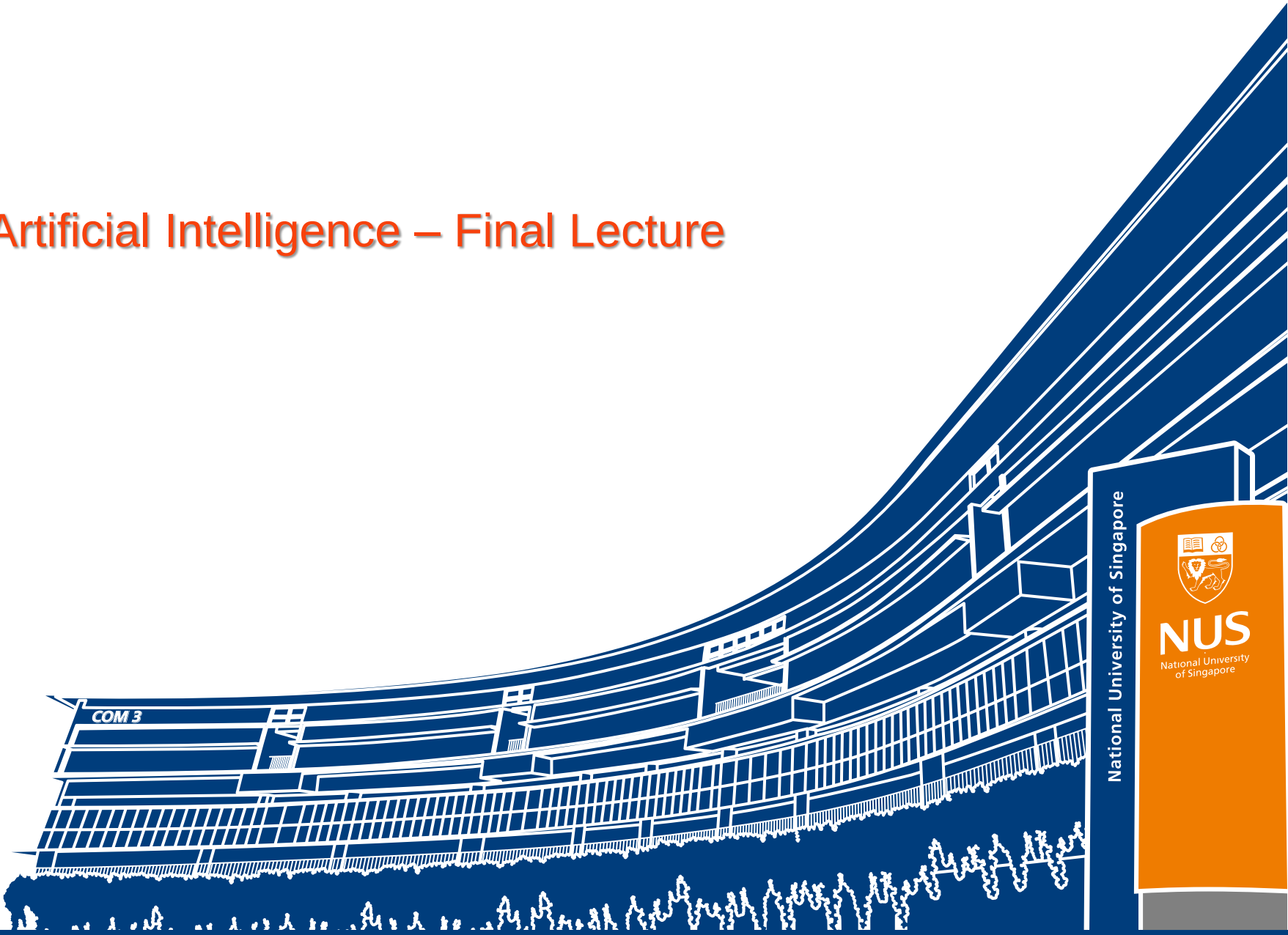
Course Review

CS3243: Introduction to Artificial Intelligence – Final Lecture



NUS | Computing
National University of Singapore

Contents

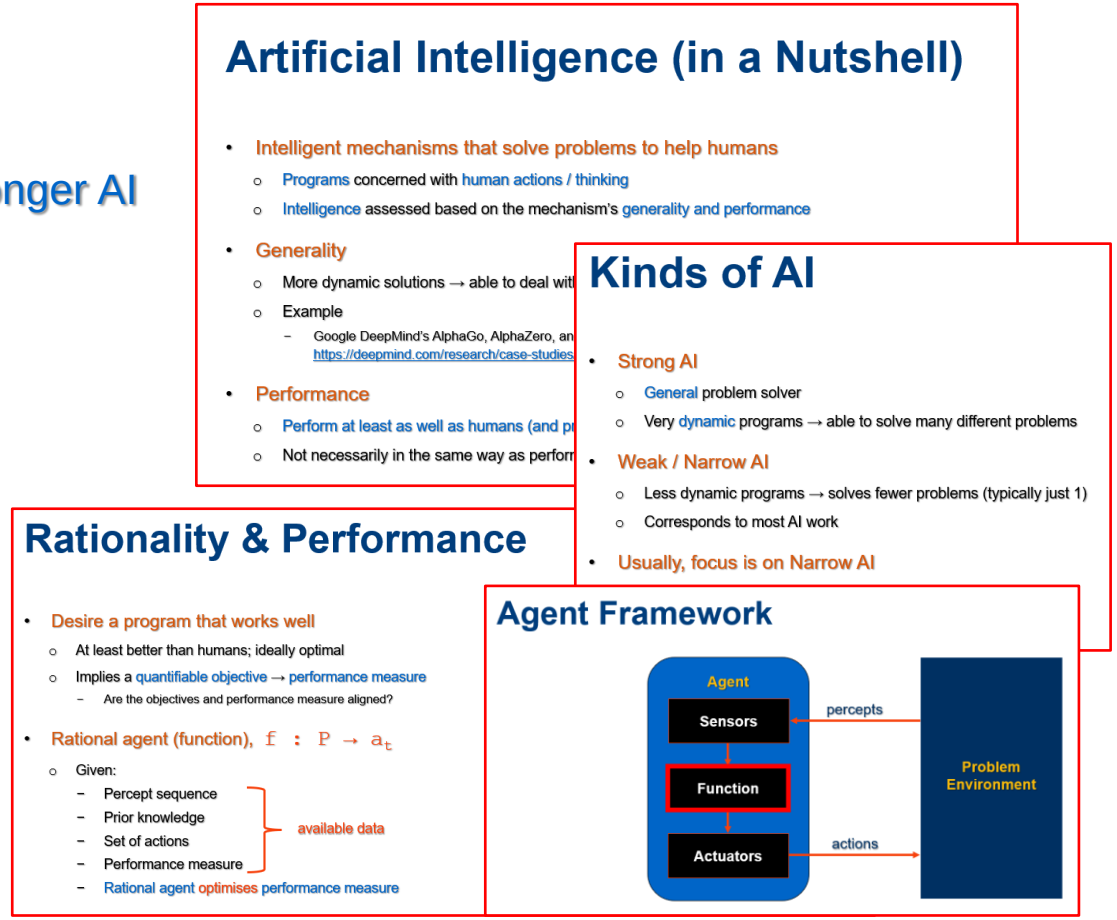
- Course Summary
- Assessment Report
- Administrative Matters

