

CSCE 580: Introduction to AI

Weeks 12-13 - Lectures 22, 23, 24, 25:
SDP: Planning and Reinforcement Learning (RL)

PROF. BIPLAV SRIVASTAVA, AI INSTITUTE

4TH, 6TH 11TH, AND 13TH NOV 2025

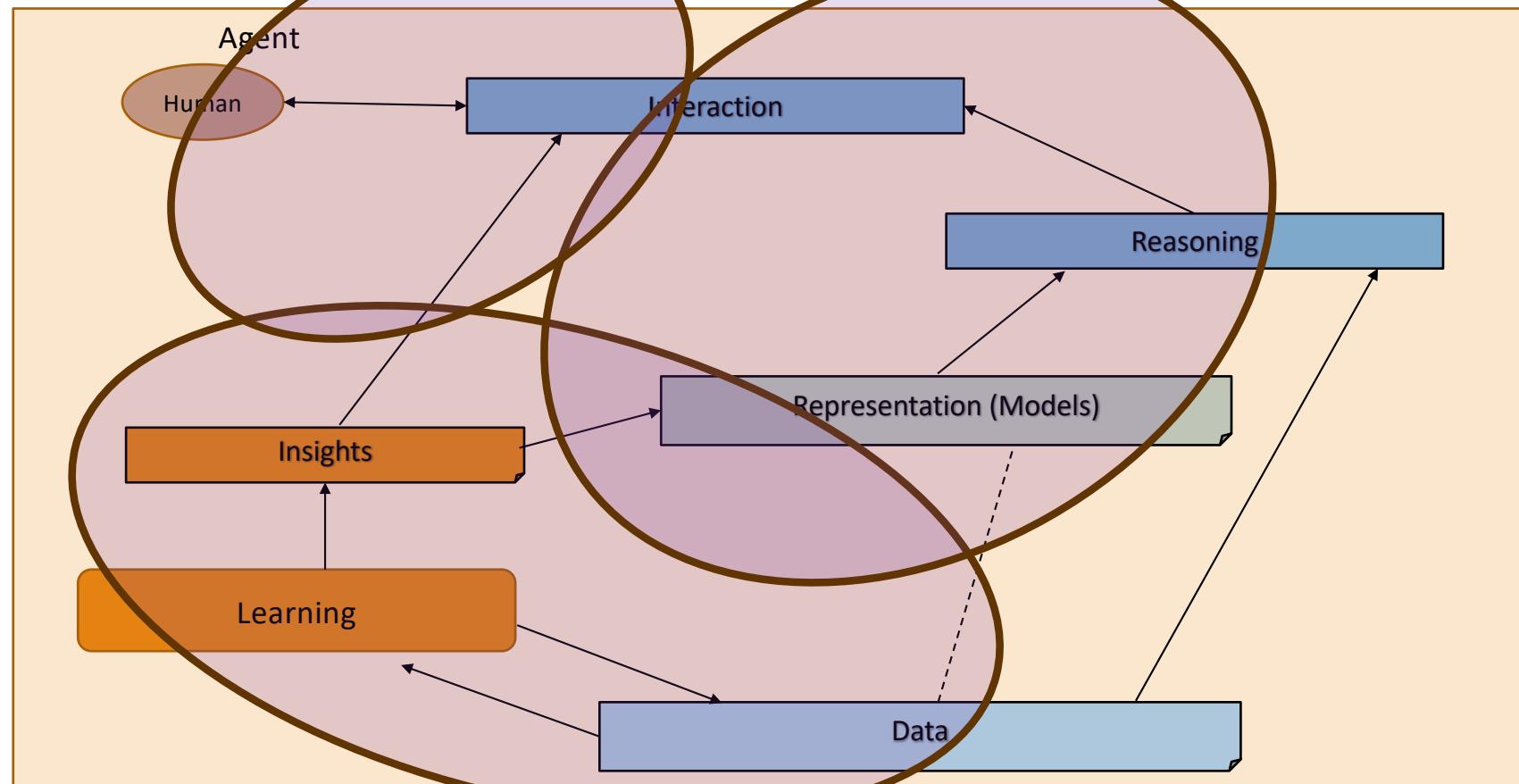
Carolinian Creed: “I will practice personal and academic integrity.”

