EIT image reconstruction with L1 data and image norms

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Motivation

- In ICU, measurement errors unavoidable due to dynamics of human body.
- High contrast resolution are preferred to differentiate various tissue types.

- Before: one-step Gauss Newton method (L2 norm)
  - Smoothed edges
  - Sensitive to measurement errors (outliers)

- L1 norm solution:
  - **Image norm:** preserve edges (non-smooth optimization)
  - **Data norm:** robust against measurement outliers

Outline

- **Objectives**:
  - Robust algorithms in clinical setting

- **Approaches**:
  - Evaluation using experimental/clinical data
    - Human lung ventilation
    - Dog breathing data
  - 4 alternatives with L1 and L2 norms on data and image terms (L2L2, L2L1, L1L2, L1L1)

L2 norm for data misfit and image prior

- L2 norm - least square solution/Tikhonov
- L2 norm for the image prior term produces smoothed edges
- L2-norm for the data misfit is more sensitive to measurement outliers, as the differences between model and data are squared

$$\arg\min_{\mathbf{x}} \left\{ \mathcal{F}(\mathbf{x}) := \overset{\text{Least square solution}}{\boxed{\frac{1}{2}||f(\mathbf{x}) - \mathbf{y}||_{\ell_2}^2}} + \overset{\text{Penalty term}}{\boxed{\lambda \frac{1}{2}||\mathbf{R}\mathbf{x}||_{\ell_2}^2}} \right\}$$

