Image-guided navigation software and novel applications

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NATIONAL CENTER FOR IGT IMAGE-GUIDED THERAPY

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  - CIMIT: "Interactive platform for MRI-guided cardiac ablation procedures"

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Overview

- Software infrastructure
  - Why special software infrastructure for IGT?
  - NaviTrack
  - SIGN and some applications
  - SIGN and Slicer3?
- MRI-Guided cardiac ablation
  - Motivation
  - Toolbox
  - MRI-scanner control and recon
  - Catheter visualization
- Whats next?

Why special software infrastructure for IGT?

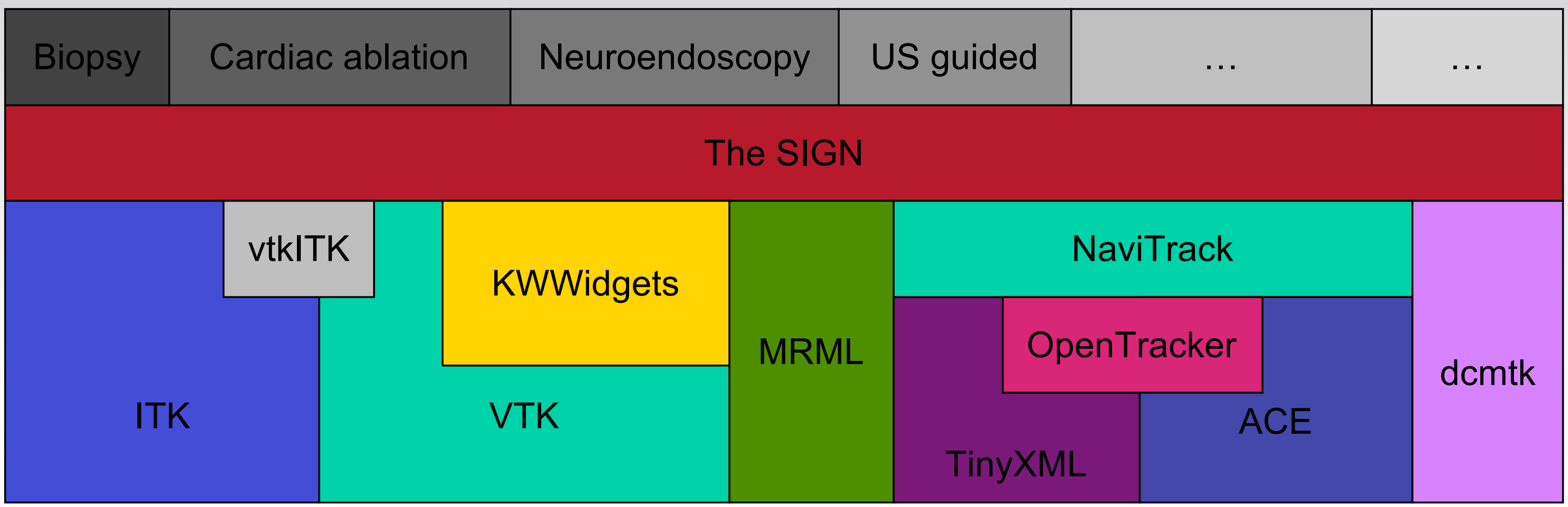
- Cutting edge IGT applications need a customized software architecture
- The architecture should be:
  - Dynamically configurable
  - Support multimodal imaging and tracking
  - Capable of handling device interaction
  - Testable and robust
  - Supportive of real time image processing and computer vision

Application Silos

- One clinical application => One software application
- Workflow oriented applications
- Facilitates streamlined documentation of chain from requirements through design, implementation and testing

The SIGN

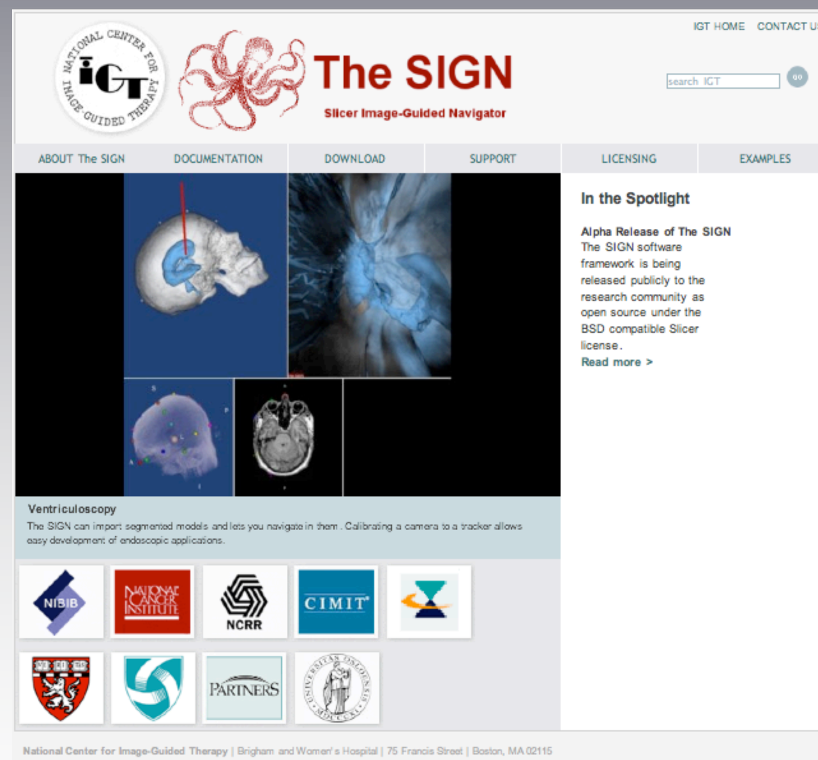
- An Application Programmer Interface for IGT applications.
- Allows programmers access to support libraries
- Supplies mechanisms for:
  - Viewers, tracking, workflow, data IO,…
- Extensible:
  - Applications
  - Workflow elements
  - Filters
  - +++



Navigation framework: SIGN

www.ncigt.org/sign

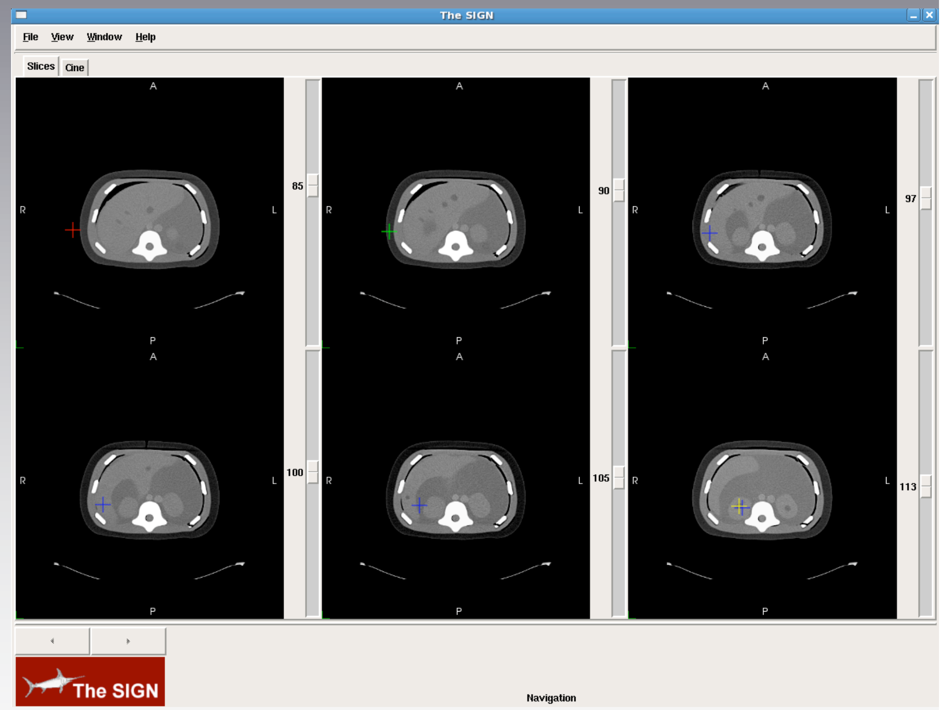
Allows the application programmer to:



