Knowledge driven segmentation of cardiovascular images

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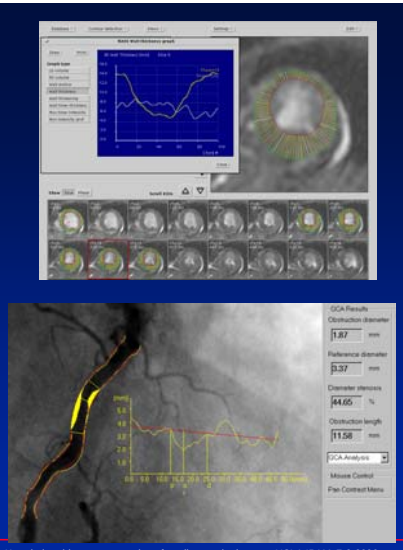
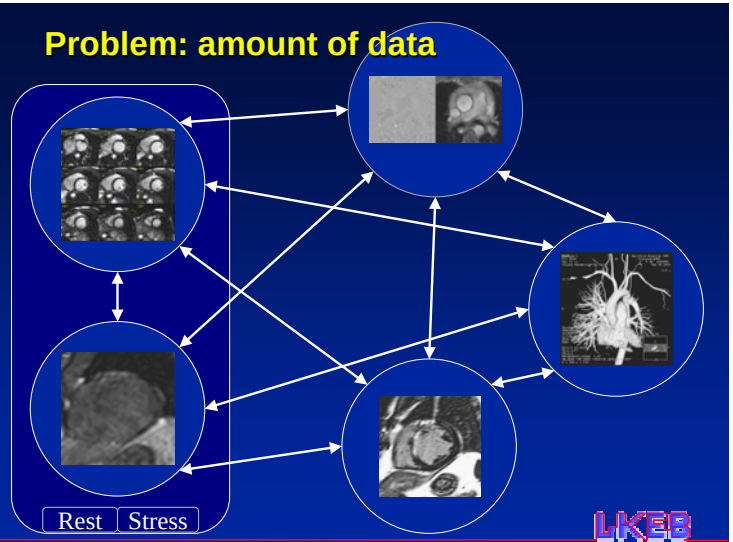
Introduction

- Introduction: why prior knowledge?
- Knowledge guided image processing
  - Model driven
  - Data driven
  - High level reasoning
- Future directions



Problem: amount of data

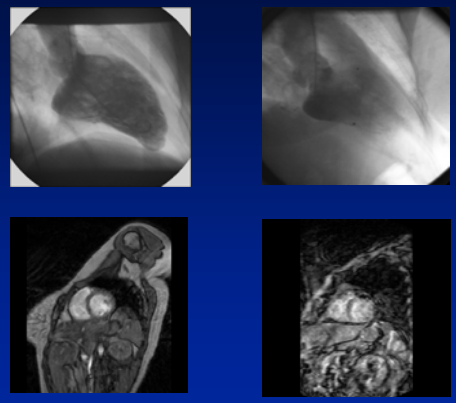


Goal: automated segmentation

- Less work!!
- More objective
  - Less difference between observers
  - Less difference in repeated measurements
- More reproducible
  - Easier to compare with others
  - Easier to perform follow ups
  - Less patients in trial

LKEB

Introduction: why knowledge?



LKEB

Why knowledge?

- Robust segmentation only possible using knowledge about:
  - Anatomical shape + shape variation + motion
  - Spatial context of organs
  - Intensity and data characteristics
  - Behavior of your algorithms
- Modality independent:
  - Current applications:
    - Cardiac MR
    - Cardiac CT
    - LV Angiography
    - Echocardiography

LKEB

General approach

- Tackle KGIP from three angles:
  - Model driven
    - Statistical shape models
      - Segmentation
      - Diagnosis
    - 3D thorax template
  - Data driven
    - Autonomous vehicle
  - High level reasoning
    - Multi-agent systems
    - Data fusion

LKEB

General approach

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Active Shape Models

- Describe the shape of an organ in a population as
  - an average shape
  - a small number of characteristic shape variations
- DEMO

AAM Model Generation

Set of examples (N=20)

Average Shape + eigenvariations

Average patch

Appearance eigenvariations

Subsets: Male vs. female

Male (N=14)

Female (N=6)

Subsets: Ass. professors vs. others

Ass. Professor (N=7)

Non – ass. professor (N=14)

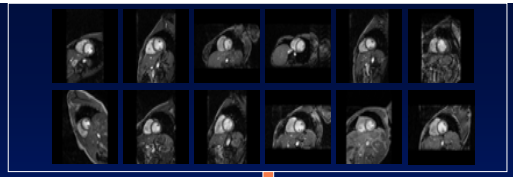
Active Appearance Models

- AAM's can be used for contour tracing by:
  - initially positioning the model
  - fitting the model to the underlying image along 'statistically plausible' deformations

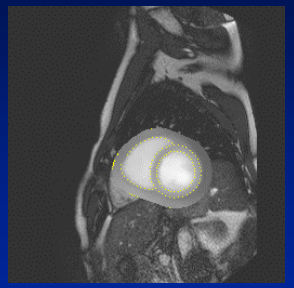
AAM Matching

Matching AAM's

- To match an AAM to an image requires:
  - a criterion function *e*:
    - the RMS error of the 'difference image' between the model and the underlying image patch
  - a minimization procedure (Levenberg Marquardt / simplex)
  - derivatives of the criterion function with respect to all 'optimizable' parameters
    - can be estimated using multiple linear regression
    - examples of derivative images

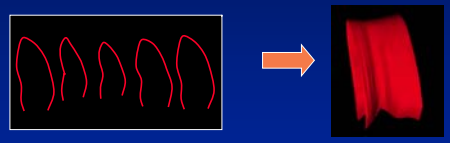


2D

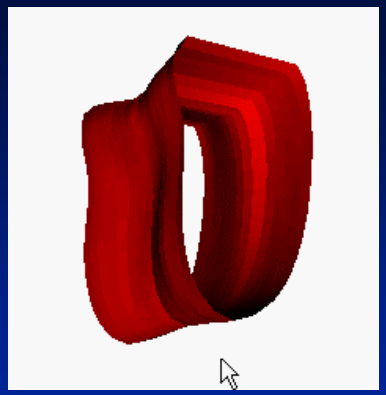


2D + time modeling

- Modeling a heartbeat
  - Define point correspondence in 2D
  - Define “time-correspondence”
    - Divide interval between ED-ES-ED in fixed # steps
    - Interpolate in time (nearest neighbor)



