UNC
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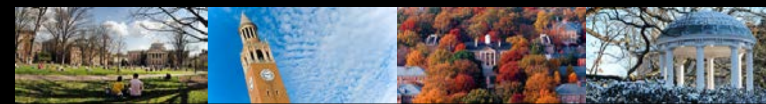


Deep Learning in Medical Image Analysis

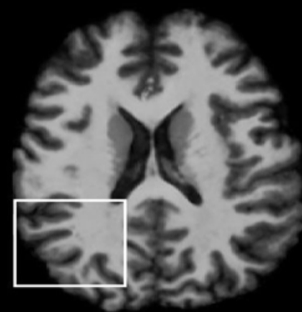
Dinggang Shen, Ph.D.

IDEA Lab, Department of Radiology, and Biomedical Research Imaging Center (BRIC)
University of North Carolina at Chapel Hill

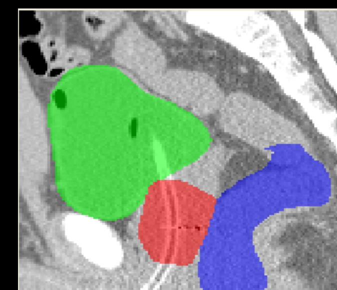
Research Lab
IDEA

Outline

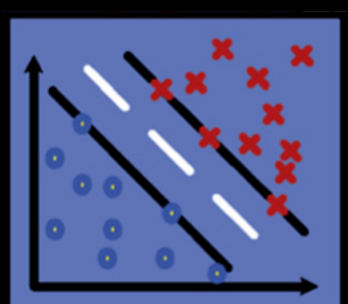
Segmentation / Registration



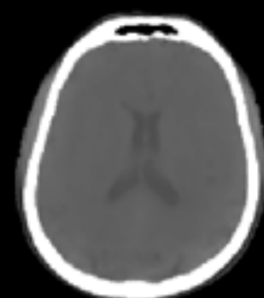
MRI Enhancement



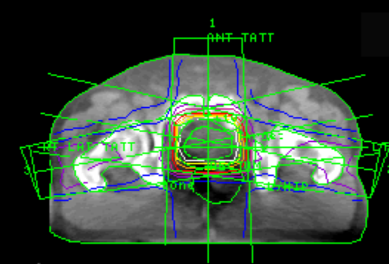
Planning CT Segmentation



Disease Diagnosis



CT Estimation from MRI



Dose Planning

Neuroimaging Analysis

Image Synthesis

Cancer Radiotherapy

Research Lab IDEA

Neuroimaging Analysis

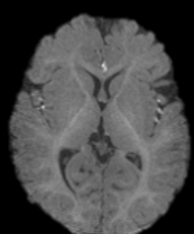
- Segmentation
- Registration
- Diagnosis

Overall Goal

Baby Connectome Project (BCP)

Alzheimer's Disease Neuroimaging Initiative (ADNI)

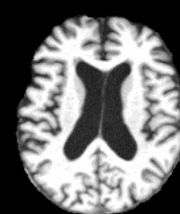
6 M → **3~4 Y**



Autism ?

Genetics

70 Y (MCI) → **75 Y**



Alzheimer's Disease (AD)

Genetics

Segmentation

Distinguishing White Matter, Gray Matter, and Cerebrospinal Fluid (CSF)

NIH Lifespan Human Connectome Projects

HCP (Human Connectome Project)

- WU-Minn HCP (5-year)
- MGH-USC (5-year)

Disease Connectome Projects

Human Diseases

Lifespan Connectome Projects

Baby Connectome Project (BCP)

0 – 5 years of age

Developmental Connectome Project

5 – 21 yeas of age

Aging Connectome Project

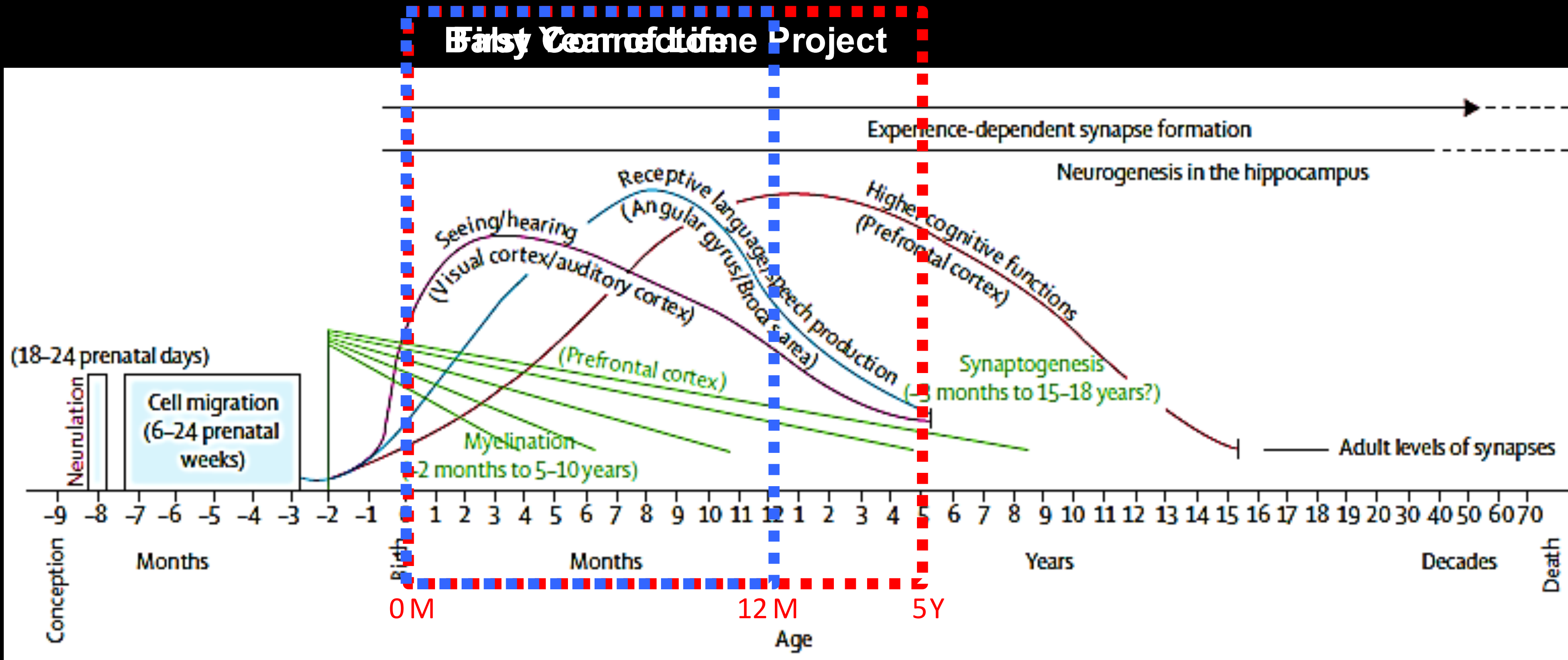
45 and above

Co-PIs:

UNC

UM

Brain Functional Maturation



Thompson RA, Nelson CA. Developmental science and the media. Early brain development. *Am Psychol*. 2001; 56:5–15.

Research Lab IDEA

NIH Blueprint for Neuroscience Research

Mapping structural and functional connections in the human brain

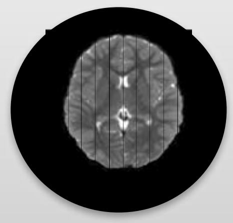
BABY Connectome Project

a UNC / UMN collaboration

Baby Connectome Project (BCP)

- The first comprehensive imaging study focuses on early brain functional and structural development.
- A joint effort between University of North Carolina at Chapel Hill and University of Minnesota
- A total of **500** normally developing children will be imaged

Brain Images

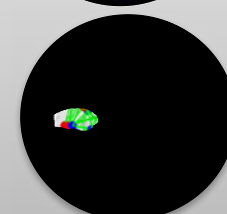


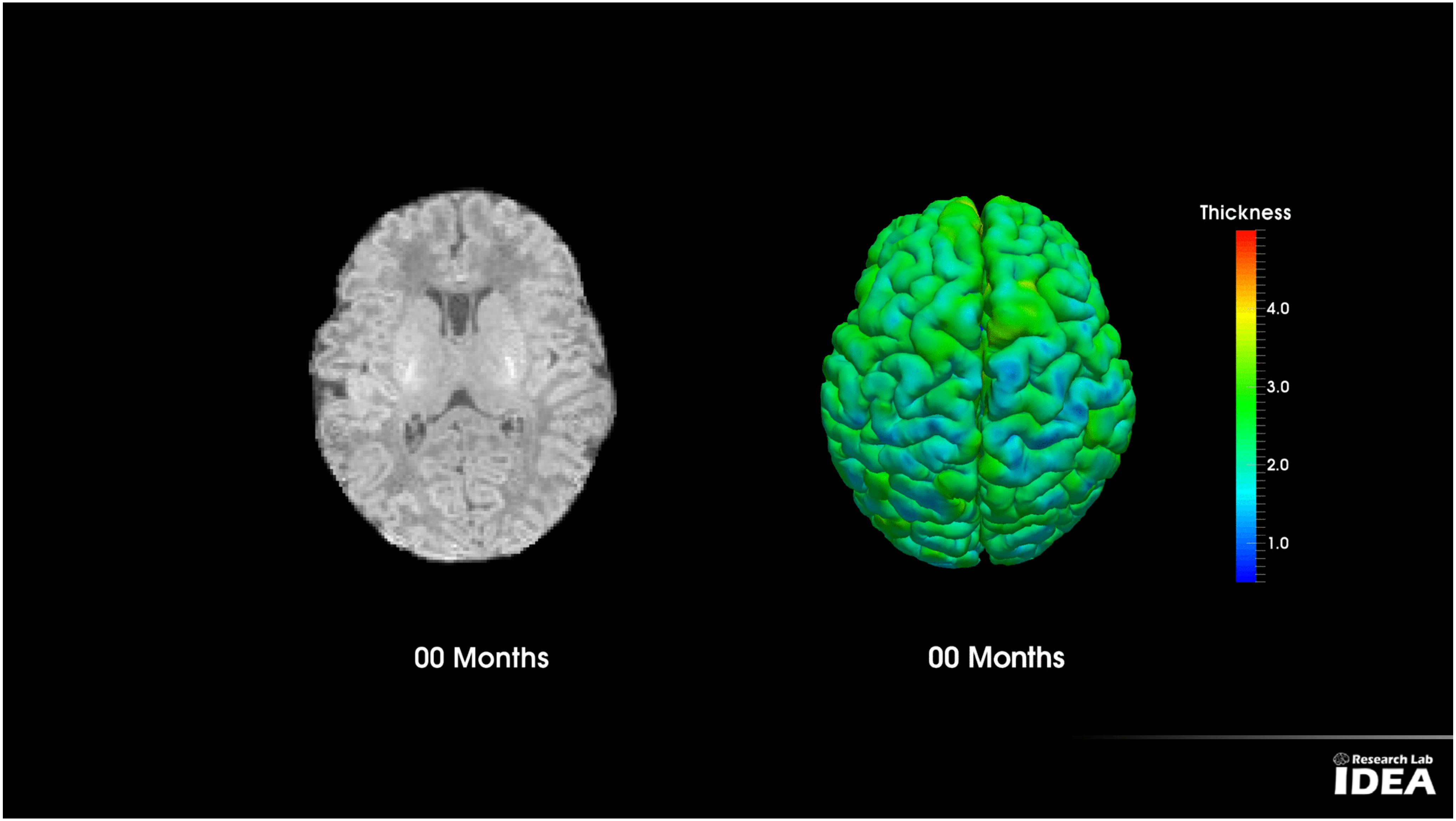
- Anatomical images
- Diffusion tensor images
- Functional connectivity (BOLD)