- Customize the user interface
- Use an established data-model (Mrml)
- Connect to a large variety of trackers and other devices
- Create simple applications with minimum effort
- Control MRI scanners and other intra-operative imagers
- Design workflow oriented applications
- Perform rapid prototyping of navigation tools

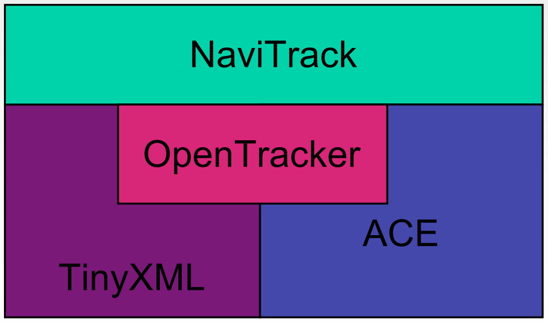
Navigation framework: SIGN

- Integrated dicom server
- Applications can be build out of workflow elements
    - Triggered by GUI events
    - Triggered by tracker / device events
    - Triggered by Dicom server
    - Triggered by program state
- Registration algorithms
    - Iterative Closest Point
    - Uncented Kalman Filter
    - Singular Value Decomposition



NaviTrack

- An Application Programmer Interface for medical device integration
  - Trackers
  - MRI scanner
  - US scanners
  - ECG monitors
  - Foot switches
  - +++
- Data flow graph defined in xml. Metaphor: sources, sinks and filter nodes
- Allows distributed setup, file logging and playback



Hybrid Examples: Optical - optical

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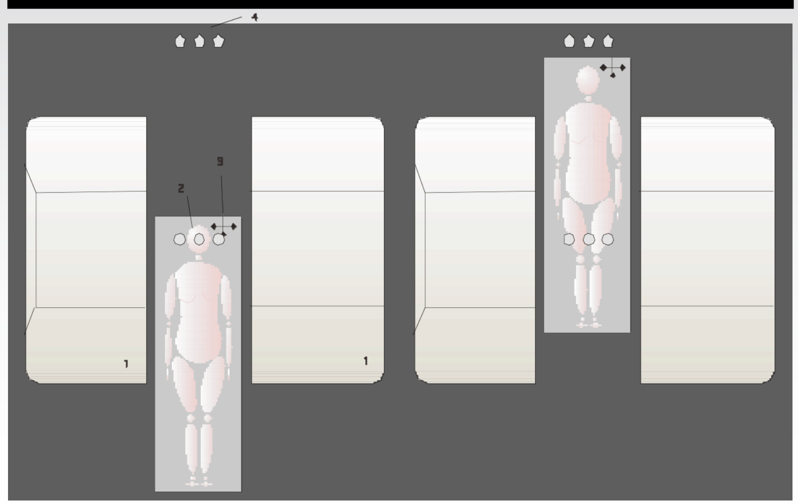
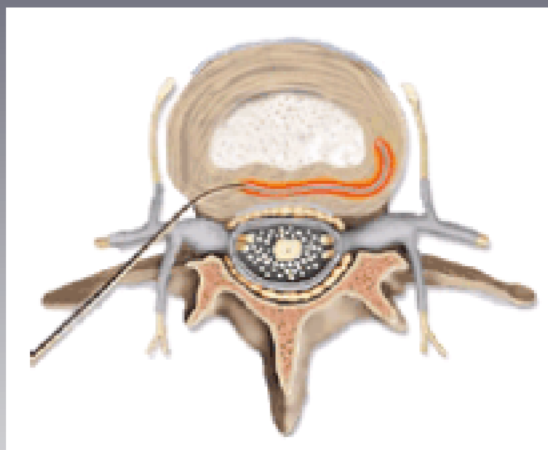
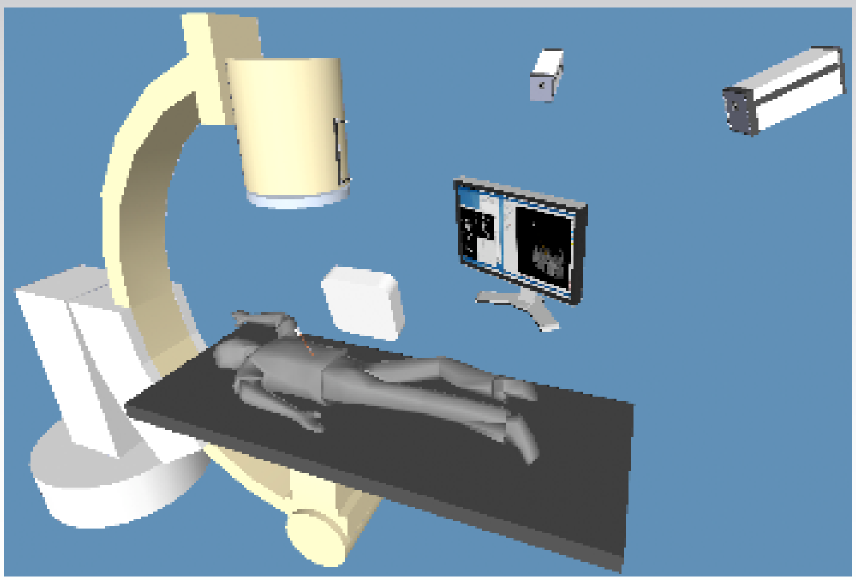


Hybrid Examples: Optical-EM



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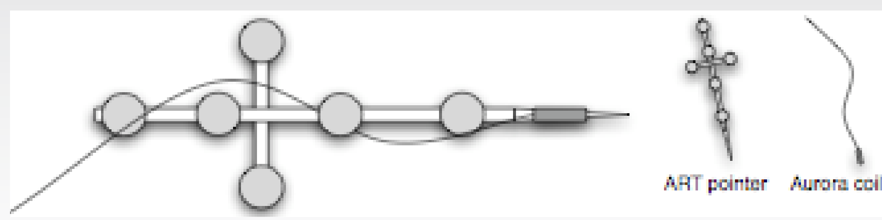
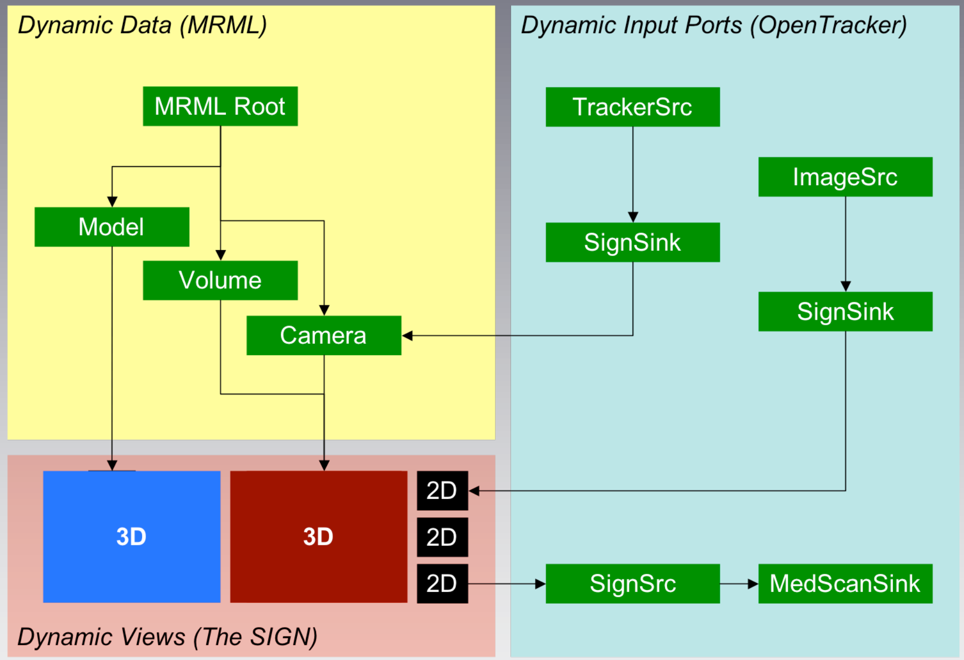


