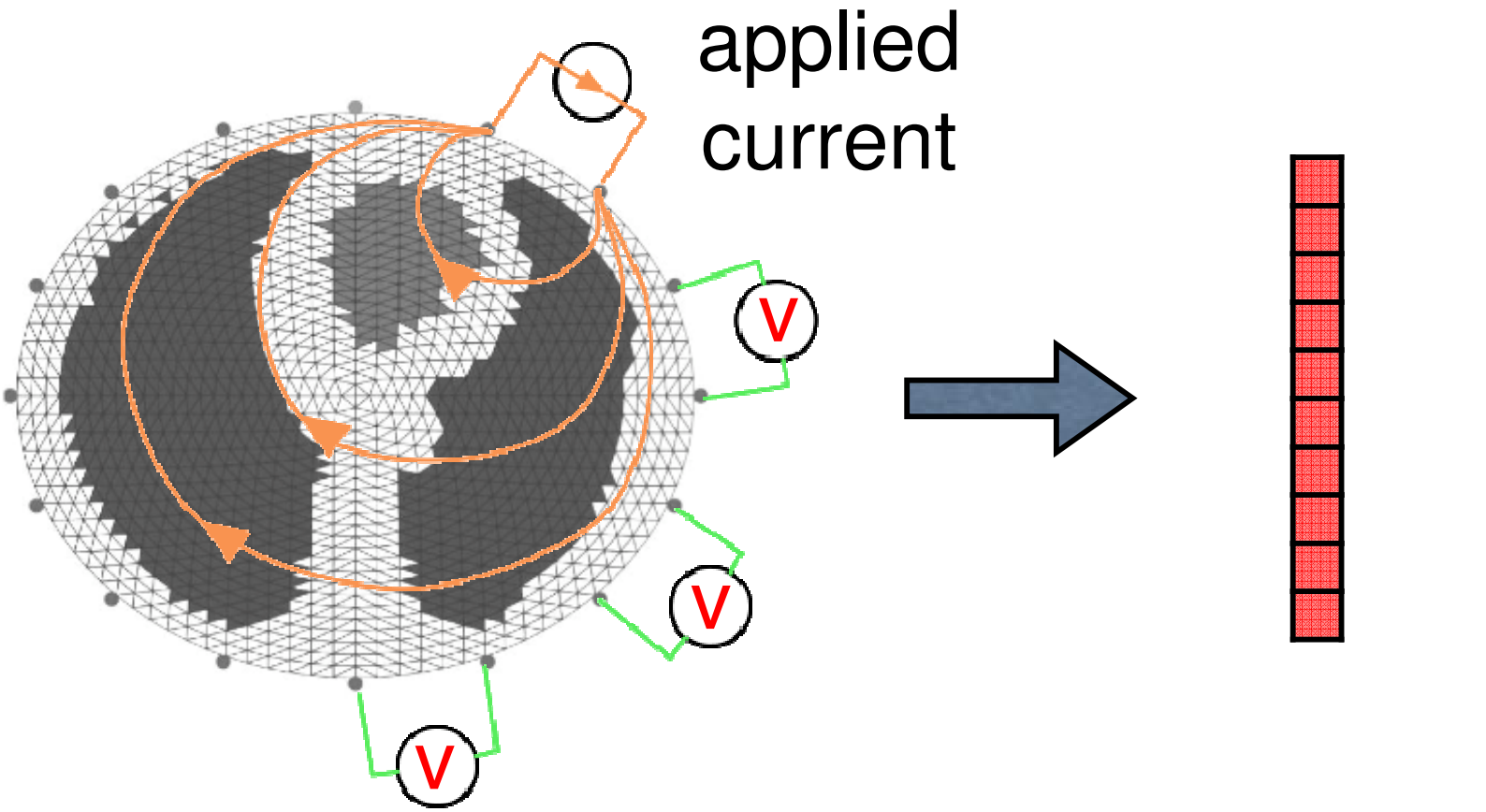
Outline

- Lung ventilation EIT
- Image variability from boundary deformation
- Electrode displacement regularization
- Imaging of deformable media
- 3D EIT Jacobian calculations

