Utilizing Shape Models Composed of Geometric Primitives for Organ Segmentation

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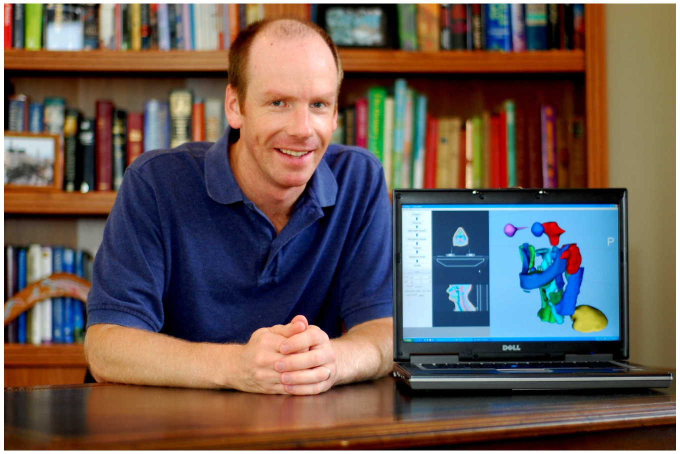
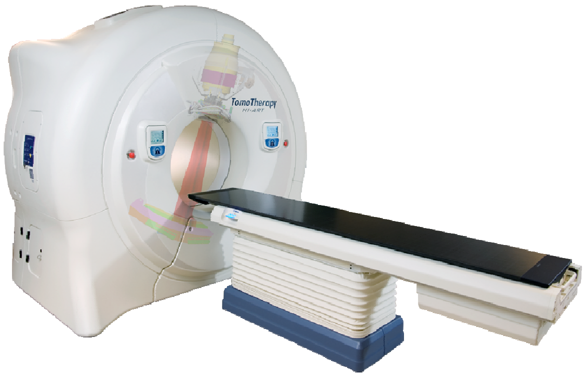
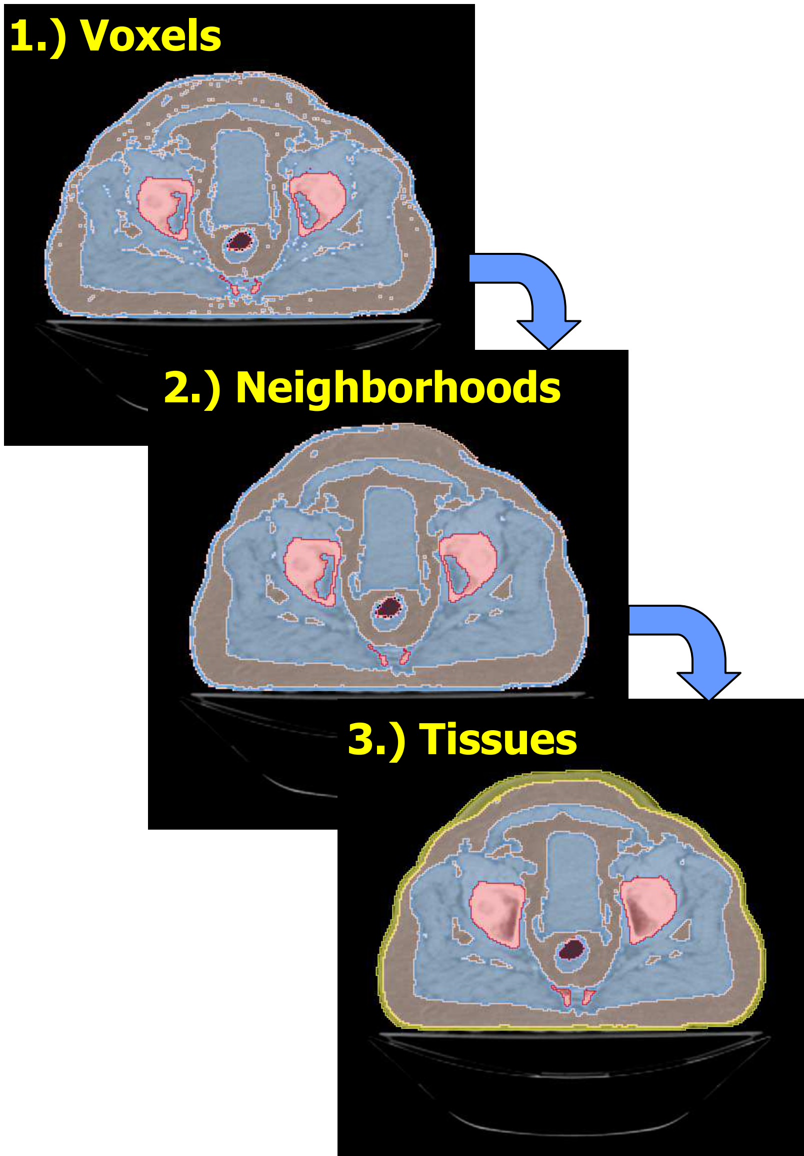
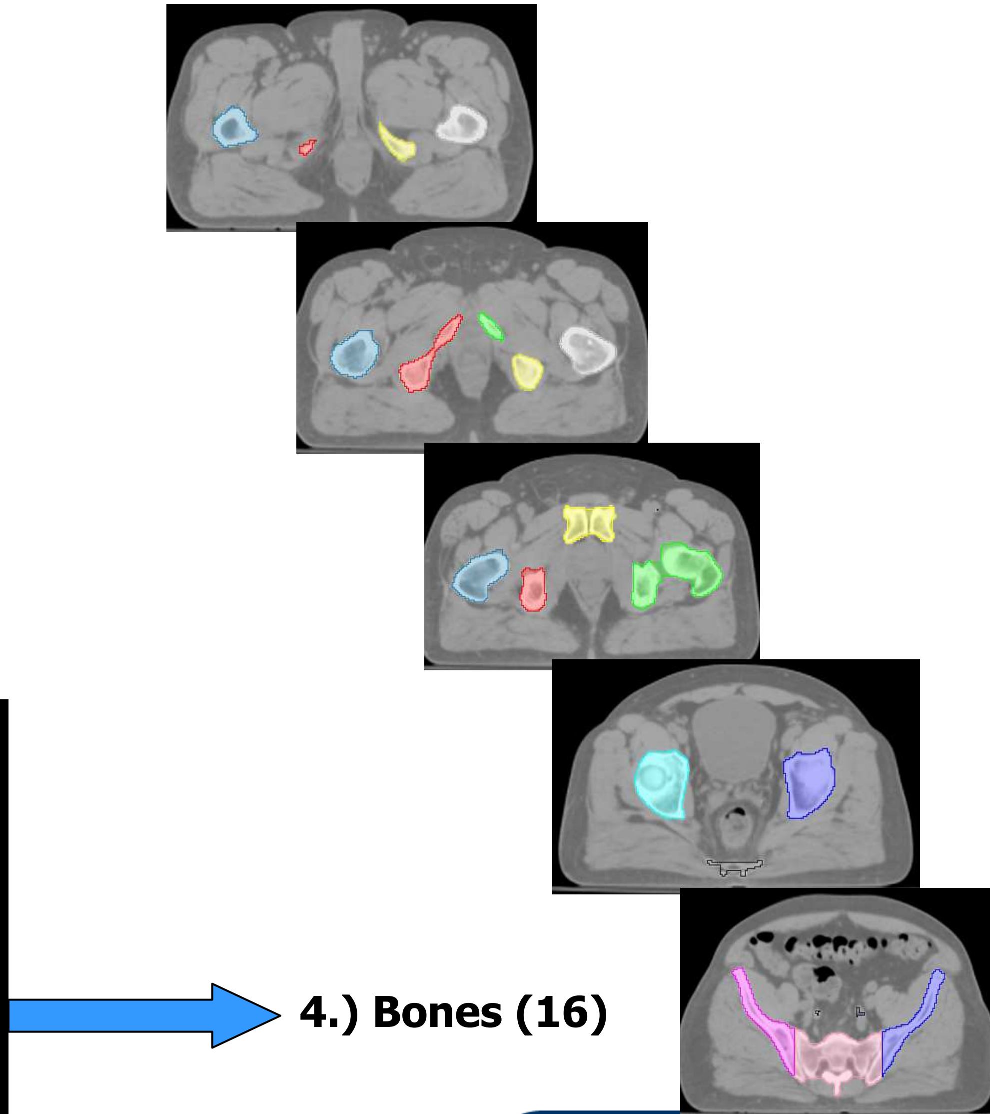




