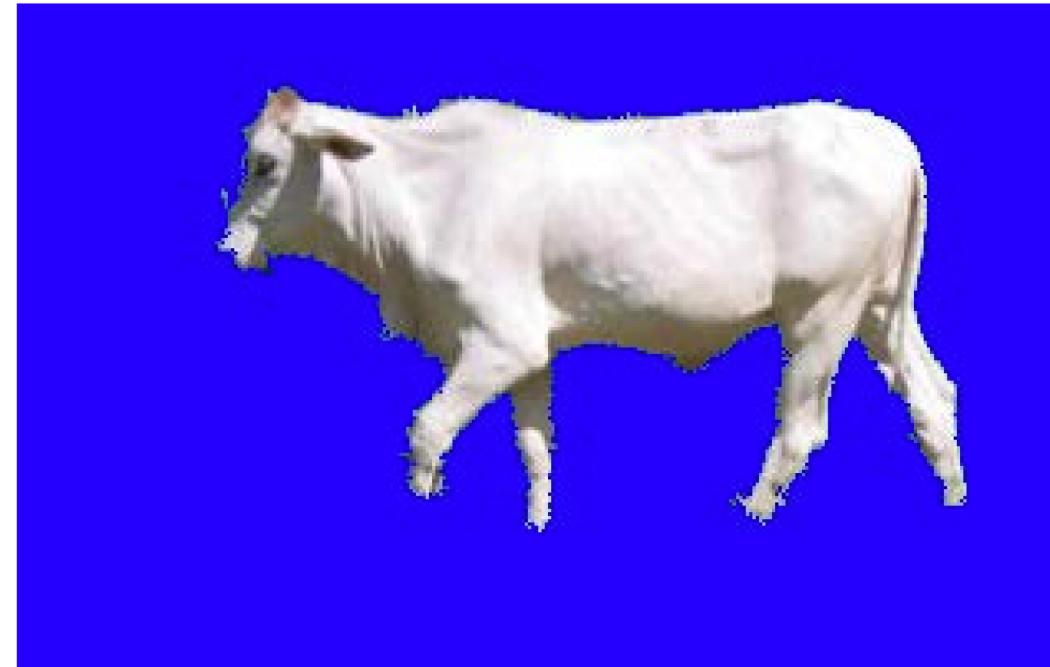


Ahsan Mahmood

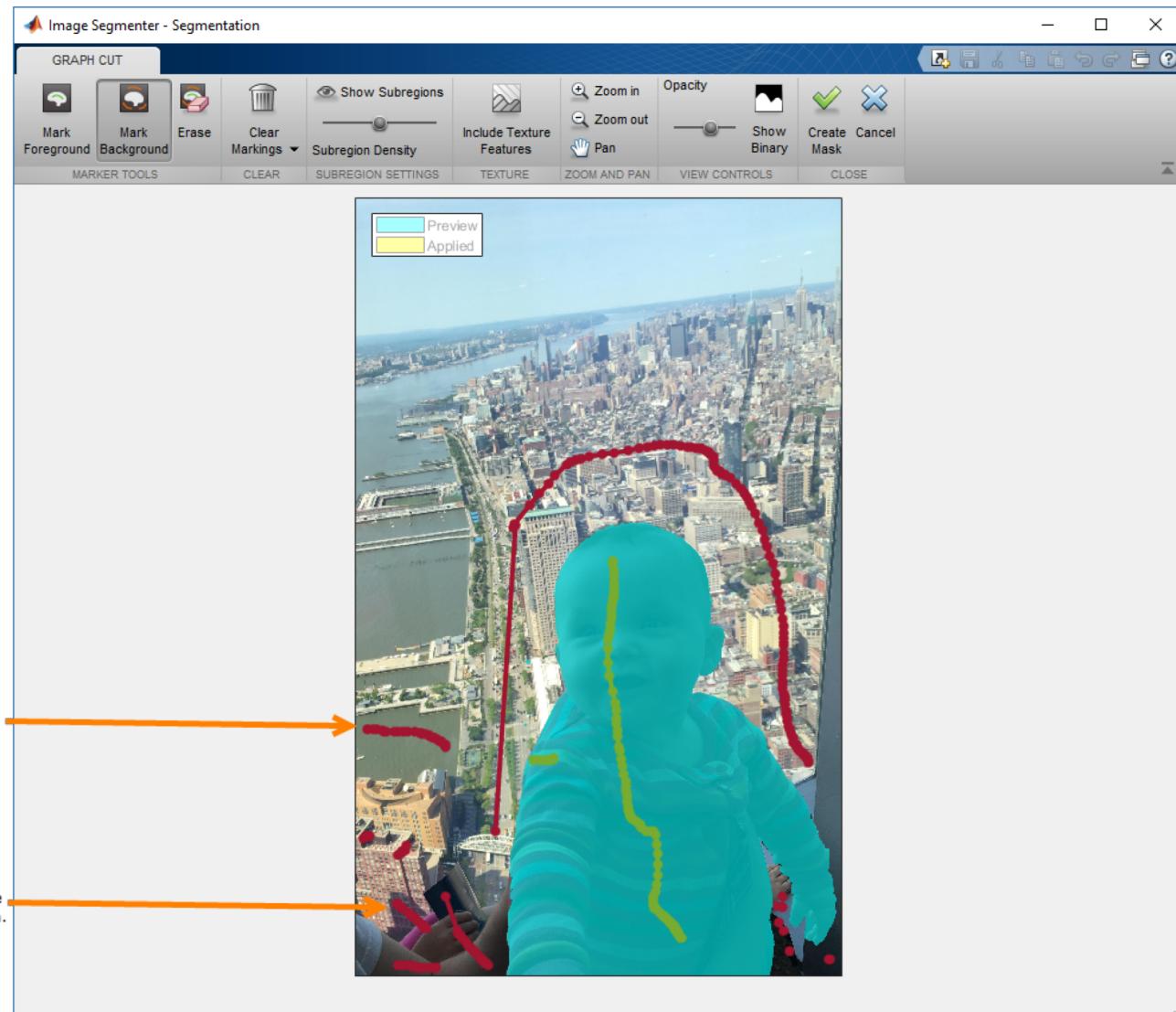
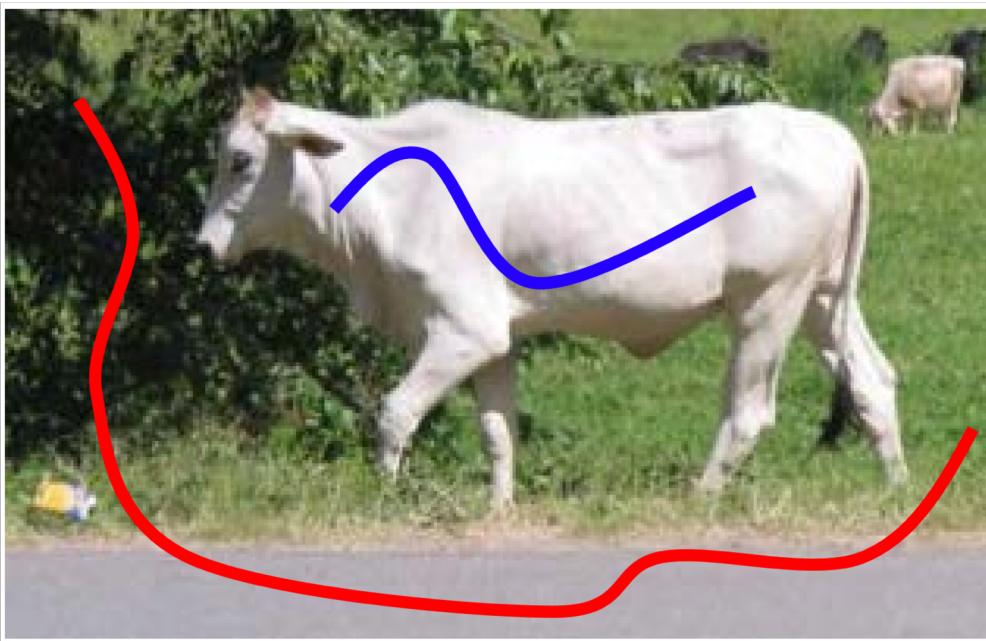
# Graph Cuts for Skull Stripping