L1-L2 norms for data misfit and image prior

- **PDIPM** - Primal Dual Interior Point Framework

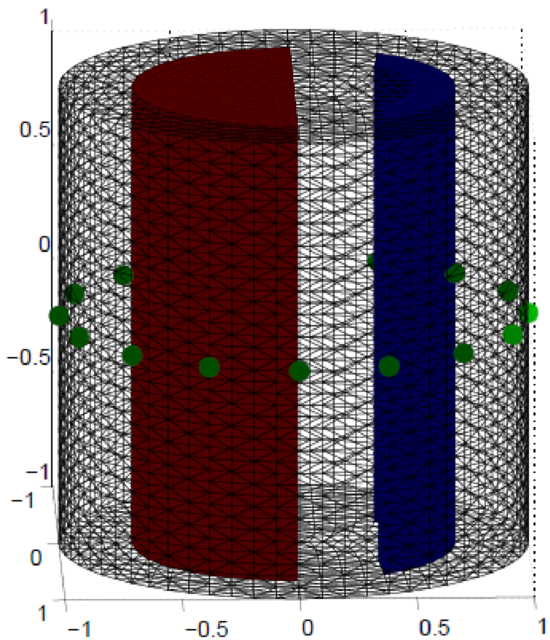
Data norm **Image norm**

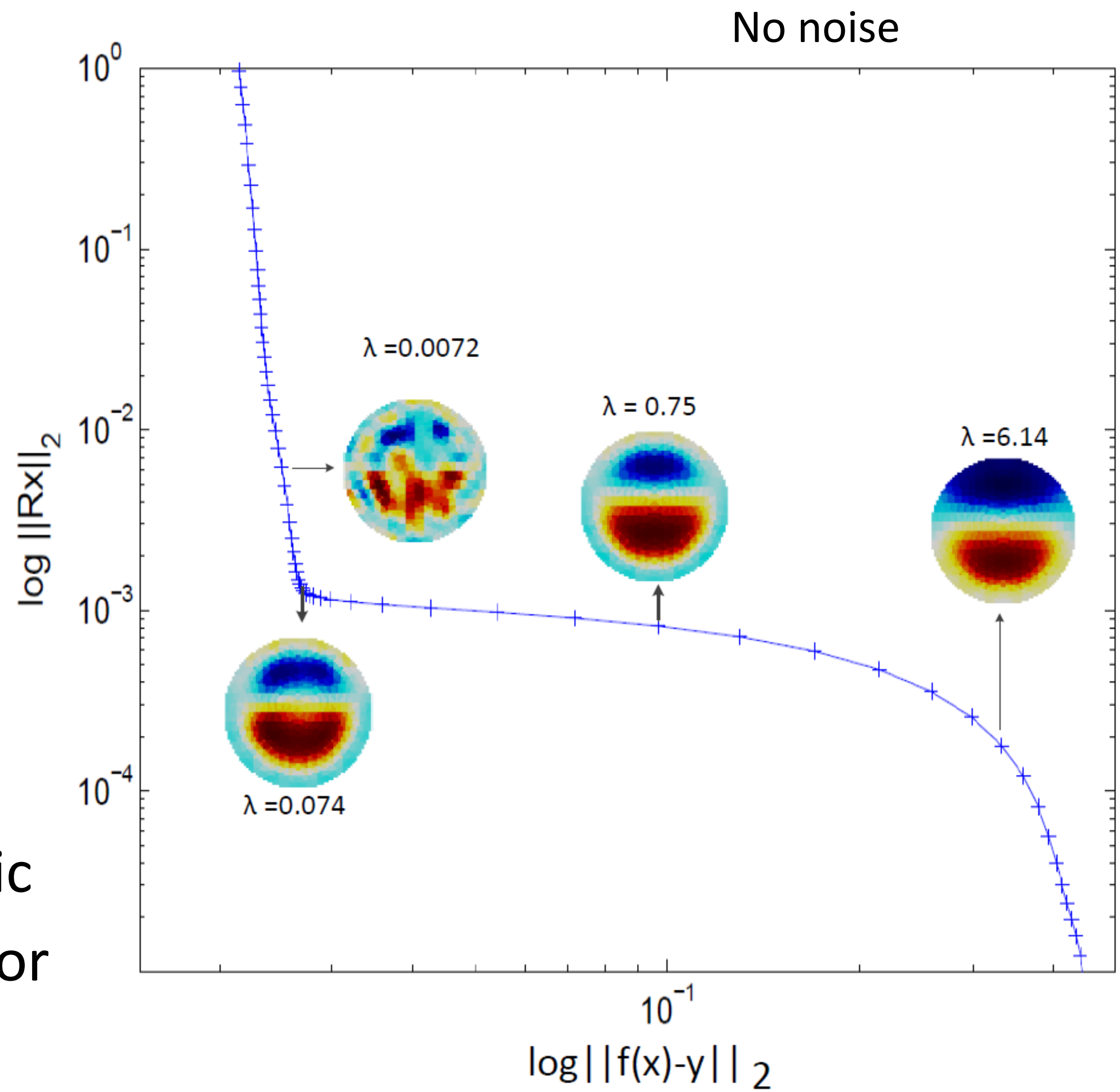
$$\underset{\mathbf{x}}{arg\ min} \{\mathcal{F}(\mathbf{x}) := \|f(\mathbf{x}) - \mathbf{y}\|_p^p + \|\lambda \mathbf{R}(\mathbf{x} - \mathbf{x}_0)\|_n^n\}$$

L1 or L2 norms

- L1 norm solution
  - **L1 norm** - sum(abs(.))
  - Data 1-norm reduces the penalty for outliers
  - Image 1-norm preserves edges and allows sharp images
  - Computationally more complex

