

# Topology Preserving Automatic Segmentation of the Spinal Cord in Magnetic Resonance Images

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Background

The Problem

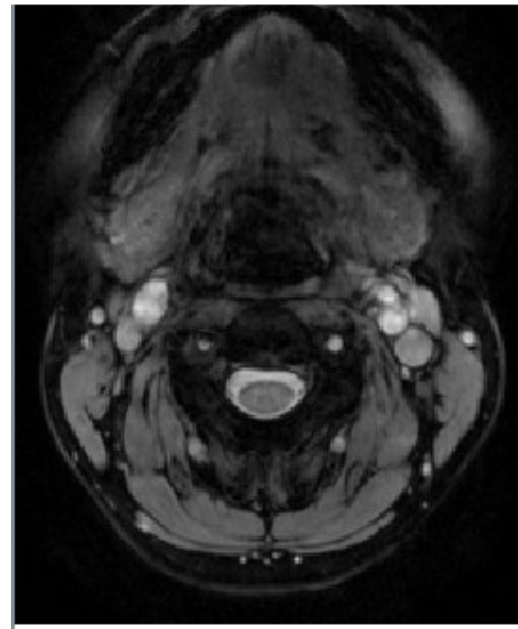
Methods

Results

Conclusion

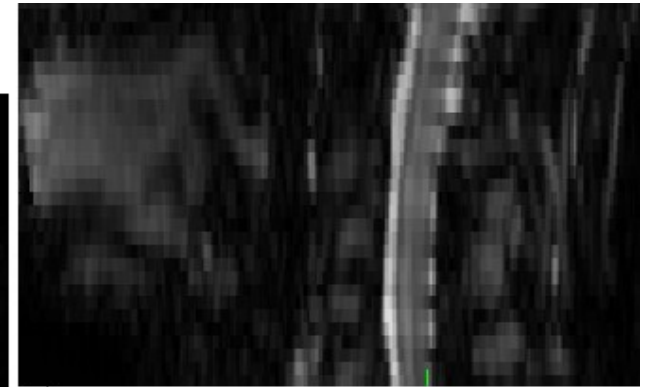
# Spinal Cord Imaging

- Study of disease or disorder in the nervous system
  - Meningitis
  - Syringomyelia
  - Multiple Sclerosis
- Correlates with disability
- Measure of potential neuroprotective therapies
- Observation of injuries



Axial

Sagittal



Coronal

Background

The Problem

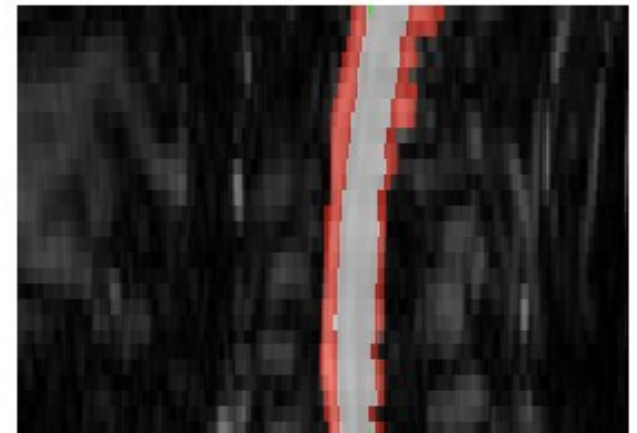
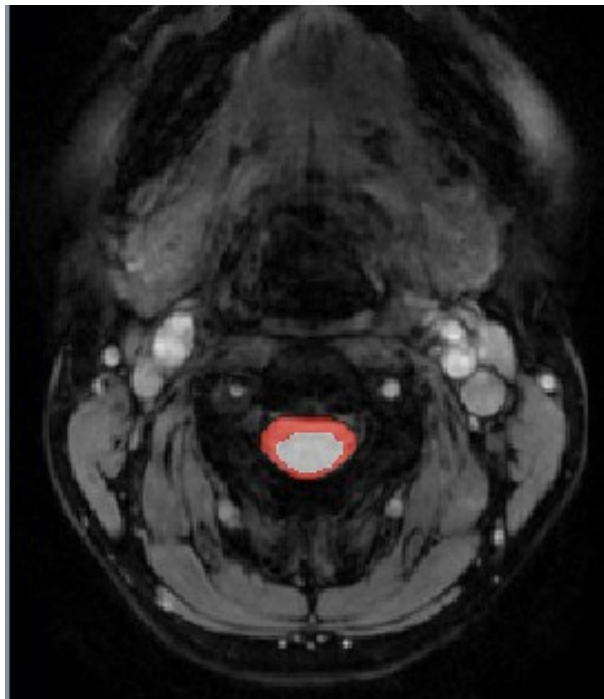
Methods

Results

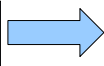
Conclusion

# Spinal Cord Segmentation

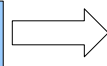
- ROI-based analysis, such as volume, MTR, average FA, etc.
- Primarily performed through manual or semi-automatic methods
  - Time consuming
  - Requires training
  - Can be inconsistent



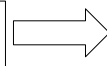
Background



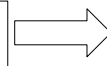
The Problem



Methods

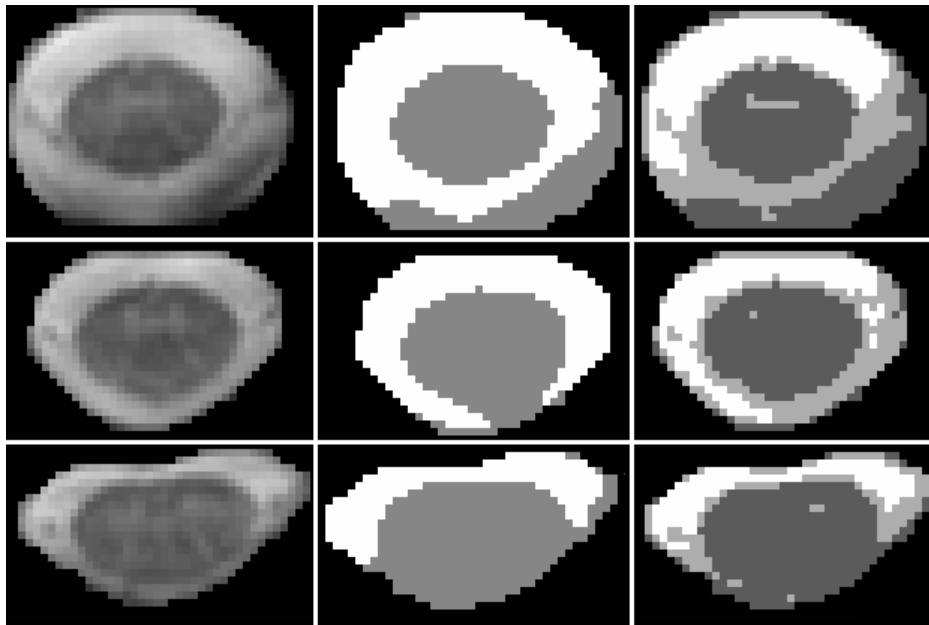


Results



Conclusion

# Challenges – Intensity Artifacts



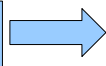
MR Image

2-Class  
Result

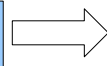
3-Class  
Result

- Presence of nerve roots
- Partial voluming with the dura mater
- Relatively small size of the spinal cord
- Influence from the vertebral bodies
- Poses difficulties for standard intensity based classification methods

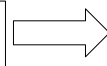
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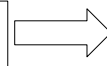
The Problem



Methods



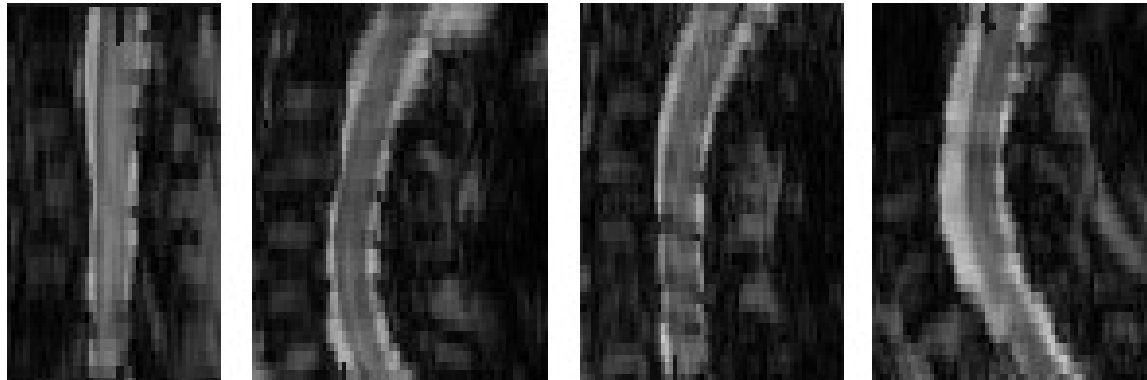
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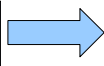
Conclusion

# Challenges – Shape Variations

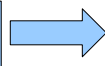
- High variability in shape
- Registration based methods have difficulties correctly aligning images and atlases



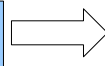
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Methods