TomoTherapy Inc. Madison, WI

Begin with Tissues & Bones





Expectation Maximization

t = Tissue labels (Observable variables)
o = Organ labels (Hidden variables

S = Shape parameters
s' = Revised shape parameters

The Shapes help us map **observed Tissue** labels to **hidden Organ** labels.

Want to choose *s'* to **maximize** the **likelihood**: $\log p(o,t \mid s')$
But, we do not know $p(o,t \mid s')$ because *o* is unobserved.

We do know the **marginal** (integrate over all possible *o* values):

$$\log p(t \mid s') = \sum \log p(o,t \mid s')$$

So we also know the **expectation** (weight each by $p(o)$):

$$\langle \log p(o,t \mid s') \rangle = \sum p(o \mid t,s) * \log p(o,t \mid s')$$

EM Algorithm

E-Step (Expectation):

Update organ probabilities using current shape parameters.

$p(o \mid t,s)$

M-Step (Maximization):

Update shape parameters using current organ probabilities.

$s' \Leftarrow \arg\max \sum p(o \mid t,s) * \log p(o,t \mid s')$

Compute the likelihoods from training data

EM Algorithm

Possible Optimization Methods:

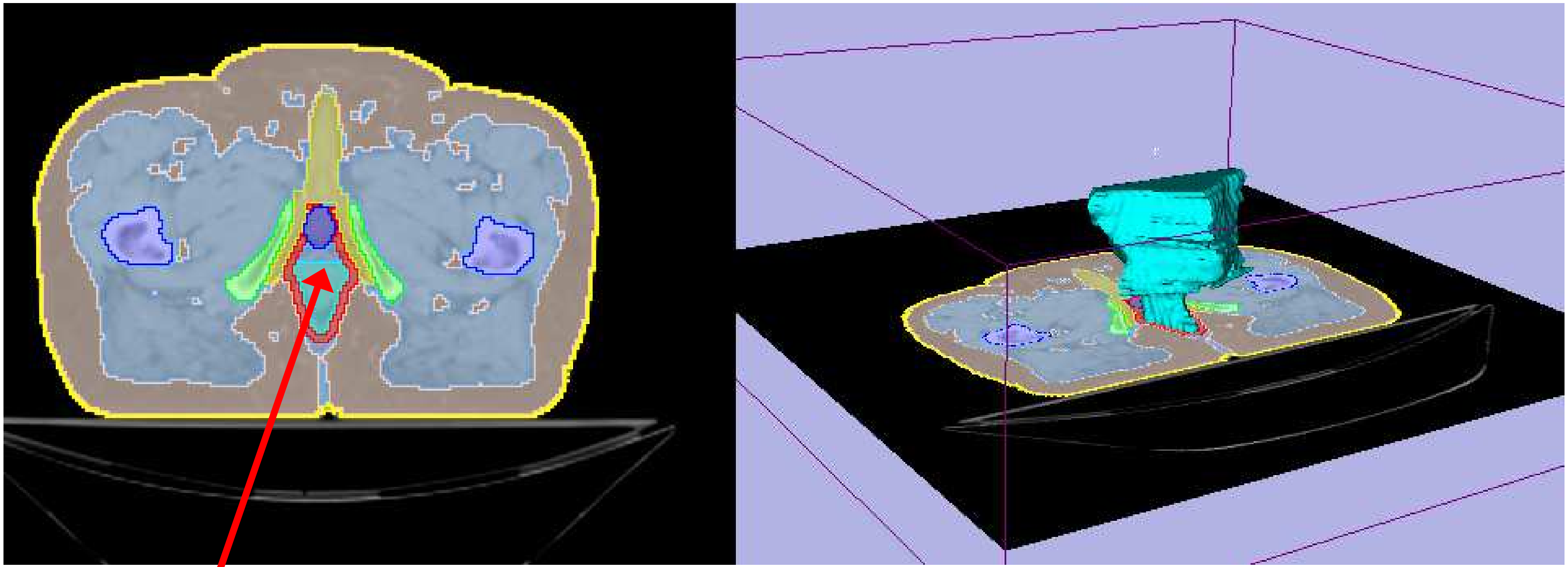
- Brute force (try every permissible set of shape parameters)
- Powell’s method (optimize each parameter one at a time)
- Efficient heuristic approximation

Ellipse has 5 parameters: x, y, r1, r2, theta

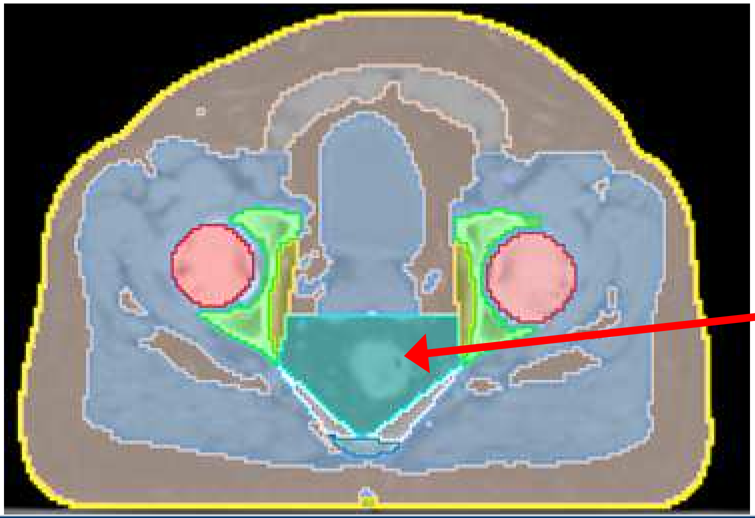
Heuristic Approximation: 6 Steps

1. Generate a **Zone** that limits where to look.
2. Generate a **Field** of candidate tissues within the Zone.
3. Recognize the **Object** within the Field that best matches expectations (e.g.: overlaps the object on the previous slice).
4. Fit a **Shape** model to the Object.
5. **Smooth** shape parameters over all slices.
6. **Refine** object boundary by reconciling shape and image data.