Lung ventilation EIT



internal
conductivity

boundary
voltage

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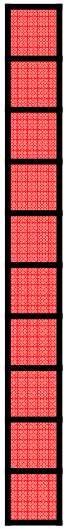
Lung ventilation EIT

inverse solution

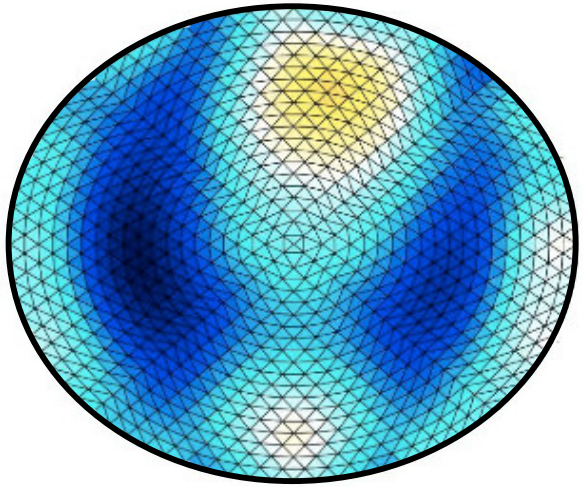
1.discretize

2.linearize

3.regularize



x $f(J,R)=$



boundary voltage

internal conductivity

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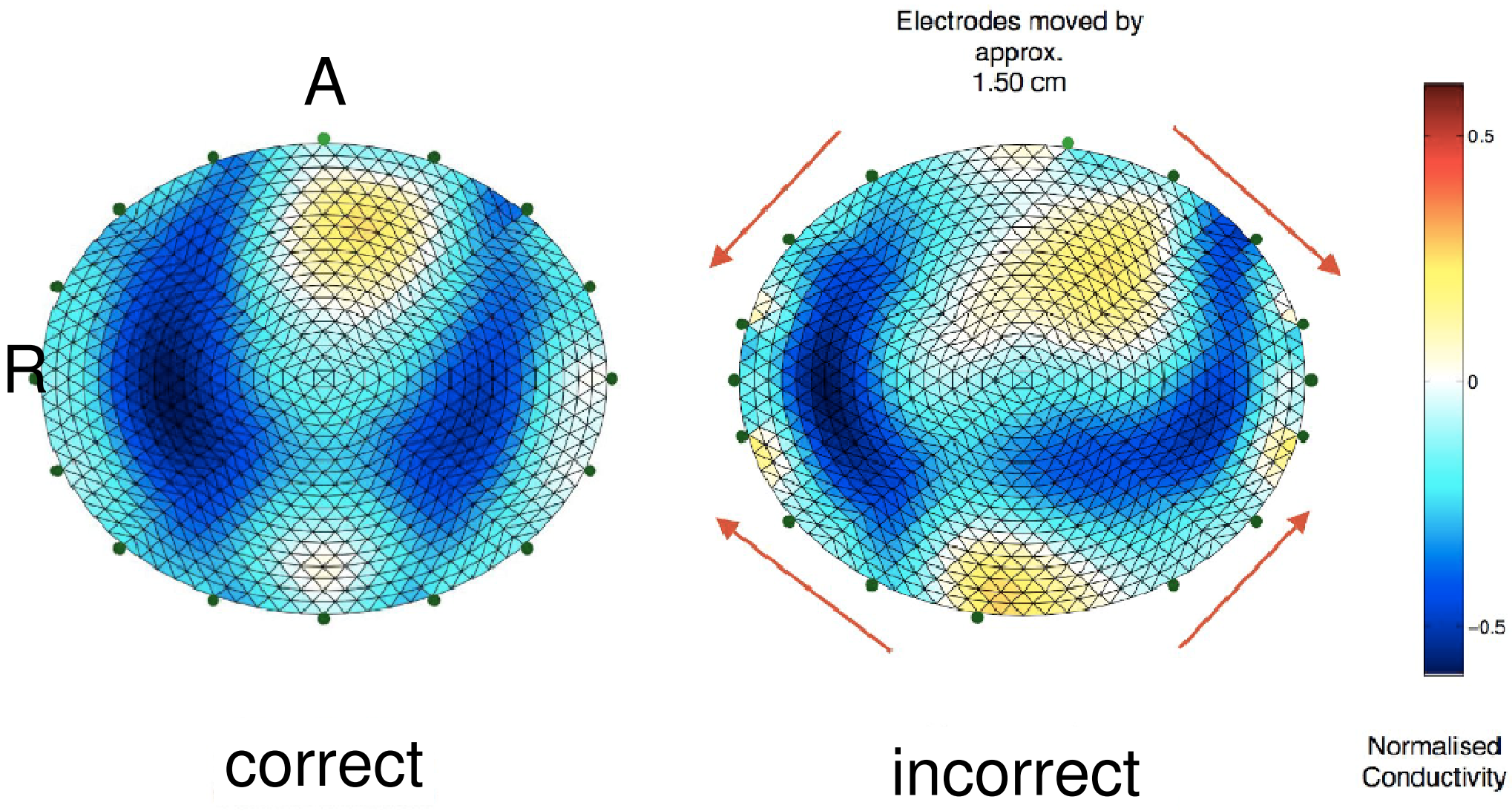
Boundary deformation

