Getting the Most Out of Your Contouring Tools
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Disclosures

• This presentation mentions several commercial software applications
  – No financial relationships

• Past employee of MIM Software Inc. (2007-2013)
  – No financial relationships
About Grayden MacLennan

- Majors, Minors, Etc.
  - Computer Science
  - Photography & Multimedia
  - Management Information Systems
  - Technology Management
  - Medical Dosimetry

- Job and Career Fields
  - Computer Technical Support
  - Videography
  - Desktop Publishing
  - Laboratory Science
  - Web Development
  - Medical Imaging Sales & Training
  - Medical Dosimetry

In Other Words

Computer stuff

Imaging stuff

Medical stuff
Cool. Let’s get started!

Setting Expectations

• I’ll assume that you already know how to draw organs

• I’ll assume you know how to operate basic contouring tools
How to Draw an Owl

1. Draw some circles
2. Draw the rest of the owl

This is Not an Anatomy Lecture

- Focus will be on the tools, not organs
- Some tools are really well suited for certain organs
- Sometimes a combination of a few tools does a great job
Understanding the CT

• Produces a 3 dimensional map of a body

• Density information based on X-Ray transmission from multiple angles

• Picture is divided into a grid of picture elements (Pixels)

Adding a 3rd Dimension

• Cross sectional slices acquired at regular spacing

• Slice spacing (thickness) gives pixels height, therefore volume

• Volumetric pixel = Voxel
Geometry Numbers for CT

- Axial field of view: 50 cm (500 mm)
- Axial grid size: 512 x 512 pixels
- Pixel size: $\frac{500}{512} = \approx 0.977 \text{ mm/pixel}$
- Interpolation can be applied to simulate higher density

With and Without Interpolation

Interpolated vs. Raw Voxels
Slice Thickness

- Isometric voxels have same dimensions on all sides
  - Look equally good in axial, sagittal, or coronal views
  - Scan must be acquired at 1 mm slice thickness

- Most scans are acquired with thicker cuts
  - Less work
  - Less radiation
  - Good enough to get the job done

CT Slice Thickness
CT Slice Thickness

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CT Slice Thickness

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More About Density Information

- Typical CTs can differentiate around 4000 intensity levels
- 12 bits needed to store 4000 possible values with binary
  \[2^{12} = 4096\]

Mismatch Problem

- We are storing 4096 different intensity values
- Computer monitors can only display 256 different intensities
- Human eyes can only pick up around 30 different intensities
- Human perception has other problems...
Human Vision

- Way more sensitive to color variation than intensity variation
- Central and peripheral vision behave very differently
- Exaggerated boundaries between areas of differing intensity — “Mach Banding”
- Brain tries to fill in “what should be there”
Environmental Factors

• The viewing environment also affects our ability to see subtle differences
  – Monitor calibration
  – Monitor type
  – Type and color spectrum of room lighting
  – And many more

Eyes Make Their Own Adjustments Too
Understanding Our Limitations

• Need to establish our capabilities and work within them

• How about a quick perception test...
It's here

Just kidding!

It's here

It's here

Just kidding!

It's here

It's here
Windowing vs Leveling

- We can selectively emphasize chosen ranges of intensity values
- On a CT, intensity represents density

- We control two values:
  - Black point
    - Anything less dense than the black point will still just be black
  - White point
    - Anything more dense will be full brightness white

Windowing and Leveling

- Windowing
  - Changing the span between black point and white point

- Leveling
  - Changing the center point (medium gray) of the range
Using Windowing Effectively

- We are choosing where to place our ~30 gray level steps to maximize the effectiveness of our limited abilities

- To differentiate two very similar things, use a small window
  - The two things might end up several gray levels apart

- To see the relationship between very different things, use a large window
  - Does the tumor invade the bone?

Which Densities Are Interesting?

- Air
- Lung
- Fat
- Muscle/organs
- Bone
- Metal
Hounsfield Units

- The Hounsfield scale was created to assign repeatable numbers to various densities

- Calibrated to two densities:
  - Air is defined as -1000 Hounsfield Units
  - Water is defined as 0 Hounsfield Units

What HU Value to Expect

- First ask “does it float?”

- Fat floats, so it must be less than 0 HU

- “Blood is thicker than water” so it must be more than 0 HU
HU Values of Different Tissue

- There are extensive published tables of expected HU values
- You can do a lot just by remembering 3 “magic numbers”
  -150 HU boundary between air/lung and fat
  0 HU boundary between fat and blood/muscle/organs
  +150 HU boundary between soft tissues and bone/metal

Prevalence of HU Values on a CT

- A histogram representation of the HU values on a CT show several clumps of values
Windowing and Leveling

- Full range
- Each tissue type only has 1 or 2 gray levels

Stepping Through Various W/L Options

- Let’s examine each cluster of HU values...
W/L – The Low End

- Lung
- Thermoplastic mask
- Body mold fabric
- Carbon fiber table

W/L – The Wide Trench

- Lung
- Thermoplastic mask
- Body mold fabric
- Carbon fiber table
W/L – The First Spike

- Adipose Tissue (fat)

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W/L – The Second Spike

- Muscle
- Blood
- Organs

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W/L – The Long Tail

- Bone
- Metal

Typical Window/Level Preset

- Most systems have presets for commonly used W/L settings
  - Soft tissue
  - Lung
  - Bone
  - Brain
Windowing and Leveling

- Soft Tissue
  - W400, L40

- Lung
  - W1324, L-362
Windowing and Leveling

- Bone
  - W1600, L450

Enough About Imaging!
What is Contouring?