1 Summary of CS3243

AI as Problem Solving

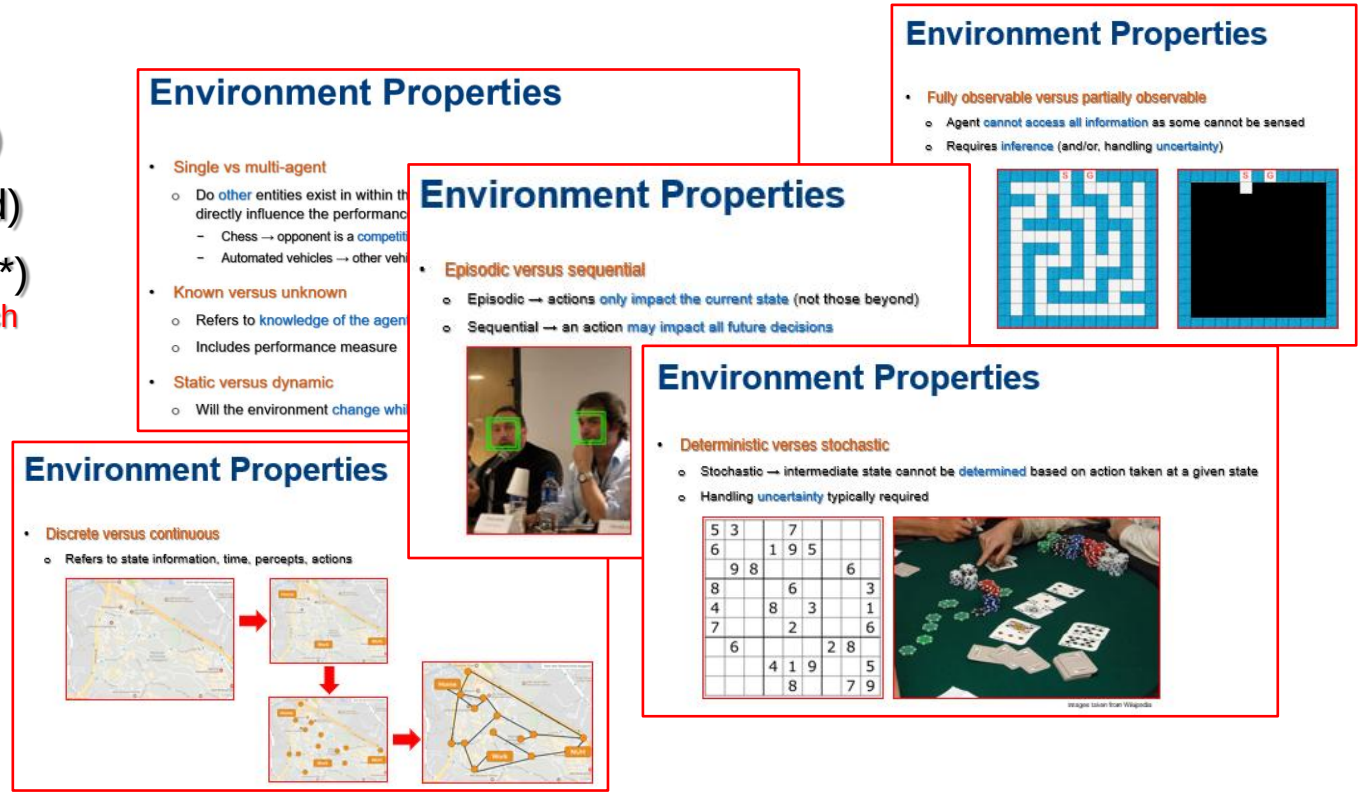
- Developing Intelligent Agents
  - Mechanisms that solve problems
  - More generically applicable → more intelligent - i.e., stronger AI
- Desire to construct rational agents
  - Optimal performance given:
    - Available information (data)
    - Performance measure (metrics)
- CS3243: Studying Symbolic AI
  - Solutions inspired by the way we (humans) do things
    - Planning
    - Reasoning
    - Learning (over Uncertainty)

  See: https://en.wikipedia.org/wiki/Symbolic_artificial_intelligence



Decomposition with Problem Environments

- Taxonomy of Problems → Problem Environment Properties
  - Fully Observable or Partially Observable
  - Deterministic or Stochastic
  - Episodic or Sequential (assume sequential)
  - Discrete or Continuous (assume discretised)
  - Single Agent or Multi-Agent (assume single*)
    * except for one competing agent under Adversarial Search
  - Known or Unknown (assume known)
  - Static or Dynamic (assume static)



Planning Topics

- Assuming complete information → Path Planning or Goal Search
  - Fully Observable and Deterministic

  1. Model problem environment as a graph and solve by finding goal path/state
     - Uninformed Search – e.g., BFS, DFS, DLS, IDS, UCS (i.e., Dijkstra's)
     - Informed Search – e.g., best-first greedy search, A* search
     - Local Search – e.g., hill-climbing
  2. Model problem environment as a constraint problem and solve by finding goal state
     - Constraint Satisfaction Problems – e.g., backtracking CSP

- Including an opposing agent → Adversarial Search
  - Fully Observable, Deterministic, and Multi-agent (i.e., one competing agent)

  3. Model problem environment as a game tree and solve by finding strategy with optimal utility
     - Adversarial Search – e.g., Minimax, α-B Pruning

Reasoning & Learning Topics

- Assuming incomplete information → Reasoning via Inference
  - Partially Observable and Deterministic

  1. Model problem environment as a knowledge base, then use inference engine to solve by finding goal path or path with optimal utility
     - Logical Agent is non-planning – i.e., directly interacting with problem-environment
     - Inference Algorithms – e.g., Truth Table Enumeration, Resolution
       Note: inference algorithms may be applied in any agent to prove things

- Assuming stochastic problem → Uncertainty handled via Bayesian Network
  - Stochastic (with Fully or Partially Observable)

  3. Model stochastic components via Bayesian Networks
     - Decision-Theoretic Agent makes decisions by optimising expected utility
     - Bayesian Algorithms - e.g., Naive Bayes, Bayesian Network
       - Note: Bayesian reasoning is categorised with Symbolic Machine Learning to handle uncertainty

Summarising the Key Ideas

Generalising Problems & Rational Agents

- Standardised problem modelling (graphs of states and actions) and design of agents
- Strive for rational agents – optimise performance based on data/info (knowledge)

Generally, assume:
Known and Static Environments

Definition of Basic Problem Paradigms

- Path planning problems (Informed & Uninformed)
- Goal composition (Local & CSPs)
- Game-playing strategies (Adversarial)

Additionally, assume:
Full Observable, Deterministic, and Discrete Environments

Note: Adversarial Search is the only topic with a Multi-Agent Environment

Dealing with Large Search Trees

- Heuristics – quantifying better actions
- Pruning – eliminating sub-trees we know we don't need (CSP Inference, α-β Pruning)

Dealing with Partial Information

- Building a KB (Logic)
- Growing a KB by making inferences (Truth-Table Enumeration, Resolution)

Assuming:
Partially Observable Environments

Dealing with Uncertainty

- Making inferences on likelihood in the face of uncertainty (Bayesian Networks)

Assuming:
Stochastic Environments

Modelling Search Problems

- Representation
  - Problem → States + Actions + Transition → Search Tree
  - Problem → Goal + Costs → Performance Measure