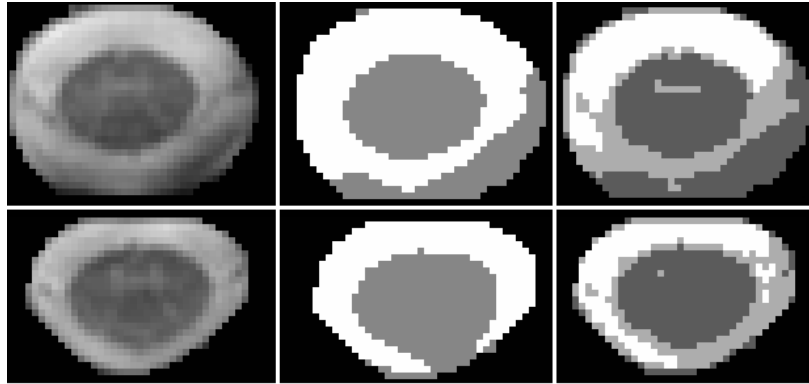
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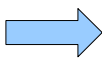
Conclusion

# Proposed Solution

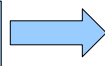
- Spinal cord has a very well defined topology



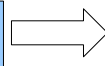
Background



The Problem



Methods



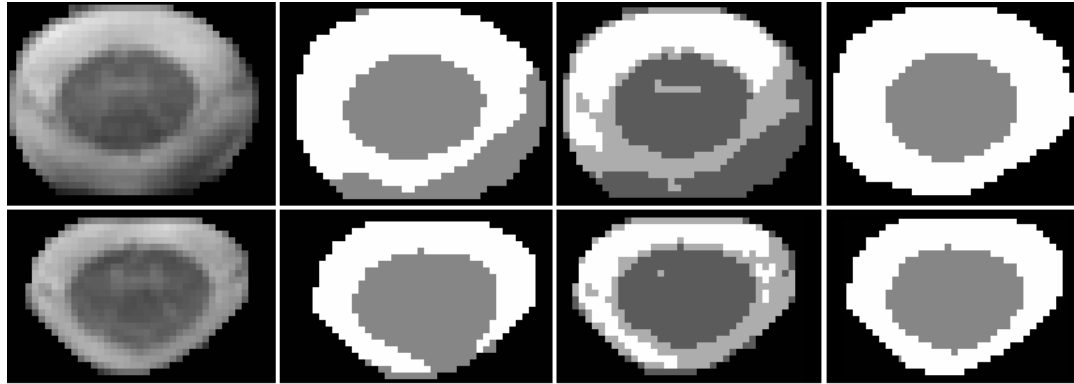
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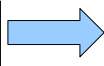
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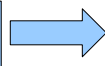
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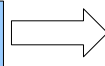
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The Problem



Methods



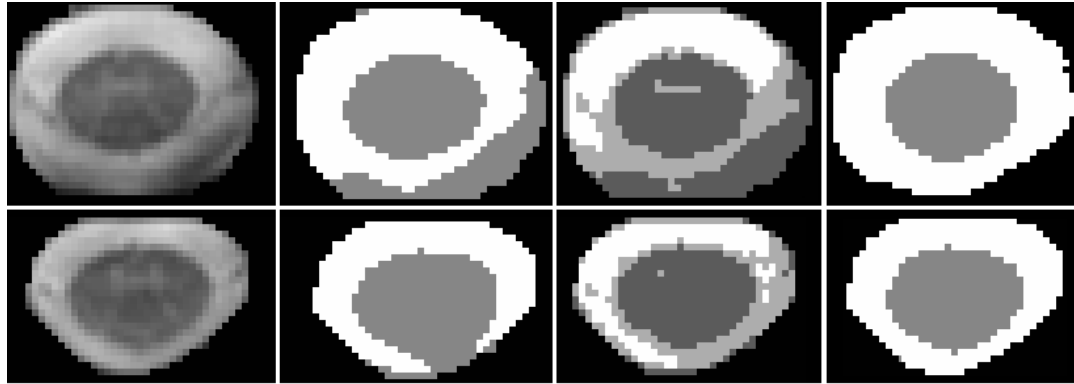
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Conclusion

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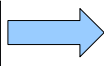
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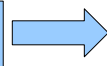
- Combination of two approaches:
  - Topology-preserving tissue classification
  - Deformable atlas registration



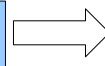
Background



The Problem



Methods



Results



Conclusion

# Topology-preserving, Anatomy-Driven Segmentation (TOADS)

- Bazin and Pham 2007, 2008
- Designed for brain segmentation
- Guarantees a segmentation consistent with a topology atlas
- Uses Digital Homeomorphism Criterion to guarantee topology is preserved
  - Multi-object extension of the Simple Point Criterion

