Graph-Based Image Segmentation: LOGISMOS

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Background

- Computer-aided segmentation of medical images plays a vital role in many biomedical applications
- Main challenges
  - Weak boundaries
  - Large variation
  - Mutual interaction between multiple objects
- Segmentation is the foundation of quantitative image analysis
- Segmentation is needed in 3D, 4D, 5D, …

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State of the Art – Clinical

- Medical imaging is everywhere
- Medical image analysis is (almost) nowhere
- Screening success → mainstream
  - Mammography
  - Virtual colonoscopy
  - Ophthalmology
  - Cardiovascular disease (IMT, FMD)
- Diagnostic/Treatment success
  - Cell microscopy for routine lab tests
  - Coronary angiography
- Research must be translated to routine clinical care

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State of the Art – Research

- Anatomy/morphology
  - Body is 3D → Analysis must be 3D
- Function
  - Frequently 4D/5D → Analysis still mainly 3D
- Multi-modality imaging
- Imaging is not enough
- → Widely accepted at conferences
- → Not so much by
  - Industry, FDA, physicians

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Medical Image Analysis is Challenging

- 3D/4D/5D segmentation tasks
- Abnormal anatomy
- Variable imaging parameters
- Low quality images
- Ambiguous appearance
- Etc.

- ➔ Virtually impossible without a priori knowledge
- ➔ Context ➔ Highest likelihood/optimality

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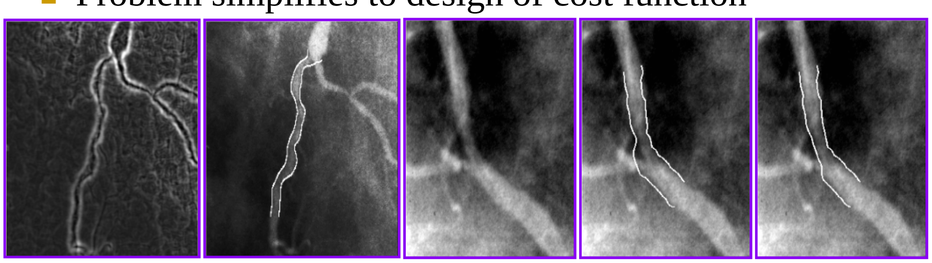
Optimal Border Detection in 2D

- 2D dynamic programming was a workhorse of Dutch cardiovascular endeavors for decades
- Still used in most QCA packages
- Problem simplifies to design of cost function



- Context-based simultaneous detection of both borders

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Dynamic Programming

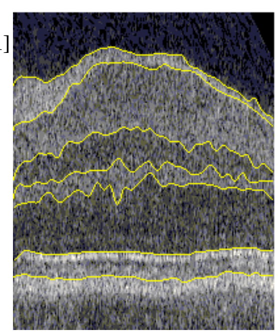
- Algorithm example
- Vascular ultrasound image analysis
  - Carotid IMT – DEMO

- Context can be represented using graphs
- Optimality can be accomplished by solving a related graph-theoretical problem

➔ **Context & Graphs & Optimality**

Main 3D … nD graph-based approaches

- Graph Cut (incl. multi-region framework) [1]
  - Topologically flexible
  - Interactive initialization
  - ➔ constraints between different regions.
- LOGISMOS – multi-object, multi-surface segmentation using graph search [2,3]
  - No human interaction required
    - (pre-segmentation required)
  - Incorporation of shape prior information
  - Interaction constraints/context between different surfaces and/or objects



Intraretinal layers of OCT images

[1] Delong, A., Boykov, Y.: Globally optimal segmentation of multi-region objects. In: *ICCV*, 2009

