Deep Learning in Medical Image Analysis

EEL 6935 Section 0003

Class Periods: Monday, Wednesday, Friday, Period 3 (9:35 AM - 10:25 AM)

Location: MAEA 0327

Academic Term: Fall 2023

Instructor:

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Course Description

Graduate level course, 3 Credit Hours

Medical imaging refers to technologies that visualize the interior of the human body. Over the last decades, medical imaging has become an increasingly important tool for the early diagnosis, prognosis, and treatment of various diseases. This course will focus on recent advances in deep learning-based medical image analysis methods. Topics covered in this course include (1) Basics of medical imaging, (2) Image visualization, (3) Convolutional neural networks, (4) Image classification, (5) Image segmentation, (6) Transformer networks, (7) Image registration, (8) Generative adversarial networks, (9) Image-to-image translation, (10) Image super-resolution, (11) Diffusion Models.

Course Pre-Requisites / Co-Requisites

EEL 5840 or equivalent is required, EEL 4930 is recommended. If you would like to waive the prerequisite, please contact the instructor.

Course Objectives

The overall objective of this course is to equip students with the theoretical and practical fundamentals necessary to design and implement deep learning methods for real-world medical image analysis problems. Through this course, students will be well-prepared to become proficient deep learning imaging scientists. Detailed learning objectives will be stated below.

	Learning Objectives
1	Understand physical coordinate system, and the DICOM and NIFTI image formats.
2	Be able to use the 3D Slicer software to visualize medical images and perform manual and semi-automated image segmentation tasks.
3	Be able to use SimpleITK to read and write images, apply transforms to deform images, extract image information such as type and physical coordinate system, perform image thresholding, carry out binary morphology operations, execute image segmentation, and conduct image registration.
4	Understand convolutional neural networks (CNN) and can implement CNN in TensorFlow.
5	Use CNN, transformer networks, and transfer learning for image classification.
6	Implement 2D and 3D U-Nets for single-class and multi-class medical image segmentation.
7	Apply CNNGeomtric Network for 2D affine and deformable image registration.
8	Apply Voxelmoprh for 3D deformable image registration.
9	Apply the pix2pix and the Cycle-GAN for paired and unpaired image-to-image translation tasks.
10	Understand and can describe generative adversarial networks, self-attention mechanisms, vision transformer, and variational diffusion models.

Materials and Supply Fees

N/A

Required Textbooks and Software

No textbook is required, the course notes are developed by the instructor. The following software tools will be used in this course.

HiPerGator: HiPerGator is the University of Florida's supercomputer. The students will develop and train their deep learning models on HiPerGator. For more information: https://www.rc.ufl.edu/about/hipergator/.

TensorFlow: TensorFlow is open-source software library developed Google for training and inference of deep neural networks. For more information: https://www.tensorflow.org.

3D Slicer: 3D Slicer is a free and open-source software package for image analysis and scientific visualization. For more information: https://www.slicer.org.

SimpleITK: SimpleITK is a simplified, open-source interface to the Insight Segmentation and Registration Toolkit. The SimpleITK image analysis library is available in multiple programming languages including Python. For more information: https://simpleitk.org.

Jupyter Notebook: he Jupyter Notebook is the original web application for creating and sharing computational documents. It offers a simple, streamlined, document-centric experience. For more information: https://jupyter.org.

