Quantitative Electrocardiography: Two Steps Forward and One Step Back

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Northeastern University

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The Credits

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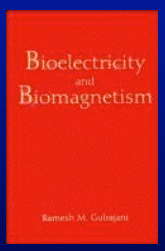
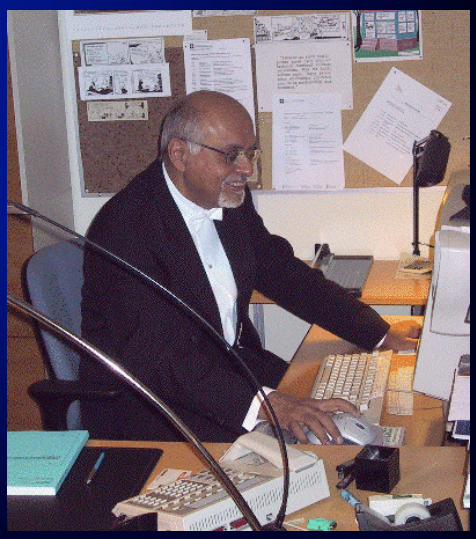
Ramesh M. Gulrajani
12.12.1944 - 18.3.2004





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Goals of Quantitative Electrocardiography

Understand mechanisms → Forward Models

Validate models

Improve diagnostics → Inverse Problems

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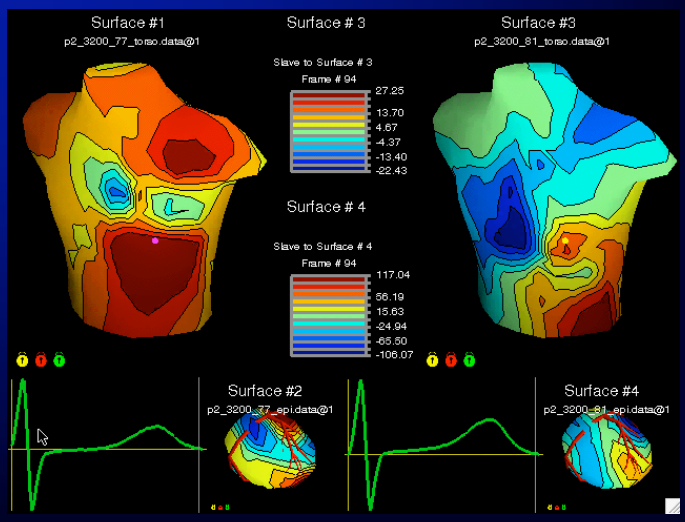
The Motivation



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Driving Themes

Technical

- Forward models:
  - myocardial tissue to whole heart
- Signal processing:
  - catheter based cardiac mapping
- Inverse solutions:
  - multiconstrained approaches
- Software:
  - making it all work

Biomedical

- Tissue function
  - coupling and anisotropy
- Organ Pathology
  - ischemia
  - arrhythmias
- Molecular biology
  - mutations/transgenics

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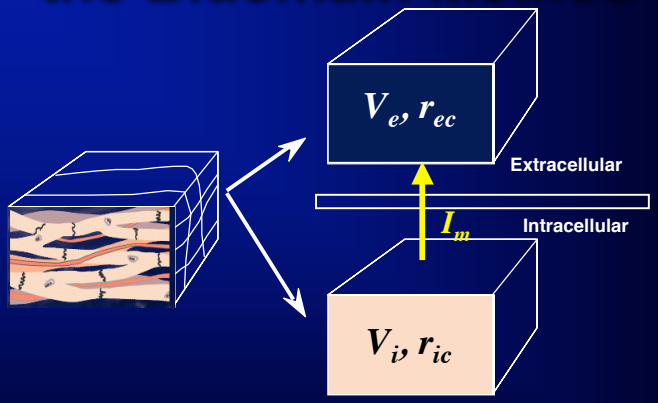
Forward Models: the Bidomain Method



- 2 domains share the same space
- Membrane separates the domains
- All properties (e.g. V_e, r_{ec}) are macroscopic averages

