NUS National University of Singapore | School of Computing

SCAN ME

CS5340
Uncertainty Modeling in AI

Asst. Prof. Harold Soh

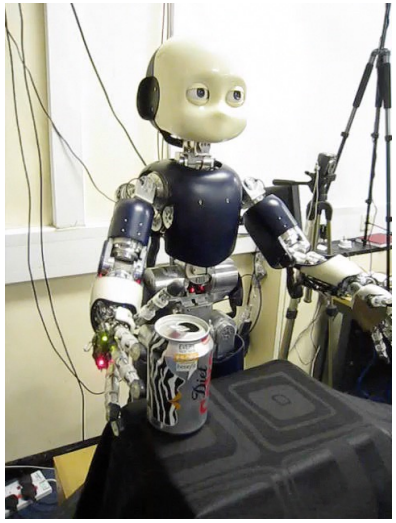
Dept of Computer Science

National University of Singapore

Poll Everywhere!

https://pollev.com/haroldsohsoo986

Introduction



Lecturer:

Harold Soh

Department of CS

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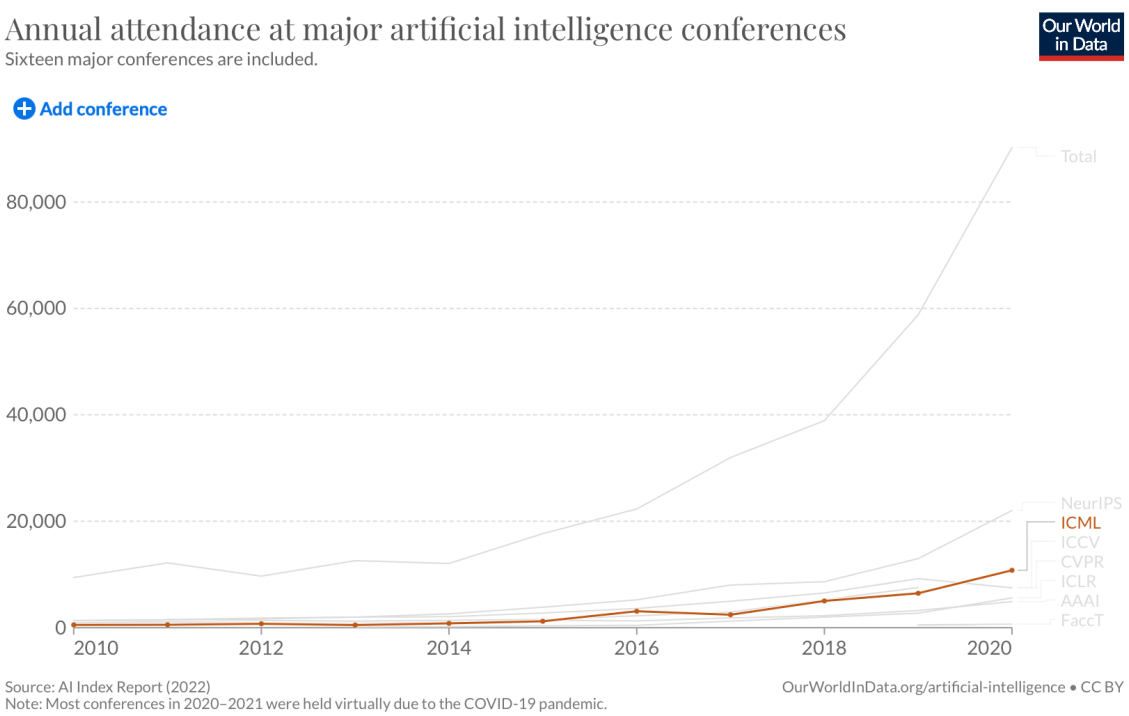
Web: https://haroldsoh.github.io

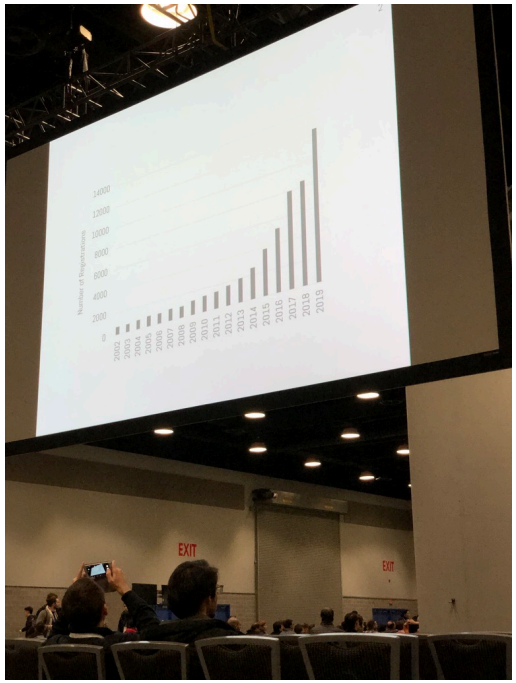
Lab: https://clear-nus.github.io

Research Interests:

Human AI/Robot Interaction, Machine Learning, AI, Robotics

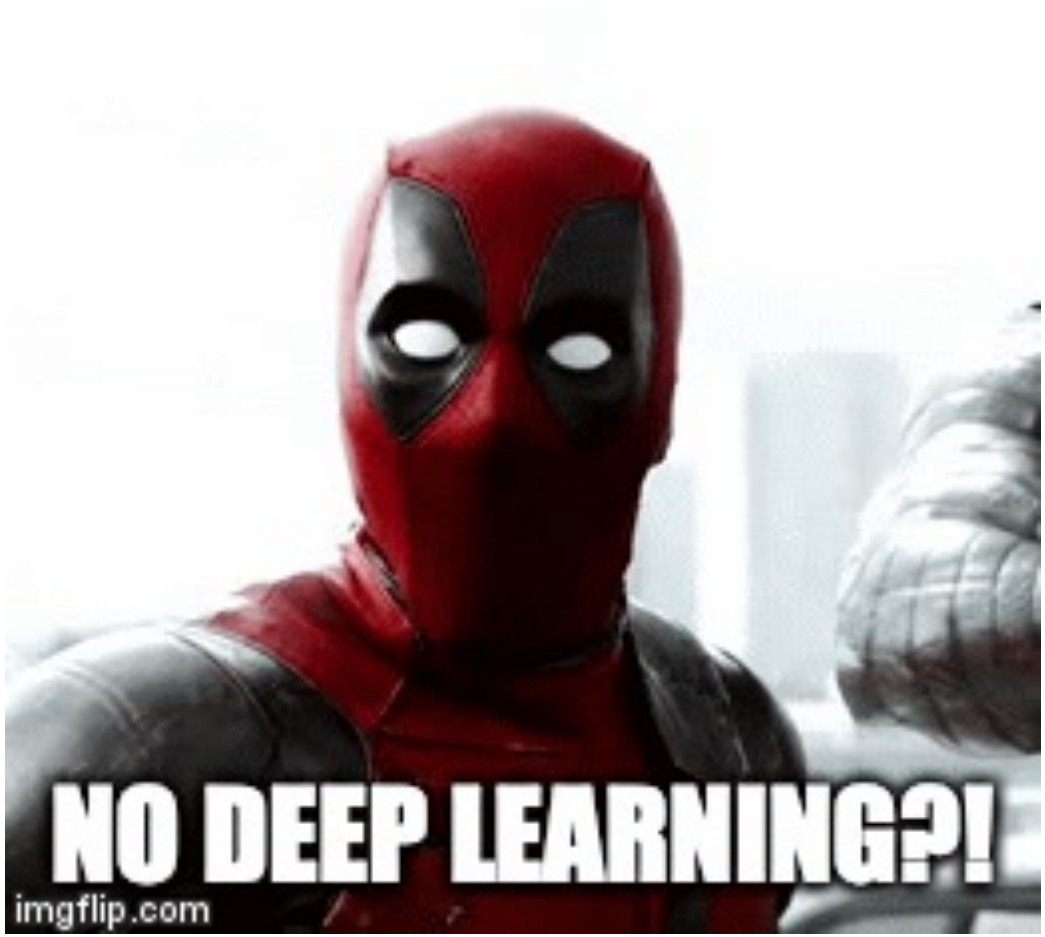
Artificial Intelligence is Cool (again)!





https://ourworldindata.org/grapher/attendance-major-artificial-intelligence-conferences