Step #1: Find zone (light blue)

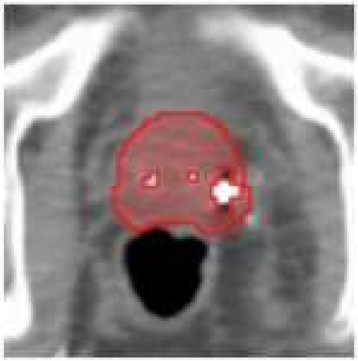


Inside Levator Ani, (red)
Below Penile Bulb (dark blue)

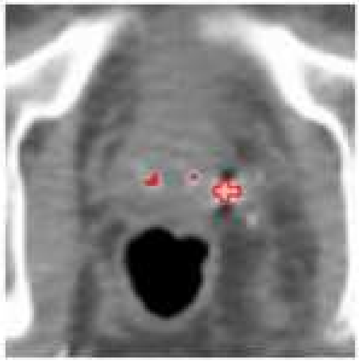


Above Pelvic Floor, (white)
Between Obturator Externus (yellow)

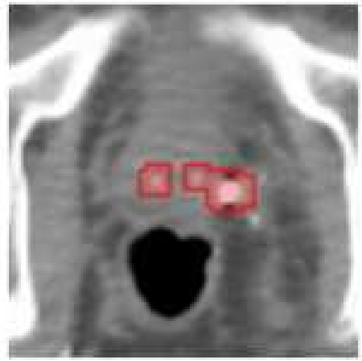
Step #2
(generate candidate tissues)



Muscle tissue within the Zone

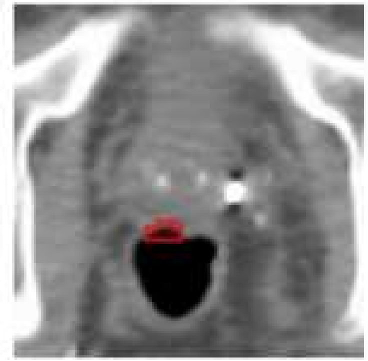


Implanted seeds

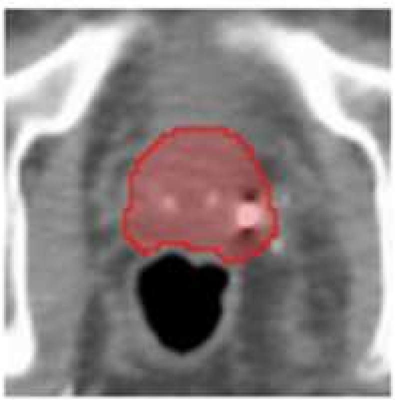


Dilated seeds which serve as an ROI for finding CT signal voids as artifacts

Signal voids

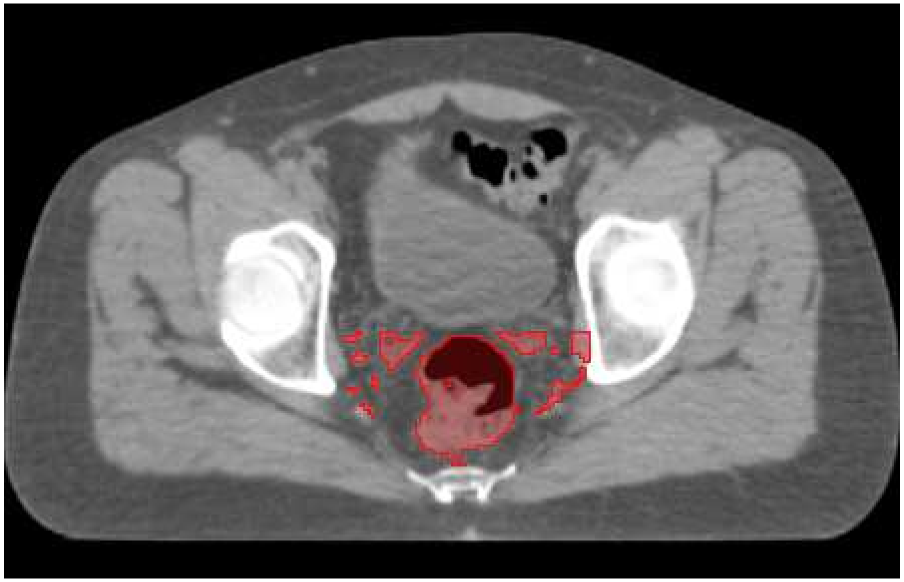


Air due to rectum rather than signal voids



Final = Muscle + Seeds + SignalVoids – RectumAir

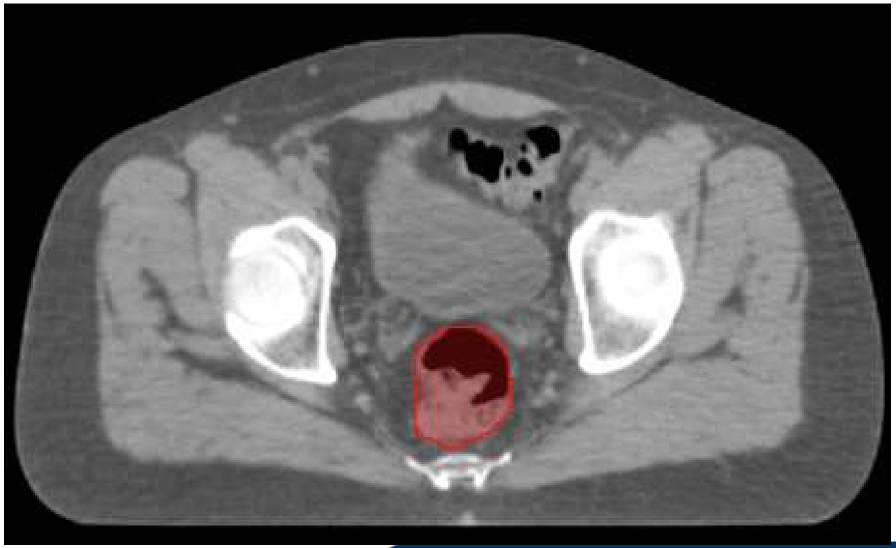
2.) Field of muscle/air tissue within the Zone.



4.) Fit ellipse to object.

3.) Object that best matches previous slice.

6.) Refine boundary.