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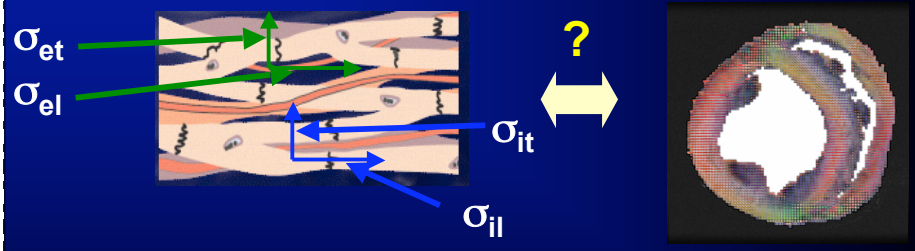
Bidomain Parameters



Tissue conductivity

Diffusion-weighted MRI

(direction)

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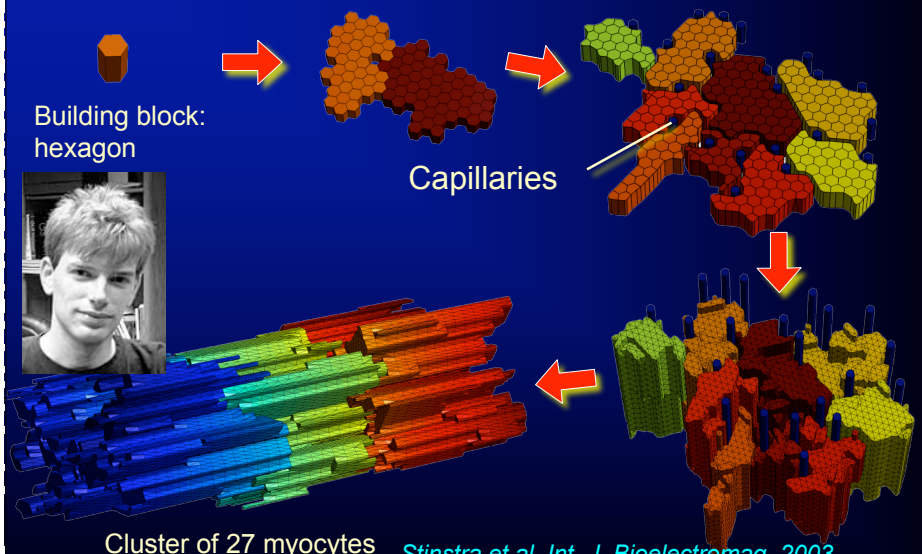
Modeling Conductivity



Stinstra et al. Int. J. Bioelectromag. 2003

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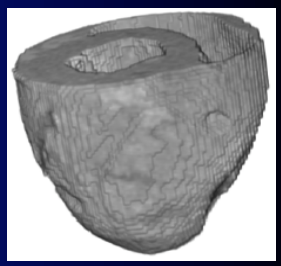
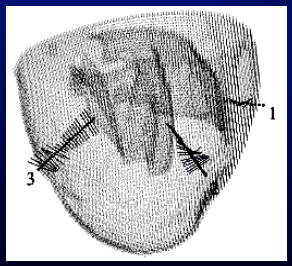
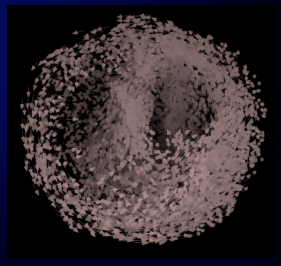
Mouse Heart Models

- MRI input data
- Segmented ventricles
- 225,236 hex elements



Craig Henriquez, Duke University





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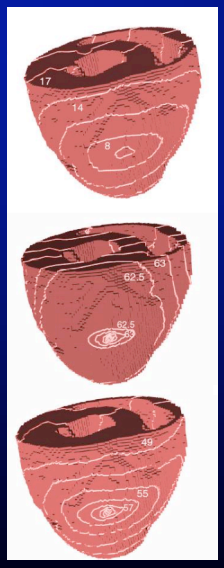
Mouse Activation Sequence