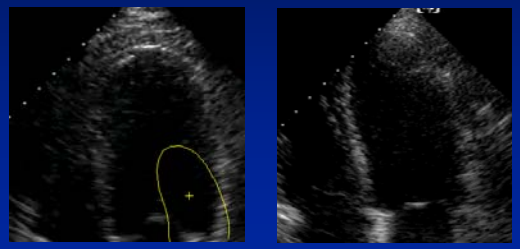
$$x = \left[\underbrace{x_{11}, y_{11}, \ldots, x_{1n}, y_{1n}}_{Phase_1}, \underbrace{x_{21}, y_{21}, \ldots, x_{2n}, y_{2n}}_{Phase_2}, \ldots, \underbrace{x_{N1}, y_{N1}, \ldots, x_{Nn}, y_{Nn}}_{Phase_N} \right]^T$$



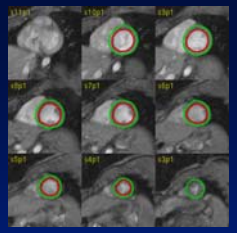
Movie: Bosch e.a.

Echocardiography

- Model initialization on average pose of training set
- Fully automated match for total sequence at once



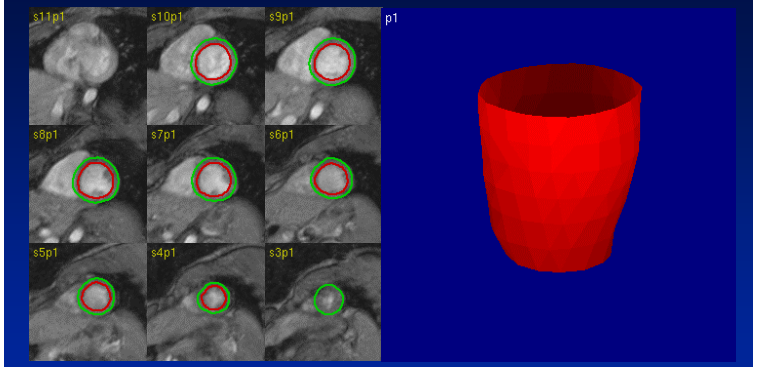
Hans Bosch (TMI 2002)



Variation 1 | Variation 2 | Variation 3

2D + time matching

2D+time



van der Geest (JCMR 2004)

Multi-view analysis

- Why?
  - Different views of same organ are correlated
  - Different views are complementary
- Goal:
  - Exploit coherence and redundancy

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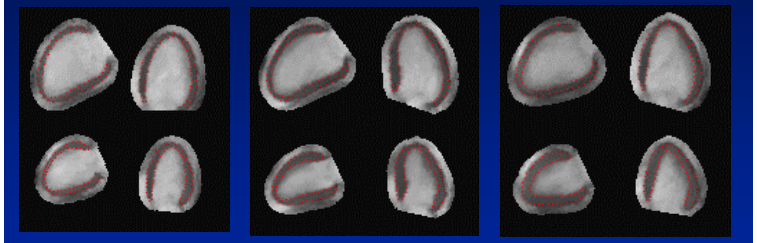
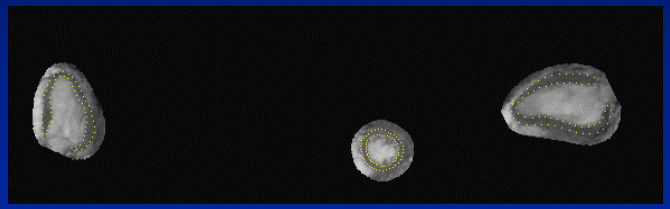
Multi-view AAM: different geometries /phases



LKEB

Multi-view AAM: Matching

- Minimize intensity error for all views:
  - shape and appearance are coupled
  - pose varies independently



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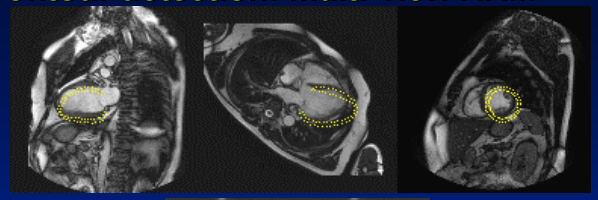
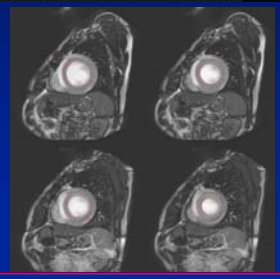
Contour detection: multi-view AAM

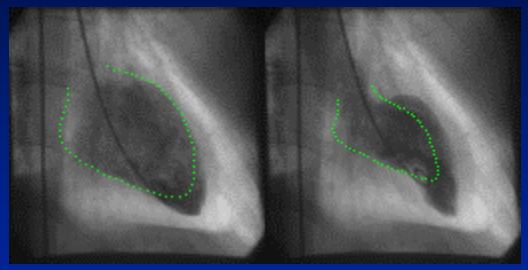




Mehmet Uzumcu
Elco Oost

LKEB

- Other applications: LV Angio



Elco Oost (FIMH 2005)

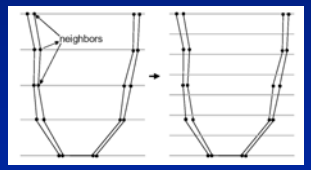
- Extension to 3D requires
  - Point correspondence
  - 3D procrustes alignment
  - 3D shape modeling
  - 3D matching mechanism

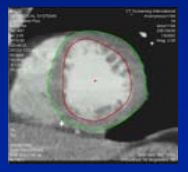
3D point correspondence

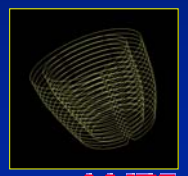
- Problem: no natural ordering in 3D
- Solutions:
  - Application specific manual (Mitchell, Stegman)
  - Through parameterization
    - Map to sphere
      - SPHARM (Brechbuhler)
      - MDL in 3D (Davies)
    - M-reps (Pizer group)
      - Object coordinate frame
  - Through registration
    - Deformable-mesh-to-binary-volume fitting (Kaus)
    - Non-rigid binary-binary registration (Frangi)

Application specific: manual

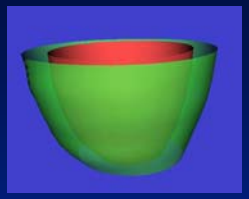
- Interpolate in through plane direction
- Fix orientation
- Radial sampling of each contour
- In cardiac MR case: problem: slice shift!



