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A Framework for Real-time Left Ventricular tracking in 3D+T Echocardiography, Using Nonlinear Deformable Contours and Kalman Filter Based Tracking

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Outline

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- Prior art
- Contour model
  - Formulation
  - Used in paper
- Local edge detection
- Measurement sequence
- Kalman filter implementation
- Experiment
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- Discussion & conclusion

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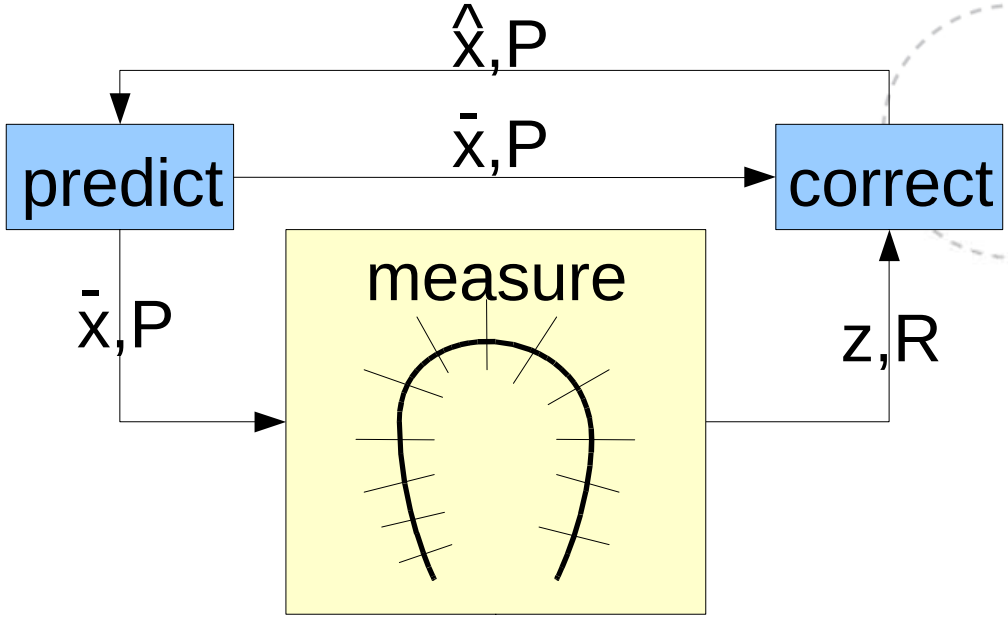
Approach

- Treat LV tracking as a *sequential state estimation* problem.
- Use a deformable contour as LV model.
  - Assign certain deformation parameters.
- Perform local edge detection in proximity to the shape.
- Track deformation state using a Kalman filter.
  - Allows for real-time implementation.



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Prior Art

- Andrew Blake, Michael Isard et al. [2-4]
  - Real-time tracking of deformable B-spline contours using Kalman filters.
- Gary Jacob, Alison Noble et al. [5-7]
  - Usage of Blake's framework for left ventricular tracking in 2D echocardiography.

- Limitations
  - Restricted to tracking in 2D image sequences.
  - Restricted to linear shape deformations, like e.g. principal component analysis (PCA) models.

[2] Blake A, Curwen R, Zisserman A. **A framework for spatiotemporal control in the tracking of visual contours**. International Journal of Computer Vision 1993;11(2):127–145.
[3] Blake A, Isard M, Reynard D. **Learning to track the visual motion of contours**. Artificial Intelligence 1995;78(1-2):179–212.
[4] Blake A, Isard M. **Active Contours**. Secaucus, NJ, USA: Springer-Verlag New York, Inc., 1998. ISBN 3540762175.

[5] Jacob G, Noble JA, Mulet-Parada M, Blake A. **Evaluating a robust contour tracker on echocardiographic sequences**. Medical Image Analysis 1999;3(1):63–75.
[6] Jacob G, Noble JA, Kelion AD, Banning AP. **Quantitative regional analysis of myocardial wall motion**. Ultrasound in Medicine Biology 2001;27(6):773–784.
[7] Jacob G, Noble JA, Behrenbruch CP, Kelion AD, Banning AP. **A shape-space based approach to tracking myocardial borders and quantifying regional left ventricular function applied in echocardiography**. IEEE Transactions on Medical Imaging 2002;21(3):226–238.