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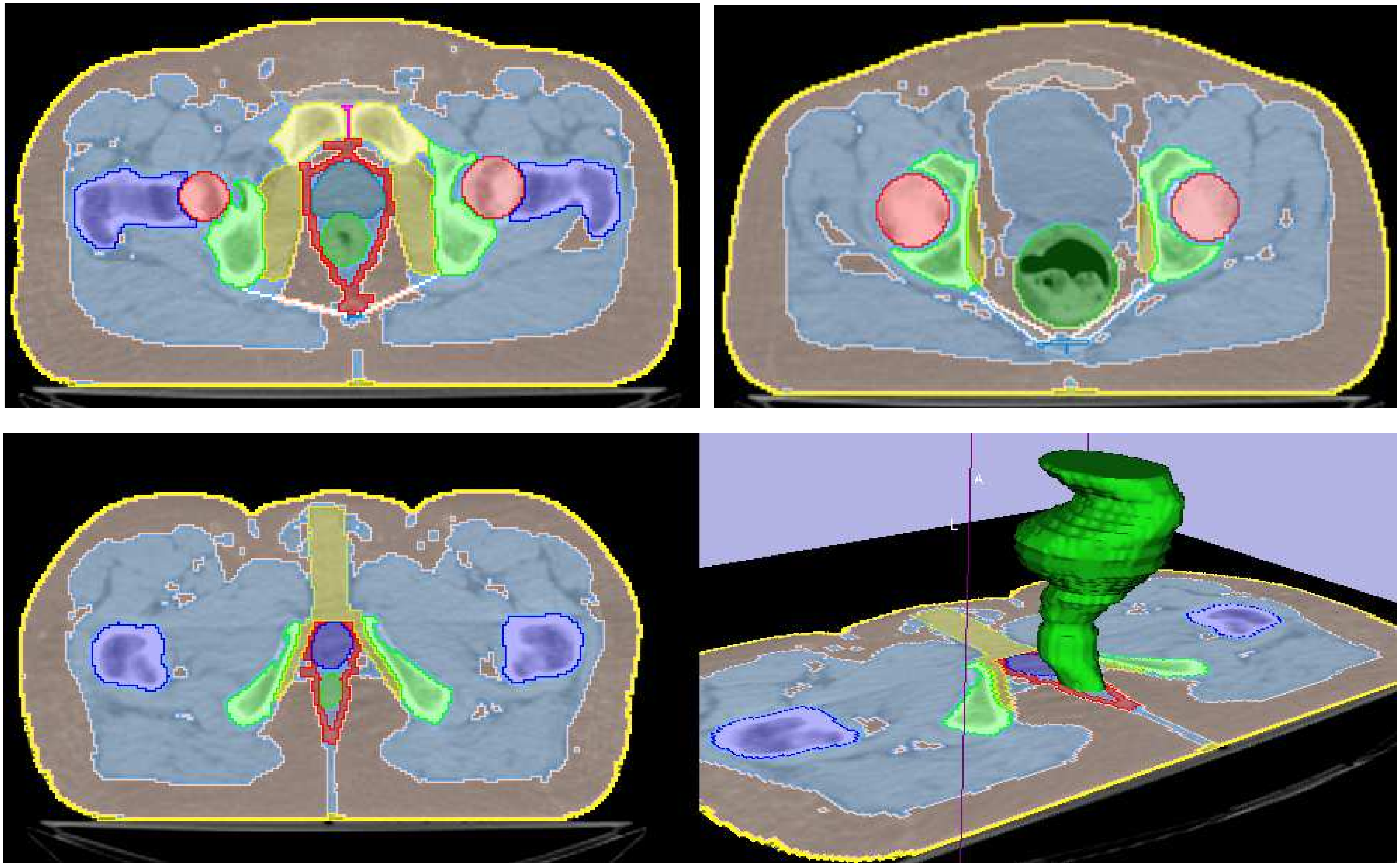
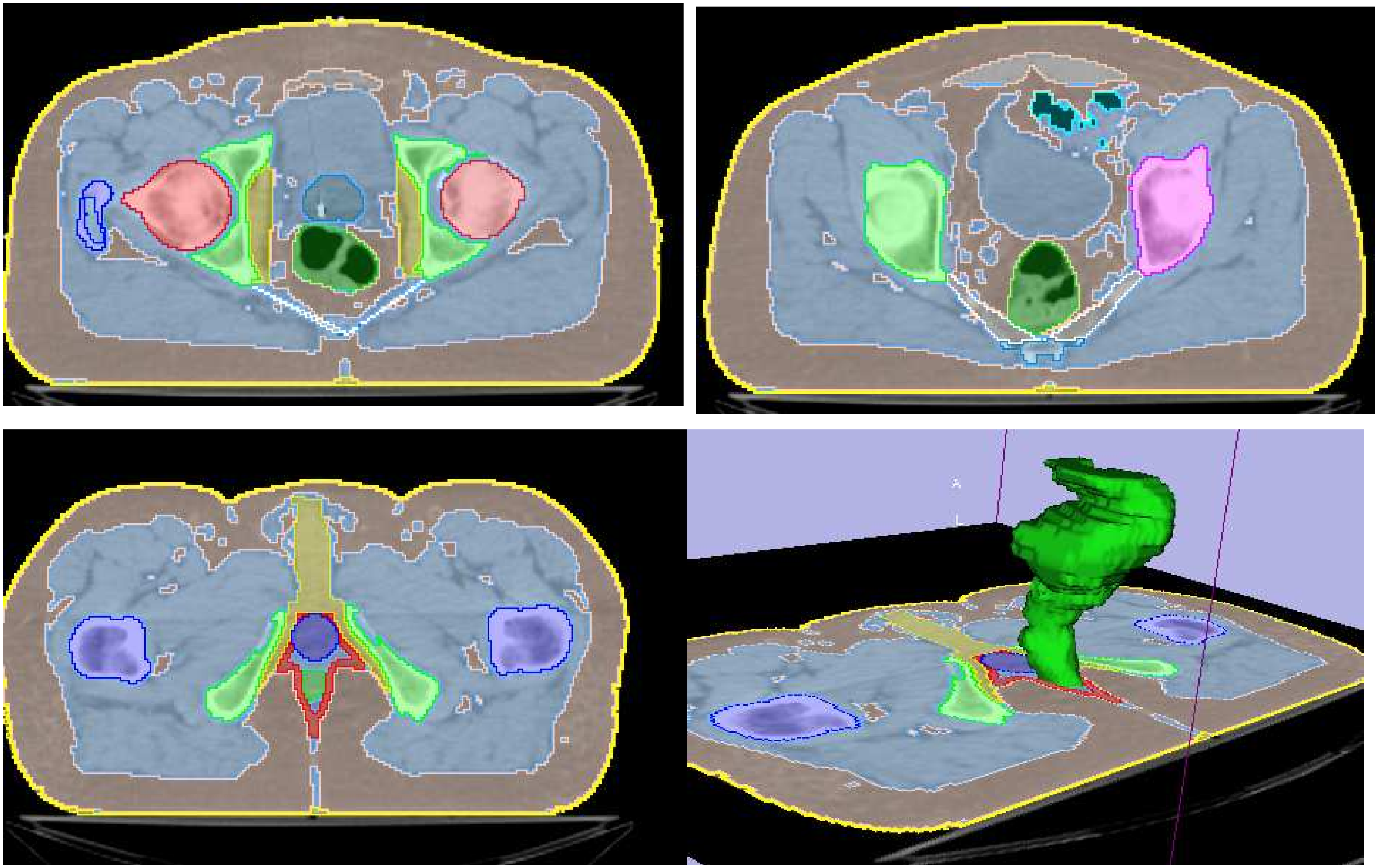
Rectum Shape model = smoothed stack of ellipses

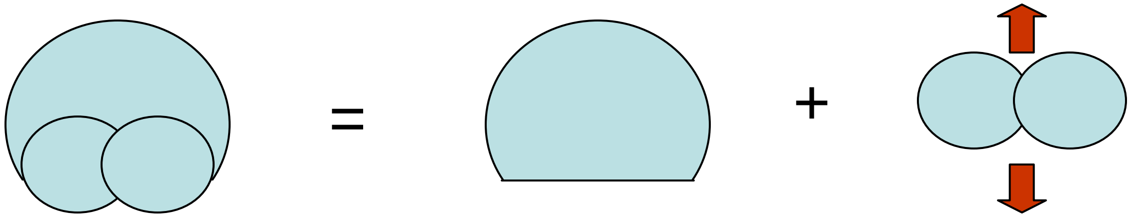


Final Rectum Segmentation (not elliptic, but similar)