Behavior/Cognition

- Age-appropriate behavioral / cognitive assessments

Brain/Cognitive




Thickness
4.0
3.0
2.0
1.0
00 Months
00 Months
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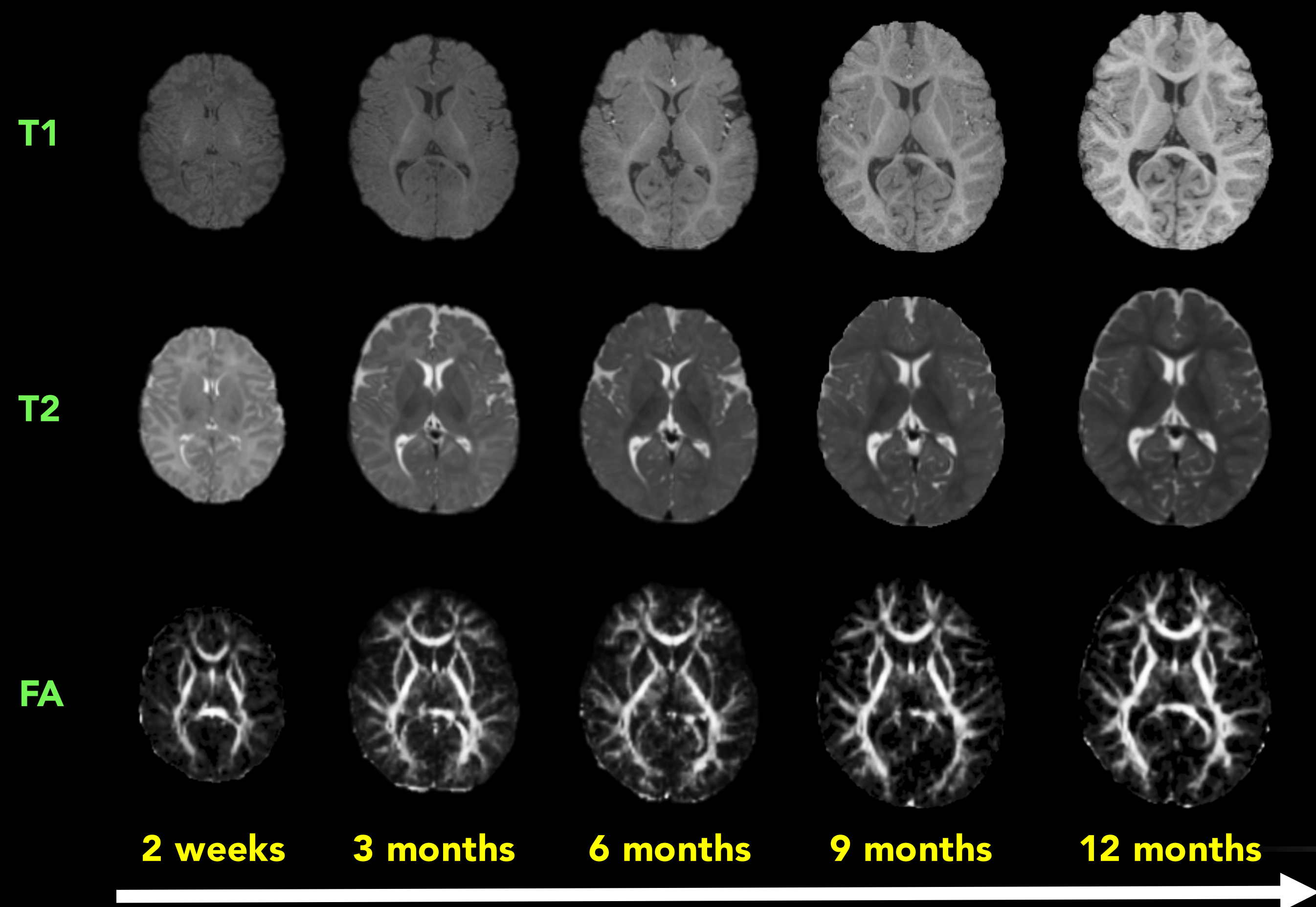
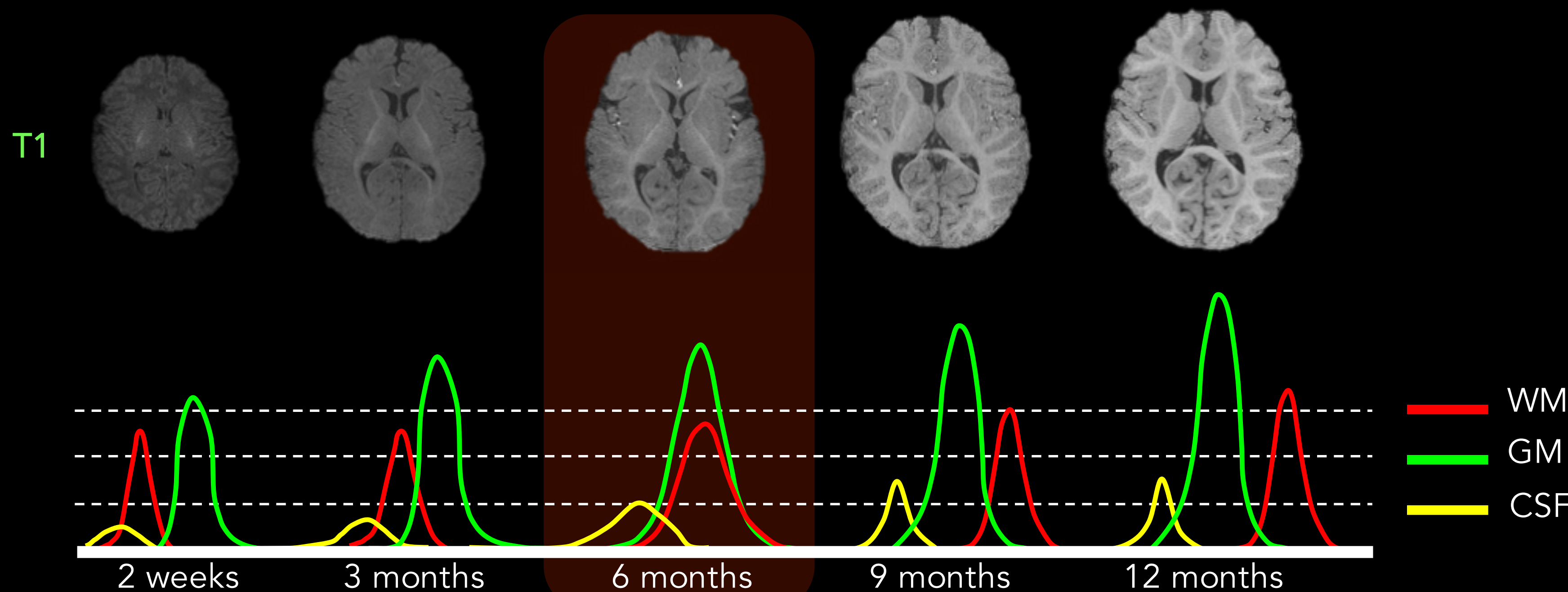
The Human Brain in the First Year of Life



A Longitudinally-scanned Subject

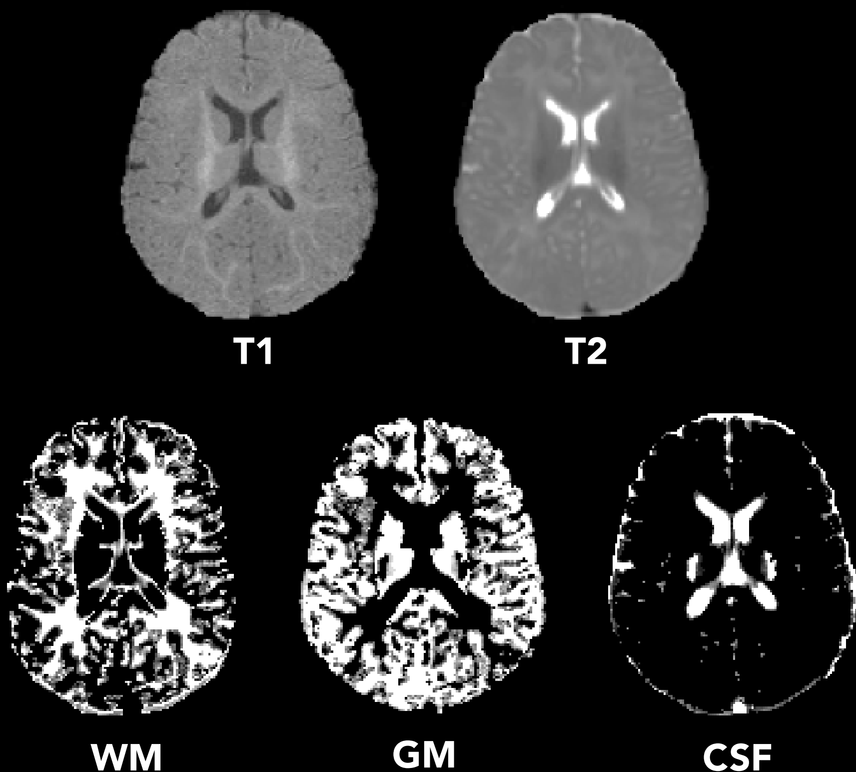
Research Lab IDEA

The Human Brain in the First Year of Life



Challenges: Low tissue contrast (especially ~6 months of age) and low spatial resolution

Challenges

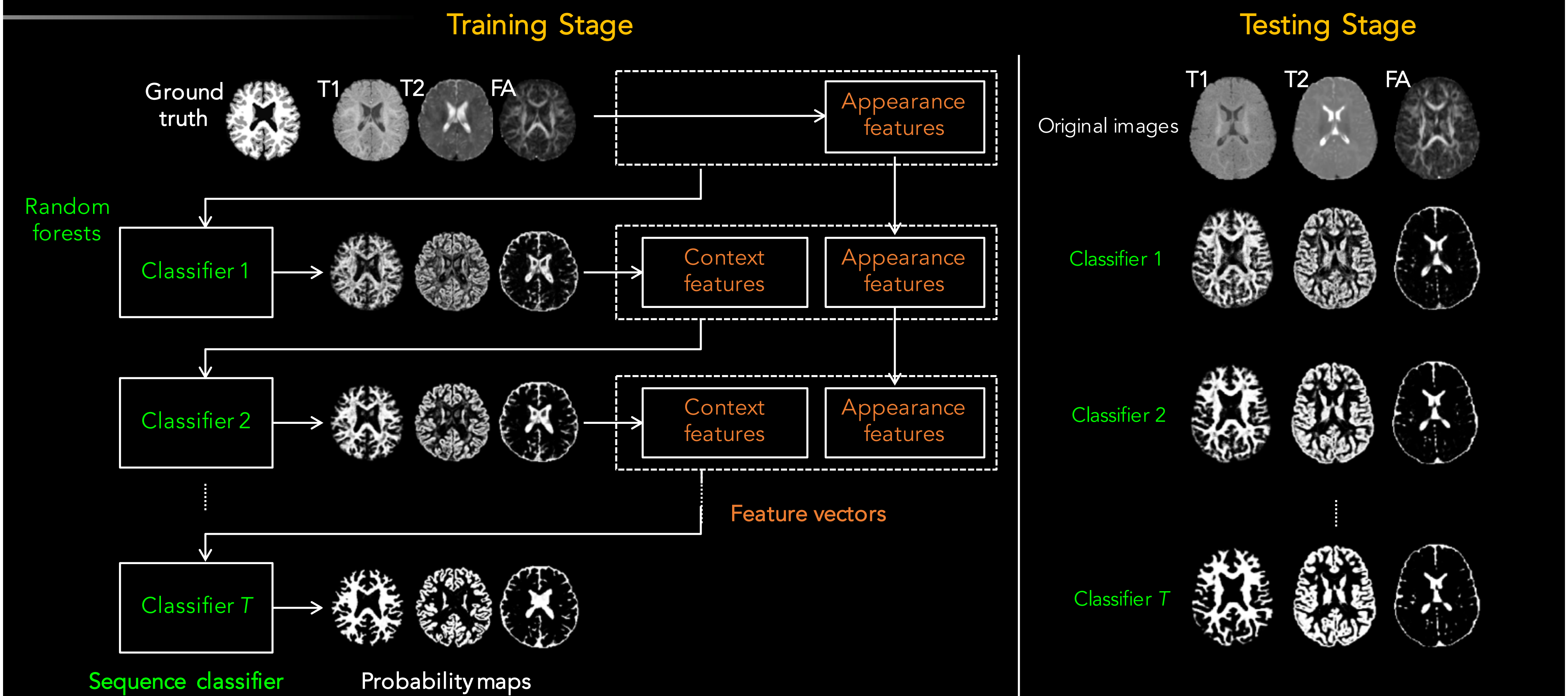


Typical FSL-FAST results for a *6-month-old* infant

- Low tissue contrast
- Low SNR
- Partial volume effect
- On-going white matter myelination

Research Lab IDEA

LINKS



L. Wang, Y. Gao, F. Shi, G. Li, J. H. Gilmore, W. Lin, D. Shen, "LINKS: Learning-based multi-source IntegratioN frameworK for Segmentation of infant brain images," *NeuroImage*, 108:160-172, 2015.