Recommended Materials

1. Shen, Dinggang, Guorong Wu, and Heung-Il Suk. "Deep learning in medical image analysis." Annual review of biomedical engineering 19 (2017): 221.
2. Litjens, Geert, et al. "A survey on deep learning in medical image analysis." Medical image analysis 42 (2017): 60-88.
3. Ronneberger, Olaf, Philipp Fischer, and Thomas Brox. "U-net: Convolutional networks for biomedical image segmentation." International Conference on Medical image computing and computer-assisted intervention. Springer, Cham, 2015.
4. Dosovitskiy, Alexey, et al. "An image is worth 16x16 words: Transformers for image recognition at scale." arXiv preprint arXiv:2010.11929 (2020).
5. Chen, Jieneng, et al. "Transunet: Transformers make strong encoders for medical image segmentation." arXiv preprint arXiv:2102.04306 (2021).
6. Balakrishnan, Guha, et al. "VoxelMorph: a learning framework for deformable medical image registration." IEEE transactions on medical imaging 38.8 (2019): 1788-1800.
7. Rocco, Ignacio, Relja Arandjelovic, and Josef Sivic. "Convolutional neural network architecture for geometric matching." Proceedings of the IEEE conference on computer vision and pattern recognition. 2017.
8. Goodfellow, Ian, et al. "Generative adversarial networks." Communications of the ACM 63.11 (2020): 139-144.
9. Isola, Phillip, et al. "Image-to-image translation with conditional adversarial networks." Proceedings of the IEEE conference on computer vision and pattern recognition. 2017.
10. Fu, Huan, et al. "Geometry-consistent generative adversarial networks for one-sided unsupervised domain mapping." Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition. 2019.
11. Mahapatra, Dwarikanath, Behzad Bozorgtabar, and Rahil Garnavi. "Image super-resolution using progressive generative adversarial networks for medical image analysis." Computerized Medical Imaging and Graphics 71 (2019): 30-39.
12. Ho, Jonathan, Ajay Jain, and Pieter Abbeel. "Denoising diffusion probabilistic models." Advances in neural information processing systems 33 (2020): 6840-6851.
13. Luo, Calvin. "Understanding diffusion models: A unified perspective." arXiv preprint arXiv:2208.11970 (2022).

Course Schedule

Week	Topic	Assignment
Week 1	Medical Imaging Basics • Differences between medical images and natural images • Images as functions • Different imaging modalities, e.g., MRI, CT, ultrasound, PET/SPECT, histopathology • Concept of physical coordinate system • Image visualization in the 3D Slicer software • Introduction to the HiPerGator computing system	
Week 2	SimpleITK Tutorial • Install SimpleITK using pip • Read and write medical images using SimpleITK • Get and set physical information of images, including image dimension, image size, image origin, image spacing, and the direction matrix • Create basic image transformations, including translation, rotation, scaling, and flipping • Apply transformations to deform images via image resampler • Create and apply the dilation and erosion morphological operations	
Week 3	Deep Neural Networks and Convolutional Neural Networks (CNN) • Artificial neurons and activation functions • Fully connected layers • Motivation of using CNN, e.g., spatial correlation between pixels, shared kernel weights, etc. • Convolutional layer, kernel size, stride, number of kernels. • Padding options, e.g., valid padding, same padding, zero padding • Pooling layers, e.g., Max pooling, average pooling, global average pooling • Sigmoid and Softmax activation functions • 2D vs 3D convolutions. • Optimizers, e.g., gradient descent, adaptive moment estimation (Adam)	Homework 1 Due (SimpleITK, 10%)
Week 4	Image Classicization using TensorFlow • TensorFlow tutorial • Medical applications of image classification • Cross entropy loss • VGG-16 • ResNet-101 • Image classification with transfer learning	In-Class Quiz 1 (5%)
Week 5	Challenges in Applying Deep Learning to Medical Imaging • Overfitting • Small dataset • Class imbalance Possible Solutions • Data augmentation, e.g., flipping, rotation, cropping, padding, color manipulation, add noise • Redesign the loss function • Generate synthetic data	
Week 6	Introduction to Image Segmentation • Medical applications of image segmentation • Challenges in medical image segmentation • Manual and semi-automated image segmentation using 3D Slicer	Homework 2 Due (Image Classification, 10%)

	• Traditional segmentation methods	
Week 7	Deep Learning Based Image Segmentation • Transposed convolution • Categorical cross entropy loss vs Dice loss • Fully convolutional networks • U-Net	In-Class Quiz 2 (5%)
Week 8	Attention Mechanism • Query, key, value • Attention function • Dot-product attention and Additive attention Transformer Networks • Self-attention • Multi-head attention • Position encoding	
Week 9	Transformer Networks for Image Classification and Image Segmentation • Vision transformer • Transformer U-Net • Swin-Transformer	Homework 3 Due (Image Segmentation, 10%)
Week 10	Introduction to Image registration • Clinical applications of image registration • Linear transforms: rigid, affine • Non-linear transforms: thin-plate spline, B-spline, diffeomorphic • Pushforward vs pullback • Interpolators: nearest neighbor, linear, bilinear • Similarity metrics: sum of squared differences, cross correlation, mutual information, SSIM • Challenges in image registration	
Week 11	2D Image Registration • Multi-resolution image registration • Traditional affine and deformable registration using SimpleITK • Image registration based on the CNN Geometric Network • Mono-modal and multi-modal image registration	In-Class Quiz 3 (5%)
Week 12	3D Image Registration • Deformable registration based on the VoxelMorph model • Transformer networks for image registration	Homework 4 Due (Image Registration, 10%)
Week 13	Generative Adversarial Network (GAN) • Generator • Discriminator • Adversarial loss • Generate images from noise vectors • Image super-resolution based on GAN	
Week 14	Image-to-image Translation • Paired vs Unpaired image-to-image translation • Pix2Pix • Cycle-GAN • Geometry-consistent GAN • Medical applications of image-to-image translation	In-Class Quiz 4 (5%)
Week 15	Diffusion Models • KL-Divergence • Variational lower bound • Denoising diffusion models	Final Project Presentation and Project Report (40%)

