QBIO 465 Artificial Intelligence in Biology and Medicine

Units: 4

TBD Semester

Lecture: Tuesdays and Thursdays 12:30-1:50 pm

Discussion: Fridays 11:00-11:50 am

Location: TBD

Instructor: Tsu-Pei Chiu, PhD
Office: RRI 413J
Office Hours: TBD
Contact Info: tsupeich@usc.edu

Teaching Assistant: TBD
Office: TBD
Office Hours: TBD
Contact Info: TBD

Short Description

AI techniques including traditional machine learning and advanced deep learning methods for genomics, systems biology, data integration, structural biology, drug discovery, and medical imaging; project-based.

Course Description

This course introduces a wide array of Artificial Intelligence (AI) techniques, emphasizing various deep learning methodologies. This course will guide students through the process of applying these sophisticated technologies to address diverse biological and medical challenges. Through a comprehensive and intuitive teaching approach, students will be immersed in hands-on activities, working directly with many different types of biological and medical datasets.

Learning Objectives

Topics covered in the course include principles and methods for genomics, system biology, structure biology, multi-omics data integration, structural biology drug discovery, medical image, brain image, ethics questions, etc. with the AI techniques including traditional machine learning and advanced deep learning methods, as well as currently emerging research areas. The primary programming language used will be Python, which will be reviewed in lectures tailored to AI and deep learning applications. Students will use the language to implement AI algorithms to analyze biological and medical datasets for their weekly computing assignments and an end-of-the-semester project. Upon successful completion of this course, students will gain a broad knowledge of the principle of AI, especially the deep learning skills, and will be able to analyze and model biological and medical data through the lecture and exercises.

Recommended Preparation: MATH 208x or QBIO 305g or QBIO 310 (or equivalent). MATH 225 or MATH 235 or MATH 245 (or equivalent). Programming experience in Python is recommended.

Course Notes

This course is taken for a letter grade. Lecture slides will be posted on Brightspace.

Technological Proficiency and Hardware/Software Required

Students will need access to a computer. It will be helpful (but not required) if students have a laptop that they can bring it to class.

Readings and Supplementary Materials

There is no textbook for this course. However, we provide suggested readings and supplementary materials below. Additional supplemental readings will be posted on Brightspace before or after each lecture.

Reading materials:
[KM] Probabilistic Machine Learning: An Introduction. Kevin Murphy.
[IG] Deep Learning. Ian Goodfellow. MIT Press.
[FC] Deep Learning with Python, 2nd Edition, Francois Chollet
[AG] Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems, 2nd Edition. Aurélien Géron. O'Reilly Press.

Supplementary materials:
[S1] Alipanahi, B., Delong, A., Weirauch, M. et al. (2015). Predicting the sequence specificities of DNA- and RNA-binding proteins by deep learning. Nature Biotechnology, 33(8), 831–838. https://doi.org/10.1038/nbt.3300
[S2] Zhou, J., Troyanskaya, O. (2015). Predicting effects of noncoding variants with deep learning–based sequence model. Nature Methods, 12(10), 931–934. https://doi.org/10.1038/nmeth.3547
[S3] Zhou, T., Yang, L., Lu, Y., Dror, I., Dantas Machado, A.C., Ghane, T., Di Felice, R., Rohs, R. (2013). DNAshape: a method for the high-throughput prediction of DNA structural features on a genomic scale. Nucleic Acids Research, 41(W1), W56-W62. https://doi.org/10.1093/nar/gkt437
[S4] Li, J., Chiu, T.P., & Rohs, R. (2024). Predicting DNA structure using a deep learning method. Nature Communications, 15, 1243. https://doi.org/10.1038/s41467-024-45191-5
[S5] Jumper, J., Evans, R., Pritzel, A. et al. (2021). Highly accurate protein structure prediction with AlphaFold. Nature, 596, 583–589. https://doi.org/10.1038/s41586-021-03819-2
[S6] Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A.N., Kaiser, Ł., & Polosukhin, I. (2017). Attention is all you need. NIPS'17: Proceedings of the 31st International Conference on Neural Information Processing Systems, 6000–6010.
[S7] Weller, J.A., & Rohs, R. (2024). DrugHIVE: Target-specific spatial drug design and optimization with a hierarchical generative model. bioRxiv. https://doi.org/10.1101/2023.12.22.573155
[S8] Ronneberger, O., Fischer, P., & Brox, T. (2015). U-Net: Convolutional Networks for Biomedical Image Segmentation. In N. Navab, J. Hornegger, W. Wells, & A. Frangi (Eds.), MICCAI 2015: Lecture Notes in Computer Science, 9351. Springer, Cham. https://doi.org/10.1007/978-3-319-24574-4_28
[S9] Goodfellow, I.J., Shlens, J., & Szegedy, C. (2015). Explaining and Harnessing Adversarial Examples. arXiv preprint arXiv:1412.6572.
[S10] Ho, J., Jain, A., & Abbeel, P. (2020). Denoising Diffusion Probabilistic Models. arXiv preprint arXiv:2006.11239.