Midterm Q1 focuses on this learning objective
Note: this is not directly assessed in the Final; but may be indirectly assessed via the formulation of other solutions (e.g., CSP, Adversarial, Logical Agent, Bayesian Network models)

- Analysis of representation
  - Correctness as the determination of a plan or legal goal
    - Planning: action sequence from initial state to goal state
    - Legal goal: a valid goal state that is reachable from initial state
  - Complexity or tree size in terms of b, m
    - b : branching factor
    - m : maximum depth

Midterm Q1 also focused on these learning objectives; at most MCQs on search tree complexities in the Final

Solving Search Problems – Uninformed Search

- Applying uninformed search algorithms – BFS / DFS / DLS / IDS (only frontier differs)
  - Systematically traverse search tree to find path to goal or legal goal
    - Complexity – given the search tree properties
    - Completeness – will the algorithm guarantee a solution
    - Optimality – will the solution have minimal cost

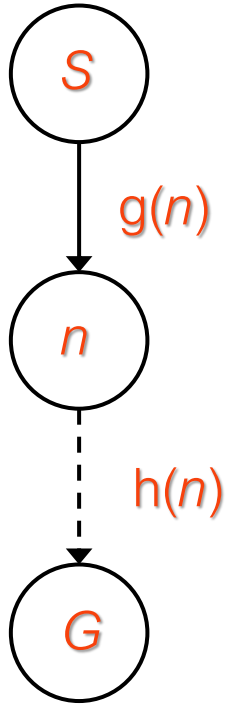
Assumes problems are:
- Fully Observable
- Deterministic
- Single-Agent

- Algorithm properties
  - Complexities
    - Time: ALL exponential
    - Space: BFS exponential; DFS/DLS/IDS linear
  - Implementations
    - BFS with early goal test reduces complexity
    - DFS with backtracking improves space complexity
    - Note Tree versus Graph variants
  - Completeness
    - BFS/IDS: if goal exists; b finite
    - DLS: $d \leq$ depth limit
    - DFS: m finite
  - Optimality
    - BFS/DFS/DLS/IDS are generally, NOT optimal

Midterm Q2 focused on these learning objectives; at most MCQs on these in the Final

Solving Search Problems – Informed Search

- Best-first Search Algorithm – frontier as priority queue
  - Evaluation function used to order nodes on Frontier
    - UCS (g(n) priority): explore paths in order of path cost (uninformed)
    - Greedy (h(n) priority): explore paths by following states closest to goal
    - A* (g(n)+h(n) priority): explore paths in order of approximate cost from initial to goal state
  - Greedy and A* are informed search algorithms – require heuristic h
- Idea: use domain knowledge to determine good heuristics (h)
  - Relax problem constraints to define (admissible) heuristics
  - Complexity of h should be low (e.g., constant or linear)
- Algorithm properties
  - Exponential complexities – dependent heuristic accuracy (effective branching factor)
  - UCS is complete and optimal; Greedy is neither
  - A* depends on heuristic properties (i.e., admissible, consistent)



Midterm Q2 & Q3 focused on these learning objectives;
expect a Q on these in the Final!

Solving Search Problems – Local, CSP, & Adversarial

- Goal search – focus on finding legal goal state; assumes path inconsequential
  - Local Search
    - Tends to use complete-state formulation – i.e., no incomplete states that preclude goal
    - Restrict frontier size to 1 (hill-climbing) or k (beam search) – many variants
    - Requires heuristic h to choose among successors to explore
  - Constraint Satisfaction Problem (CSP)
    - Generalised goal-search solution
    - Formulation → Variables + Domains + Constraints (with constraint graph representation)
    - Uses backtracking search (DFS)

- Adversarial search – assumes 2-player, zero-sum game
  - Formulation additionally requires: Player + Terminal + Utility
  - Assume an opponent strategy to plan
  - Minimax algorithm (based on backtracking) – assumes optimal opponent (given utility)

Adversarial search assumes problems are multi-agent

Midterm up to Local Search;
Finals may include MCQs local search (recall that only up to 20% of Final on Midterm topics)

Finals **WILL** include a CSP modelling question! No need to focus on trace/proof Qs!

No question on problem modelling or evaluation function modelling since these were covered in Project 3;
instead, focus on the Minimax and α-β Pruning algorithms – i.e., trace/proof Qs!

Heuristics & How They Help

- Estimating path cost of goal (to generate/expand fewer nodes)
  - Informed search algorithms use them to direct search
  - Local search uses them to estimate proximity to a solution
  - Domain-specific
- As evaluation functions (for limited depth traversal in games)
  - To estimate utility at non-terminal game states
  - Domain-specific
- Determining value/variable order (remove subtrees in CSPs)
  - Strategies to find better orderings, which in turn allow more pruning
  - Domain-generic

Less emphasis on evaluation function formulation; for heuristic design, focus on informed and local search

Make sure that you are able to trace the various CSP heuristics!

Shrinking Search Spaces

- α-β Pruning
  - Do not explore sequences of moves that would never be taken
  - Optimal ordering → $O(b^m)$ to $O(b^{m/2})$
  - Random Ordering → $O(b^m)$ to $O(b^{3m/4})$
- Inference in CSPs via Forward Checking or AC-3
  - Can we infer if a state is terminal?
  - Shrinking domains (fewer actions to try)
  - Can be expensive
    - Is there really a saving?
    - Just pre-processing?

Similar to Minimax algorithm: focus on the α-β Pruning algorithm – trace/proof Qs

Make sure you also focus on the Forward Checking and AC-3 algorithms!

Knowledge Representation

- Representing Knowledge
  - Logic
  - Others?
- Growing knowledge via Inference Engine (inference via automated theorem proving)
  - Truth-table enumeration
  - Resolution – proof by contradiction (over CNF KB)
- Logical agents and queries
  - Use domain knowledge to formulate queries
    - Answering queries directs decision making

Now assumes problems are:
- Partially Observable

Finals WILL include a Logical Agent modelling question! Including how to determine queries for IE

Can you formulate KB from context? What about CNF KB? (ref. past-sem. papers)

Handling Uncertainty

- Use Bayesian Networks (BN)
  - Infer what is most probable to make decisions
  - Only store/reference some of the joint probability distribution table by defining beliefs about variable relationships
  - Assume conditional independence between non-connected variables
    - Reduces number of probabilities required

Now assumes problems are:
- Stochastic

Includes Naïve Bayes algorithm; make sure you can apply from tabular data (ref. part-sem. papers)

No need to model BN from context; just apply BN to determine probabilities

Questions about the Lecture?