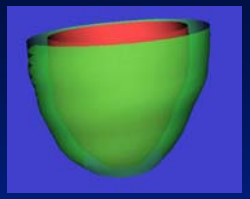




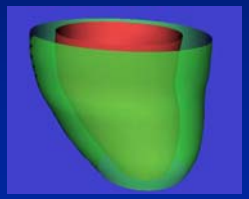
Eigen deformation #1



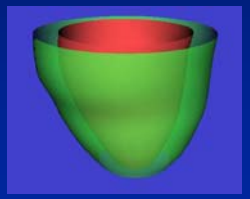
Eigen deformation #2



Eigen deformation #3



Eigen deformation #4

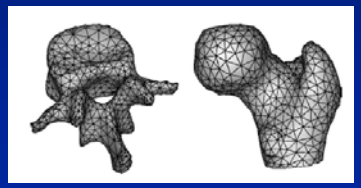


Van Assen e.a.

Point correspondence

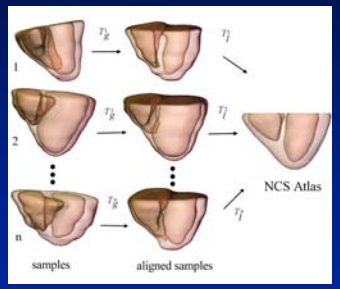
- 3D Mesh-to-binary registration (Kaus)
  - Represent one sample as triangle mesh
  - Rigidly align mesh to other samples
  - Non-rigid “snake-like” deformation, balancing an external with an internal energy

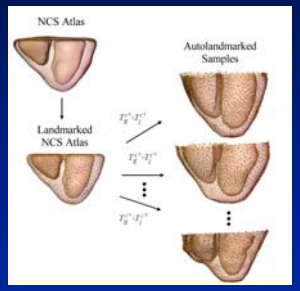
+not restricted to spherical maps
-non “optimal” parameterization



Point correspondence

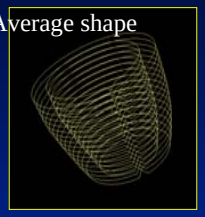
- Non-rigid registration (Frangi, Rueckert)



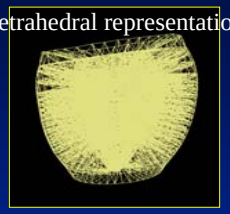


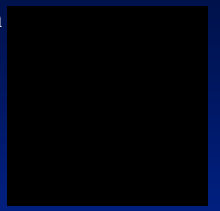
3D AAM Model Generation: MRI (Mitchell)

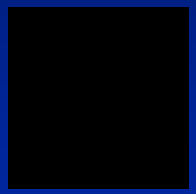
Average shape

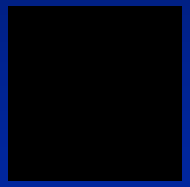


Tetrahedral representation

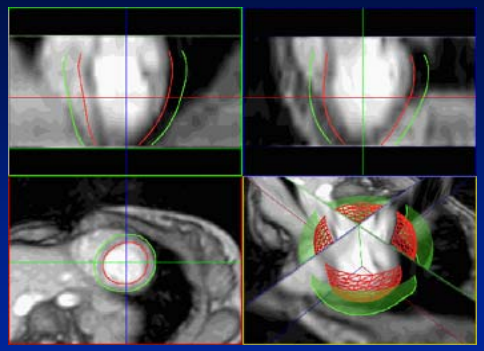








3D

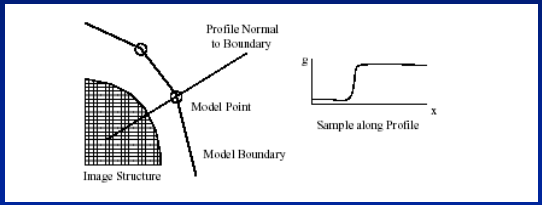


4D AAM (Stegmann)

c9285_opt_hires_c.avi

ASM Matching

- Updates on scanline can be generated by
  - Edge detector
  - Gray level model
  - Classifier



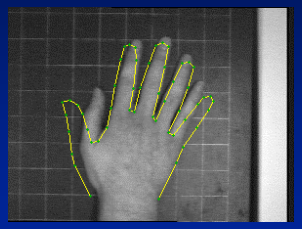
ASM: Matching

- Vector *y* = candidate points
- Vector $x = \bar{x} + \Phi b$ = current model state
  - Align *y* to current shape in model frame
  - Scale y with $1/(y \cdot \bar{x})$
  - Update model parameters to match y

    $b = \Phi^T (y - \bar{x})$
  - Apply constraints on *b*
    - *Per parameter:* $|b_i| \le 3\sqrt{\lambda_i}$
    - *Mahalanobis distance:* $\left(\sum_{i=1}^{t} \frac{b_i^2}{\lambda_i} \right) \le M_t$
  - Repeat until convergence

ASM: matching

- Active Shape Models
  - Point distribution model with matching

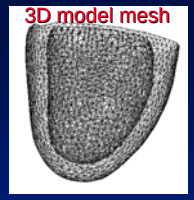


Movies: Tim Cootes

3D ASM Matching: van Assen approach

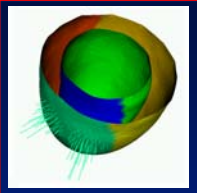
- Solution to voxel anisotropy
  - Piecewise 2D matching: update 3D model state with 2D image info
  - Enables anisotropic data
  - Enables multiple orientations in data

