NUS National University of Singapore | School of Computing

CS5340
Uncertainty Modeling in AI

Asst. Prof. Lee Gim Hee

AY 2020/21

Semester 1

Course Information

Lecturer:

Dr. Lee Gim Hee

Department of Computer Science

Office: COM2-03-54

Email: gimhee.lee@comp.nus.edu.sg

Class Schedule: Every Wednesday, 1830hrs – 2130hrs

Teaching Modes:

1. Pre-recorded video lectures; and
2. Occasional discussions on Microsoft Teams

Teaching Assistants

Yew Zi Jian
Department of Computer Science
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Lab: AS6-05-02

Kennard Ng
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Lab: AS6-05-02

Mode of Assessments

- This grades of this module is based on **100% CA**:

1. 4x coding assignments (15% each; individual work)

2. 20% mid-term quiz + 20% final quiz (conducted online, open-book)

Logistics: Assignments

- We will use Python as the programming language for the assignments.
- Nonetheless, you can use any programming language of your choice.
- But the helper functions and our support will be given only in Python.
- Ask my TAs on all questions regarding the assignments.

Assignment Late Policy

- All assignments are due at 2359hrs of the dates specified on the module schedule.
- 25% of the total marks will be deducted for each day of late submission.
- Deduction of marks does not apply to the late submissions with valid reasons. Please email me your reasons to seek for approval.

Logistics: Online Quizzes

- Quizzes are conducted online at a fixed date and time (see schedule for the dates).
- Please arrange your schedule, NO make-up quiz is possible. Alternative arrangements can be made be valid reasons.
- **Format (more details later):**

1. Questions are released at the start of the quiz
2. Write your answers on self-provided papers
3. Take photos of your solutions and upload them into Luminus

Honor Code

- **Assignments:** You may discuss and/or refer to online references, but plagiarism is strictly not allowed.
- **Online quizzes:** Discussions with anyone and copying of solutions are strictly not allowed.
- **Violation of rules:** Zero will be given, and disciplinary actions that could lead to your expulsion from NUS will be taken!

Tutorials

- No formal tutorials.

- Two sets of exercise questions and solutions will be provided.

- I will go through some of the solutions during the discussion sessions on request.

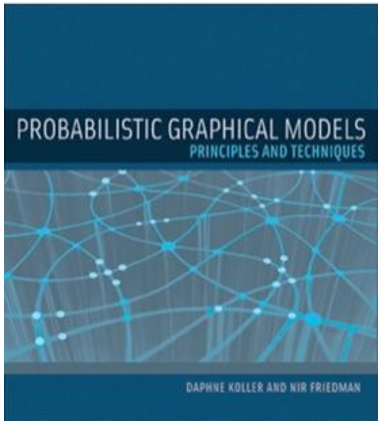
Consultations

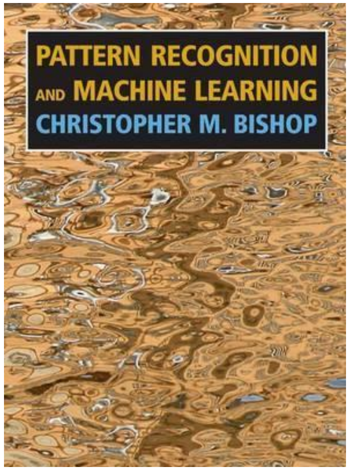
- Please send all questions to me **via email**.
- To make sure your email gets my attention, use "[CS5340] xxx" as the title of your email.
- If necessary, we can arrange for online consultation sessions too.
- But I would prefer you to email me your questions, so that I can also share your doubts with the class during the online sessions via MS Teams.