CS5340 is **not** a "deep learning" class



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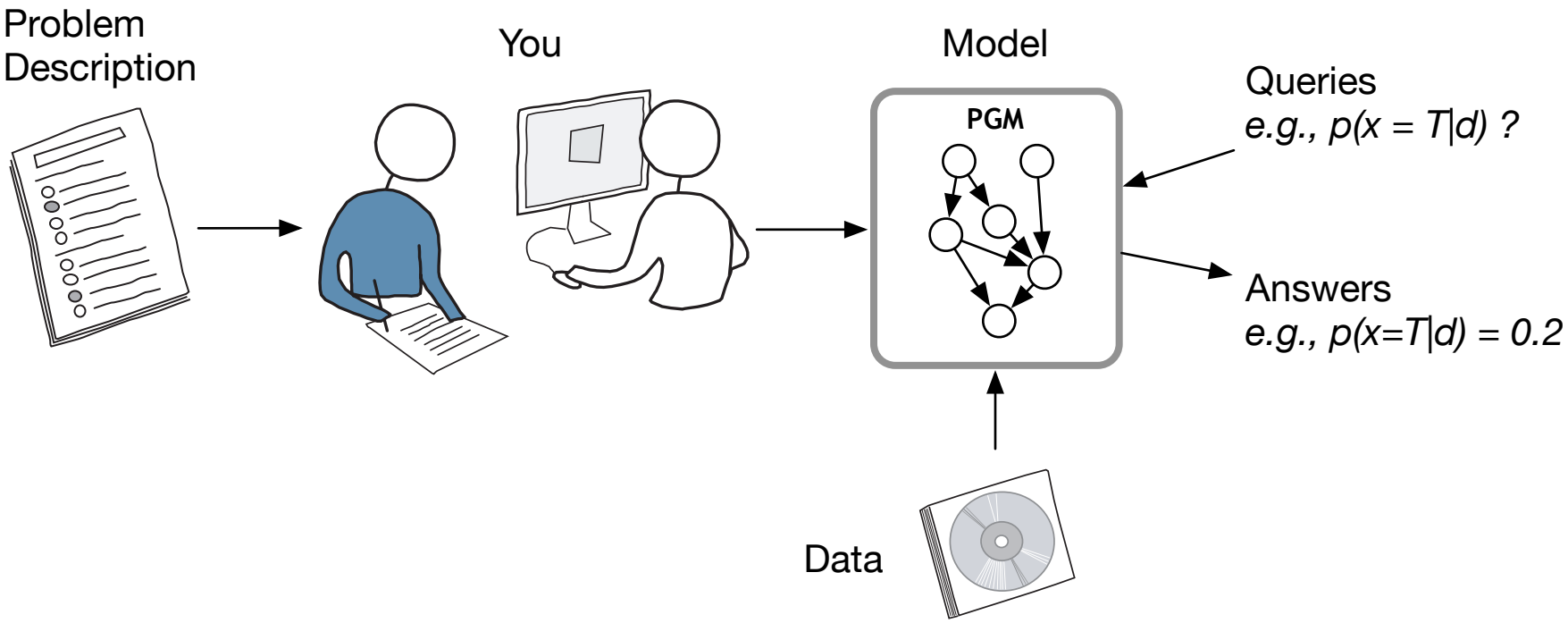
So, what is CS5340 about?

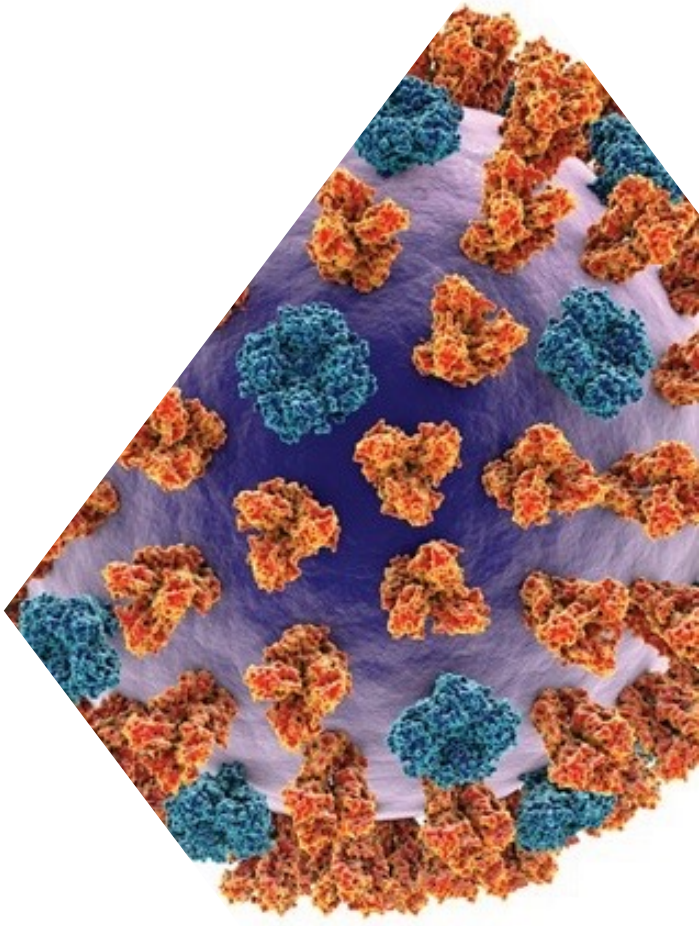
CS5340 in a nutshell

CS5340 is about how to "**represent**" and "**reason**" with uncertainty in a computer.



A Modeling Exercise: Influenza

- You're hired to design an AI Diagnostician.
- Scope: **Influenza** (Flu)
- **Problem:** *Given a patient X and information available, does X have the flu?*
- Modeling steps:
  - What are the *relevant variables*?
  - What are the *relationship* between the variables?



Possible Relevant Variables

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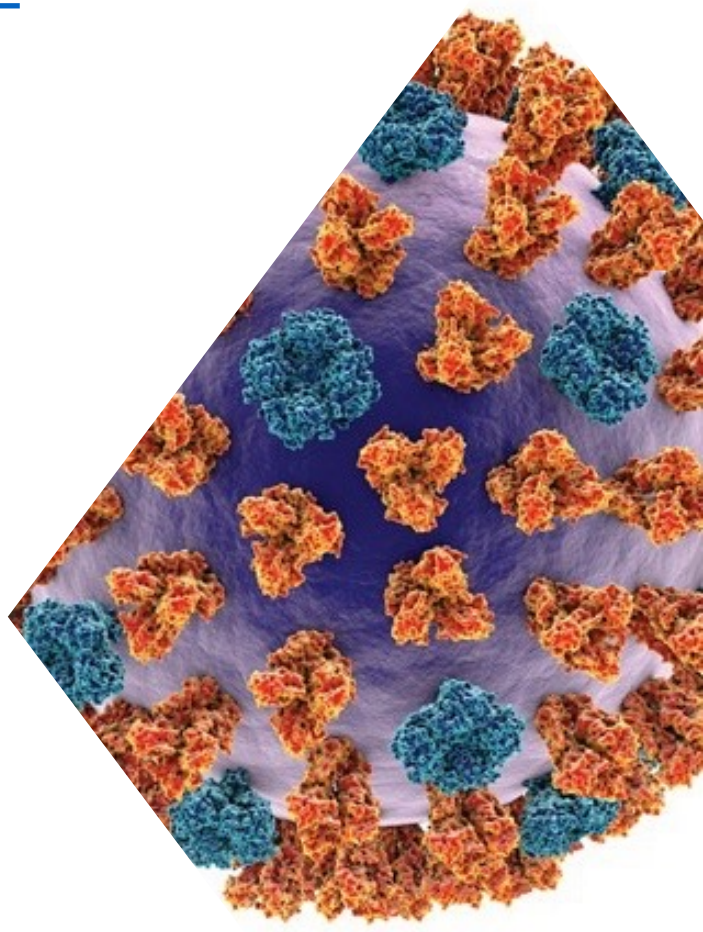
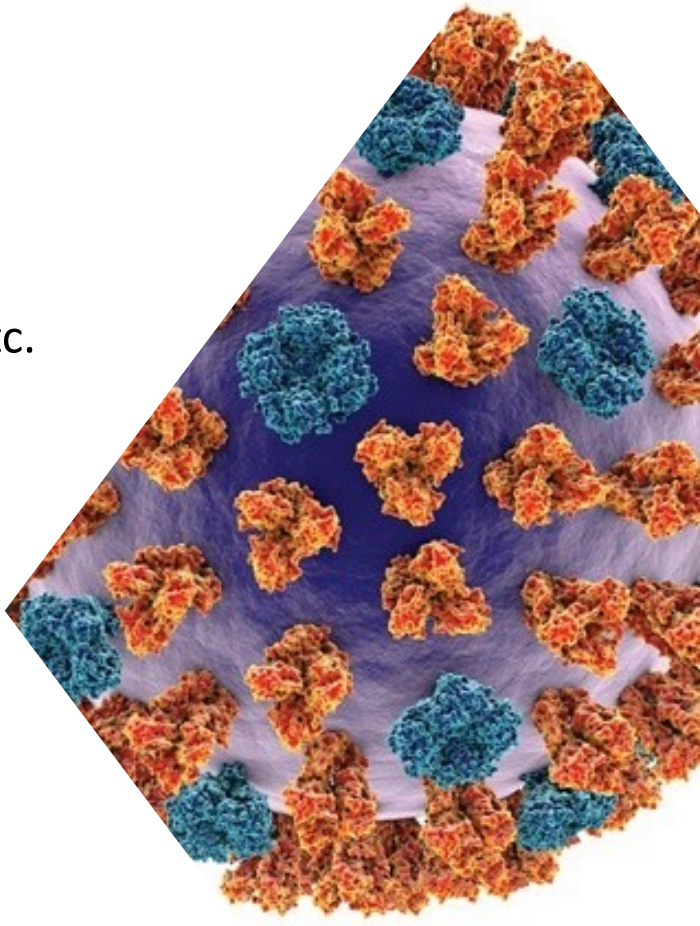