Iterative matching algorithm



Next iteration

Align model to update points cloud, change b-vector



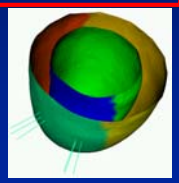
Intersect with image planes

Propagate updates

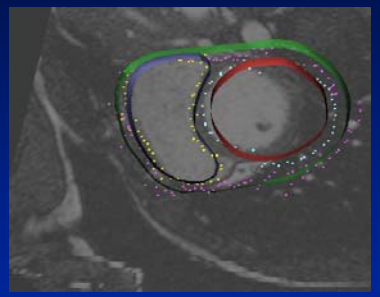
Place in data set

Classify surrounding pixels, and detect edge positions

Map results to mesh

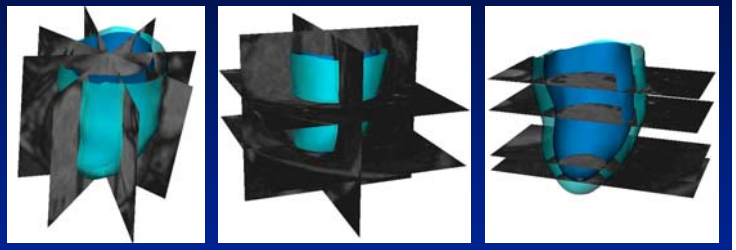


3D ASM on densely sampled data



Hans van Assen

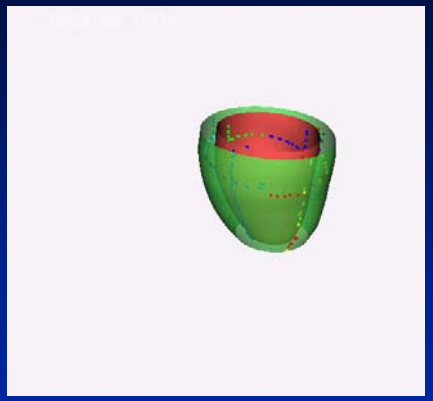
Application to sparse data



Radial LA | Multi-view (2SA+2LA) | SA

Hans van Assen, MEDIA 2006

3D ASM on sparse data: LA / SA fusion



Hans van Assen

ASM versus AAM

- 3 key differences:
  - ASM only uses texture in small region around landmark, AAM complete patch
  - ASM searches around current positions, AAM only under current position
  - ASM minimizes distance to boundary, AAM intensity difference

ASM versus AAM (Cootes)

- General
  - ASM is faster
  - AAM possible with fewer landmarks
  - AAM has “interpretable” convergence criterion
    - automatic failure detection (Thodberg, Stegmann)

Statistical model limitations

- How to balance training set?
- How many samples necessary?
- Manual annotation of training samples
- Local refinement necessary
- Dimensionality vs nr training samples

3D ASM matching: Kaus approach

- Deformable model based on energy
  $E = E_{ext} + E_{\text{int}}$
- Shape model is integrated in E_{int}
  - Term for PDM for each single surface
  - Term for connections between surfaces term
  - General shape & connectivity constraint term
- Local intensity model in E_{ext}
  - Every scanline has different feature detector (3 classes)

Multi-surface Cardiac Modelling, Segmentation, and Tracking

Jens von Berg and Cristian Lorenz
Philips Research Laboratories, Hamburg

Courtesy of Jens von Berg, Philips Research Laboratories, Hamburg
Presented at FIMH 2005

General approach

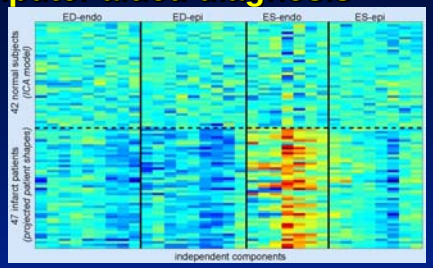
- Tackle KGIP from three angles:
  - Model driven
    - Statistical shape models
      - Segmentation
      - Diagnosis
    - 3D thorax template
  - Data driven
    - Autonomous vehicle
  - High level reasoning
    - Multi-agent systems
    - Data fusion

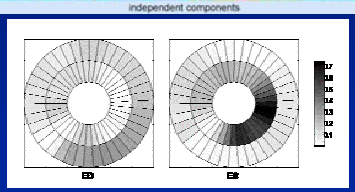
Computer-aided diagnosis

- Construct a model of normal motion
- Classify and localize deviations from normal

- Demo

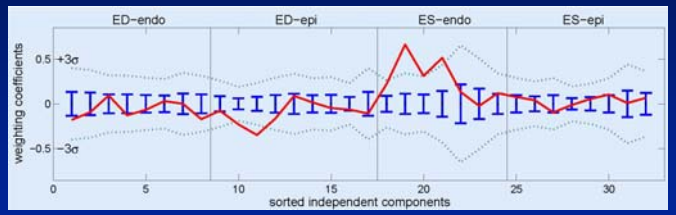
Computer aided diagnosis





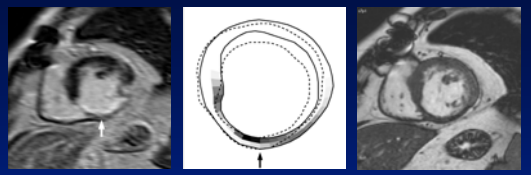
Avan Suinesiaputra (MICCAI 2004)

Detection of Abnormal Contractility Patterns

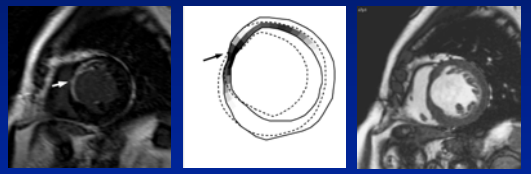


Avan Suinesiaputra

Case 1:

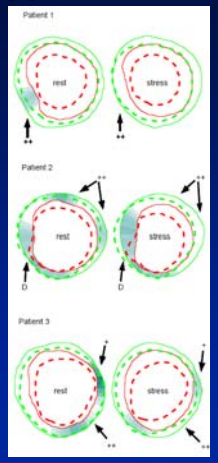


Case 2:



Avan Suinesiaputra

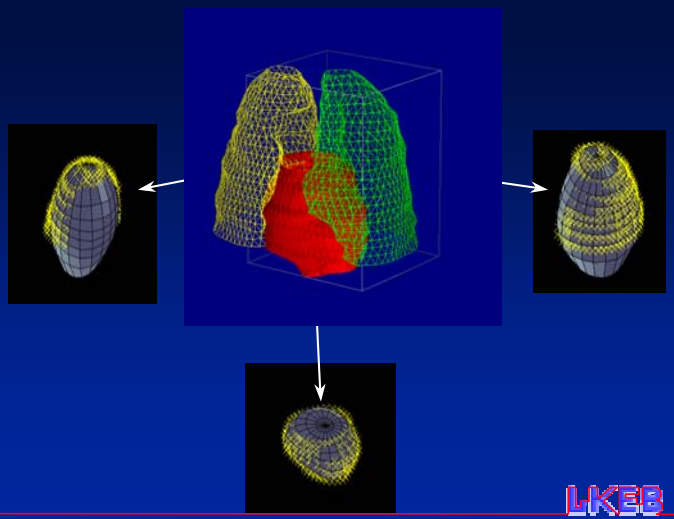
Rest-stress comparison

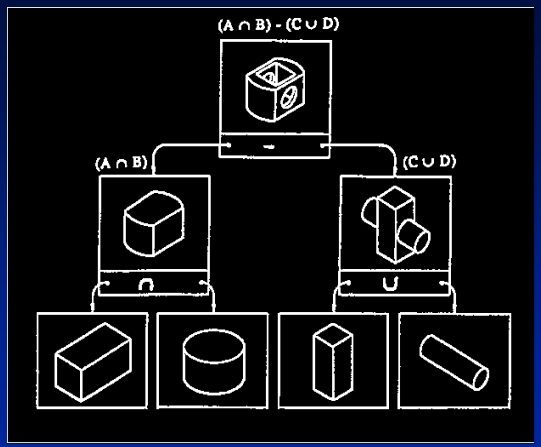


Avan Suinesiaputra (IPMI 2005)

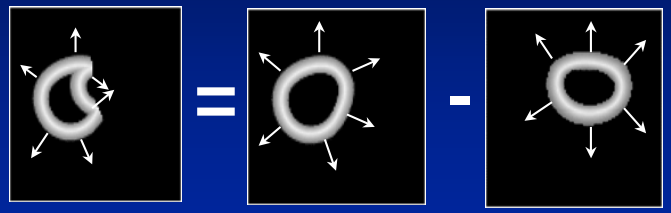
General approach

- Tackle KGIP from three angles:
  - Model driven
    - Statistical shape models
      - Segmentation
      - Diagnosis
    - 3D thorax template
  - Data driven
    - Autonomous vehicle
  - High level reasoning
    - Multi-agent systems
    - Data fusion



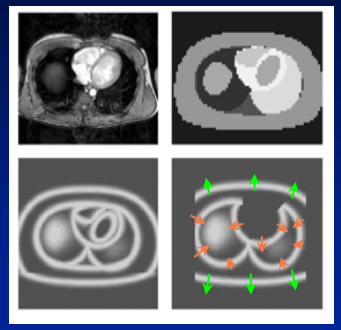


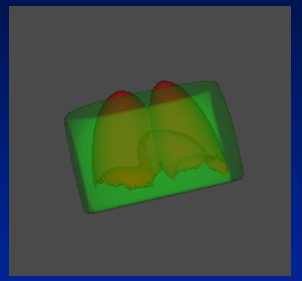
$$b(x,y,z) = 1 - \frac{1}{w}\left|\frac{f(x,y,z)-c}{\|\nabla f(x,y,z)\|}\right|$$