- Defining the geometry of regions of interest
  - Targets
  - Organs at Risk (OAR)
  - Patient immobilization or support structures
  - Areas that need special attention
    - Density overrides
    - Avoidances
  - Dose shaping
    - Heat up or cool down this area

What is a Contour?

- One or more location points that represent something of interest
  - Points of Interest are just contours that only have one point
  - Open Planar: all points in the same plane (coplanar), ends not connected
  - Open Nonplanar: “can be used to represent objects best described by a single, possibly non-coplanar curve, such as a brachytherapy applicator”
  - Closed planar: Coplanar, last point is connected to the first point, defining a polygon

Common RT-Struct Conventions

Where does the polygon connect to each voxel?

Corners?

4 nearest neighbors
Common RT-Struct Conventions

Where does the polygon connect to each voxel?

Corners?

4 nearest neighbors
Common RT-Struct Conventions

Another option: use the middle of each edge

2x connection points

4 new directions

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Drawing Shapes in Daily Work

• When we contour, we are trying to follow the intensity boundaries of things we see in the images.

• Rasterization is very common

Those Eyes Again

Interpolated

Raw Voxels
Arbitrary Placement

Contour Point Positioning

Whole voxel  Half voxel  Arbitrary?
Why Use Those Chunky Grids?

• Speed & Precision

• Well defined grids are easy for computers to:
  – Compare
  – Move, rotate, stretch

• If point placement is arbitrary, it might have to be snapped to a grid in order to do some of these operations
1/20 mm gap

(maybe it IS close enough)
Accuracy vs Precision

• “Chunky Grids”
  – Good Precision
    • Same result every time
  – Moderate Accuracy
    • Placement may not line up perfectly

Accuracy vs Precision

• Arbitrary Point Placement
  – Moderate Precision
    • Repeatability suffers
  – Good Accuracy
    • On average it lines up nicely
Remember Our Subject Matter

- Humans are squishy
- Image resolution is 1 mm
- Dose resolution is 2-3 mm
- Setup tolerance can be ever bigger

Aren’t we supposed to be talking about contouring tips?
Common Types of Drawing Tools

- Basic Tools
  - Pen
  - Paintbrush
  - Smart brush
  - Flood Fill
- Refinement Tools
  - Smooth
  - Expand and Contract
  - Boolean

Thresholds & Morphological Closing

- Also known as the “Expand Contract Trick”
- Selectively fills in valleys without altering high points.
- Expansion size is like roller going across valleys

Start With a HU Threshold Contour

Expand it by 5mm...
…and then contract by 5mm

Doing Exactly the Opposite

• Morphological Closing (expand/contract)
  – Fills in trenches, holes, on outer surface
  – Like pressing sheet metal onto the outer surface with a roller

• Morphological Opening (contract/expand)
  – Shaves off spikes, ridges, and outliers on outer surface
  – Like pressing sheet metal onto the inner surface with a roller
Drawing a Brain

• General characteristics
  – Large
  – Uniform in density
  – Clear boundaries

• Challenges
  – Lots of slices
  – Complicated geometry with grooves and foramina
Brain Tools

- Lots of options:
  - Flood fill (region growing)
  - Model Based Segmentation
  - Smart brushes

- Lots of problems:
  - They don’t hug the skull
  - They leak out through gaps
  - They cross over bone voxels

This is a perfect task for morphological opening (the contract/expand trick)

My Approach to Brains

- Take advantage of HU predictability and clear boundary

1. **Isolate** all soft tissue voxels (-150 HU to +150 HU)
   - Brain needs to be disconnected from spinal canal
2. **Contract** the ROI 0.5-0.7 cm
3. **Discard** everything but the Brain
4. **Expand** the same 0.5-0.7 cm
Brain My Way: Eclipse

- Use **Image Thresholding** from -150 HU to +150 HU
  - Place a **VOI** box snug around the head
  - Bottom of the VOI must be at the foramen magnum

- Use **Post Processing** in Extraction mode
  - Select “Keep the ‘n’ largest parts” set at 1
  - Select “Modify Connections Before Extraction”
    - Disconnect with Radius 0.5 cm

Brain My Way: MIM

- With **2D paintbrush**:  
  - Draw a big circle encompassing head the at the level of the foramen magnum  
  - Draw a similar large circle just above the head
- **Interpolate**
- **Range Lock** -150 HU to +150 HU

- **Contract** ROI 0.5 cm
- **Clean** Volumetrically
  - Keep largest piece
- **Expand** ROI 0.5 cm
**Brain My Way: Velocity**