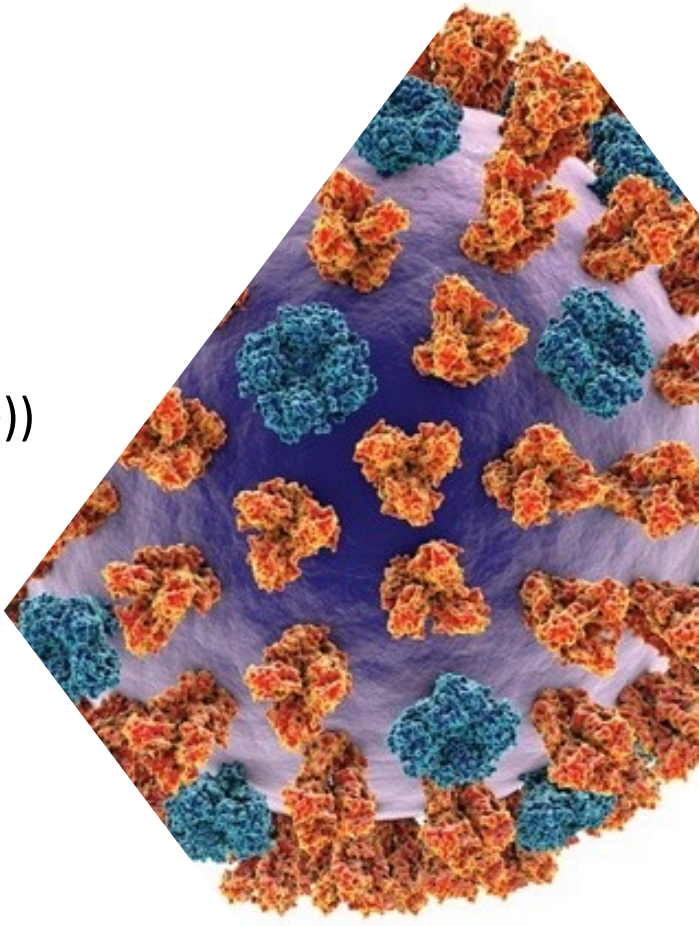
Possible Relevant Variables

- Whether X has the flu or not.
- Immunity to influenza
- Vaccinated
- Genetically immune
- Symptoms present or not:
  - Fever, Cough, Sore throat, Runny nose, Etc.
- Whether the person came into contact with a person with the flu recently.
- Current prevalence of flu in the population
- Structure of the population
- Flu test result
- and so on ...



Modeling the Relationships

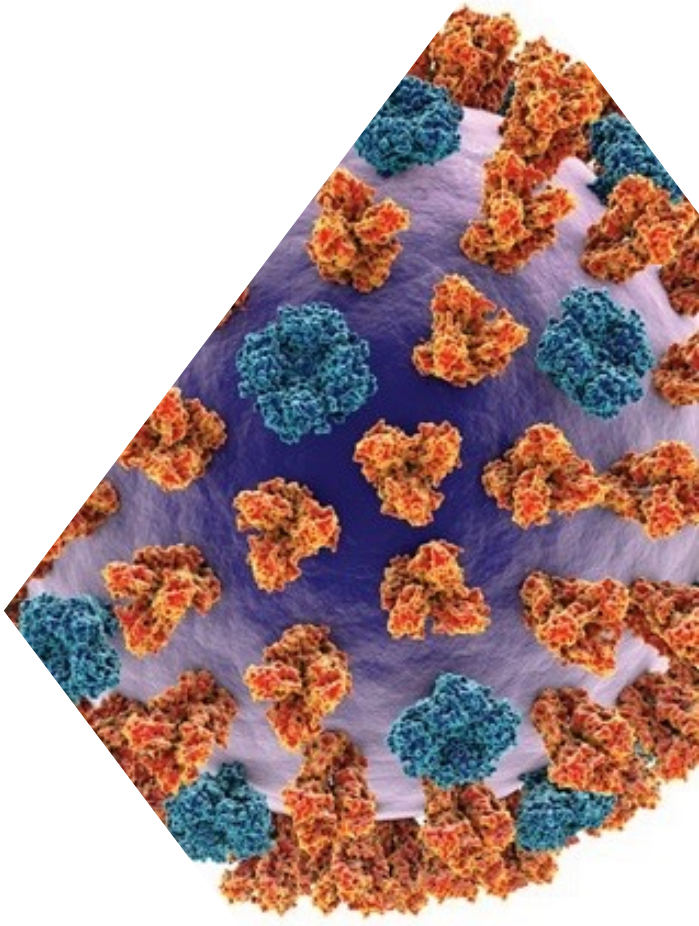
- Consider binary variables.
- How can we *represent* how the variables are related?
- One simple way:
  - Rules, e.g.,
    - **IF** (fever **AND** cough **AND** (**NOT** immune))
      THEN flu=TRUE
      ELSE flu=FALSE
- What are the problems?



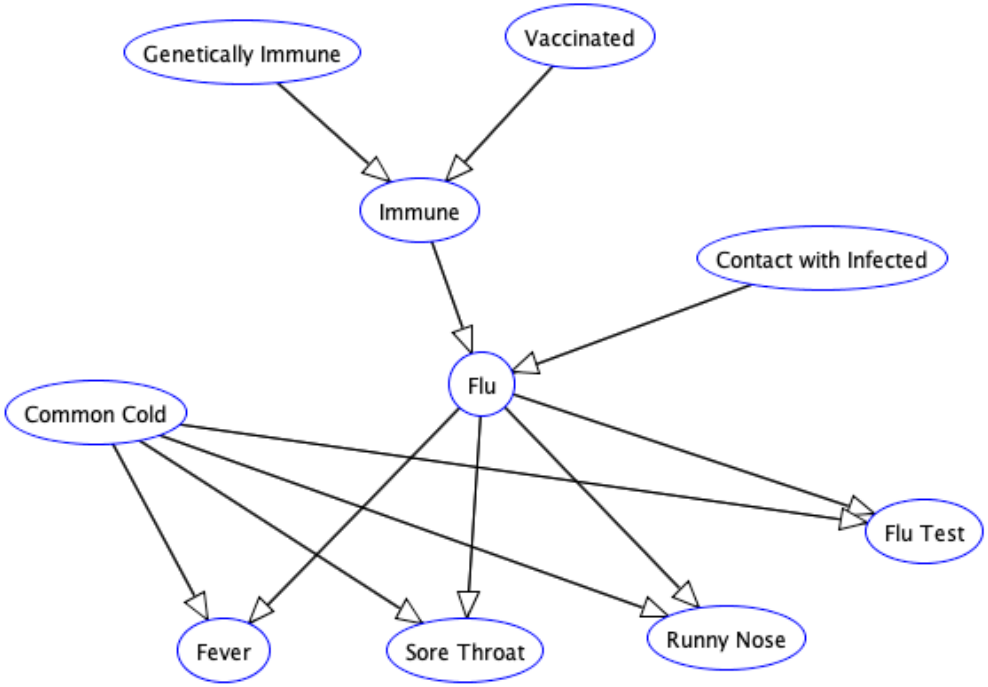
Generative (Causal) Modeling of Relationships between Variables

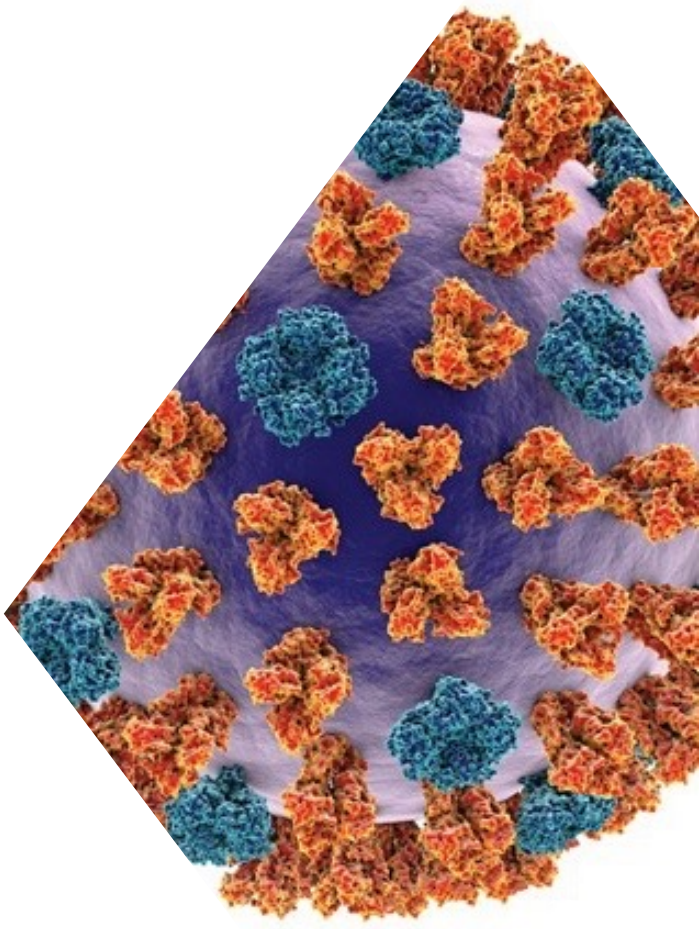
- A probabilistic approach.
- Capture the generative process to model the ***structure*** between variables and the ***conditional probabilities*** involved.