LKEB

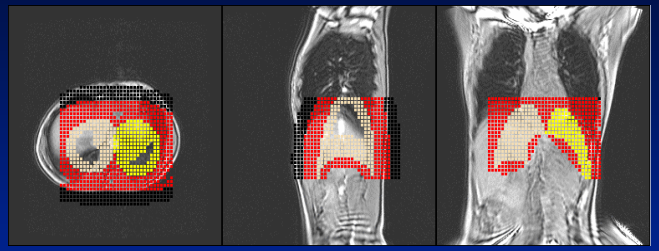
Deformable thorax template





LKEB

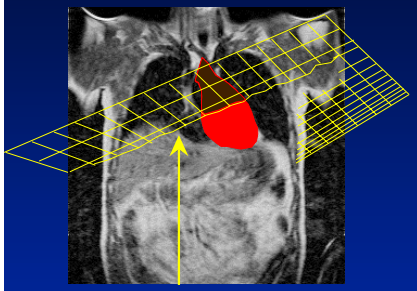
Deformable thorax template

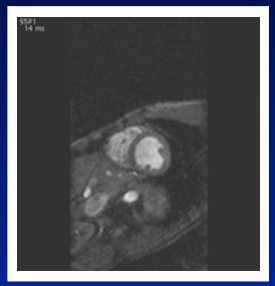


- = Left lung
- = Right lung
- = Air
- = Other

LKEB

CMR scan planning



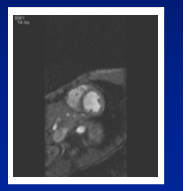


LKEB

CMR scan planning

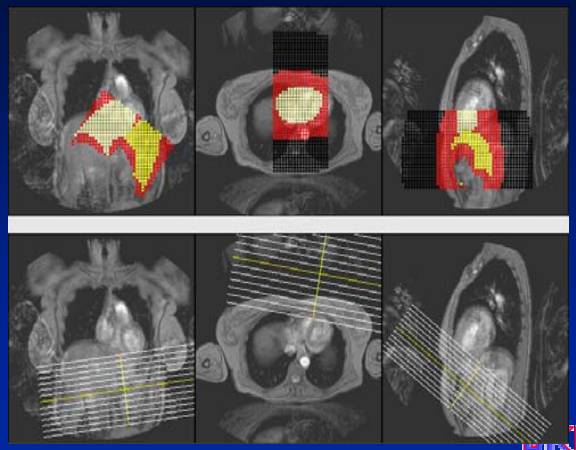
Scout views

Short-axis view



LKEB

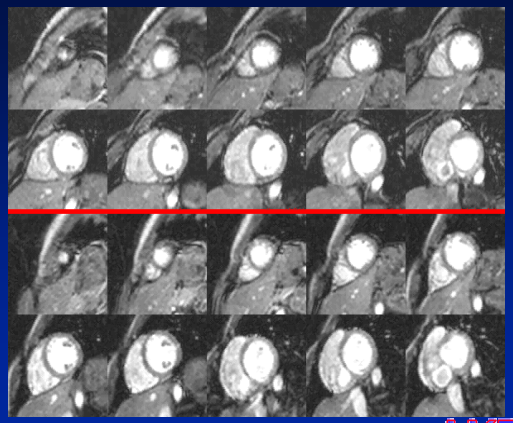
Deformable thorax template



LKEB

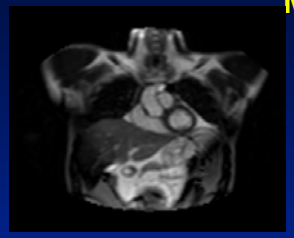
Manual

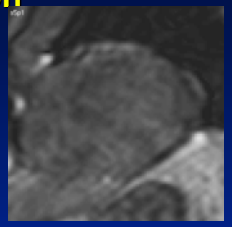
Automatic



LKEB

Characteristic of Cardiac Respiratory Motion

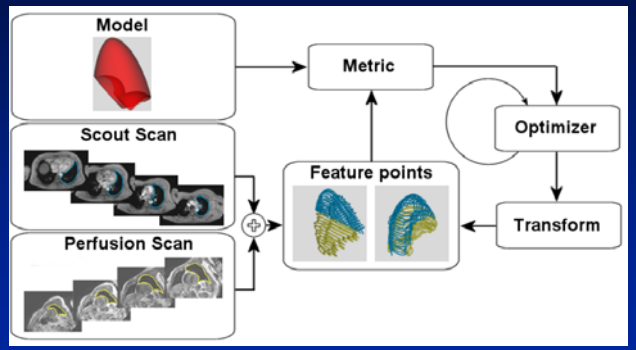




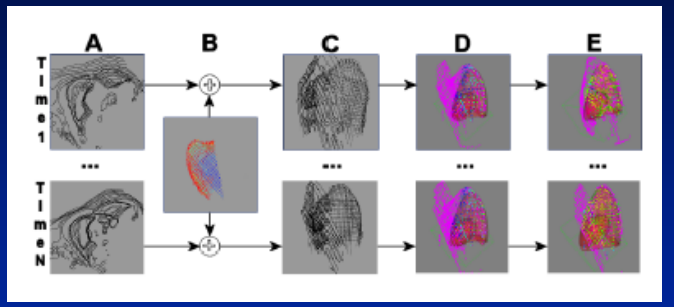
- Induced by changes in lung volumes
- Motion occurs in inferior and anterior direction. (truely 3D)
- Heart is adjacent to left lung

LKEB

Data fusion between scout & perfusion scans

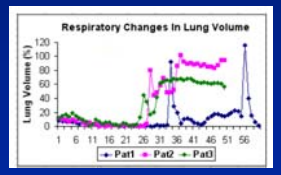


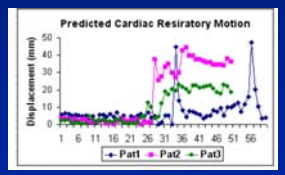
LKEB



LKEB

- Data from 3 infarct patients
  - Model fitted to fused feature points from scouts / perfusion scan
  - Lung volume correlated between manual contours and model lung





LKEB

General approach

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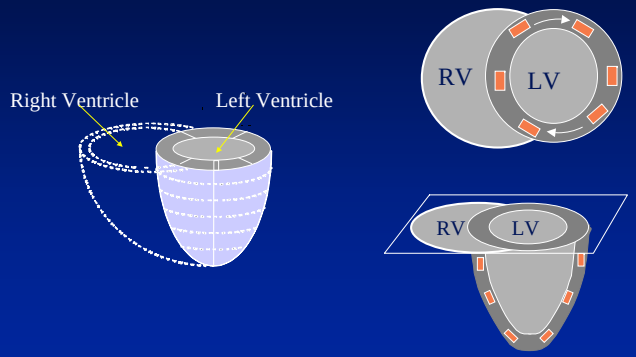
      - Segmentation
      - Diagnosis
    - 3D thorax template
  - Data driven
    - Autonomous vehicle
  - High level reasoning
    - Multi-agent systems
    - Data fusion

LKEB

A Virtual Exploring Robot for Left Ventricle Contour Detection



LKEB

Sensor system (Perception devices)

Range Sensors
- Navigation
- Contour Detection

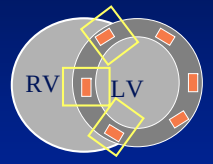
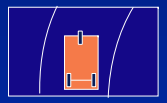
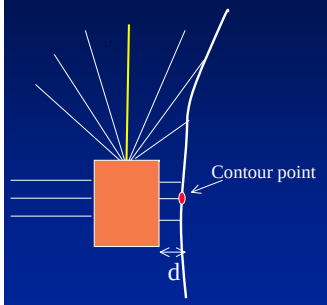


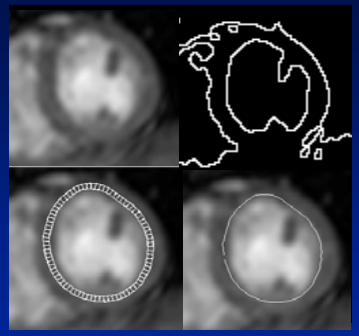
Image Sensor (camera)
- Recognition
- Region Labeling