- Lung ventilation imaging is prone to
  - throacic deformation
  - posture change
- Thorax expansion per manoeuvre
  - tidal breathing: circumference increases 1%
  - total lung capacity: circumference increases 5%
- These deformations cause significant artefacts

Boundary deformation



correct

incorrect

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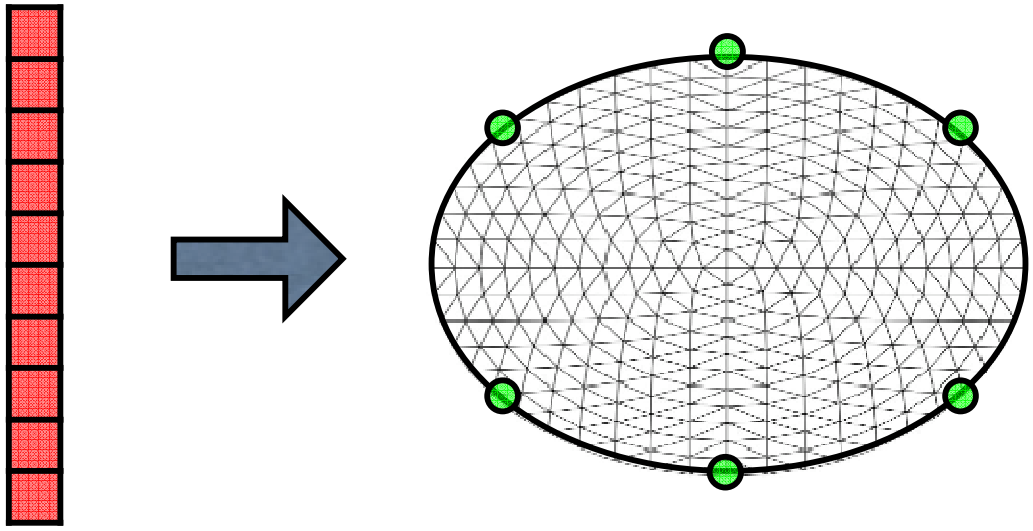
Electrode displacement regularization

boundary voltage

internal conductivity

image



electrode displacement

$\mathbf{v}$

$\mathbf{x}$

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Electrode displacement regularization

$$\mathbf{x} = f_{\mathbf{J},\mathbf{R}}(\lambda,\mu) \times \mathbf{v}$$

$$\mathbf{x} = \left(\mathbf{J}^\top\mathbf{J} + \lambda^2\mathbf{R}\right)^{-1}\mathbf{J}^\top\mathbf{v}$$