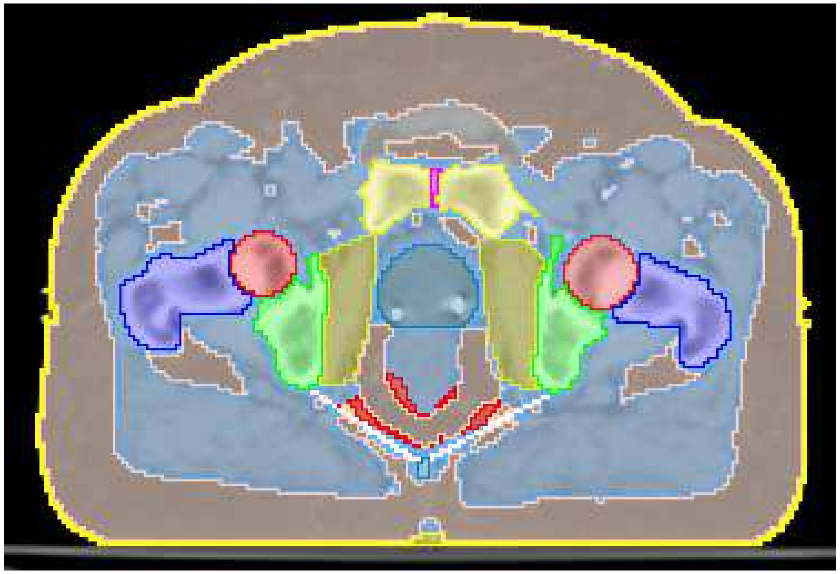


Prostate

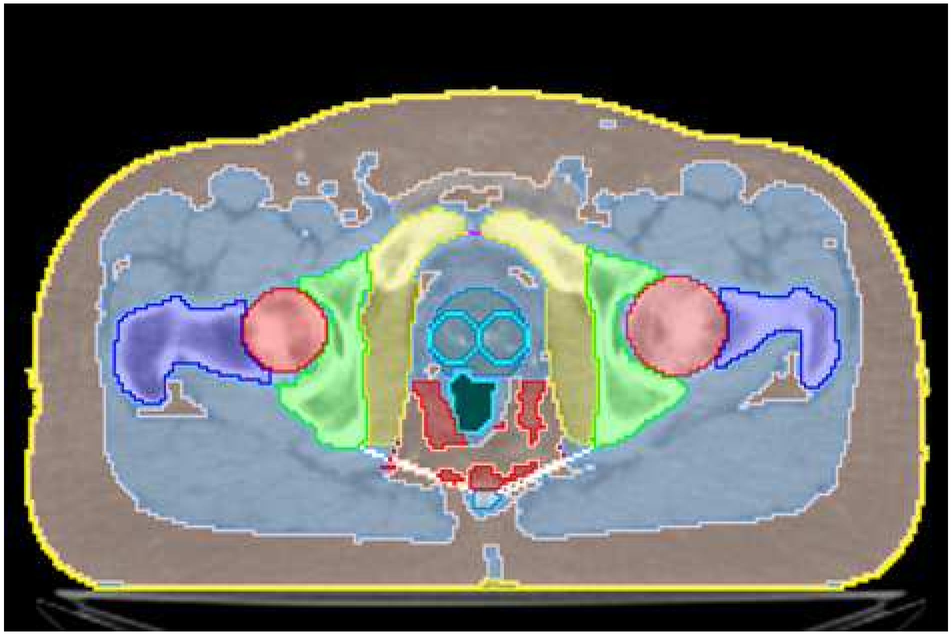
Shape model = (cut-off circle) + (round feet)



Circle with bottom ¼ cut off.

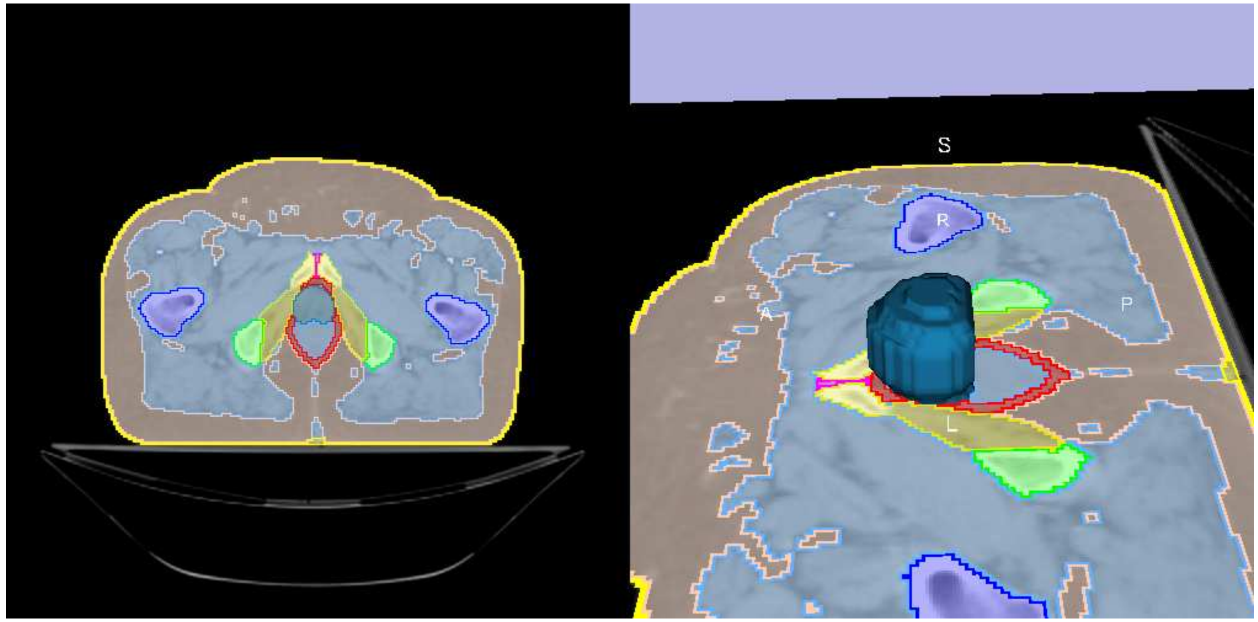


Feet (light blue) are lowered into position until reaching edge of muscle tissue.