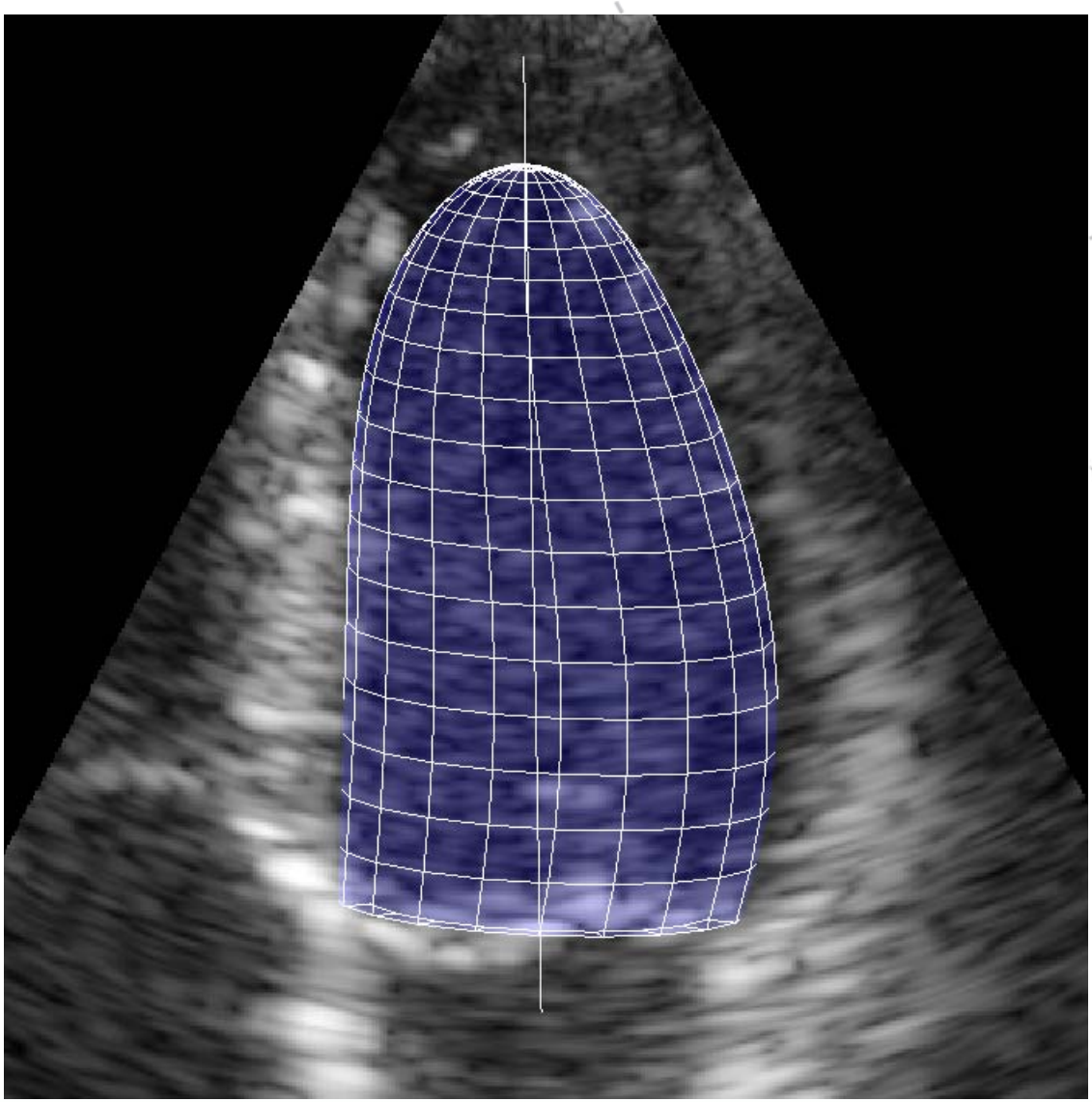
Contour Model (1/2)

- Contour template
  - Prior shape model for the contour being tracked.
  - Set of surface points, with associated surface normals p_0, n_0
- Deformation model
  - General nonlinear formulation $p = D(p_0, X)$
  - Deforms points on contour template based on a shape state vector.
  - Function must be differentiable wrt. the shape state.