MICCAI Grand Challenge on 6-month Infant Brain Segmentation (iSeg)

- Data
  - Training: 10 subjects (each with T1- and T2-weighted MRI)
  - Testing: 13 subjects
- Evaluation Metrics
  - Dice Ratio (DR)
  - Modified Hausdorff Distance (MHD)
    - 95th Percentile Hausdorff Distance
  - Average Surface Distance (ASD)
- Teams
  - 21 teams

http://iseg2017.web.unc.edu/

Research Lab IDEA

Ranking – DR

			WM
RANK	TEAM	DATE	DR
1	MSL_SKKU	08/05/2017	0.901
2	LIVIA	07/12/2014	0.897
3	Bern_IPMI	07/24/2017	0.896
4	TU/e IMAG/e	06/25/2017	0.890
5	UPF_simbiosys	05/24/2017	0.885
6	NeuroMTL	08/01/2017	0.885
7	nic_vicorob	07/24/2017	0.885
8	UPC_DLMI	07/31/2017	0.882
9	CAMP_TUM	08/06/2017	0.880
10	QuIIL	08/07/2017	0.877
11	Cumed	08/08/2017	0.876
12	STH	08/01/2017	0.870
13	BIGS2	08/07/2017	0.867
14	UofL-BioImaging	08/07/2017	0.867
15	LRDE	07/25/2017	0.861
16	BUUA_braintech	08/06/2017	0.855
17	Authman	08/08/2017	0.838
18	CatholicU	07/18/2017	0.827
19	Xidian	08/08/2017	0.765
20	ASU-BNI	08/05/2017	0.739
21	BuzzLightDay	08/02/2017	0.686

			GM
RANK	TEAM	DATE	DR
1	MSL_SKKU	08/05/2017	0.919
2	LIVIA	07/12/2014	0.919
3	Bern_IPMI	07/24/2017	0.916
4	nic_vicorob	07/24/2017	0.910
5	UPC_DLMI	07/31/2017	0.907
6	TU/e IMAG/e	06/25/2017	0.904
7	UPF_simbiosys	05/24/2017	0.903
8	NeuroMTL	08/01/2017	0.902
9	CAMP_TUM	08/06/2017	0.901
10	Cumed	08/08/2017	0.896
11	UofL-BioImaging	08/07/2017	0.895
12	QuIIL	08/07/2017	0.894
13	STH	08/01/2017	0.892
14	BIGS2	08/07/2017	0.892
15	LRDE	07/25/2017	0.887
16	BUUA_braintech	08/06/2017	0.887
17	Authman	08/08/2017	0.872
18	CatholicU	07/18/2017	0.868
19	ASU-BNI	08/05/2017	0.781
20	BuzzLightDay	08/02/2017	0.768
21	Xidian	08/08/2017	0.767

			CSF
RANK	TEAM	DATE	DR
1	MSL_SKKU	08/05/2017	0.958
2	LIVIA	07/12/2014	0.957
3	Bern_IPMI	07/24/2017	0.954
4	nic_vicorob	07/24/2017	0.951
5	BIGS2	08/07/2017	0.948
6	TU/e IMAG/e	06/25/2017	0.947
7	UPC_DLMI	07/31/2017	0.945
8	UofL-BioImaging	08/07/2017	0.942
9	CAMP_TUM	08/06/2017	0.940
10	STH	08/01/2017	0.936
11	NeuroMTL	08/01/2017	0.935
12	Cumed	08/08/2017	0.935
13	UPF_simbiosys	05/24/2017	0.929
14	QuIIL	08/07/2017	0.929
15	LRDE	07/25/2017	0.928
16	BUUA_braintech	08/06/2017	0.922
17	Authman	08/08/2017	0.917
18	CatholicU	07/18/2017	0.915
19	Xidian	08/08/2017	0.876
20	ASU-BNI	08/05/2017	0.876
21	BuzzLightDay	08/02/2017	0.781

Popular Methods: Deep Learning

Only 1 team used conventional method:

Other 20 teams used deep learning:

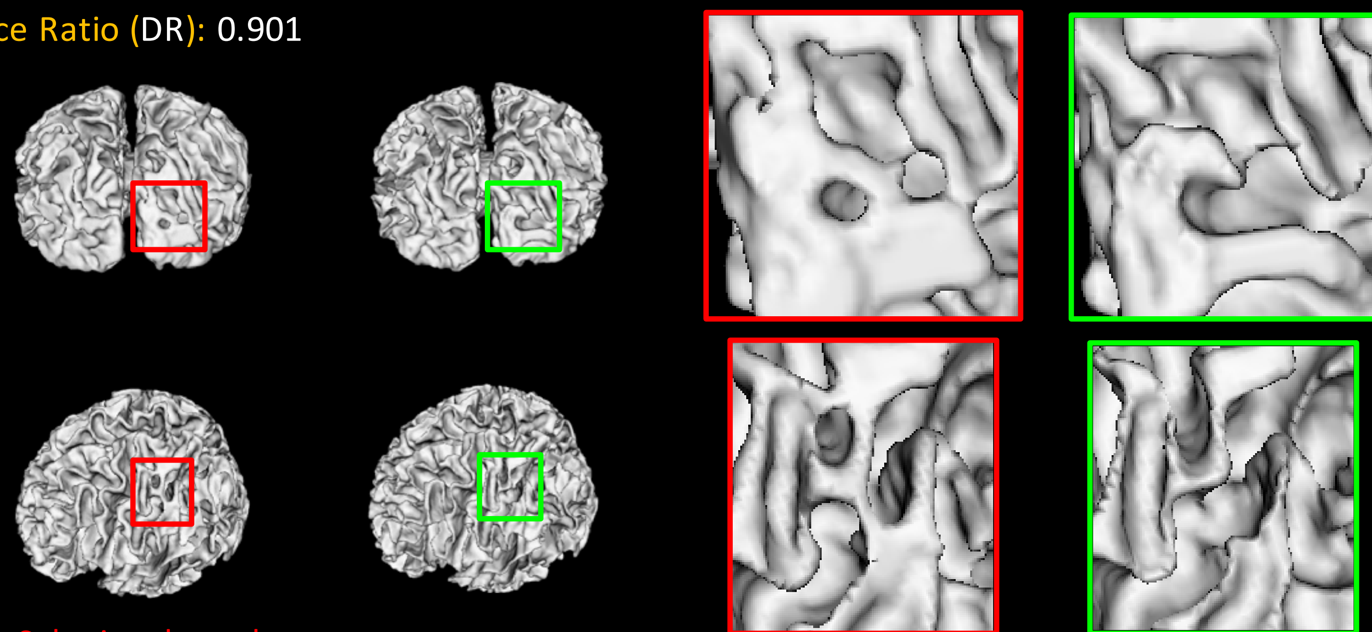
- U-Net: 9 teams
- CNN: 4 teams
- FCN: 4 teams
- DenseNet: 3 teams

RANK	TEAM	METHOD
1	MSL_SKKU	DenseNet
2	Bern_IPMI	U-Net
3	LIVA	Ensemble CNN
4	TU/e IMAG/e	Dilated CNN
5	UPC_DLMI	U-Net
6	UPF_simbiosys	Ensemble label fusion
7	NeuroMTL	U-Net
8	LRDE	FCN
9	Cumed	DenseNet
10	QuIIL	ResNet+U-Net
11	nic_vicorob	FCN
12	BIGS2	CNN
13	STH	U-Net
14	CAMP_TUM	FCN
15	UofL-BioImaging	CNN
16	BUUA_braintech	DenseNet
17	Authman	U-Net
18	CatholicU	U-Net
19	ASU-BNI	FCN
20	Xidian	U-Net
21	BuzzLightDay	U-Net

Research Lab IDEA

Limitations

Dice Ratio (DR): 0.901



Submitted result
(Team: MSL_SKKU)

Manual result

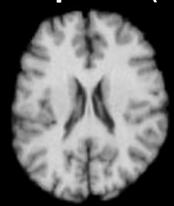
Research Lab IDEA

Registration

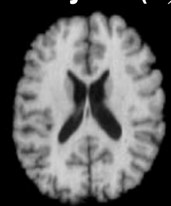
Deep Learning-based Image Registration

Deep Learning Based Deformable Registration – Current Methods

Template (T)

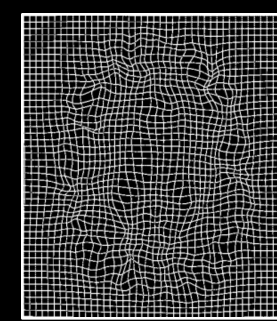


Subject (S)



Deep Learning based
Deformable Registration

Deformation field φ



Limitations:

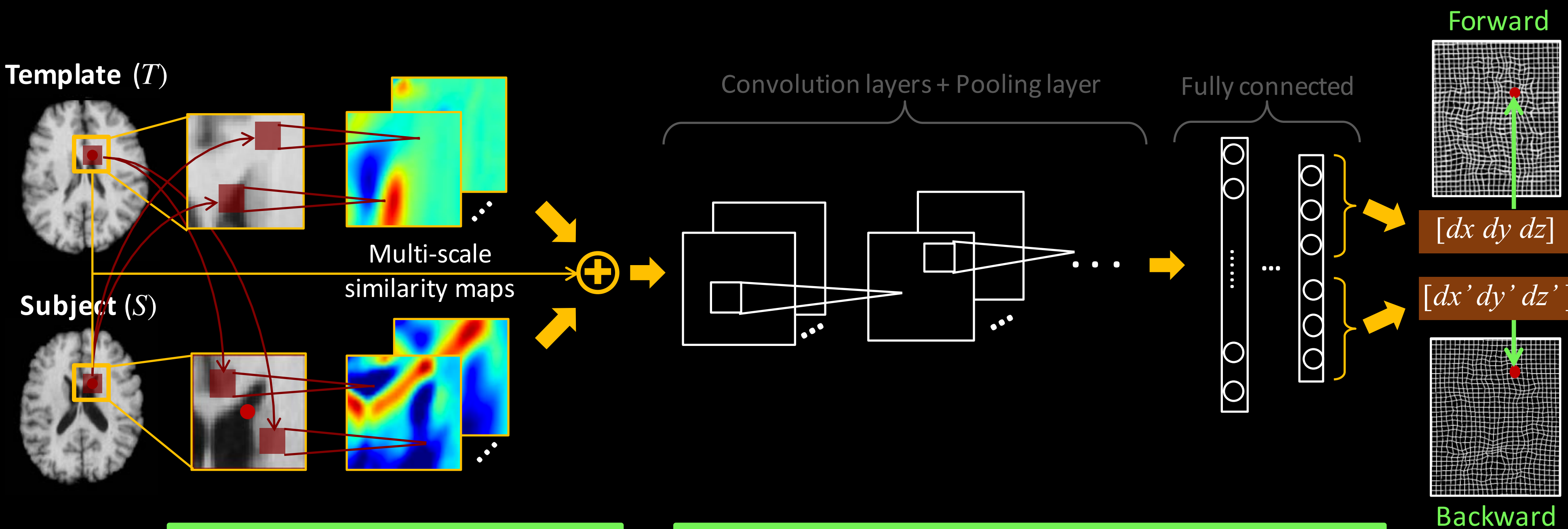
- Ignore intrinsic matching process
- Not symmetric

Improvements:

- Learn intrinsic matching process
- Symmetric registration framework

Research Lab
IDEA

Deep Learning Based Deformable Registration – Our Proposed Method



Part I: Network Preparation
Multi-scale auxiliary contextual cue

Part II: Network Learning
Learn intrinsic local matching

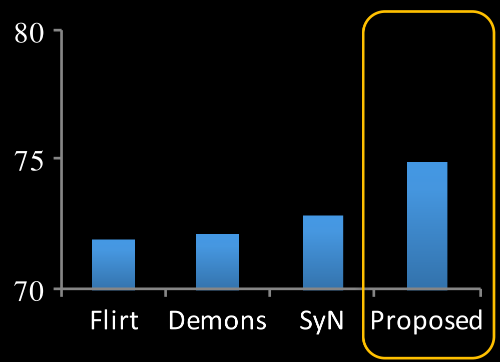
Kernels are not trainable

Kernels are trainable

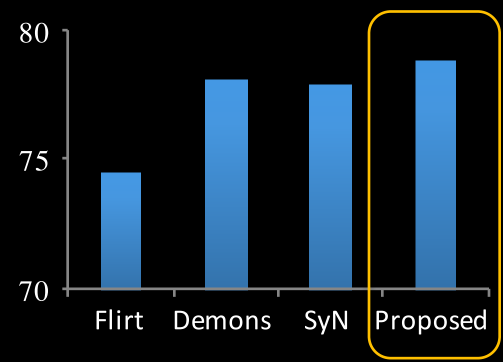
X. Cao, J. Yang, J. Zhang, D. Nie, M. Kim, Q. Wang, D. Shen, "Deformable Image Registration based on Similarity-Steered CNN Regression", *MICCAI* 2017.