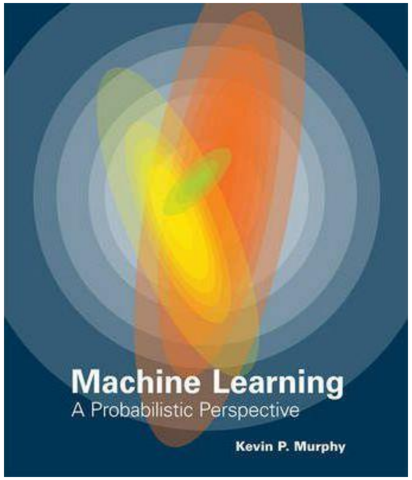
Course Schedule

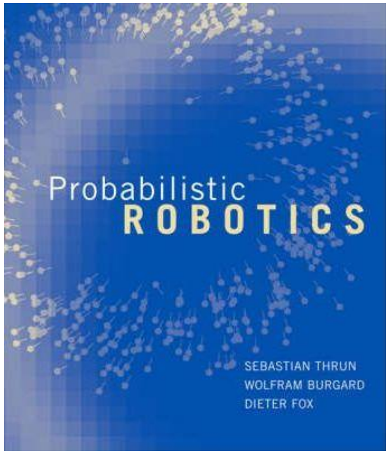
Week	Date	Topic	Remarks
1	12 Aug	Introduction to probabilistic reasoning	**1830hrs: MS Teams (Live Introduction)**
2	19 Aug	Bayesian networks (Directed graphical models)	
3	26 Aug	Markov random Fields (Undirected graphical models)	**1830hrs: MS Teams discussions**
4	02 Sep	Variable elimination and belief propagation	**Assignment 1:** Belief propagation and maximal probability (15%)
5	09 Sep	Factor graph and the junction tree algorithm	
6	16 Sep	Parameter learning with complete data	**Assignment 1:** Due **Assignment 2:** Junction tree and parameter learning (15%) **1830hrs: MS Teams discussions**
-	23 Sep	Recess week	**No lecture**
7	30 Sep	Mixture models and the EM algorithm	**Assignment 2:** Due **Online quiz 1 (20%)**
8	07 Oct	Hidden Markov Models (HMM)	**Assignment 3:** Hidden Markov model (15%)
9	14 Oct	Monte Carlo inference (Sampling)	**1830hrs: MS Teams discussions**
10	21 Oct	Variational inference	**Assignment 3:** Due **Assignment 4:** MCMC Sampling (15%)
11	28 Oct	Variational Auto-Encoder and Mixture Density Networks	
12	04 Nov	Graph-cut and alpha expansion	**Assignment 4:** Due **1830hrs: MS Teams discussions**
-	11 Nov	--	**Online quiz 2 (20%)**

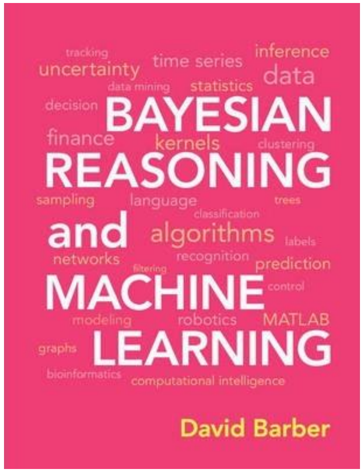
Recommended Readings (Not Compulsory)











Probabilistic Graphical Modeling

One of the most exciting advances in machine learning (AI, signal processing, coding, control, robotics, computer vision . . .) in the last decades.

Adapted from: “Probabilistic Graphical Modeling” Lectures NYU, David Sontag

Probabilistic Graphical Modeling

before deep learning

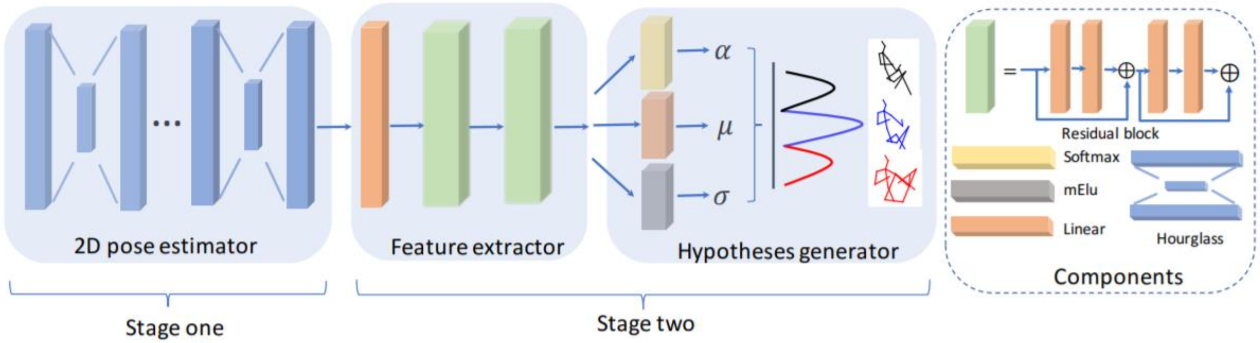
One of the most exciting advances in machine learning (AI, signal processing, coding, control, robotics, computer vision . . .) in the last decades.