- Was anything unclear?
- Do you need to clarify anything?
- Ask on Archipelago
  - Specify a question
  - Upvote someone else's question

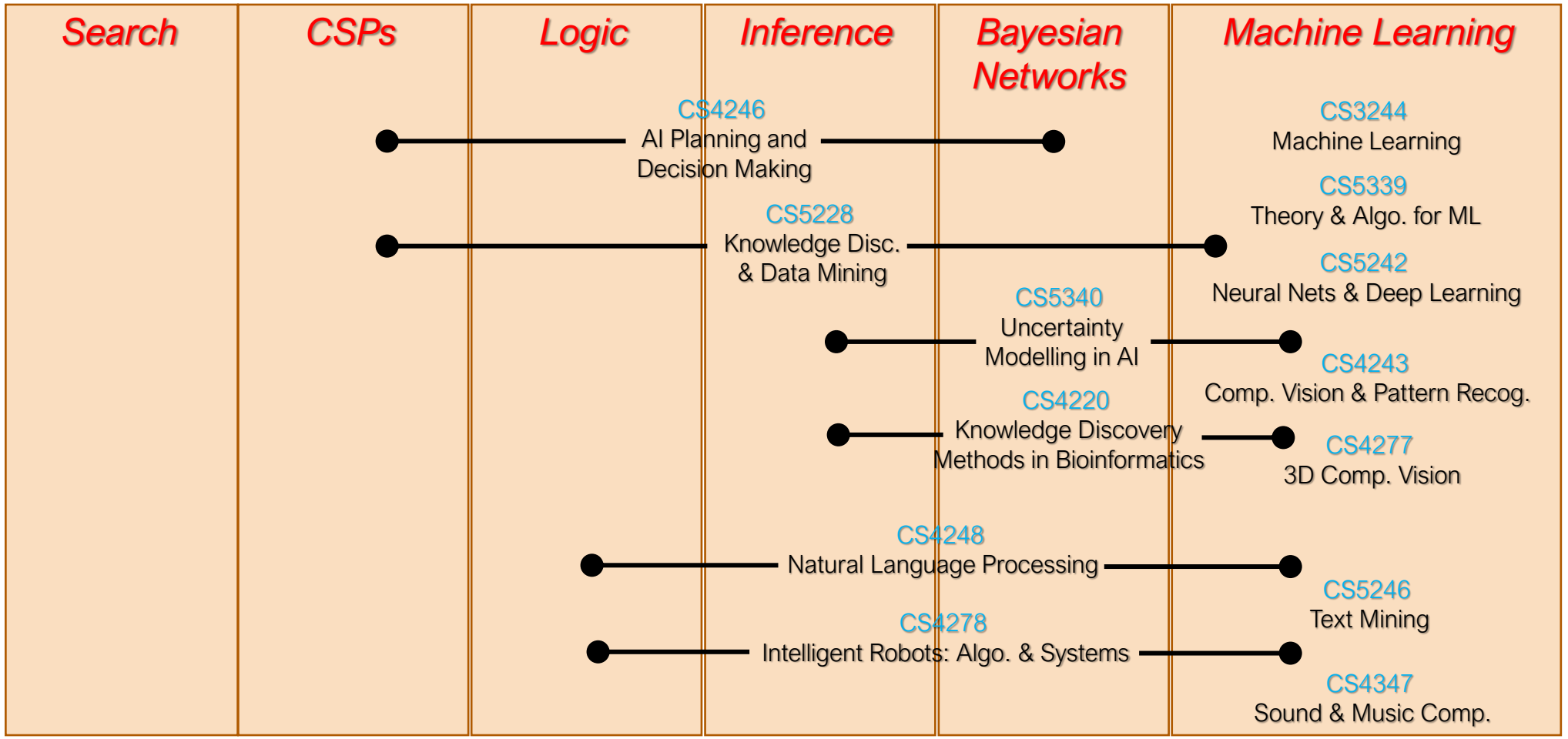
Invitation Link (Use NUS Email --- starts with E)
https://archipelago.rocks/app/resend-invite/92727263219

2 Possible Next Steps in AI

Learning More About AI

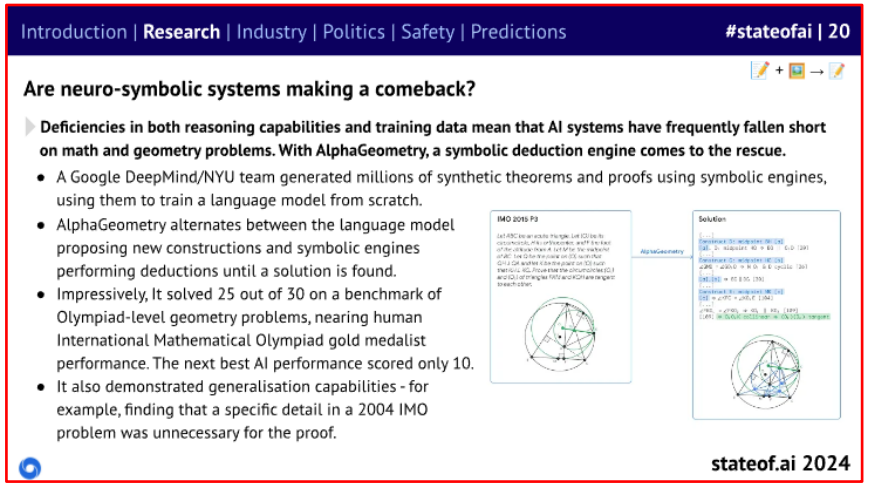
- Theory: more on algorithms
  - Domain expertise = algorithms
  - Problem categories
    - (more) planning and search
    - (more) reasoning with logic and knowledge representation
    - (machine) learning
    - etc.
- Practice: more on formulation and representation
  - Domain expertise = problem domains
    - Data-specific – e.g., text, images, video, etc.
    - Problem-specific – e.g., medicine, games, etc.

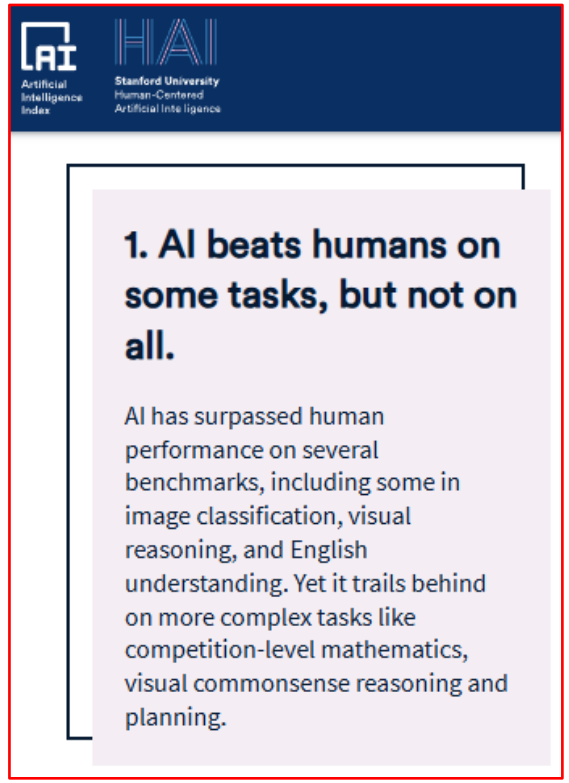
Further CS Courses in AI



Research Horizon: Synthesis & Back to Symbolic AI

- Going back towards Strong(er) AI
  - Driven by successes in deep learning
- Requires synthesis of various AI fields
  - Neuro-symbolic AI
    - Integrates neural and symbolic AI architectures to overcome weaknesses of each
    - Providing robust AI capable of reasoning, learning, and cognitive modelling
  - Dual-cognition systems
    - System 1: fast, reflexive, intuitive, and unconscious (e.g., pattern recognition)
    - System 2: handles planning, deduction, and deliberative thinking
    - Both are required for a robust, reliable AI that can learn, reason, and interact with humans to accept advice and answer questions





The following AAAI Presidential Address by Bart Selman in 2022 describes this further:
https://aaai-2022.virtualchair.net/plenary_2.html
(scroll down and watch the video from the 1h 40m mark)