Registration Results

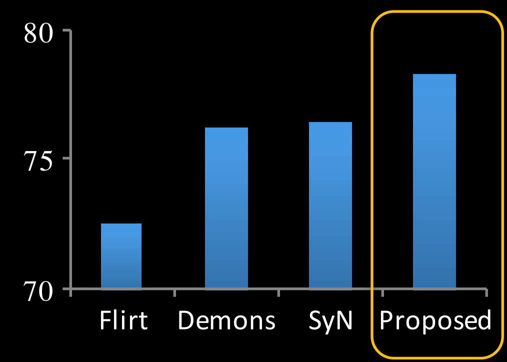
- On **three** datasets: Overall (GM+WM) Dice Ratio (%)



ADNI dataset



LONI dataset



IXI dataset

Advantages:

- No parameter tuning
- No iterative optimization
- Good generalization for different datasets
- Better robustness and accuracy

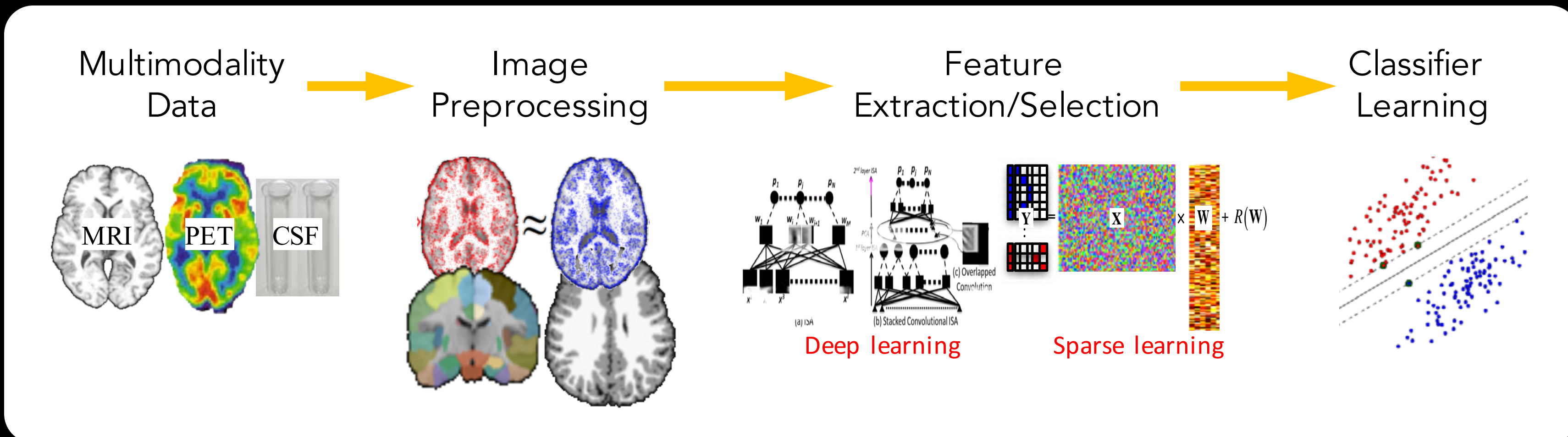
X. Cao, J. Yang, J. Zhang, D. Nie, M. Kim, Q. Wang, D. Shen, "Deformable Image Registration based on Similarity-Steered CNN Regression", *MICCAI* 2017.

Research Lab IDEA

Disease Diagnosis

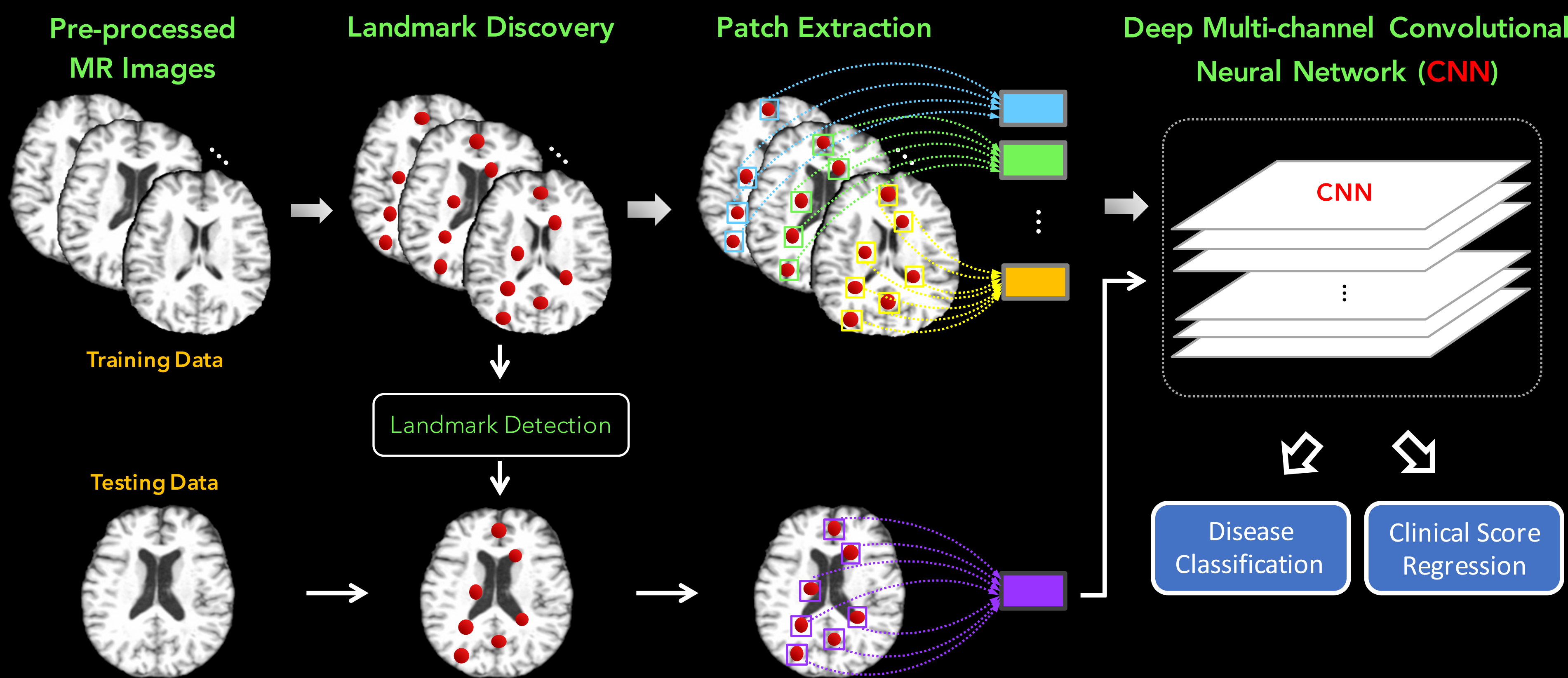
Landmark-based Deep Multi-task Multi-channel Learning

Diagnosis of Neurodegenerative Disorders – Typical Pipeline



M. Liu, D. Zhang, D. Shen, "View-centralized multi-atlas classification for Alzheimer's disease diagnosis," *Human Brain Mapping*, 36(5):1847-1865, 2015.

Landmark-based Deep Multi-task Multi-channel Learning (DM^{2}L)

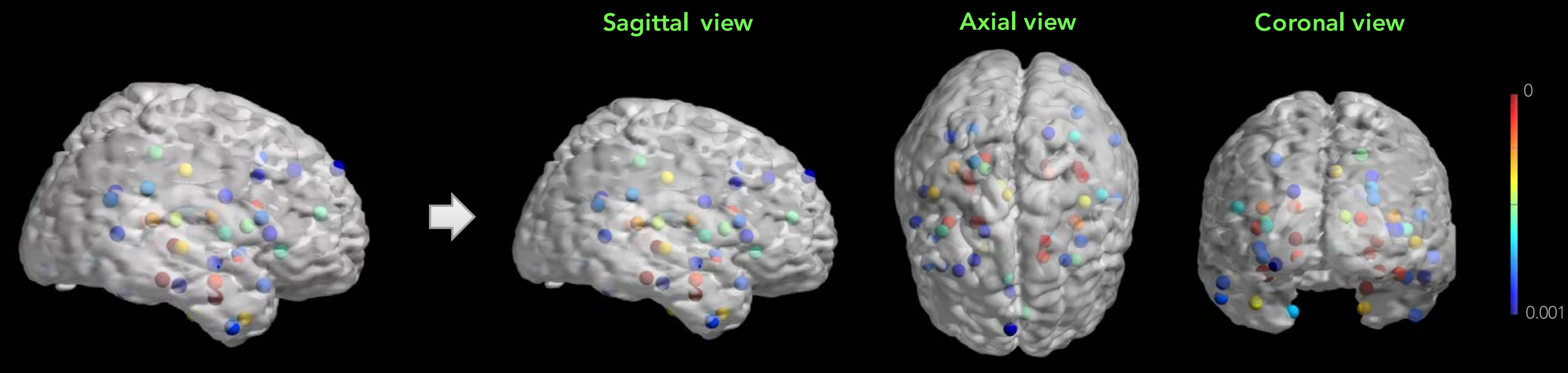


M. Liu, J. Zhang, E. Adeli, D. Shen, "Deep Multi-task Multi-channel Learning for Joint Classification and Regression of Brain Status", *MICCAI* 2017.

Research Lab IDEA

Landmark Discovery

- **Top 50 landmarks identified from AD and NC subjects in ADNI-1 with baseline MRI:**

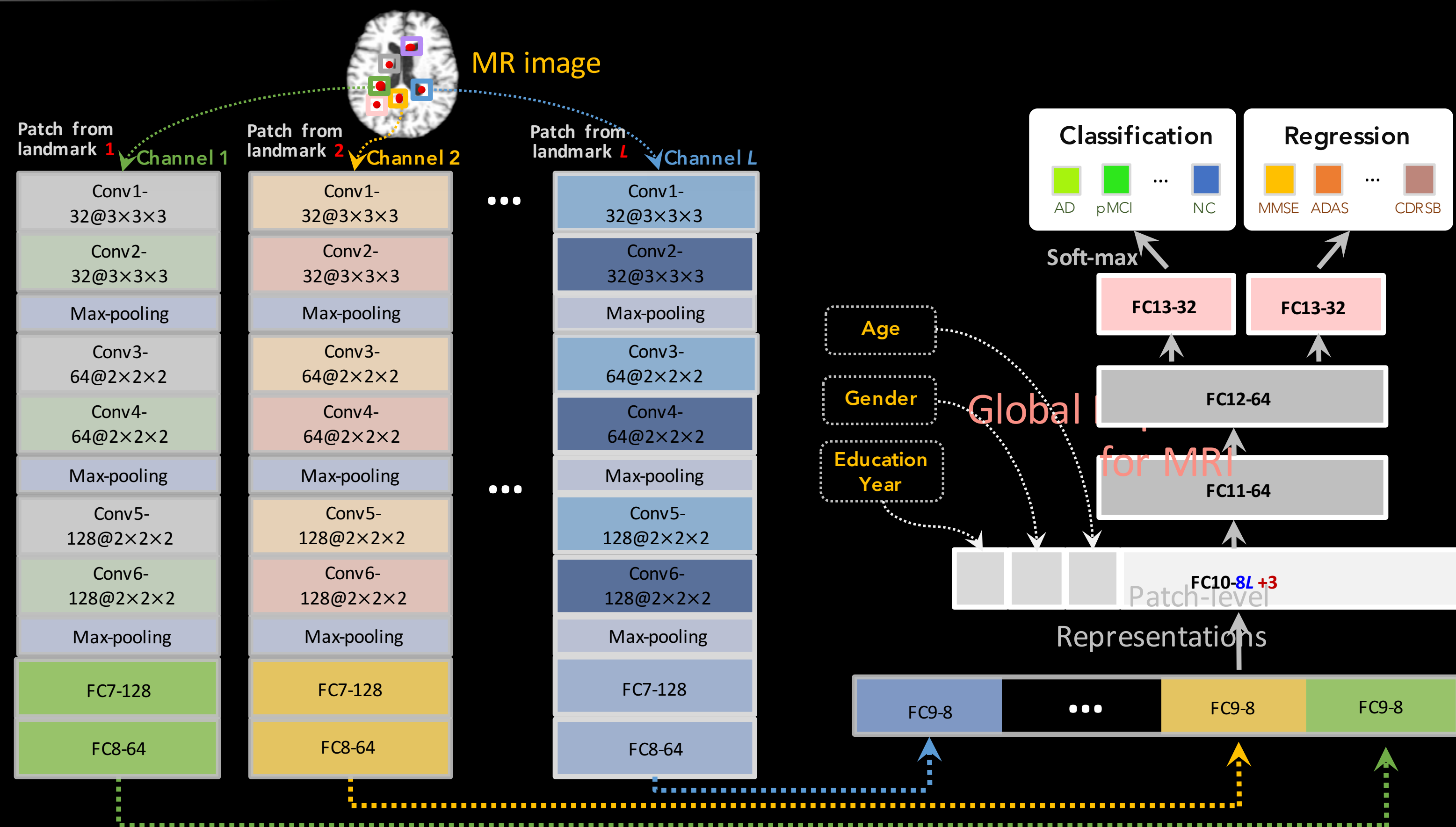


Landmark selection criteria:

1) Discriminative power (*p*-value in group comparison)
2) Euclidean distance >=20

J. Zhang, Y. Gao, Y. Gao, B.C. Munsell, D. Shen, "Detecting Anatomical Landmarks for Fast AD Diagnosis", *IEEE TMI*, 2016.

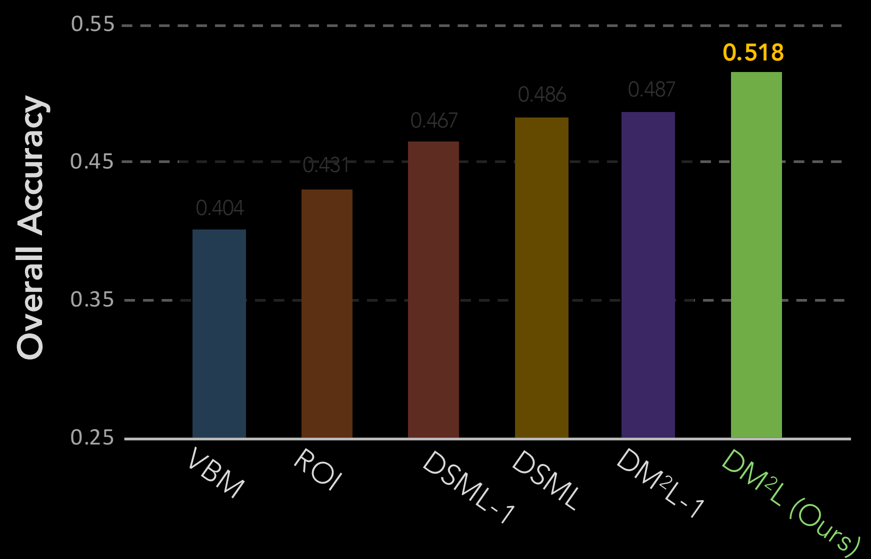
Deep Multi-task Multi-channel CNN



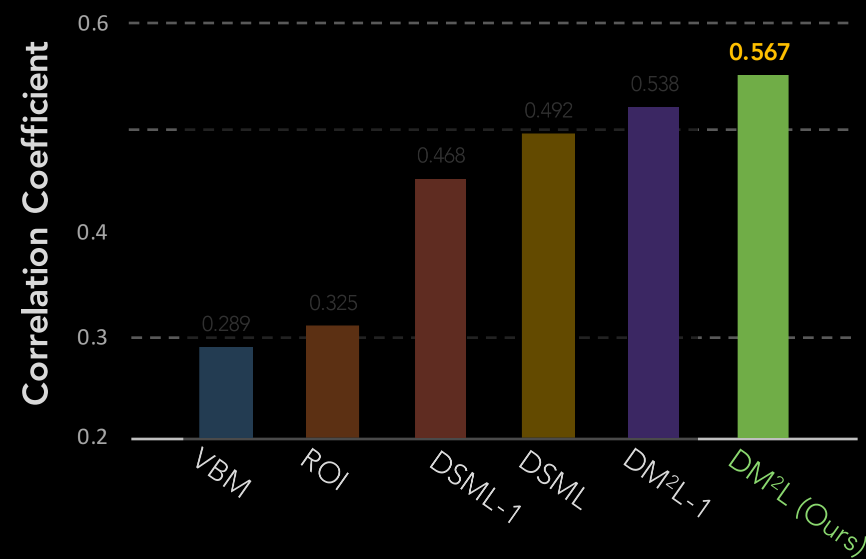
M. Liu, J. Zhang, E. Adeli, D. Shen, "Deep Multi-task Multi-channel Learning for Joint Classification and Regression of Brain Status", *MICCAI* 2017.

Research Lab IDEA

Results of Classification and Regression



Classification Results for AD vs. sMCI vs. pMCI vs. NC diagnosis



Regression Results for MMSE

M. Liu, J. Zhang, E. Adeli, D. Shen, "Deep Multi-task Multi-channel Learning for Joint Classification and Regression of Brain Status", *MICCAI* 2017.

Research Lab IDEA

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Image Synthesis

- MRI Enhancement (3T → 7T)
- Estimating CT from MRI

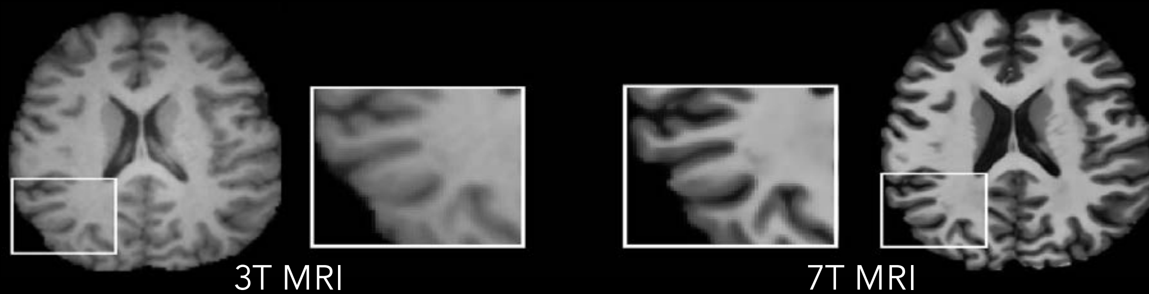
Research Lab IDEA

MRI Enhancement

7T-MRI-Guided 3T MRI Enhancement and Segmentation using Deep Learning

7T MRI vs. 3T MRI

- 7T MRI
  - Higher spatial resolution and better tissue contrast, compared to 3T MRI
  - SNR of 7T MRI = 2.3 * SNR of 3T MRI

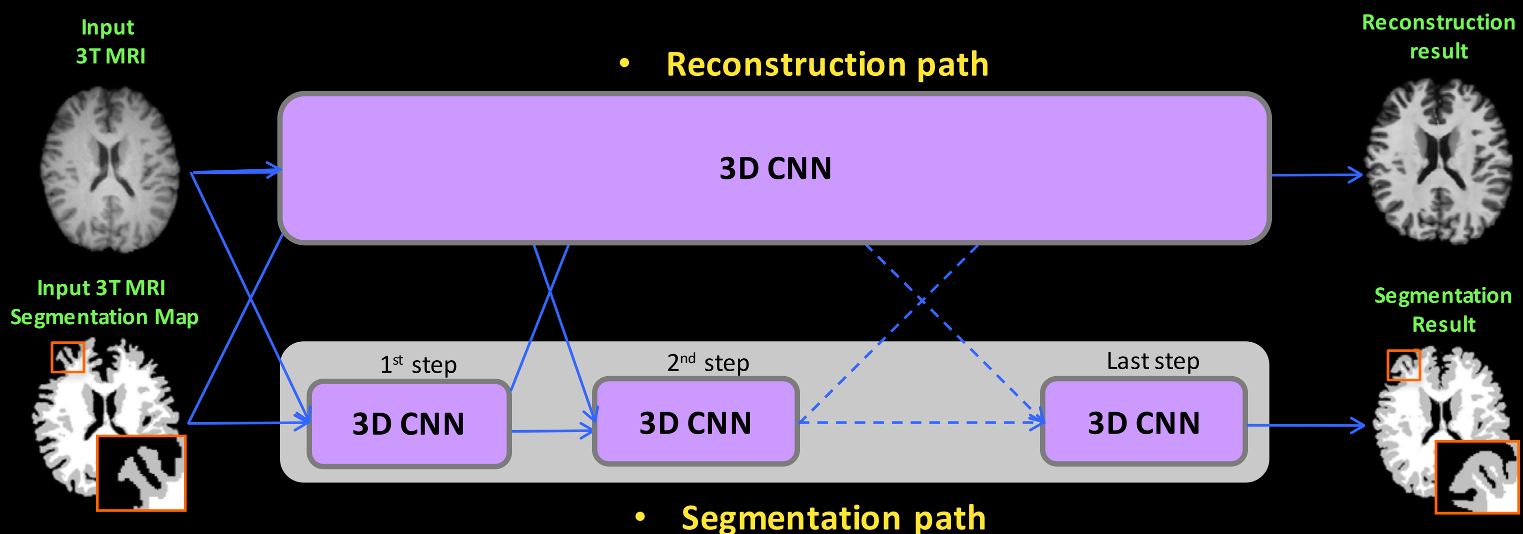


- Lower availability and higher price of 7T MRI scanners
  - 20,000 3T scanners vs. 50 7T scanners in the world

➡ Reconstruction of 7T-like images from 3T MRI

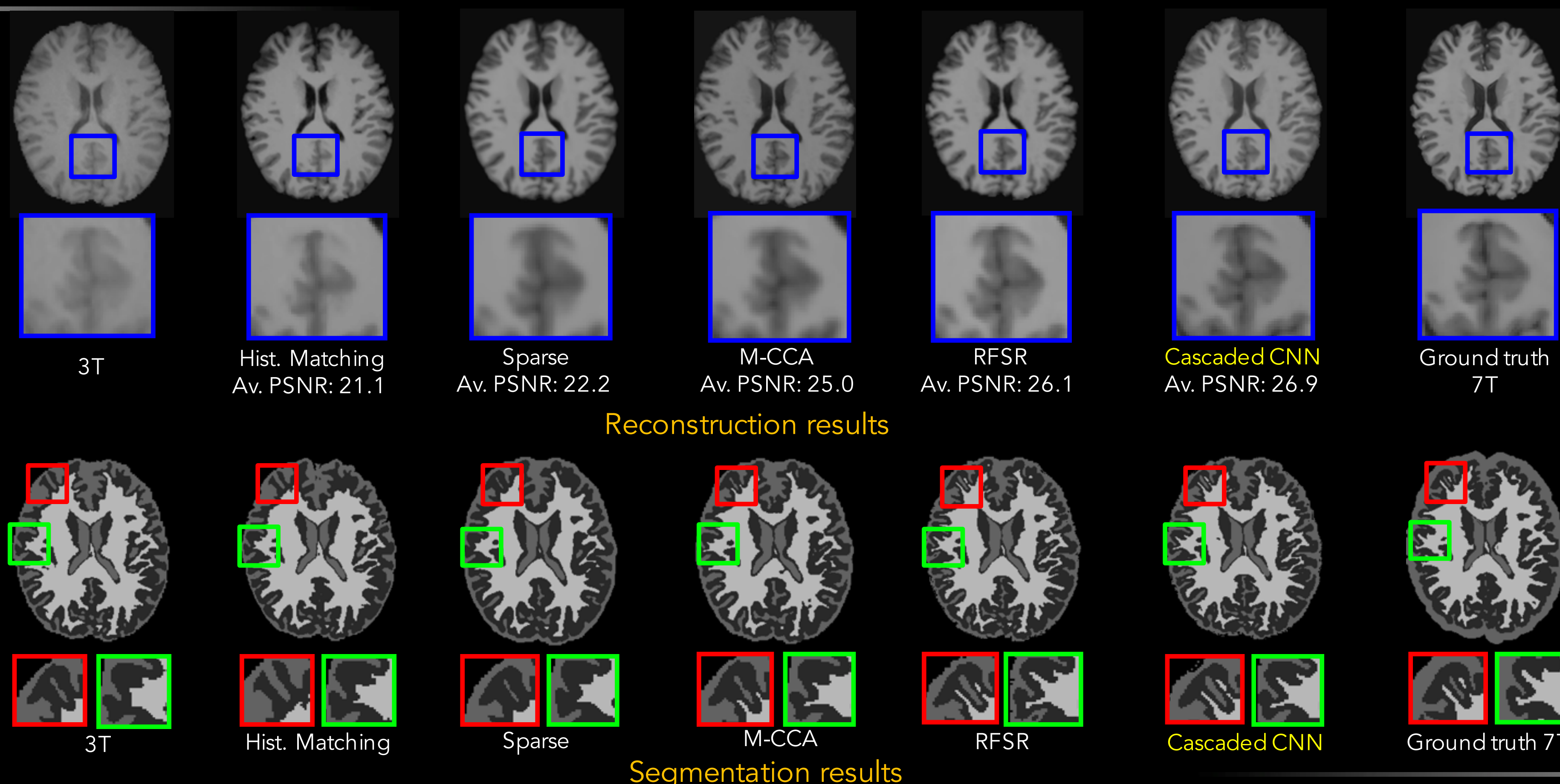
Cascaded 3D CNN for Joint Reconstruction-Segmentation