The SIGN - configuration paradigm

- Data is configured in MRML-file
- Trackers are configured in NaviTrack-file
- Connections are configured in MRML-file



SIGN & Slicer3

- Slicer is the “Swiss Army Knife” of medical image computing
- Slicer provides a good data model (Mrml) for data exchange
- SIGN can be used to make a “Surgical Scalpel” tailored for a specific clinical task, *complementary to Slicer*
- SIGN is independent of Slicer, but the use of the same data model and basic tools *reduces* duplication and *enables* interaction
- SIGN is currently being integrated in the Slicer3 bundle shortly and build using getbuildtest.tcl

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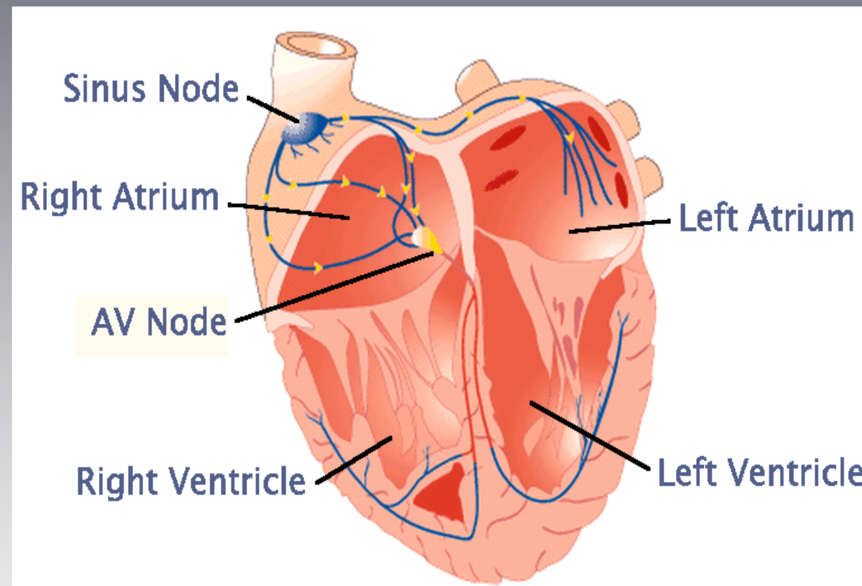
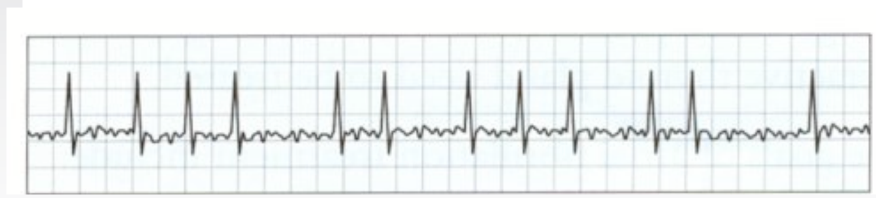
Atrial Fibrillation and Ventricular Tachycardia

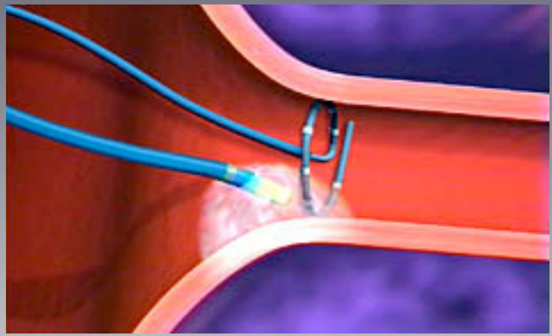
- Prevalence of disease
  - Atrial Fibrillation (AFIB)
    - 2 million afflicted in U.S.
    - 25 million in U.S., Europe, China, India, and Japan.
    - 15% of strokes caused by AFIB
  - Ventricular Tachycardia
    - 200,000 treated each year in U.S.
    - Increased risk of sudden death
  - Prevalence increases as population ages
  - Characterized by abnormal cardiac electrical activity



http://www.a-fib.com/



Cardiac ablation



- Objectives:
  - Regain normal heart rhythm
  - Control the heart rate
  - Prevent stroke
- Alternative to implantable cardioverter defibrillator, pacemaker, and pharmaceuticals
- Catheter based ablation with EP mapping has proven effective in 2/3 of the cases

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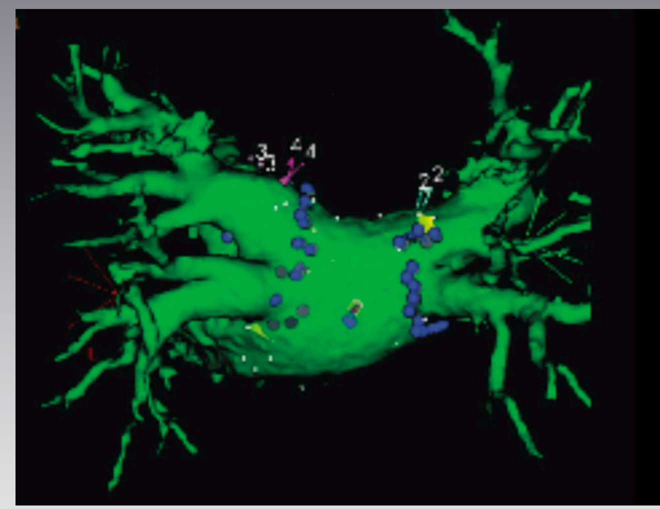
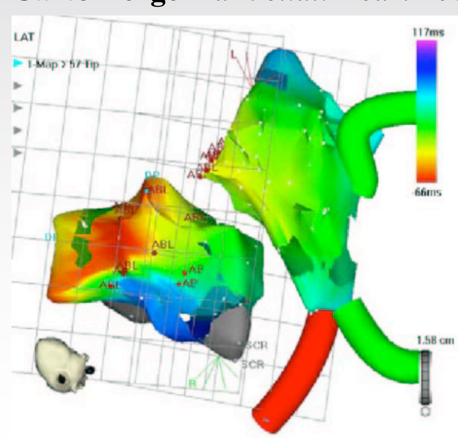
Electro Physiological Mapping

- Measures electric potential
- Detects arrhythmic foci
- Requires catheter tracking
- Surface map can be generated based on:
  - Tracked points
  - Merge with pre-op MRI

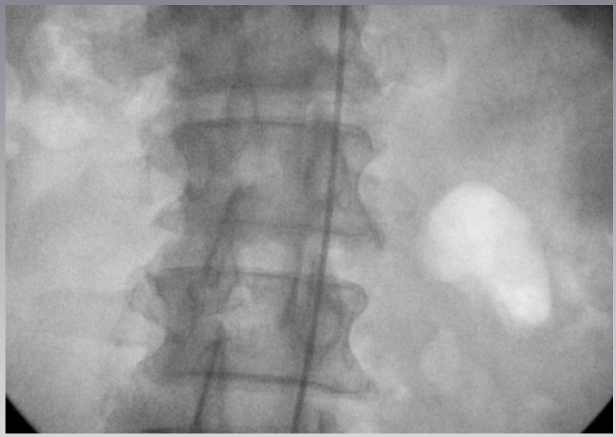


CartoMerge *Mark el.al. Heart 2006;92;266-274*



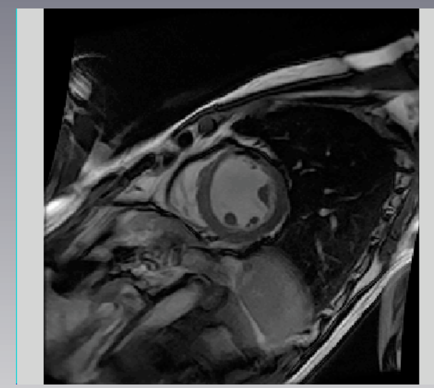
X-ray guided intervention

- Current procedure is guided by X-ray
  - Unsatisfactory visualization of anatomy
  - Radiation issues
  - Nephroroxic contrast agents
  - Musculoskeletal issues related to wearing lead