Assignments

The assignments include weekly computing assignments and an end-of-the-semester project. Computer-based problem sets in Python will be assigned most weeks. These assignments are designed to promote a deeper understanding of the principles discussed in lecture as well as provide hands-on experience with computing methods. The end-of-the-semester project will require students to design and carry out a research project. Students will write a report explaining their project and results in a 3 to 5-page report due at the end of the semester. Students will have the freedom to choose their project topic related to the lectures. Topics can be suggested to students if needed, and graduate students can use their thesis data if they wish. Students should submit a one-page proposal and discuss the topic of their research project with me by week 10.

Grading Breakdown

Assessment	Points	% of Grade
In-class quiz	0.5 each, 16 in total	8
Weekly computing assignments	7 each, 70 in total	70
Final project proposal	2	2
Final project presentation	5	5
Final project report	15	15

Assignment Submission Policy

Most weeks there will be a computing assignment. Assignments will both be posted and submitted on Brightspace.

Course Specific Policies

Late assignments will not be accepted without prior approval. Every student must submit their own assignment.

The professor reserves the right to make changes to the syllabus; these changes will be announced as early as possible so that students can adjust their schedules.

Academic Integrity

The University of Southern California is foremost a learning community committed to fostering successful scholars and researchers dedicated to the pursuit of knowledge and the transmission of ideas. Academic misconduct is in contrast to the university's mission to educate students through a broad array of first-rank academic, professional, and extracurricular programs and includes any act of dishonesty in the submission of academic work (either in draft or final form).

This course will follow the expectations for academic integrity as stated in the USC Student Handbook. All students are expected to submit assignments that are original work and prepared specifically for the course/section in this academic term. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s). Students suspected of engaging in academic misconduct will be reported to the Office of Academic Integrity.

Other violations of academic misconduct include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage.

The impact of academic dishonesty is far-reaching and is considered a serious offense against the university and could result in outcomes such as failure on the assignment, failure in the course, suspension, or even expulsion from the university.

For more information about academic integrity see the student handbook or the Office of Academic Integrity's website, and university policies on Research and Scholarship Misconduct.

Course Content Distribution and Synchronous Session Recordings Policies

USC has policies that prohibit recording and distribution of any synchronous and asynchronous course content outside of the learning environment.

Recording a university class without the express permission of the instructor and announcement to the class, or unless conducted pursuant to an Office of Student Accessibility Services (OSAS) accommodation. Recording can inhibit free discussion in the future, and thus infringe on the academic freedom of other students as well as the instructor. (Living our Unifying Values: The USC Student Handbook, page 13).

Distribution or use of notes, recordings, exams, or other intellectual property, based on university classes or lectures without the express permission of the instructor for purposes other than individual or group study. This includes but is not limited to providing materials for distribution by services publishing course materials. This restriction on unauthorized use also applies to all information, which had been distributed to students or in any way had been displayed for use in relationship to the class, whether obtained in class, via email, on the internet, or via any other media. (Living our Unifying Values: The USC Student Handbook, page 13).

Course Schedule

	Topics/Daily Activities	Readings/ Preparation	Deliverables
Week 1	**Introduction to AI in Biology and Medicine** Lecture 1: The intersection of AI, Biology, and Medicine Lecture 2: Fundamentals of AI	Posted on Brightspace	(none)
Week 2	**Python for AI** Lecture 3: Python review Lecture 4: Python continued (exploring data science packages)	[AG] Ch.1	(none)
Week 3	**Genomics and AI I (Machine Learning focus)** Lecture 5: Supervised learning: Regression with *in vitro* protein-DNA binding data Lecture 6: Python continued (exploring popular machine learning libraries)	[KM] Ch.1.2, Ch.10-11	Assignment #1
Week 4	Lecture 7: Supervised learning: Classification with *in vivo* protein-DNA binding data Lecture 8: Unsupervised learning: Clustering with gene expression data	[KM] Ch.1.2, Ch.10	Assignment #2
Week 5	**Genomics and AI II (Deep Learning focus)** Lecture 9: Neural Networks (NNs) and their application to aforementioned biological questions Lecture 10: Optimization techniques and Python continued (exploring popular deep learning libraries)	[IG] Ch.6-8 [FC] Ch.1-3	Assignment #3
Week 6	**Systems Biology and AI I** Lecture 11: Convolutional Neural Networks (CNNs) in predicting genome state Lecture 12: Recurrent Neural Networks (RNNs) for modeling biological networks over time	[IG] Ch.9-10	Assignment #4
Week 7	**Systems Biology and AI II** Lecture 13: Graph Neural Networks (GNNs) in modeling biological regulatory networks Lecture 14: Review and more biological applications	[IG] Ch.9-10	Assignment #5
Week 8	**Multi-Omics Data Integration** Lecture 15: Autoencoders (AEs) for vast and high-dimensional multi-omics data Lecture 16: Transfer learning (TL) for scarcity, shared patterns, and heterogeneous biological data	[IG] Ch.13-14	Assignment #6
Week 9	**Structure Biology and AI I (DNA focus)** Lecture 17: DNAshape and Deep DNAshape for predicting DNA 3D structure (NNs revisit) Lecture 18: DeepRec for mining DNA physicochemical signatures (CNNs revisit)	[S1-4]	Assignment #7