Activation

Recovery (-60 mV)

APD

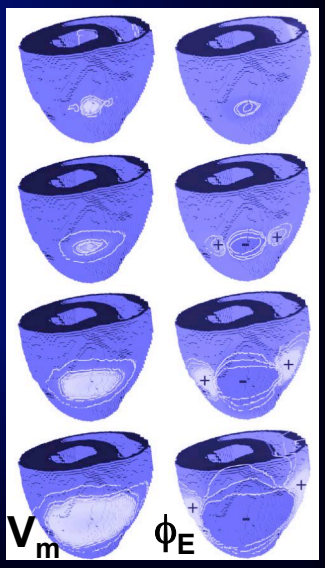


0.5 ms

6.5 ms

8.5 ms

10.5 ms



V_m ϕ_E

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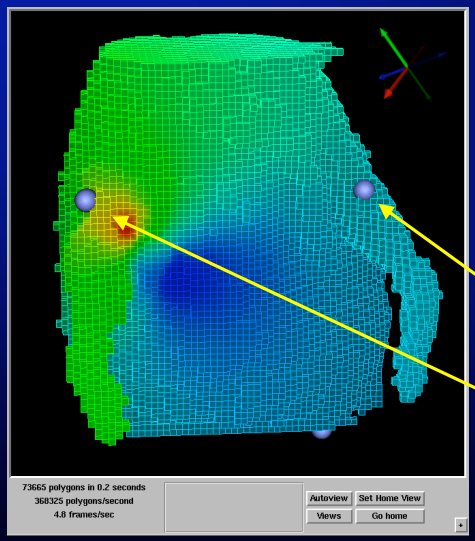
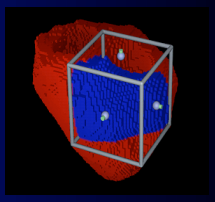
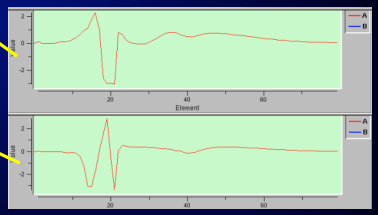
Forward Computation of ECG







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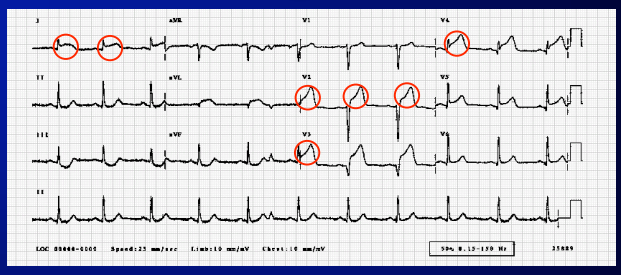
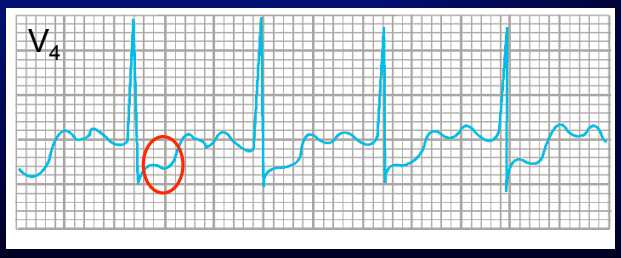
Modeling Ischemia