Attendance Policy, Class Expectations, and Make-Up Policy
Excused absences must be consistent with university policies in the Graduate Catalog (https://catalog.ufl.edu/graduate/regulations) and require appropriate documentation. Additional information can be found here: https://gradcatalog.ufl.edu/graduate/regulations/

Evaluation of Grades

Assignment	Total Points	Percentage of Final Grade
Quizzes (4)	25 each	20%
Homework Sets (4)	25 each	40%
Final Project	100	40%
		100%

All students will propose and work on their own AI imaging project independently from week 8 to week 15. Each student will be evaluated based on the project report and the oral presentation. The distribution of points is as follows.

Project Report	Problem Statement (10 points)	Rigor of Approach (30 points)	Writing Quality (10 points)
Oral Presentation	Problem Statement (10 pints)	Rigor of Approach (30 points)	Presentation Skills (10 points)

Grading Policy
The following is given as an example only.

Percent	Grade	Grade Points
93.4 - 100	A	4.00
90.0 - 93.3	A-	3.67
86.7 - 89.9	B+	3.33
83.4 - 86.6	B	3.00
80.0 - 83.3	B-	2.67
76.7 - 79.9	C+	2.33
73.4 - 76.6	C	2.00
70.0 - 73.3	C-	1.67
66.7 - 69.9	D+	1.33
63.4 - 66.6	D	1.00
60.0 - 63.3	D-	0.67
0 - 59.9	E	0.00

More information on UF grading policy may be found at:
UF Graduate Catalog
Grades and Grading Policies

Students Requiring Accommodations
Students with disabilities who experience learning barriers and would like to request academic accommodations should connect with the disability Resource Center by visiting https://disability.ufl.edu/students/get-started/. It is important for students to share their accommodation letter with their instructor and discuss their access needs, as early as possible in the semester.

Course Evaluation
Students are expected to provide professional and respectful feedback on the quality of instruction in this course by completing course evaluations online via GatorEvals. Guidance on how to give feedback in a professional and respectful manner is available at https://gatorevals.aa.ufl.edu/students/. Students will be notified when the evaluation period opens, and can complete evaluations through the email they receive from GatorEvals, in their Canvas course menu under GatorEvals, or via https://ufl.bluera.com/ufl/. Summaries of course evaluation results are available to students at https://gatorevals.aa.ufl.edu/public-results/.

In-Class Recording
Students are allowed to record video or audio of class lectures. However, the purposes for which these recordings may be used are strictly controlled. The only allowable purposes are (1) for personal educational use, (2) in connection with a complaint to the university, or (3) as evidence in, or in preparation for, a criminal or civil proceeding. All other purposes are prohibited. Specifically, students may not publish recorded lectures without the written consent of the instructor.

A "class lecture" is an educational presentation intended to inform or teach enrolled students about a particular subject, including any instructor-led discussions that form part of the presentation, and delivered by any instructor hired or appointed by the University, or by a guest instructor, as part of a University of Florida course. A class lecture does not include lab sessions, student presentations, clinical presentations such as patient history, academic exercises involving solely student participation, assessments (quizzes, tests, exams), field trips, private conversations between students in the class or between a student and the faculty or lecturer during a class session.

Publication without permission of the instructor is prohibited. To "publish" means to share, transmit, circulate, distribute, or provide access to a recording, regardless of format or medium, to another person (or persons), including but not limited to another student within the same class section. Additionally, a recording, or transcript of a recording, is considered published if it is posted on or uploaded to, in whole or in part, any media platform, including but not limited to social media, book, magazine, newspaper, leaflet, or third party note/tutoring services. A student who publishes a recording without written consent may be subject to a civil cause of action instituted by a person injured by the publication and/or discipline under UF Regulation 4.040 Student Honor Code and Student Conduct Code.