Stanford AI Index Report 2024:
https://aiindex.stanford.edu/report/

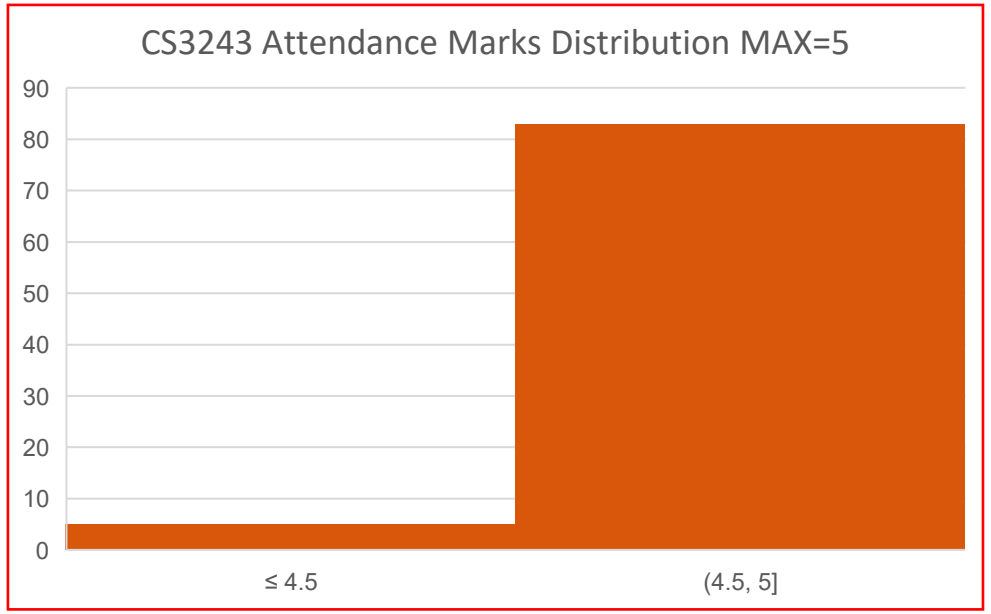
3 Report on Assessments

Assessments & Course Weights

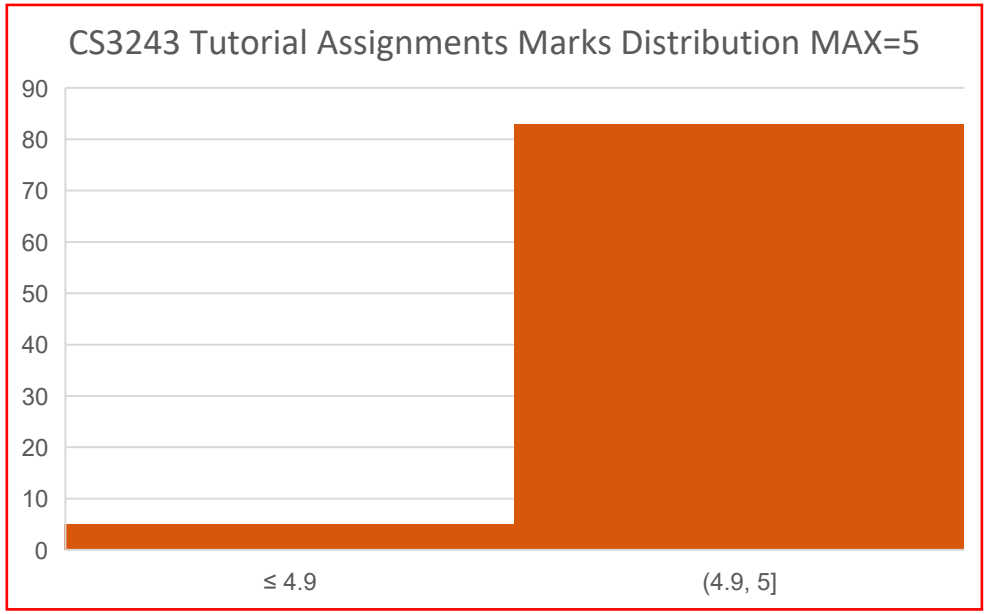
- Course Participation (11)
  - Total 5%
  - Tutorial Attendance
- Tutorial Assignments (9)
  - Total 5%
  - Each worth 1% (best 5 taken)
- Midterm Examination (1)
  - Total 20%
  - Closed Book + Cheat Sheet (1 x A4 Sheet)
  - In-person + Written
- Python Projects (5)
  - Total 30%
    - Projects 1.1 + 1.2: 10%
    - Projects 2.1 + 2.2: 10%
    - Project 3: 10%
  - Individual
  - Bonus marks available (covering projects)
- Final Examination (1)
  - Total 40%
  - Closed Book + Cheat Sheet (1 x A4 Sheet)
  - In-person + Written

Summary of Assessments

- Attendance (AT – MAX 5%)
  - Mean: 4.85
  - Median: 5



- Tutorial Assignments (TA – MAX 5%)
  - Mean: 4.85
  - Median: 5



Summary of Assessments

- Why Attendance and TAs (and DQs)?

