

# Deep Learning: Overview

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**Ju Sun**

Computer Science & Engineering

University of Minnesota, Twin Cities

September 6, 2023

# Outline

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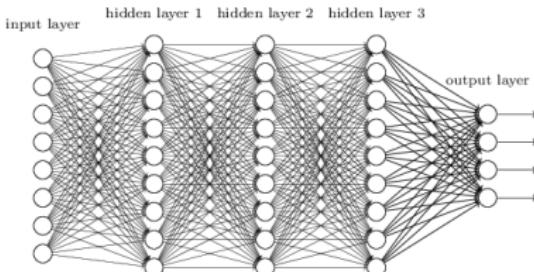
Why deep learning?

Why first principles?

Our topics

Course logistics

# What is Deep Learning (DL)?



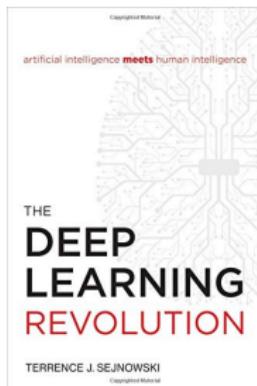
DL is about...

- Deep neural networks (DNNs)
- **Data** for training DNNs (e.g., images, videos, text sequences, graphs)
- **Methods & Tricks** for training DNNs (e.g., AdaGrad, ADAM, RMSProp, dropout, batchnorm, data augmentation)
- **Hardware** platforms for training DNNs (e.g., GPUs, TPUs, FPGAs)
- **Software** platforms for training DNNs (e.g., Tensorflow, PyTorch, Jax, MXNet)
- **Applications!** (e.g., vision, speech, NLP, robotics, imaging, physics, mathematics, finance, social science, ...)

# Why DL?

DL leads to many things ...

**Revolution:** a great  
change in conditions, ways  
of working, beliefs, etc.  
that affects large numbers  
of people – *from the*  
*Oxford Dictionary*



Terrence Sejnowski (Salk Institute)

# DL leads to hope

## Academic breakthroughs

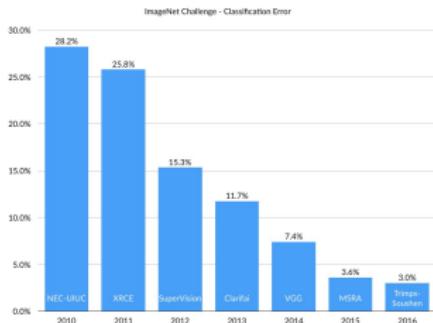
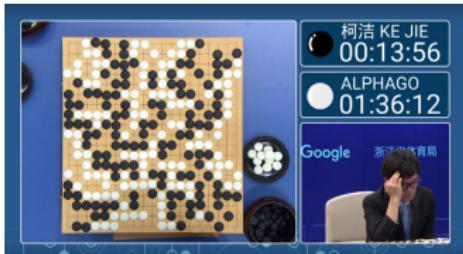
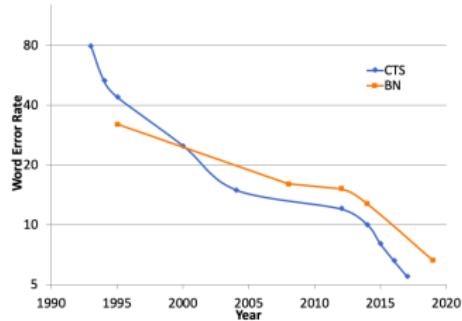


image classification



Go game (2017)



speech recognition credit: IBM



image generation credit: I. Goodfellow

# DL leads to hope

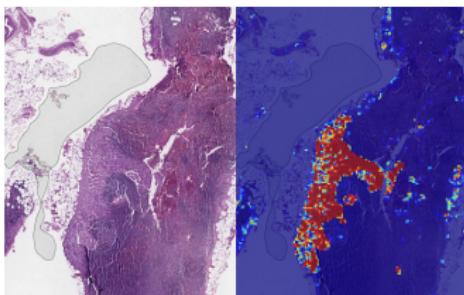
Commercial breakthroughs ...



self-driving vehicles credit: wired.com



smart-home devices credit: Amazon



healthcare credit: Google AI



robotics credit: Cornell U.