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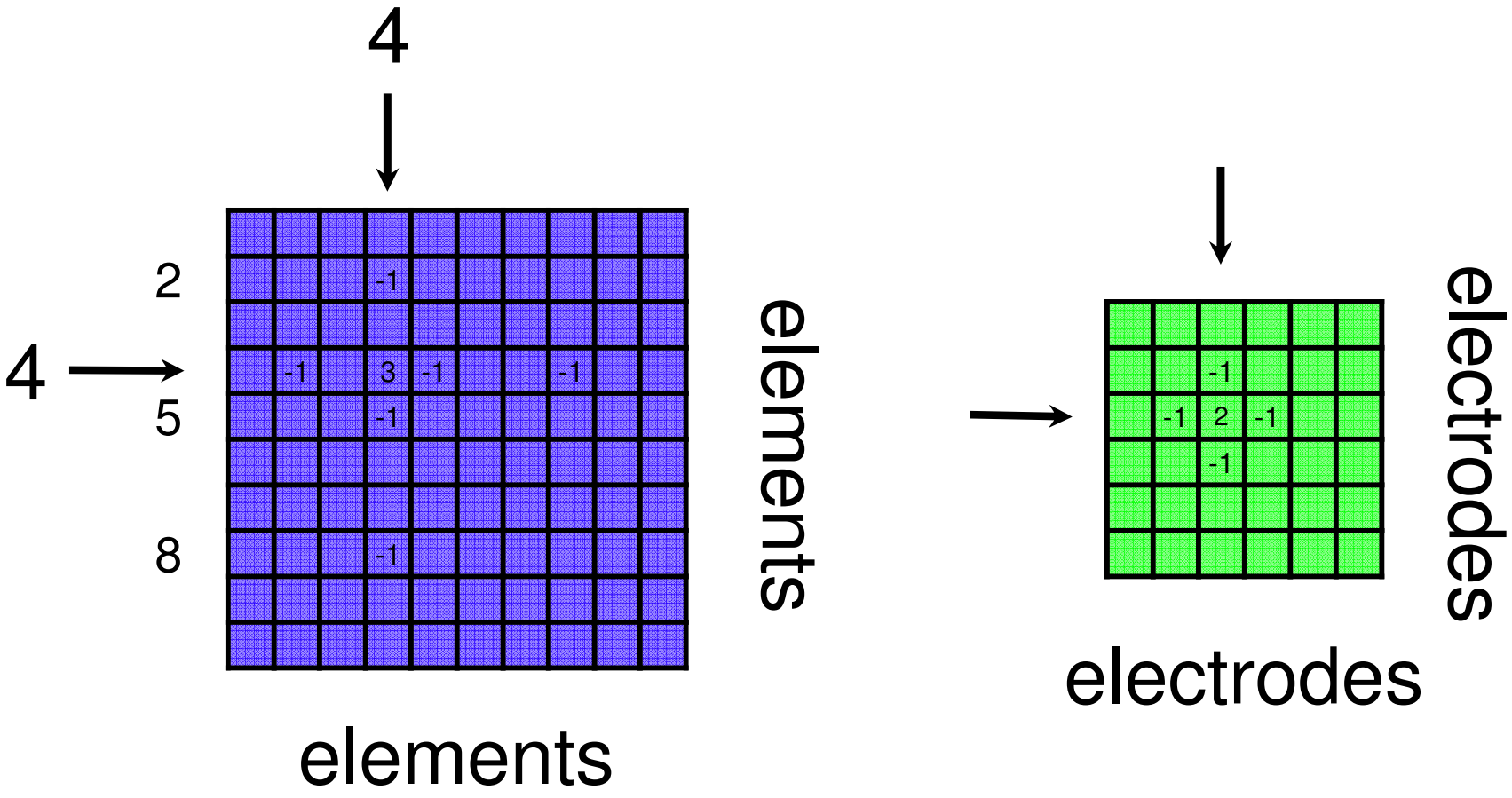
Electrode displacement regularization

- Building *R*: a priori claims
  - conductivity distribution is smooth
  - adjacent electrode displacements are correlated

Electrode displacement regularization



Electrode displacement regularization

$$R = \begin{bmatrix} \text{blue block} & 0 \\ 0 & \mu^2 \text{ block} \end{bmatrix}$$