Magnetic Resonance guided Cardiac Ablation

- MRI can:
  - Give good depiction of the anatomy
  - Visualize the tissue to be treated
  - Visualize / track the catheter
  - Visualize the treatment effect
- Contrast enhanced MRI can detect focal necrosis in the myocardium.
- MRI has the potential to:
  - Improve safety through better visualization
  - Improve speed through better navigation
  - Improve outcome through better monitoring / quality control

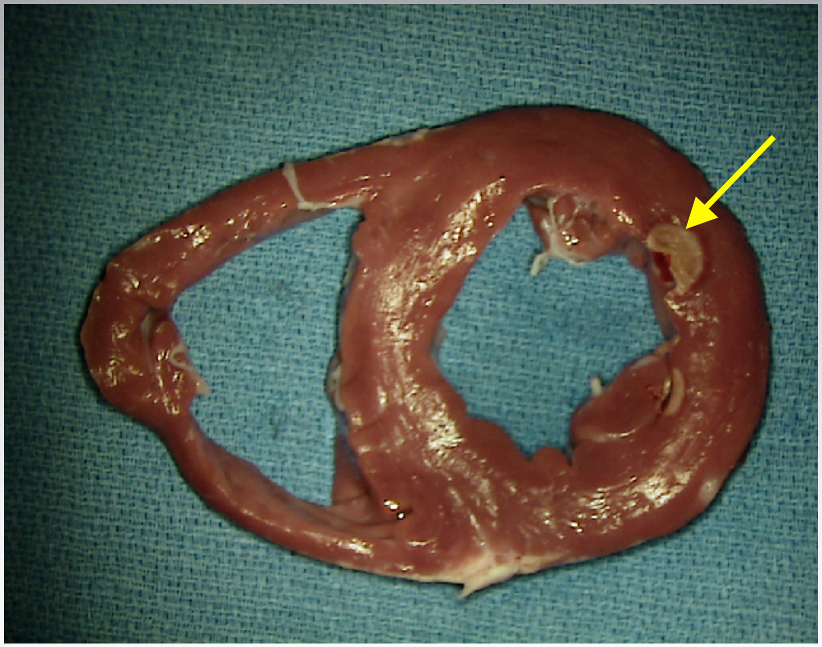


RF Ablation during RT MR Imaging

- Injury seen with myocardial dynamic contrast enhanced 3D

3D MDE

MGH - *Courtesy of Ehud Schmidt GE Healthcare*



Histology

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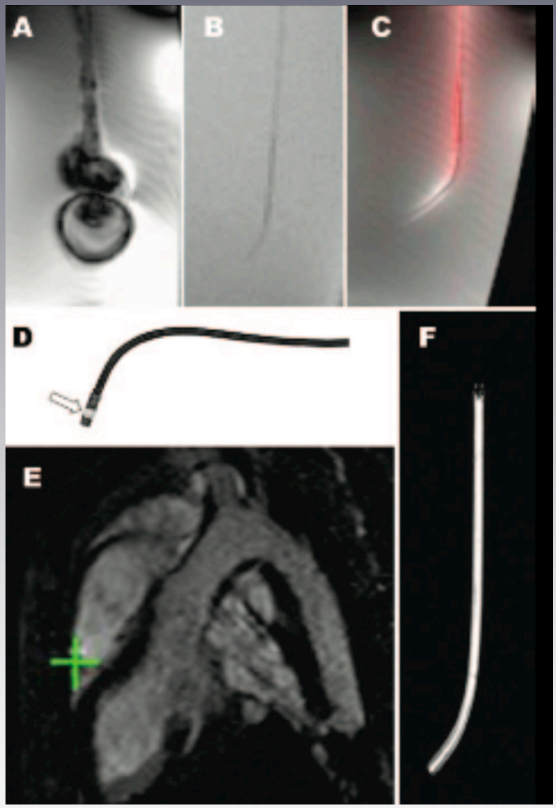
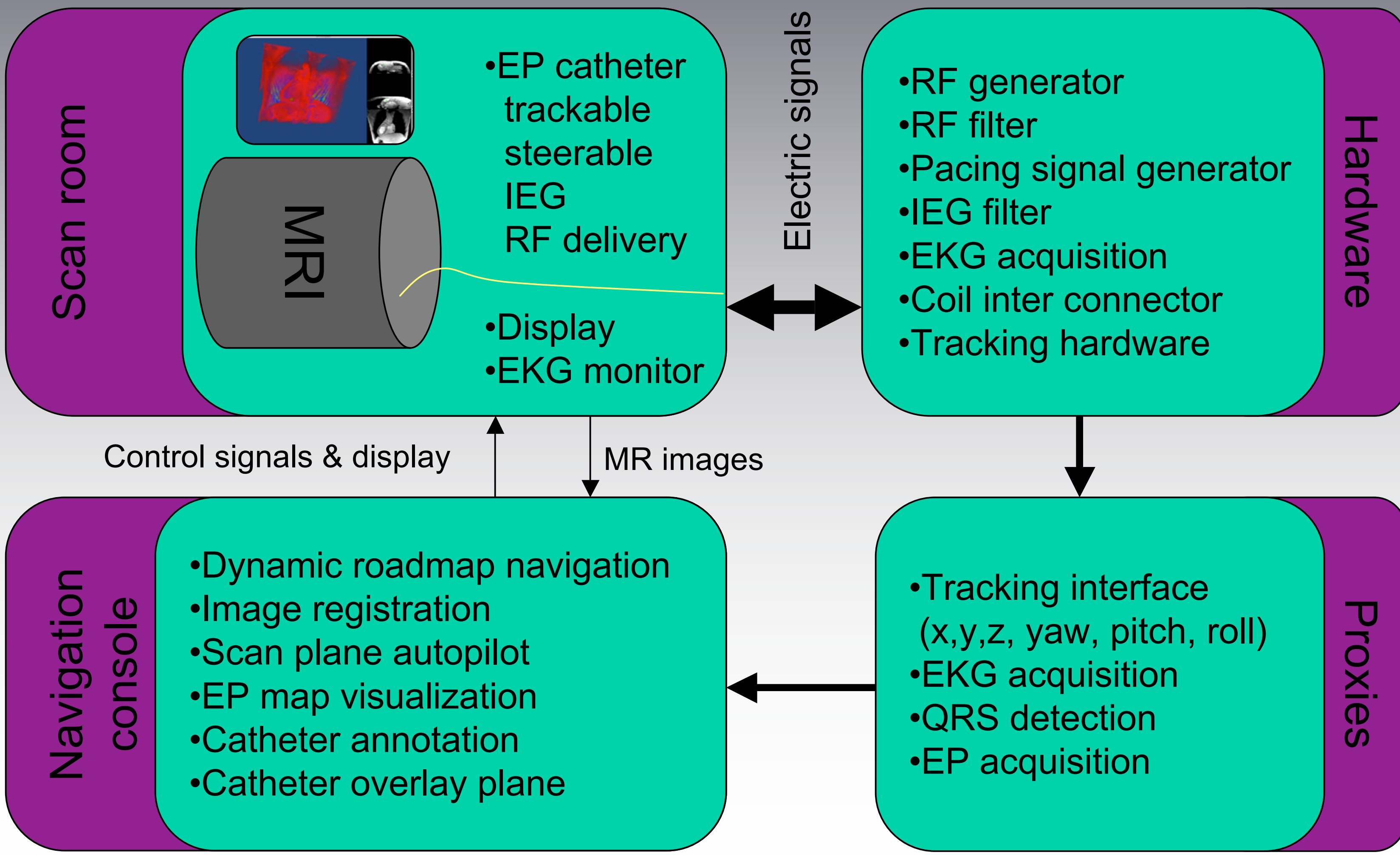
Catheter visualization