# Binary Segmentation

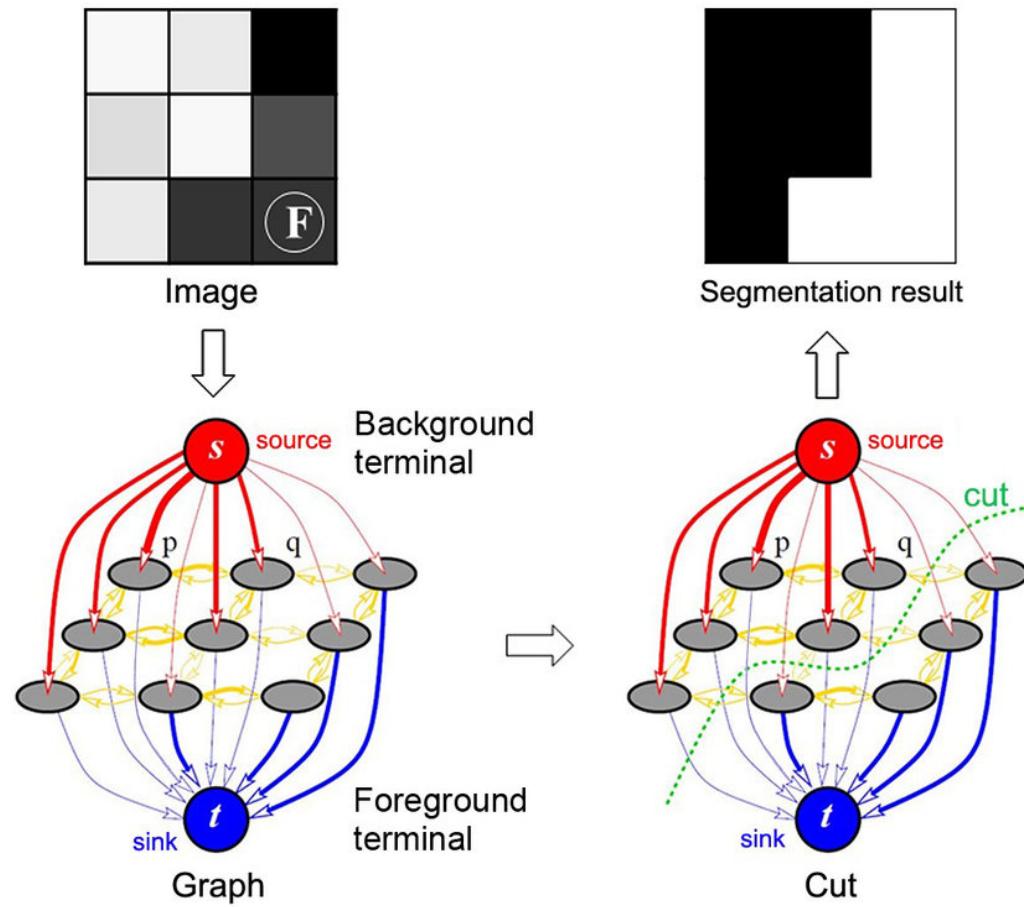
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# Graph Cuts

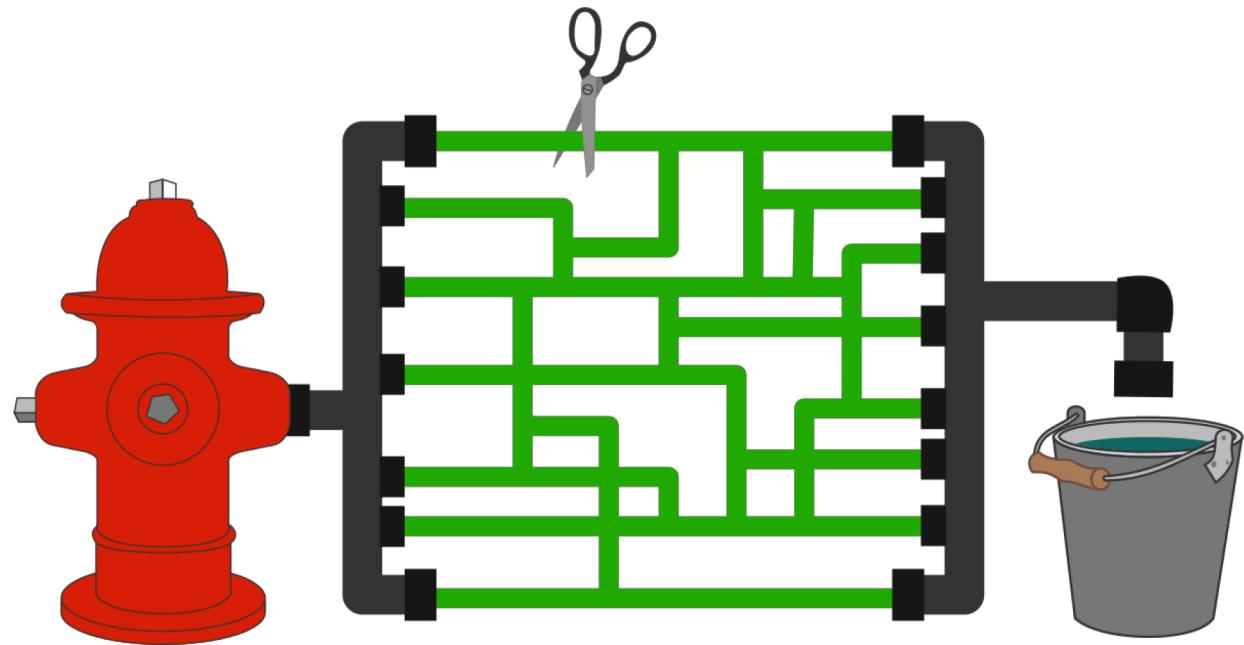


# Graph Cuts

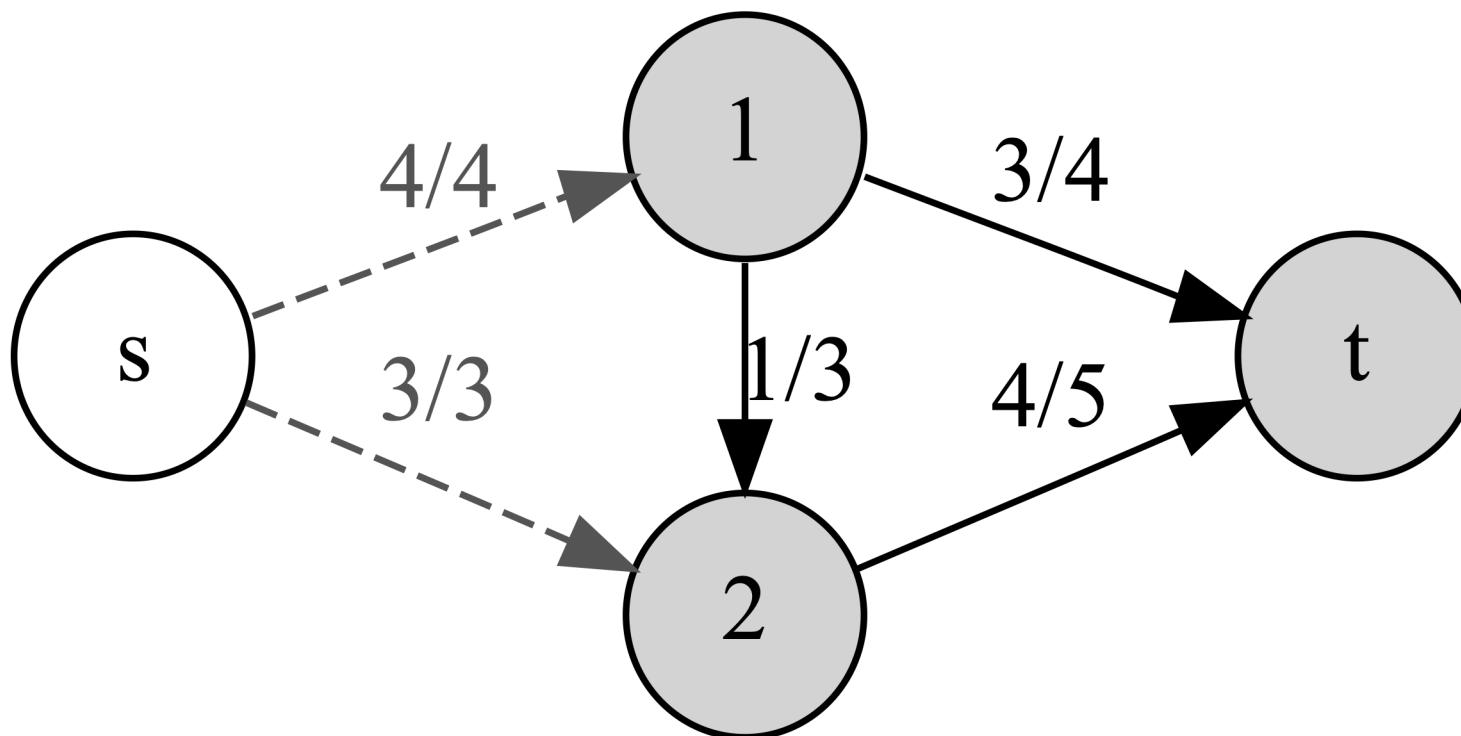


# Maxflow

- The **max-flow min-cut theorem** states that in a flow network, the maximum amount of flow passing from the source to the sink is equal to the total weight of the edges in the minimum cut
- **Cut:** Edges which if removed would disconnect the source from the sink