Background

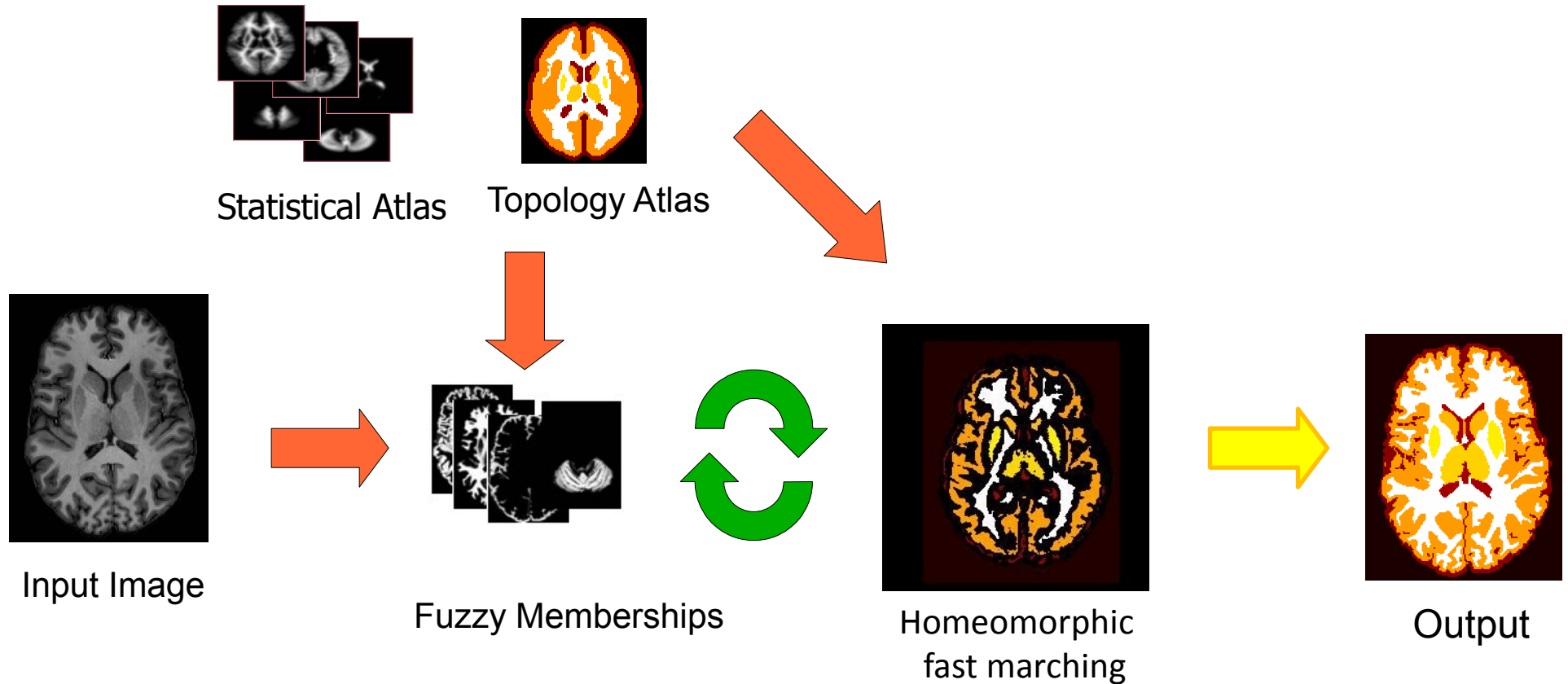
The Problem

Methods

Results

Conclusion

# TOpology-preserving, Anatomy-Driven Segmentation (TOADS)



Background

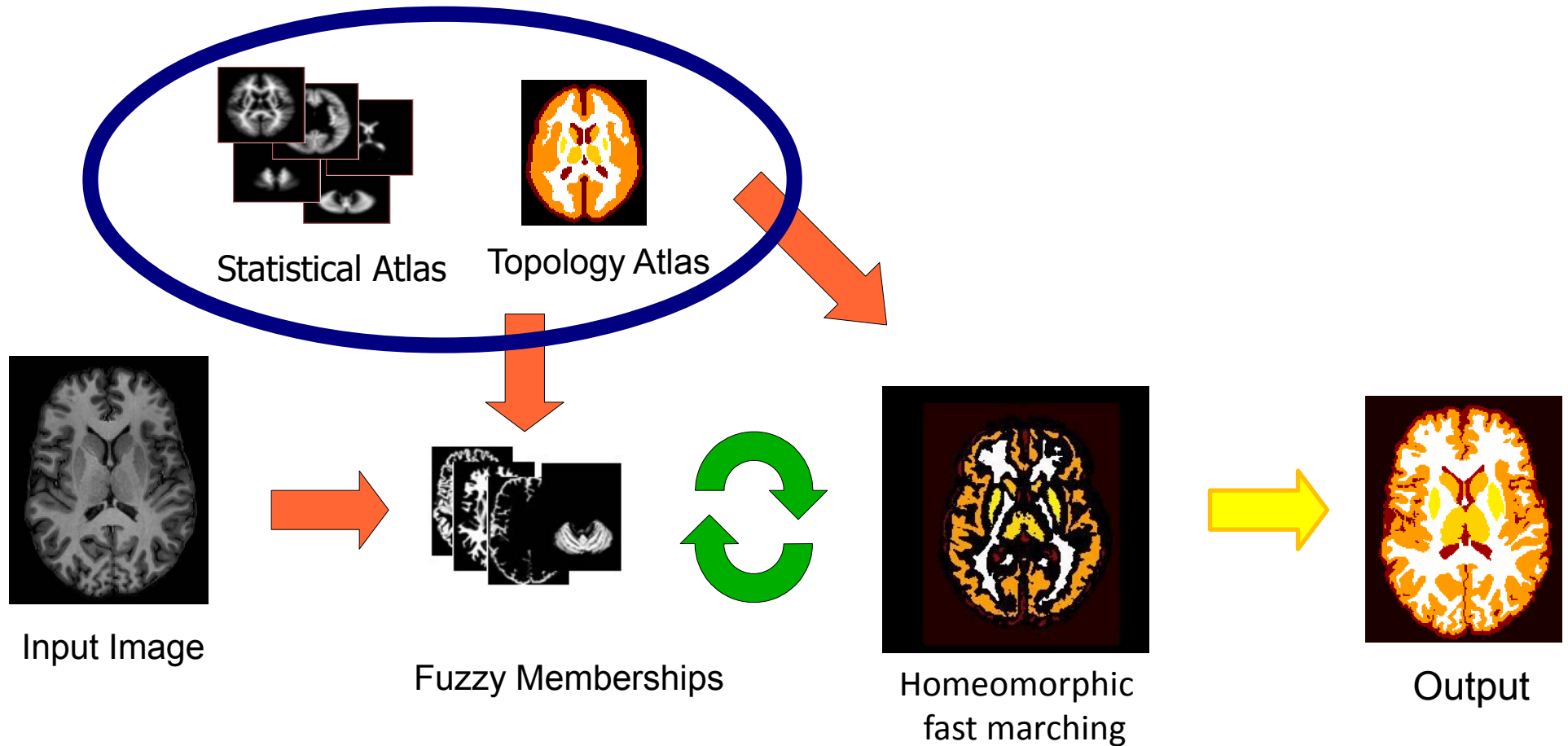
The Problem

Methods

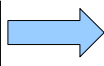
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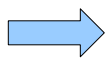
# TOpology-preserving, Anatomy-Driven Segmentation (TOADS)



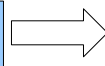
Background



The Problem



Methods



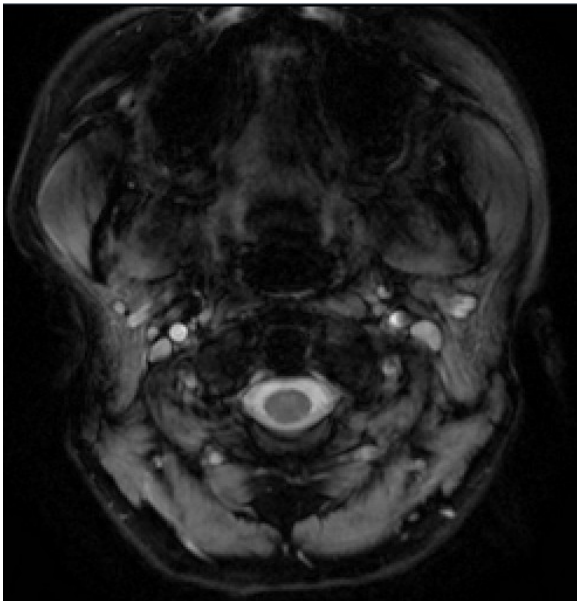
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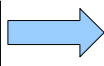
Conclusion

# Using TOADS with the Spinal Cord

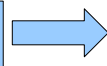
- TOADS requires a skull-stripped image of the brain
  - **The problem we're trying to solve for the spinal cord**



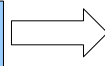
Background



The Problem



Methods



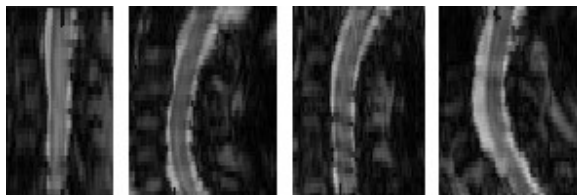
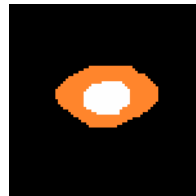
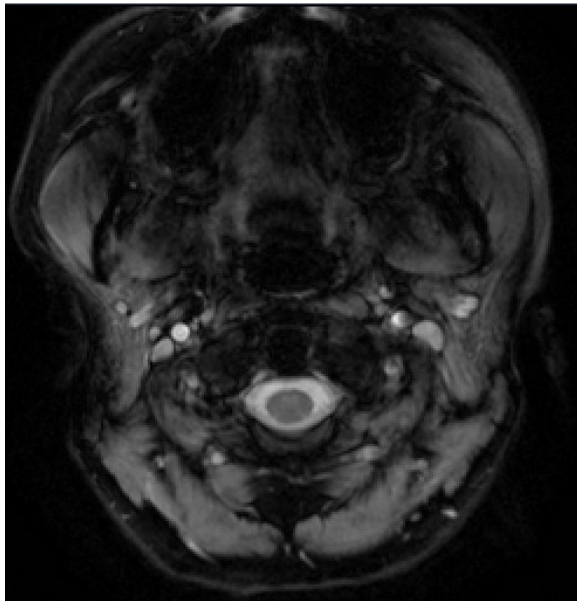
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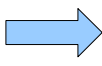
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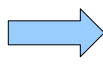
- TOADS requires a skull-stripped image of the brain
  - **The problem we're trying to solve for the spinal cord**
- TOADS relies on affine registration for atlas initialization
  - **Cannot account for variability in the spinal cord**



Background



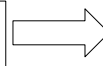
The Problem



Methods



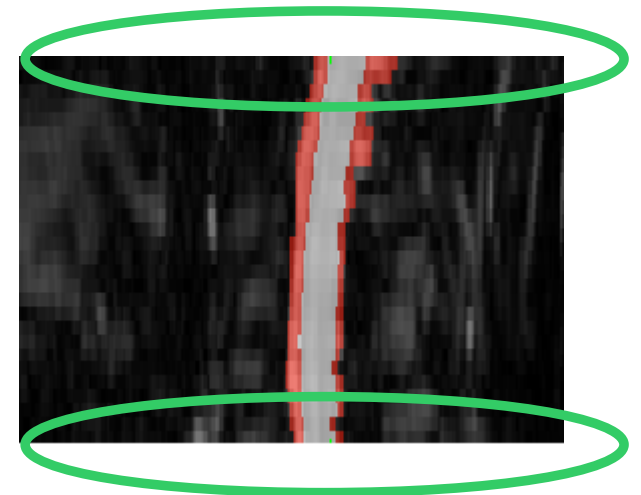
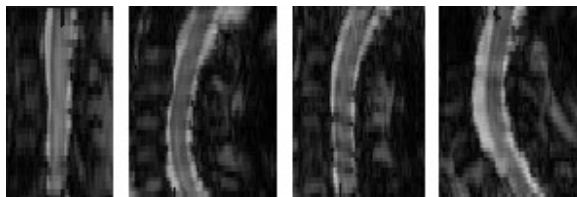
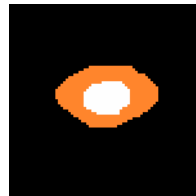
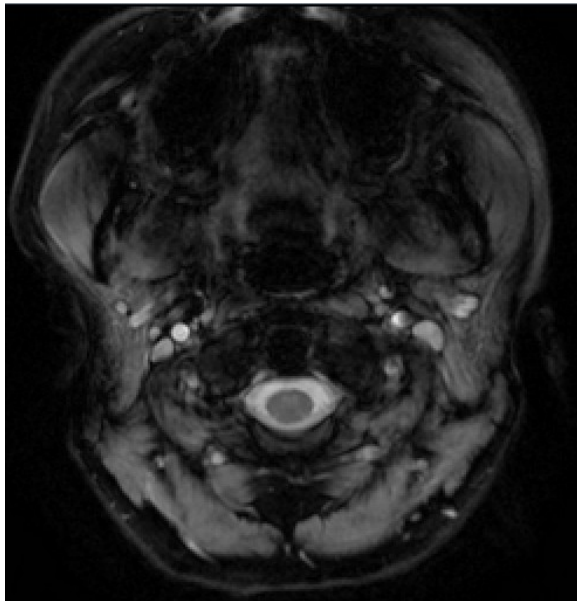
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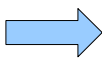
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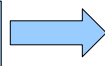
- TOADS requires a skull-stripped image of the brain
  - **The problem we're trying to solve for the spinal cord**
- TOADS relies on affine registration for atlas initialization
  - **Cannot account for variability in the spinal cord**
- Spinal cord topology is complicated by boundary conditions



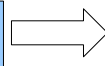
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The Problem