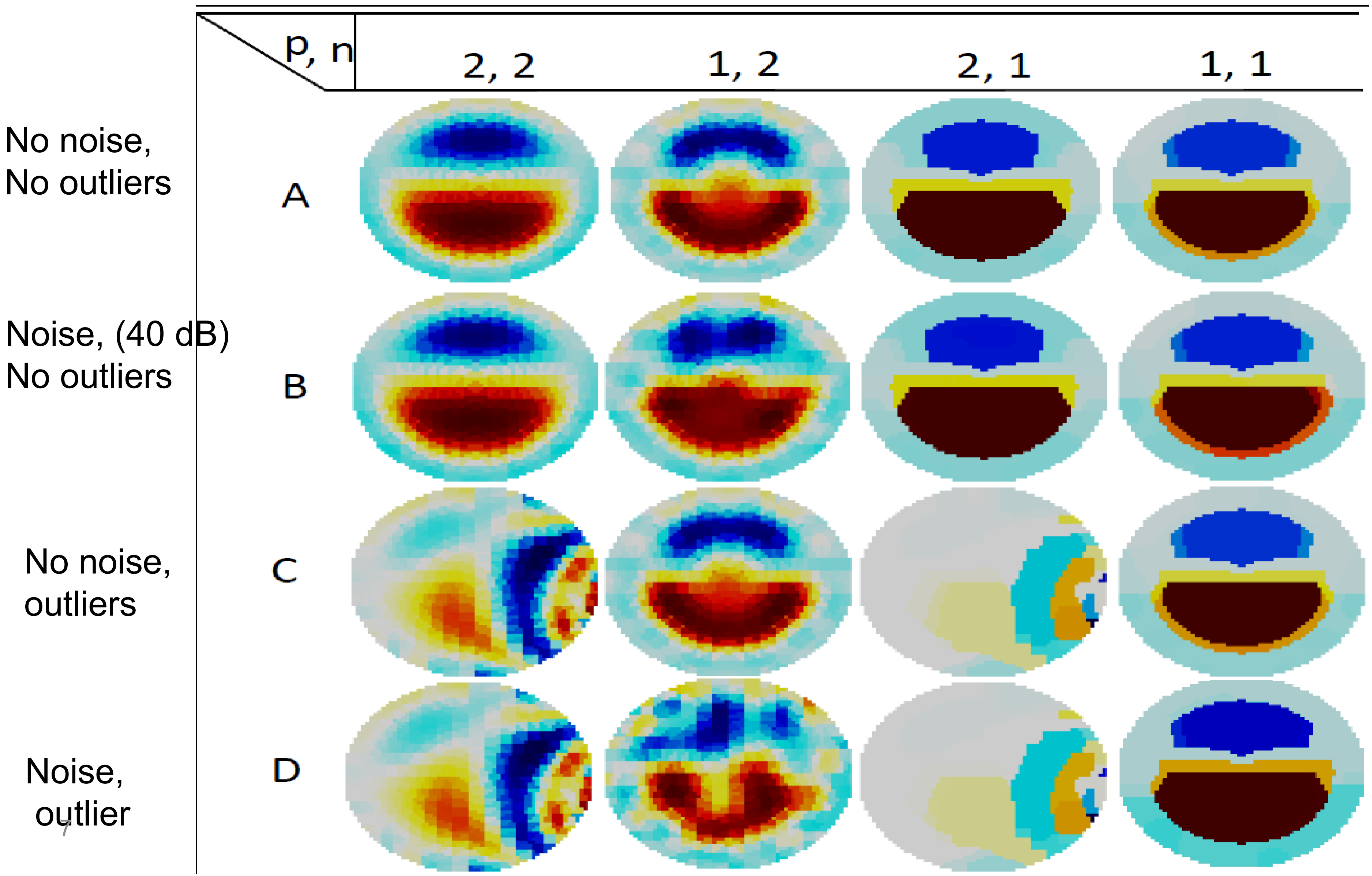
Hyperparameter Estimation (L-curve)