Contour Model (2/2)

- Truncated ellipsoid
- Deformation parameters:
  - Translation (t_x, t_y, t_z)
  - Rotation/orientation (r_x, r_y)
  - Scaling (s_x, s_y, s_z)
  - “Bending” (c_x, c_y)

  10 degrees of freedom.

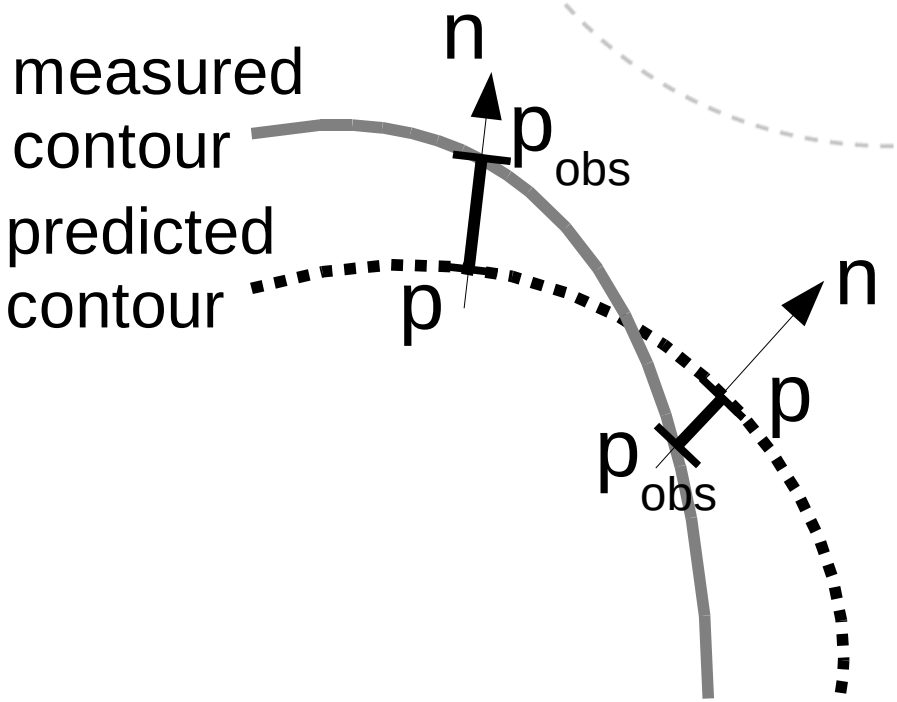


Local Edge Detection

- Perform edge detection in *normal direction* of contour surface.
- Calculate the *normal displacement* between predicted and measured contour points

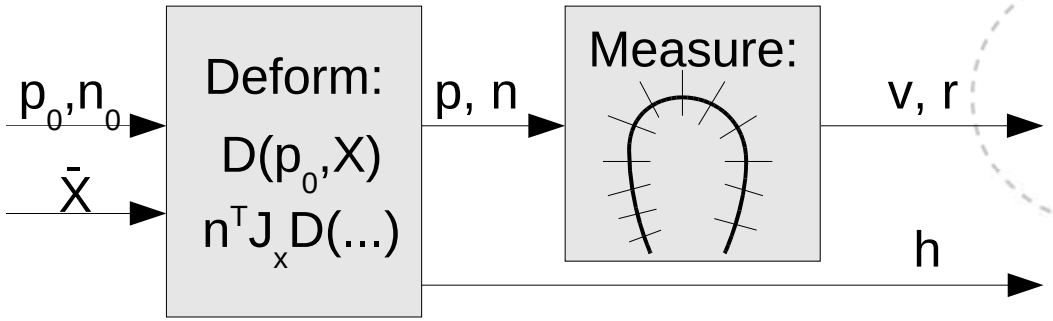
$$v = n^T(p_{obs} - p)$$

- Dimensionally invariant.