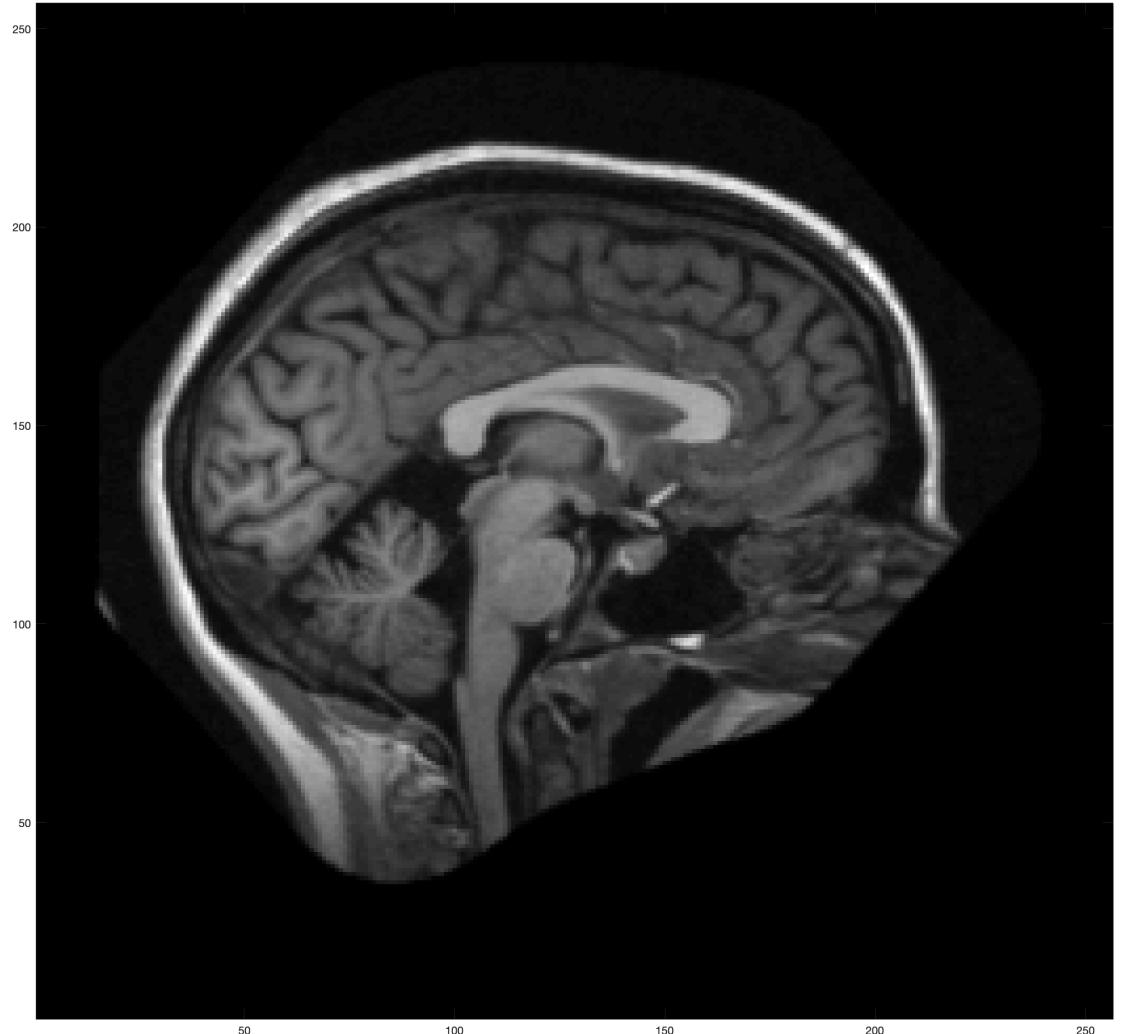


# Maxflow



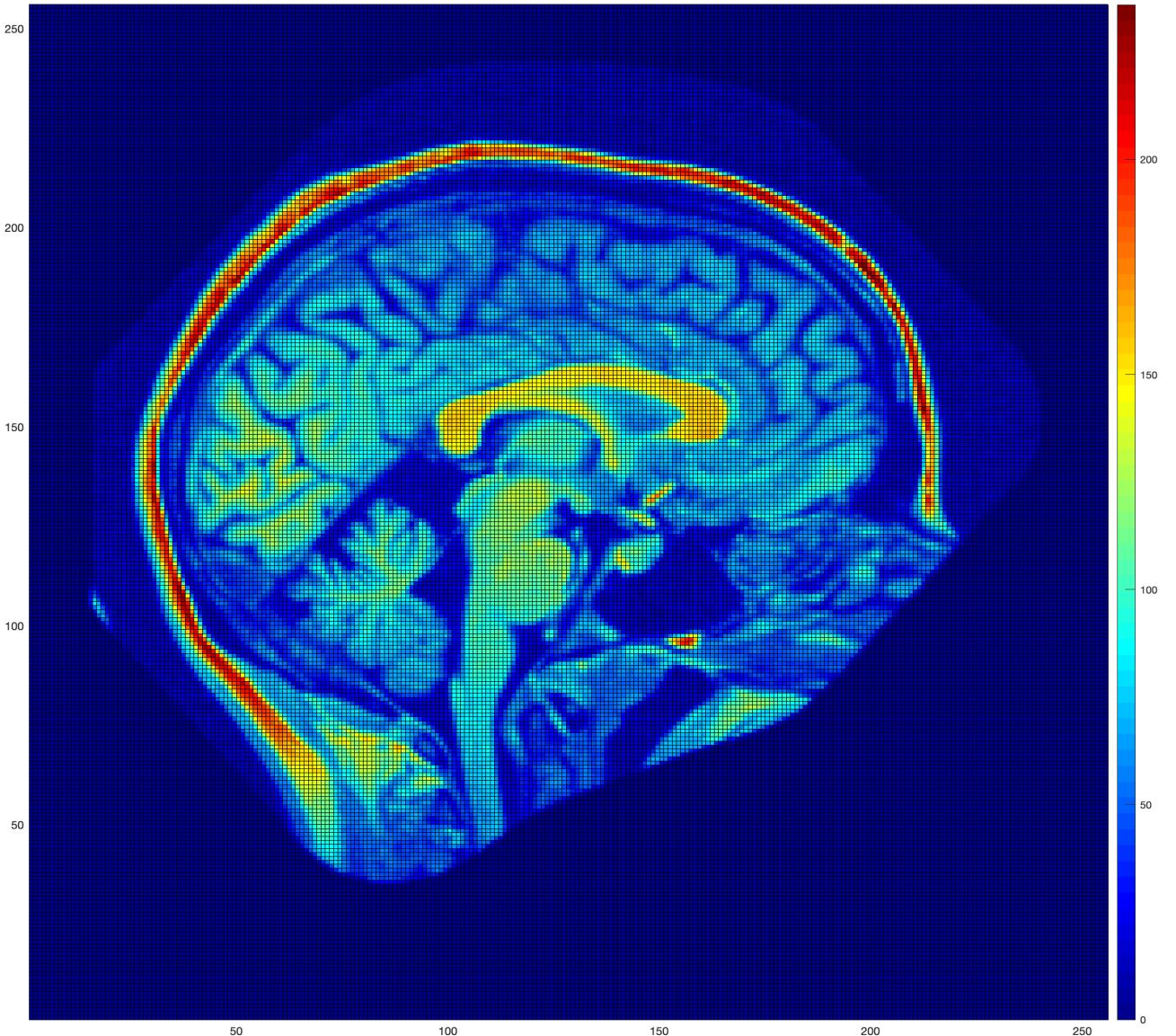
# Data

- T1 weighted MRI Images from assignment in BME 775
- Sagittal sections
- Corpus Callosum clearly visible



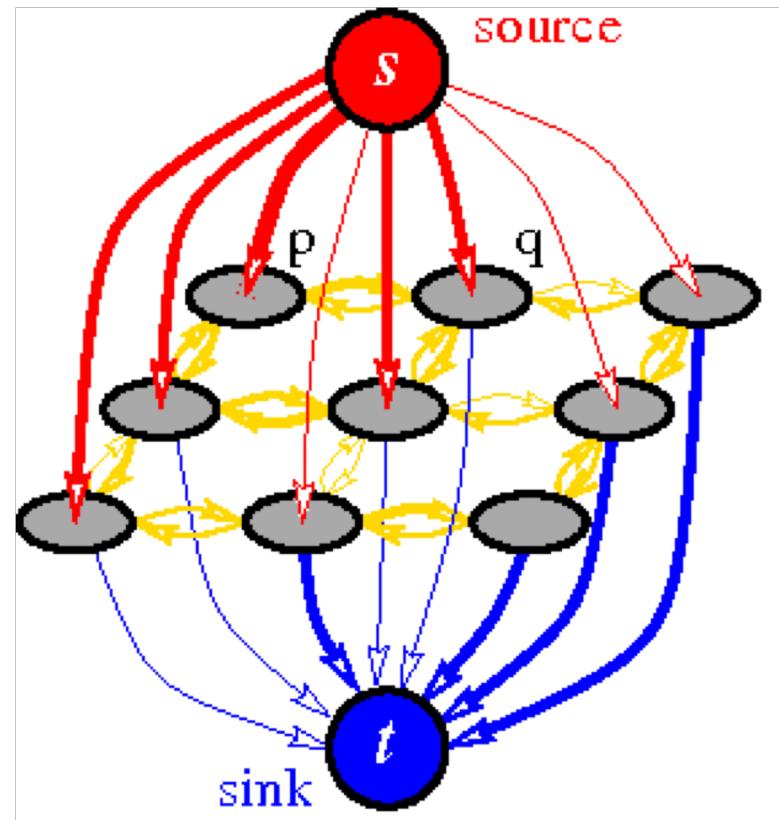
# Data

- Background noise
- Used hard threshold to remove it
- Some non-brain anatomical structures visible