- Let's try this out.
- Belief and Decision Networks
  - http://www.aispace.org/downloads.shtml



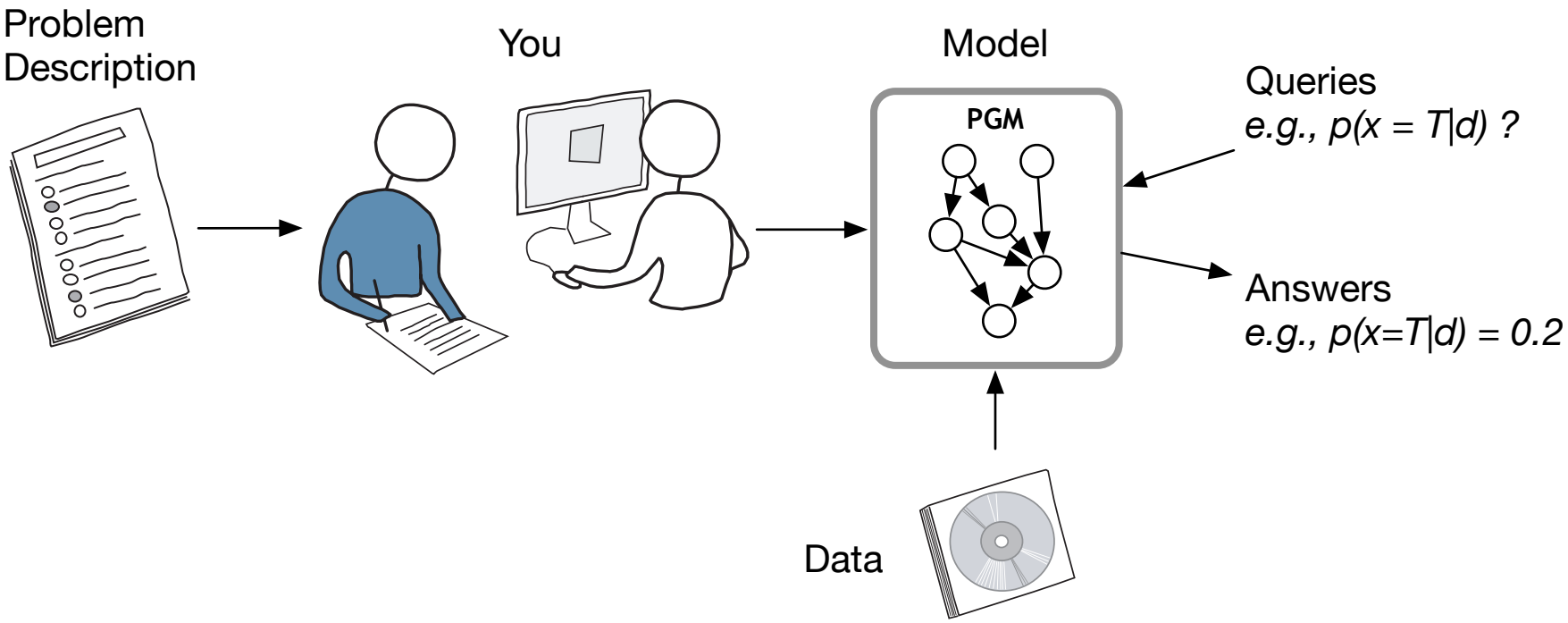
Generative (Causal) Modeling of Relationships between Variables





CS5340 in a nutshell

CS5340 is about how to "**represent**" and "**reason**" with uncertainty in a computer.



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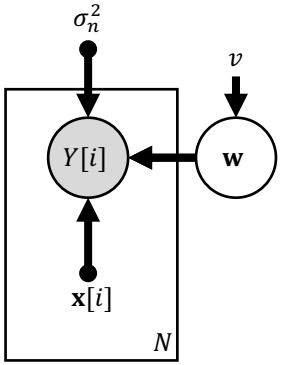
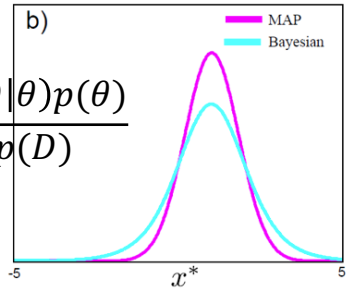


$$p(\theta|D) = \frac{p(D|\theta)p(\theta)}{p(D)}$$



Representation: The *language* is probability and probabilistic graphical models (PGM).

The language is used to model problems.

Reasoning: We use learning and inference algorithms to answer questions.

e.g., Belief-propagation/sum-product, MCMC, and variational Bayes

Types of Uncertainties

- **Aleatoric Uncertainty**
  - *Natural* randomness in the process
  - A parameter's value can change with each trial (the variability is random)
- **Epistemic Uncertainty**
  - Uncertainty in the *model*
  - A parameter takes on a certain value but we're not sure what that value is.

- **Exercise:** Consider the influenza diagnosis problem. What are the *aleatoric* and *epistemic* uncertainties present?

PGM: Applications

Robotics

Medical Diagnosis

Recommender Systems

Financial Modeling

Natural Language Processing

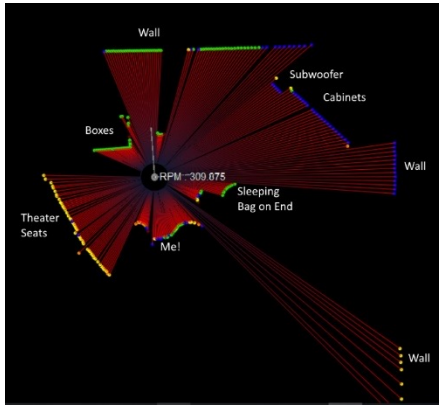
Computer Vision

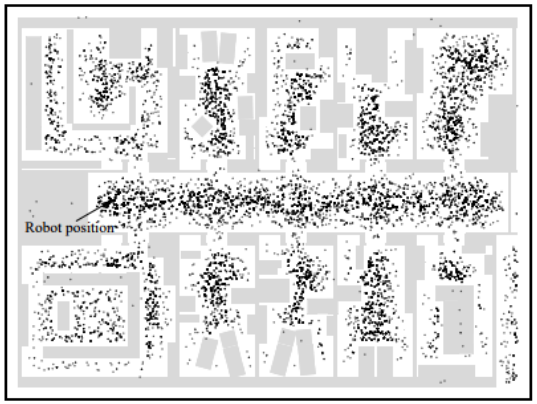
Generative Modelling

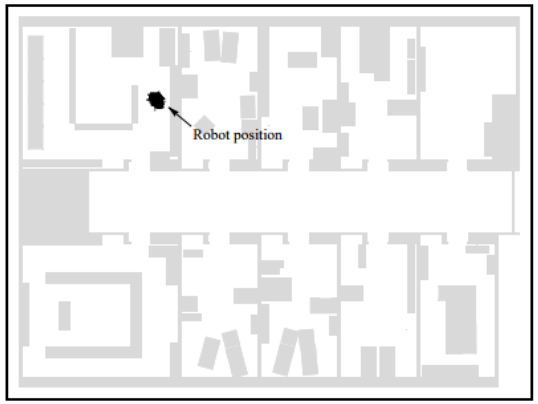
And many more!

Applications

Markov Localization







" Monte Carlo Localization for Mobile Robots", Frank Dellaert et. al., ICRA 1999

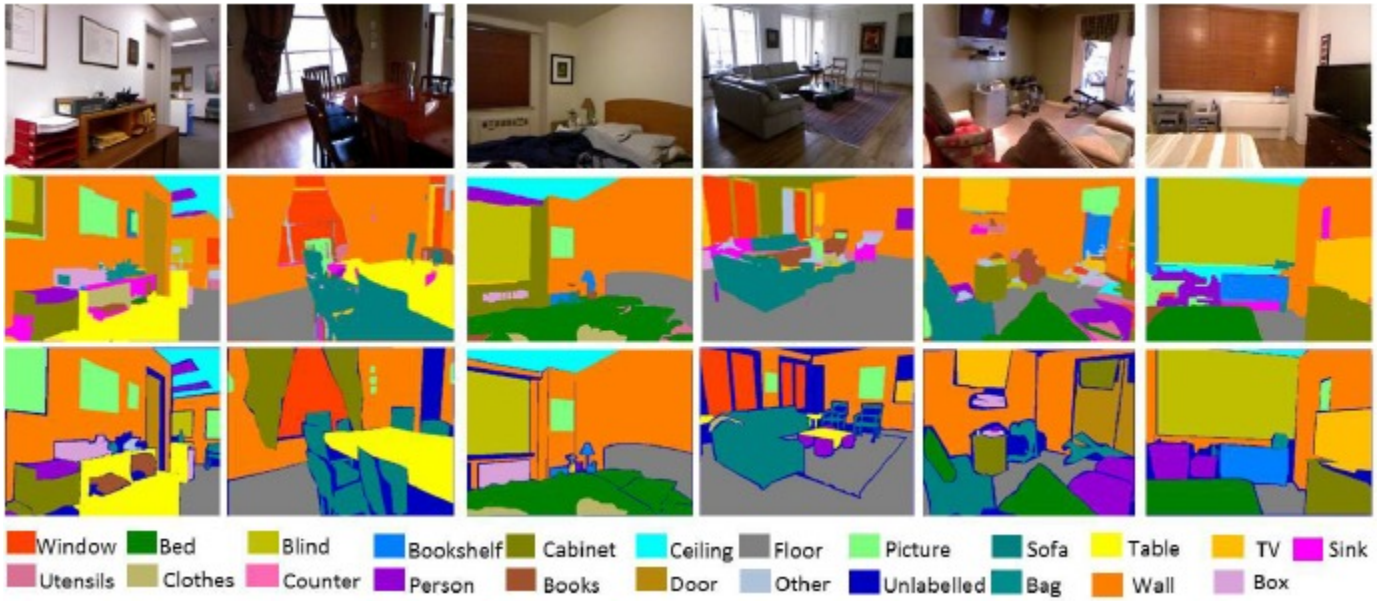
Applications

Markov Localization

https://www.youtube.com/watch?v=P8wLQz9mpjg

Applications

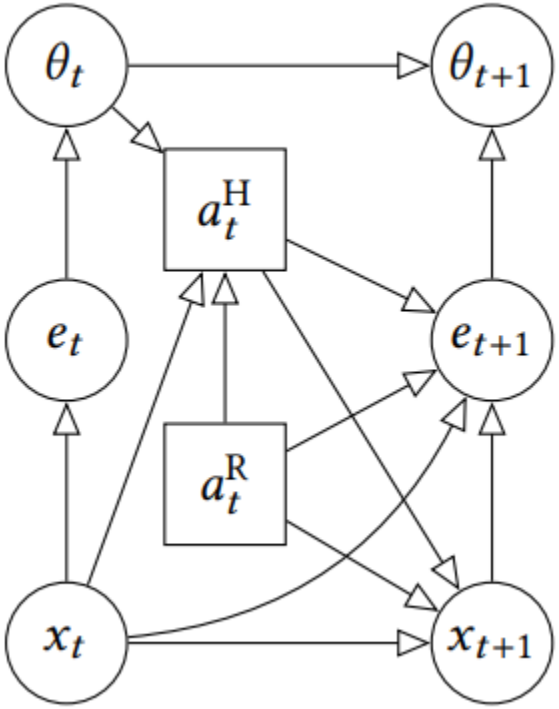
Scene Understanding



"Geometry Driven Semantic Labeling of Indoor Scenes", Salman Hameed Khan et. Al. ECCV 2014