Methods



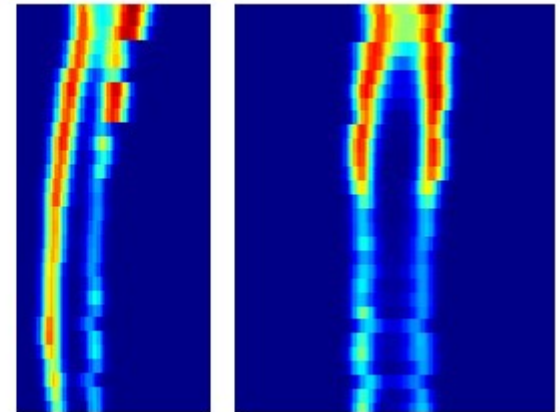
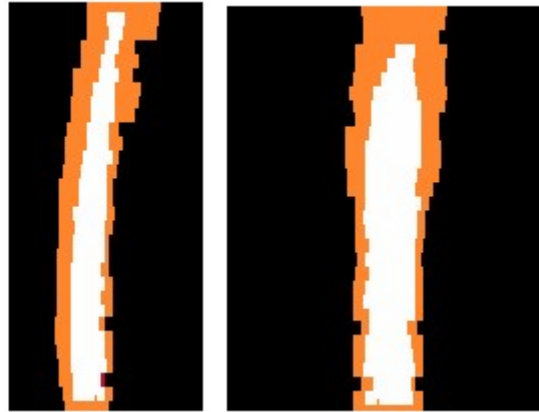
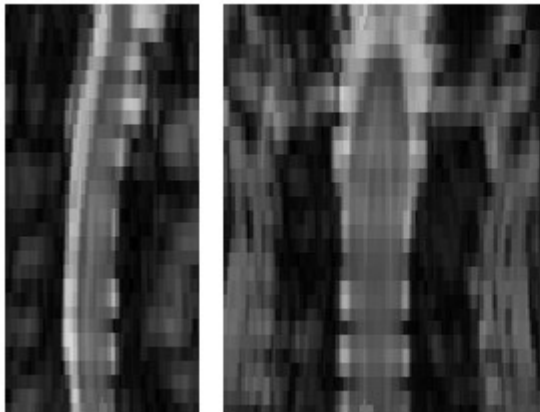
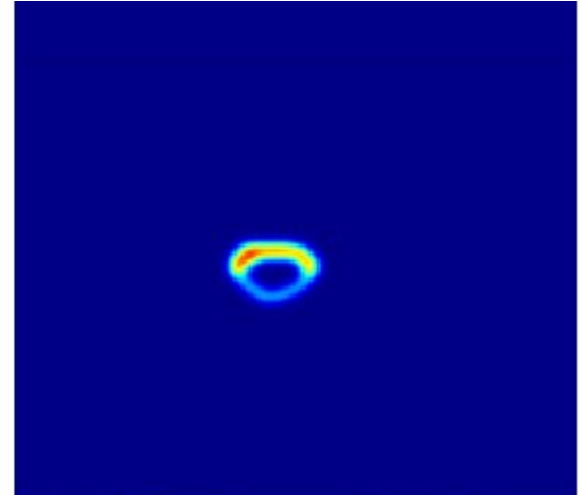
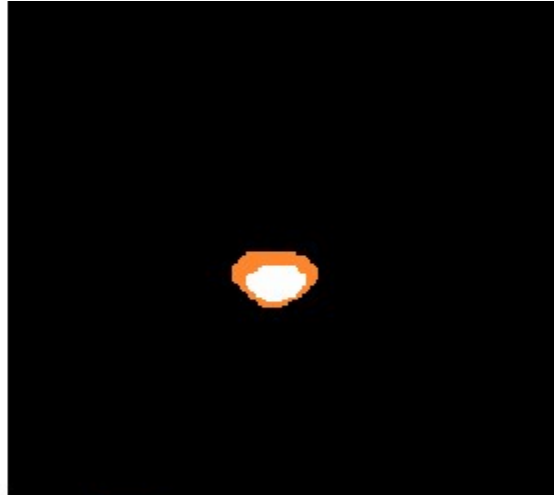
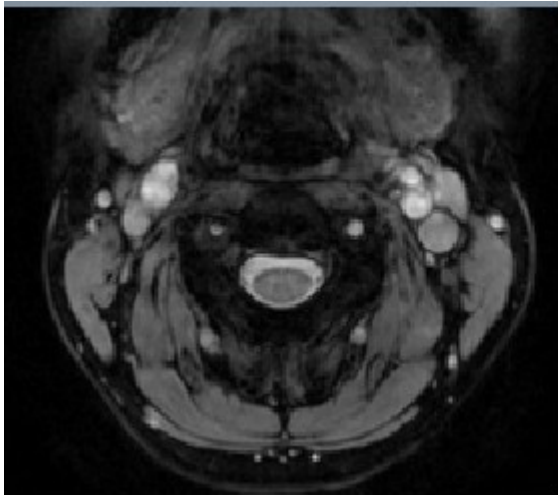
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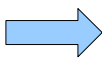
Conclusion

# Adapting TOADS for the Spine

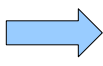
- Introduce an additional intensity atlas:



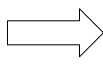
Background



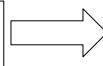
The Problem



Methods

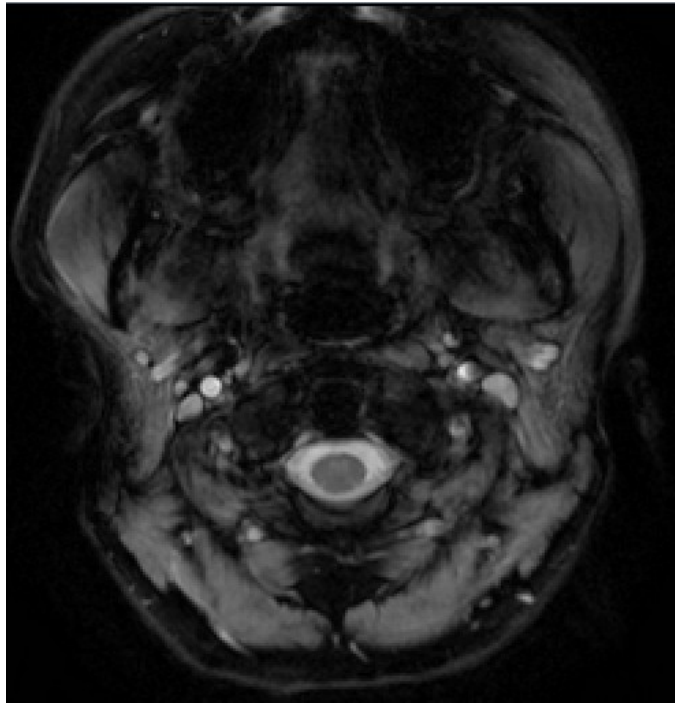


Results

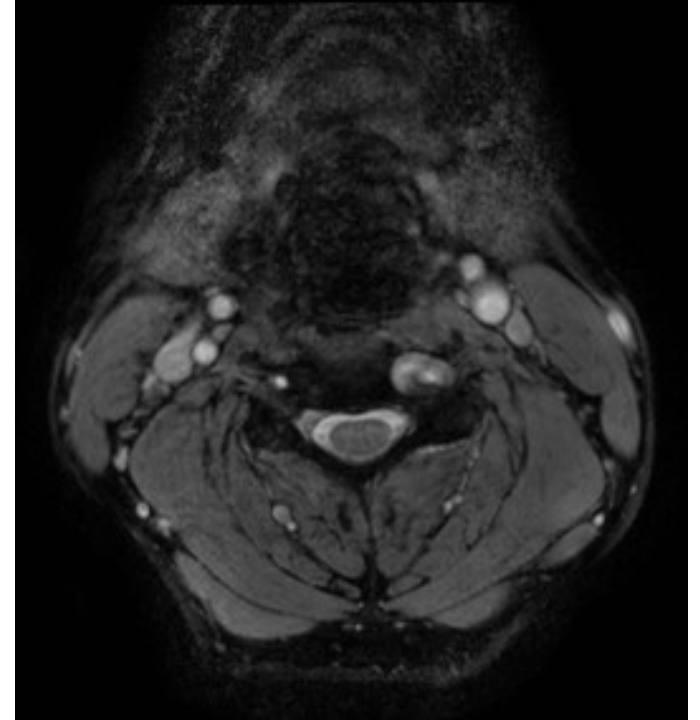
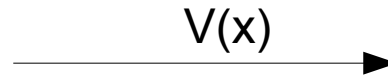