ST-segment elevation



ST-segment elevation

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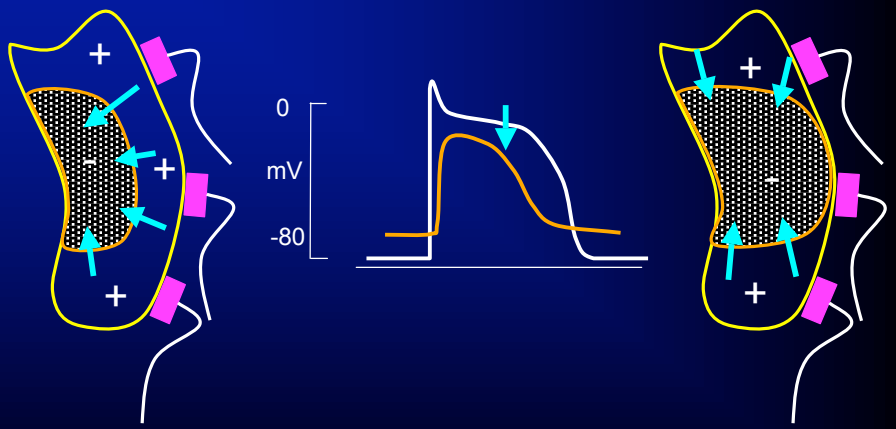
Biophysics of Acute Ischemia



Intracellular current

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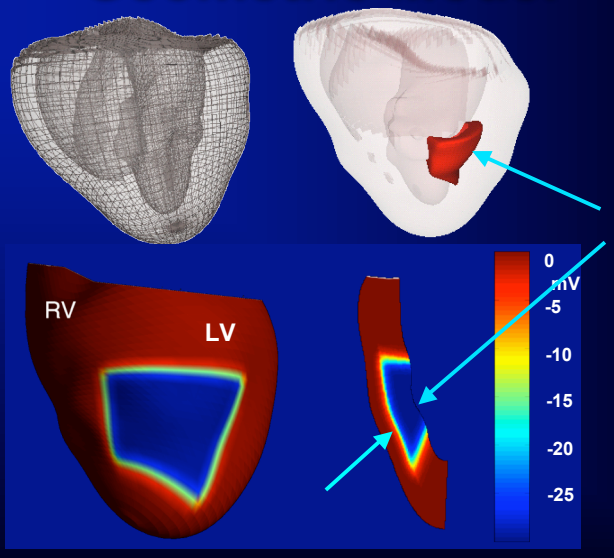
Geometric Model



Hopenfeld et al. JCE, 15:1200, 2004

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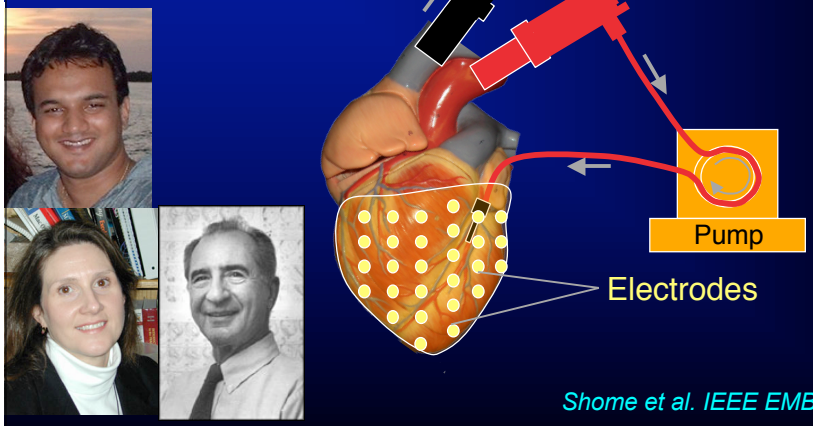
Validation: Experimental Preparation



Shome et al. IEEE EMBS, 2004

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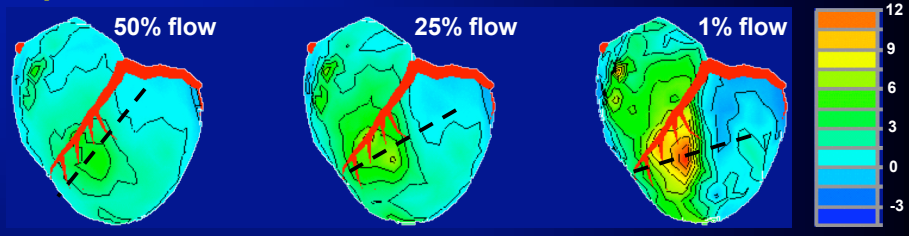
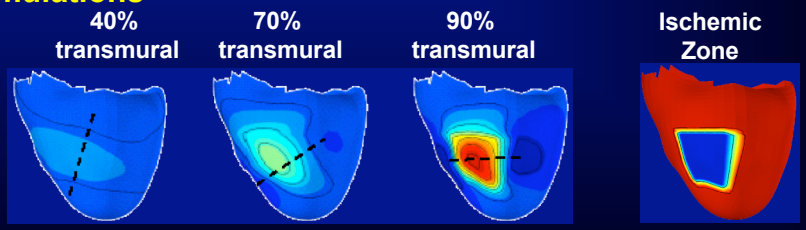
Extent of Ischemia