# Building Graph

- Each pixel assigned a corresponding node
- Each edge between pixels assigned a flow capacity
- Created virtual source and sink
- Source forward connected to pixels
- Pixels forward connected to sink



# Pixel – Pixel Weights

- High if belong to the same class (target or background)
  - Low otherwise
- How to determine if in same class?
  - Gradients!
- Very likely to be in the same class if gradient directions parallel
- Weighting function  $W_{st} = I_s * (1 + \cos(\nabla_v I_s - \nabla_v I_t))$

# Source/Sink – Pixel Weights

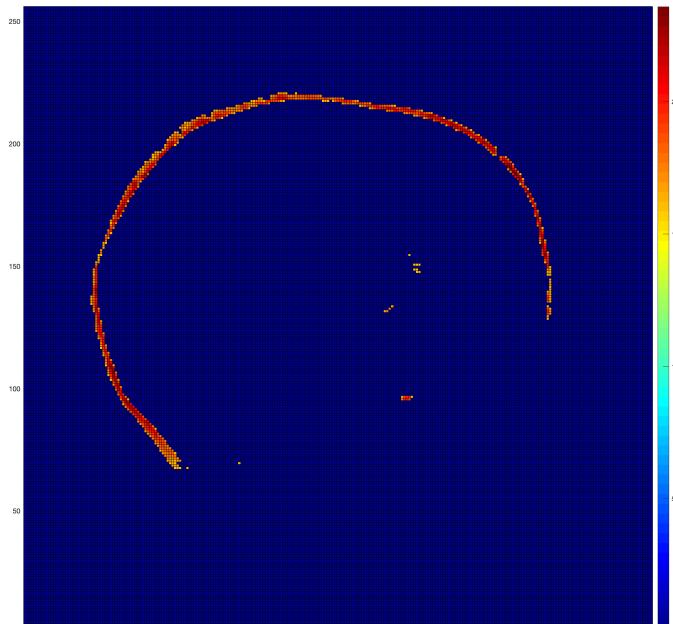
- Source -> Pixel : high if background class
- Pixel -> Sink: high if target class
- How to tell if target or background?
  - Seeds!
- What does “high” even mean?
  - I don’t know

# Generating Seeds

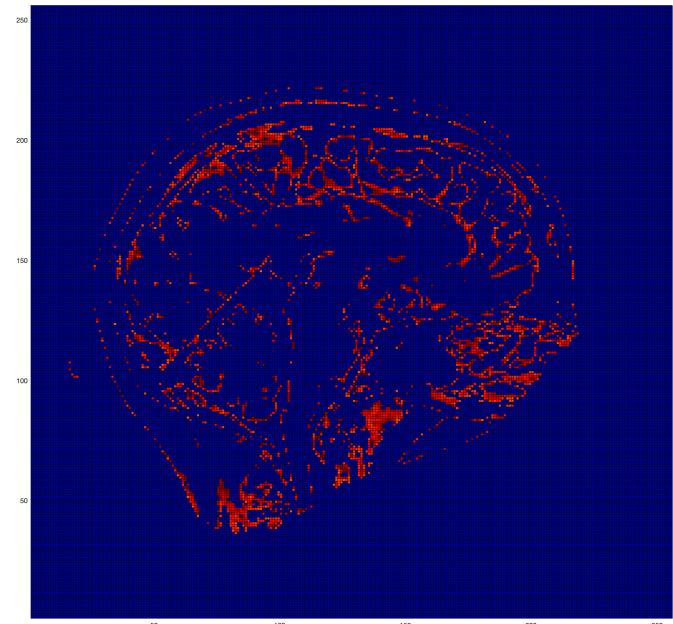
- Usually seeds added via user interaction
- Automation would be nice
- Use a heuristic inspired by thresholding and quantiles
- Main Idea: Skull generally appears brighter than white matter
- Get all pixels that fall within one standard deviation of the class mean

# Generating Seeds

- Used 98<sup>th</sup> percentile as a threshold for skull
- Intensities between 50<sup>th</sup> and 70<sup>th</sup> percentile worked well for “white matter” class



Skull Seeds



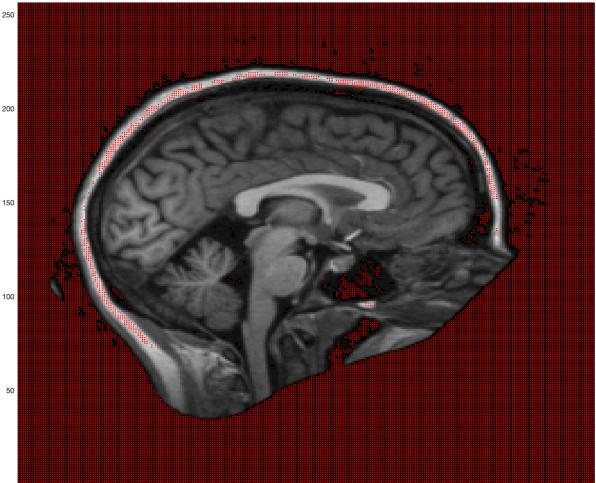
“WM” Seeds

# Strict Cutoff

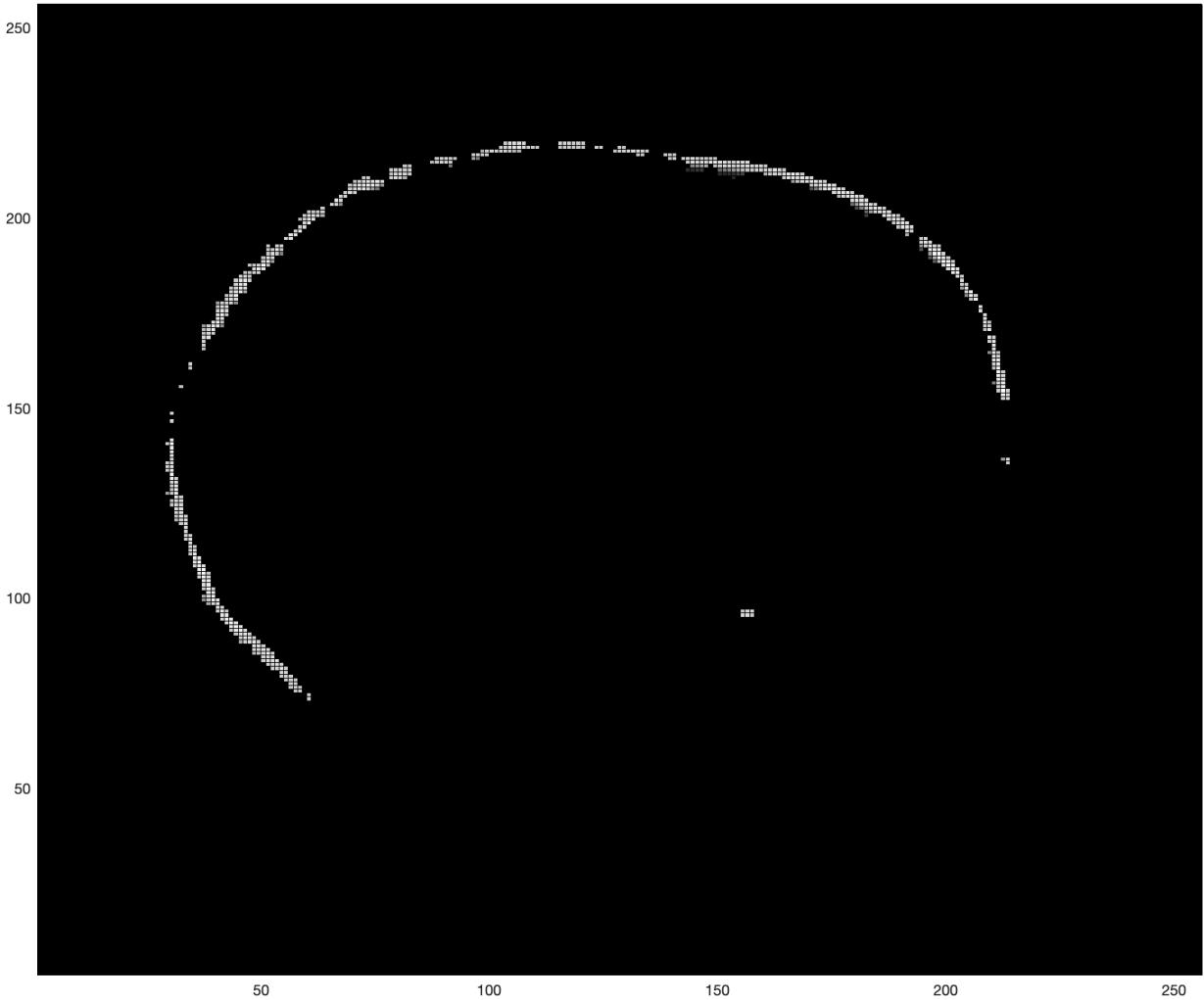
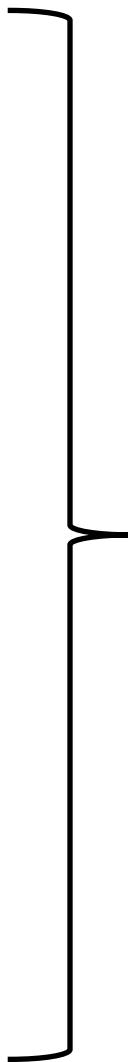
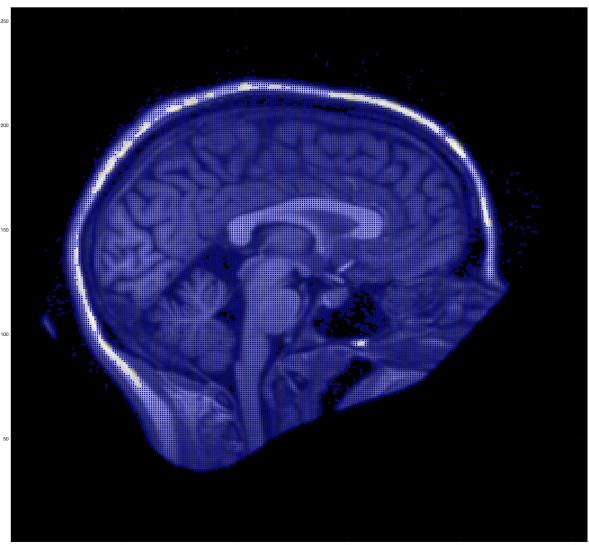
- Target is skull
- Source -> Pixel: Only connected to background
  - If pixel intensity < target mean
- Pixel -> Sink : Only connected if pixel is in target class
  - If pixel intensity > target mean
- Weights to connected pixels: Intensities of the pixels
- Not connected means edge weight is set to zero