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Organization of Week 12 - Lectures 22-25

- Introduction Section
 - Recap from Week 11 (Lectures 20 and 21)
 - AI news
- Main Section
 - Lecture 22: SPD: Planning
 - Lecture 23: Language Models and Planning
 - Lecture 24: Quiz 3
 - Lecture 25: SDP: RL
- Concluding Section
 - About next week – W14: Lectures 26, 27
 - Ask me anything

Relationship Between Main AI Topics (Covered in Course)



Recap of Week 11

We discussed

- Lecture 20: Making Decisions - Simple
- Lecture 21: Making Decisions - Complex

- Week 1: Introduction, Aim: Chatbot / Intelligence Agent
- Weeks 2-3: Data: Formats, Representation and the Trust Problem
- Week 3: Machine Learning – Supervised (Classification)
- Week 4: Machine Learning - Unsupervised (Clustering) –
- Topic 5: Learning neural network, deep learning, Adversarial attacks
- Week 6: Large Language Models – Representation and Usage issues
- Weeks 7-8: Search, Heuristics - Decision Making
- Week 9: Constraints, Optimization – Decision Making
- Topic 10: Markov Decision Processes, Hidden Markov models - Decision making
- Topic 11-12: Planning, Reinforcement Learning – Sequential decision making
- Week 13: Trustworthy Decision Making: Explanation, AI testing
- Week 14: AI for Real World: Tools, Emerging Standards and Laws; Safe AI/ Chatbots

Introduction Section

Upcoming Evaluation Milestones

- **Projects B: Sep 30 – Nov 20**
- Quiz 2: Oct 7
- **Quiz 3: Nov 11**
- Paper presentation (grad students only) : Nov 18
 - Put paper names in spreadsheet
- Finals: Dec 11

AI News

#1 NEWS – Law School Tests Trial With Jury Made Up of ChatGPT, Grok, and Claude

- Link: <https://futurism.com/artificial-intelligence/law-school-trial-ai-jury>

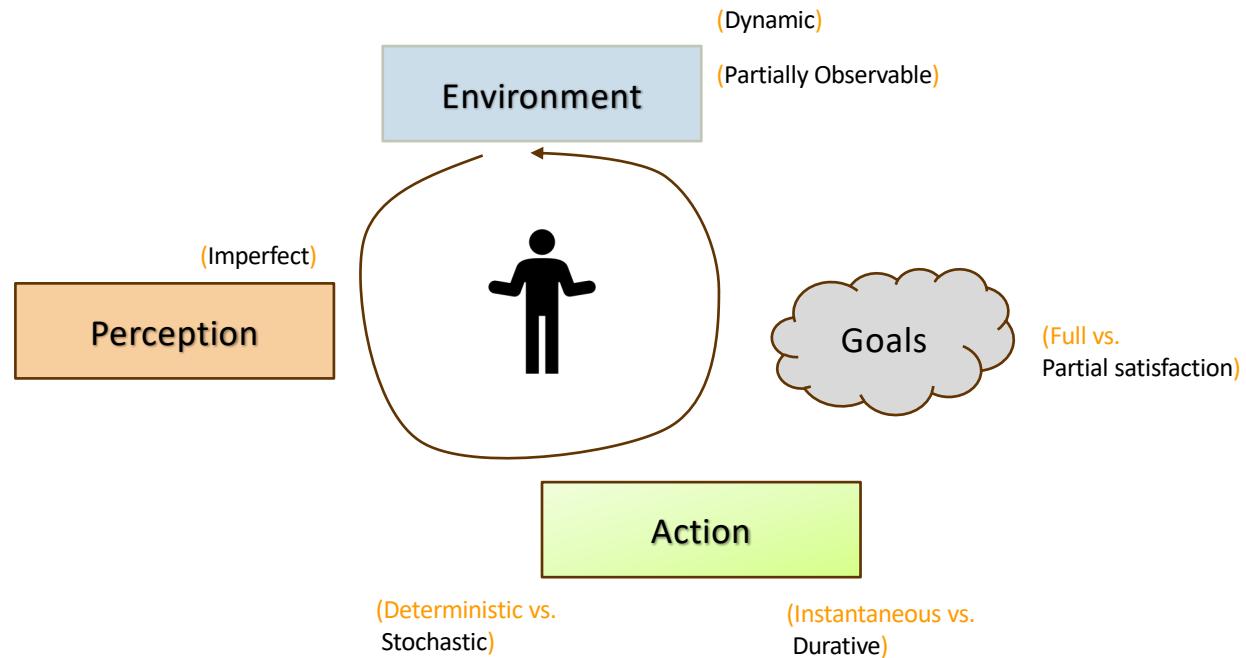
 - University of North Carolina School of Law had a mock trial
 - Chatbots acted as “jurors” who would determine the fate of a man charged with juvenile robbery - *The Trial of Henry Justus*
 - AI “jurors” (ChatGPT, Grok and Claude) were given a real-time transcript of the proceedings and then “deliberated” in front of the audience
 - Uneven performance
 - “most in the audience came away believing that trial-by-bot is not a good idea”
- Lawyers have been using chatbots in different use cases in law
 - <https://www.404media.co/18-lawyers-caught-using-ai-explain-why-they-did-it/>

Main Section

Lecture 22: (Automated) Planning

Complex Decisions

- Making a sequence of decisions
- Making a single decision but with
 - Environment changing
 - Actions not being deterministic
 - Perception not being perfect
 - ...