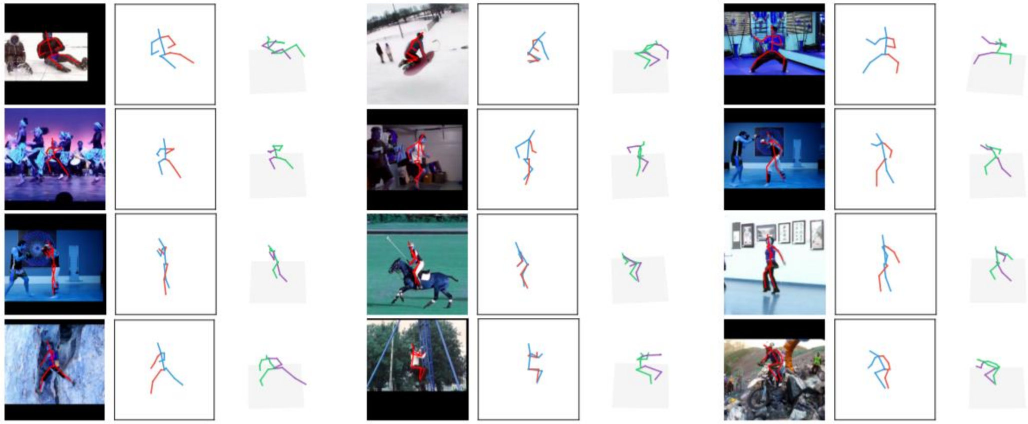
Knowledge on PGM helps formulate some of the most important deep networks, e.g., deep generative models (Lecture 11) !

Adapted from: “Probabilistic Graphical Modeling” Lectures NYU, David Sontag

PGM in Deep Learning

Example: Mixture density network for 3D human pose estimation





$$p(\mathbf{y} \mid \mathbf{x}, \mathbf{w}) = \sum_{i=1}^{M} \alpha_i(\mathbf{x}, \mathbf{w}) \phi_i(\mathbf{y} \mid \mathbf{x}, \mathbf{w}),$$

$$\phi_i(\mathbf{y} \mid \mathbf{x}, \mathbf{w}) = \frac{1}{(2\pi)^{d/2} \sigma_i(\mathbf{x}, \mathbf{w})^d} \exp - \frac{\|\mathbf{y} - \mu_i(\mathbf{x}, \mathbf{w})\|^2}{2\sigma_i(\mathbf{x}, \mathbf{w})^2}.$$

Chen Li, Gim Hee Lee, **Generating Multiple Hypotheses for 3D Human Pose Estimation with Mixture Density Network**, CVPR 2019

Probabilistic Graphical Modeling

How can we gain global insight based on local observations?

Adapted from: "Probabilistic Graphical Modeling" Lectures NYU, David Sontag

Probabilistic Graphical Modeling

How can we gain global insight based on local observations?

Example:

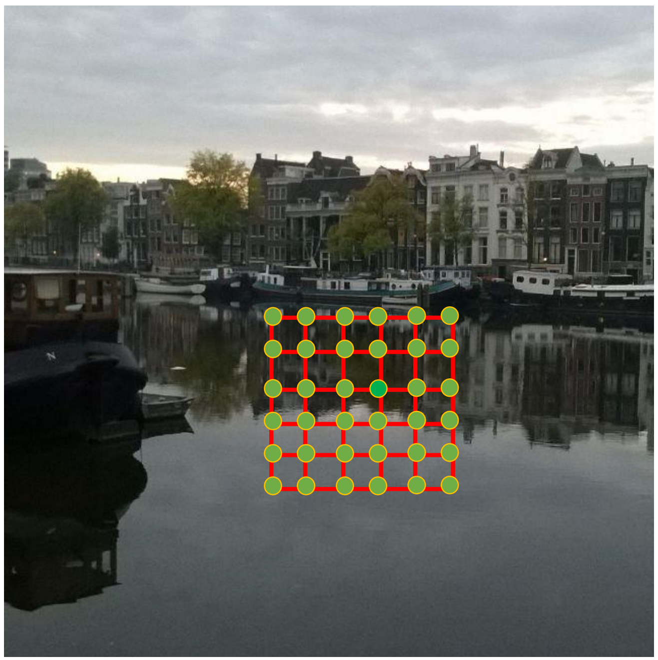


Photo Source:
G.H. Lee “Amsterdam”