- L-curve based automatic parameter estimation for all L1/L2 combinations

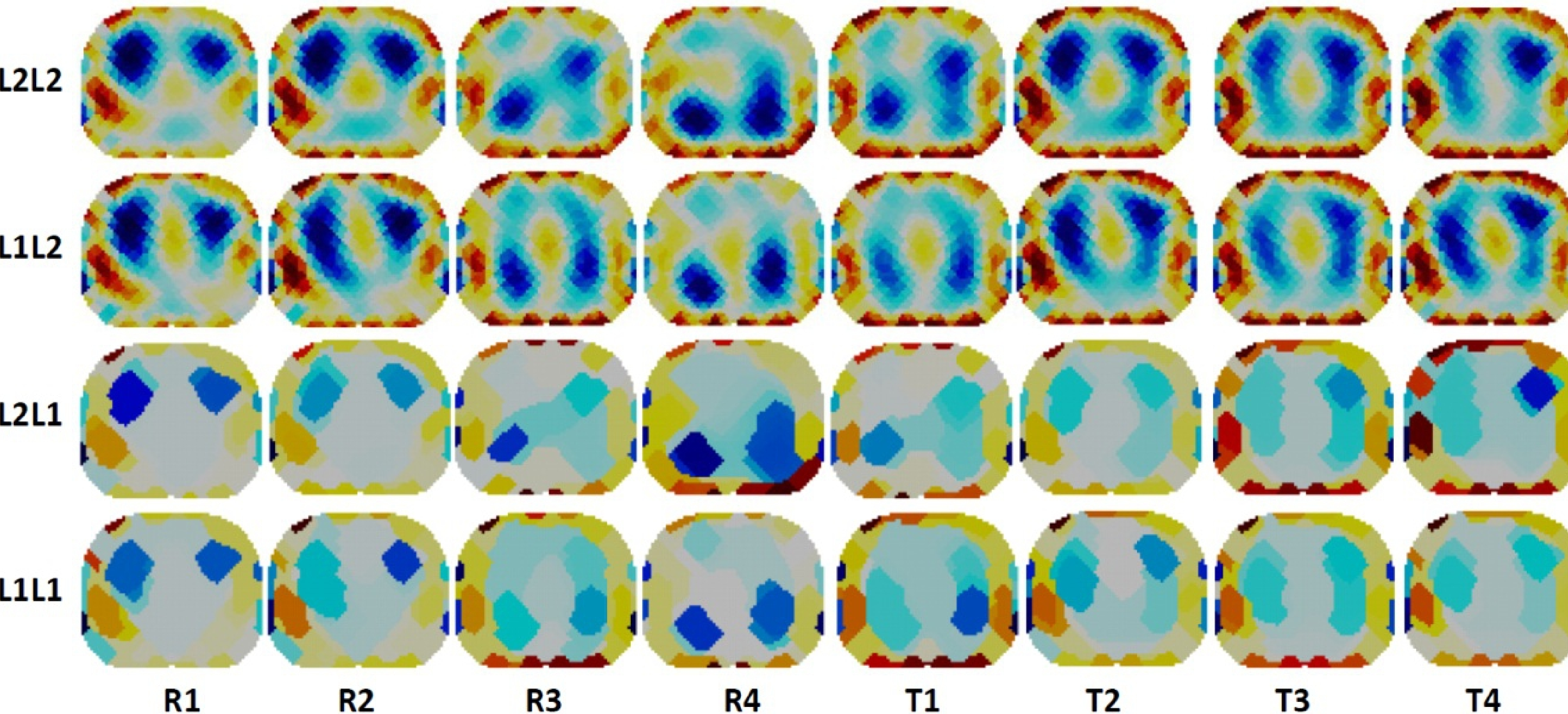
Results 1: Simulation



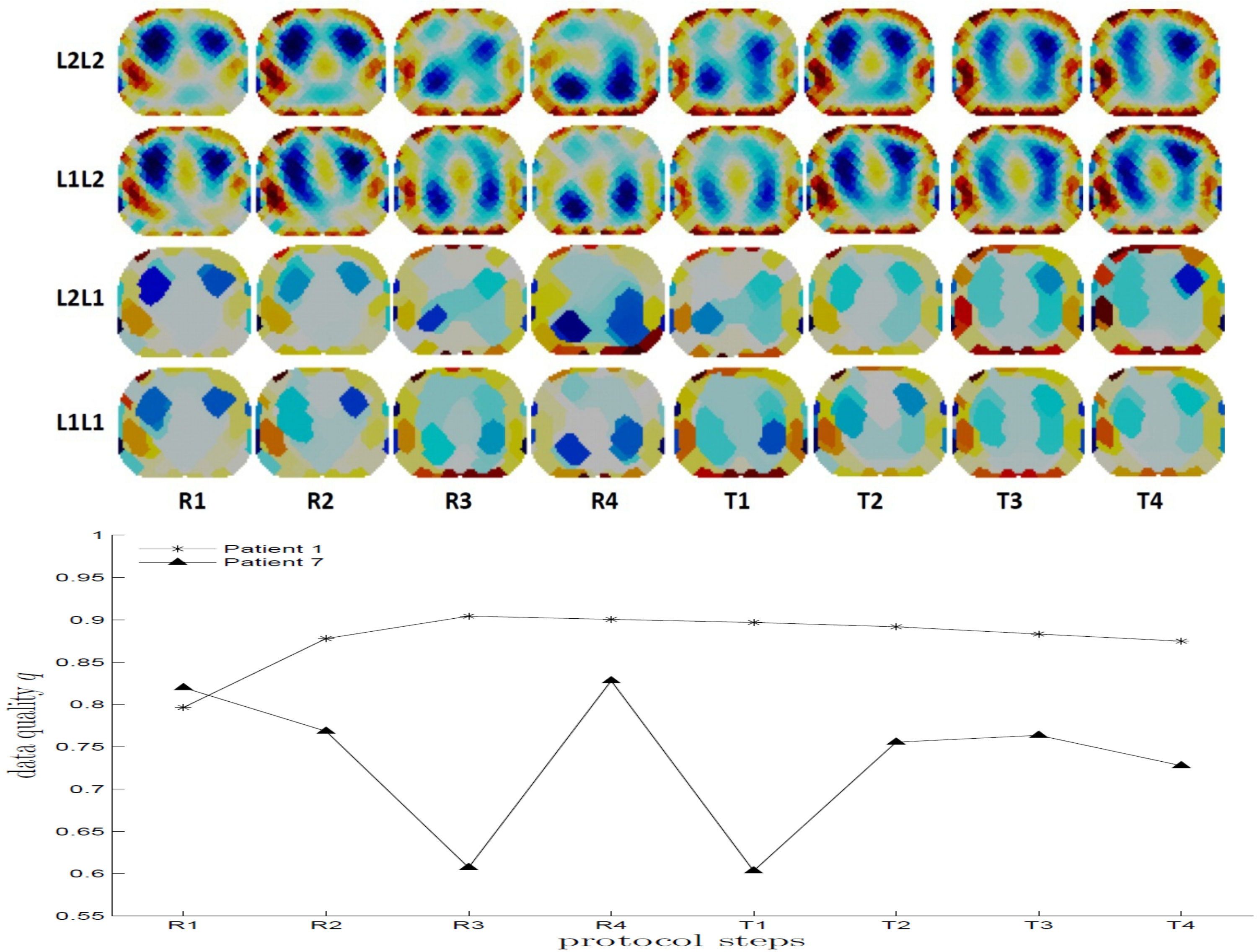
Experimental Protocol– Human Ventilation