Conclusion

# Align Intensity Atlases by Deformable Registration



Intensity Atlases



Target



Background

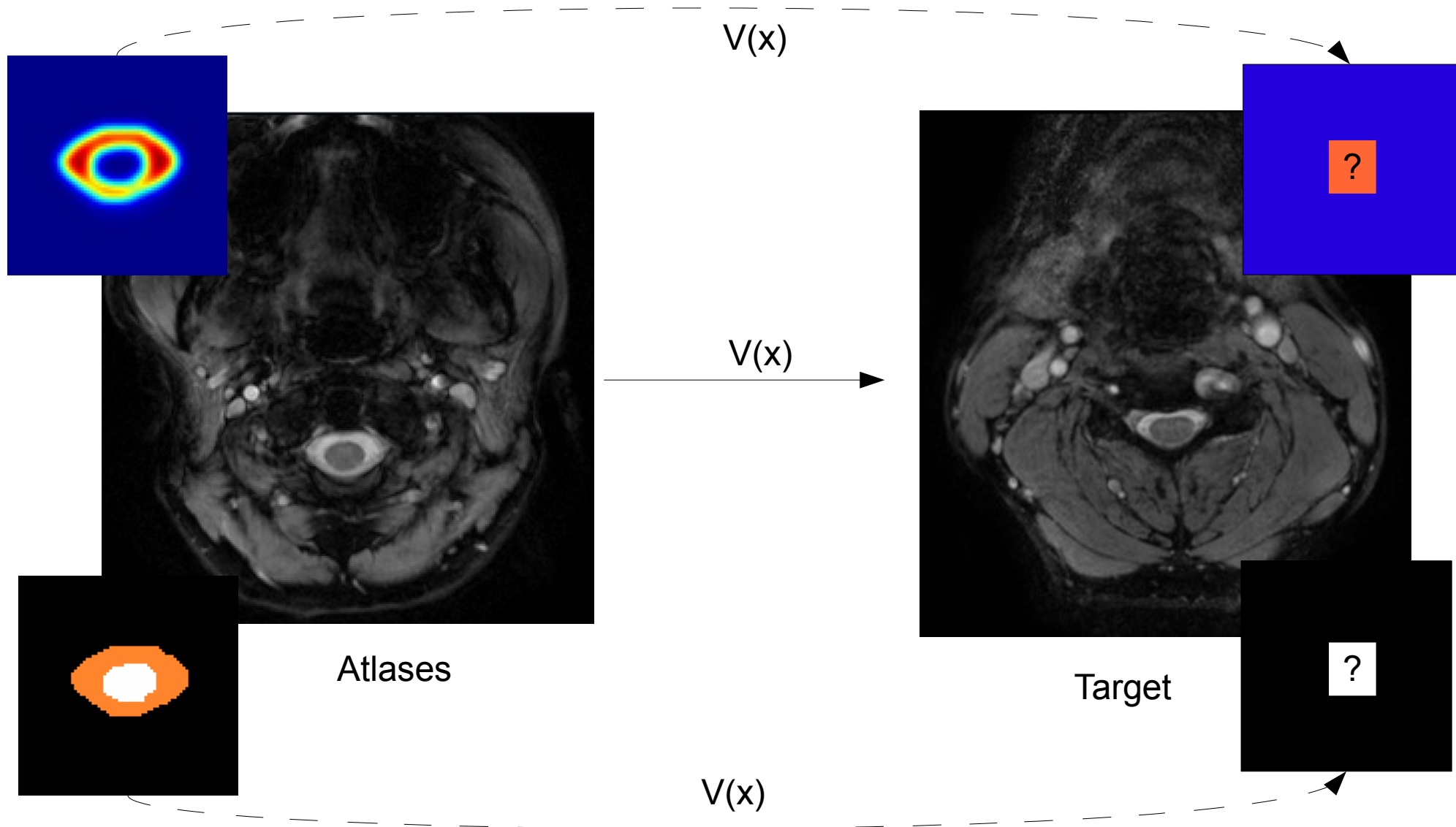
The Problem

Methods

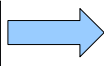
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# Apply Learned Deformation to Atlases



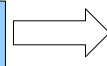
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Methods



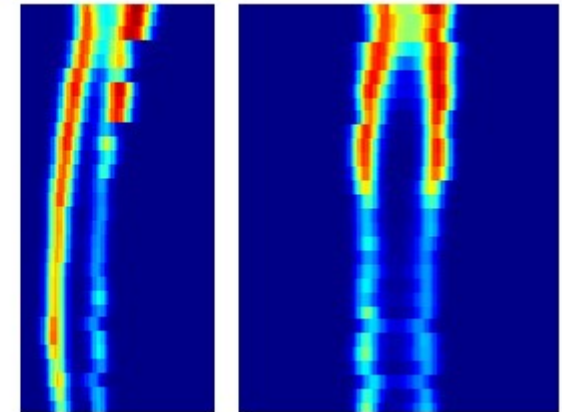
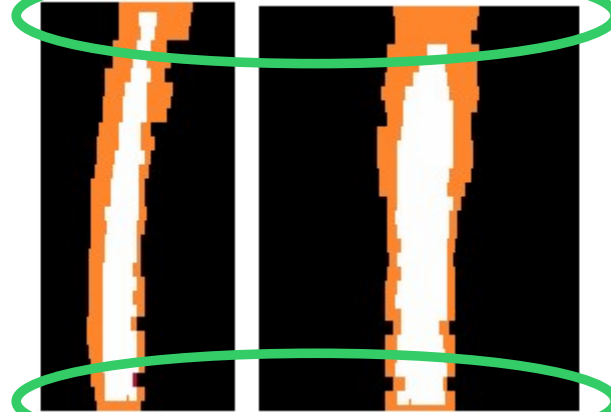
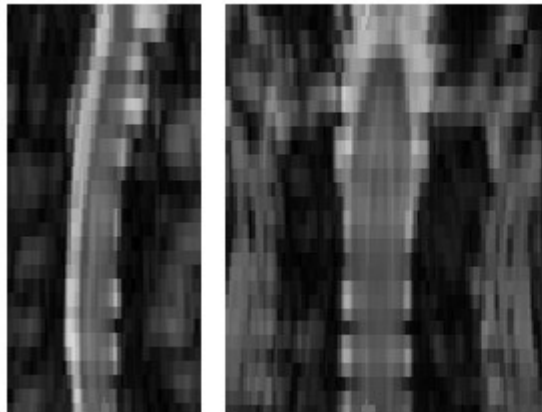
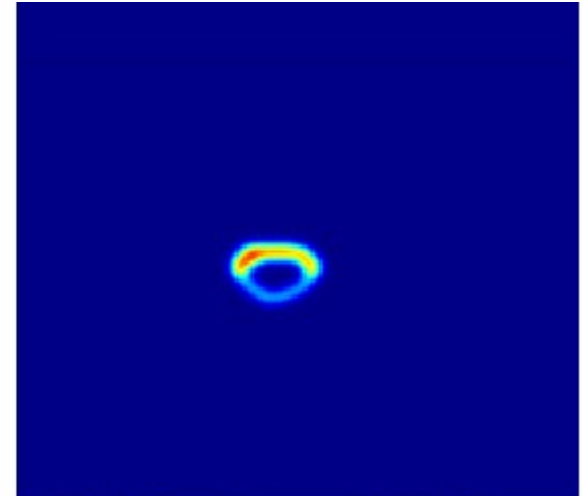
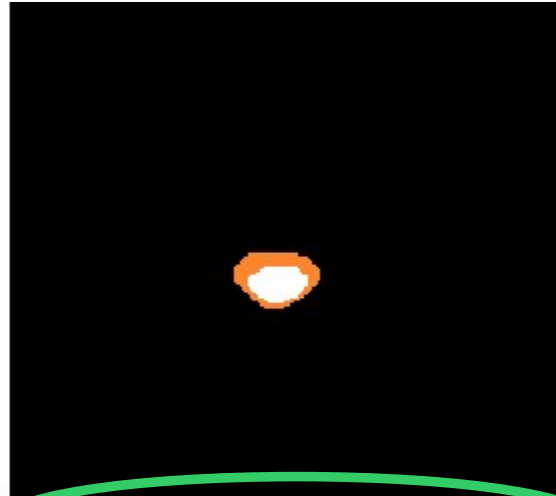
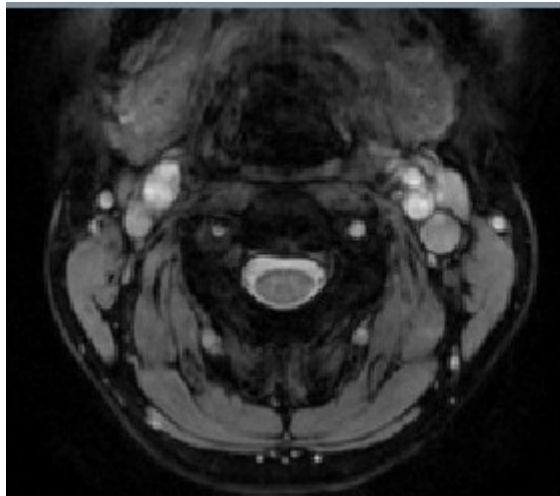
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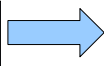
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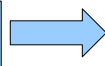
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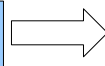
Background



The Problem



Methods



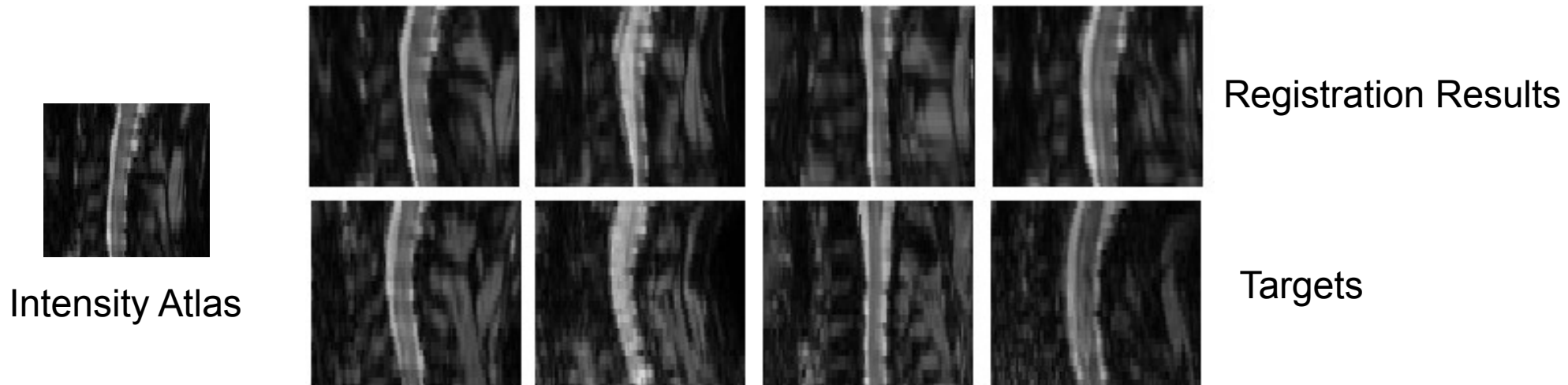
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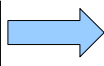
Conclusion