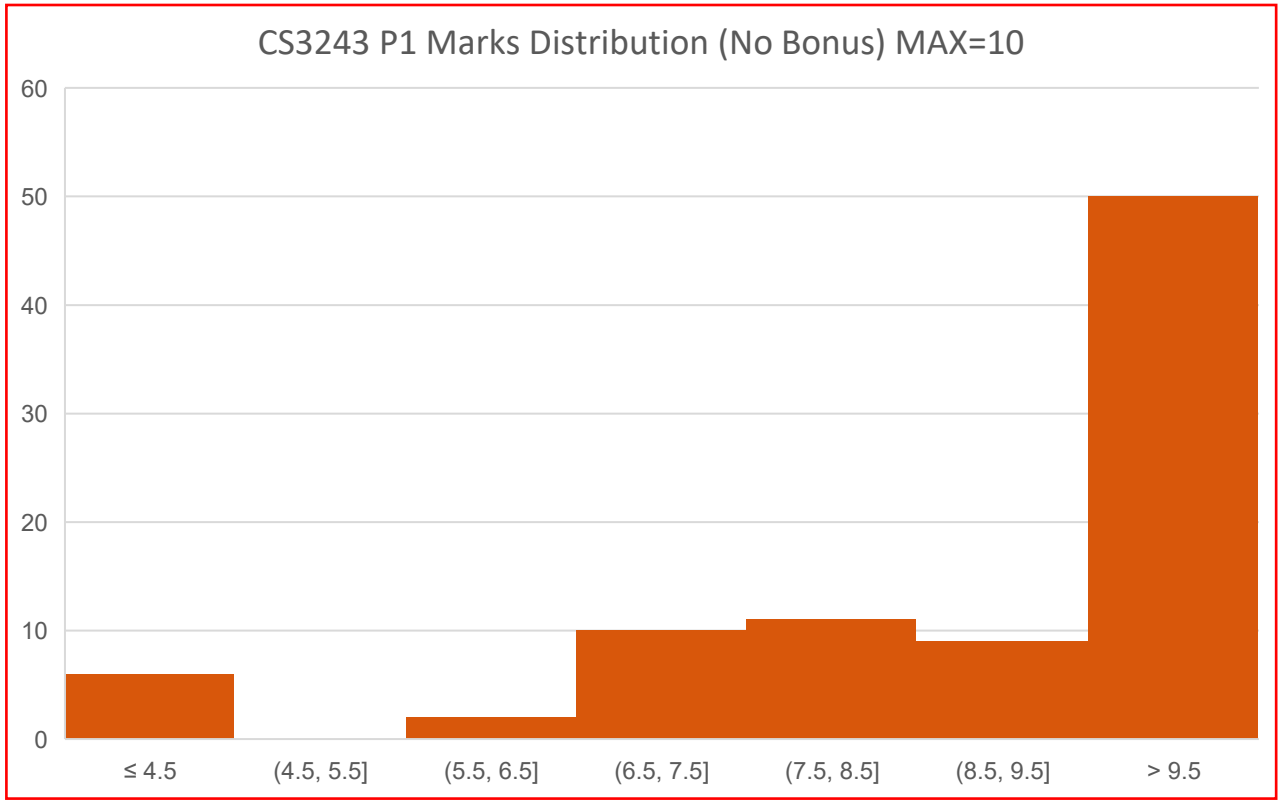
Motivate Consistent Effort

Highlight Importance of Tutorials

Foster Higher Self-Efficacy

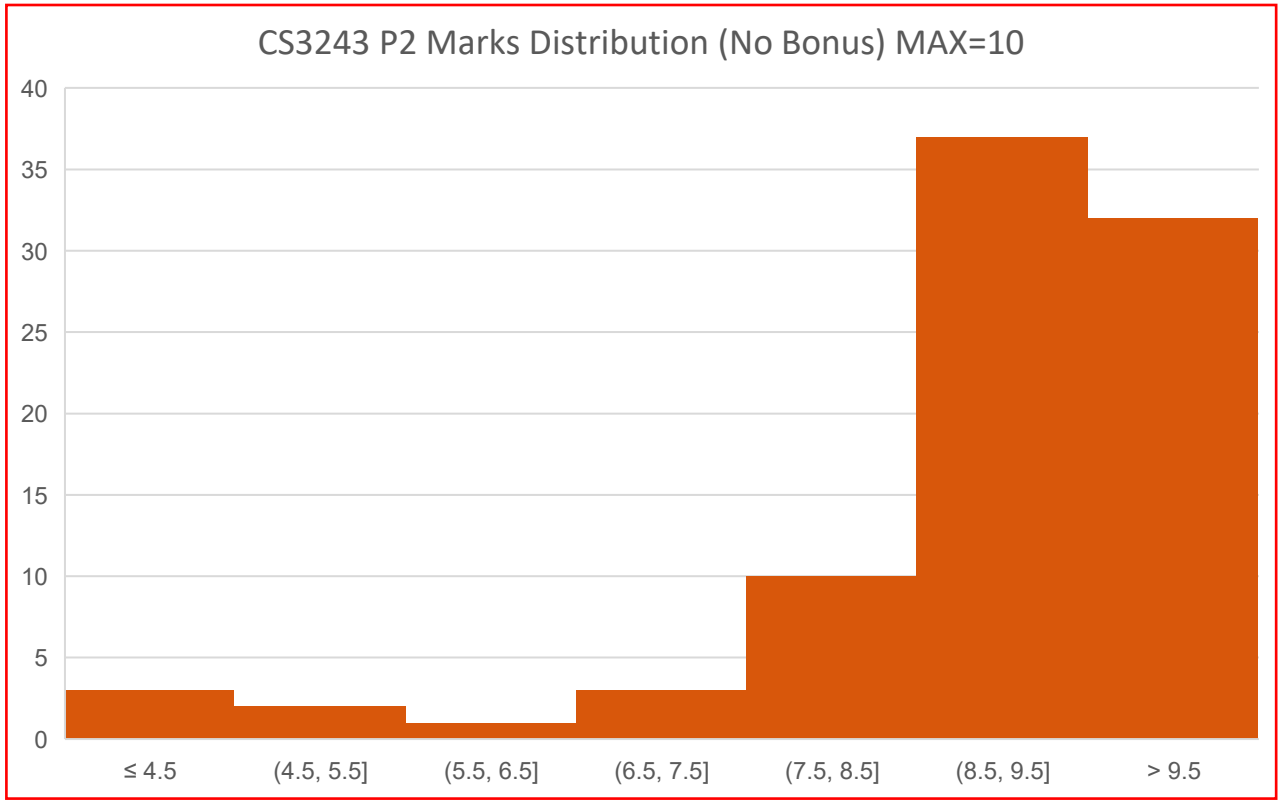
Summary of Assessments

- Project 1.1 (MAX = 3)
  - Mean: 2.89
  - Median: 3
- Project 1.2 (MAX = 7)
  - Mean: 5.83
  - Median: 6.89



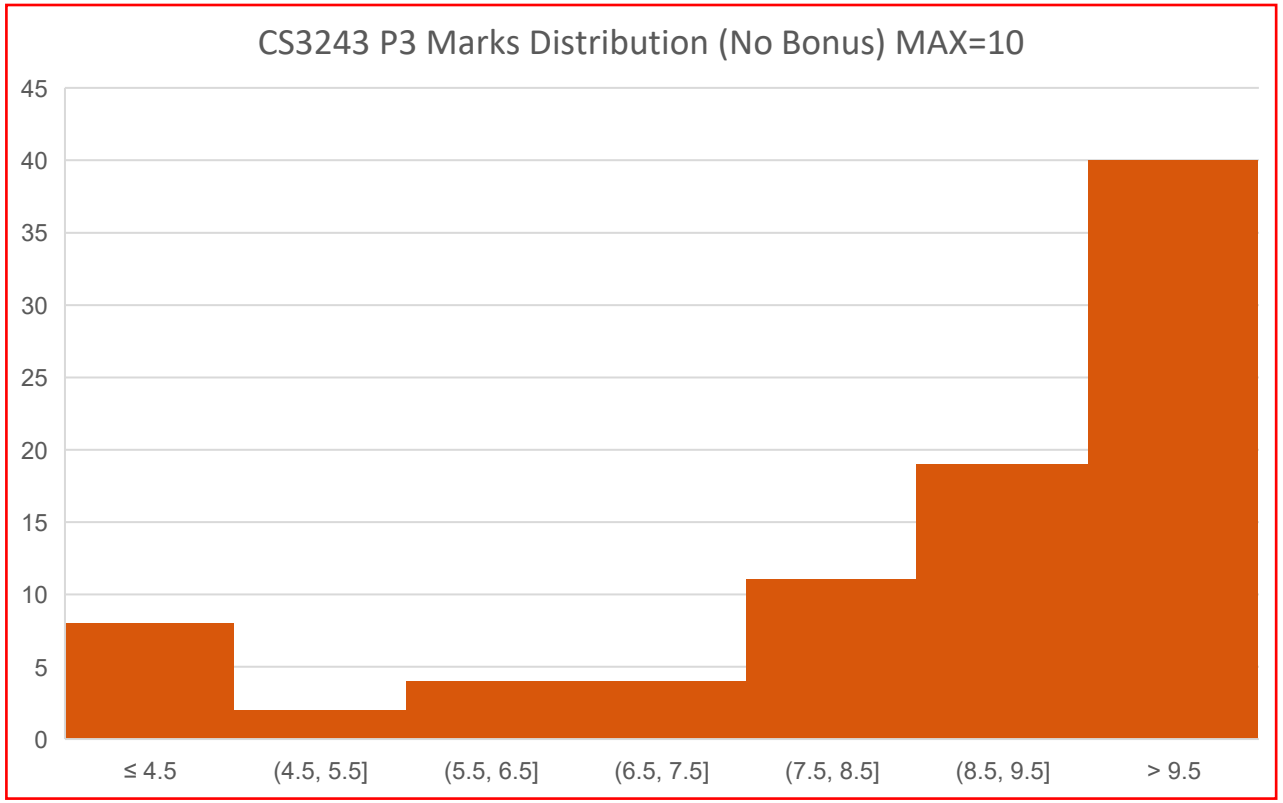
Summary of Assessments

- Project 2.1 (MAX = 3)
  - Mean: 2.73
  - Median: 2.8
- Project 2.2 (MAX = 7)
  - Mean: 6.12
  - Median: 6.5
- Project 2 Bonus (MAX = 3)
  - Mean: 1.63
  - Median: 2.0