Given: Local observations

- Each node takes 1-of-K labels and
- a smoothness prior, i.e, neighboring nodes linked by an edge should take the same label

We can find the label assignment of each pixel that is globally consistent!

Probabilistic Graphical Modeling

Key Ideas:

- Represent the world as a collection of random variables $X_1, \dots, X_N$ with joint distribution $p(X_1, \dots, X_N)$.
- Learn the distribution from data.
- Perform "inference" (compute conditional distributions $p(X_i \mid X_1 = x_1, \dots, X_N = x_N)$).

Adapted from: "Probabilistic Graphical Modeling" Lectures NYU, David Sontag

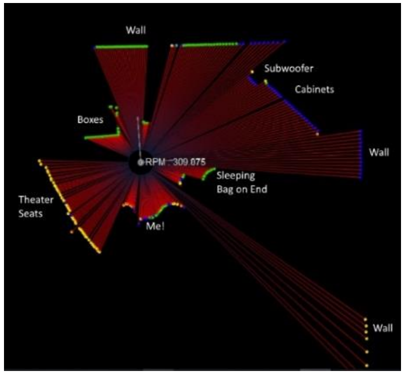
Reasoning Under Uncertainty

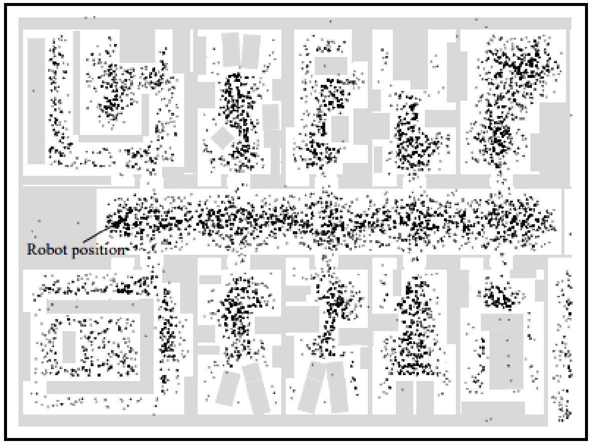
- As humans, we are continuously making predictions under uncertainty.
- Classical AI and ML research ignored this phenomena.
- Many of the ~~most recent~~ advances in technology are possible because of this probabilistic approach.

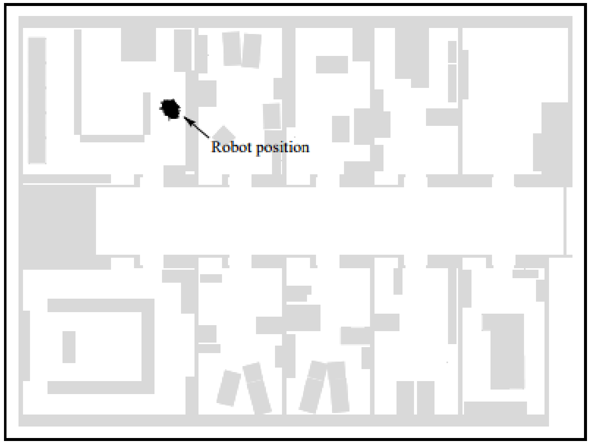
Adapted from: "Probabilistic Graphical Modeling" Lectures NYU, David Sontag