# Strict Cutoff

Background  
Nodes



Foreground  
Nodes

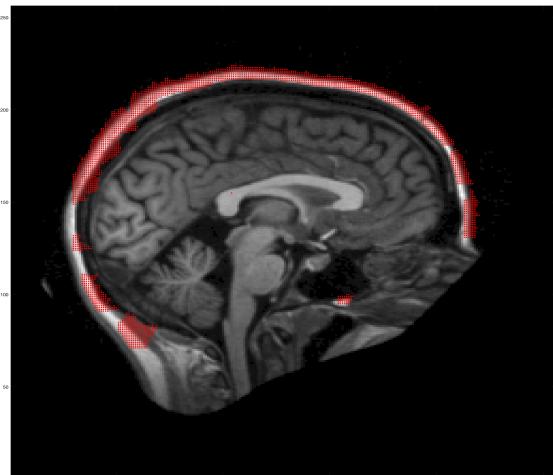


# Intensity Difference

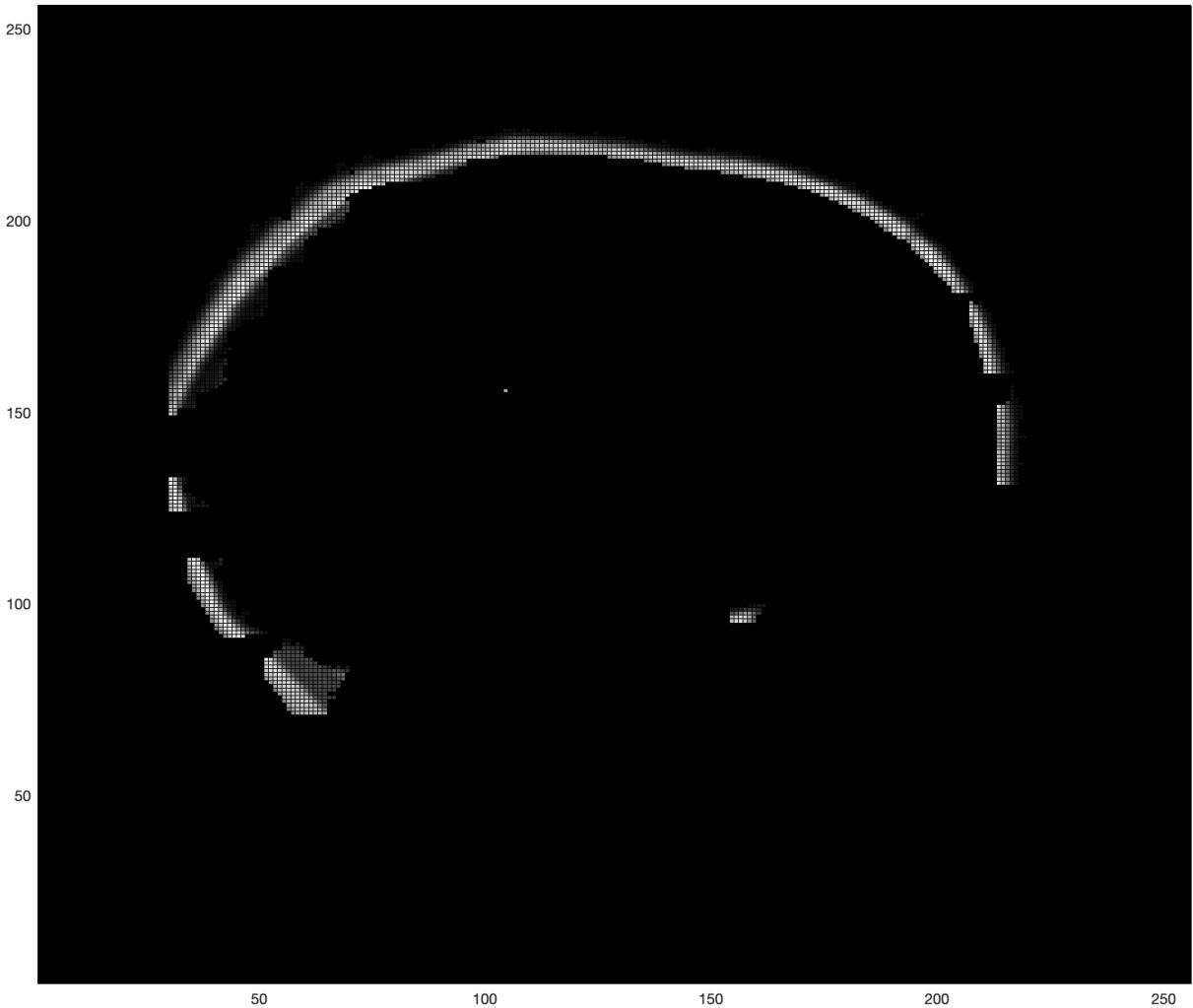
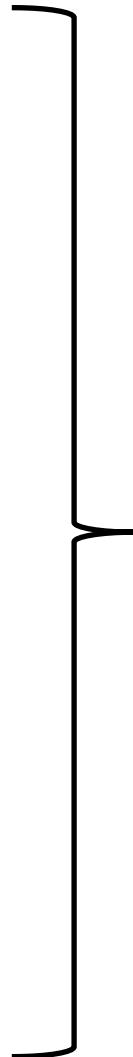
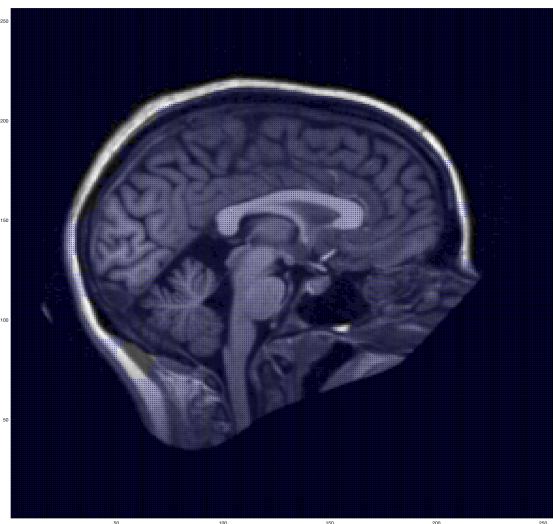
- Flow capacities should vary on a range
- As the difference from the target class mean intensities change, so should the corresponding weights to source/sink.
- Source/Sink connected to all pixels
- Edge weights: Intensities weighted by squared difference from class mean
  - Other decays tended to over/undershoot
- Background Class: Skull
- Target Class: White Matter