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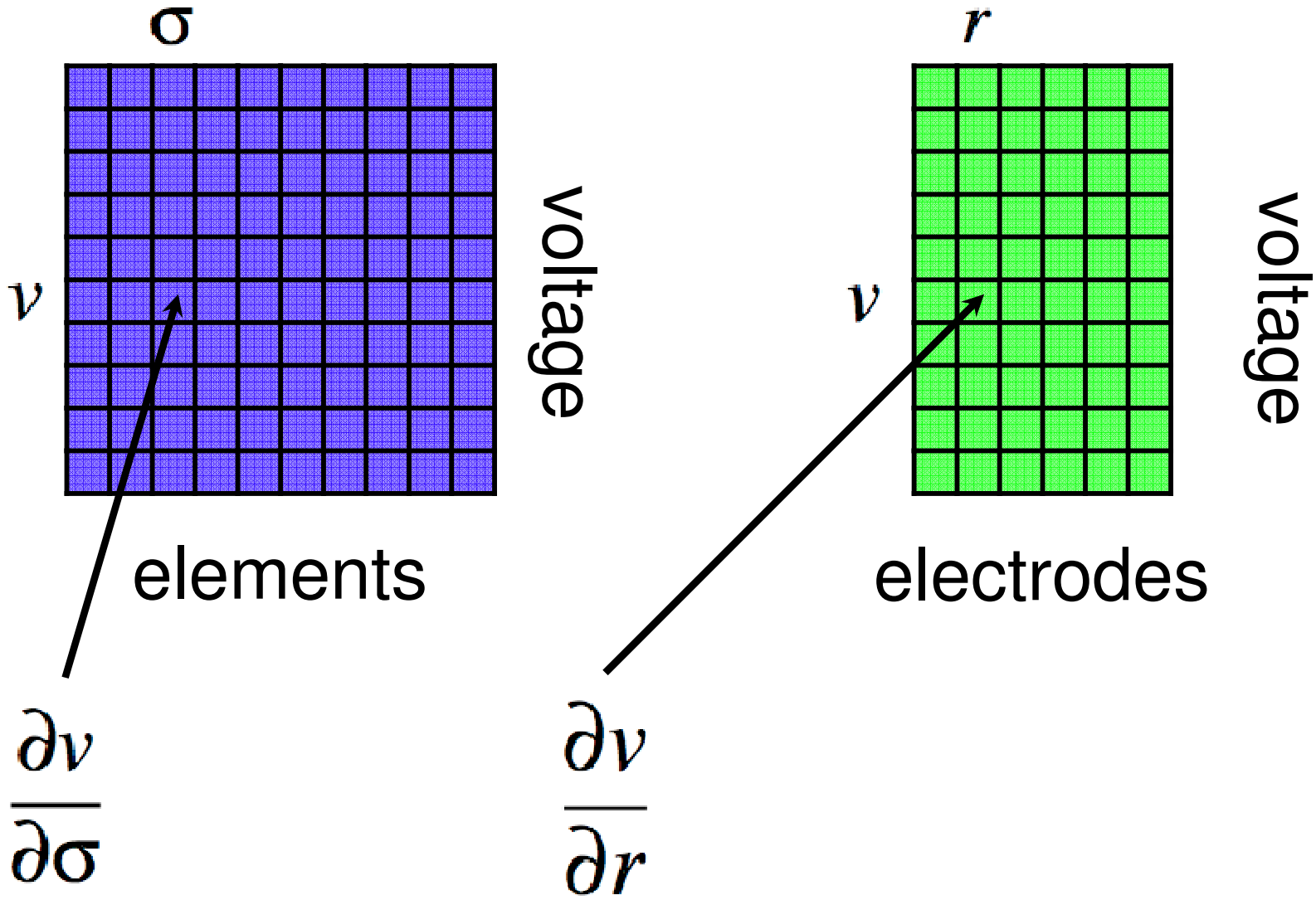
Electrode displacement Jacobian