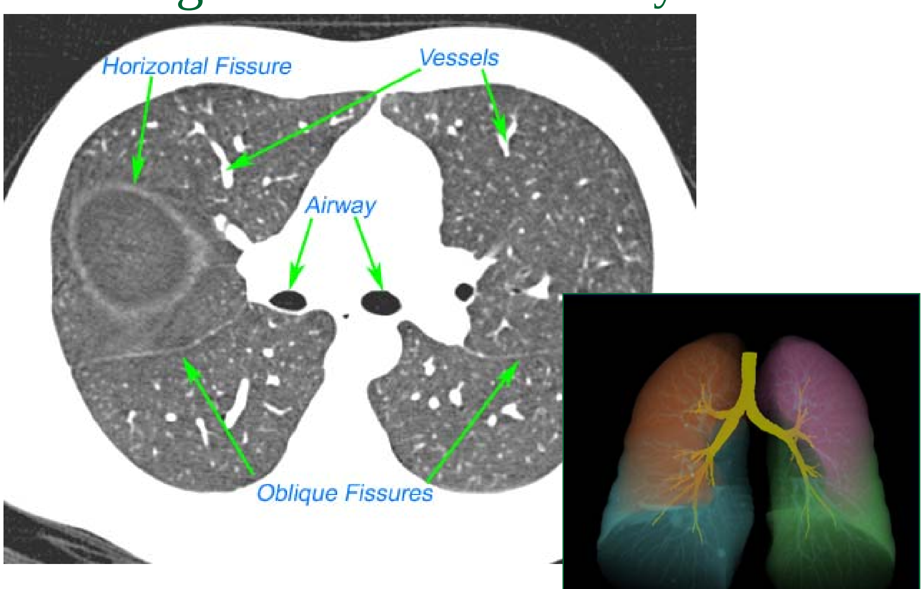
[2] Li, K., Wu, Xu., Chen, D., Sonka, M.: Optimal surface segmentation in volumetric images – a graph theoretic approach. IEEE T-PAMI, 2006

[3] Yin, Y., *et al.*: LOGISMOS – layered optimal graph image segmentation of multiple objects and surfaces: Cartilage segmentation in the knee joints. *IEEE Trans. Medical Imaging*, 2010

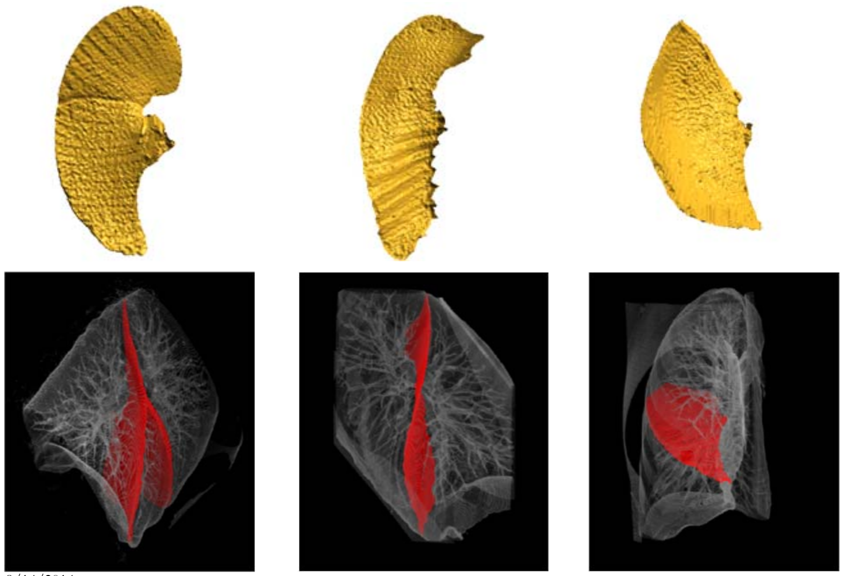
3D & 4D – Surfaces

- 3D slice by slice segmentation – 3D context missing (spatial, temporal, both)
- Extension of 2D dynamic programming to 3D
  - Combinatorial explosion
- Optimal surface detection in 3D and above
  - Seemingly NP complete
  - Solutions were missing for decades
  - 2002 – Chen & Wu - single surface graph-based solution in low-order polynomial time and formal proof of optimality
- ***While graph cut is used for optimization, this is NOT Boykov's graph cut segmentation***