- Black catheter by artifact (A)
- Black catheter by signal void (B)
- Bright catheter with MRI antenna (C)
- Tracked catheter with MRI micro coil (D)
- Position of tracked catheter superimposed on image (E)
- Wireless inductively coupled coil (F)



Cardiovascular Interventional Magnetic Resonance Imaging
Lederman etal Circulation 2005 112:3009-3017

Integrated MRI-guided EP package

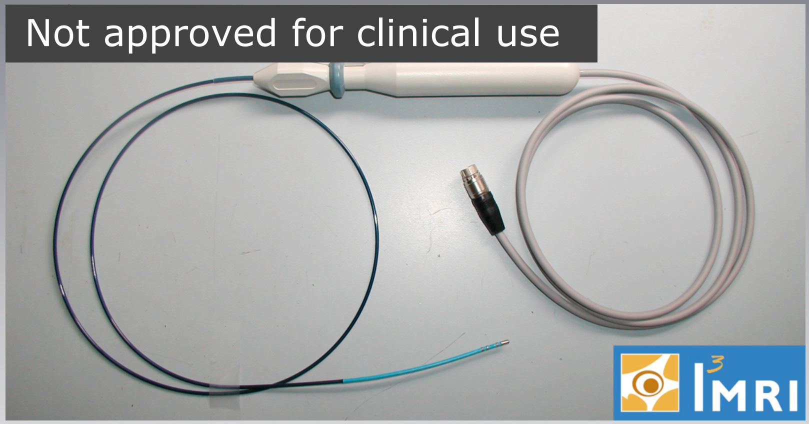


Methods

- MRI-compatible EP catheter
  - Trackable
  - Safe
- Navigation framework
  - Catheter visualization
  - Interactive and fast imaging
  - Time-synchronized roadmap
  - EP map visualization
- Image processing
  - Myocardium segmentation
  - Scar detection

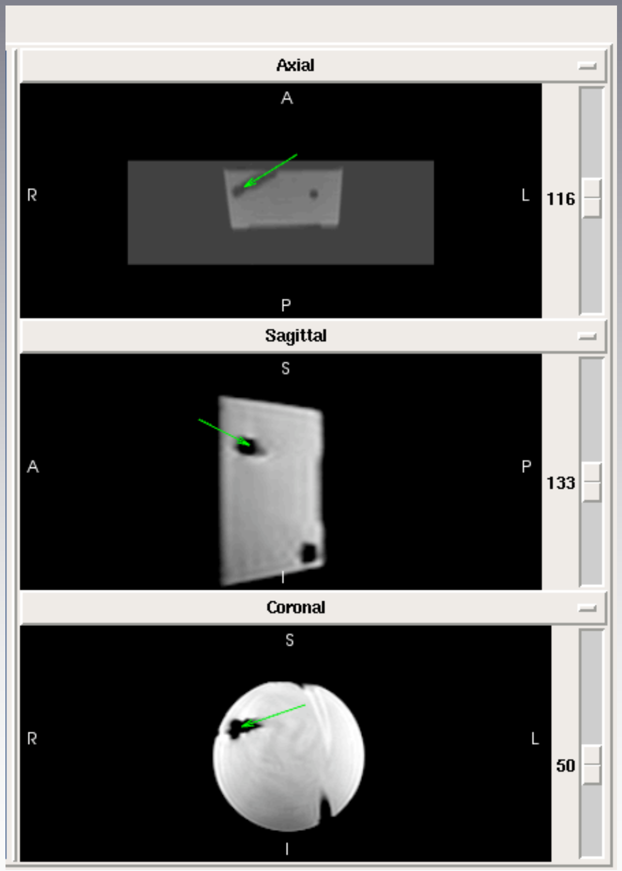
MRI-compatible EP, tracked catheter

- Fully MRI-compatible catheter with deflection
- Capable of measuring bipolar EP and deliver RF energy
- Safe
- Two embedded 6DOF tracking sensors
- Coordinates given in true image space
- MRI vendor independent



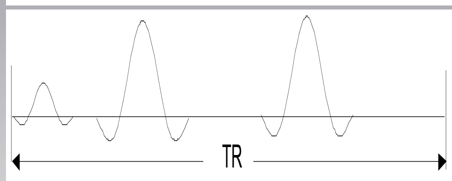
EM tracked catheter

- Tracking based on current induced in coil by MR gradients
- Signal compared to gradient driver signal
- Coordinates given in true image space
- Gives direction as well as position
- Does not take up MR receive channels

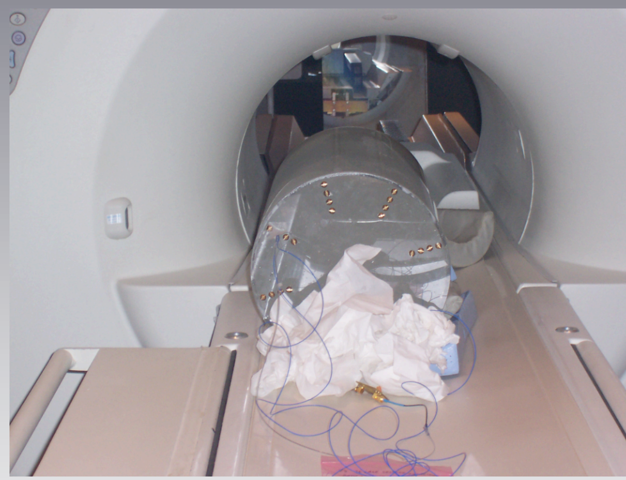


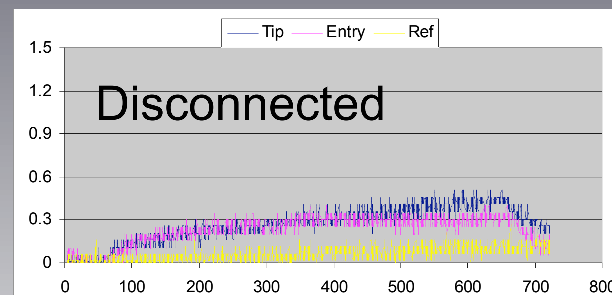
Safety Testing

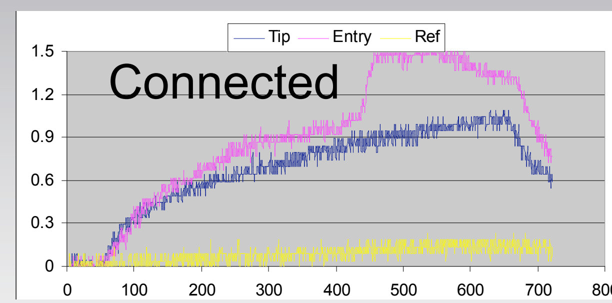
$$B_{1rms} = \sqrt{\frac{1}{T}\int_0^T B_1^{\,2}(t)\,dt}$$



$$B_{1rms} = \sqrt{\frac{1}{TR}}\;\sqrt{\sum_{i=1}^{n}\int_{t_{0i}}^{t_{1i}} B_{1i}^{2}(t)\,dt}$$