Applications

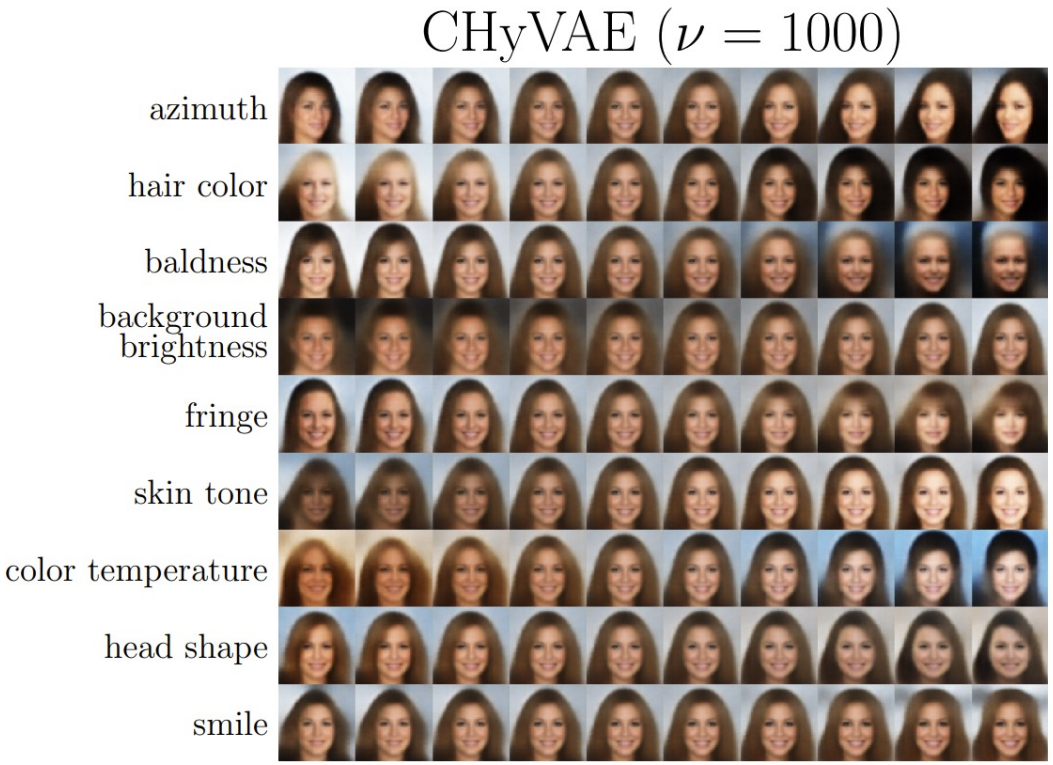
Human-Robot Collaboration



"Trust-Aware Decision Making for Human-Robot Collaboration: Model Learning and Planning", Chen et al., HRI 2018

Applications

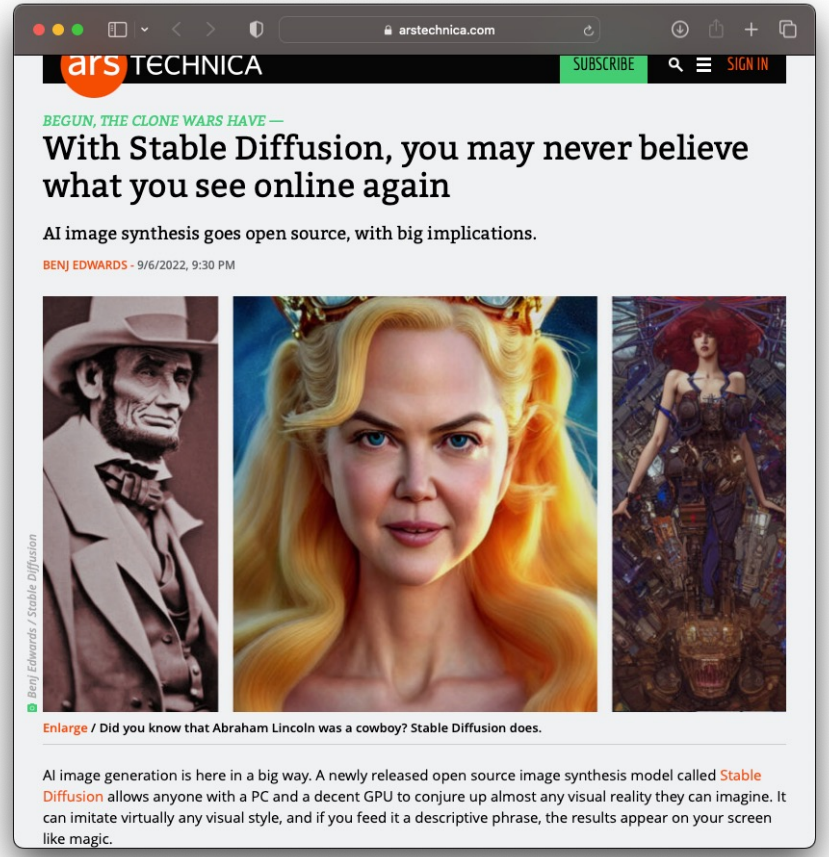
Generative Modeling



Ansari, Abdul Fatir, and Harold Soh. "Hyperprior induced unsupervised disentanglement of latent representations." *Proceedings of the AAAI Conference on Artificial Intelligence*. Vol. 33. 2019.

Applications

Generative Modeling via Diffusion Models



https://arstechnica.com/information-technology/2022/09/with-stable-diffusion-you-may-never-believe-what-you-see-online-again/

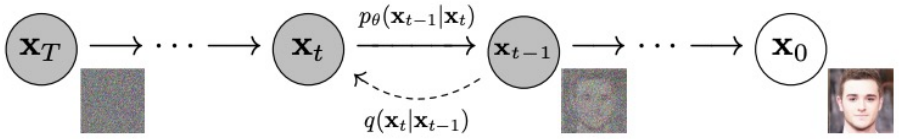
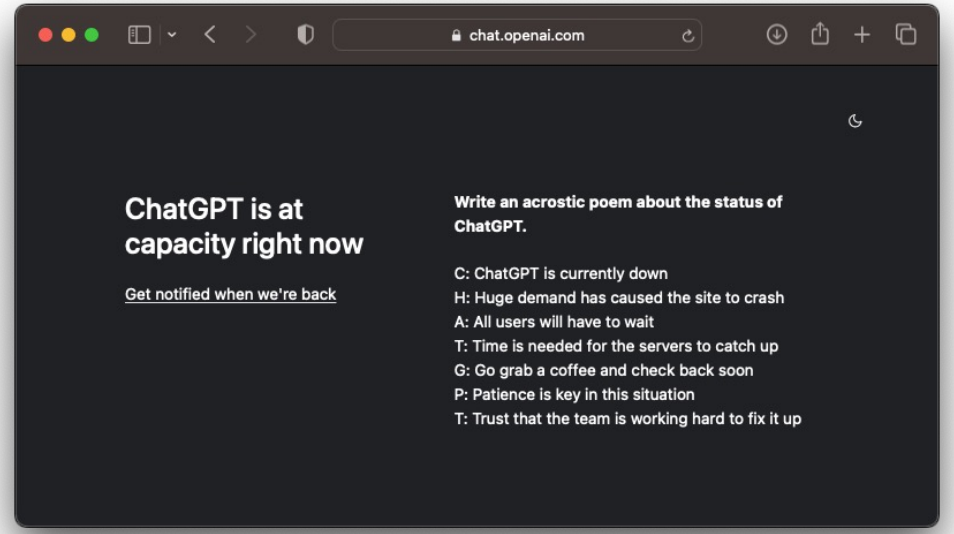


Figure 2: The directed graphical model considered in this work.

Ho, Jonathan, Ajay Jain, and Pieter Abbeel. "Denoising diffusion probabilistic models." *Advances in Neural Information Processing Systems* 33 (2020): 6840-6851.

Applications

- Language Modeling



2. Approach

At the core of our approach is language modeling. Language modeling is usually framed as unsupervised distribution estimation from a set of examples $(x_1, x_2, ..., x_n)$ each composed of variable length sequences of symbols $(s_1, s_2, ..., s_n)$. Since language has a natural sequential ordering, it is common to factorize the joint probabilities over symbols as the product of conditional probabilities (Jelinek & Mercer, 1980) (Bengio et al., 2003):

$$p(x) = \prod_{i=1}^{n} p(s_n|s_1, ..., s_{n-1}) \quad (1)$$

This approach allows for tractable sampling from and estimation of $p(x)$ as well as any conditionals of the form $p(s_{n-k}, ..., s_n|s_1, ..., s_{n-k-1})$. In recent years, there have been significant improvements in the expressiveness of models that can compute these conditional probabilities, such as self-attention architectures like the Transformer (Vaswani et al., 2017).

Radford, Alec, et al. "Language models are unsupervised multitask learners." *OpenAI blog* 1.8 (2019): 9.