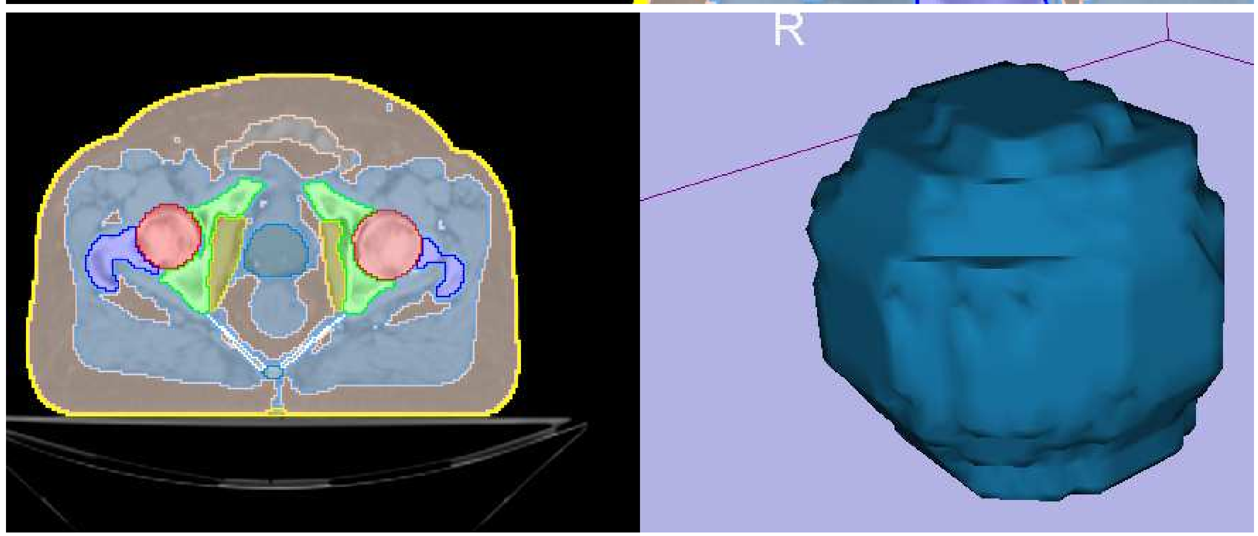


Prostate

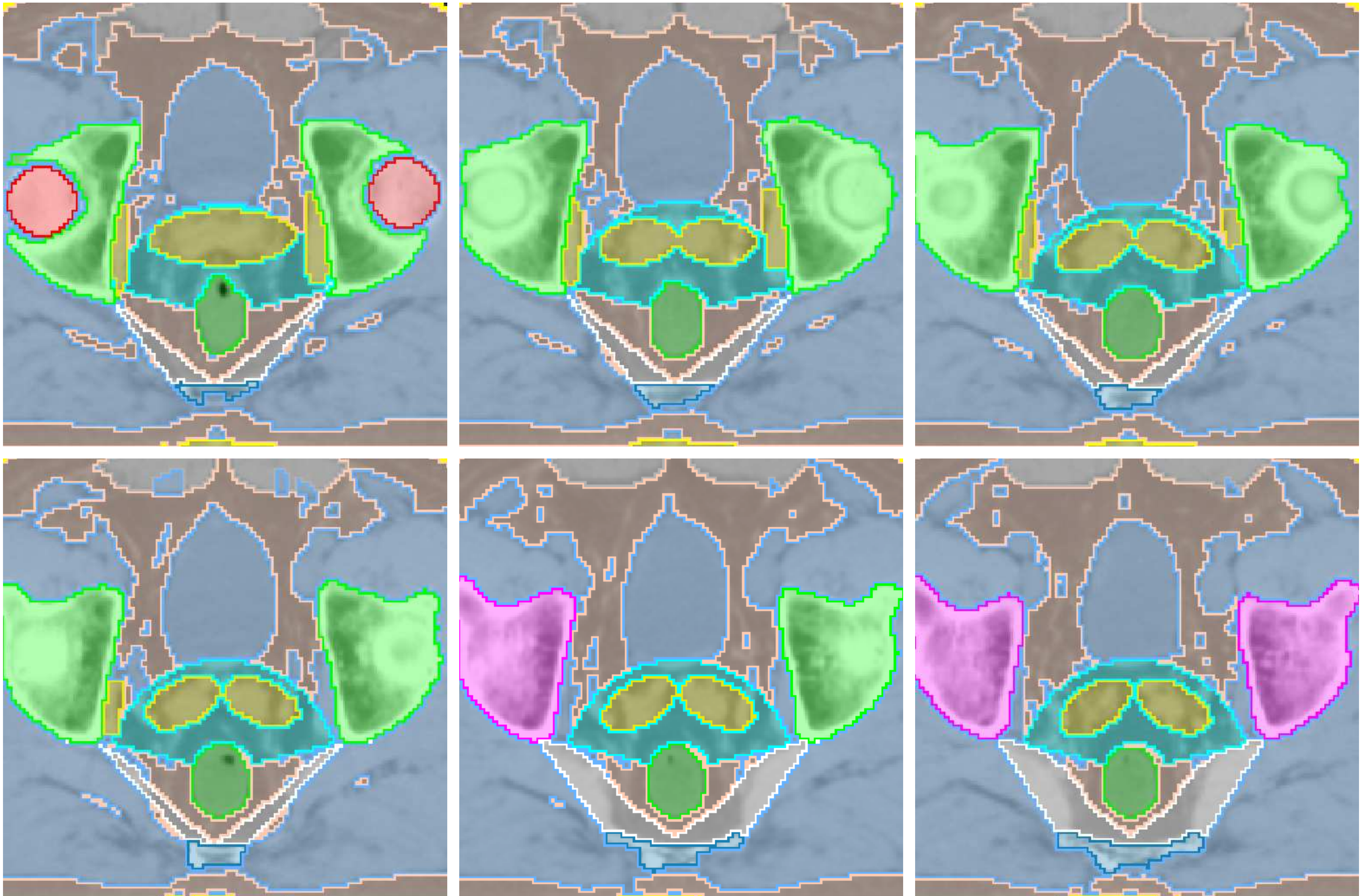
Shape Alone:



Final Result:

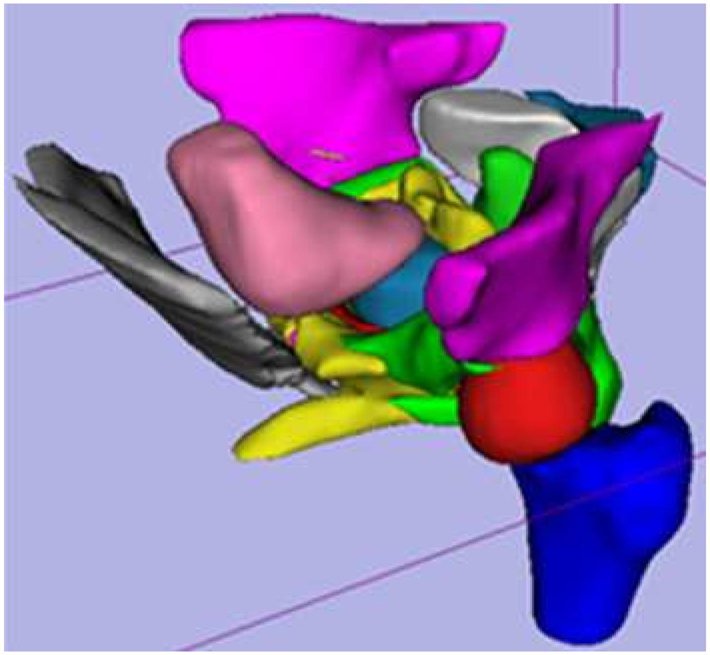


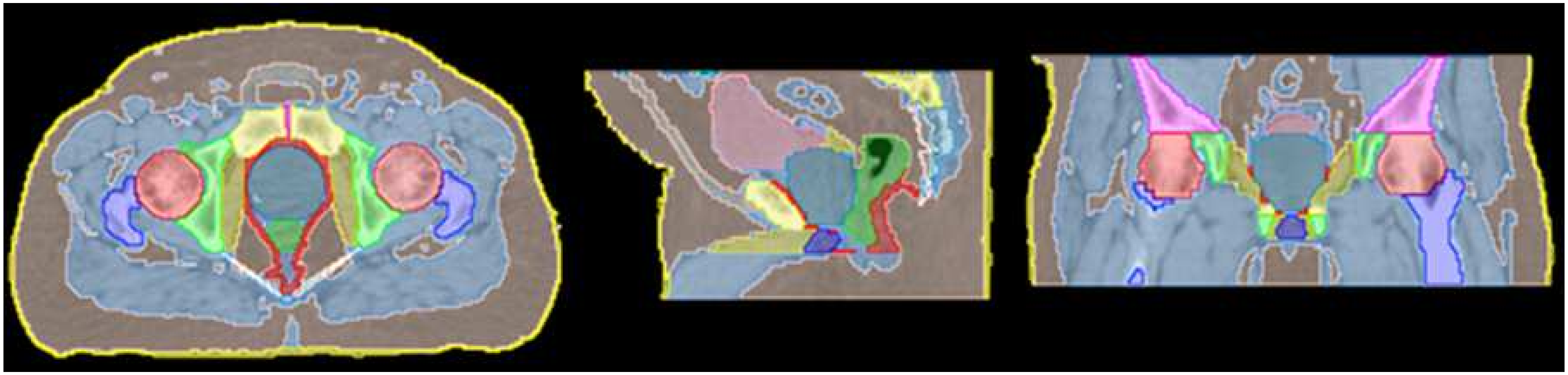
Seminal Vesicles: ellipse splits and bends downward



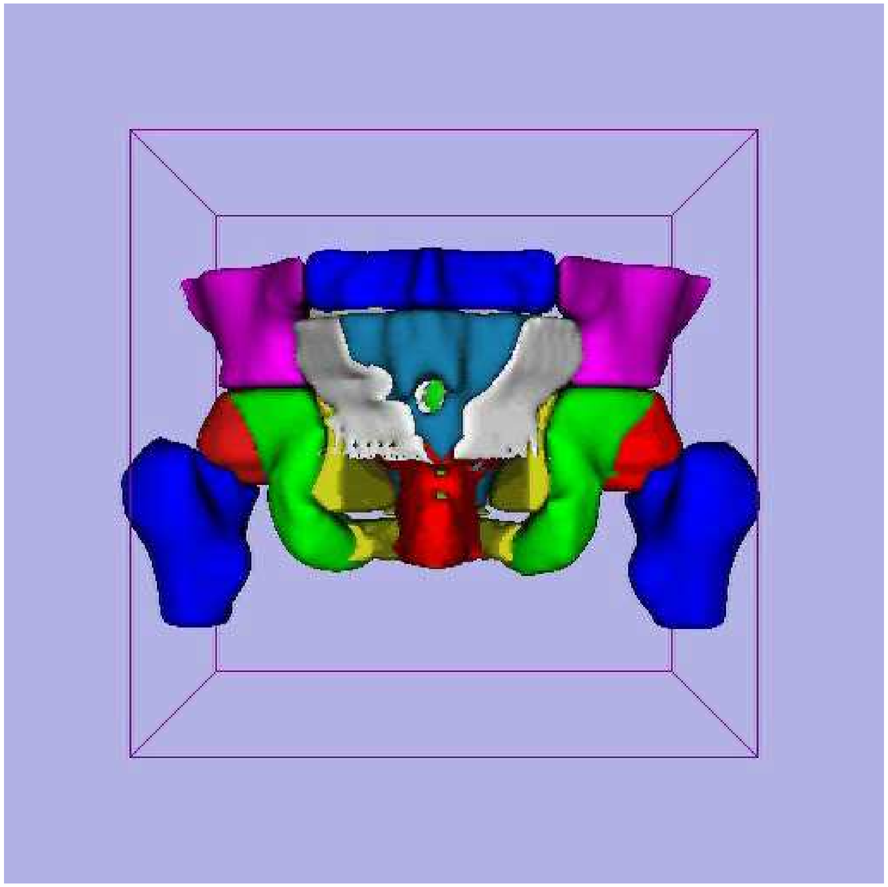
Conclusion

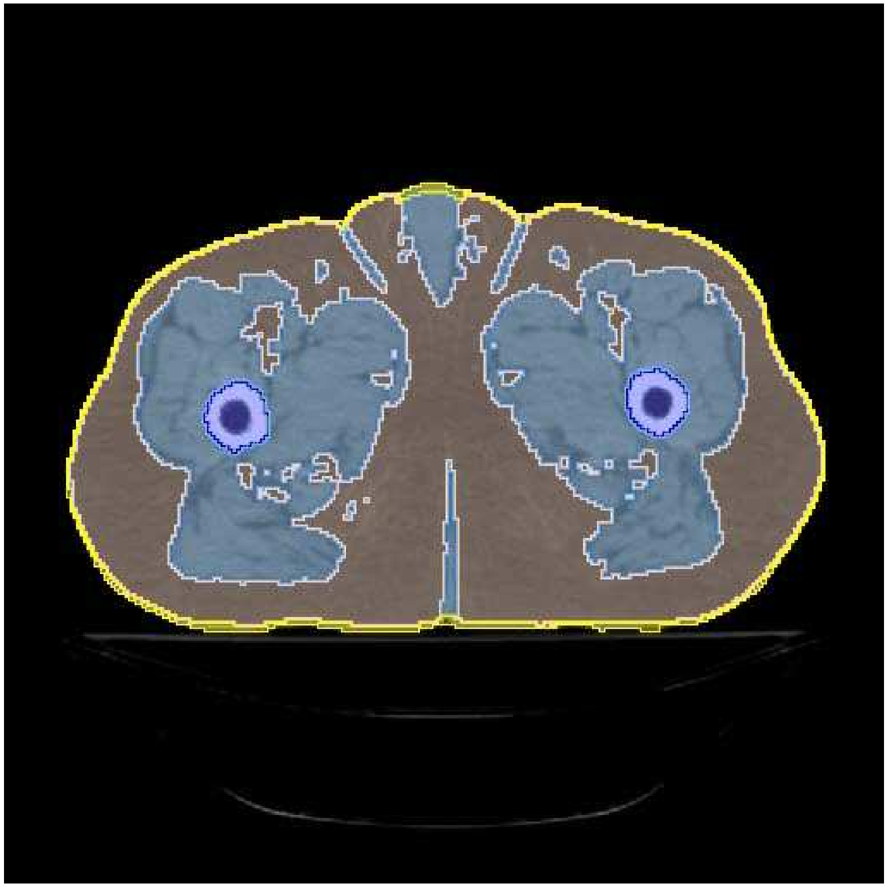
- Finds all organs simultaneously (2 iterations).
- Fully automatic – no human interaction.
- Processing time is 40 seconds for 256 x 256 x 90 CT on a standard PC.
- Robust – shape models force reasonable results on every slice.
- Trained & tested on 50 prostatic datasets. (qualitative, not quantitative yet).