Goal-Based Agents Generating Sequence of Actions

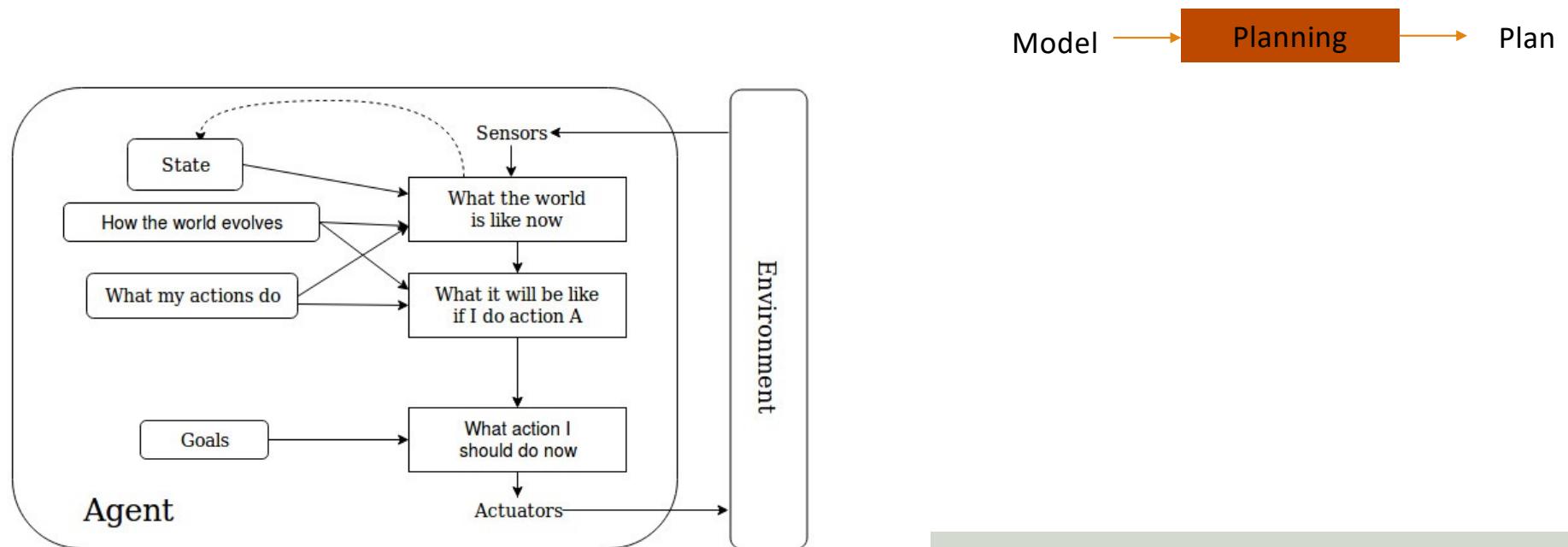
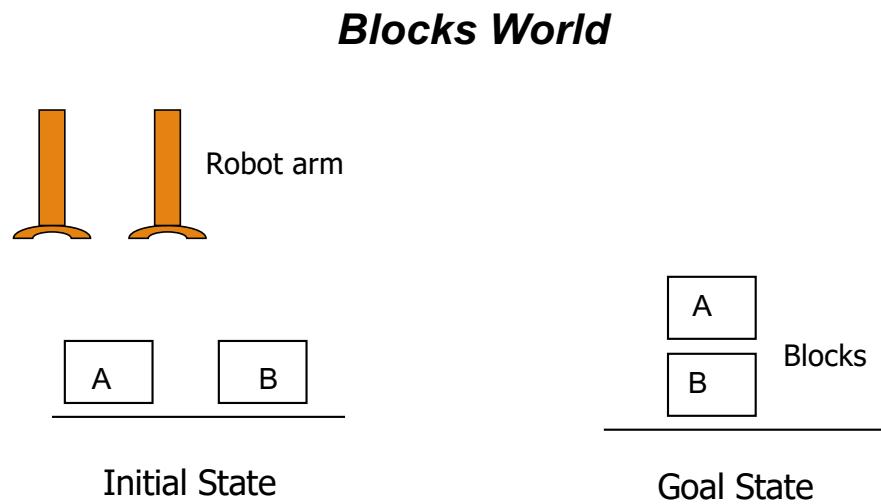