PGM: Applications

Markov Localization





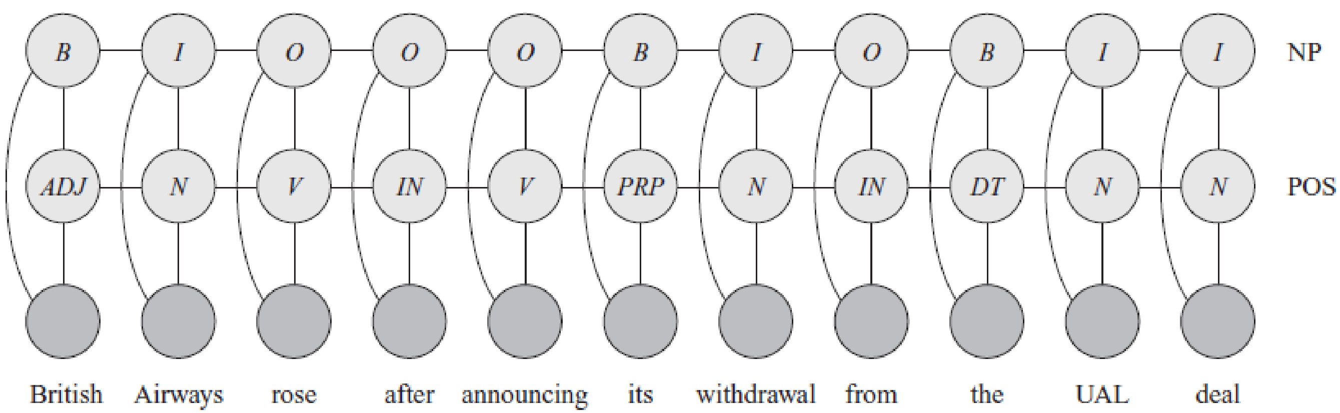


" Monte Carlo Localization for Mobile Robots", Frank Dellaert et. al., ICRA 1999

PGM: Applications

Part of Speech Tagging

A. Big hungry **bears** are coming.
B. Your friend **bears** gifts.



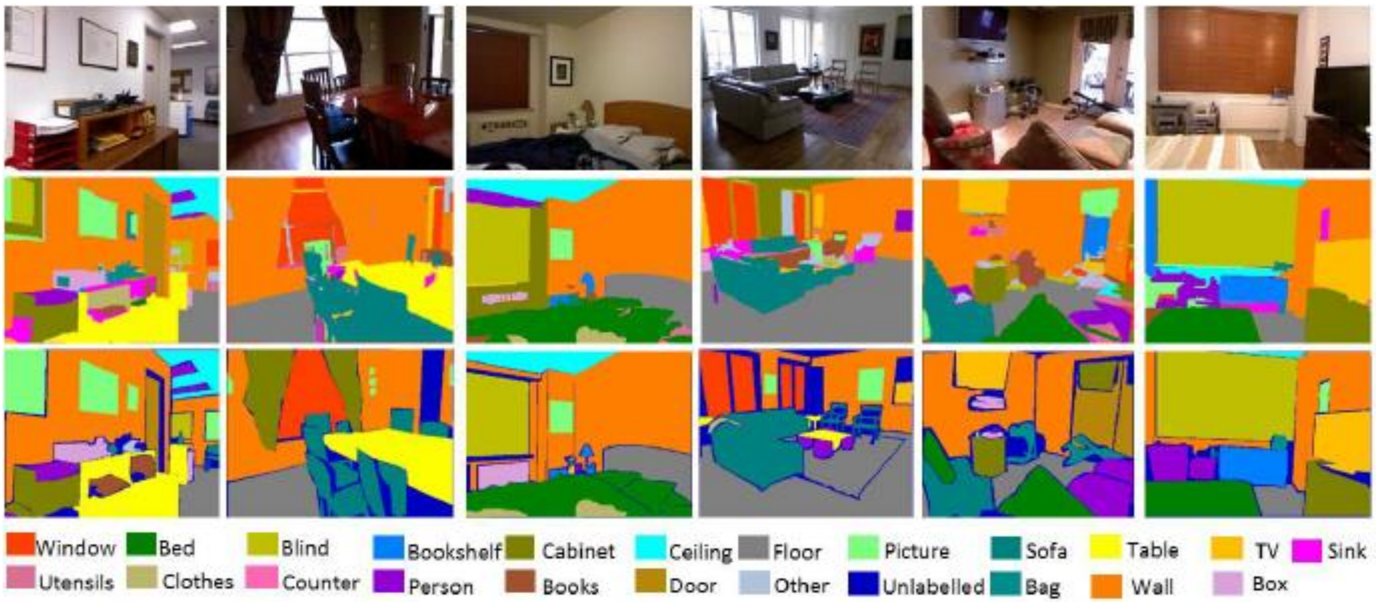
KEY

B	Begin noun phrase	*V*	Verb
I	Within noun phrase	*IN*	Preposition
O	Not a noun phrase	*PRP*	Possesive pronoun
N	Noun	*DT*	Determiner (e.g., a, an, the)
ADJ	Adjective		