# Deformable Registration of the Spinal Cord

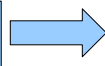
- Adaptation of **Adaptive Bases Algorithm** (Rohde *et al.* 2003)
  - Optimizes over NMI and uses radial basis function to construct the deformation



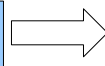
Background



The Problem



Methods



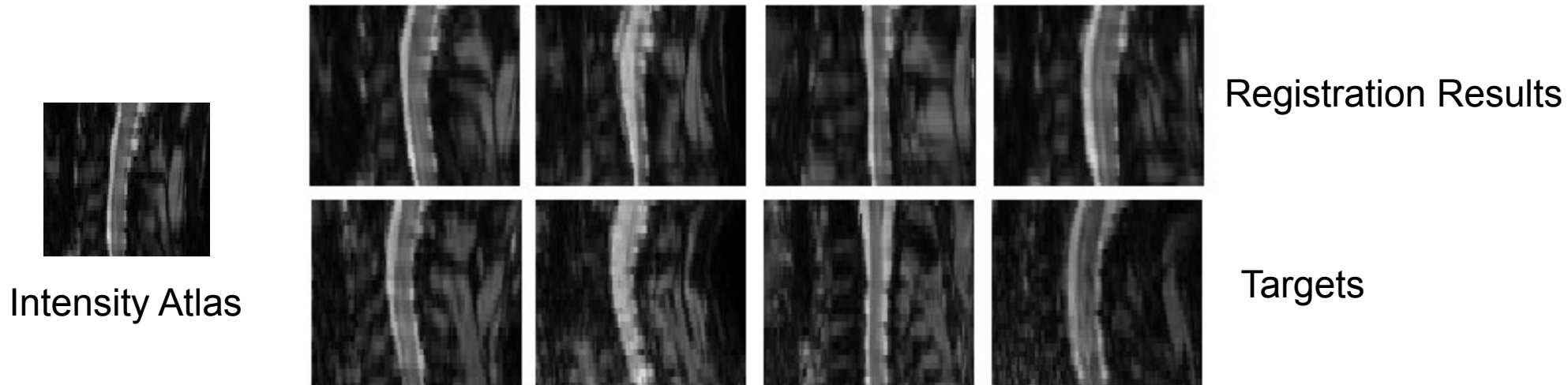
Results



Conclusion

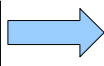
# Deformable Registration of the Spinal Cord

- Adaptation of **Adaptive Bases Algorithm** (Rohde *et al.* 2003)
  - Optimizes over NMI and uses radial basis function to construct the deformation

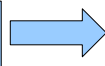


- Deformable registration can introduce topological errors into the template

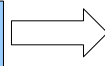
Background



The Problem



Methods



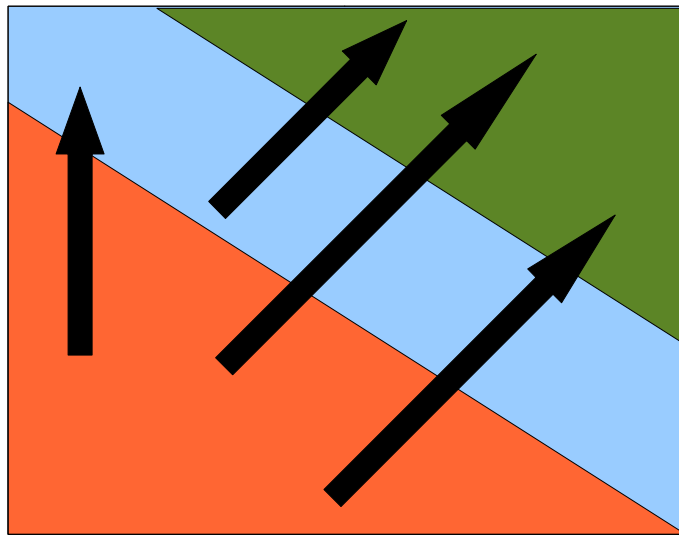
Results



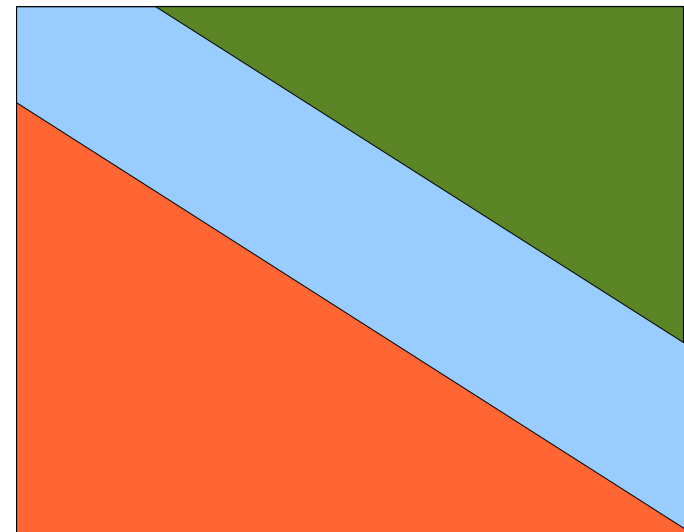
Conclusion

# Homeomorphic Approximation of the Deformation Field

- Find homeomorphic approximation of the deformation field
  - Stepwise reconstruction of the original field
  - Check the digital homeomorphism criterion at each step

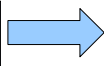


Original Deformation

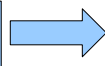


Approximated Homeomorphic Deformation

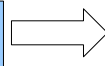
Background



The Problem



Methods



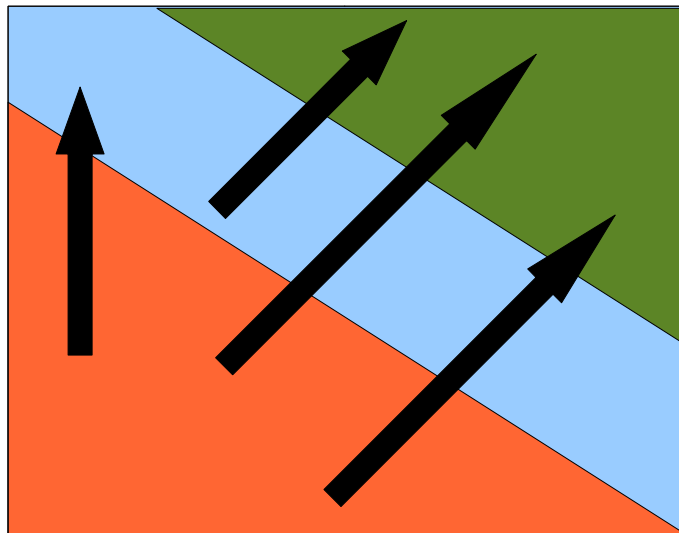
Results



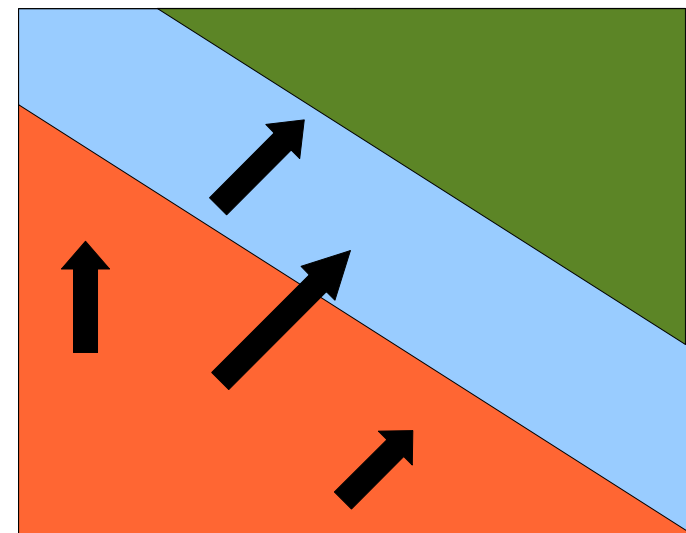
Conclusion

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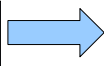


Original Deformation

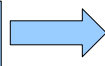


Approximated Homeomorphic Deformation

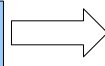
Background



The Problem



Methods



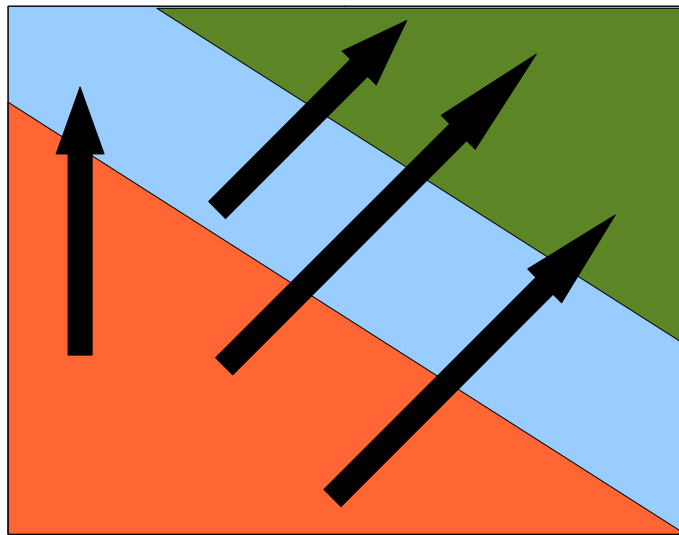
Results



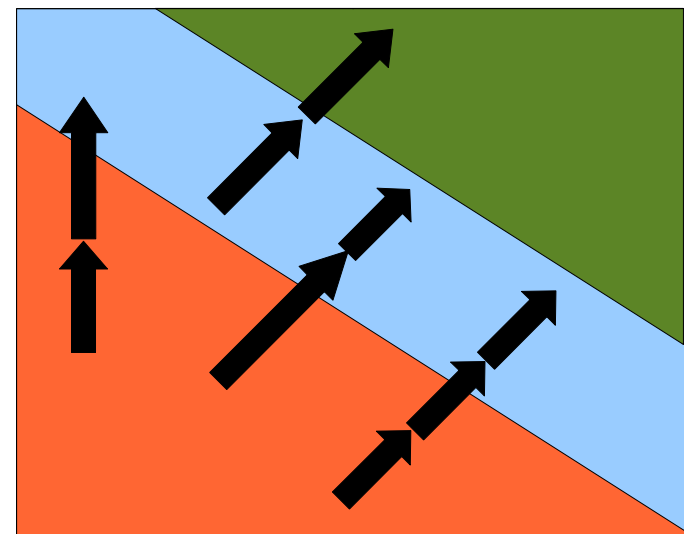
Conclusion

# Homeomorphic Approximation of the Deformation Field

- Find homeomorphic approximation of the deformation field
  - Stepwise reconstruction of the original field
  - Check the digital homeomorphism criterion at each step