Figure Source: Russell & Norvig, AI: A Modern Approach

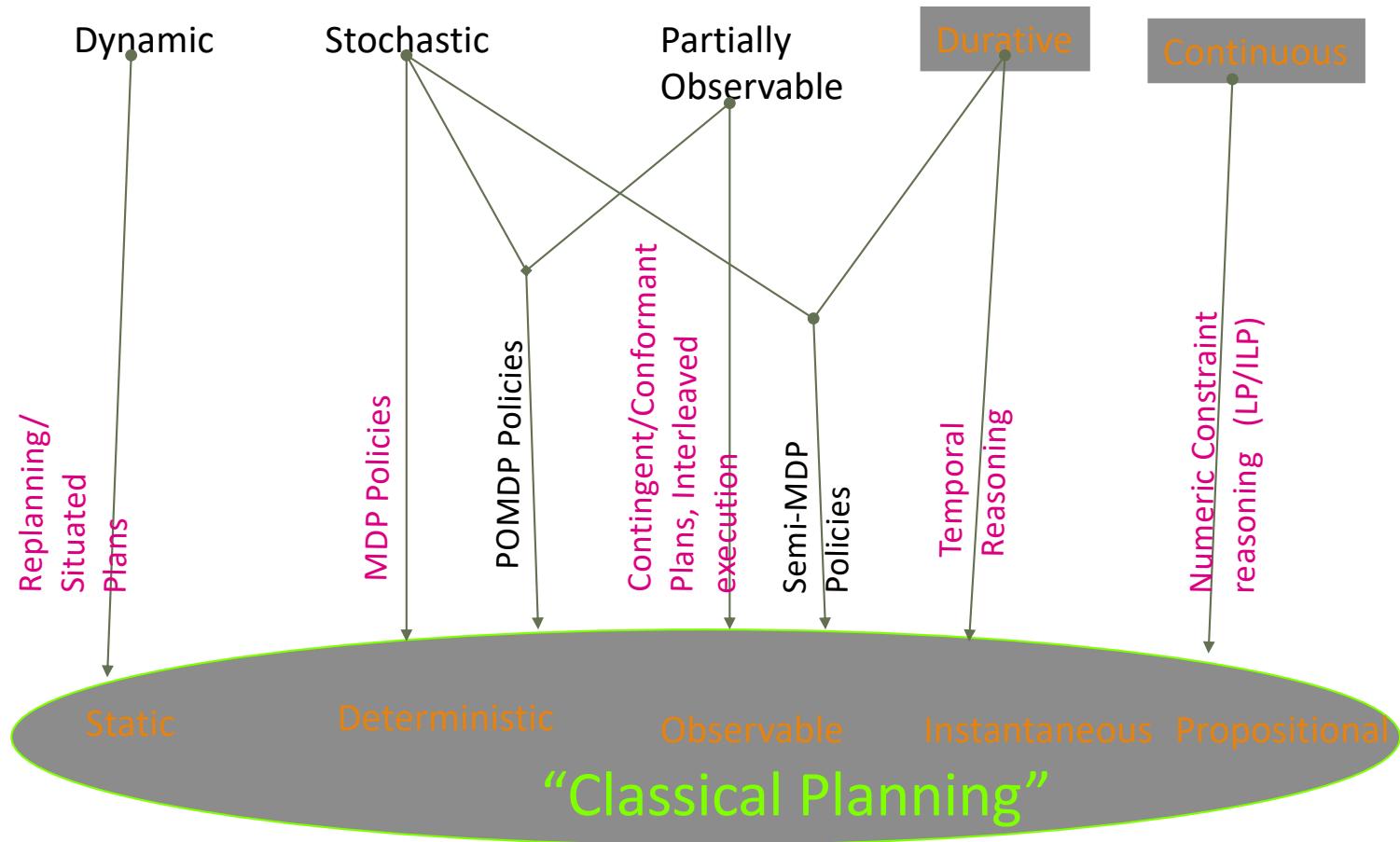
Reasoning Illustration - Planning Example