Measurement Sequence

1. Create contour template
2. Calculate deformed contour, and associated Jacobi matrix based on predicted state.
3. Measure *normal displacements* based on deformed contour.



Kalman Filter Implementation

- Using an *extended* Kalman filter for tracking
  - Enables usage of nonlinear deformation models.
  - Linearizes model around predicted state.
- Kinematic prediction
  - Augment state vector to contain state from last two successive frames.
  - Models motion, in addition to state/position
- Measurement update in information space
  - Assumption of independent measurements allow efficient implementation
  - Create information-vector and -matrix from measurements
  - Use information filter formulation of Kalman filter for measurement update.

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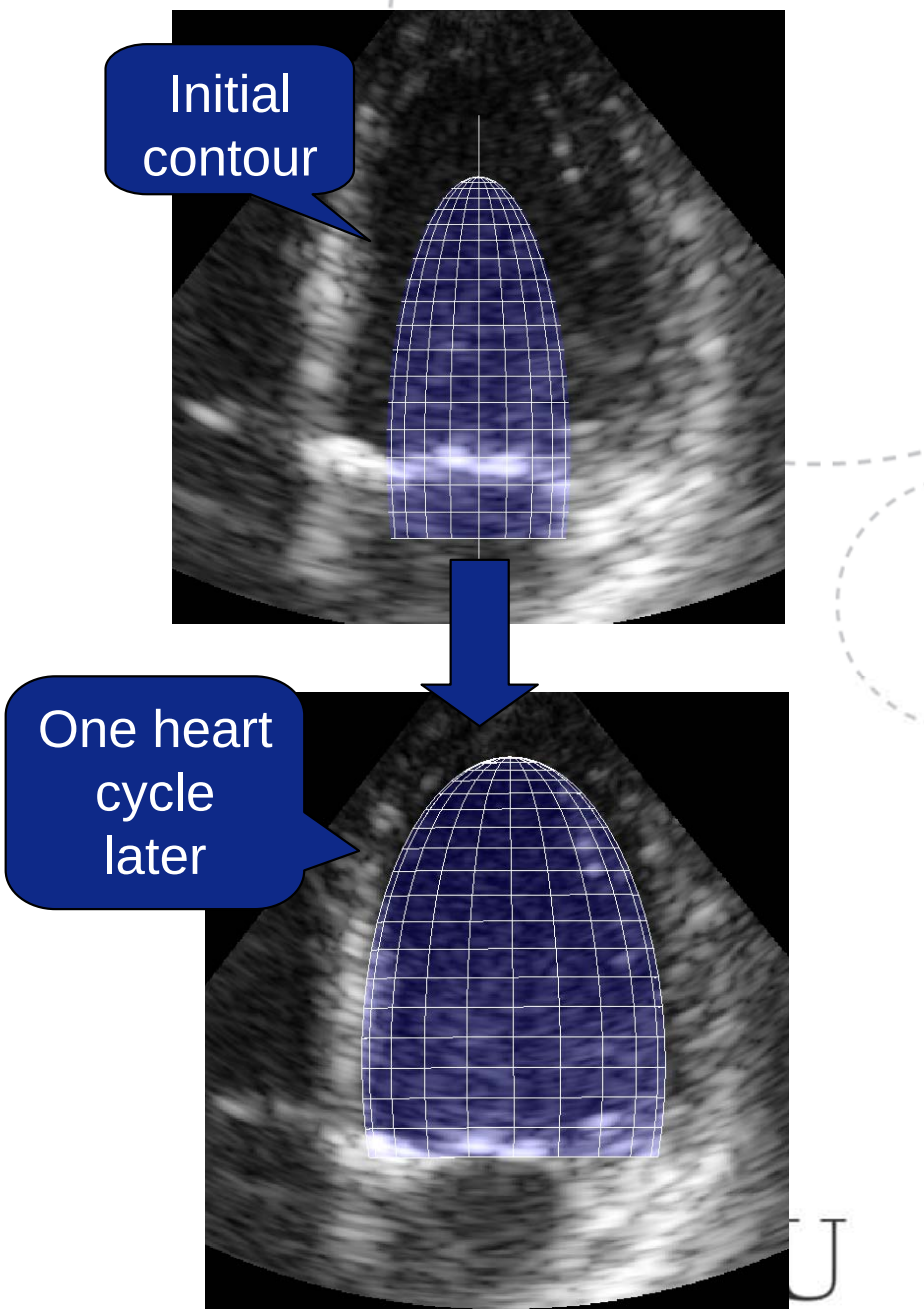
Experiment

