Recent Advances in Virtual Tools for Validation of 3D/4D Breast Imaging Systems (TG234)

Development of a virtual breast phantom from a multi-modality perspective

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Motivation

- diversity of breast imaging modalities beyond x-ray
  including magnetic resonance and ultrasound, recommended for screening by ACR
- hybrid imaging systems (PET/CT)
- following a patient through a diagnostic workflow
- inter-modality comparisons important for public health
- not having to re-invent the wheel

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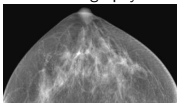
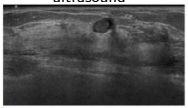
Multi-modality considerations

magneticc resonance[1]

mammography[2]



ultrasound[3]



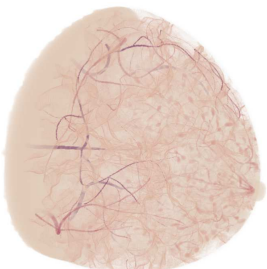
- resolution
- positioning
- complexity - different modalities may be sensitive to different biological features
- paradigm - procedural vs image-driven

Credits: [1] S. Kohara, Nagoya U. School of Medicine, [2]E Lee, Soonchunhyang U, [3]HJ Shin, Ulsan College of Medicine, CC License

Project Goals

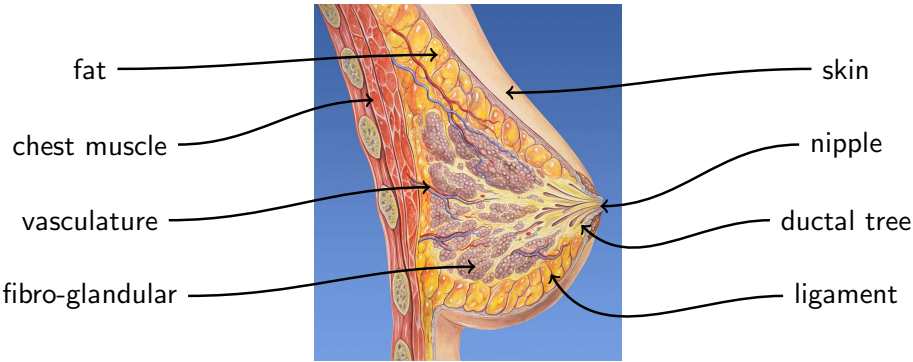
Develop a virtual breast phantom that is...

- procedurally generated,
- incorporates major breast anatomical structures,
- flexible,
- ... and multi-modality.



Anatomy

Several major tissue types that effect breast function and appearance of breast images:

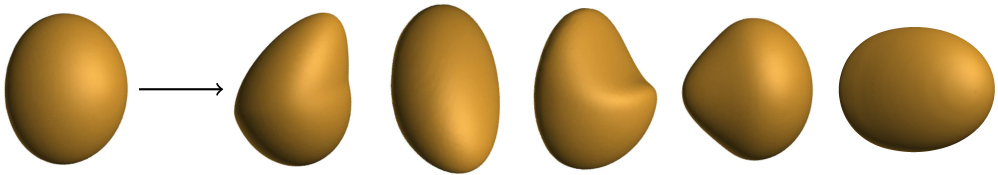


credits: Patrick J. Lynch; C. Carl Jaffe, MD

Surface Shape*/Skin/Nipple

base super-quadric

transformations



*based on Chen, D., et al. Modeling for plastic and reconstructive breast surgery, Proceedings MICCAI, LNCS 1935, (2000).

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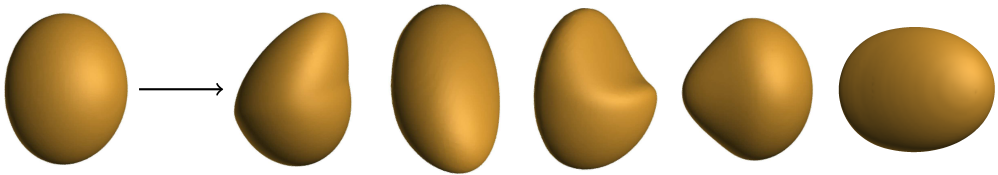
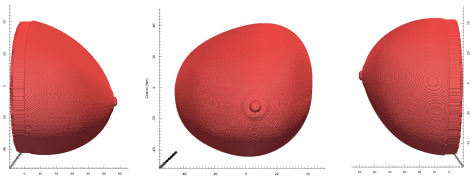


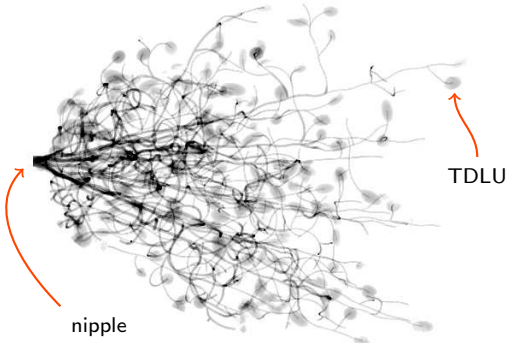
skin/nipple layer
grown on transformed shape



*based on Chen, D., et al. Modeling for plastic and reconstructive breast surgery, Proceedings MICCAI, LNCS 1935, (2000).