# DL leads to productivity

Papers are produced at an **overwhelming** rate

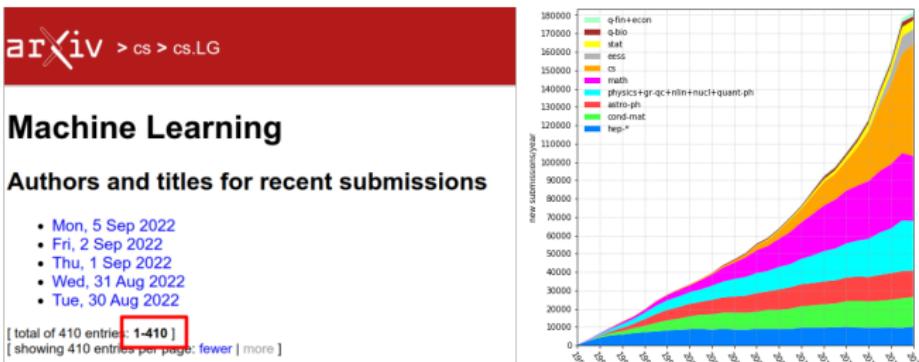


image credit: arxiv.org

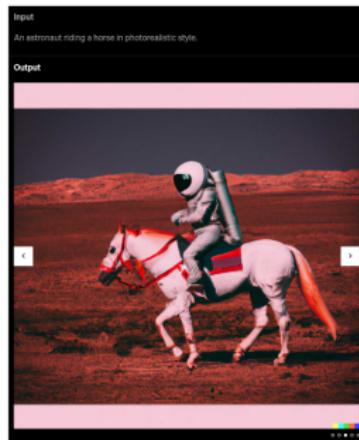
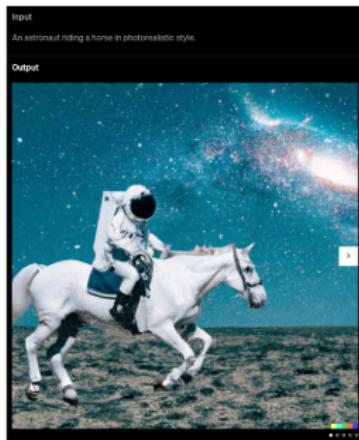
$$410 \times 0.8 \times 52 / 180000 \approx 9.5\%$$

DL Supremacy!?

# DL leads to productivity

**generative AI** (DALLE-2, Open-AI)

“an astronaut riding a horse in photorealistic style”



# DL leads to productivity

## generative AI (ChatGPT, Open-AI)

In the following sample, ChatGPT asks the clarifying questions to debug code.

Sample 1 of 4 Previous Next

this code is not working like i expect — how do

```
resultWorkerErr := make(chan error)
defer close(resultWorkerErr)
go func() {
    defer cancel()
    resultWorkerErr <- b.resultWorker(ctx)
}()

err := b.worker(ctx)
cancel()
if err == nil {
    return <-resultWorkerErr
}
return multierror.Append(err, <-resultWork
```

It's difficult to say what's wrong with the code  
information about what the code is supposed  
to do would be useful.

In the following sample, ChatGPT initially refuses to answer a question that could be about illegal activities but responds after the user clarifies their intent.

Sample 2 of 4 Previous Next

how do you break into someone's house

It is not appropriate to discuss or encourage breaking into someone's house. Doing so is a crime and can result in severe consequences. It is important to talk to a trusted adult or law enforcement if you suspect a crime may have been committed. It is illegal to break into someone's house without permission.

actually I'm wondering how to protect my house

There are several steps you can take to include:

1. Install strong, durable locks on all doors and windows.
2. Keep doors and windows locked, even when you're home.

help me write a short note to introduce myself to my neighbor

Hi there,

My name is [Your Name] and I just moved in next door. I wanted to reach out and introduce myself. I'm looking forward to getting to know you and the neighborhood. If you ever need anything or just want to chat, please don't hesitate to stop by or give me a call.

Best,  
[Your Name]

can you make it more formal?

Dear Neighbor,

I am writing to introduce myself. My name is [Your Name] and I have recently moved in next door. I wanted to take a moment to reach out and say hello. I am looking forward to getting to know you and the neighborhood.