- PEEP – Positive end-expiratory pressure
- Experimental Protocol consisted of:
  - Baseline ventilation stage
  - Lung recruitment stage (increased airway pressure): R1 – R4
  - PEEP titration stage (decreased airway pressure): T1–T4
- Goe-MT II EIT device (CareFusion, Hoechberg, Germany)

Results 2: Human Lung Ventilation



Results 2: Human Lung Ventilation

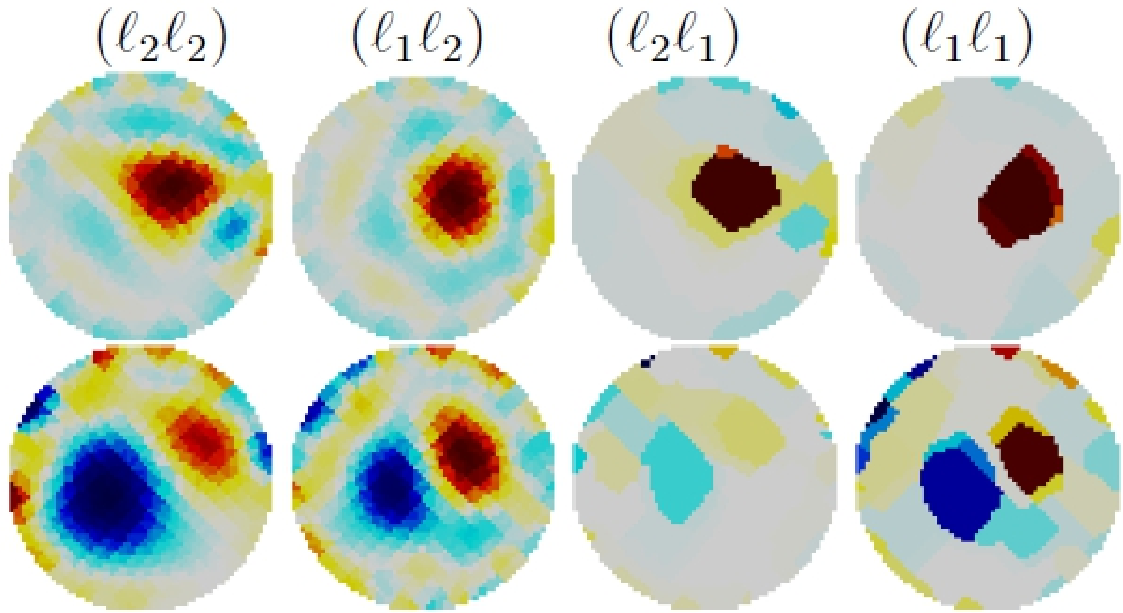


Results 3: Dog breathing data

Reconstructed images of anaesthetized and ventilated dog

At fluid injection
of 100 ml -- 700 ml inspiration

60 minutes after fluid injection



- Known electrode errors in the data
- L2L2 is suffered the most from the electrode noise
- L1L1 is the best candidate with less artifact

Discussion

- L1 norm is robust against data errors
- L1 norm for the data misfit provided clinically relevant information under electrode error
- Blocky L1 image norm is not necessarily good

- L1 norm is computationally expensive
- Code is publicly available under EIDORS