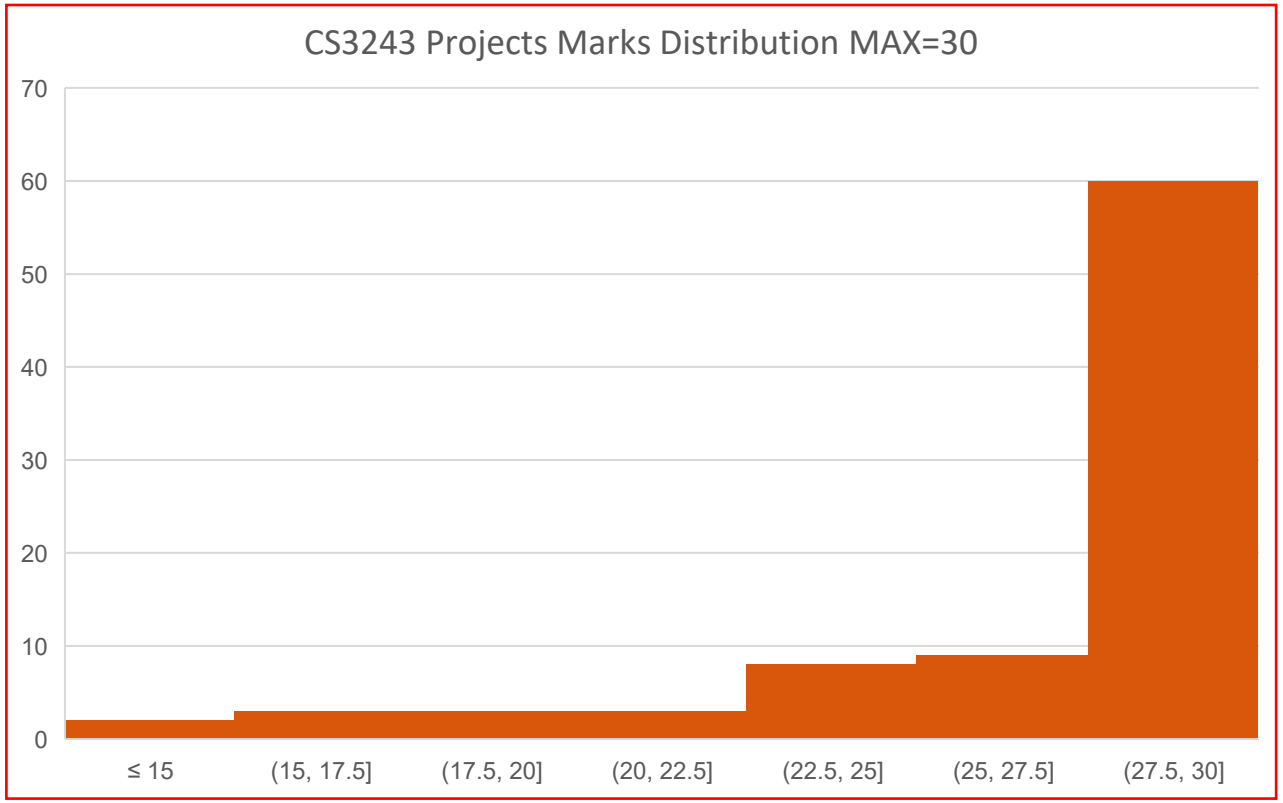
Summary of Assessments

- Project 3 (MAX = 10)
  - Mean: 8.81
  - Median: 9.5
- Project 3 Bonus (MAX = 2)
  - Mean: 1.15
  - Median: 1



Summary of Assessments

- Overall Projects (P – MAX = 30)
  - Mean: 27.34
  - Median: 30



Summary of Assessments

- Why did I have to implement a representation, algorithms, etc.?