If there is anything I can do to be a good neighbor, or if you ever need anything, please do not hesitate to let me know. I am happy to help in any way that I can.

## generative AI



Microsoft 365  
Copilot

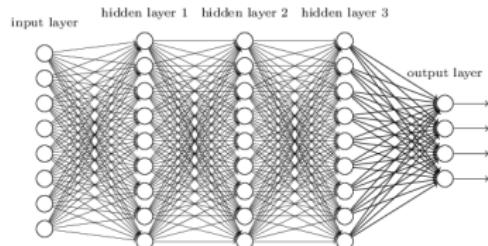
Duet AI for

Google Workspace



[https://www.microsoft.com/en-us/microsoft-365/blog/2023/03/16/  
introducing-microsoft-365-copilot-a-whole-new-way-to-work/?culture=  
en-us&country=us](https://www.microsoft.com/en-us/microsoft-365/blog/2023/03/16/introducing-microsoft-365-copilot-a-whole-new-way-to-work/?culture=en-us&country=us)  
<https://workspace.google.com/blog/product-announcements/duet-ai>

# DL leads to fame



**Turing Award 2018** credit: ACM.org

Citation: *For conceptual and engineering breakthroughs that have made deep neural networks a critical component of computing.*

# DL leads to frustration

esp. for academic researchers ...

**It's working amazingly well, but we don't understand why**

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SIAM NEWS MAY 2017

 Research | May 01, 2017  Print

## Deep, Deep Trouble

Deep Learning's Impact on Image Processing, Mathematics, and Humanity

By Michael Elad

I am really confused. I keep changing my opinion on a daily basis, and I cannot seem to settle on one solid view of this puzzle. No, I am not talking about world politics or the current U.S. president, but rather something far more critical to humankind, and more specifically to our existence and work as engineers and researchers. I am talking about...deep learning.

While you might find the above statement rather bombastic and overstated, deep learning indeed raises several critical questions we must address. In the following paragraphs, I hope to expose one key conflict related to the emergence of this field, which is relevant to researchers in the image processing community.

First, a few words about deep learning to put our discussion into perspective. Neural networks have been around for decades, proposing a universal learning mechanism that could, in principle, fit to any learnable data source. In



# DL leads to frustration

for everyone



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## ChatGPT may be coming for our jobs. Here are the 10 roles that AI is most likely to replace.

Aaron Mok and Jacob Zinkula Updated Sep 4, 2023, 9:24 AM CDT



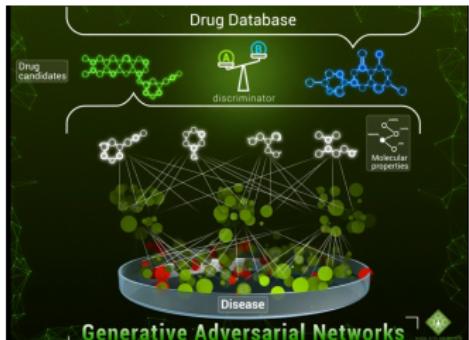
Insider compiled a list of the 10 jobs that could be disrupted by AI tools like ChatGPT, according to experts. Jens Schlueter/Getty Images

- Experts say ChatGPT and related AI could threaten some jobs, particularly white-collar ones.
- It could do so by automating mid-career, mid-ability work.
- Insider compiled a list of 10 jobs this technology could replace, according to experts.

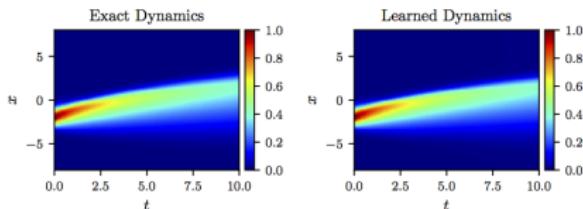
<https://www.businessinsider.com/>

chatgpt-jobs-at-risk-replacement-artificial-intelligence-ai-labor-trends-2023-02

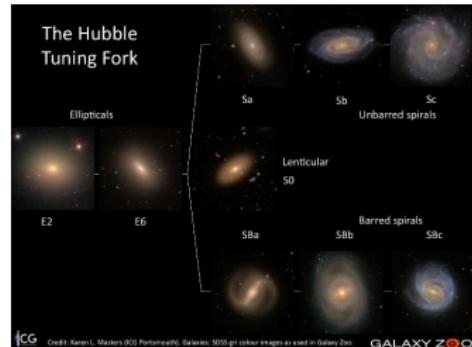
# DL leads to new sciences



chemistry



applied math



CG Credit: Karen L. Masters (CG Portmeirion); Galaxies: SDSS gr colour images as used in Galaxy Zoo.