- Objective:
  - Evaluate *feasibility* of method to automatically track the dominant left ventricular motion and shape changes
- Data:
  - Collection of 21 3D echocardiography recordings of good quality
  - Initial contour automatically placed at 80mm depth in first frame of every recording



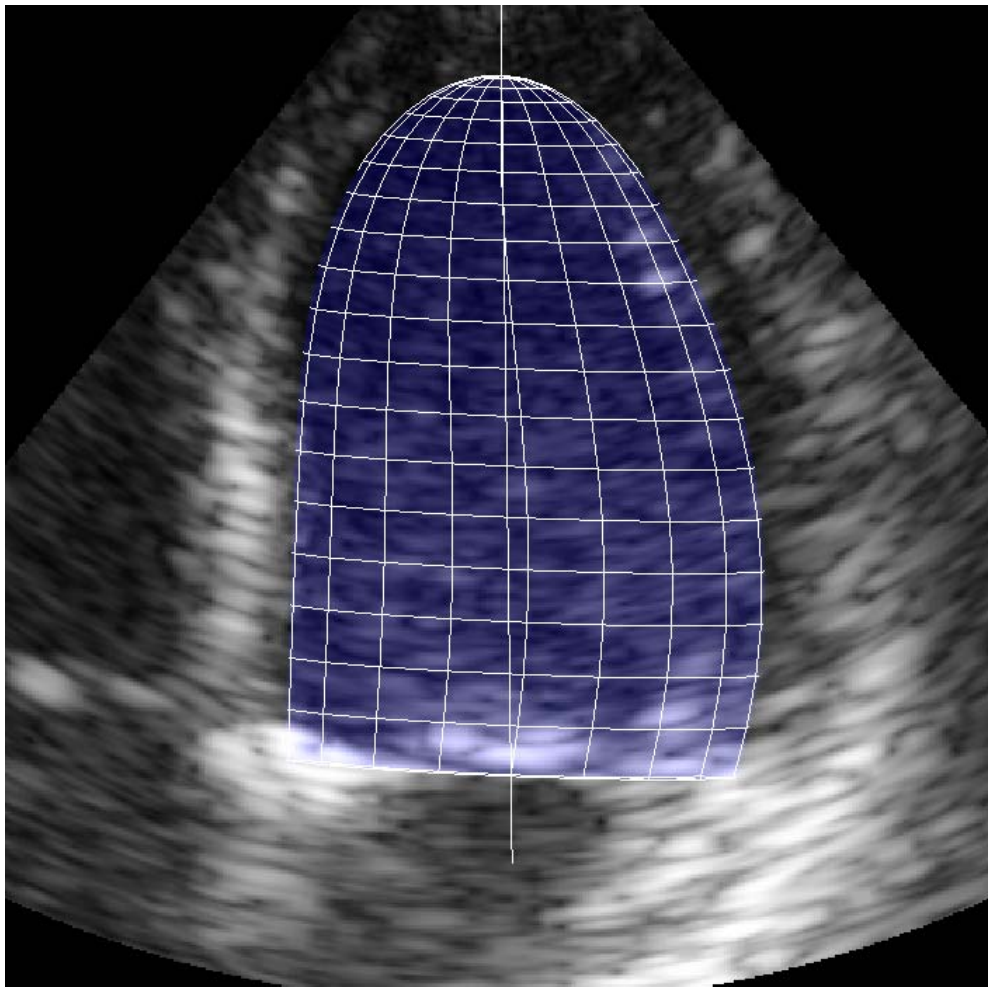