Ducts/TDLUs

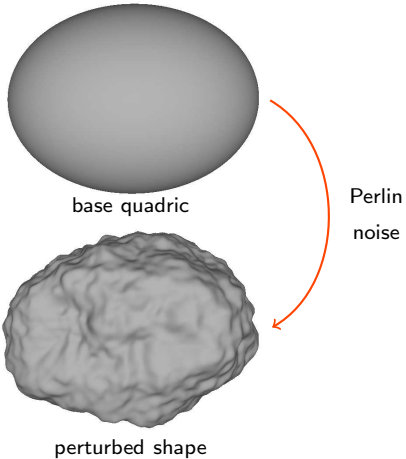
- one duct tree per glandular compartment
- terminal duct lobular units (TDLU)
- random branching toroidal segments
- cost function to promote growth in nipple-chest direction and filling of compartment



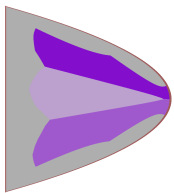
ductal tree with TDLU

Lobules/Ligaments

- add random fat lobules to glandular compartment
- base quadric shape perturbed by Perlin noise
- retain functional ducts/TDLUs
- create more complex fat/glandular interface
- control fat fraction

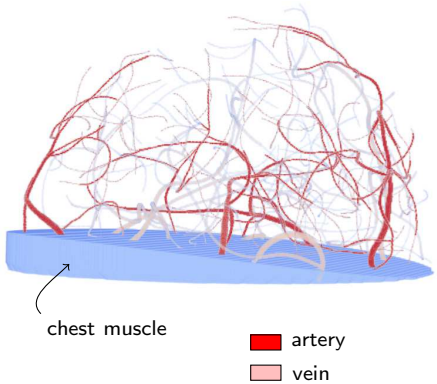


initial voronoi fat/glandular segmentation



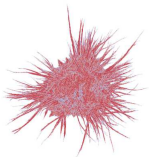
Vasculature

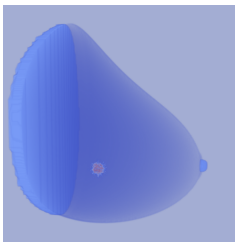
- blood supply from several major chest vessels
- generated similar to duct tree algorithm
- cost function tracks distance to vessel map



Pathology

- irregular shapes with spiculated growth*
- μ-calcs modeled as random clusters of spheroids
- randomly inserted in normal breast tissue



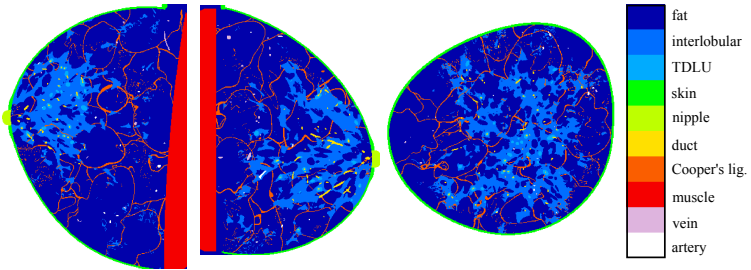


*Luis de Sisternes et al. *A computational model to generate simulated three-dimensional breast masses*, Medical Physics, **42**, 1098-1118 (2015)

Voxelized Phantom

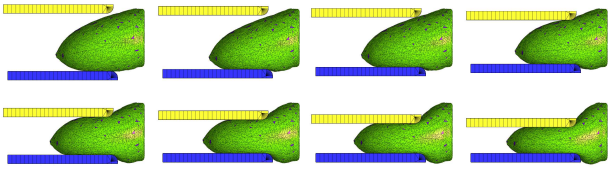
phantom rendering

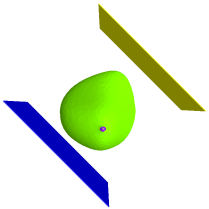
- voxelized phantom stored in compressed XML format
- 10 tissue types (additional abnormal tissue types)
- arbitrary resolution ($\geq$ 40 μm practical, here 100 μm)