Experiments



Simulations



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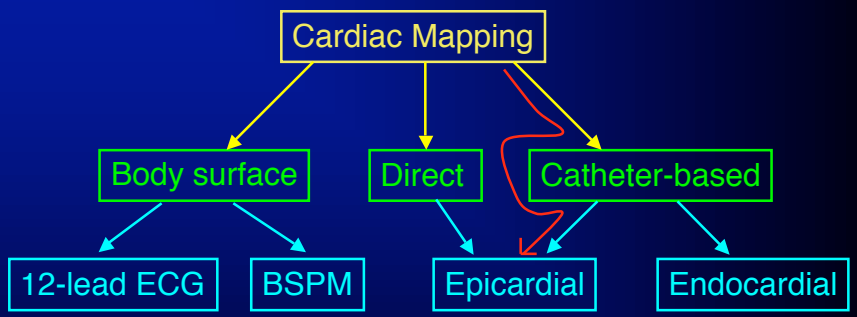
Signal Processing: Detection of Arrhythmias



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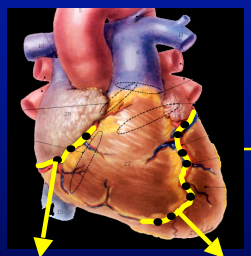
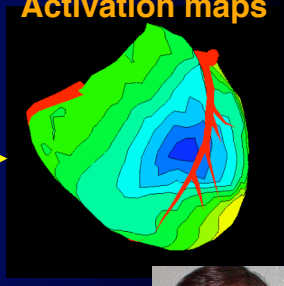
Overcoming Limited Resolution

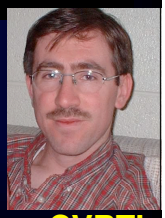
Sparse catheter measurements

Signal processing

High-resolution Activation maps







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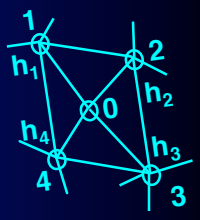
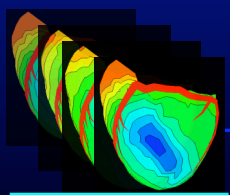
Signal Processing

- How do we determine the relationships between known and unknown sites?
  - Interpolation
    - global pre-assumptions
  - Estimation
    - create these assumptions from a previously acquired set of data (training data)





Training Data

Learning Phase

Estimation Phase

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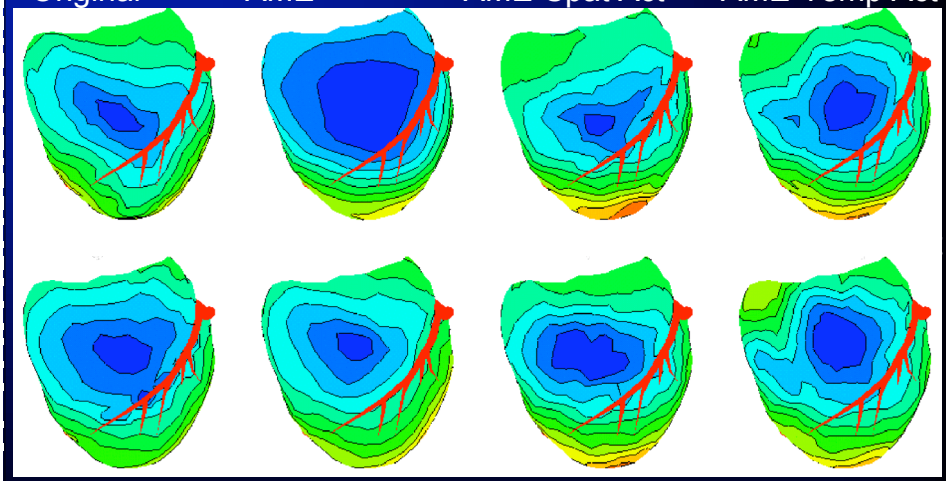
Estimation Results