- Joint reconstruction and tissue segmentation
  - Improve both reconstruction of 7T-like MRI and tissue segmentation for 3T MRI



K. Bahrami, I.Rekik, F. Shi, D. Shen, "Joint Reconstruction and Segmentation of 7T-like MR images from 3T MRI based on Cascaded Convolutional Neural Networks", *MICCAI* 2017.

Improved Reconstruction and Tissue Segmentation



K. Bahrami, I.Rekik, F. Shi, D. Shen, "Joint Reconstruction and Segmentation of 7T-like MR images from 3T MRI based on Cascaded Convolutional Neural Networks", *MICCAI* 2017.

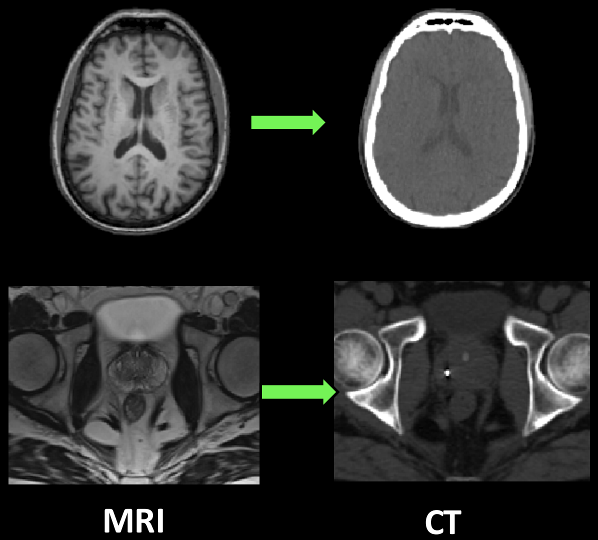
Research Lab IDEA

Estimating CT from MRI

Deep Learning-based Automatic Estimation of CT from MRI

CT

- CT images are highly desired for:
  - Specific diagnosis
  - Dose planning
  - PET attenuation correction
- Issues:
  - Health concerns of CT scan
  - Unavailability of CT images

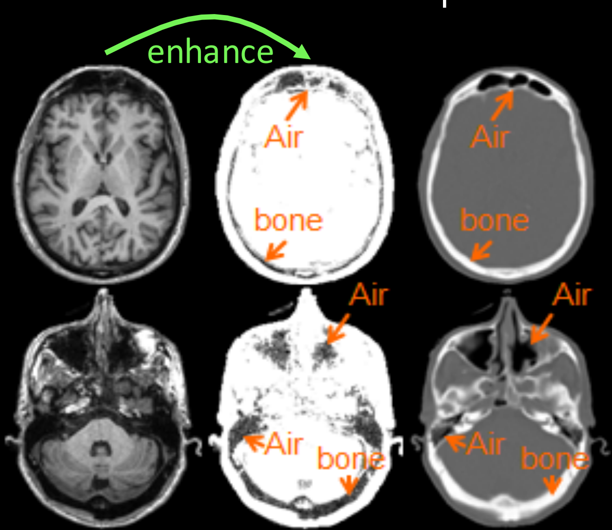


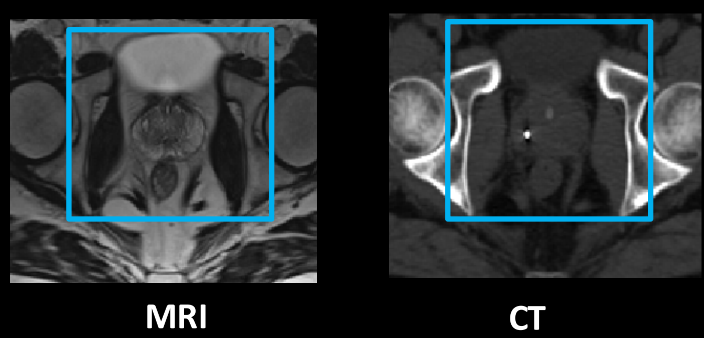
Can we synthesize CT image from a single MRI image?

T. Huynh, Y. Gao, J. Kang, L. Wang, P. Zhang, J. Lian, D. Shen, "Estimating CT Image from MRI Data Using Structured Random Forest and Auto-context Model", *IEEE Transactions on Medical Imaging*, 35(1):174-183, 2016.

CT vs. MRI

- Different structures in MRI and CT
  - Similarity of some regions (e.g., air and bone) in MRI
- Difficulty in accurate deformable registration between MRI and CT
  - High deformation around prostate area



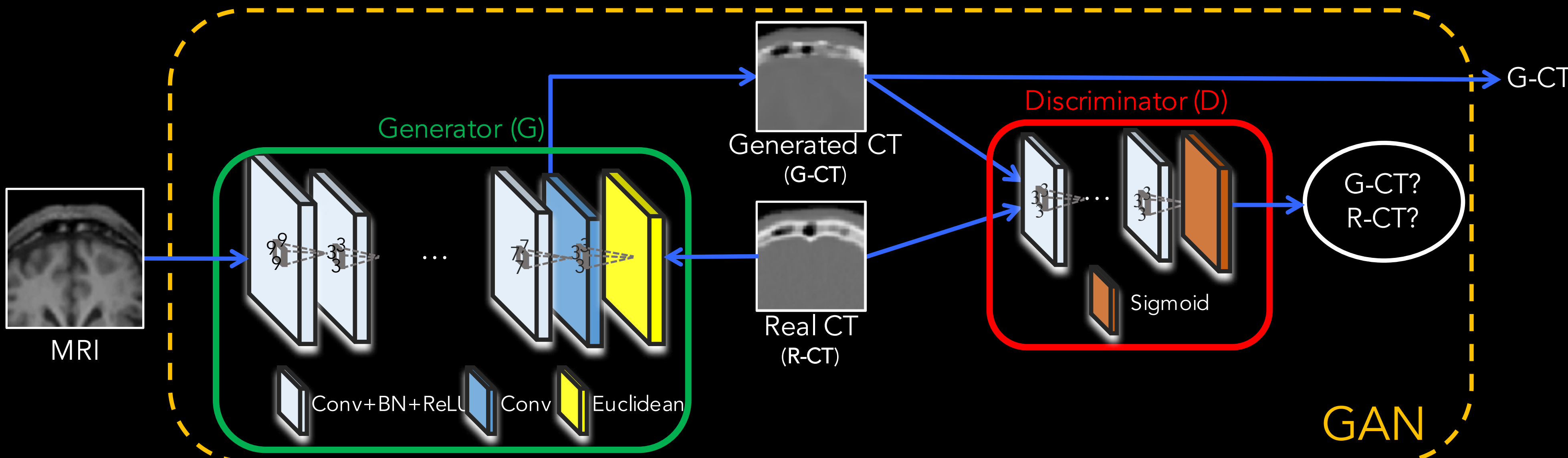


T. Huynh, Y. Gao, J. Kang, L. Wang, P. Zhang, J. Lian, D. Shen, "Estimating CT Image from MRI Data Using Structured Random Forest and Auto-context Model", *IEEE Transactions on Medical Imaging*, 35(1):174-183, 2016.

Research Lab IDEA

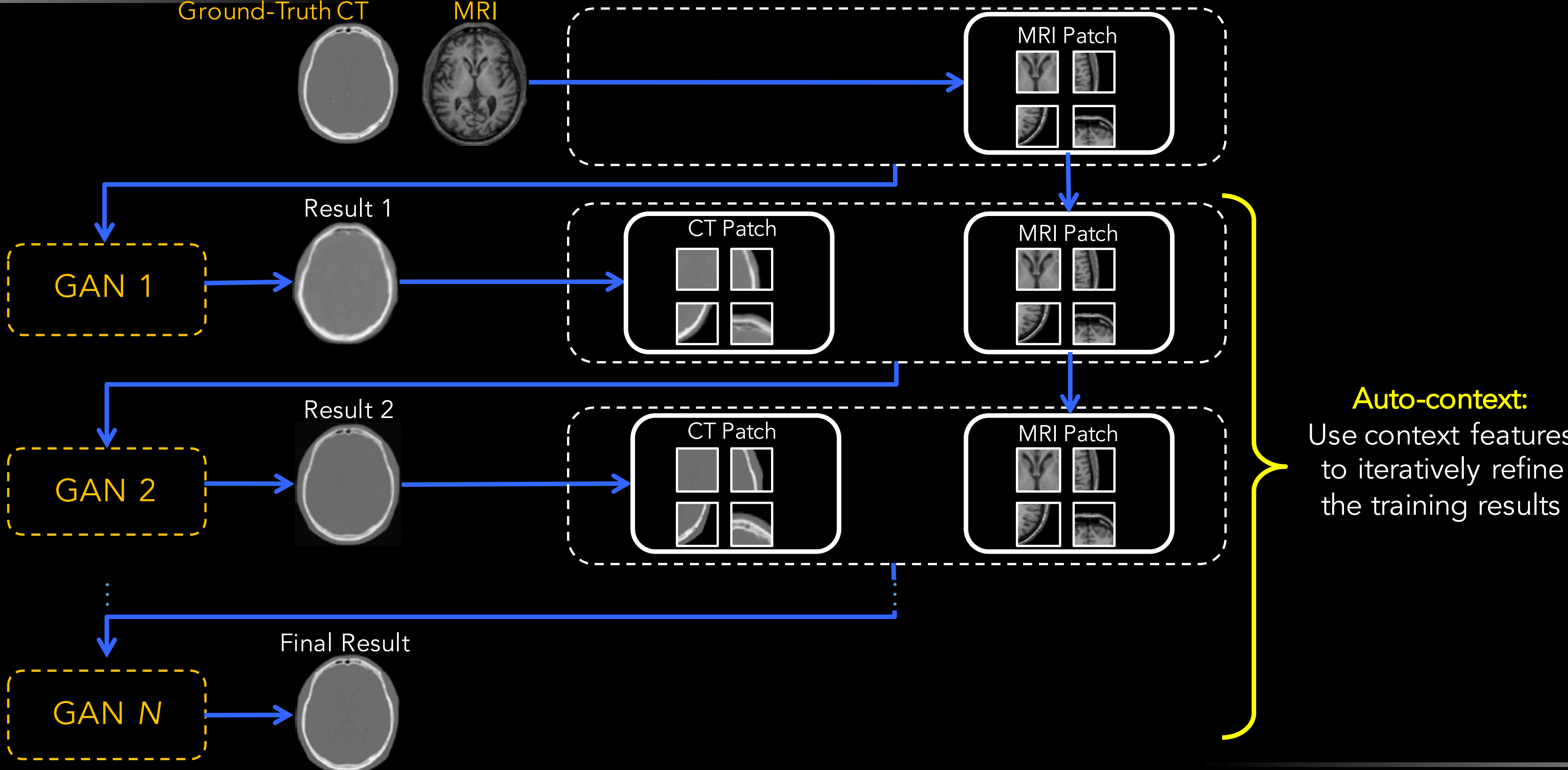
Generative Adversarial Networks (GAN)

- A game between Discriminator (D) and Generator (G)
  - G: Generate CT as real as possible to fool the D
  - D: Distinguish the real CT and generated CT as much as possible



D. Nie*, R. Trullo*, J. Lian, C. Petitjean, S. Ruan, D. Shen, "Medical Image Synthesis with Context-Aware Generative Adversarial Networks", *MICCAI*, 2017.