Week 10	**Structure Biology and AI II (Protein focus)** Lecture 19: Transformer and Attention in protein 3D structure prediction (AlphaFold) Lecture 20: Reinforcement learning (RL) in protein folding and Molecular Dynamics Simulations	[S5-6]	Assignment #8
Week 11	**Drug Discovery and AI** Lecture 21: Generative Adversarial Networks (GANs) in generating potential drug candidates Lecture 22: Guess speaker	[IG] Ch.20 [S7]	Assignment #9
Week 12	**Medical/Brain Image and AI** Lecture 23: 3D CNNs/Segmentation Networks in analyzing imaging data Lecture 24: Introduction to Medical/Brain Image and related databases	[S8]	Assignment #10
Week 13	**Ethics and AI** Lecture 25: Adversarial Attacks for evaluating computational model robustness and security Lecture 26: Review of previous methods and introduction to Ethics in AI	[S9]	Final project
Week 14	**Emerging technology I** Lecture 27: Introduction to Diffusion and its application in biology Lecture 28: Introduction to Large Language Model (LLM) in genomics research	[S10]	Final project
Week 15	Lecture 29: Project presentations I Lecture 30: Project presentations II	Posted on Brightspace	Final project
Final	**Final project due in university assigned final exam period**		

Statement on Academic Conduct and Support Systems

Academic Integrity:
The University of Southern California is a learning community committed to developing successful scholars and researchers dedicated to the pursuit of knowledge and the dissemination of ideas. Academic misconduct, which includes any act of dishonesty in the production or submission of academic work, compromises the integrity of the person who commits the act and can impugn the perceived integrity of the entire university community. It stands in opposition to the university's mission to research, educate, and contribute productively to our community and the world.

All students are expected to submit assignments that represent their own original work, and that have been prepared specifically for the course or section for which they have been submitted. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s).

Other violations of academic integrity include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), collusion, knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage.

The impact of academic dishonesty is far-reaching and is considered a serious offense against the university. All incidences of academic misconduct will be reported to the Office of Academic Integrity and could result in outcomes such as failure on the assignment, failure in the course, suspension, or even expulsion from the university.

For more information about academic integrity see the student handbook or the Office of Academic Integrity's website, and university policies on Research and Scholarship Misconduct.

Please ask your instructor if you are unsure what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

Students and Disability Accommodations:

USC welcomes students with disabilities into all of the University's educational programs. The Office of Student Accessibility Services (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at osas.usc.edu. You may contact OSAS at (213) 740-0776 or via email at osasfrontdesk@usc.edu.

Support Systems:

Counseling and Mental Health - (213) 740-9355 – 24/7 on call
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

988 Suicide and Crisis Lifeline - 988 for both calls and text messages – 24/7 on call
The 988 Suicide and Crisis Lifeline (formerly known as the National Suicide Prevention Lifeline) provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week, across the United States. The Lifeline is comprised of a national network of over 200 local crisis centers, combining custom local care and resources with national standards and best practices. The new, shorter phone number makes it easier for people to remember and access mental health crisis services (though the previous 1 (800) 273-8255 number will continue to function indefinitely) and represents a continued commitment to those in crisis.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL) – 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender- and power-based harm (including sexual assault, intimate partner violence, and stalking).

Office for Equity, Equal Opportunity, and Title IX (EEO-TIX) - (213) 740-5086
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

The Office of Student Accessibility Services (OSAS) - (213) 740-0776
OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.

USC Campus Support and Intervention - (213) 740-0411
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity, Equity and Inclusion - (213) 740-2101
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-1200 – 24/7 on call
Non-emergency assistance or information.

Office of the Ombuds - (213) 821-9556 (UPC) / (323-442-0382 (HSC)
A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.

Occupational Therapy Faculty Practice - (323) 442-2850 or otfp@med.usc.edu
Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.