Results

- Goal is to get a crude approximation to LV size, position and orientation

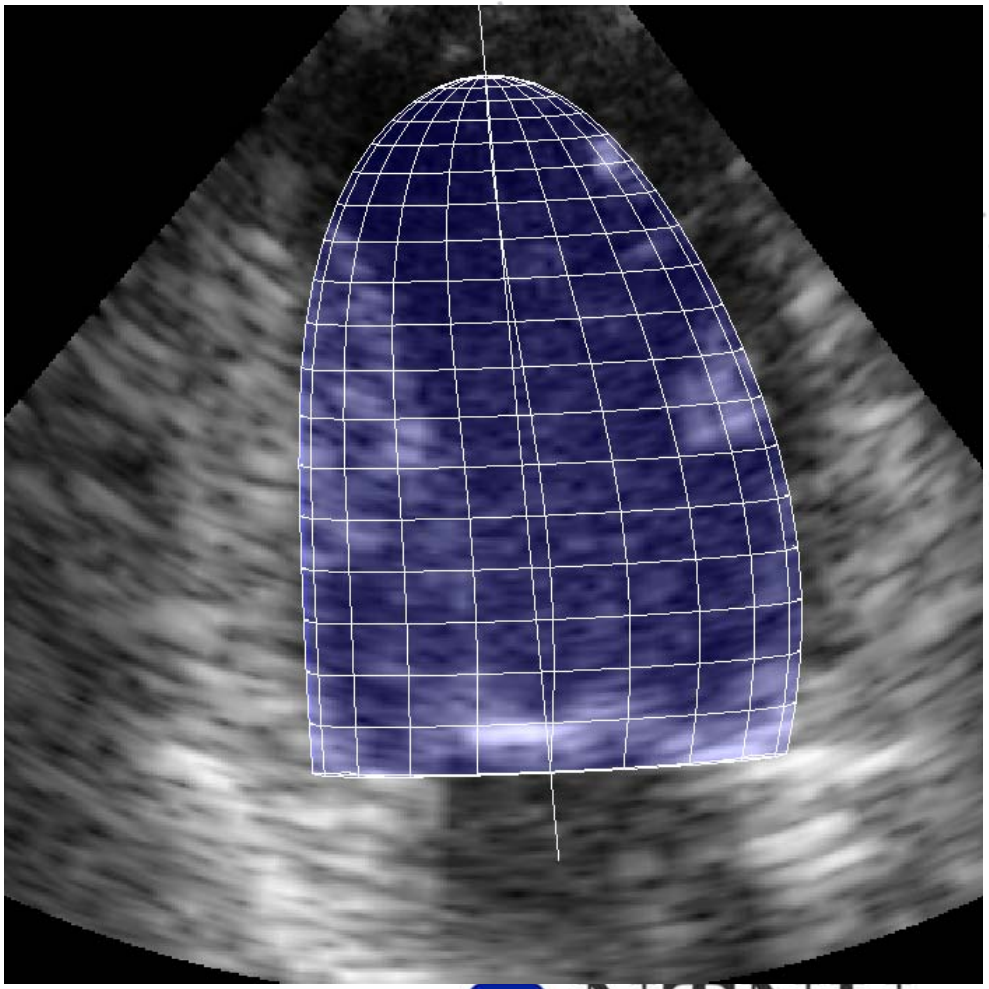
- Subjectively scored by author.

Quality	Count	Description
Good	16	Tracking performed well
Adequate	3	Tracking with reduced accuracy
Fair	1	Tracking with low accuracy
Poor	1	Unable to automatically track