All robots are equivalent

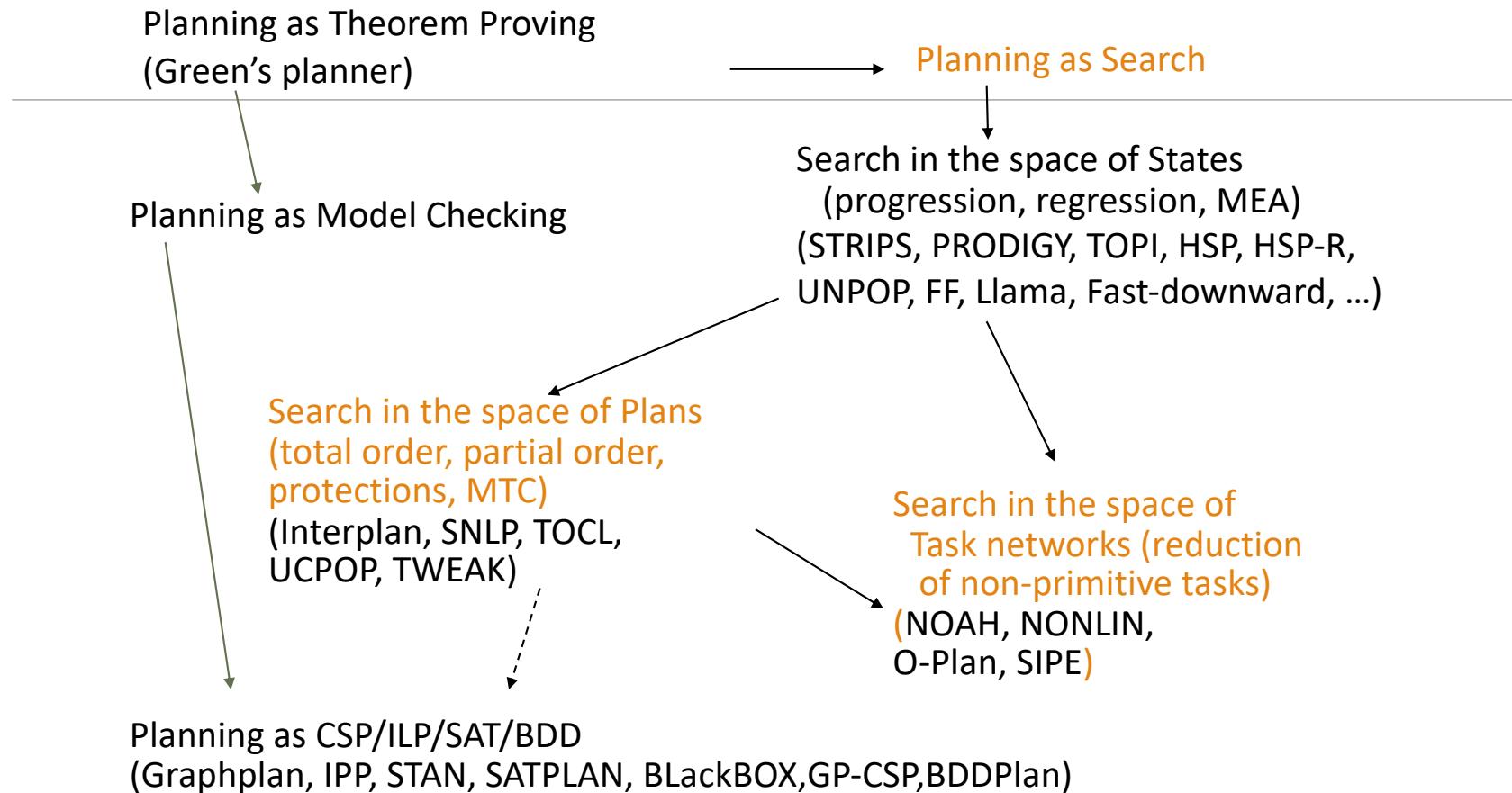
Planning Types: Procedural v/s Declarative v/s Utility

- Procedural
 - User: Tells **how** to do
 - System: does (executes) as is told to do
- Declarative
 - User: Tells **what** to do
 - System: finds **how** to do, then **does** (executes) as it finds to do
- Utility-based
 - User: Tells **what** is important
 - System: finds **what** to do, **how** to do, then **does** (executes) as it finds to do



Credits: portions derived planning tutorial slides of Prof. Subbarao Kambhampati, Arizona State University

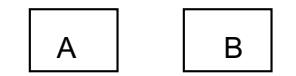
The (too) Many Brands of Classical Planners



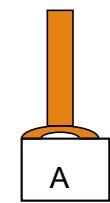
Credits: portions derived planning tutorial slides of Prof. Subbarao Kambhampati, Arizona State University

Reasoning Illustration - Representation

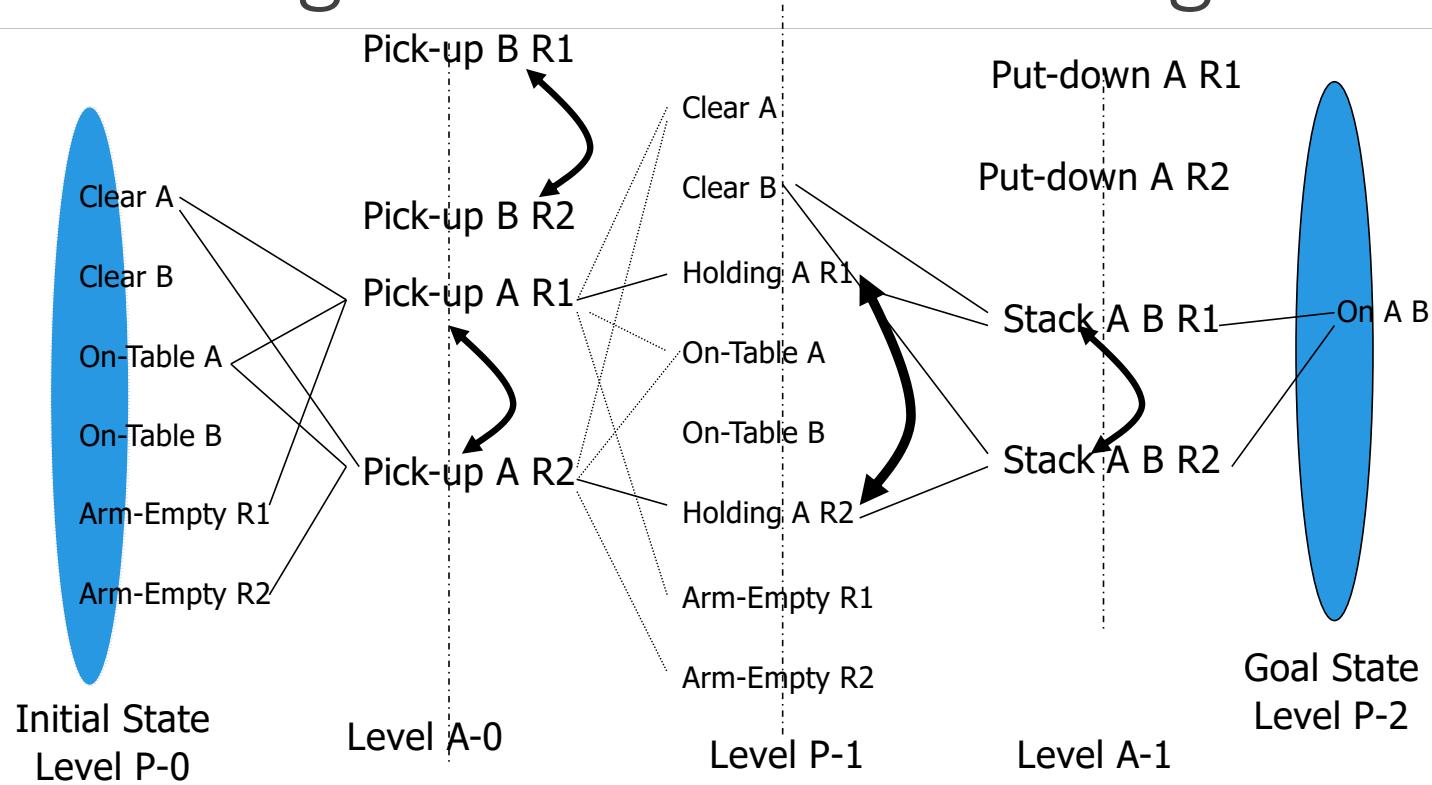
States: ((On-Table A) (On-Table B) ...)