# Intensity Difference

Background  
Nodes



Foreground  
Nodes

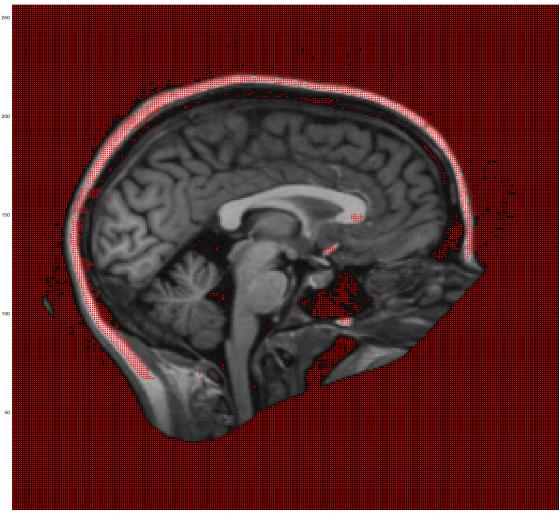


# Hybrid Approach

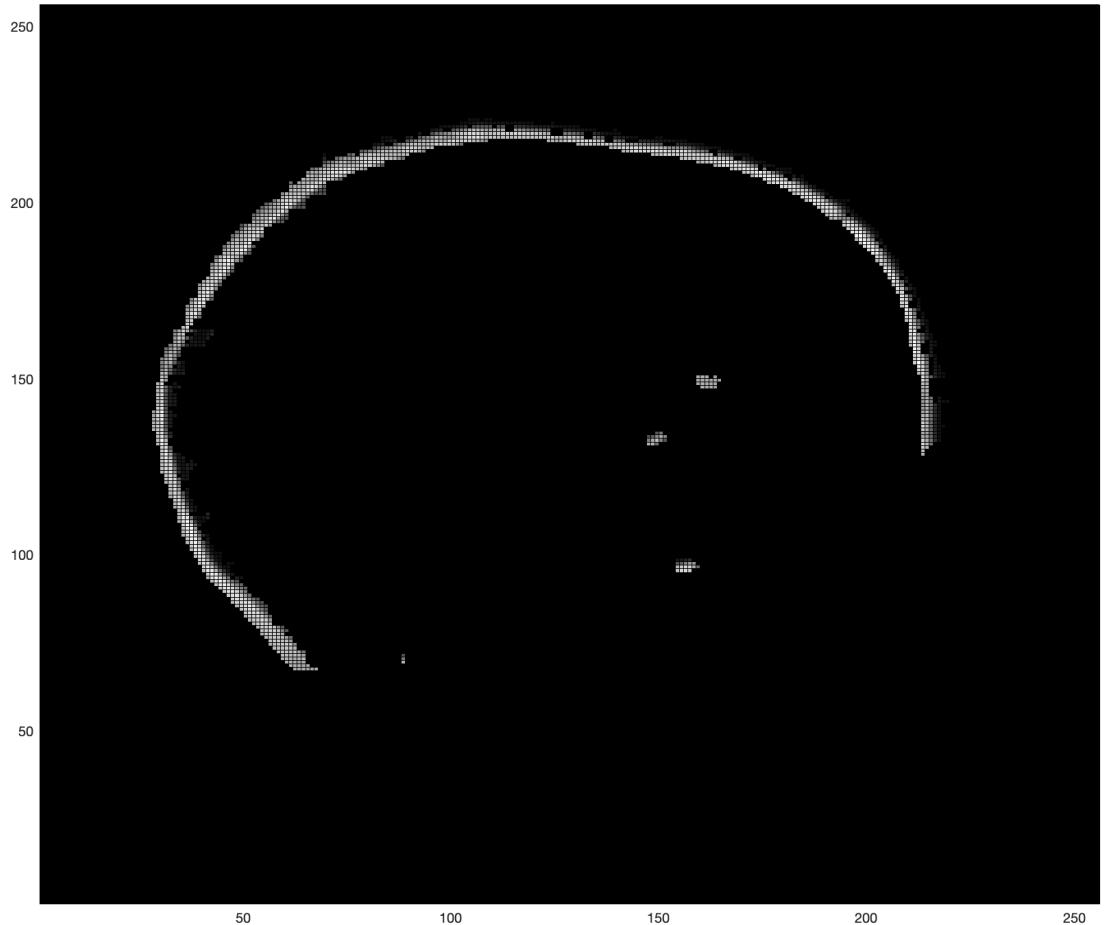
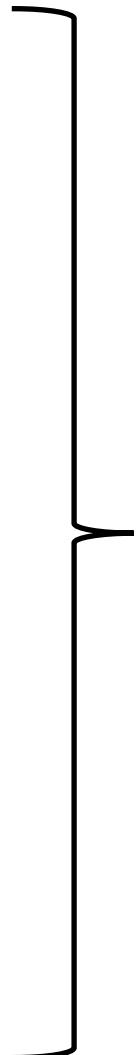
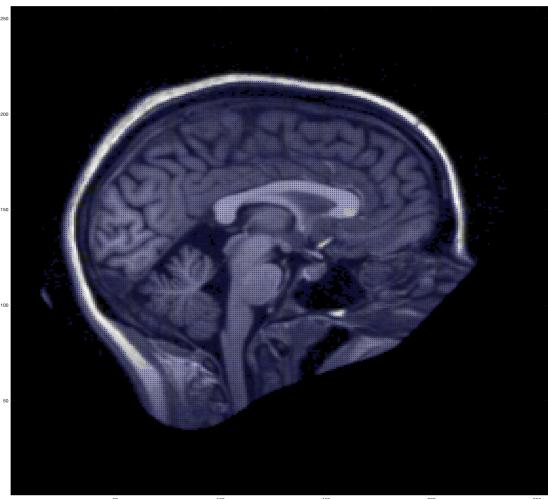
- Combines cutoffs based on classes and intensity differences
- Source is only connected to background pixels (pixels lying outside the brain) and the skull seeds
  - The weights on these edges are set to the maximum flow value
- Conversely the sink is only connected to non-background pixels
  - The weights for edges connecting white matter seeds are set to maximum
  - Other non-skull regions are weighed according to intensity differences from the white matter class mean

# Intensity Difference

Background  
Nodes



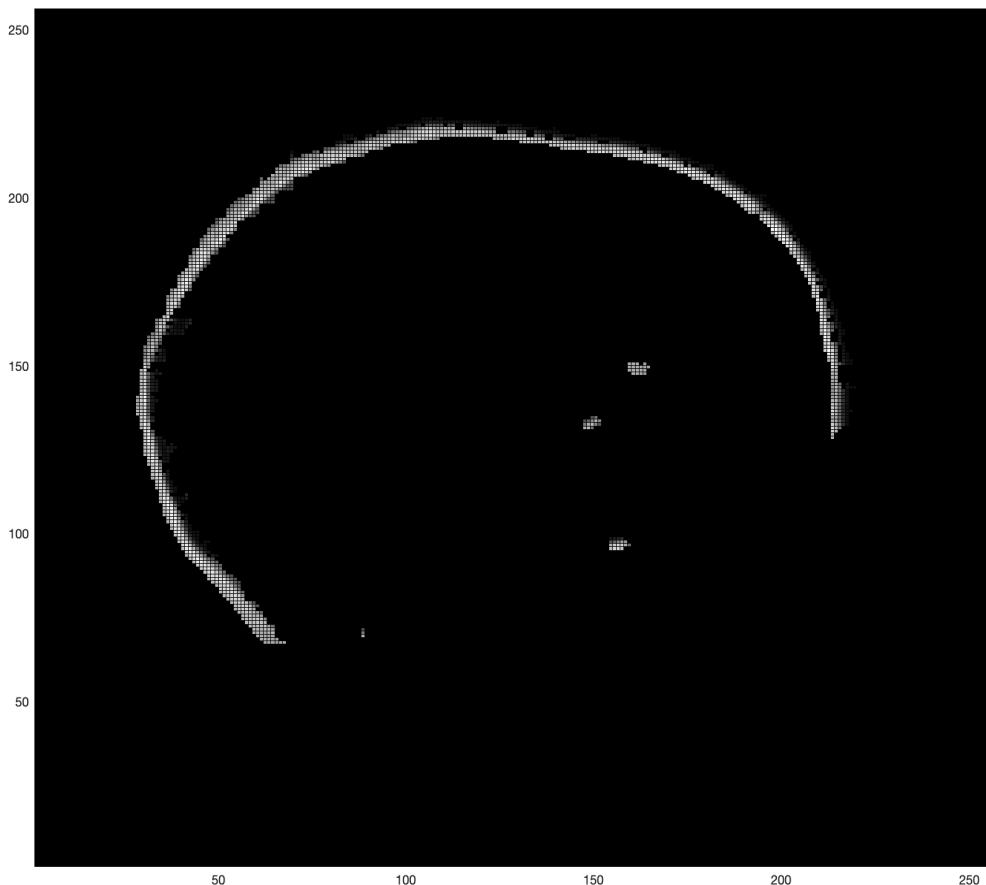
Foreground  
Nodes



# Pruning

- An final optimization
- Lots of background pixels (very low intensity)
  - Have high pixel-pixel weights
  - Algorithm wants to push flow through them and not the skull
- Solution: DESTROY them
- Remove pixel – pixel edges that are solely between very low intensity pixels