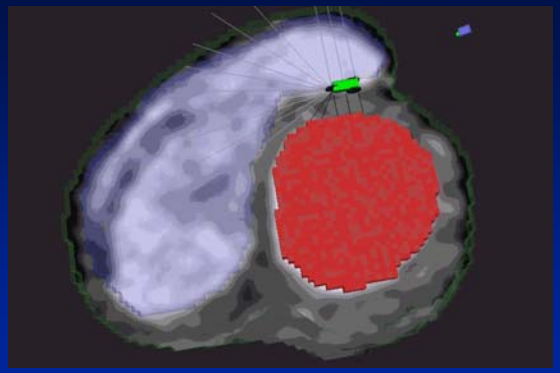
LKEB

Endocardium Detection





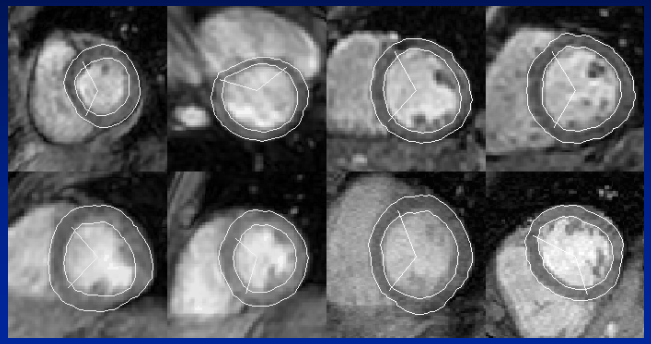
LKEB



Luca Ferrarini, Hans Olofsen, Faiza Behloul

LKEB

Epicardium delineation



Luca Ferrarini

General approach

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      - Diagnosis
    - 3D thorax template
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    - Autonomous vehicle
  - High level reasoning
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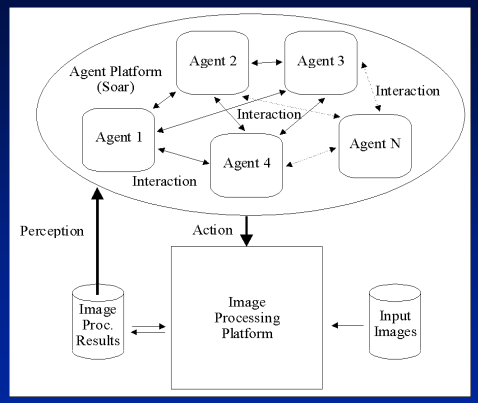
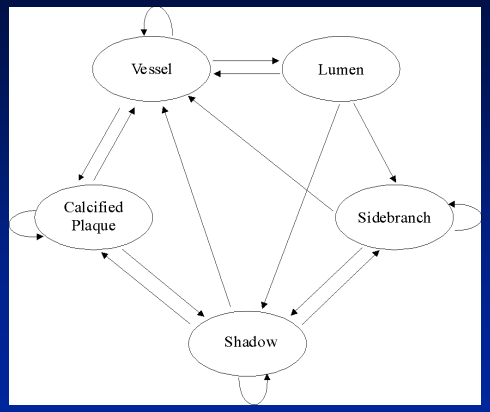
    - Data fusion

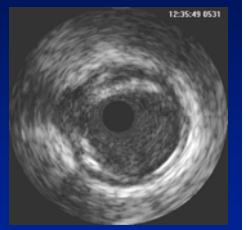
MA image processing



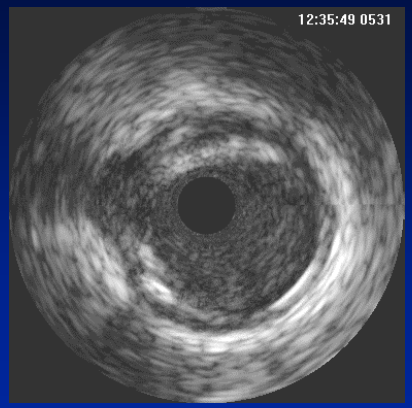
Ernst Bovenkamp (PATREC 2004)

MA image processing: agent relations

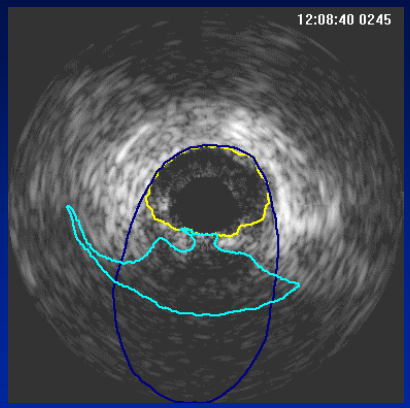




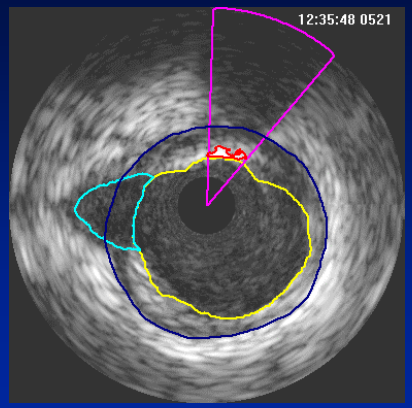
Example: conflict resolution



Example: test-hypothesis



Example: segmentation results



General approach

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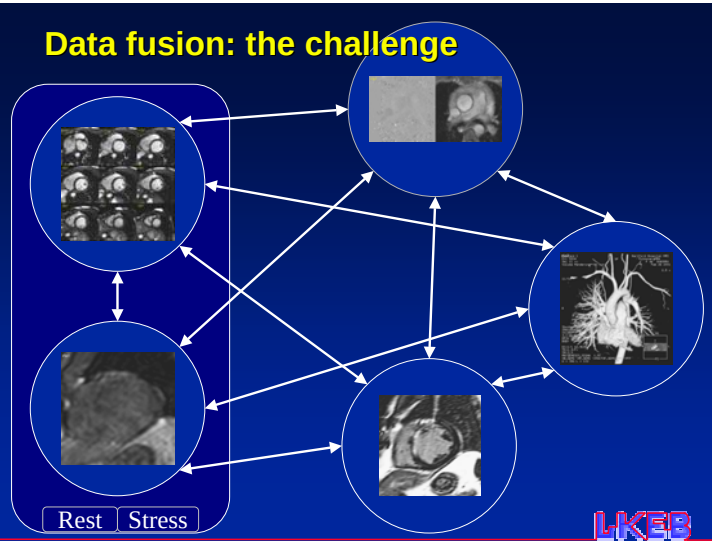
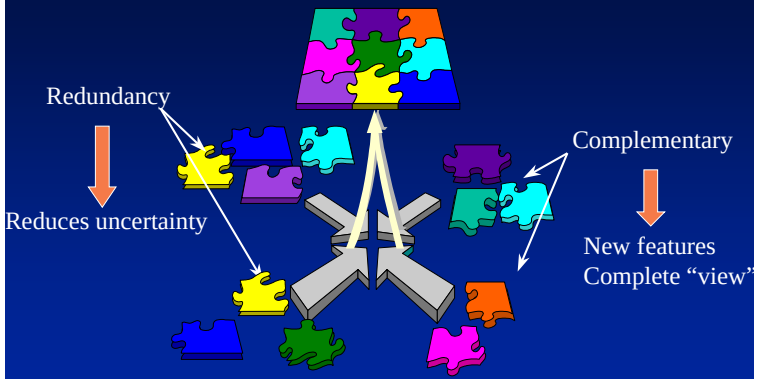
Data fusion: the challenge