University Honesty Policy
UF students are bound by The Honor Pledge which states, "We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honor and integrity by abiding by the Honor Code. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: "On my honor, I have neither given nor received unauthorized aid in doing this assignment." The Honor Code (https://sccr.dso.ufl.edu/process/student-conduct-code/) specifies a number of behaviors that are in violation of this code and the possible sanctions. Furthermore, you are obligated to report any condition that facilitates academic misconduct to appropriate personnel. If you have any questions or concerns, please consult with the instructor or TAs in this class.

Commitment to a Safe and Inclusive Learning Environment
The Herbert Wertheim College of Engineering values broad diversity within our community and is committed to individual and group empowerment, inclusion, and the elimination of discrimination. It is expected that every person in this class will treat one another with dignity and respect regardless of gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture.

If you feel like your performance in class is being impacted by discrimination or harassment of any kind, please contact your instructor or any of the following:
• Your academic advisor or Graduate Program Coordinator
• Jennifer Nappo, Director of Human Resources, 352-392-0904, jpennacc@ufl.edu

• Curtis Taylor, Associate Dean of Student Affairs, 352-392-2177, taylor@eng.ufl.edu
• Toshikazu Nishida, Associate Dean of Academic Affairs, 352-392-0943, nishida@eng.ufl.edu

Software Use
All faculty, staff, and students of the University are required and expected to obey the laws and legal agreements governing software use. Failure to do so can lead to monetary damages and/or criminal penalties for the individual violator. Because such violations are also against University policies and rules, disciplinary action will be taken as appropriate. We, the members of the University of Florida community, pledge to uphold ourselves and our peers to the highest standards of honesty and integrity.

Student Privacy
There are federal laws protecting your privacy with regards to grades earned in courses and on individual assignments. For more information, please see: https://registrar.ufl.edu/ferpa.html

Campus Resources:
Health and Wellness

U Matter, We Care:
Your well-being is important to the University of Florida. The U Matter, We Care initiative is committed to creating a culture of care on our campus by encouraging members of our community to look out for one another and to reach out for help if a member of our community is in need. If you or a friend is in distress, please contact umatter@ufl.edu so that the U Matter, We Care Team can reach out to the student in distress. A nighttime and weekend crisis counselor is available by phone at 352-392-1575. The U Matter, We Care Team can help connect students to the many other helping resources available including, but not limited to, Victim Advocates, Housing staff, and the Counseling and Wellness Center. Please remember that asking for help is a sign of strength. In case of emergency, call 9-1-1.

Counseling and Wellness Center: https://counseling.ufl.edu, and 392-1575; and the University Police Department: 392-1111 or 9-1-1 for emergencies.

Sexual Discrimination, Harassment, Assault, or Violence
If you or a friend has been subjected to sexual discrimination, sexual harassment, sexual assault, or violence contact the **Office of Title IX Compliance**, located at Yon Hall Room 427, 1908 Stadium Road, (352) 273-1094, title-ix@ufl.edu

Sexual Assault Recovery Services (SARS)
Student Health Care Center, 392-1161.

University Police Department at 392-1111 (or 9-1-1 for emergencies), or http://www.police.ufl.edu/.

Academic Resources

E-learning technical suppor*t*, 352-392-4357 (select option 2) or e-mail to Learning-support@ufl.edu. https://lss.at.ufl.edu/help.shtml.

Career Connections Center, Reitz Union, 392-1601. Career assistance and counseling; https://career.ufl.edu.

Library Support, http://cms.uflib.ufl.edu/ask. Various ways to receive assistance with respect to using the libraries or finding resources.

Teaching Center, Broward Hall, 392-2010 or 392-6420. General study skills and tutoring. https://teachingcenter.ufl.edu/.

Writing Studio, 302 Tigert Hall, 846-1138. Help brainstorming, formatting, and writing papers. https://writing.ufl.edu/writing-studio/.

Student Complaints Campus*:* https://sccr.dso.ufl.edu/policies/student-honor-code-student-conduct-code/;https://care.dso.ufl.edu.

On-Line Students Complaints*: https://distance.ufl.edu/state-authorization-status/#student-complaint.*