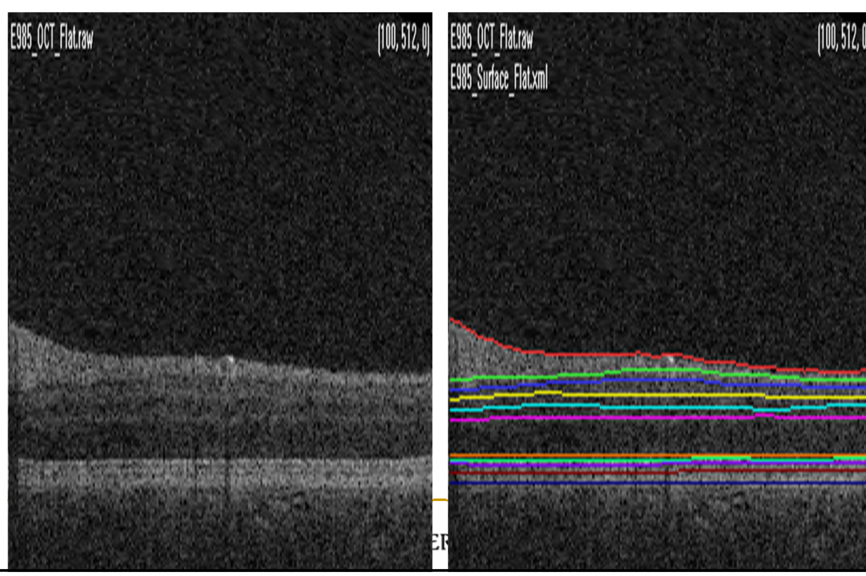
Finding Surfaces – Pulmonary Fissures



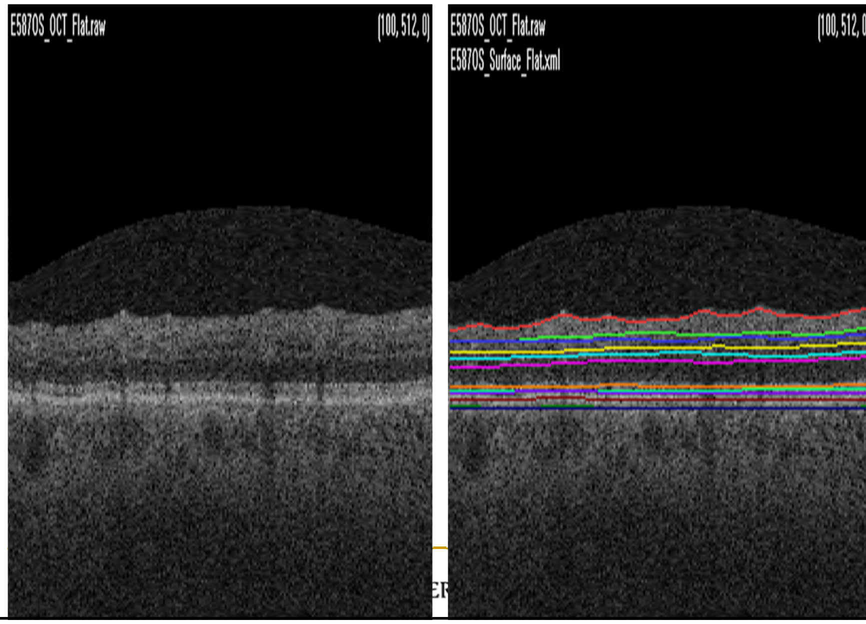
Finding Surfaces – Pulmonary Fissures



Retinal Image Analysis – 3D OCT - macula

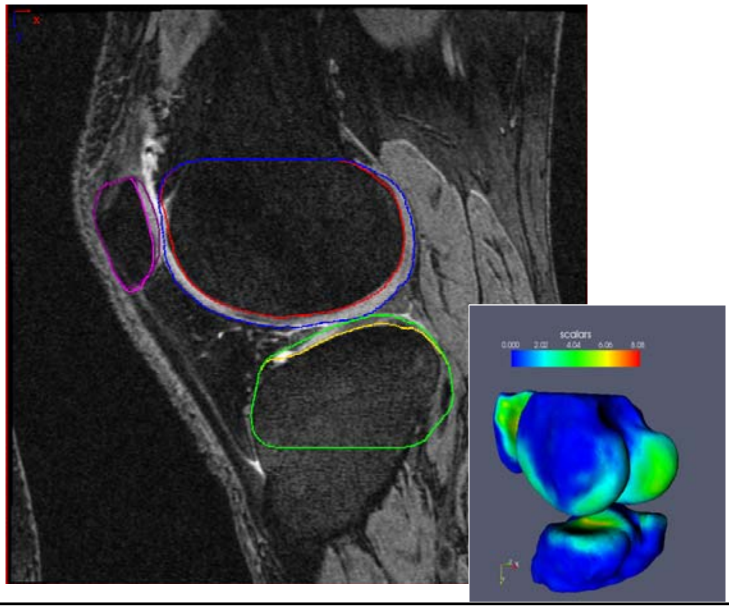


Retinal Image Analysis – ONH

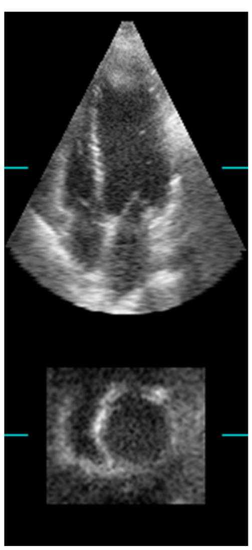


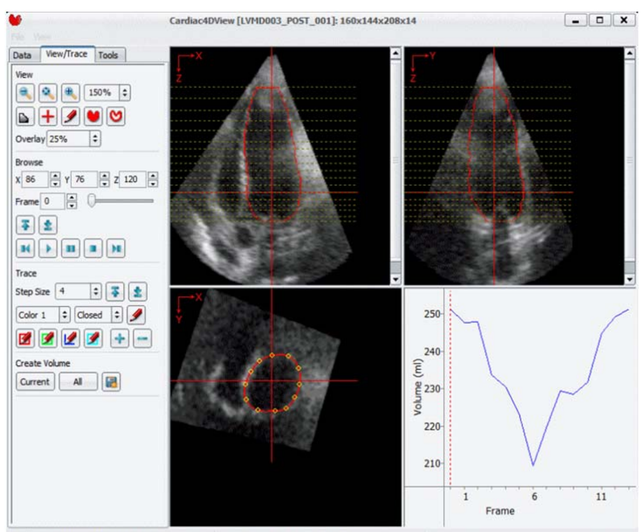
MR Images of Knee Joint

MR Images of Knee Joint



RT3DE





LOGISMOS: Layered Optimal Graph Image Segmentation of Multiple Objects and Surfaces

- Single surfaces
- Multiple interacting surfaces
- Cost functions
- Complex and topology-changing surfaces
- Multiple objects and multiple surfaces
- Non-segmentation use – Image Resizing & Stitching

Just Enough Interaction

- Robustness in clinical-quality images
- Close-to 100% success rate – Just Enough Interaction (JEI) paradigm.
- JEI paradigm inherently tied to LOGISMOS
- Highly efficient minimal (just-enough) user interaction to refine automated segmentation
- Clinically acceptable results obtained with no or only small increase in human analyst effort
- Pulmonary and IVUS case studies

Specific Translational Research Applications of LOGISMOS

- Ophthalmology
  - SEADs
  - Multi-field segmentation
- Cardiovascular imaging
  - IVUS
  - Aorta – DEMO
  - LV/RV
- Brain
  - Humans
  - Rats
- Cancer
  - Tumors
  - Lymph nodes
- Etc.

More Context, Shape Priors

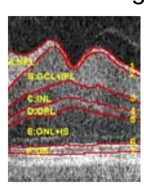
Details

Regional Priors

$$E = \frac{E_{gs}}{E_{region}}$$

Details

Shape & Context priors for multi-surface segmentation

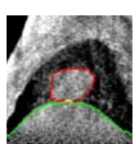


$$E = E_{gs} + E_{shape} + E_{context}$$

Details

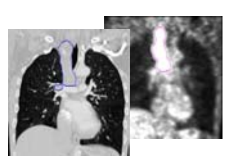
Surface-Region segmentation with context constraints