Original AME AME-Spat Act AME-Temp Act



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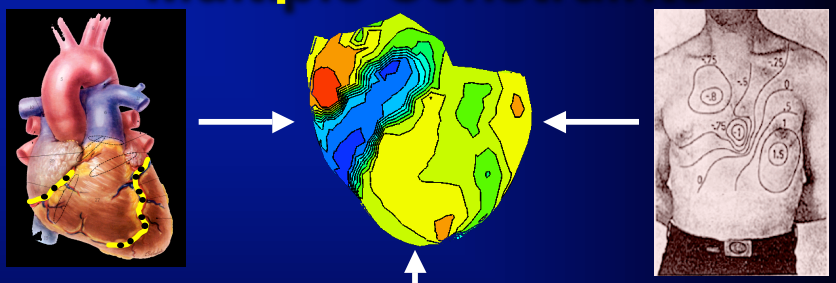
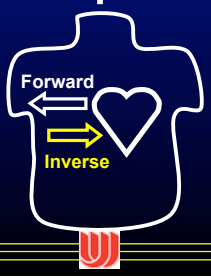
Inverse Solutions by Multiple Constraints





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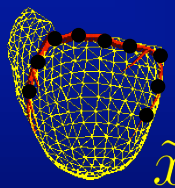
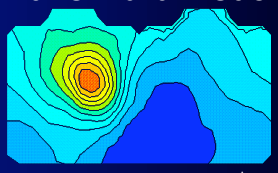
Combing Information Sources

Sparse Epicardial Measurements (SEP)



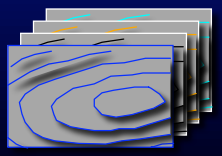
$\tilde{x}_m$

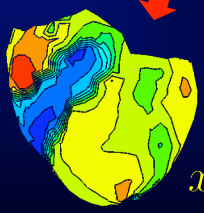
Torso measurements and forward model (TOR)



y, A

Training dataset of epicardial maps (TS)





$$x = \begin{bmatrix} x_m \\ x_u \end{bmatrix}$$

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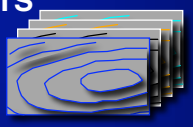
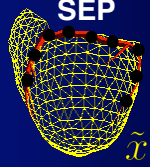
Solution Approaches