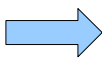


Original Deformation

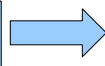


Approximated Homeomorphic Deformation

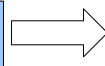
Background



The Problem



Methods



Results



Conclusion

# Homeomorphic Approximation of the Deformation Field



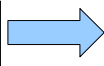
Deformation without  
homeomorphic  
approximation



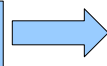
Deformation with  
homeomorphic  
approximation



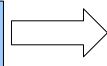
Background



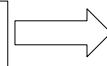
The Problem



Methods



Results



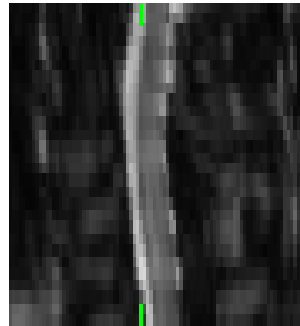
Conclusion

# Final Atlases Alignment

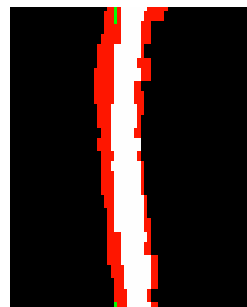
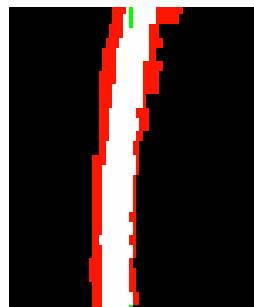
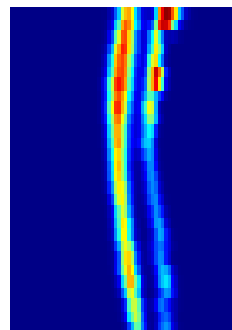
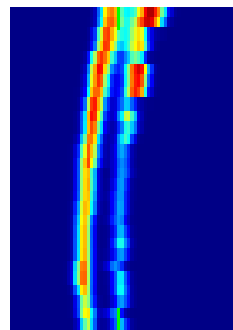
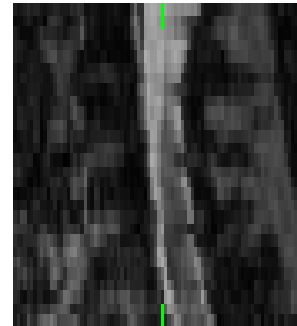
Original  
Atlases



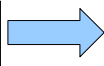
Registered  
Atlases



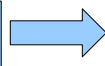
Target



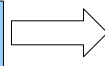
Background



The Problem



Methods



Results



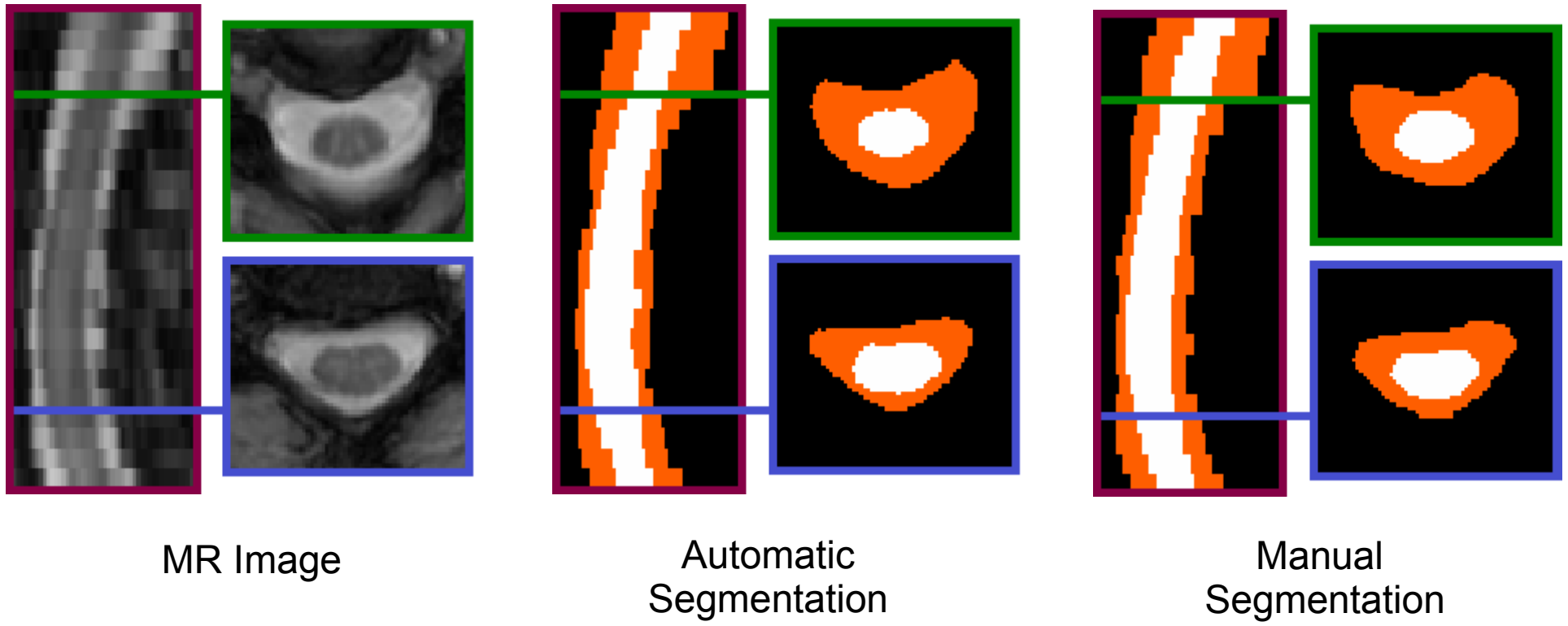
Conclusion

# Data and Validation

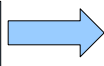
- 20 Magnetic Transfer Weighted MR images
- Resolution: .6mm x .6mm x 2.25mm
- C2-C6 region of the spinal cord
- Compared to manual segmentations
- Four were segmented by two separate raters



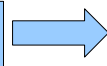
# Qualitative Comparison



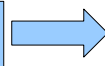
Background



The Problem



Methods



Results



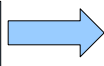
Conclusion

# Dice Comparison to Manual Raters

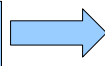
Mean and standard deviation of Dice overlap compared to manual raters

| Method                          | CSF                  | Spinal Cord          | Spinal Cord + CSF    |
|---------------------------------|----------------------|----------------------|----------------------|
| Atlas Registration              | 0.711 (0.070)        | 0.821 (0.065)        | 0.732 (0.064)        |
| <b>Topology Preserving Seg.</b> | <b>0.843 (0.034)</b> | <b>0.904 (0.035)</b> | <b>0.866 (0.029)</b> |
| 2nd Manual Rater                | 0.884 (0.008)        | 0.937 (0.011)        | 0.903 (0.003)        |