CS5340 in a nutshell

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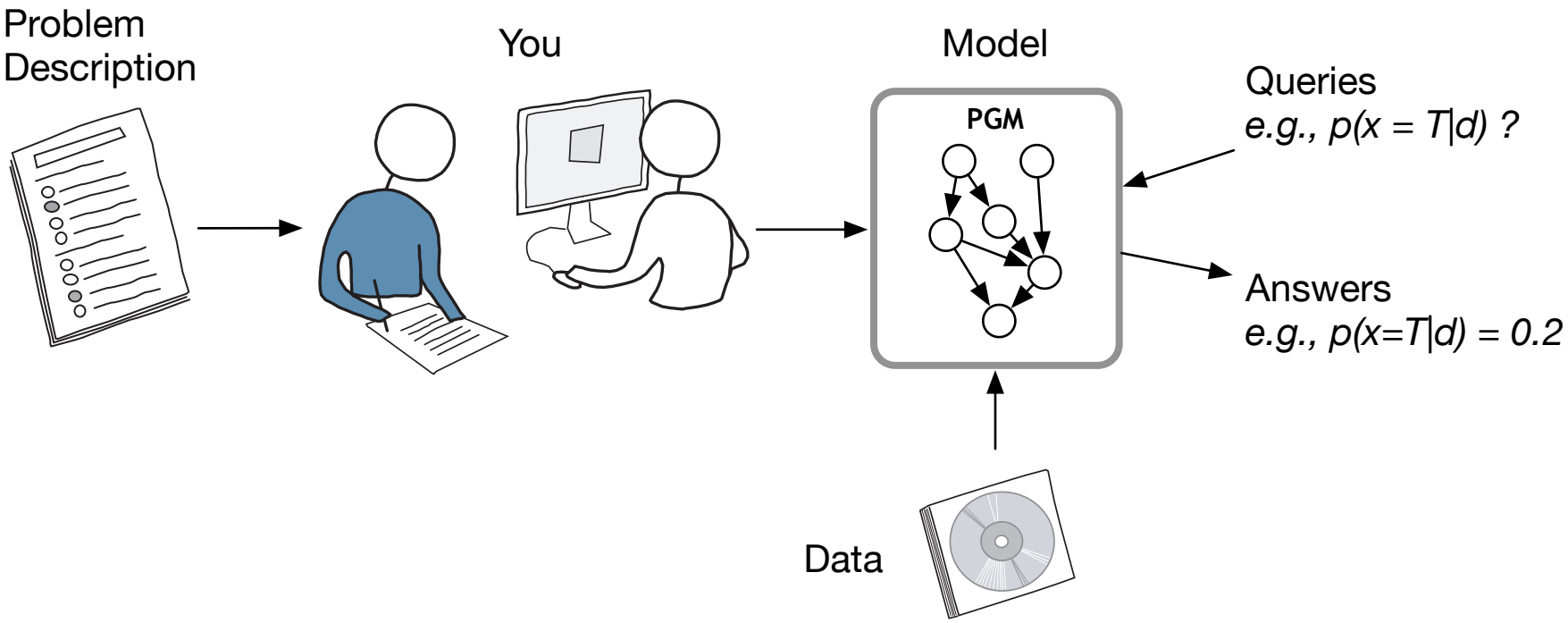

Questions?

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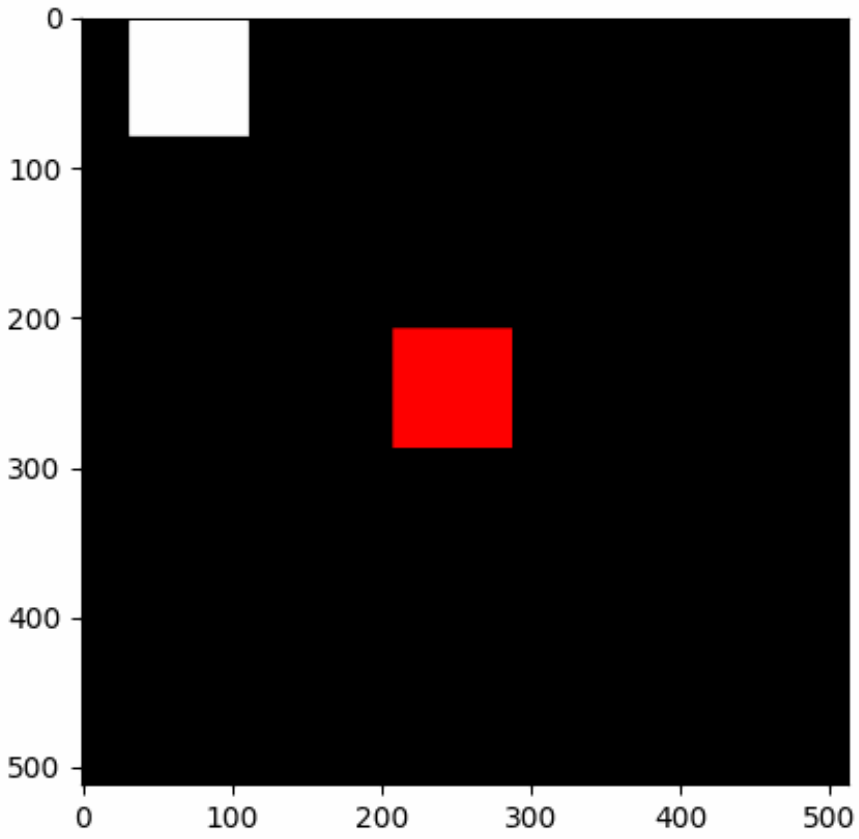
Course Administration

Course Info, Schedule, and Assessments

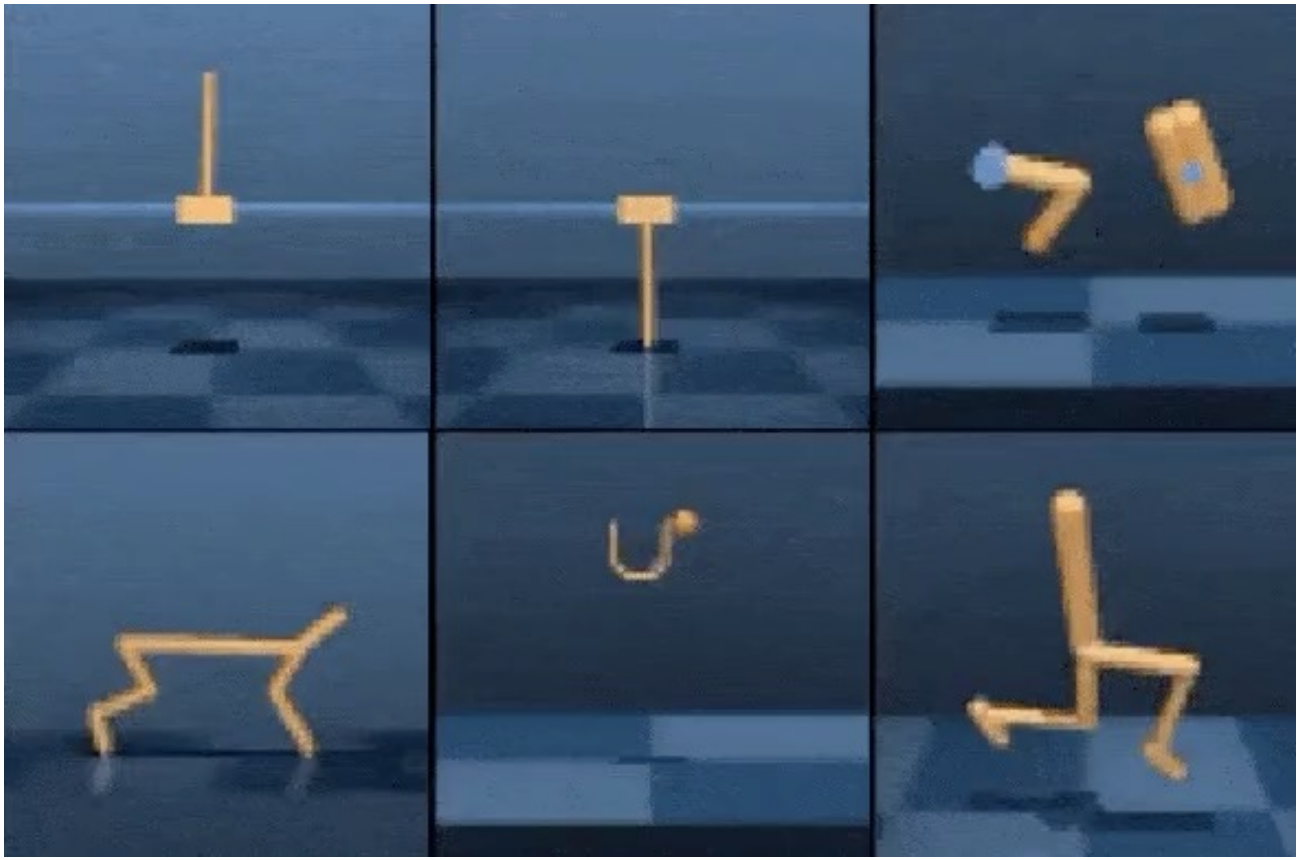
Course Schedule (Tentative)

