PET Image Segmentation for Radiation Therapy

Handout
(images available upon request)

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PET auto-segmentation

I. Types of PET segmentation tasks
   - Treatment planning: a) segmentation; b) dose painting
   - Treatment Assessment
   - New PET tracer Evaluation

II. Classifications and examples

III. Limitations: PET image specifics, inaccuracy and uncertainties

IV. Challenges for contour evaluation

Image segmentation is a two stage process

- Recognition
  - a high level process

- Delineation
  - a low-ER level process

Deficiencies of manual PET Segmentation

- Large intra and inter-observer variation
- Image windowing
- Time consuming

Classifications of PET auto-segmentation methods

Classification of Zaidi & El Naqa, EJNM 2010

- Thresholding:
  - fixed and variable threshold

- Variational:
  - region growing, level sets, gradient, active contours

- Learning:
  - supervised (classif.) or unsupervised (clustering)
    - K-means, fuzzy C-means

- Stochastic:
  - Expectation maximization (EM); EM + spatial dependence

  - J. Lee, Radiotherapy & Oncology, 96, p.302, 2010

1. Fixed threshold
   - 40 % of Peak Activity (or 36 to 44 %), Erdi et al, 1997
   - 50% Mah et al, IJROBP 2002,
   - 40% Bradley et al, IJROBP 2004
   - SUV = 2.5, Paulino et al, IJROBP, 2005
   - ...

Biehl et al 2006 (J. Nuc. Med. 47, 1808) : "No single threshold ... provides accurate volume definition..."
2. Adaptive threshold methods

- Black et al, IJROBP 60(4), p 1272, 2004:
  \[ T_{SUV} = 0.307 \times (\text{mean target SUV}) + 0.588 \]
  optimized for their scanner and procedures!

- Nestle et al, J N M, 46 (8) p. 1342, 2005:
  \[ I_{\text{threshold}} = (0.15 \times I_{\text{mean}}) + I_{\text{background}} \]
  optimized for their scanner and procedures!

- Nehmeh et al, Med. Phys. 36, p.4803, 2009:
  Iteratively find a point on the correlation between threshold and volume
  optimized for their scanner and procedures!

Such methods may need re-adaptation and adjustment if used on a different scanner or protocol!

3. Advanced methods: customization also required, more or less

- Gradient based:
  - Geets et al, 2007; ... SNM 2010: Nelson et al, abstract # 24, Yang C, abstract # 28
  - Region growing: Li et al, 2008; Day et al, 2009, ...

- Statistical:
  - K- Means clustering
  - Markov Models, Montgomery et al, 2007, Hatt et al, 2007, ...
  - Stochastic, Hatt et al, 2008, Dewalle-Vignon et al, 2011...
  - Textural, Yu et al, 2009; ..., Maroy et al, SNM 2010, abstract # 23
  - ...

- Combination: artifact correction + segmentation
  - De Bernardi et al, Med. Phys. 2009,
  - Bhatt et al, SNM 2010, abstract # 1290

Factors affecting PET Accuracy

- Biological - glucose level, inflammation, patient comfort (stress), motion..

- Physical - positron annihilation physics, detector limitations, reconstruction,

- Technical - activity specification, administration, time of injection, ...


Evaluation criteria for segmentation algorithms

- Accuracy (validity)
- Precision (reliability)
- Efficiency (viability)


- Robustness


Effect of the main physical PET artifacts on segmentation accuracy

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect on segmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET Resolution</td>
<td>Smearing; threshold depends on object size</td>
</tr>
<tr>
<td>Attenuation</td>
<td>Shifts and artifacts =&gt; relative voxel intensities</td>
</tr>
<tr>
<td>Photon Scatter</td>
<td>Local intensities after attenuation correction</td>
</tr>
<tr>
<td>Reconstruction</td>
<td>OSEM: Ringing artifacts; iteration number; filters</td>
</tr>
<tr>
<td>Registration</td>
<td>Attenuation artifacts, and scatter artifacts</td>
</tr>
</tbody>
</table>

Challenges in contour evaluation TG211:

- Experimental images
  - Simple phantoms - unrealistic
  - Realistic phantoms - expensive
  - Patients - ground truth

- Simulated images
  - Monte Carlo simulated - expensive
  - Analytically simulated - approximate
Selection of evaluation criteria

TG211:

- **Unknown ground truth**
  - Dice similarity index $\sim N(\text{overlap}) / N(\text{mean})$

- **Known ground truth**
  - Classification Error $\sim N(\text{incorrect}) / N(\text{true})$
  - Sensitivity $\sim N(\text{correct}) / N(\text{true})$
  - Positive Predictive Value $\sim N(\text{correct}) / N(\text{predicted})$

- The ground truth has associated uncertainty:
  - Reversed-AUC, Shepherd T *et al*., Segmentation challenge, Univ. of Turku, May 2011

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Summary: PET image segmentation for RT

**A. Auto - segmentation methods**

- Potential use as an initial approximation for physicians
- Need robustness to non-uniform activity irregular shape tumors $\Rightarrow$ advanced methods
- Imperative evaluation and validation for each PET scanner model and protocol

**B. Both Manual and Auto – segmentation**

- Depend on segmentation task
- Limited by the physical and biological uncertainties of the PET images

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**Acknowledgements**

MC: Manus *et al*., Letters to the Editor, Int. J. Rad. Onc. Biol. and Physics, 60 (3) 2004:

- “We do not have answers to these questions but are wary of simple numerical class solutions that tend to simplify a very complex problem to a level where frequent exceptions could be made”

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MSKCC

- AAPM TG 211
- Caldwell, Curtis, Ph.D.
- Das, Shiva, Ph.D.
- De Bernardi, Elisabetta Ph.D.
- Geets, Xavier M.D.
- Gregoire, Vincent, M.D.
- Hatt, Mathieu Ph.D.
- Jeraj, Robert, Ph.D.
- Lee, John, Ph.D.
- Lu, Wei, Ph.D.
- Nelson, Arden, Ph.D.
- Nestle, Ursula, M.D.
- Schmidtlein, C. Ross  Ph.D.
- Schöder, Heiko M.D.
- Shepherd, Tony, Ph.D.
- Visvikis, Dimitris, Ph.D.