Temperature increase without safety measures: up to 25ºC

B-spline interpolation

$$P_i = (x_i, y_i, z_i)$$

$$P(s) = (x(s), y(s), z(s))$$

$$P(0) = (x(0), y(0), z(0)) = (x_i, y_i, z_i) = P_i$$

$$P(1) = (x(1), y(1), z(1)) = (x_{i+1}, y_{i+1}, z_{i+1}) = P_{i+1}$$

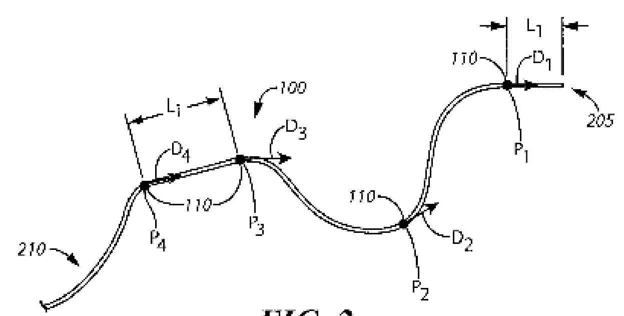


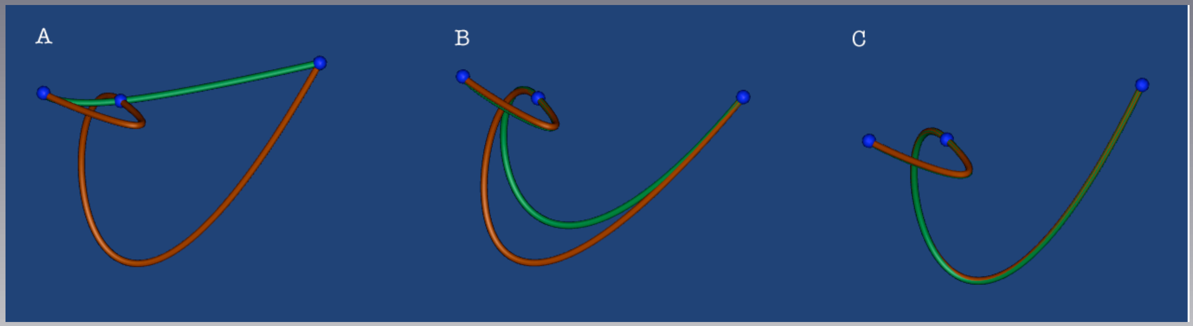
FIG. 2

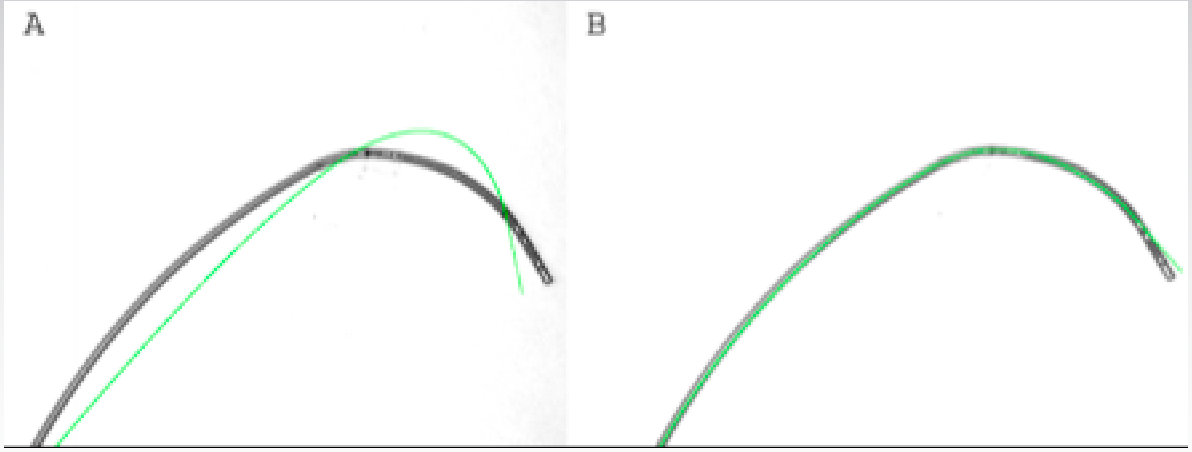
$$D_i = \left(\frac{dx}{ds}, \frac{dy}{ds}, \frac{dz}{ds}\right)$$

$$P(s) = s \cdot h \cdot C = \begin{bmatrix} s^3 & s^2 & s & 1 \end{bmatrix} \cdot \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} P_i \\ P_{i+1} \\ D_i \\ D_{i+1} \end{bmatrix}$$

$$\arg\min_{D_i} \left(L_i - \int_0^1 \sqrt{\left(\frac{dx(s)}{ds}\right)^2 + \left(\frac{dy(s)}{ds}\right)^2 + \left(\frac{dz(s)}{ds}\right)^2} \, ds \right)$$

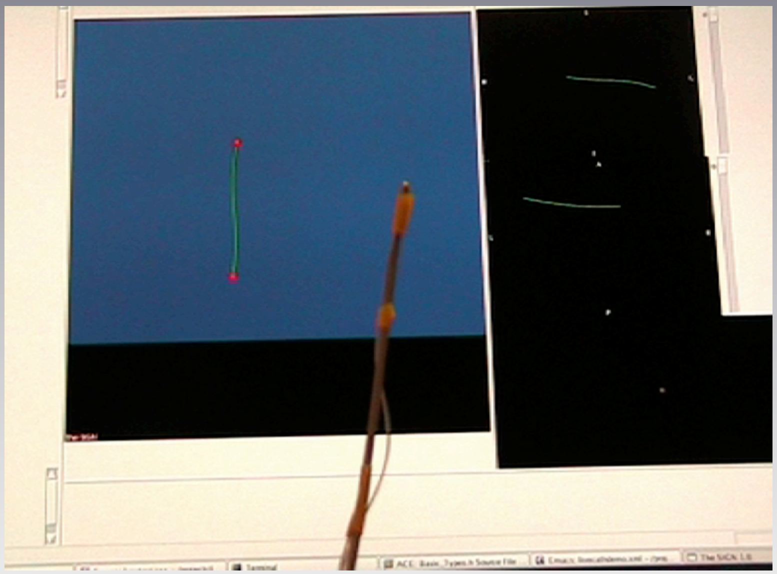
B-spline interpolation





Catheter visualization

- 6DOF tracking enables accurate depiction of the catheter, based on tracking data
- Spline interpolated catheter visualization based on knowledge of:
  - Sensor position
  - Sensor orientation
  - Length between sensors



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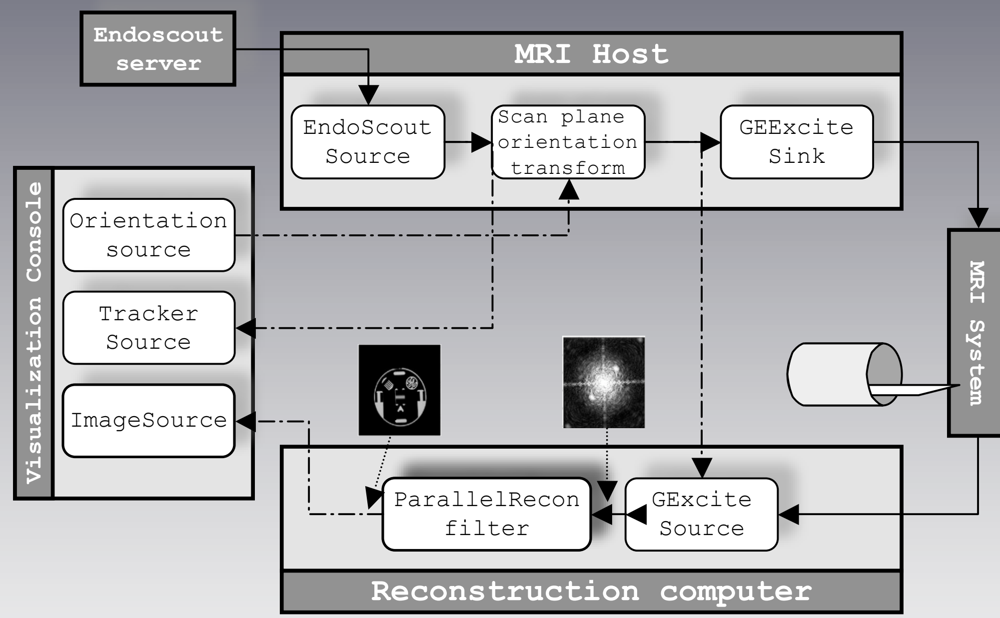
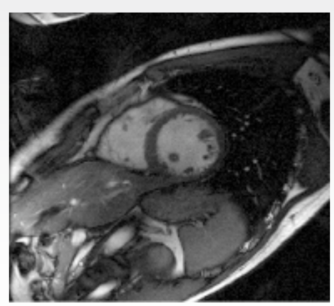
iGT