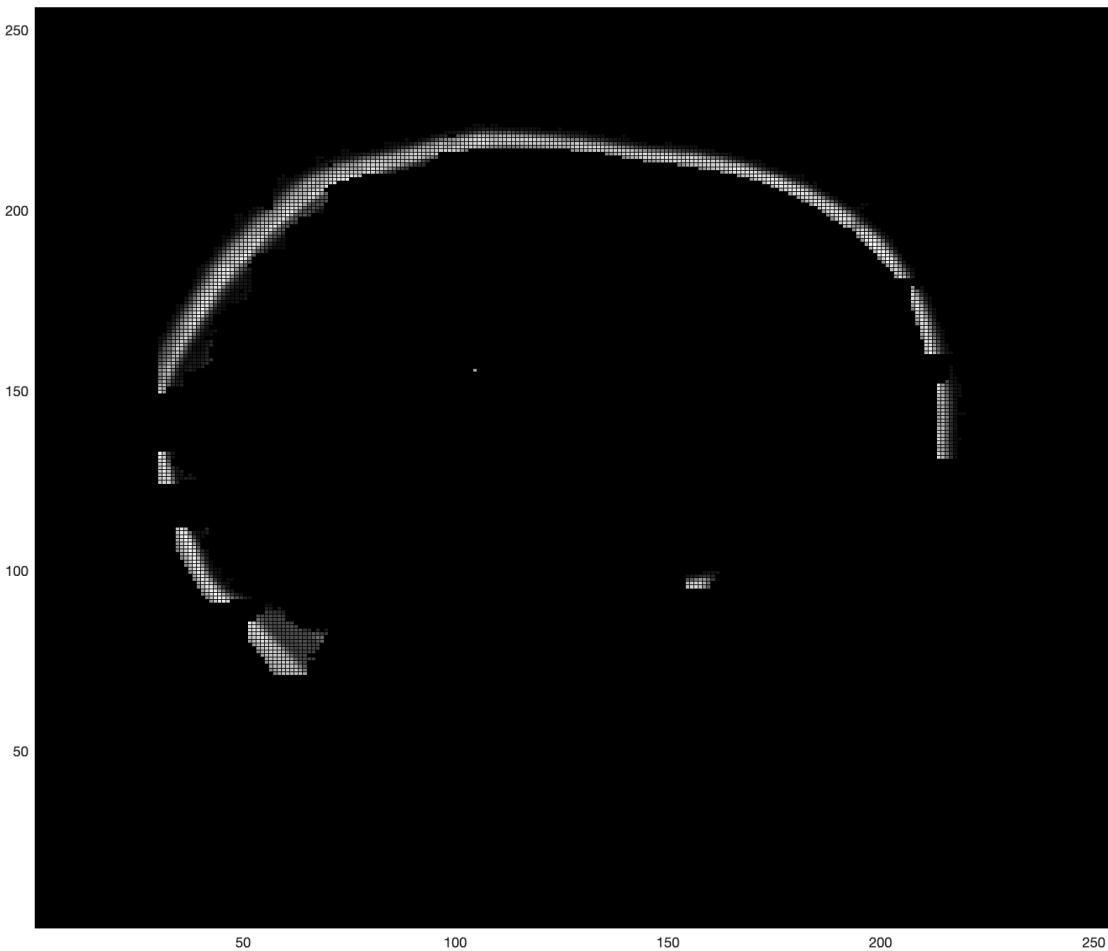
# Pruning - Hybrid



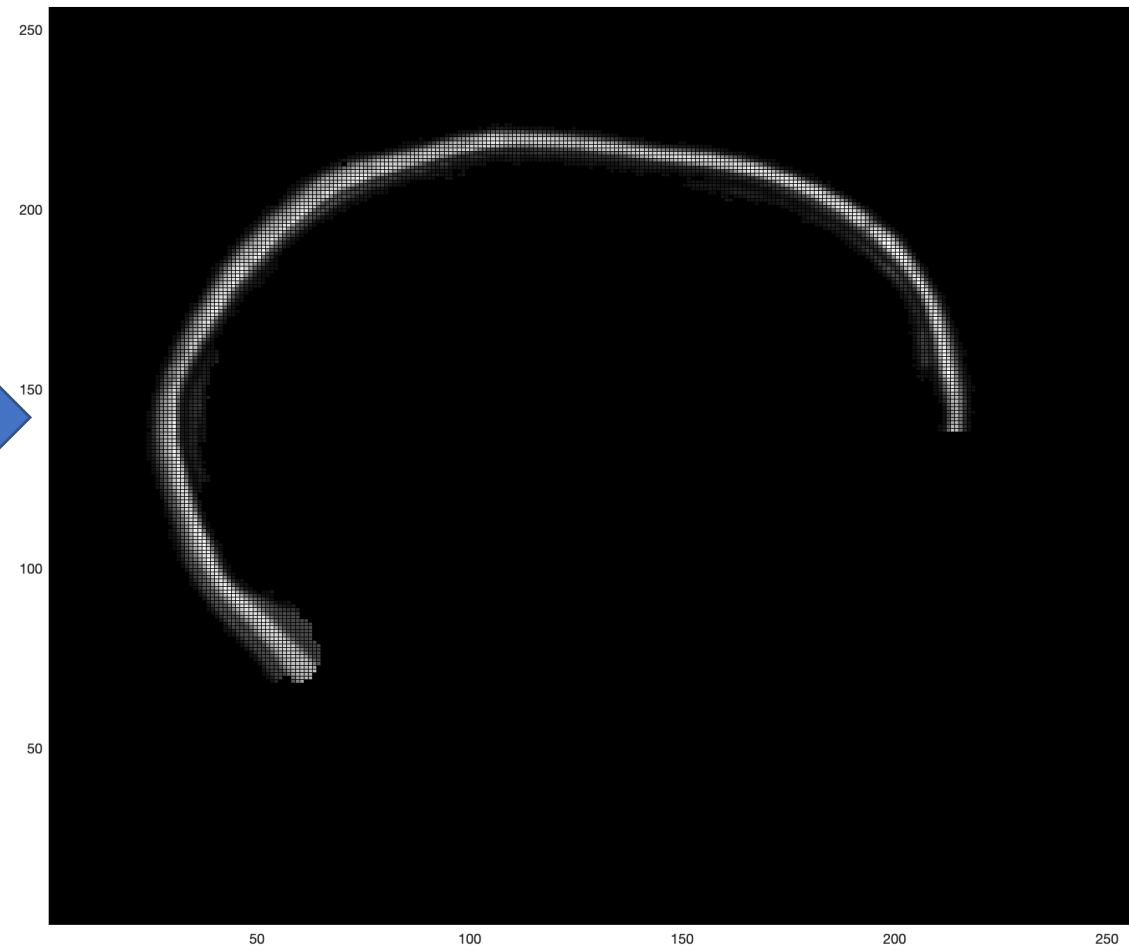
After  
Pruning



# Pruning – Intensity Difference

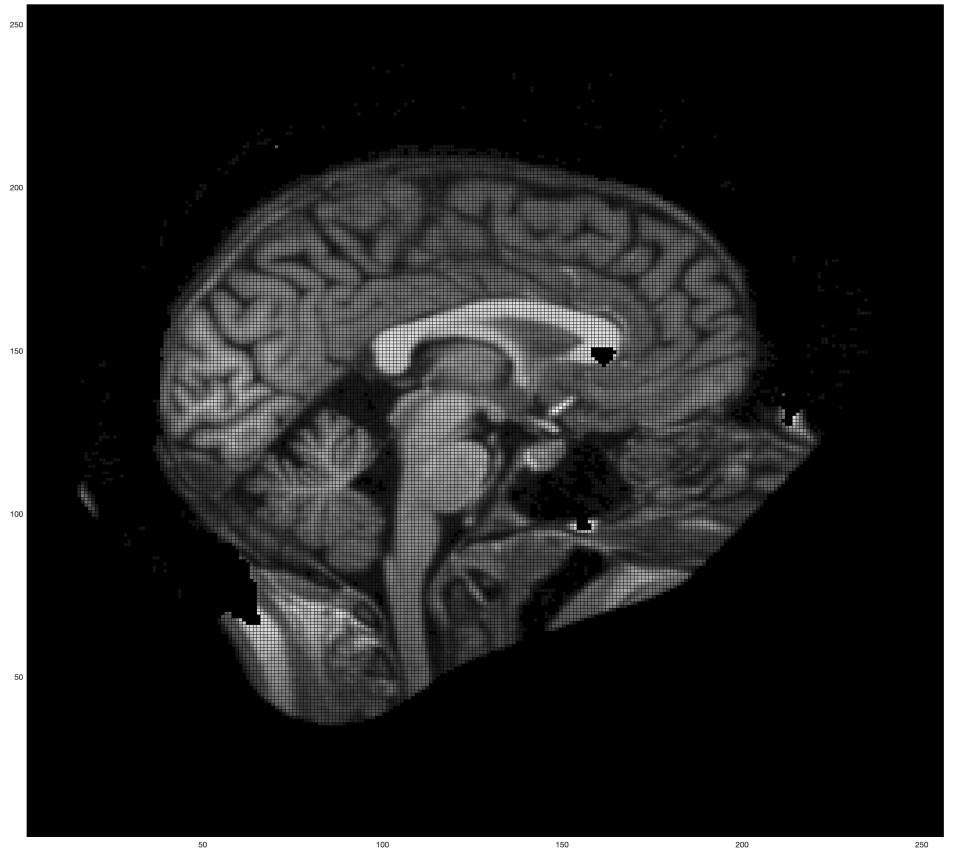
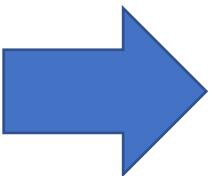
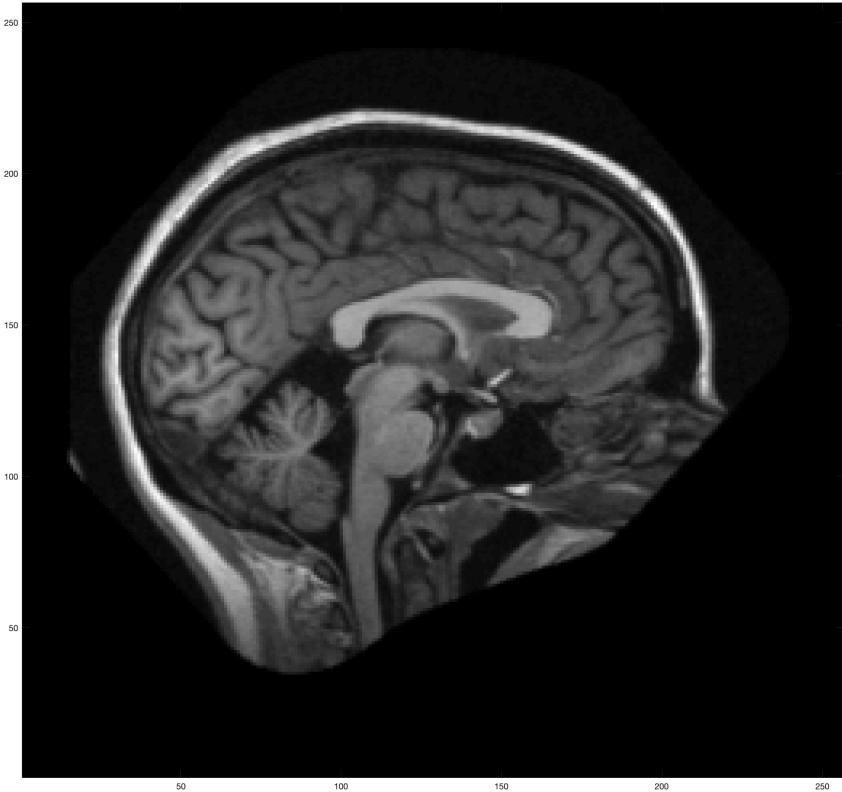


After  
Pruning

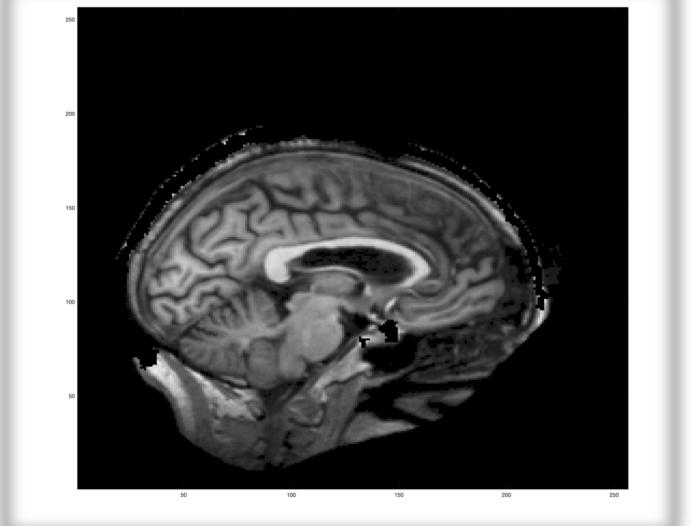
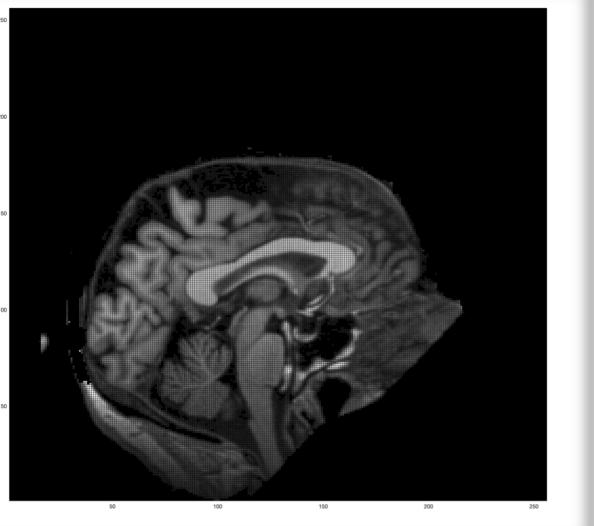
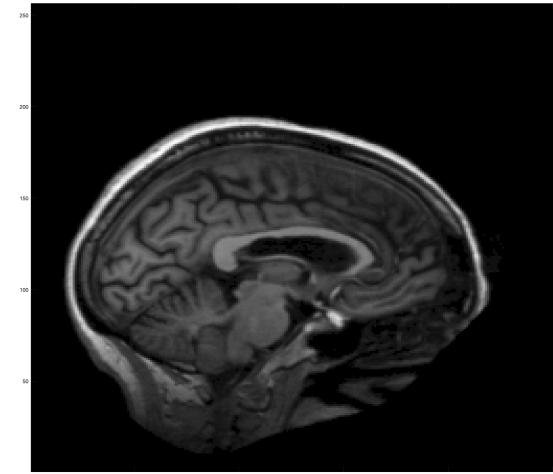
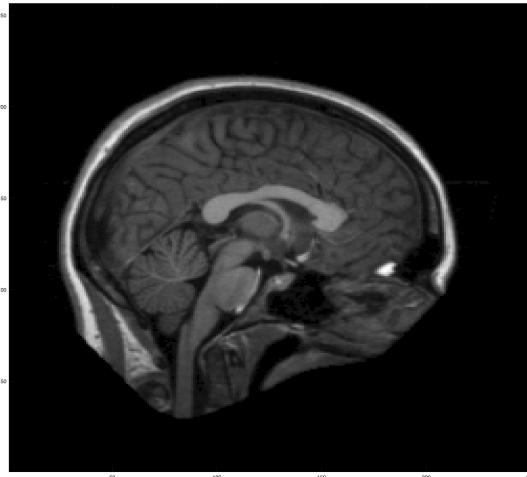