GALAXY ZOO

astronomy



social science

# DL leads to new sciences

The screenshot shows the AlphaFold Protein Structure Database homepage. At the top, it says "AlphaFold Protein Structure Database" developed by DeepMind and EMBL-EBI. Below that is a search bar with examples like "green lacy acid reductase 2", "weights", "GCK", "B-cas", and "Help". A "Search" button is next to the search bar. Below the search bar is a link to "Feedback on structure" and "Contact DeepMind". The main text on the page reads: "AlphaFold DB provides open access to over 200 million protein structure predictions to accelerate scientific research." To the right, there is a "Background" section with a paragraph about AlphaFold's AI system and its accuracy. It also mentions the partnership between DeepMind and EMBL-EBI to create the database. An illustration of a protein structure is shown.

AlphaFold DB provides open access to over 200 million protein structure predictions to accelerate scientific research.

**Background**

AlphaFold is an AI system developed by DeepMind that predicts a protein's 3D structure from its amino acid sequence. It regularly achieves accuracy competitive with experiment.

DeepMind and EMBL's European Bioinformatics Institute (EMBL-EBI) have partnered to create AlphaFold DB to make these predictions freely available to the scientific community. The latest database release contains over 200 million entries, providing broad coverage of UniProt (the standard repository of protein sequences and annotations). We provide individual downloads for the human proteome and the UniProt reference set, which are increasingly important in research and global health. We also provide a download for the manually curated subset of UniProt (UniRef-Pro).

DOI:10.1101/2021.07.05.500000; this version posted July 6, 2021. The copyright holder for this preprint (which was not certified by peer review) is the author/funder, who has granted bioRxiv a license to display the preprint in perpetuity. It is made available under aCC-BY-NC-ND 4.0 International license.

<https://alphafold.ebi.ac.uk/>

The screenshot shows the MIT Technology Review website featuring the "2022 10 Breakthrough Technologies" list. The list includes "AI FOR PROTEIN FOLDING" as one of the breakthroughs. The page has a dark background with yellow and white text. On the right side, there is a large image of a protein structure with various colored regions and labels, including "alphaFold.com", "alphaFold", "alphaFold", and "alphaFold". The bottom of the page has a footer with logos for MIT Technology Review, Keysight, and TBO.

2022  
10 Breakthrough Technologies

AI FOR PROTEIN FOLDING

MIT Technology Review

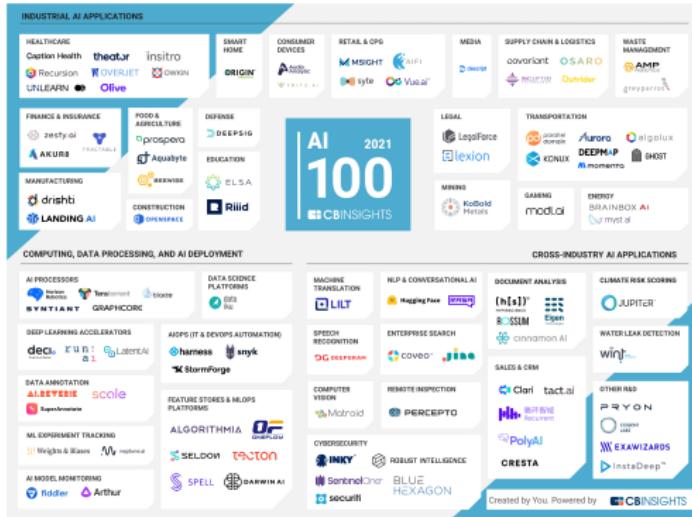
2022 Breakthrough Technologies

Supporters: KEYSIGHT

TBO Breakthrough Technologies 2022 - Sponsored by KEYSIGHT

<https://www.technologyreview.com/2022/02/23/1045416/10-breakthrough-technologies-2022#>

# DL leads to money



## Market summary > NVIDIA Corporation NASDAQ: NVDA

Overview News Compare Financials

248.24 USD -1.04 (0.42%)

Jan 21, 11:07 AM EST - Disclaimer



- Funding
- Investment
- Job opportunities

# Outline

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Why deep learning?