Interactive MR imaging using parallel acquisition and parallel reconstruction

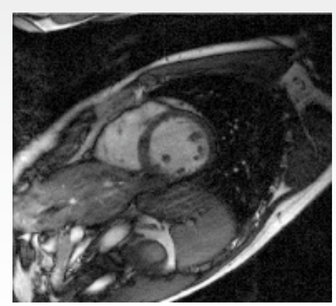
E Samset, WS Hoge, FA Jolesz

- Interactive MR imaging for image-guided therapy requires high frame-rate and low latency
- Parallel imaging at high imaging speeds requires automatic regularization, which can lengthen reconstruction time
- Parallelization of the reconstruction algorithm resulted in reduction of the reconstruction time below the acquisition time
- Fast, regularized SPACERIP with self-referenced coil-sensitivity estimates enables interactive scan-plane manipulation with *no temporal filtering*





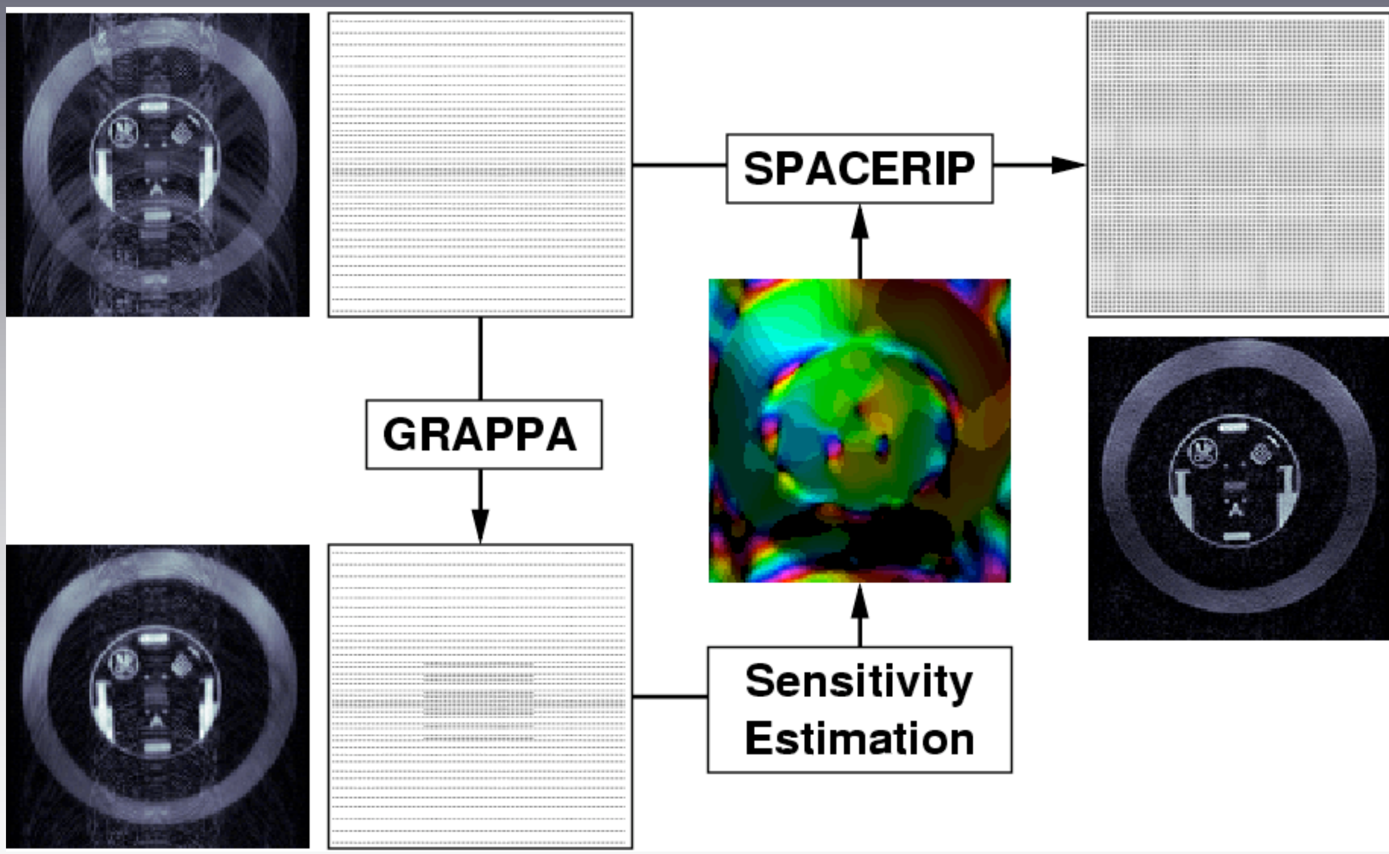
SPACERIP 2x



SPACERIP 3.4x

See Poster: 1125

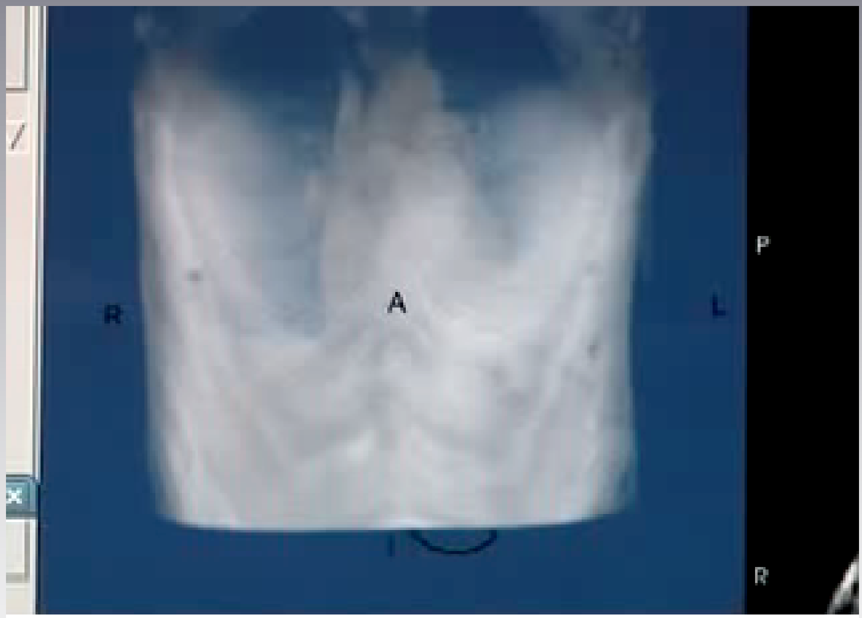
Parallel imaging w/ SPACERIP



Parallelization of all major computation elements results in recon time 100-120ms (fat node)

Cardiac Navigation Software

- Time synchronized with intra-operative ECG
- Dynamic roadmap combined with RT imaging
- Volume rendering and projected views



MRI scanner interaction

- All parameters supported by PSD to be controlled in real-time, can be controlled:
  - Field of View
  - Slice thickness
  - Flip Angle
  - AutoNex
  - Swap phase-frequency
  - Fat-saturation / Spatial saturation
  - Flow compensation
  - Inversion Recovery
- FGRE only - recent development: FIESTA

Time synchronized roadmap

- Trigger-delay and # of time points used to determine time function
- Software calculates inter-image delay based on previous cycle
- QRS detection triggers reset