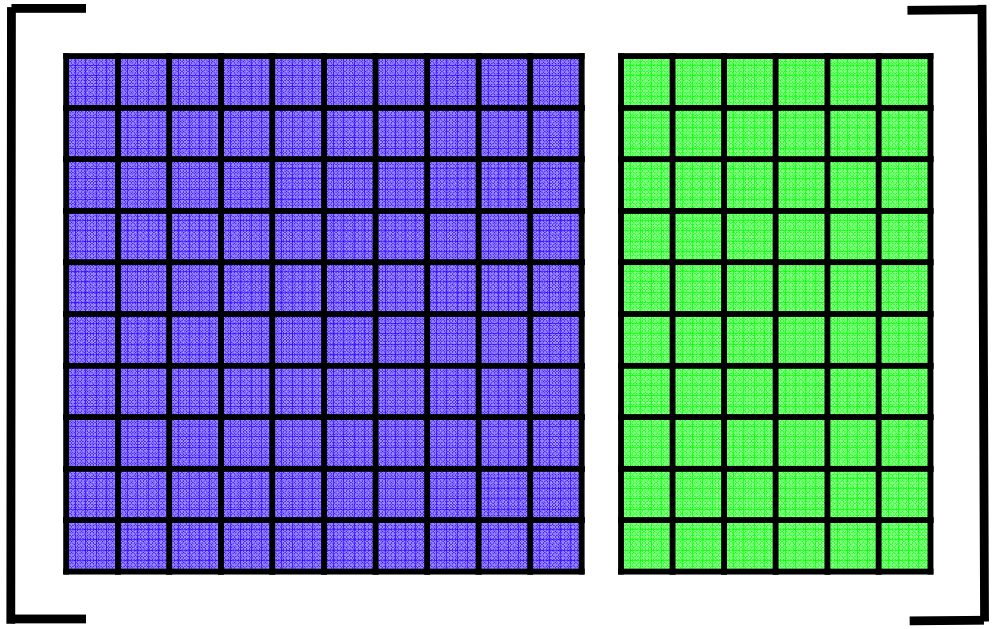
- Building J: sensitivity to deformation
  - conductivity change will affect boundary voltage
  - displacements will affect boundary voltage

