Disclosure Statement
I receive research funding from ...

UNIVERSITY OF MICHIGAN
National Center Institute
U.S. National Institutes of Health | www.cancer.gov
VARian medical systems | A partner for life

Act I

Turning Patients into Numbers

# images
# rows
# cols

16 bits
Δx, Δy, Δz

René Magritte
The best metric for image resolution is:

1. Pixel Size
2. Slice thickness
3. Number of bits
4. Minimum resolvable line pair
5. Slice thickness x pixel size x pixel size
Question 1
The best metric for image resolution is

4. Minimum resolvable line pair

Reference ACT I

Act I
Turning Patients into Numbers

Computed Tomography
Magnetic Resonance
Nuclear Medicine

Physics
Anatomy
Physiology

Act II
Turning numbers into other numbers

Patient Modeling
Definition of Plan Geometry

Plan Evaluation
Implementation of Therapy

Image Processing

Enhancement
Visualization
Segmentation
Registration
Quantification

Anniversary Paper: Image processing and manipulation through the pages of Medical Physics

Santos O. Aranha Jr. 2011
Department of Radiology, The University of Chicago, 5841 South Maryland Avenue, Chicago, Illinois 60637
Brain and Spine Center Image Sciences Institute, University Medical Center Utrecht, Heidelberglaan 100, Room 102.4.10, 3584 CE Utrecht, The Netherlands

2008
Image Processing for T_x Planning

Enhancement
- enhance / suppress features or noise for delineation

Visualization
- n-D rendering for delineation planning & evaluation

Segmentation
- delineation for planning, evaluation & registration

Registration
- fusion to support improved delineation

Quantification
- improved delineation and dose calculations

Question 2
I would like you to concentrate on ...

1. Enhancement
2. Segmentation
3. Registration
4. Visualization
5. Quantification

Question 2
I would like you to concentrate on ...

20% 1. Enhancement
21% 2. Segmentation
20% 3. Registration
19% 4. Visualization
20% 5. Quantification
Each representation has pros and cons!
40 - 100+ images / series
5 - 10+ structures / image

numbers turned into other numbers

margins & field shaping

point samples for IMRT calcs
Image Segmentation
numbers turned into other numbers

circa 1988 (… 2009?)
40 - 100+ images / series
5 - 10+ structures / image

… now we also have 4D CT!
Multiple breathing states!
40 - 100+ images / phase
5 - 10+ structures / image

Image Segmentation
numbers turned into other numbers

Numerous MD outlines
Couple of Experts + Image Processing

PHYSICS CONTRIBUTION
REDUCE VARIATION AND IMPROVE EFFICIENCY OF TARGET VOLUME DELINEATION BY A COMPUTER-ASSISTED SYSTEM USING A DEFORMABLE IMAGE REGISTRATION APPROACH

user beware!

adjust intensity mapping
Different Thresholds

PET / CT

% max SUV

Scene

Object

Background

Image Segmentation

Intensity

Scene

Object

Background

Does a \textit{mm} make a difference?

Volume of Sphere = \(\frac{4}{3} \pi r^3 = \pi \frac{d^3}{6}\)

and \(\delta V = (\pi \frac{d^2}{2}) \delta d\)

then \(\frac{\delta V}{V} = \{\pi \frac{d^2}{2} \delta d\} / \{\pi \frac{d^3}{6}\}\)

or \(\frac{\delta V}{V} = 3 \frac{\delta d}{d}\)

... adding a \textit{1 mm} margin to a \textit{6 cm} target increases the volume by 10%!

\(\frac{\delta V}{V} = 3 \frac{\delta d}{d} = 3 \cdot 2 \times 1 \text{mm} / 60 \text{mm}\)

\(= 0.1 = 10\%\)
Image Segmentation

numbers turned into other numbers

➢ We need to automate!
➢ We need to standardize!

Image Processing to the Rescue

Question 3

Image processing is important for

<table>
<thead>
<tr>
<th></th>
<th>1. Enhancement</th>
<th>2. Segmentation</th>
<th>3. Registration</th>
<th>4. Visualization</th>
<th>5. All of the above</th>
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<td>%</td>
<td>15%</td>
<td>25%</td>
<td>30%</td>
<td>20%</td>
<td>20%</td>
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Question 3

5. All of the above

Image Segmentation

Edge detection
Clustering methods
Histogram-based
Region growing
Level set methods
Graph partitioning
Watershed transform
Model based
Image Segmentation

Boundary Methods
- simple edge detection - high contrast objects
- deformable models - active contours / surfaces

Region Methods
- feature space - image intensity
- region growing / voxel recruitment
- morphologic techniques

Edge Detection

Good detection
algorithm should mark as many real edges in the image as possible

Good localization
edges marked should be as close as possible to the edge in the real image

Minimal response
a given edge in the image should only be marked once, and where possible, image noise should not create false edges.