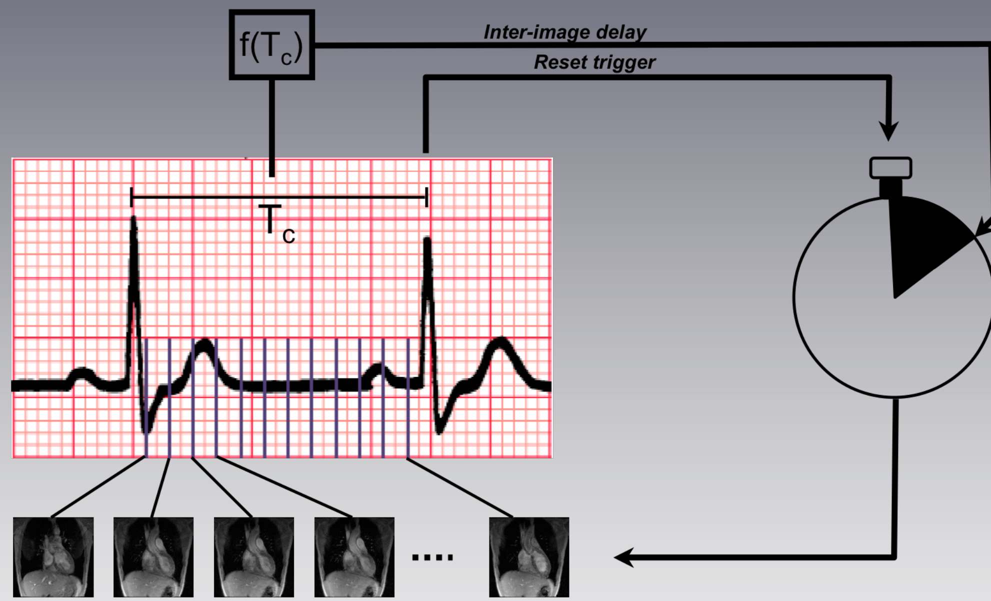
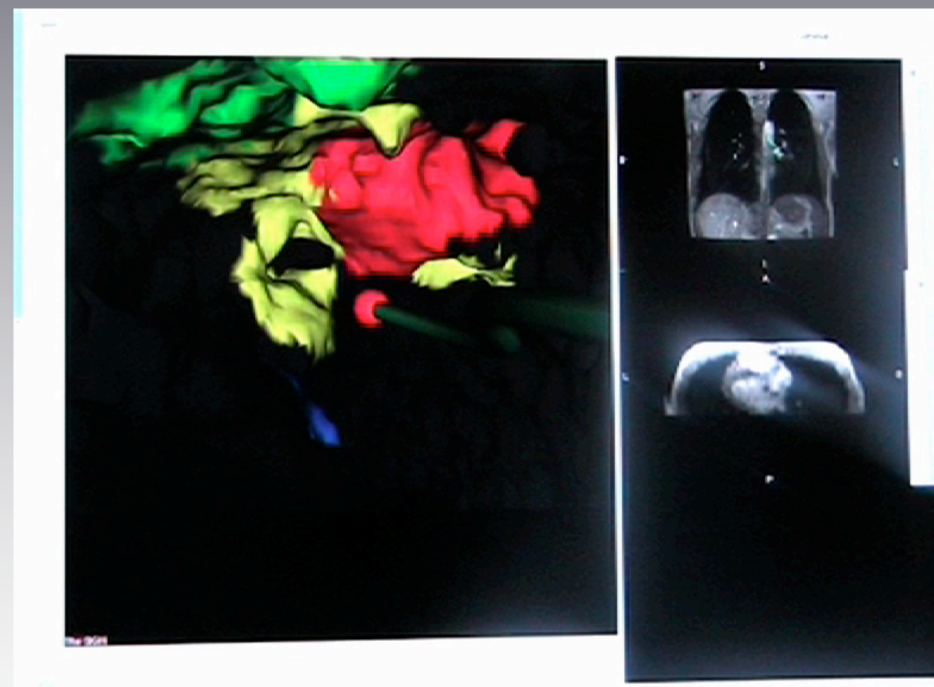


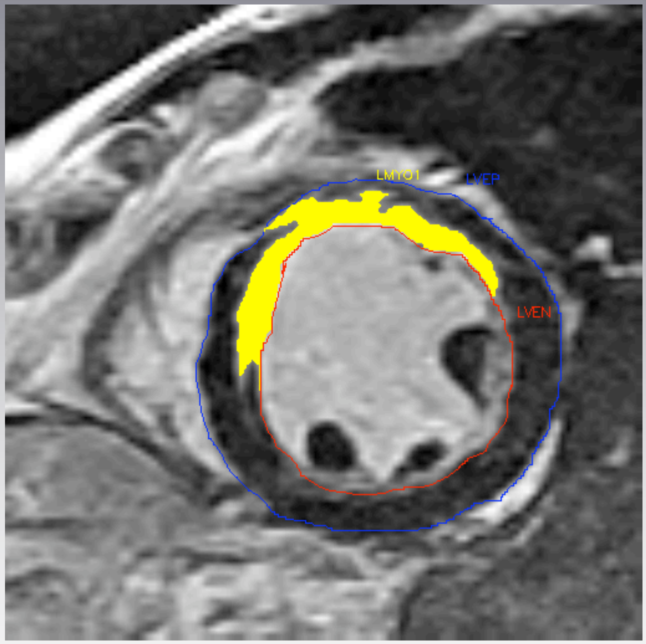
Image-registration and mapping

- Pre-operative dynamic roadmaps registered with segmented models, and fast real-time imaging
- EP mapping on anatomical surface models



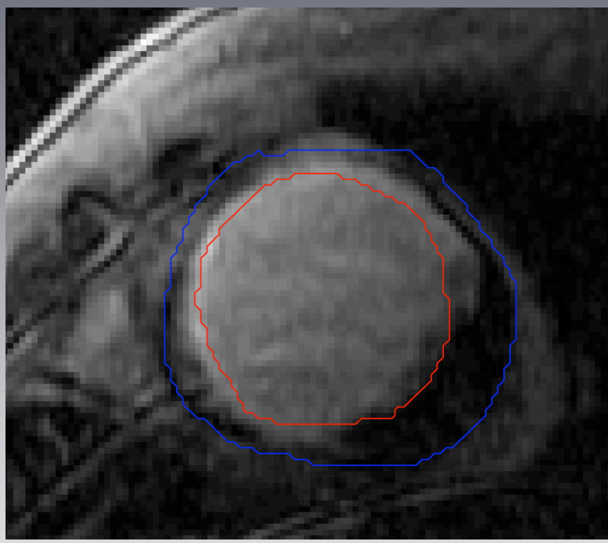
Automatic scar segmentation

- Myocardial scar edges correlates with electro physiological foci
- Automatic segmentation for improved targeting

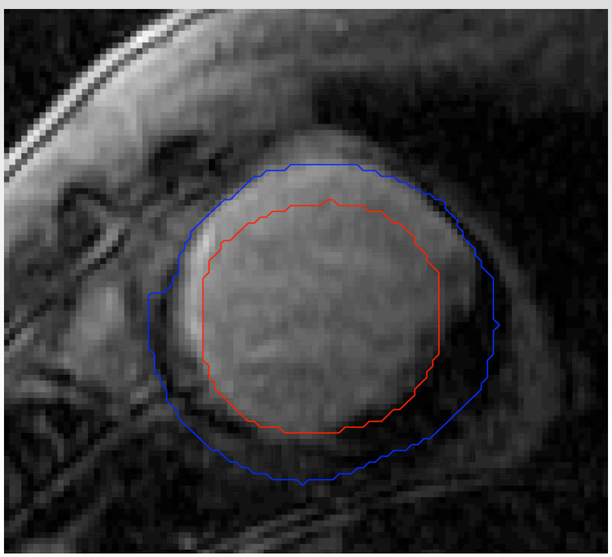


Courtesy of Raymond Kwong

Automatic scar segmentation



Manual



Automatic

- Automatic segmentation in contrast enhanced MRI
- Classifier (computed from training set) forms the joint basis for:
  - Coupled level sets
  - Particle filtering

Summary / Future Work

- MR-guided cardiac ablation is feasible, and will be continued to be developed between BWH, UiO, I3 and Robin Medical
- SIGN is a generic OpenSource framework for IGT applications, and will continue to be supported by my group in Oslo
- NaviTrack is intergrated with Slicer3 and will continue to be a collaborative effort