Actions: ((Name: (Pickup ?block ?robot)
Precondition: ((Clear ?block)
 (Arm-Empty ?robot)
 (On-Table ?block))
Add: ((Holding ?block ?robot))
Delete: ((Clear ?block)
 (Arm-Empty ?robot))...)



Reasoning Illustration - Planning Process



Active Area of Research

Considerations : single-agent

- What to find:
 - **Any** workable plan
 - **Optimal** plan – but then what is the criteria
 - All plans
 - Diverse plans
- When to find (generate)
 - Plan **at the end**
 - Plan **anytime**
- How to
 - Represent problem
 - Find solution (search, learning, ...)
 - Explain solution
- Applications

Considerations: multi-agent

- What to find:
 - **Any** workable plan
 - **Optimal** plan – but then what is the criteria
- When to find (generate)
 - Plan **at the end**
- How to
 - Represent problem
 - Find solution (search, learning, ...)
 - Explain solution
- Applications
 - Traffic lights, automated cars
 - Warehouses

Hands On With Planning

- Coding examples: <https://github.com/biplav-s/course-ai-f25/tree/main/sample-code/class22-planning>
 - Api.planner
 - <http://planning.domains/>; Try the editor: <https://editor.planning.domains/#>
 - Code sample
 - Pyperplan
 - Demo

Exercise: 10 mins

- Try any domain from domain.pddl or classical planning repo:
<https://github.com/biplav-s/course-ai-f25/blob/main/sample-code/class22-planning/API%20Based%20Planner%20Invocation-PlanUtils.ipynb>
- Change sample code with domain and problem files
- Run the sample code

Forms of Uncertainty and Planning

- Uncertain knowledge, caused by
 - Incomplete knowledge
 - Incorrect knowledge
- Uncertain actions, caused by
 - Physics of the domain
 - External events

Forms of Uncertainty

- Uncertain knowledge, caused by
 - Incomplete knowledge
 - Incorrect knowledge
 - Uncertain actions, caused by
 - Physics of the domain
 - External events
- Alternative approaches to represent
- Degree of belief: Probability. The sentence still is true or false
 - Degree of truth: Fuzzy logic

Language	Ontological Commitment (What exists in the world)	Epistemological Commitment (What an agent believes about facts)
Propositional logic	facts	true/false/unknown
First-order logic	facts, objects, relations	true/false/unknown
Temporal logic	facts, objects, relations, times	true/false/unknown
Probability theory	facts	degree of belief 0...1
Fuzzy logic	degree of truth	degree of belief 0...1

Credits:

- Russell & Norvig, AI - A Modern Approach
- Deepak Khemani - A First Course in AI

Forms of Uncertainty

- Uncertain knowledge, caused by
 - Incomplete knowledge
 - Incorrect knowledge
- Uncertain actions, caused by
 - Physics of the domain
 - External events



Use Probability Theory
Infer using probabilities

Decision Processes = create
situational policies (state-action based)