Context-aware GAN



D. Nie*, R. Trullo*, J. Lian, C. Petitjean, S. Ruan, D. Shen, "Medical Image Synthesis with Context-Aware Generative Adversarial Networks", *MICCAI*, 2017.

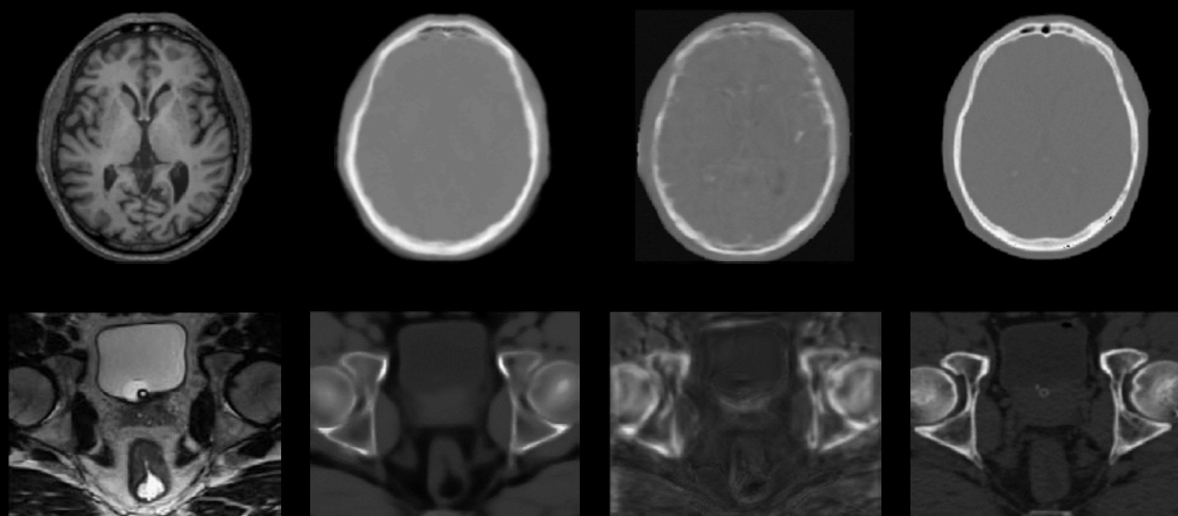
Research Lab IDEA

GAN vs. FCN / Auto-context Refinement

MRI | GAN 1st Layer | FCN | Ground Truth

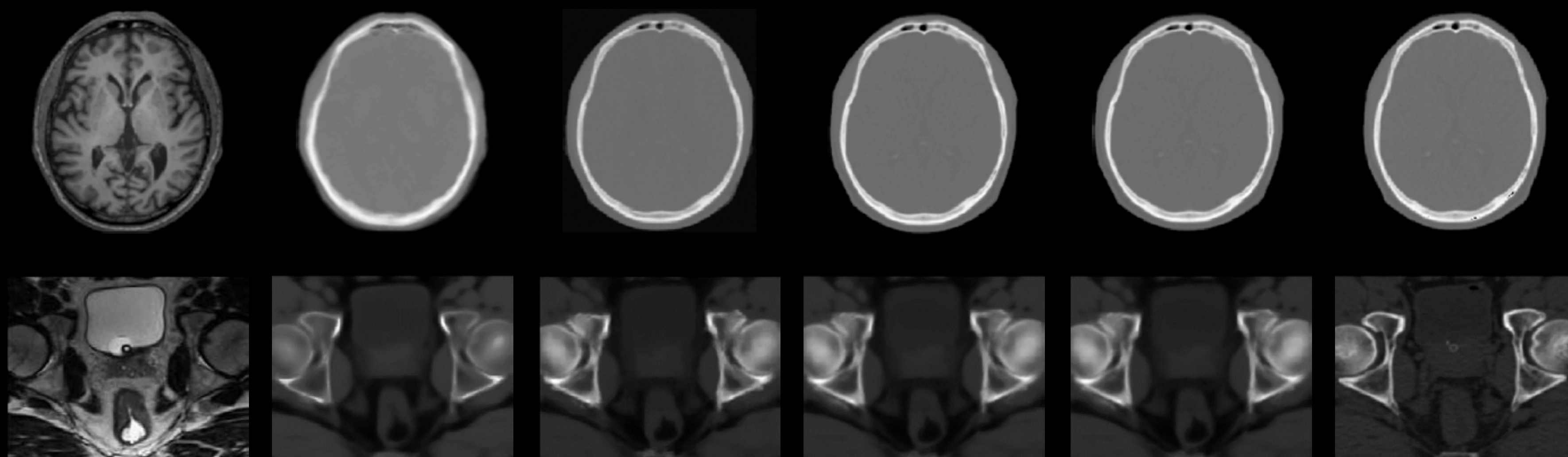
Brain image

Pelvic image



D. Nie*, R. Trullo*, J. Lian, C. Petitjean, S. Ruan, D. Shen, "Medical Image Synthesis with Context-Aware Generative Adversarial Networks", *MICCAI*, 2017.

Auto-context Refinement



D. Nie*, R. Trullo*, J. Lian, C. Petitjean, S. Ruan, D. Shen, "Medical Image Synthesis with Context-Aware Generative Adversarial Networks", *MICCAI*, 2017.

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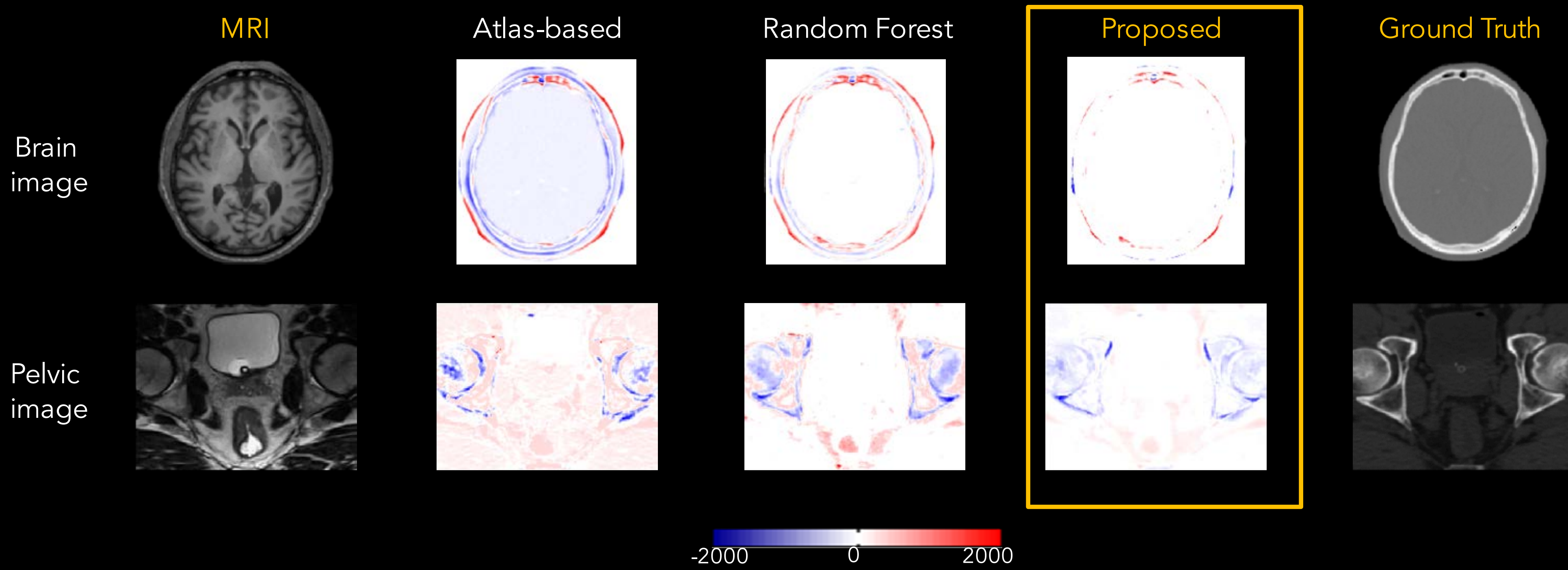
Comparison with Other Methods



D. Nie*, R. Trullo*, J. Lian, C. Petitjean, S. Ruan, D. Shen, "Medical Image Synthesis with Context-Aware Generative Adversarial Networks", *MICCAI*, 2017.

Cancer Radiotherapy

- Segmenting Planning CT

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Segmenting Planning CT

Automatic Segmentation of Planning CT for Prostate Cancer Therapy

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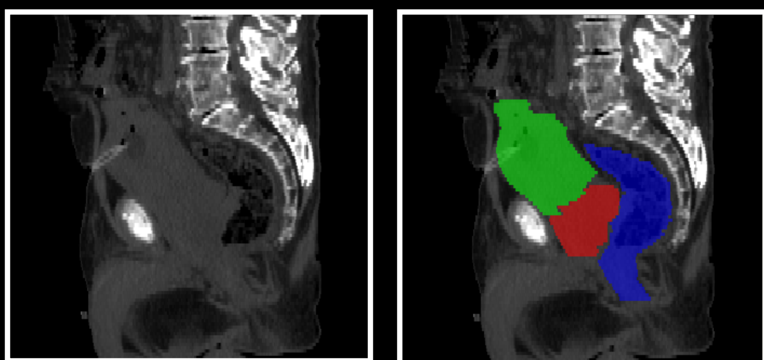
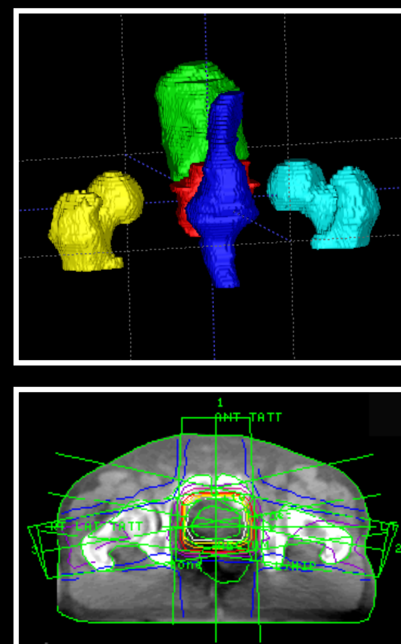
Planning CT Pelvic Segmentation for External Beam Radiotherapy



Planning CT Segmentation

(prostate, bladder, rectum,
left femoral head, right femoral head)



Dose Planning

Daily Treatment

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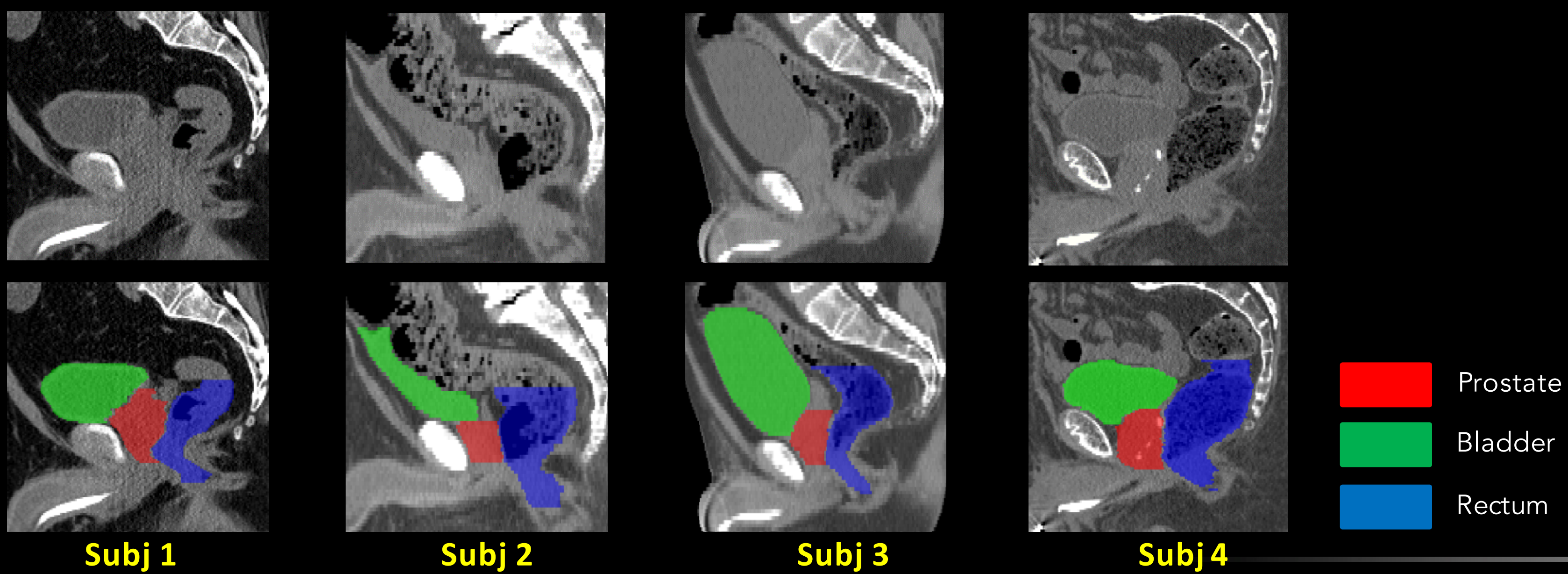
Planning CT Pelvic Segmentation