Week	Date	Lecture Topic	Tutorial
1	16 Jan	Introduction to Uncertainty Modeling + Probability Basics	~~Introduction~~
2	23 Jan	Simple Probabilistic Models	Introduction and Probability Basics
3	30 Jan	Bayesian networks (Directed graphical models)	More Basic Probability
4	6 Feb	Markov random Fields (Undirected graphical models)	DGM modelling and d-separation
5	13 Feb	Variable elimination and belief propagation	MRF + Sum/Max Product
6	20 Feb	Factor graphs	**Quiz 1**
-	-	**RECESS WEEK**	
7	5 Mar	Mixture Models and Expectation Maximization (EM)	Linear Gaussian Models
8	12 Mar	Hidden Markov Models (HMM)	Probabilistic PCA
9	19 Mar	Monte-Carlo Inference (Sampling)	Linear Gaussian Dynamical Systems
10	26 Mar	Variational Inference	MCMC + Sequential VAE
11	2 Apr	Inference and Decision-Making	Diffusion Models
12	9 Apr	Gaussian Processes (Special Topic)	**Quiz 2**
13	16 Apr	Project Presentations	Closing Lecture

From Zero to Control via Pixels



From Zero to Control via Pixels



https://planetrl.github.io

Course Information

Lecture and Tutorials: Blended Classroom style

- **Lecture Videos Online:** Posted on Canvas (Panopto) every Wednesday
- Tutorial Questions: Posted on Canvas every Wednesday
- **Tutorial:** Tuesday 18:30 to 20:30(-ish) at LT18

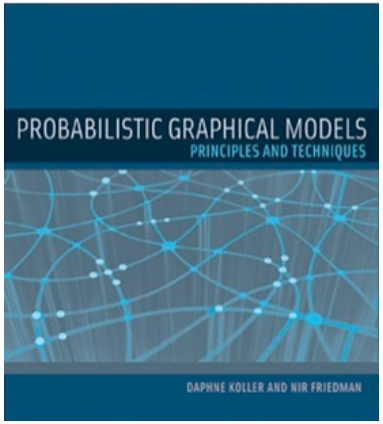
Prerequisites:

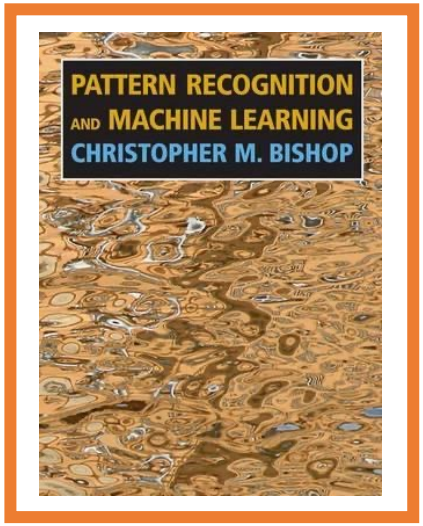
- A statistics/probability course: CS3243 and (EE2012/A or ST2132 or ST2334 or ((MA2216 or ST2131) and (ST1131/A or ST1232 or DSC2008)))
  - **Please note:** we will spend very little time on basic probability.
- CS3243/CS3263 Introduction to Artificial Intelligence

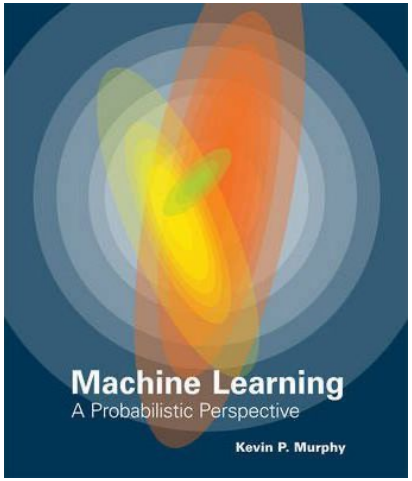
Drop Dates (Please verify):

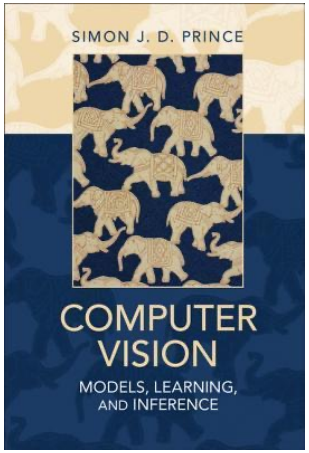
- **'W'** grade: **29 Jan 2024, 23:59hrs** onwards.
- **'F'** grade: **4 Mar 2024, 23:59hrs** onwards.

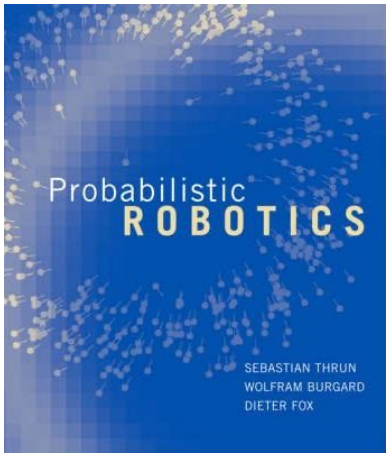
Recommended Readings (Not Compulsory)