Tracking Example (1/2)



azimuth view



elevation view

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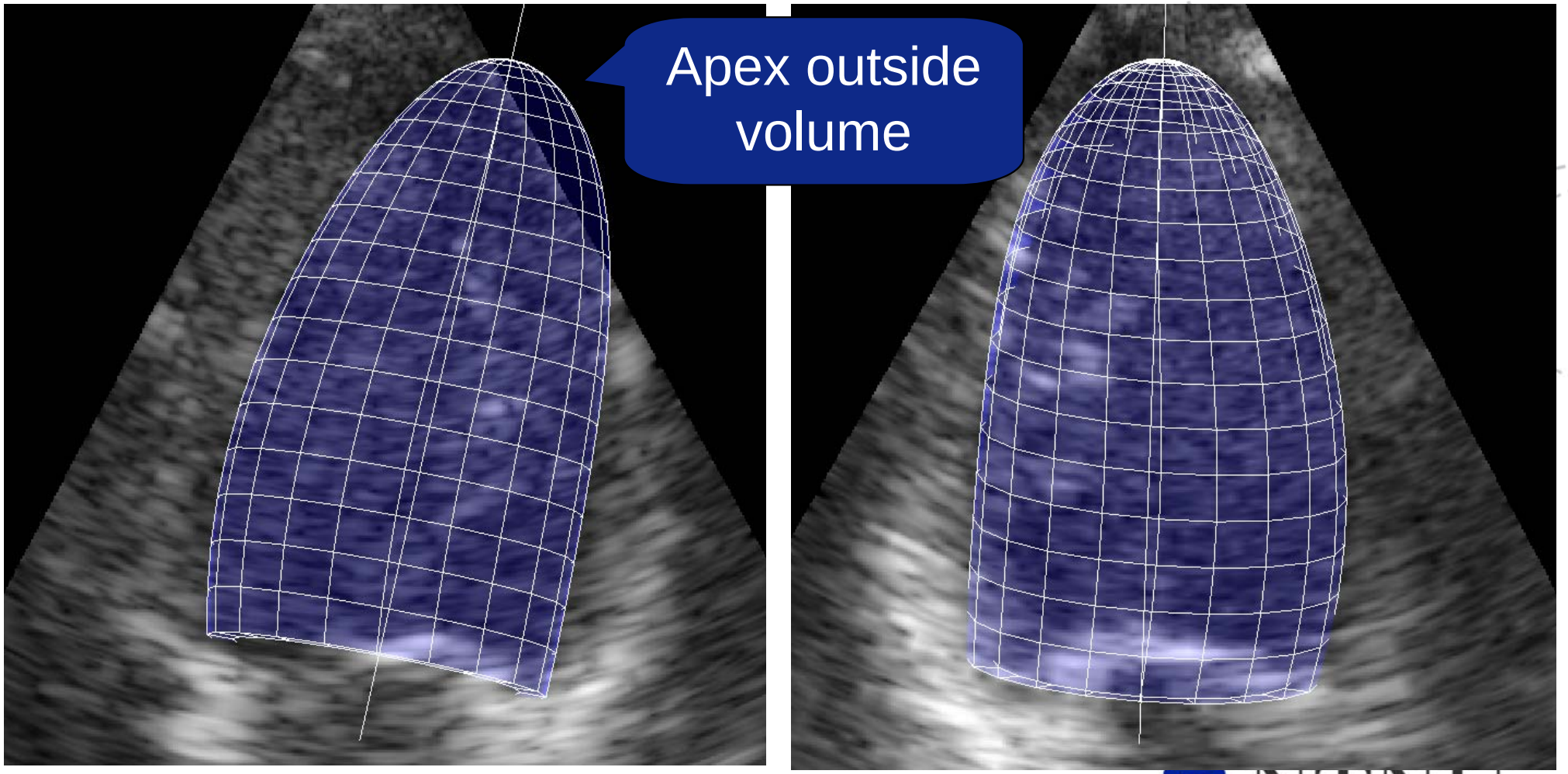
Tracking Example (2/2)



azimuth view

elevation view

Discussion (1/2)

- Advantages:
  - Allows for **real-time LV-tracking in 3D echocardiography**
  - **Fully automatic**. No user intervention required
  - Yields “crude” LV position, size and orientation.
- Disadvantages
  - Not an accurate segmentation technique.

Real-time tracking in 25fps 3D echocardiography recordings yields a modest *CPU load of approx. 18%* on a Pentium 4 computer.

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Discussion (2/2)

- Framework allows for more advanced deformation models
  - Needs not be linear
  - Ellipsoid model can be replaced with a more realistic biomechanical model.
  - This is likely to yield better model fitting, and hence improve tracking accuracy.

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