Decision-theoretic Agent

Probability theory: degree of belief in sentences

- Summarizes the uncertainty t

Utility theory: represent and reason with preferences

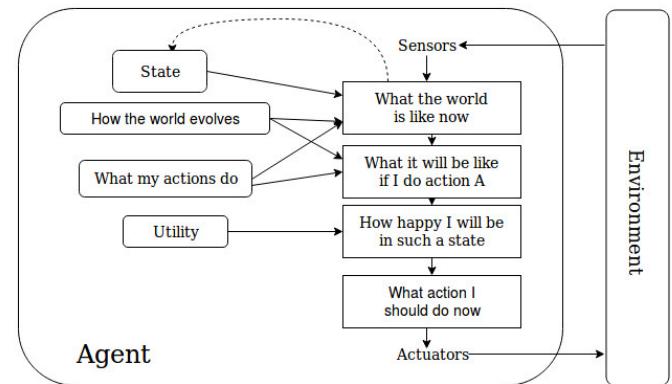
function DT-AGENT(*percept*)**returns** an *action*

static: a set probabilistic beliefs about the state of the world

calculate updated probabilities for current state based on
available evidence including current percept and previous action
calculate outcome probabilities for actions,

given action descriptions and probabilities of current states
select *action* with highest expected utility
given probabilities of outcomes and utility information

return *action*



Source: Russell & Norvig, AI - A Modern Approach

Lecture 22: Planning

- We talked about
 - Planning
 - Classical planning
 - Procedural / Declarative / Utility based planning
 - Planners and examples

Lecture 23: Large Language Models and Planning

Lecture 24:

Quiz 3

Lecture 25: SDP / RL

Lecture 23: Outline

We will discuss

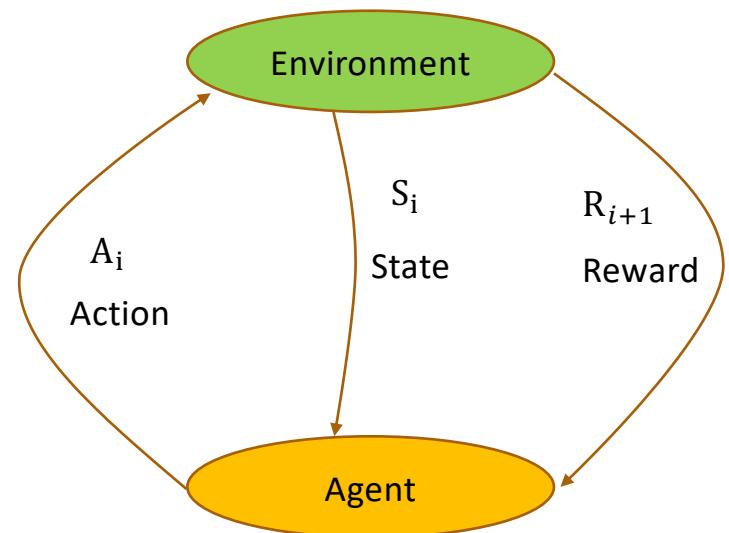
- RL
- Inverse RL
- Multi-Arm Bandit problems

Reinforcement Learning



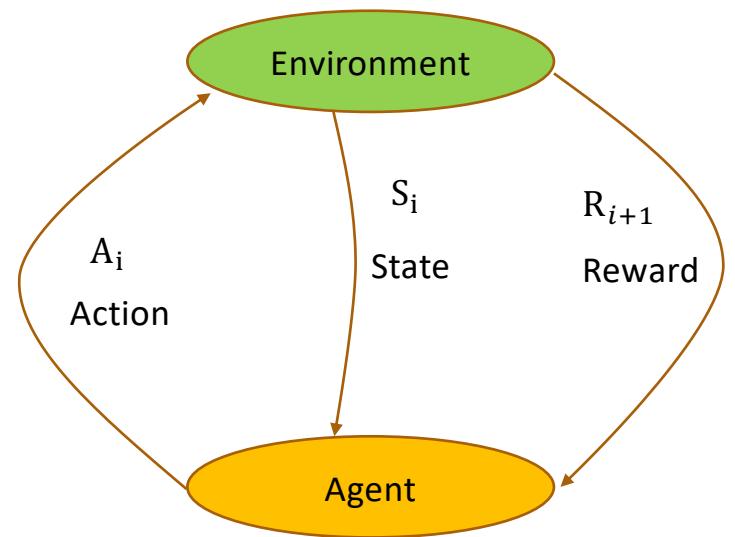
Reinforcement Learning Setting

- An agent in an environment
- Agent
 - Can see **state**
 - Can take **action**
 - Will get **rewards**
- Precisely, at each time step i
 - In state S_i , agent takes action A_i
 - Based on state s_i and action a_i , the environment transitions to state S_{i+1} and outputs reward R_{i+1}
- **Objective:** learn mapping of **states** to **actions** so that the agent maximizes the **reward** from the **environment**.