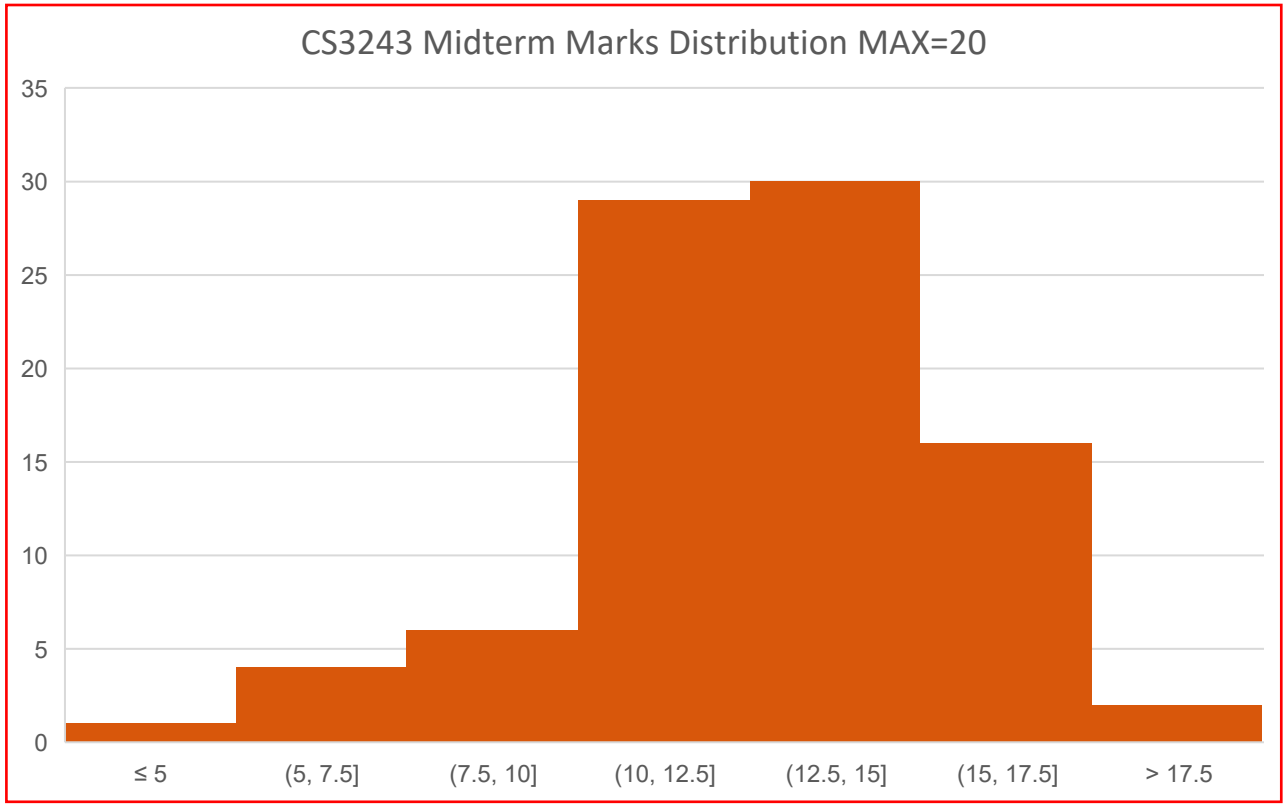
Enhances Algo. Understanding

Representation is Vital

Integration of Agent within Environment

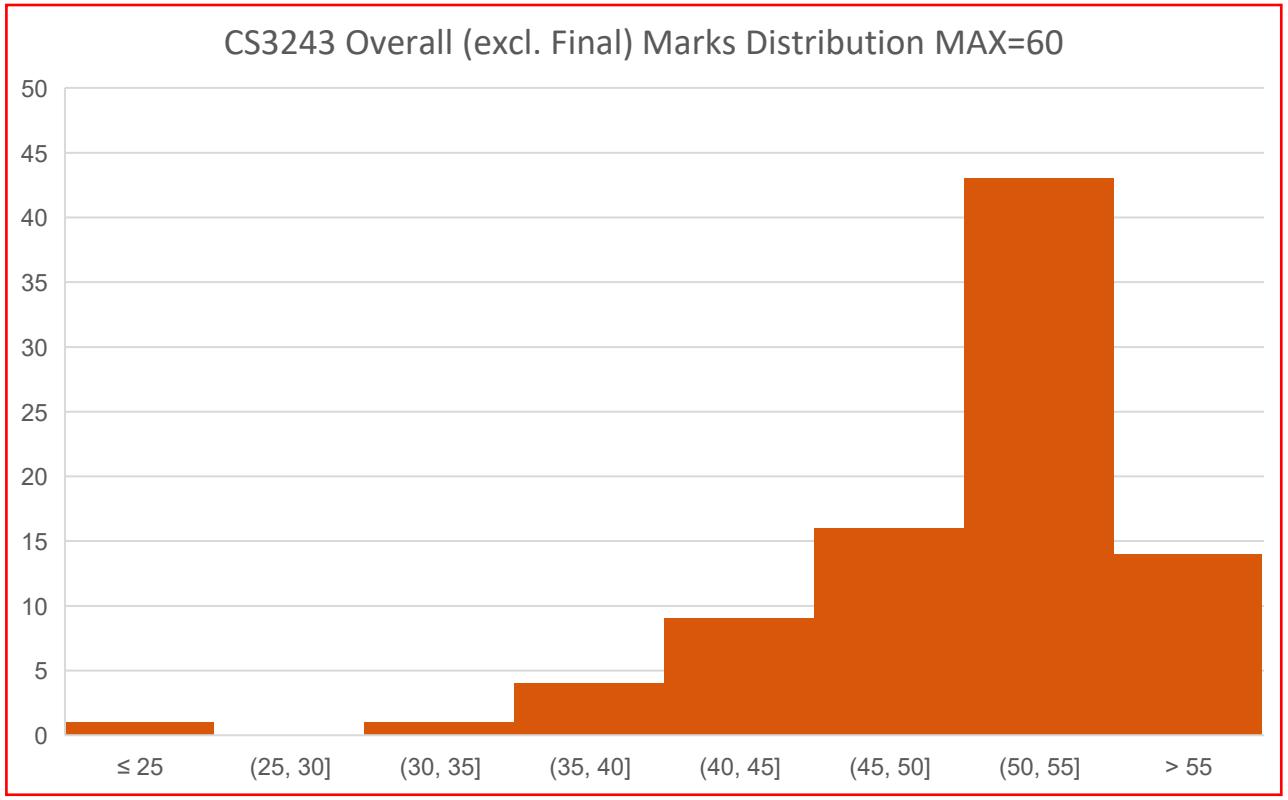
Summary of Assessments

- Midterm Q1 (%)
  - Mean: 32.33
  - Median: 30.0
- Midterm Q2 (%)
  - Mean: 76.16
  - Median: 80.0
- Moderated Midterm (MAX = 20)
  - Mean: 12.67
  - Median: 12.8



Summary of Assessments

- Overall
  (AT+TA+P+MT – MAX = 60)
  - Mean: 49.71
  - Median: 51.6



4 Administrative Matters

Appeals on Assessments

- Tutorial Attendance & Assignments
  - Deadline: Next Monday (18 NOV), 2359 hrs

Check all marks on Canvas:

Canvas > CS3243 > Grades

- Project 3
  - Deadline: Next Monday (18 NOV), 2359 hrs

- Submitting Appeals
  - Email me: dler@comp.nus.edu.sg

Final Assessment

- Schedule & Venue
  - Tuesday (3 DEC), 0900-1100 hrs
  - MPSH 1A
- Format (similar to the Midterm)
  - Duration: 2 hours
  - Total: 60 marks
  - Closed-book + Cheat Sheet (1 × Double-sided A4 Sheet)
- Topics
  - All topics
  - About 75% of the paper will focus on topics not covered in the Midterm
- Practice Papers
  - Canvas > CS3243 > Flies > Past Papers > Final Papers

You **MUST** **confirm your Finals Schedule on the Student Portal** (including time and venues)

Student Feedback Exercise

Your Voice Matters!

Be Constructive

Comments on your learning experience increase the value of your feedback.

Be Specific

Provide examples of how you think your teacher or the way the module is organised have helped (or not helped!) your learning.

Be Considerate

Improper language or personal comments are highly inappropriate, and undermine your feedback. Abusive comments are unacceptable.

Your feedback counts

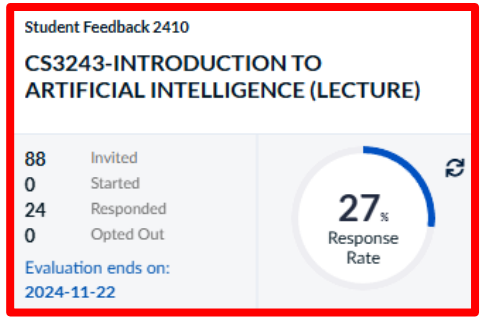
Your constructive feedback helps professors to improve their modules and is one source of evidence for the university's appraisal decisions.

It's confidential

Your professors will never see your name. They will only get an aggregate report after the exam results have been released.

It's quick

Complete your module feedback on campus, at home, or on the go! It is easy to use and mobile compatible.



Provide your feedback now >>

https://blue.nus.edu.sg/blue/

CS3243 Teaching Team Positions

- Work on projects during the Break
  - Applications open from now ...
  - ... or until roles filled

- TA for AY24/25 Semester 2
  - Apply before Week 0 next semester
  - The sooner the better ...

- Contact me if interested
  - Email: dler@comp.nus.edu.sg

Questions about the Lecture?

- Was anything unclear?
- Do you need to clarify anything?
- Ask on Archipelago
  - Specify a question
  - Upvote someone else's question

Invitation Link (Use NUS Email --- starts with E)
https://archipelago.rocks/app/resend-invite/92727263219