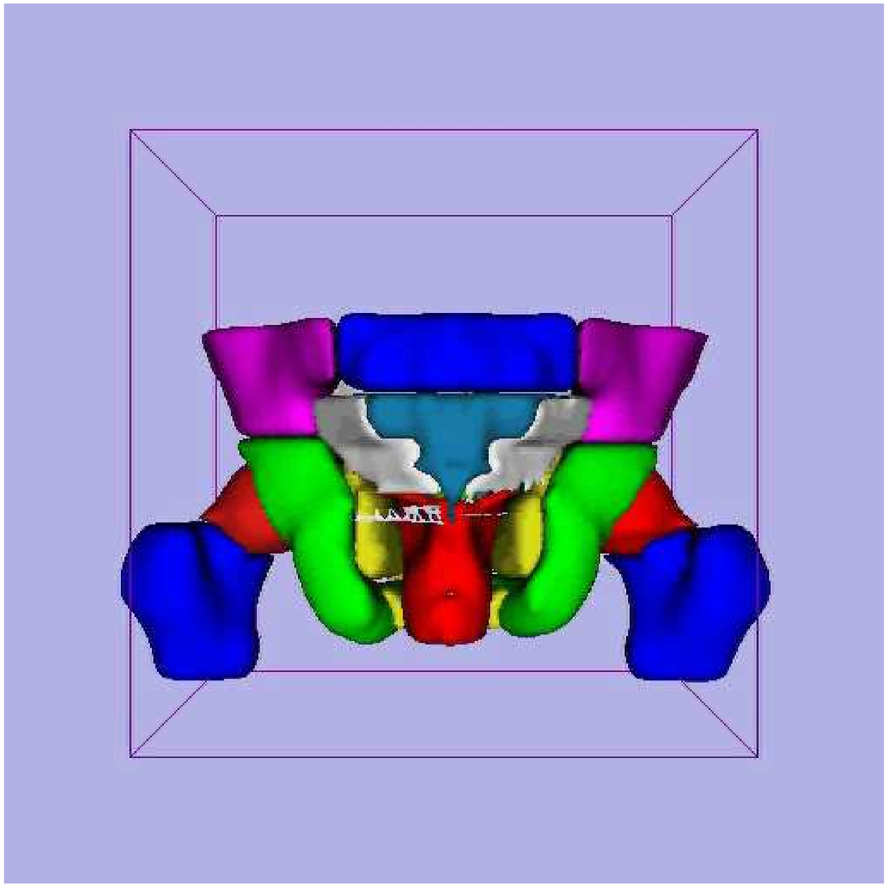


Results #1

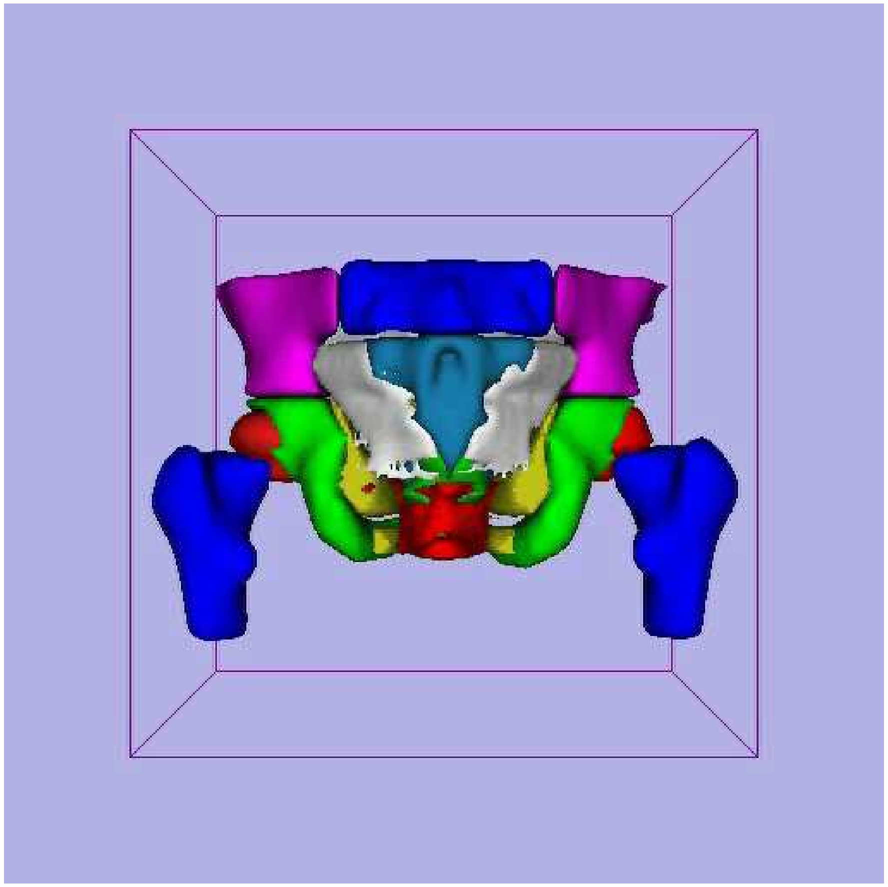


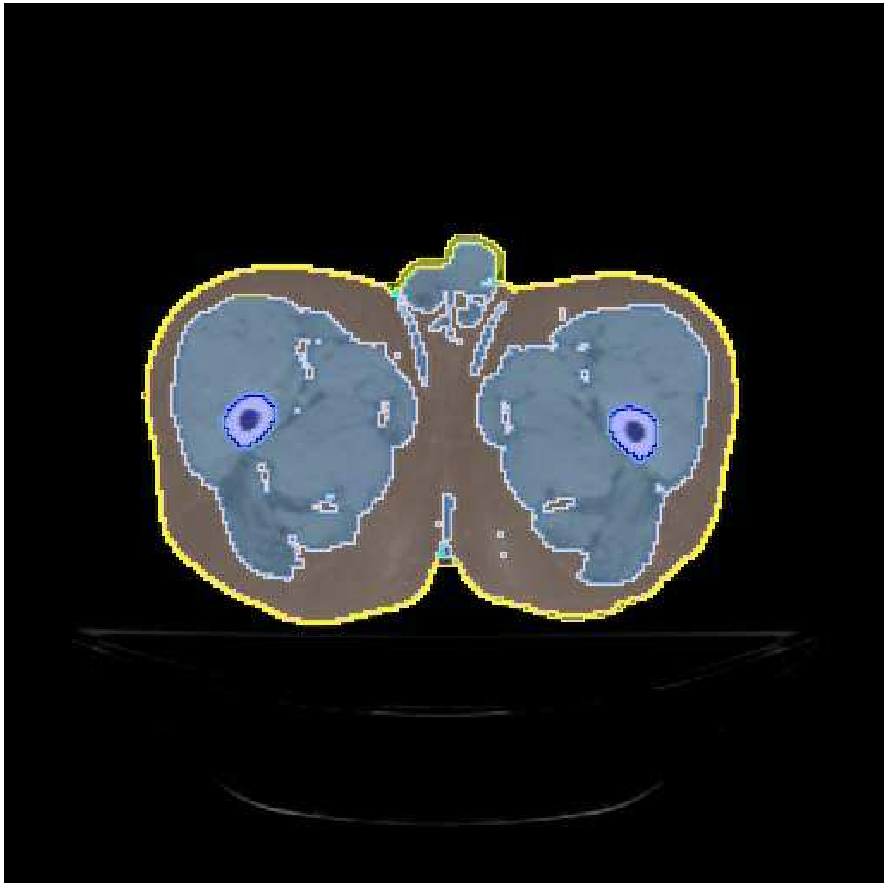


Results #2



Results #3





Results #4