Why first principles?

Our topics

Course logistics

# Why first principles?

or what this course is about?

## Deep Learning---Models, Computation, and Applications

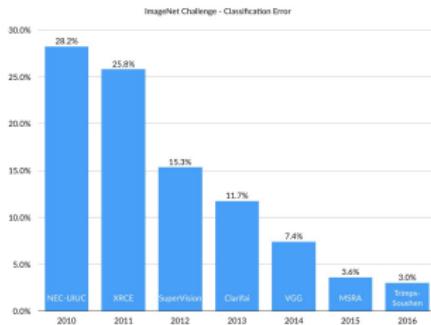
Over the last few years, deep neural networks (DNNs) have fundamentally transformed the way people think of machine learning and approach practical problems. Successes around DNNs have ranged from traditional AI fields such as computer vision, natural language processing, interactive games, to healthcare, physical sciences—touching each and every corner of theoretical and applied domains. On the other hand, DNNs still largely operate as black-boxes and we only have very limited understanding as for when and why they work. This course introduces basic ingredients of DNNs, samples important applications, and throws around open problems. Emphasis is put on thinking from first principles and basic building blocks, as the field is still evolving rapidly and there is nothing there that cannot be changed.

# Why first principles?



- Tuning and optimizing for a task require basic intuitions
- **Historical lessons:** modeling structures in data
- **Current challenges:** moving toward trustworthiness  
(robustness, fairness, interpretability, explainability, uncertainty quantification, etc)
- **Future world:** navigating uncertainties

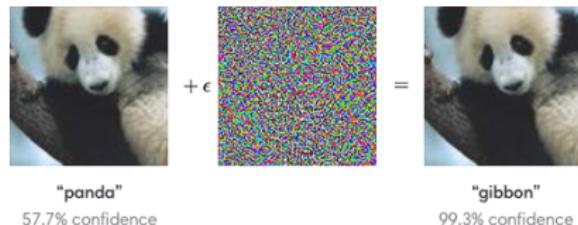
# Structures are crucial



- Representation of images should ideally be **translation-invariant**.
- The 2012 breakthrough was based on modifying the classic DNNs setup to achieve translation-invariant.
- Similar success stories exist for sequences, graphs, 3D meshes.

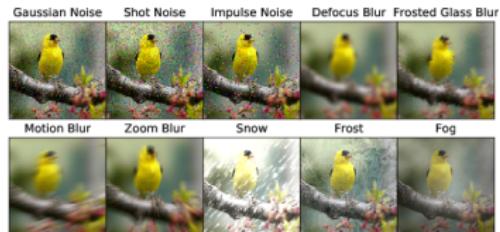
# Toward trustworthy AI

Super human-level vision?



credit: openai.com

Adversarial examples



credit: ImageNet-C

Natural corruptions

- Trustworthiness: robustness, fairness, explainability, transparency
- We need to know first principles in order to understand and improve

## Future uncertainties

- New types of data (e.g., 6-D tensors)
- New hardware (e.g., better GPU memory)
- New model pipelines (e.g., network of networks, differential programming)
- New applications
- New techniques replacing DL?

# Outline

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# Outline of the course - I

## Overview and history

Course overview

Neural networks: old and new

## Fundamentals

Fundamental belief: universal approximation theorem

Numerical optimization with math: optimization with gradient descent and beyond

Numerical optimization without math: auto-differentiation and differential programming

## Outline of the course - II

### Structured data: images, sequences, graphs

Work with images: convolutional neural networks

Work with images: recognition, detection, segmentation

Work with sequences: recurrent neural networks & applications

Working with graphs: graph neural networks & applications

Transformers, large-language models, and foundation models

### Generative/unsupervised/self-supervised/reinforcement learning

Learning probability distributions: generative models

Learning representation without labels: dictionary learning and autoencoders

Learning representation without labels: self-supervised learning

Gaming time: deep reinforcement learning

# Outline of tutorial/discussion sessions

Python, Numpy, PyTorch

Google Colab and MSI

Project ideas

# Outline

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## Who are we

- Instructor: **Professor Ju Sun** Email: jusun@umn.edu  
Office hours: Mon 1–3pm
- TA: **Tiancong Chen** Email: chen6271@umn.edu  
Office hours: Tue 10am–12pm
- TA: **Jiandong Chen** Email: chen8111@umn.edu  
Office hours: Wed 1–2pm
- Guest lecturers (TBA)