TS

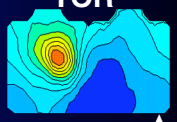


SEP



$\tilde{x}_m$

TOR



y, A

Tikhonov			✓
Tikhonov - ED		✓	✓
MAP	✓		✓
MAP - ED	✓	✓	✓
Epi. Est.	✓	✓	

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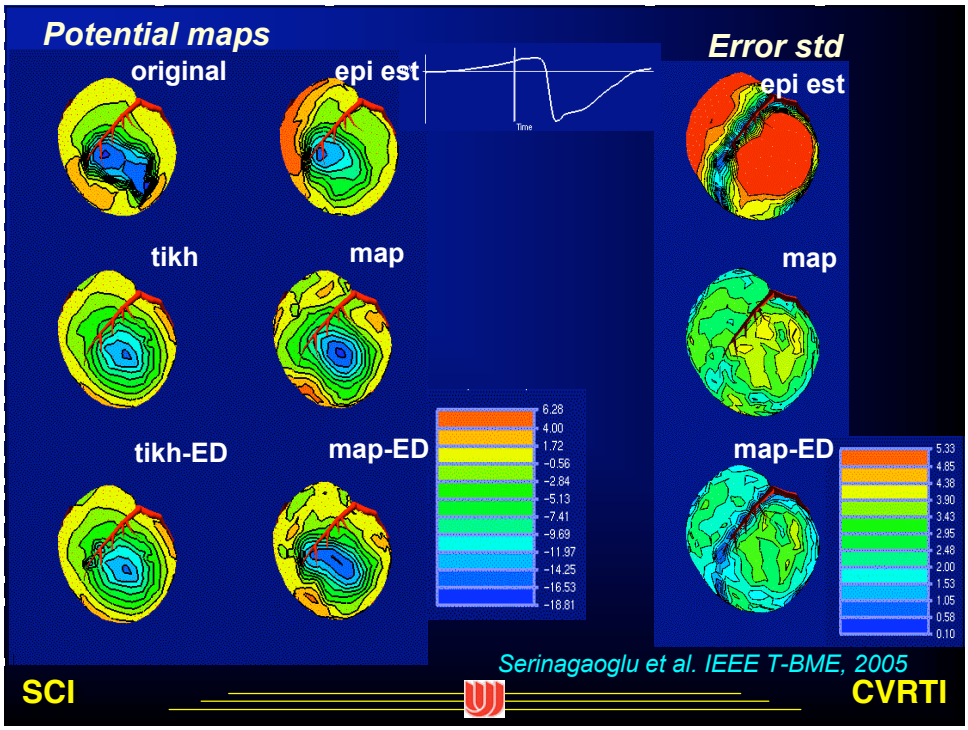
Potential maps
original
epi est
tikh
map
tikh-ED
map-ED
Error std
epi est
map
map-ED
Time
6.28
4.00
1.72
-0.56
-2.84
-5.13
-7.41
-9.69
-11.97
-14.25
-16.53
-18.81
5.33
4.85
4.38
3.90
3.43
2.95
2.48
2.00
1.53
1.05
0.58
0.10
Serinagaoglu et al. IEEE T-BME, 2005
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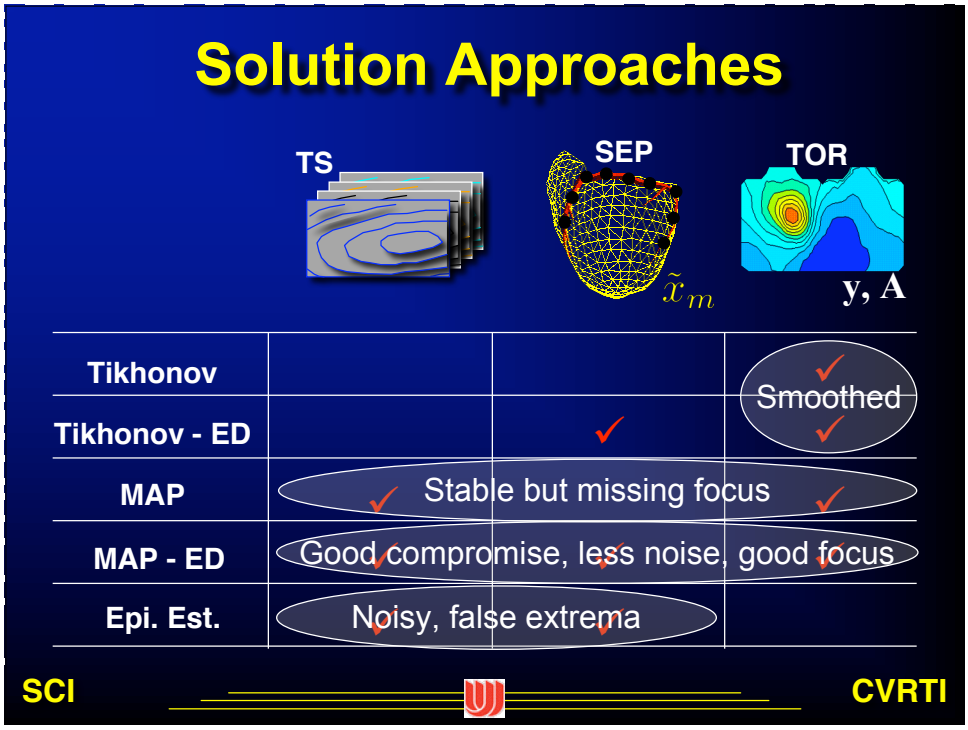
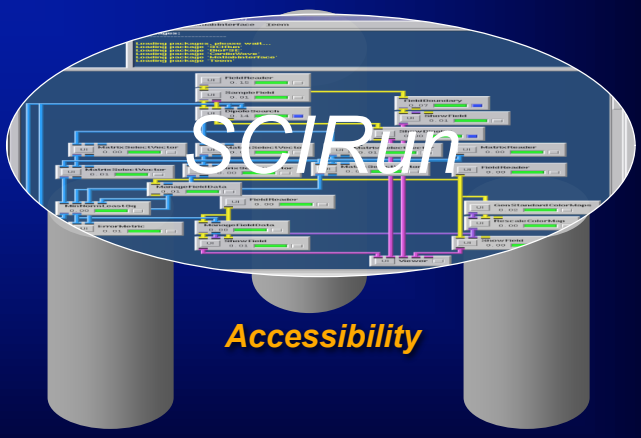