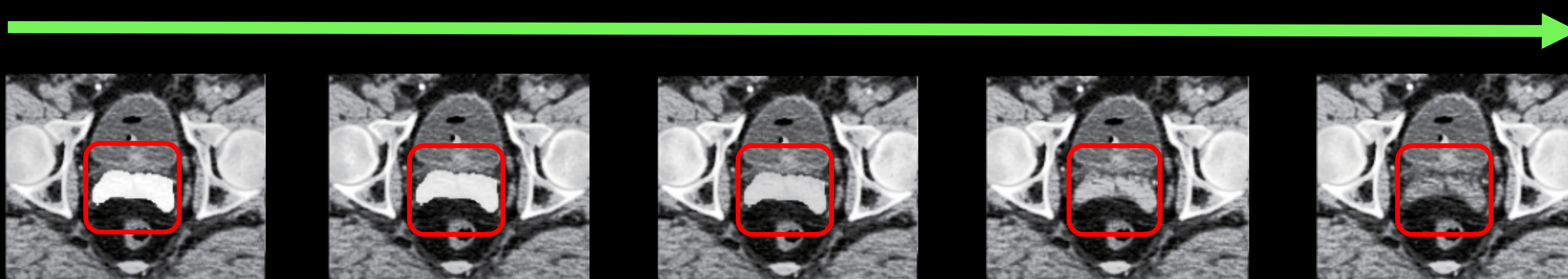
- Challenges
  - Low contrast
  - Large shape and appearance variations



Motivation

- Use manual delineations to guide better feature learning
  - Overlay manual delineations to original CT with different ratios ("0.2"→"0")

Simple Case Difficult Case



"0.2" "0.1" "0.05" "0.01" "0"

Y. Shi, W. Yang, Y. Gao, D. Shen, "Does Manual Delineation Only Provide the Side Information in CT Prostate Segmentation?", *MICCAI*, 2017.

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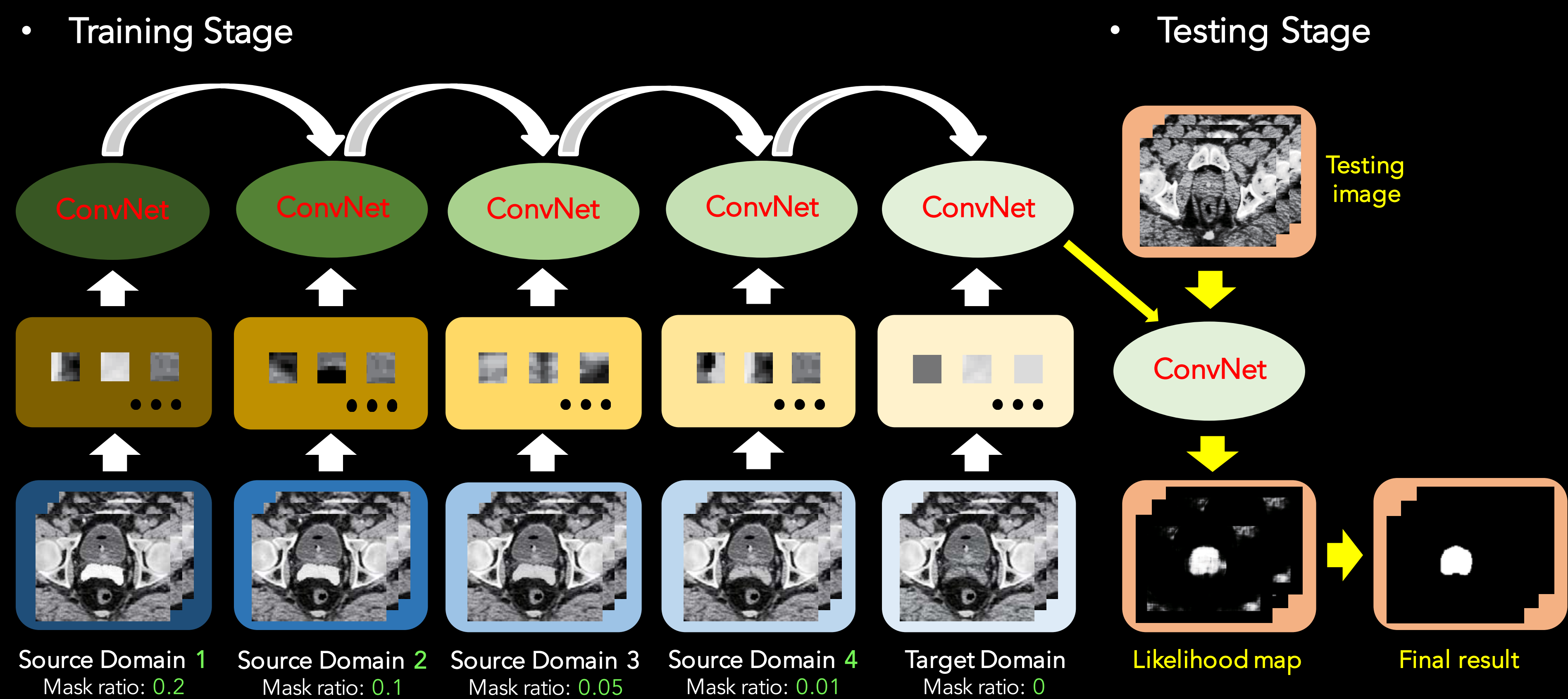
Cascaded Deep Domain Adaptation (CDDA)



Y. Shi, W. Yang, Y. Gao, D. Shen, "Does Manual Delineation Only Provide the Side Information in CT Prostate Segmentation?", *MICCAI*, 2017.

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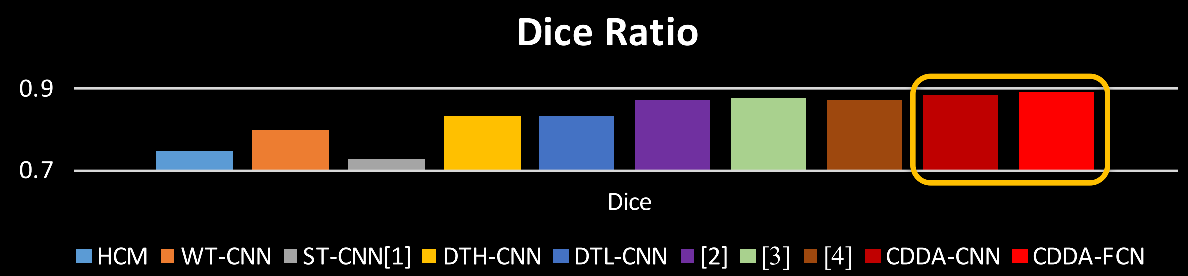
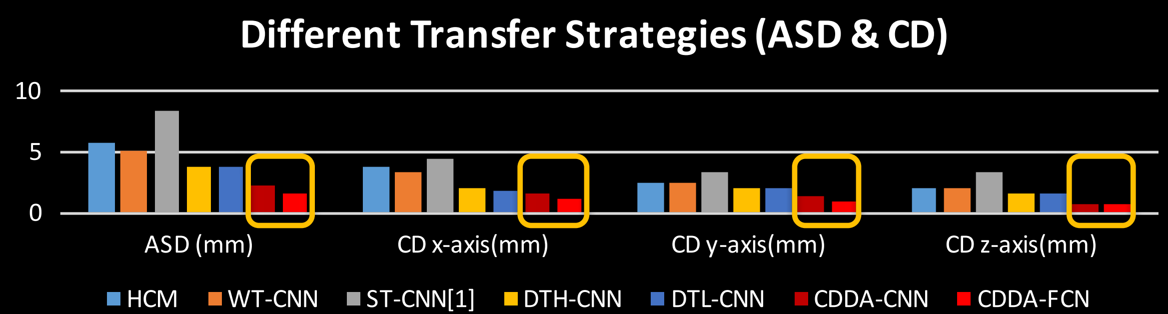
Results





HCM: Hand-crafted Method
WT-CNN: Without Transfer
ST-CNN: Selective Transfer
DTH-CNN: 0.2->0
DTL-CNN: 0.01->0

[1] J. Yosinski, J. Clune, Y. Bengio, H. Lipson. How transferable are features in deep neural networks? In NIPS, 2014.
[2] F. Martinez, et al., Segmentation of pelvic structures for planning CT using a geometrical shape model tuned by a multi-scale edge detector. Physics in Medicine and Biology, 2014.
[3] Y. Shao, Y. Gao, Q. Wang, X. Yang, and D. Shen. Locally-constrained boundary regression for segmentation of prostate and rectum in the planning CT images. Medical Image Analysis, 2015.
[4] Y. Gao, et al. Accurate segmentation of CT male pelvic organs via regression-based deformable models and multi-task random forests. IEEE TMI, 2016.

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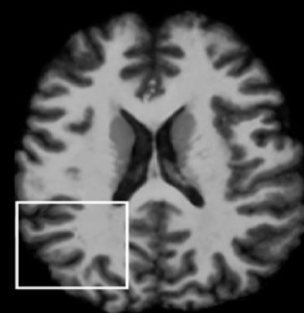
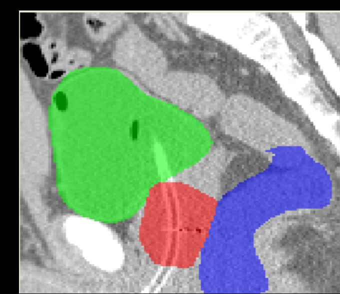
Outline

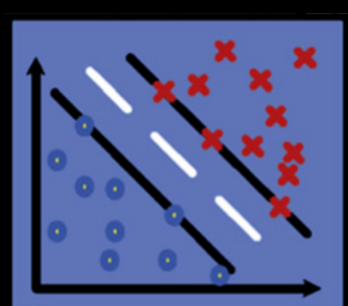
Segmentation / Registration



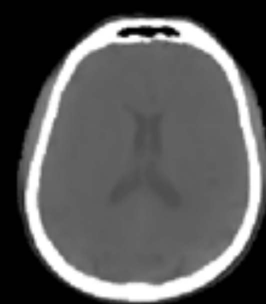
MRI Enhancement



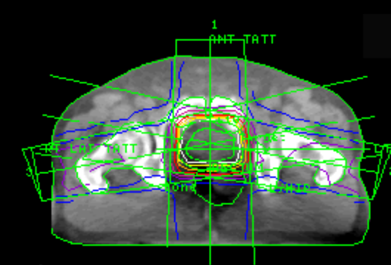
Planning CT Segmentation



Disease Diagnosis



CT Estimation from MRI



Dose Planning

Neuroimaging Analysis

Image Synthesis

Cancer Radiotherapy

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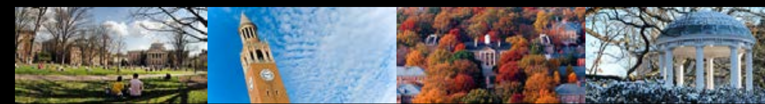

Thank you!

For more details, please visit:

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