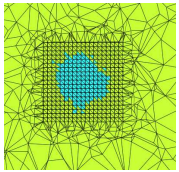
Compression Modeling

- finite element elastic compression simulation using FeBio*

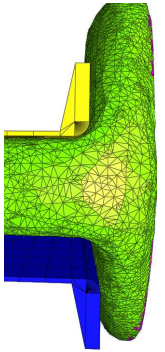




Arbitrary compression direction



Adaptive mesh size

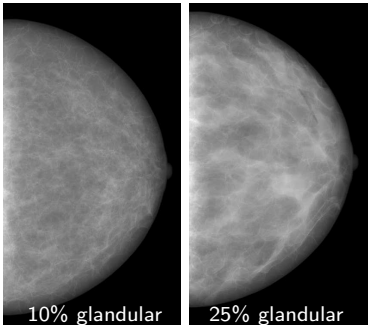


Dynamic re-meshing for large deformations

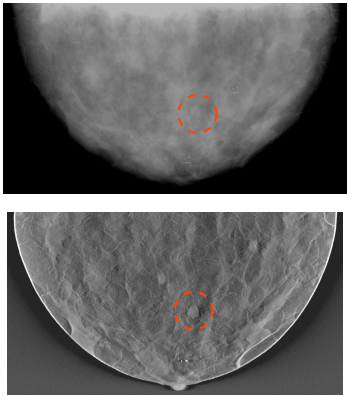
*joint work with Jonathan Rosenberg FDA/UMD

Images

mammographic projections

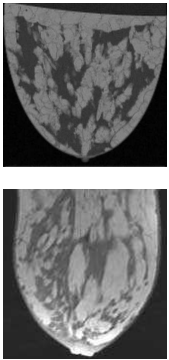


mammography and DBT of same breast with inserted masses*



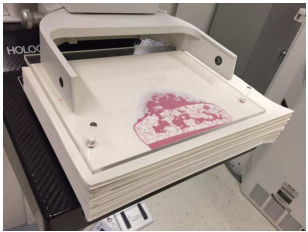
*credit: VICTRE team

T_1-weighted MRI
simulated (top)
real (bottom)

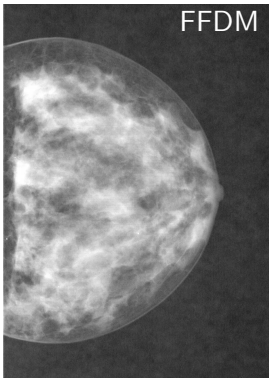


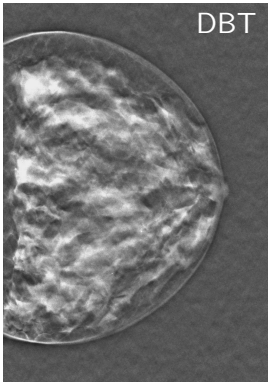
Physical Phantoms

- Exploring 3D printing including innovative ink jet printer technique*



printed as 70 μm slices on parchment paper with iodine-doped ink





*joint work with Lynda Ikejimba, Shani Rosenthal, Andreu Badal-Soler, Bahaa Ghammraoui, Joseph Lo and Steve Glick

Challenges

- modality-specific tissue properties
- anatomical parameter distributions
- validation
- motion/dynamic properties
  (e.g., MRI often uses dynamic contrast)

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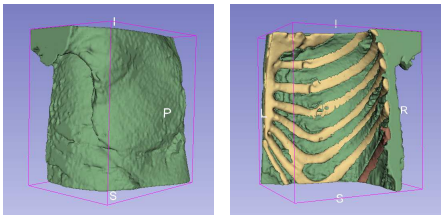
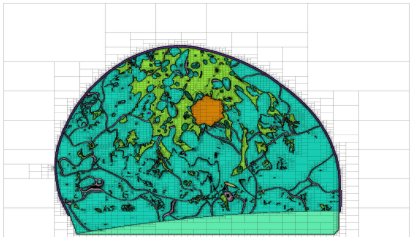
Sample of Ongoing Work



- Using segmented CT data to provide muscle/bone structure for more realistic MLO views



- binary trees for efficient representation of high resolution in silico phantoms

see ePoster by Andreu Badal, TU-H-CAMPUS-IeP2-4, Tuesday, 5-5:30 PM

Application: VICTRE

Virtual Imaging Clinical Trials for Regulatory Evaluation

- FDA research project to study the use of VCTs for regulatory evaluation of imaging devices
- replicate an existing DBT clinical study in silico
- results and virtual imaging chain will be released as open source

Aldo Badano
project lead

Andreu Badal
x-ray physics

Christian Graff
anatomical models

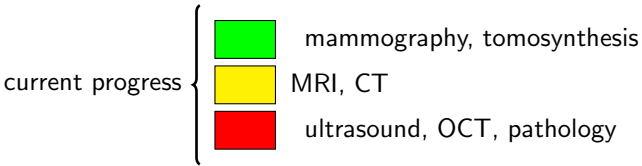
Frank Samuelson
study design

Diksha Sharma
software development

Rongping Zeng
image recon/reader models

Conclusions

- Developing multi-modality phantoms can be challenging



- Potential for collaboration across modalities
- Regulatory use could lead to faster/less burdensome approval of new imaging technologies