**EE279AS Physical Algorithms**

**Optical Data Sciences and Physics-AI Symbiosis**

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**Office Hours**: Fridays at 3-4pm on Zoom

https://ucla.zoom.us/j/96480120951

Meeting ID: 964 8012 0951

[www.photonics.ucla.edu](http://www.photonics.ucla.edu/)

[www.linkedin.com/in/jalali-labs](http://www.linkedin.com/in/jalali-labs)

<https://github.com/JalaliLabUCLA>

[youtube.com/@jalali-lab](http://youtube.com/@jalali-lab)

Acting TA’s:

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**Project Assignment Survey Form (All students must fill this out by this Friday 1/8/24 12pm):**

<https://forms.gle/egtQG8S4tTzCM1m36>

**Course Management System:**

Professor will use the new BruinLearn system (<https://bruinlearn.ucla.edu/>) for sending announcements to students and posting files. Please make sure you can access the “Announcement” and the “Files” tabs of BruinLearn.

**Motivation [1]:** The phenomenal success of physics in explaining nature and engineering machines is predicated on low dimensional deterministic models that accurately describe a wide range of natural phenomena. Physics provides computational rules that govern physical systems and the interactions of the constituents therein. Led by Deep Neural Networks (DNNs), Artificial Intelligence (AI) has introduced an alternate data-driven computational framework, with astonishing performance in domains that don’t lend themselves to deterministic models such as image classification and speech recognition. These gains, however, come at the expense of predictions that are inconsistent with the physical world as well as computational complexity, with the latter placing AI on a collision course with the expected end of the semiconductor scaling known as Moore’s Law. This paper argues how an emerging symbiosis of physics and AI can overcome such formidable challenges, thereby not only extending AI’s spectacular rise but also transforming the direction of engineering and physical science.

**Course Description**: Low-complexity computational imaging tools​ with surprisingly high performance​ can be created by ​coding physical phenomena as algorithms.​This approach to computational imaging, known as PhyCV, treats images as complex particles propagating through a virtual medium. In contrast to all existing algorithms that are based on the real-valued pixel brightness, PhyCV works with complex numbers and is based on spatiotemporal and spectral phase operations emulating physical processes of diffraction and coherent detection.

​This course will begin by overview of some UCLA research that forms the backdrop for this course, then we will review the fundamentals of electromagnetic diffraction and dispersion followed by the intuition for converting the physics equations into fast algorithms for edge detection, low light enhancement, and motion detection. Topics also include physical implementation of algorithms in analog hardware for accelerated computing. The course will be project-based ranging from edge and cloud implementations and their integration into optical communication, robotics and realtime smart vision systems.

**Grades** will be based on the term projects, and also student’s participation in class and during project presentations by other students.

**Prerequisites**: A basic understanding of electromagnetics and optics is required as well as familiarity with Python. ECE170A and 170B or equivalent are recommended.

**Topics:**

Realtime ultrafast measurements, sensing and imaging

Nonlinear Schrodinger Equation (NLSE) and numerical techniques for solving it

NLSE as a template for image processing

Phase retrieval and carrier less optical communication (classical and AI techniques)

Electromagnetic wave propagation

Spatial diffraction and temporal dispersion

Coherent Detection

Edge and texture detection in digital images

Low light imaging and digital image enhancement

Object detection

Reinforcement Learning from Human Feedback (RLHF)

Edge computing and implementation of physical algorithms on embedded processors

**Calendar (subject to change)**

**Week 1 (Jan 8th and 10th)**

Introduction and Motivation. Physics-AI Symbiosis

1D dispersion and nonlinearity, NLSE and SSFM, NN solver for NLSE

**Week 2 (Jan 15th and 17th)**

Jan. 15th: MLK Holiday

2D diffraction and Phase Stretch Transform (PST)

**Week 3 (Jan 22dn and 24th)**

PST and PAGE algorithms and their application, PhASR algorithm

Vision Enhancement via Virtual diffraction and coherent Detection (VEViD)

**Week 4**

Jan. 29th: Mid-term Presentation

Jan. 31st: Mid-term Presentation

**Week 5**

Feb. 5th: Mid-term Presentation

Feb. 7th: Mid-term Presentation

**Week 6 (Feb 12th and 14th)**

Generalized PhyCV Framework

Other physics related algorithms: Diffusion Models, Physics-informed Neural Networks, Light-field Imaging.

**Week 7 (Feb 19th and 21st)**

Feb. 19th: President’s Day Holiday

Guest lecture by Dr. Tingyi Zhou on Nonlinear Schrodinger Kernel, Neural Network for Coherent Time Stretch

**Week 8 (Feb 26th and 28th)**

Guest Lecture by Dr. Hamed Dalir

Guest lecture by Jason Chou on advanced sensing and measurements techniques

**Week 9**

Mar. 4th: Final Presentation

Mar. 6th: Final Presentation

**Week 10**

Mar. 11th: Final Presentation

Mar. 13th: Final Presentation

**Final Project**

**Guidelines for student presentations**

* Indicate topic # and title on first page. Slides should be numbered.
* Your slide #2 should be description of how you partitioned the work. What was the role of each team member.
* You will give a midterm presentation on your progress in the midterm week and will receive feedback from the Professor. Present your outline, what you have already done and plans for what you intend to cover in your final report.
* You will give a final 20-minute presentation in Week 10.
* You should go over your code during the presentation. Your code should be annotated and in the \*.ipynb format (in Colab) and should contain comments and explanations as well as a block diagram/flowchart of your code. Your slide deck should contain the same block diagram/flow chart.
* Your presentation should cover these essentials:

1. Background: applications, motivation (why is this topic/technology important)
2. Methods (technical approach)
3. Results
4. Outlook/Discussion/Conclusion
5. References

* If you have a figure in your slide that you copied from another source (paper or URL), the source needs to appear on the same slide.

**Midterm (interim) Presentation**

* We will give you questions that need to be addressed in your final presentation. Make sure you write them down and ensure you work on them and have the answer (supported by slides) in your final presentation and handout. If you are not sure what the questions are, ask during or after your presentation.
* Bring your own laptop. Class projector has both HDMI and VGA cables. If your computer needs an adaptor, bring one with you.
* If you don’t know the answer to a question, it’s best to acknowledge it and say you will investigate and answer it later. Don’t try to make up an answer.

**Final Deliverables (Due: Mar. 22nd)**

* PowerPoint presentation (.pptx), block diagrams/flowcharts of your code.
* GitHub Repo (depending on the project)
* Colab notebook [<https://colab.research.google.com/#scrollTo=Nma_JWh-W-IF>]
* Readme file explaining the code delivered in .docx or .txt
* Naming Conventions: Team#\_TopicName\_Content (TopicName is the Shorthand Name for the title of your project in the list of topics)

**Important Notice:**

The class is essentially a public forum. Some students may want to tailor their project to be aligned with their thesis research. If so, the student must provide written consent from their advisor indicating that they are ok with disclosing the data and algorithms with the class.

**Best Project Award**

The final projects for the 279AS course will be part of a friendly competition to showcase the best student work. The top teams will have their projects featured and cited on the lab website, YouTube channel, and GitHub repository. Results may also be publicized at conferences and in publications. Winning teams will receive extra credit in the course. All participants will gain experience communicating research methods and results. We encourage creativity and look forward to seeing what you come up with! Good luck!

References

[1] Jalali, B., Zhou, Y., Kadambi, A., & Roychowdhury, V. (2022). Physics-AI symbiosis. Machine Learning: Science and Technology, 3(4), 041001.