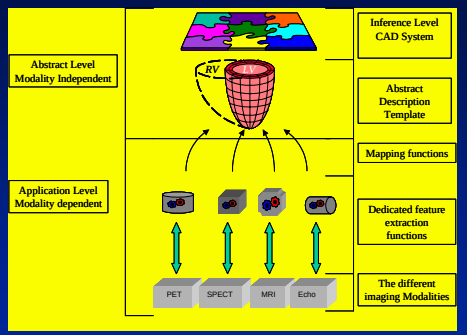


Why Image (data) fusion ?

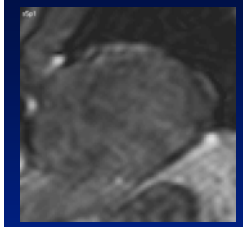


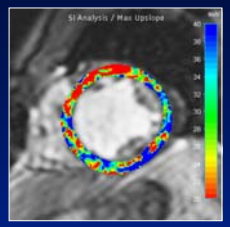
PET / MRI Symbolic data fusion

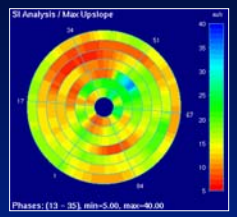
(Behloul e.a., TMI 2001)

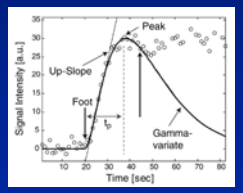


Data fusion: perfusion quantification



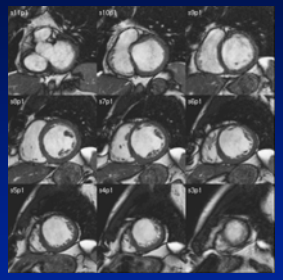


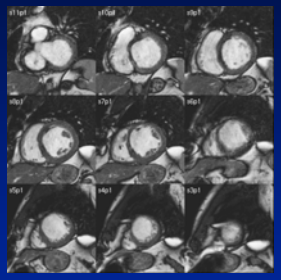




M. Jerosch-Herold et al., JMRI, 2004

Data fusion: myocardial viability

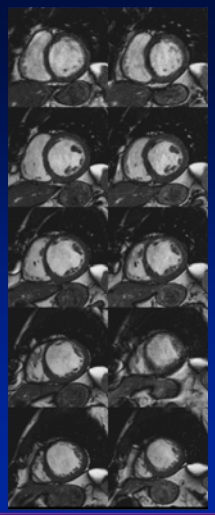


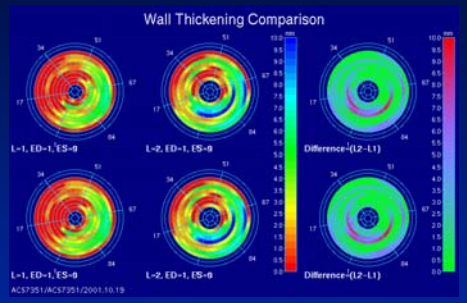


Rest

Stress

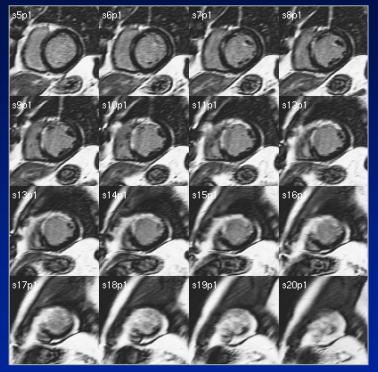
(low dose dobutamine)



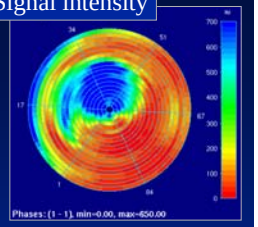


Rob van der Geest

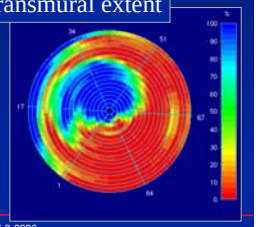
Delayed enhancement



Signal intensity



Transmural extent



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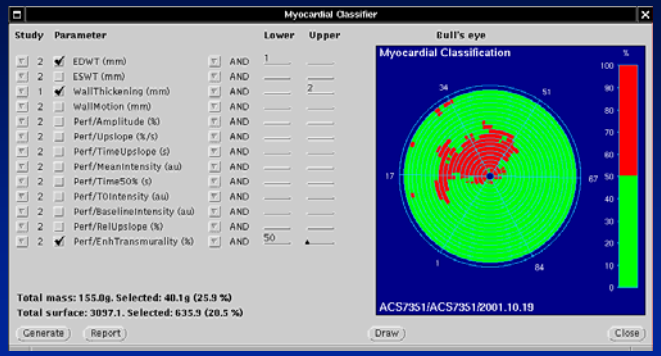

Rob van der Geest

To summarize ….

- Tackle KGIP from three angles:
  - Model driven
    - statistical shape and template models for segmentation, diagnosis
  - Data driven
  - High level reasoning
    - coordinating multiple segmentation sources
    - fusion of complementary information

What's next?

- Integrating the three main directions
- Automatic "quality control"
- Computer aided diagnosis
- Data fusion for segmentation and analysis

Acknowledgements

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Milan Sonka