$$E = E_{gs} + E_{gc} + E_{context}$$



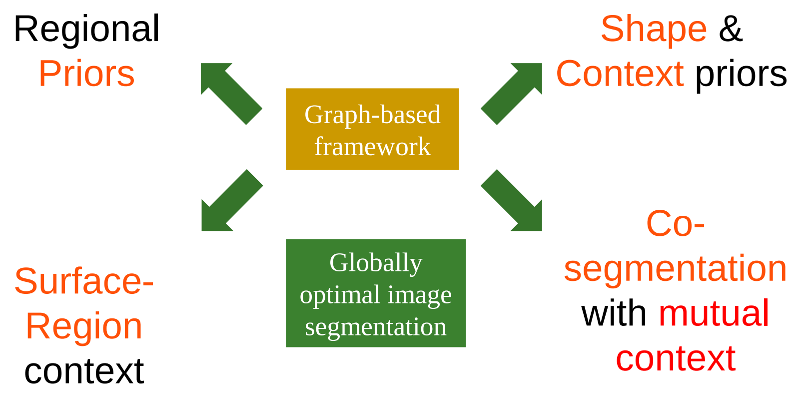
Details

Co-segmentation of multi-modality data with mutual context



$$E = E_{CT} + E_{PET} + E_{context}$$

Priors …



Conclusion

- A low-order polynomial-time algorithm for detecting multiple interacting optimal surfaces for multiple objects
- Optimality achieved with respect to cost function(s), smoothness constraints, mutual surface relationship constraints, mutual object-relationship constraints
- Many nice properties:
  - Complexity-bound is independent of the smoothness constraints
  - Solves the circular connectivity criterion of cylindrical surfaces with no performance penalty
  - Directly extendible to n-D

Conclusion

- Novel graph-based approaches for multi-object – multi-surface segmentation
- Incorporation of
  - Regional information
  - Shape priors
  - Context
    - Surface to surface
    - Object to object
    - Modality to modality
- Globally optimal solution obtained in low-order polynomial time via single maximum flow
- Performance improvement demonstrated in numerous applications

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This is a TEAM Work

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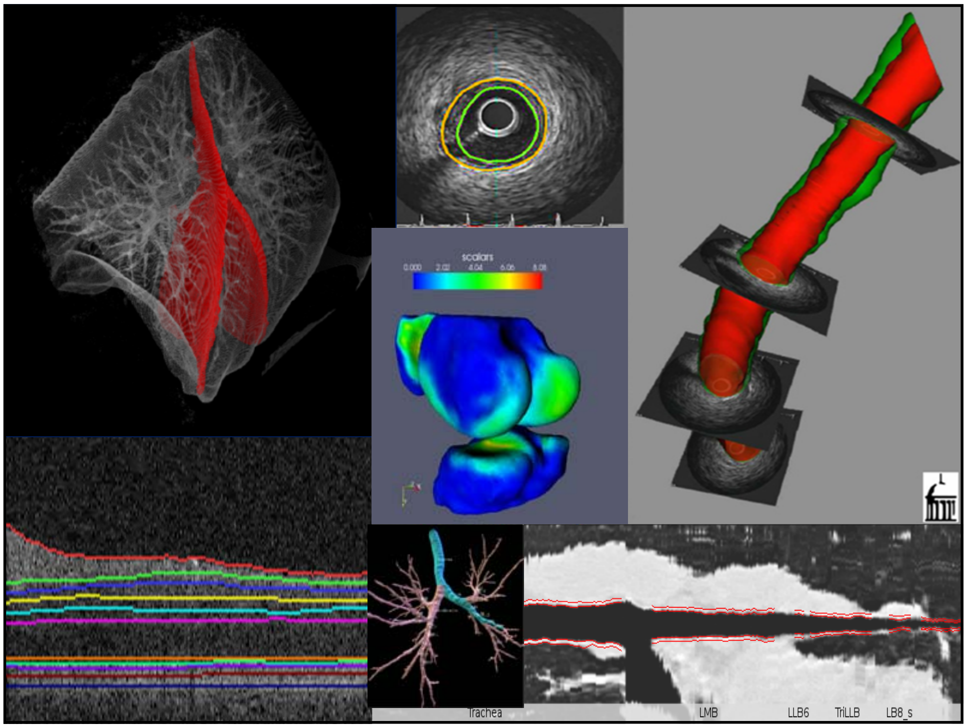
scalars
0.000 2.02 4.04 6.06 8.08
Trachea
LMB
LLB6
TriLLB
LB8_s