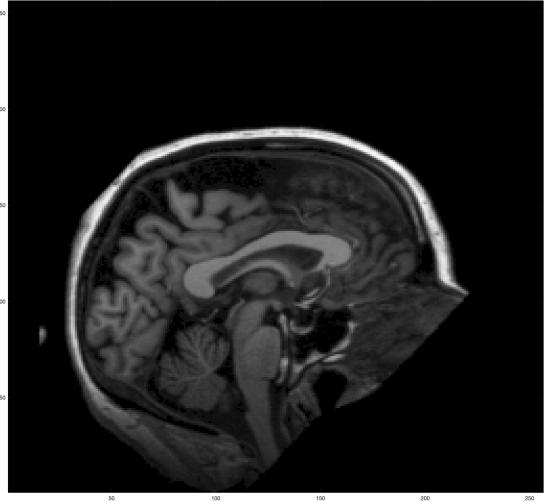


# Final Mask

- Combined result from hybrid and intensity difference



# Some Additional Examples



# Conclusion

- Not a straightforward graph cut problem
  - No clear boundary edges
- Lingering issues
  - Noise
  - Smoothness
  - That pesky corpus callosum
- Adding an explicit distance metric will prevent unlikely cut and act as a smoothness term
- Postprocessing steps like morphological dilation and erosion could solve issues with holes