D. Koller et. al. 2009

PGM: Applications

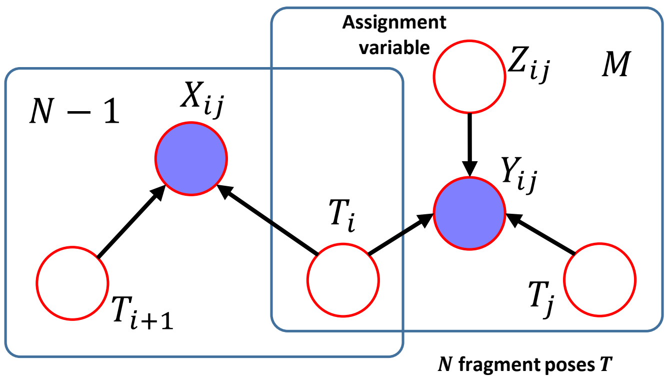
Scene Understanding

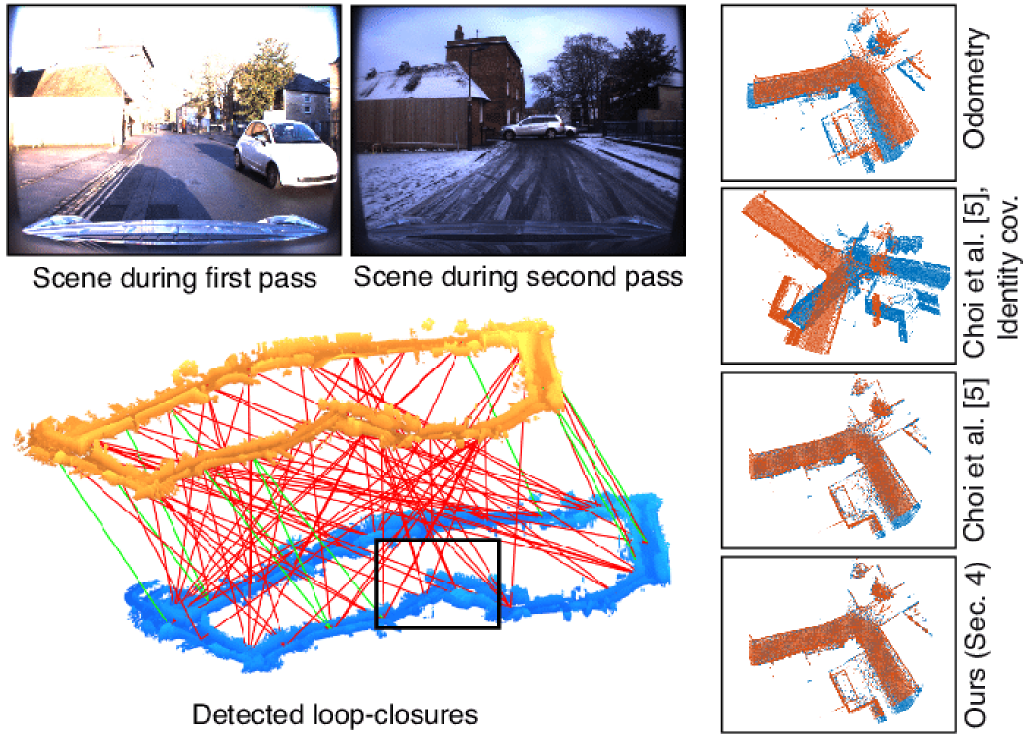


“Geometry Driven Semantic Labeling of Indoor Scenes”, Salman Hameed Khan et. Al. ECCV 2014

PGM: Applications

Robust 3D Reconstruction





Ziquan Lan, Zi Jian Yew, Gim Hee Lee, “Robust Point Cloud Based Reconstruction of Large-Scale Outdoor Scenes”, CVPR 2019