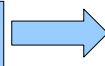
Background



The Problem



Methods

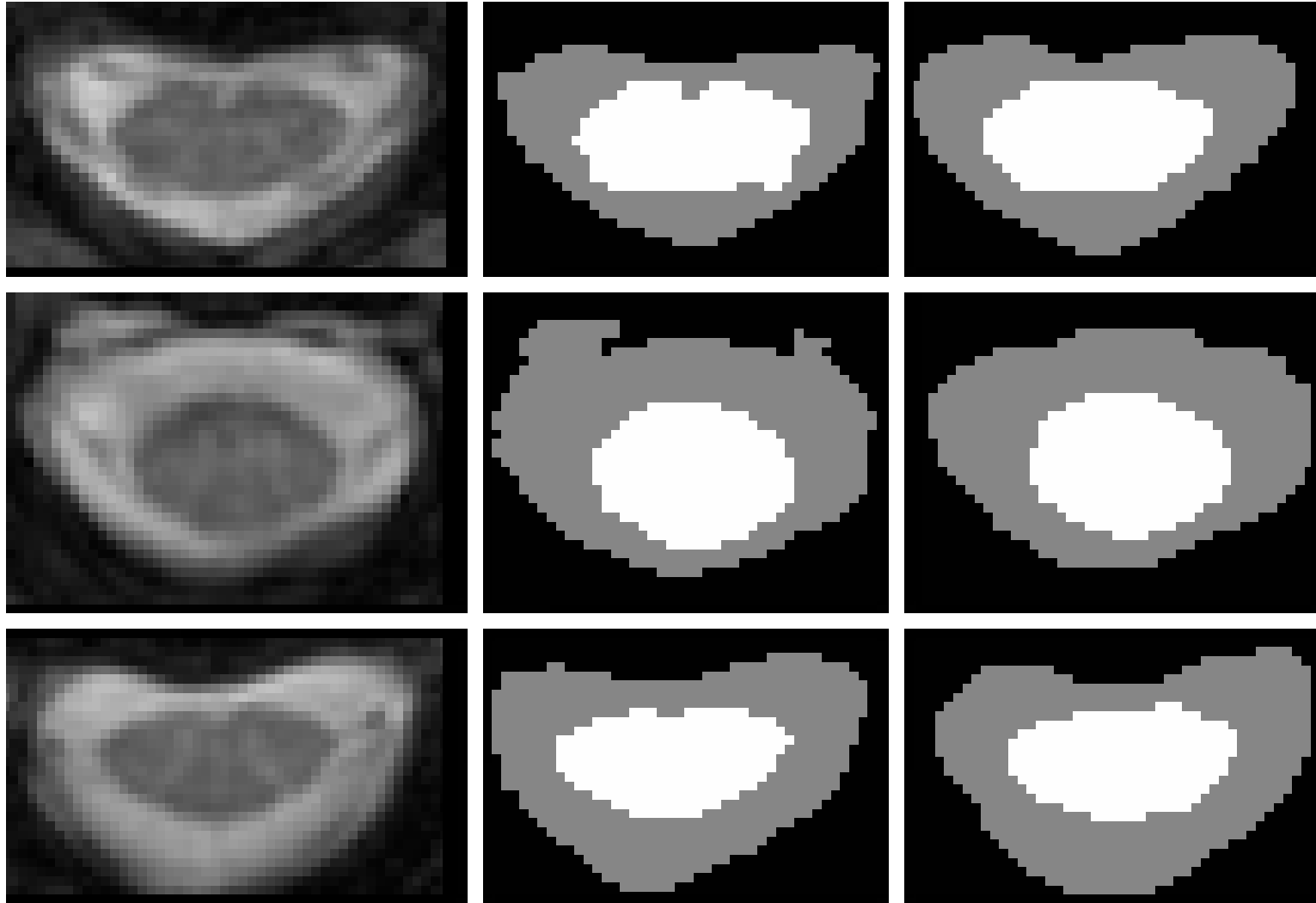


Results



Conclusion

# Potential Differences

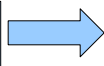


MR Image

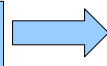
Automatic  
Segmentation

Manual  
Segmentation

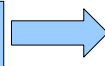
Background



The Problem



Methods



Results



Conclusion

# Summary

- Fully automatic spinal cord segmentation
- Topologically consistent with the anatomy
- Comparable to manual segmentations
- Used deformable registration(with homeomorphic approximation) to generalize the TOADS algorithm
- Future Considerations: Segmentations of finer structures
  - Grey matter
  - White matter columns

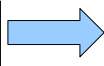
# Acknowledgments

IACL at Johns Hopkins University

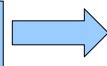
This work was supported by the Intramural Research Program of NINDS and NIH grants R01NS056307 and R01NS070906.

Data acquisition was supported by the National Multiple Sclerosis Society under a Tissue Repair grant to Peter Calabresi (Johns Hopkins University).

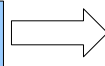
Background



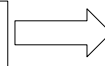
The Problem



Methods



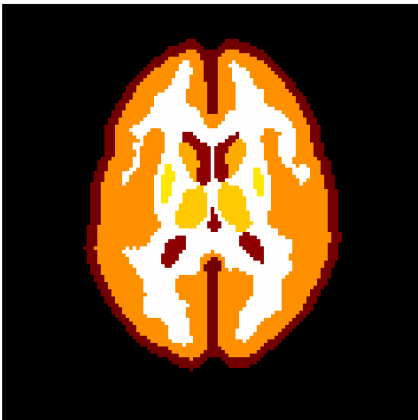
Results



Conclusion

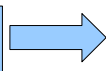
# TOpology-preserving, Anatomy-Driven Segmentation (TOADS)

- Homeomorphic fast marching with fuzzy memberships

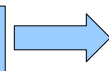




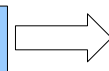
Background



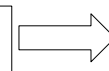
The Problem



Methods



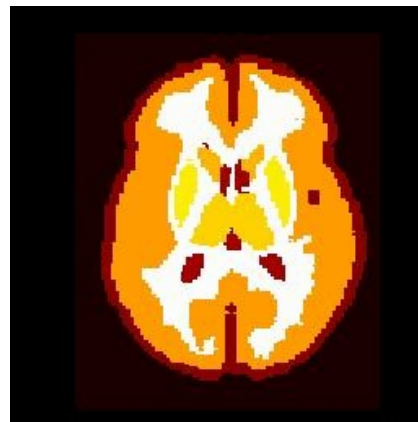
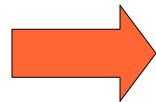
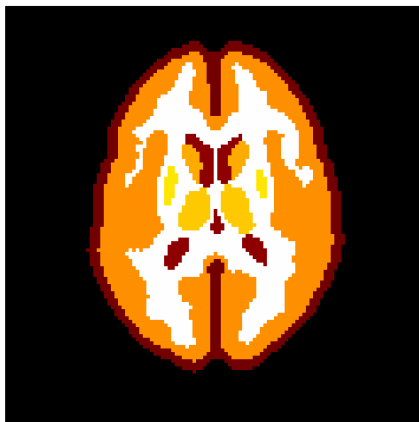
Results



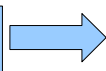
Conclusion

# TOADS: Topology-preserving, Anatomy-Driven Segmentation

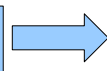
- Homeomorphic fast marching with fuzzy memberships
  - Thin out low memberships



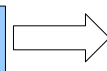
Background



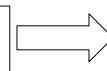
The Problem



Methods



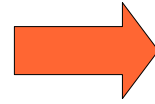
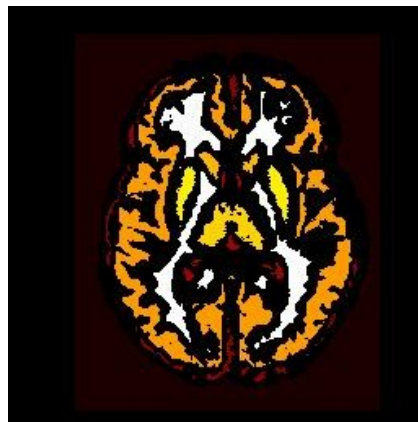
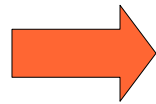
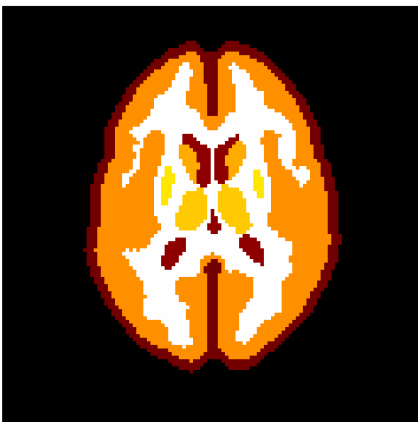
Results



Conclusion

# TOpology-preserving, Anatomy-Driven Segmentation (TOADS)

- Homeomorphic fast marching with fuzzy memberships
  - Thin out low memberships
  - Grow back high memberships



Background

The Problem

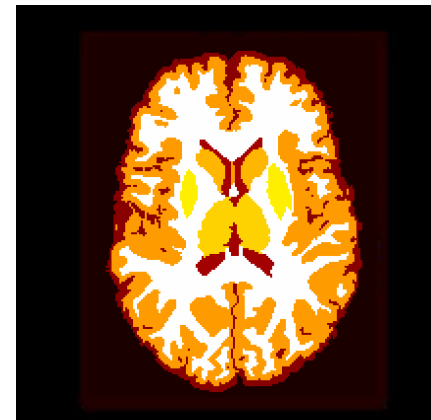
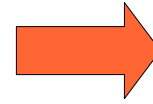
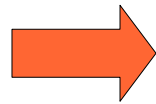
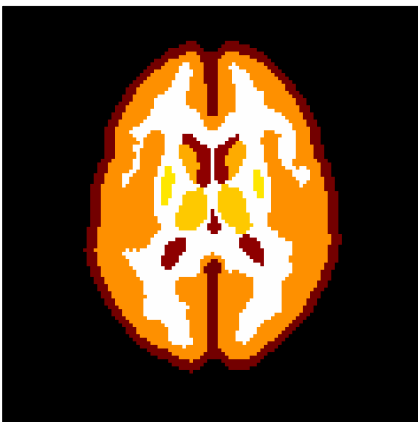
Methods

Results

Conclusion

# TOpology-preserving, Anatomy-Driven Segmentation (TOADS)

- Homeomorphic fast marching with fuzzy memberships
  - Thin out low memberships
  - Grow back high memberships
- Check digital homeomorphism criterion
  - Multi-object extension of the simple point criterion



Background

The Problem

Methods

Results

Conclusion

# TOpology-preserving, Anatomy-Driven Segmentation (TOADS)

- Homeomorphic fast marching with fuzzy memberships
  - Thin out low memberships
  - Grow back high memberships
- Check digital homeomorphism criterion
  - Multi-object extension of the simple point criterion
- Recalculate memberships and iterate to convergence