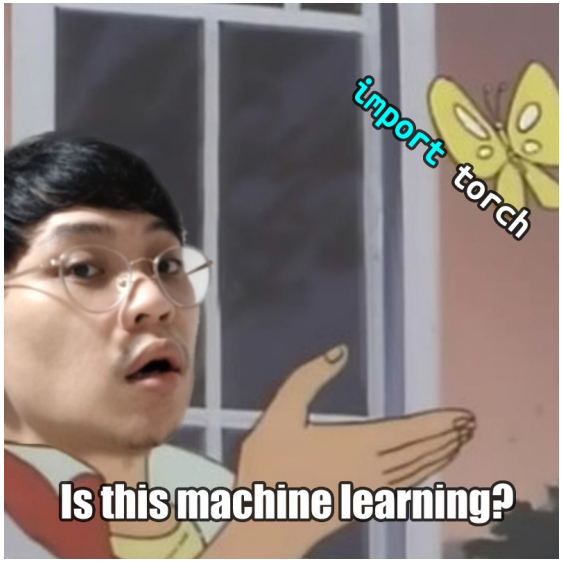








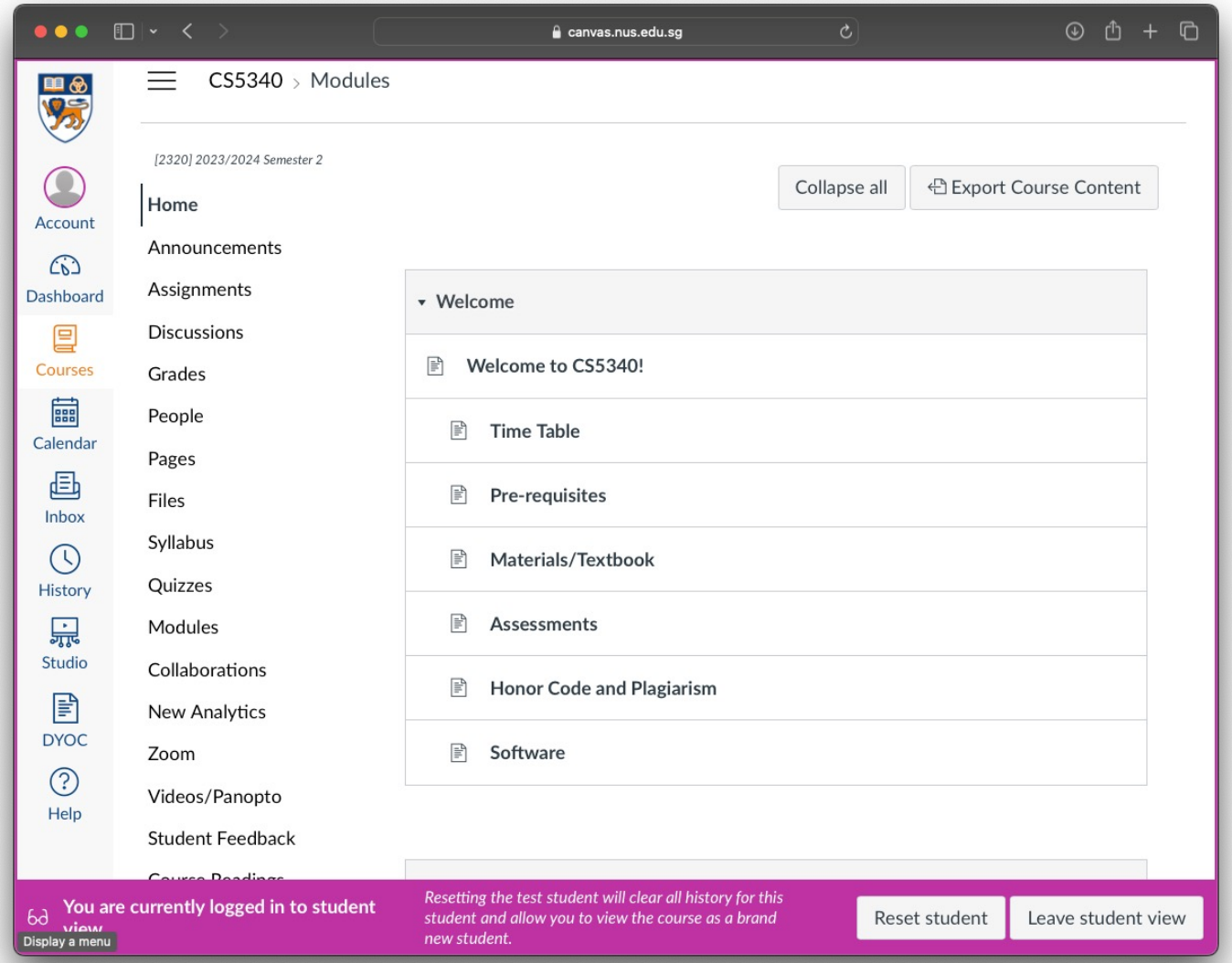
Teaching Assistant



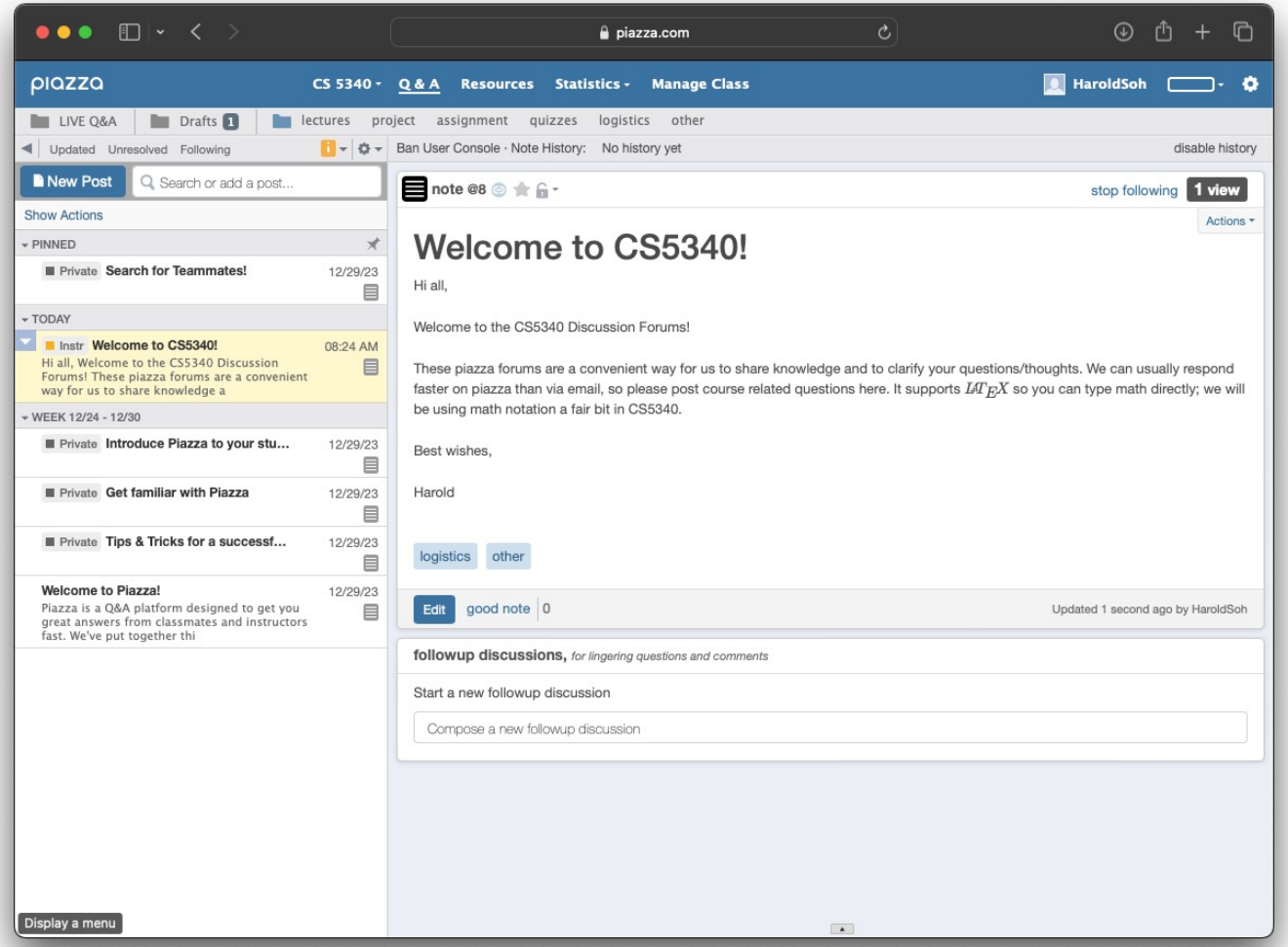
Eugene Lim
PhD. Candidate
Department of Computer Science
Email: elimwj@u.nus.edu

Research Interests: Multi-Armed Bandits, Generative Models, AI Theory.

Canvas


canvas.nus.edu.sg
CS5340 › Modules
[2320] 2023/2024 Semester 2
Account
Dashboard
Courses
Calendar
Inbox
History
Studio
DYOC
Help
Home
Announcements
Assignments
Discussions
Grades
People
Pages
Files
Syllabus
Quizzes
Modules
Collaborations
New Analytics
Zoom
Videos/Panopto
Student Feedback
Collapse all
Export Course Content
Welcome
Welcome to CS5340!
Time Table
Pre-requisites
Materials/Textbook
Assessments
Honor Code and Plagiarism
Software
You are currently logged in to student view
Display a menu
Resetting the test student will clear all history for this student and allow you to view the course as a brand new student.
Reset student
Leave student view

Piazza Discussion Forums



Assessments

- **No** Final Exam ☺
- **Team Project:** 30%
- **Quizzes:** 40%
- **Tutorials:** 20%
- **Participation:** 10%
  - Forum Participation

Project (30%)

- **Team-based**
- 4 to 5 people per team
- Key Dates:
  - Form Teams: **6 Feb**
  - Abstract Due: **27 Feb**
  - Presentations: **16 April**
  - Report Due: **26 April**
- Deliverables:
  - Abstract
    - NeurIPS LaTeX Template
    - Up to 4 pages excl. references
  - Technical report
    - NeurIPS LaTeX Template
    - Up to 8 pages excl. references
  - 5-10 mins Presentation

Example Past Projects

- **Computer Vision / Image Processing**
  - Techniques for Image Denoising
  - Image Background Generation with VAEs and MRFs
- **Financial / Economic / Political Modeling**
  - Uncertainty Distribution of Sales
  - Modeling Political Behaviors with PGMs
  - Portfolio Risk and Return
- **Robotics Prediction / Control**
  - Robust Deep Reinforcement Learning
  - Drone Trajectory Estimation with HMMs
- **Natural Language Processing**
  - Repairing Multilingual Subtitles with Deep Markov Models
- **Infectious Disease Modeling/Diagnosis**
  - Uncertainty in Patient Diagnosis
  - Modeling the Mortality Risk of COVID-19
  - Modeling COVID-19 Spread

More Project Ideas

- Robot Social Navigation
  - Human Crowd Perception and Modeling
  - Human Perception using Multi-modal sensors (mmWave, Wifi)
  - Diffusion-based Generation of New Test/Adversarial Environments.
- Imitation Learning
  - Generative-style imitation learning
  - Incorporating norms into generative imitation learning.
- Uncertainty in LLMs
  - Incorporating uncertainty estimation into LLMs.

Project Abstract

- **Introduction**
  - What is the problem you want to solve?
  - Why do you want to solve it?
  - Why is it important/interesting?
- **Related Work**
  - What other work has been done in this area?
- **Approach/Methodology**
  - How do you propose to solve it?
  - Why do you want to solve it this way?
- **Preliminary Results** (if any)
  - What have you done so far?
- **Ethical/Social Impact Statement**
  - What ethical/social impact would this project have (if any)?
- **AI Tool Use**
  - If you used AI Tools (e.g., LLMs), discuss how they were used.

- **Note:** Support your statements with evidence (references and/or results)

Quizzes

- **Quiz 1: 20%**
  - **20 Feb 2024**
  - Covers all material up to Week 5 (Variable Elimination and Belief Propagation)
- **Quiz 2: 20%**
  - **9 Apr 2024**
  - Covers all material up to Week 10 (Variational Inference)
- **Rules:**
  - Open book.
  - No electronic equipment

Academic Honesty

- Do ***NOT*** cheat
- **Strict** Plagiarism policy:
  - If you cheat, we will report you to the disciplinary board
  - If found guilty, you will get an F (University Policy)
- Please be **academically honest**.
  - *"Give credit where credit is due"*
- AI Tools (e.g., LLMs)
  - **Write your own reports/abstracts**.
  - Using LLMs:
    - as enhanced editors to correct grammar/spelling is OK.
    - as intermediate tools to discuss and brainstorm with is OK.
    - If you use LLMs: At the end of your report/abstract, you **MUST** add a section on "AI Tool Use".

Tutorials

- Every Tuesday from 6:30pm to 8:30pm
- Graded Questions on Canvas “Quiz” Platform
- Each tutorial is worth 2.5% of your grade.
- Best 8 out of 10 tutorials to calculate your final score.
- **IMPORTANT:** The tutorial “quiz” is only open from 6:30pm to 9:30pm. No late entries will be allowed.
- We’re going to do one today!

Course Schedule (Tentative)

Week	Date	Lecture Topic	Tutorial
1	16 Jan	Introduction to Uncertainty Modeling + Probability Basics	~~Introduction~~
2	23 Jan	Simple Probabilistic Models	Introduction and Probability Basics
3	30 Jan	Bayesian networks (Directed graphical models)	More Basic Probability
4	6 Feb	Markov random Fields (Undirected graphical models)	DGM modelling and d-separation
5	13 Feb	Variable elimination and belief propagation	MRF + Sum/Max Product
6	20 Feb	Factor graphs	**Quiz 1**
-	-	**RECESS WEEK**	
7	5 Mar	Mixture Models and Expectation Maximization (EM)	Linear Gaussian Models
8	12 Mar	Hidden Markov Models (HMM)	Probabilistic PCA
9	19 Mar	Monte-Carlo Inference (Sampling)	Linear Gaussian Dynamical Systems
10	26 Mar	Variational Inference	MCMC + Sequential VAE
11	2 Apr	Inference and Decision-Making	Diffusion Models
12	9 Apr	Gaussian Processes (Special Topic)	**Quiz 2**
13	16 Apr	Project Presentations	Closing Lecture

Questions?

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