Edge Detection

\[
G = \sqrt{G_x^2 + G_y^2}
\]

Sobel kernel

Image Processing Basics

Original

... just a bunch of numbers
**Edge Detection**

Original * Sobel kernel = Filtered

**Sobel kernel**

**Smoothing**

<table>
<thead>
<tr>
<th>2</th>
<th>4</th>
<th>5</th>
<th>4</th>
<th>2</th>
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<td>9</td>
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<td>4</td>
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<tr>
<td>5</td>
<td>12</td>
<td>15</td>
<td>12</td>
<td>5</td>
</tr>
</tbody>
</table>

\[
s = \frac{1}{115}
\]

**Gaussian kernel**

\[
\sigma = 1.4
\]

**Smoothing**

Original * Gaussian kernel = Filtered

**Gaussian kernel**

**Edge Detection**

Original * Gaussian then Sobel kernel = Filtered

**Gaussian then Sobel kernel**

"our objects are "closed"
Image Segmentation

Boundary Methods
- simple edge detection - high contrast objects
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Region Methods
- voxel recruitment - region growing
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- morphologic techniques

Model-based Segmentation

Simple analytic shapes
super-quadrics, spherical harmonics

Population averaged models
mean position and variance

Model-based Segmentation

3D extension of Snakes / Active Contours

Model-based Segmentation

Place model into image volume

right kidney

Circa 1992
Model-based Segmentation

Optimize model to match image data

\[ E_{\text{total}} = \omega E_{\text{int}} + E_{\text{ext}} \]

- \( E_{\text{int}} \) = model forces (curvature, elastic, population variance)
- \( E_{\text{ext}} \) = image forces (edges/surfaces)

raw edges
filtered edges

optimizing
\[ E_{\text{total}} \text{ minimized} \]
Model-based Segmentation

Segmentation Example

Model-based Segmentation

Segmentation Example

Tracking prostate during treatment using segmentation from ultrasound
Model-based Segmentation

- Initialized
- Optimized

Atlas-based Segmentation

Image Segmentation
Object Representation

Object  Boundary  Region

Each representation has pros and cons!

Image Segmentation

Boundary Methods
- simple edge detection - high contrast objects
- deformable models - active contours / surfaces

Region Methods
- voxel recruitment - region growing
- feature space - image intensity
- morphologic techniques

Image Segmentation

Boundary Methods
- simple edge detection - high contrast objects
- deformable models - active contours / surfaces

Region Methods
use some feature of the data to determine the intrinsic grouping in a set of unlabeled data

... think "membership"

Intensity Feature

Simple intensity thresholds
Intensity Feature

Simple intensity thresholds

Simple intensity thresholds

Intensity Feature

"fuzzy" thresholds

a voxel can be a member of more than one group...

... use intensity vectors

Vector Intensity Feature
Vector Intensity Feature

PET  CT  PET / CT

... from different modalities!

Image Segmentation

numbers turned into other numbers

user beware!

Image Segmentation

Image Segmentation

Watershed Transform

... consider gradient magnitude of an image as a topographic surface
**Image Segmentation**

**Image Processing to the Rescue**

**Validation Studies**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Surgical specimen</th>
<th>Simple Threshold</th>
<th>Gradient-based method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.1</td>
<td>4.7</td>
<td>4.7</td>
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<tr>
<td>2</td>
<td>5.2</td>
<td>7.4</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Total laryngectomy – surgical specimen is sliced, digitized, delineated, and registered

<table>
<thead>
<tr>
<th>Total laryngectomy – surgical specimen is sliced, digitized, delineated, and registered</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>mean</td>
</tr>
<tr>
<td>RMSE</td>
</tr>
</tbody>
</table>

* Daisne, Gregoire

**Segmentation / Registration**

**Image Registration**

**Transformation Models**

- **Series A**: Identity? Rigid Deformable
- **Series B**: How many DOF?

- **0**
- **3 or 6**
- **3 x N**
Image Registration

Geometric / Physical Methods
- Point matching
- Surface matching
- Finite element models

Intensity Methods
- Cross correlation / SSD
- Diffusion / Demons
- Mutual information

Registration / Segmentation

Structure Mapping / Propagation
- ...what about doing this for doses too?

Original Segmentation
Mapped Structure

Registration / Segmentation

Several independent products are there or almost there!

I have no commercial interest in any of these companies.

Multimodality Targeting

Morphology
GTV
PTV

Hypoxia
- PET
- F-miso

Tumor Burden
- MRI/MRS
- choline / citrate

Tumor Growth
- PET
- IUDR

Biology versus Morphology

Biological Target Volume

Ling / MSKCC

I have no commercial interest in any of these companies.
**Multimodality Targeting**

- MR volumes mapped to CT study

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**Act II**

*Turning numbers into other numbers*

- Patient Modeling
- Definition of Plan Geometry
- Plan Evaluation
- Implementation of Therapy
Image Processing Basics

\[ g(x) = H[f(x)] \]

Image processing is any form of signal processing for which the input is an image.
Image Processing Basics

\[ f(x) \rightarrow \text{System } H \rightarrow g(x) \]

\[ g(x) = \text{kernel} \otimes f(x) \]

Convolution

Convolution

\[ g(x) = \int \text{kernel}(\tau) \cdot f(x-\tau) d\tau \]

\[ a \otimes b = \mathcal{F}(a) \cdot \mathcal{F}(b) \]

Convolution theorem

Convolution

Did we just add a margin to the object?
Image Processing Basics

The gradient of an image is one of the basic building blocks in image processing.