Electrode displacement Jacobian



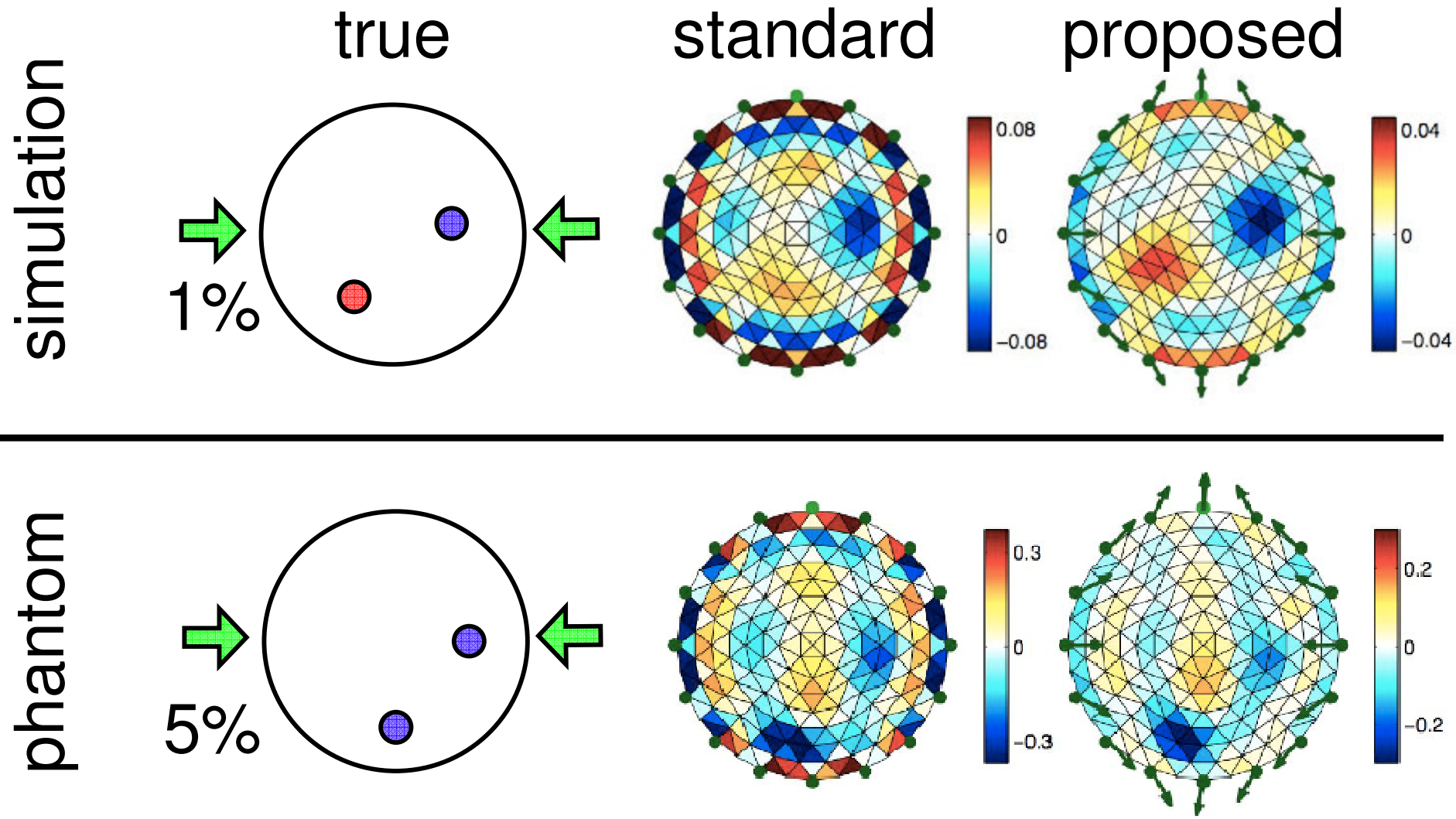
Electrode displacement Jacobian

$$J = \left[\quad \right]$$



Calculating the Jacobian becomes time consuming for large FEM > 30,000 elements

Imaging deformable media



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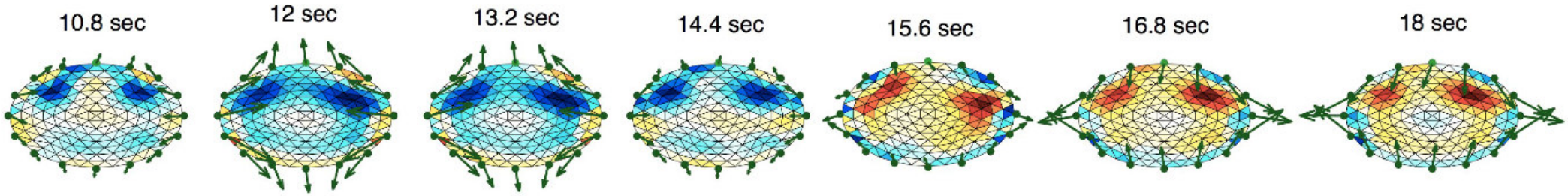
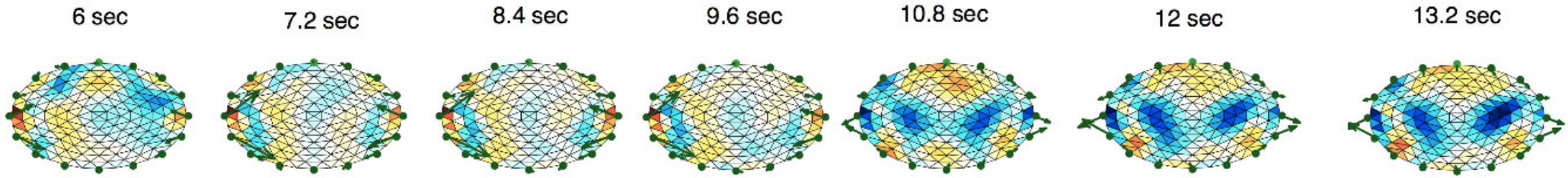
Imaging deformable media