- **Threshold** at 150 HU
  - Place guide box with bottom edge at foramen magnum
    - Include lots of air around head
  - Select “Invert ISO edge” so it grabs everything below 150 HU
- **Margin** with “Shrink” checked and 5 mm
- **Post Processing**: Remove largest 1 part (air)
- **Post Processing**: Keep largest 1 part (brain)
- **Margin** with “Grow” checked and 5 mm
- Rename the final ROI, delete others

  Cumbersome manually, but works well as a script

**Brain My Way: RayStation**

- **Gray level threshold** (-150 HU to +150 HU)
  - This is global across dataset
- With **Brush**, separate the brain from the spinal canal
- **Contract** 0.5 cm
- Select shrunken brain ROI with **Keep component** tool
- **Expand** 0.5 cm
Drawing Lungs and Airways

- The order matters
  1. Carina
  2. Trachea
  3. Left Lung
  4. Right Lung

- Why? Each one can be subtracted from the others.

Lungs & Airways: Carina

- Switch to Lung W&L
- Locate top of Carina
  - Divider between main bronchi
- Make note of slice position
  - We go 2 cm up and down from here
Lungs & Airways: Carina

- 2 cm down from carinal ridge
- Use density-aware paintbrush

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Lungs & Airways: Carina

- 2 cm down from carinal ridge
- Use density-aware paintbrush

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Lungs & Airways: Carina

• Keep going up

• Can skip slices
Lungs & Airways: Carina

- Let’s zoom in a bit

Lungs & Airways: Carina

- In a Soft Tissue W&L it looks underdrawn
Lungs & Airways: Carina

- In a Soft Tissue W&L it looks underdrawn
- Re-draw? Up to you.

Lungs & Airways: Trachea

- Use a smart brush to draw the Trachea
Lungs & Airways: Carina & Trachea

- Use 3D view to verify shape
- When you draw the lungs, subtract these contours to keep them from flooding up the airways

Lungs

- Several ways to draw lungs
  - Flood Fill (region growing)
  - Model Based
  - Smart brush
  - HU threshold
Cleaning up the Lung ROI

• What’s wrong here?

• Hole filling has included part of the Liver inside the Lung ROI
Avoiding Improper Lung Filling

- Hole filling is often perilous with lungs
- Some contouring software has volumetric filling options
  - Hole has to be enclosed 3 dimensionally to be considered a hole
- Universal method is morphological closing
  - The “expand contract trick”

Drawing the Esophagus

- Esophagus can be a tough organ to draw
  - Similar density to surrounding structures
  - Can disappear for several slices with indistinct edges
  - Makes several bends around other structures
• Descending Aorta is large and obvious

• Azygos Vein
  – Returns blood from intercostal muscles
  – Runs parallel to esophagus for a short time

Images from McCall, MacLennan, Taylor, et al. (https://doi.org/10.1016/j.meddos.2016.08.004)
Lesson: Verify your shapes in another plane

Images from McCall, MacLennan, Taylor, et al. (https://doi.org/10.1016/j.meddos.2016.08.004)

Drawing Eyes

- Eyes are roughly spherical
- Many contouring packages can draw spheres
  - Spherical paintbrush
  - Drop a shape
Drawing Retinas

- General characteristics
  - 3mm wall at back of Eye

- Challenges
  - Must line up with inside of Eye
  - Fine motor control needed
  - Making it pretty

Retina the Hard Way

- Completely manual
- May not hug edge
- Ends are not clean
- Will differ between slices
- Have to draw every slice
In-Plane vs Volumetric Rings

- 3 mm rings in each plane
- 3 mm volumetric ring

Making a Volumetric Wall

- Most contouring systems have a wall tool

- In a worst case scenario:
  - Contract original shape 3mm
  - Subtract the contracted shape from the original shape
  - Remainder is a 3 mm wall
Use the Crosshair as a Guide!

- Localization Crosshair will maintain its position from slice to slice
- Use it as a guide to cut the front half off at the same place on each slice

Honestly…

These are terrible solutions
Fun Variation

• What if the patient’s gaze is not straight forward?

• If you have a rotate tool, use it before deleting front half
Our Final Retinas

Computer-Driven Tools

- Atlas Based Segmentation
- Model Based Segmentation
- Artificial Intelligence
  - Machine Learning & Deep Learning
Atlas Based Segmentation

- An atlas is a collection of patients who have previously been contoured
  - Provided by vendor or made in-house
- Algorithm will search for existing patient with similar anatomy and then deform the atlas subject to fit the current patient
- Contours from atlas subject are then mapped over to current patient
- Can use multiple matches to create consensus contours

Model Based Segmentation

- 3D mesh models of idealized organs are aligned to anatomy and warped to try to fit the shape
- Mesh models have rules about preserving the general shape
Artificial Intelligence

• Good Old Fashioned Artificial Intelligence (GOFAI)
  – Humans carefully craft rules
  – For X input, perform Y action

• Machine Learning
  – Human provide a way for computers to adjust their own rules based on outcomes and past experience

• Deep Learning
  – Mimics organic brain connections
  – Good outcomes are reinforced, bad outcomes are squelched
  – Rules spontaneously form with no intervention from humans

That’s All For Today
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Questions?