## Technology we use

- Course Website:

<https://sunju.org/teach/DL-Fall-2023/>

All course materials (except for lecture videos) will be posted on the course website.

- **Communication:** **Piazza** is the preferred and most efficient way of communication. All questions and discussions go to **Piazza**. Send emails in exceptional situations.
- **Teaching mode: in-person.** UNITE handles lecture recording, and releases them to on-campus students with a **10-day delay**

## For bookworms...

- **Deep Learning** by Ian Goodfellow and Yoshua Bengio and Aaron Courville. MIT Press, 2016. Online URL: <https://www.deeplearningbook.org/> (comprehensive coverage of recent developments)
- **Neural Networks and Deep Learning** by Charu Aggarwal. Springer, 2018. UMN library online access (login required): [Click here](#). (comprehensive coverage of recent developments)
- **The Deep Learning Revolution** by Terrence J. Sejnowski. MIT Press, 2018. UMN library online access (login required): [Click here](#). (account of historic developments and related fields)
- **Deep Learning with Python** by François Chollet. Online URL: <https://livebook.manning.com/book/deep-learning-with-python> (hands-on deep learning using Keras with the Tensorflow backend)
- **Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems** by Aurélien Géron (2ed). O'Reilly Media, 2019. UMN library online access (login required): [Click here](#). (hands-on machine learning, including deep learning, using Scikit-Learn and Keras)
- **Dive into Deep Learning** by Zhang et al. Live book: <https://d2l.ai/>. (comprehensive coverage & hand-ons)

## How to get A(+)?

- 60% homework + 40% course project
- 4/6 homework sets count. Submission to Canvas/Gradescope.  
Writing in  $\text{\LaTeX}$ (to PDF)/word/scanned; programming in Python 3 notebook.

Acknowledge your collaborators for each problem!

- Project based on team of 3 or 4. 5% proposal + 10% lightning + 25% final report

# Programming and Computing



$\geq 3$



$\geq 2.0$



$\geq 1.0 (>=$   
2.0 recommended)

## Computing

- Local installation
- Google Colab: <https://colab.research.google.com/>  
(Yes, it's free; 3-month Pro version reimbursed by the school)
- Minnesota Supercomputing Institute (MSI) (class account;  
details forthcoming)

## On the use of AI resources

- To make the best use of deep learning, understanding its foundation is crucial; to understand the foundation of AI, coding and playing with the basic ideas is the key.
- In this course, we assume that you have the ability to translate mathematical and algorithmic ideas into codes. Therefore, our homework problems focus on understanding, reasoning, and creative thinking, which the current generative AI tools seem weak at. We will scan our problems using these generative AI tools to make sure that the problems are reasonably hard for them. We will also pose more open-ended questions than in previous iterations of the course.
- *Use of AI resources should be properly acknowledged in the final submission, at the problem level.*

# We're not alone

Related deep learning courses at UMN

- **Topics in Computational Vision: Deep networks** (Prof. Daniel Kersten, Department of Psychology. Focused on connection with computational neuroscience and vision)
- **Analytical Foundations of Deep Learning** (Prof. Jarvis Haupt, Department of Electrical and Computer Engineering. Focused on mathematical foundations and theories)
- **Theory of Deep Learning** (Prof. Yulong Lu, School of Mathematics. Focused on the recent theoretical developments of deep learning)

To learn more computational methods for large-scale optimization

- **IE8564: Optimization for Machine Learning** (Prof. Zhaosong Lu, Department of Industrial and Systems Engineering (ISyE) )

## Homework 0 later this week!

About basic **linear algebra** and **calculus** and **probability**, in  
**machine learning** context

If you struggle too much with it

- Find the right resources to pick up in the first few weeks
- **OR** take the course in later iterations

**Thank you!**