Human TLC-RC breathing: 1.2 sec. increments



Human “paradoxical” breathing: 1.2 sec. increments



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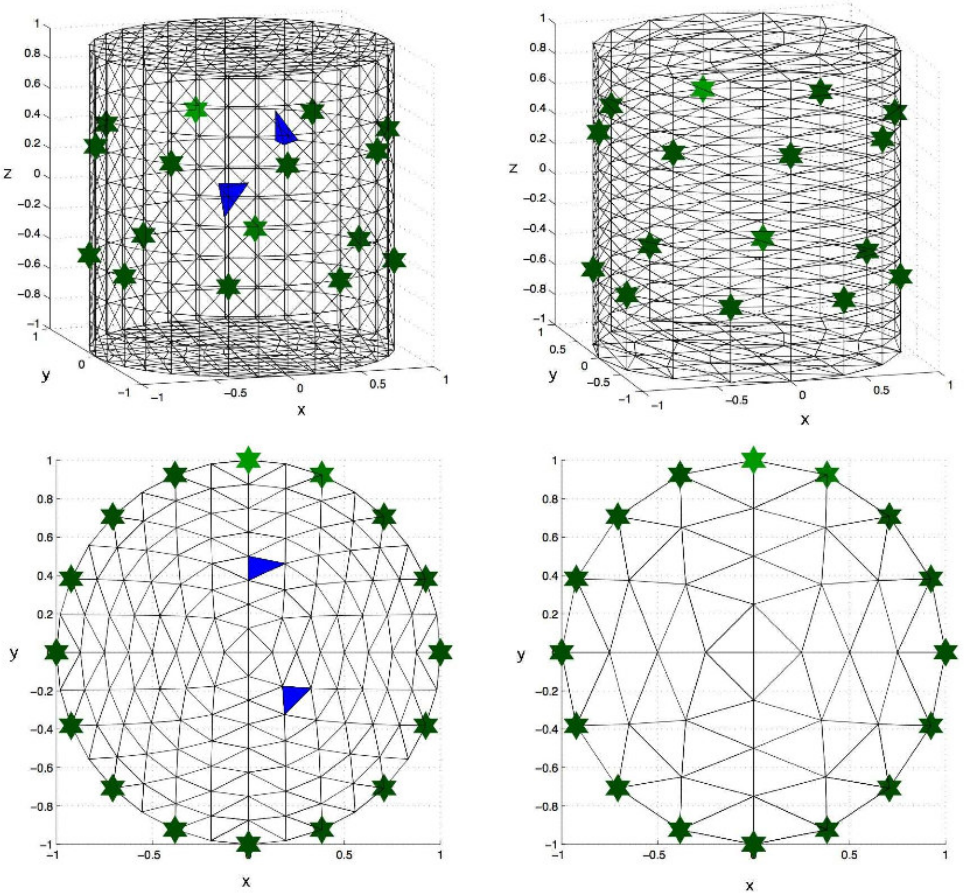
3D EIT Jacobian

- Jacobian calculation time increases exponentially for large 3-D FEM

Model pair	Elements	
	forward	inverse
A	7,680	1,536
B	15,360	3,072



3D EIT Jacobian

- Save time by calculating *J* directly from the FEM system matrix

$$\mathbf{V} = \mathbf{Y}(\boldsymbol{\sigma}, \mathbf{r})^{-1}\mathbf{Q}$$

$$\mathbf{Y}(\boldsymbol{\sigma}, \mathbf{r}) = \mathbf{C}^{\top}\,\mathbf{D}(\boldsymbol{\sigma})\,\mathbf{S}(\mathbf{r})\,\mathbf{C}$$

$$\mathbf{S} = \begin{bmatrix} \mathbf{S}_1 & 0 & \cdots & 0 \\ 0 & \mathbf{S}_2 & & \vdots \\ \vdots & & \ddots & 0 \\ 0 & \cdots & 0 & \mathbf{S}_{N_k} \end{bmatrix}$$

3D EIT Jacobian

- Derived *J* using rank-one asymmetric matrix perturbations

$$\mathbf{J}_m = \left[\frac{\partial \mathbf{V}}{\partial \mathbf{r}_1} \cdots \frac{\partial \mathbf{V}}{\partial \mathbf{r}_{N_e}} \right]$$

$$\frac{\partial \mathbf{S}_i}{\partial \mathbf{r}} = \frac{2}{N_d!} \left[\frac{1}{|\det \mathbf{A}_i|} \left(\mathbf{b}^\top \mathbf{A}_i \mathbf{a} \mathbf{B}_i^\top \mathbf{B}_i + \frac{\partial \mathbf{B}_i^\top}{\partial \mathbf{r}} \mathbf{B}_i + \mathbf{B}_i^\top \frac{\partial \mathbf{B}_i}{\partial \mathbf{r}} \right) \right]$$

Model pair	Computation Time (ms)		Relative Norm
	Direct	Indirect	$\|\|\mathbf{J}_{\text{indir}} - \mathbf{J}_{\text{dir}}\|\| \,/\, \|\|\mathbf{J}_{\text{dir}}\|\|$
A	840	22,420	1.48×10^{-6}
B	1,460	41,430	1.57×10^{-6}

Thank you:

- ICEBI Graz Committee
- My supervisor: Dr. Andy Adler
- Bio-impedance scientific community