Solution Approaches
TS
SEP
TOR
$\tilde{x}_m$
y, A
Tikhonov
Tikhonov - ED
MAP
MAP - ED
Epi. Est.
Smoothed
Stable but missing focus
Good compromise, less noise, good focus
Noisy, false extrema
SCI
CVRTI

The Software: Requirements (Wish List)

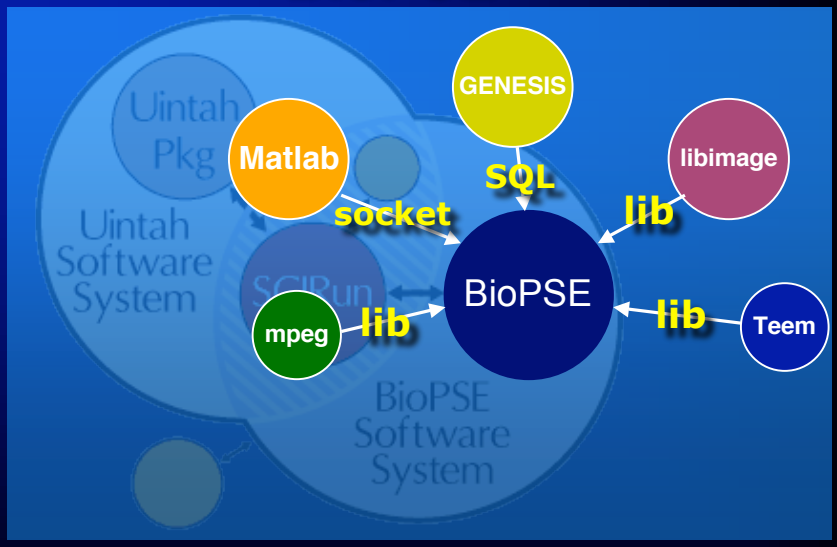
- Flexible
- Portable
- Integrated
- Extensible
- Powerful
- Efficient
- Easy to learn
- Cheap (aka free)

- MATLAB
  - Brainstorm
  - MatMap
  - utility code
- SCIRun/BioPSE
- *map3d*
- Cardiowave
- ECGSim
- NeuroFEM/Vgrid

Pillars of SCIRun



BioPSE



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One Step Back

- What is the role of tissue structure?
  - gap junctions
  - discrete vs. continuous models
- How can we use ischemia models?
  - body surface information
  - effects on propagation
- What do cardiac maps tell us?
  - covariance matrix
  - detection of arrhythmias
- What are relevant inverse constraints?
  - identification
  - parameterization
- How do we span scales?
  - multiscale modeling
  - inclusion of molecular biology information

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