Reinforcement Learning

- **Objective:** learn mapping of **states** to **actions** so that the agent maximizes the **reward** from the **environment**.
- **Output**
 - Deterministic: $a = \pi(s)$
 - Stochastic: $\pi(a|s) = P(A_i = a|S_i = s)$

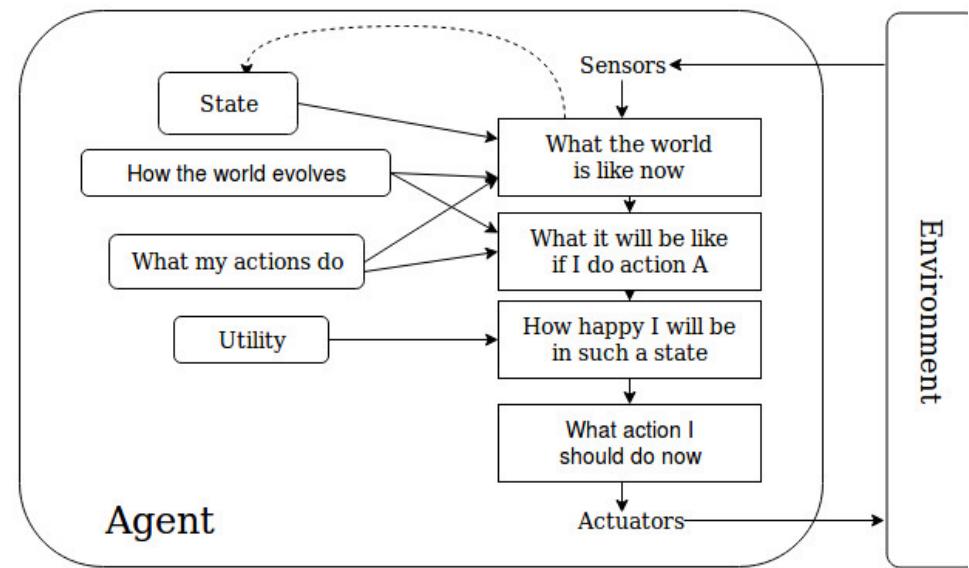
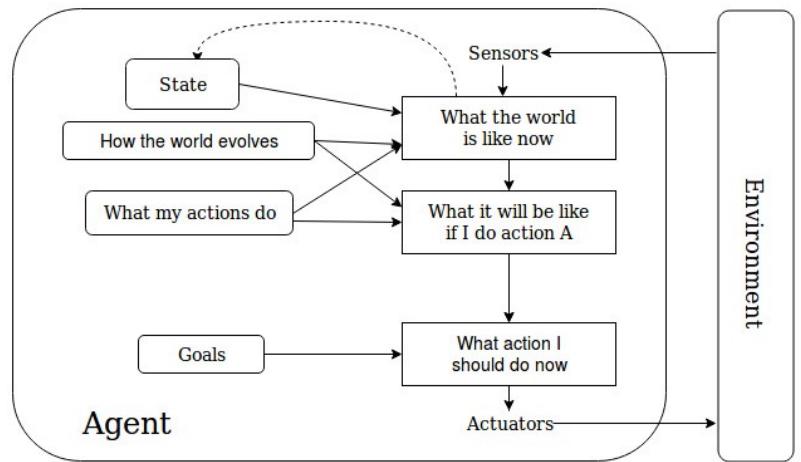


Comparison With Other Learning

- Supervised learning
 - Training information: labels
 - Objective: learn (input-label) mapping
 - Goodness criteria: $\text{Reduce error} = (\text{Predicted label} - \text{Actual label})$
- Reinforcement learning
 - Training information: reward functions
 - Objective: learn policy
 - Goodness criteria: maximal reward
- These two forms of learning are orthogonal – for different tasks

RL as a Learning-Based Agent

A general, alternative way of solving goal-based problems from just execution traces

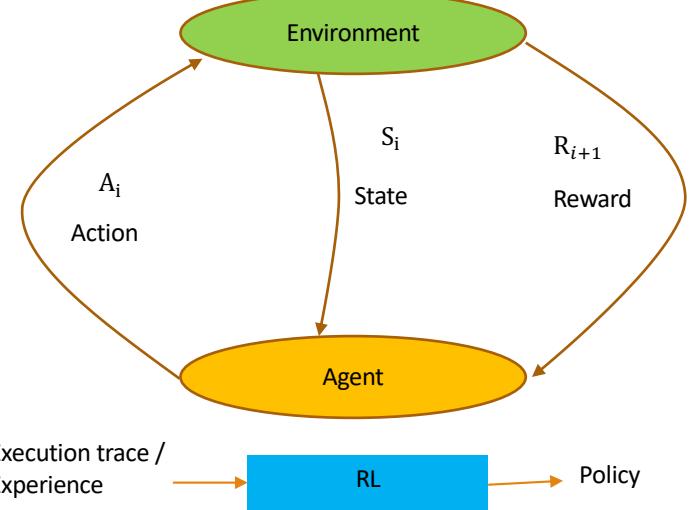
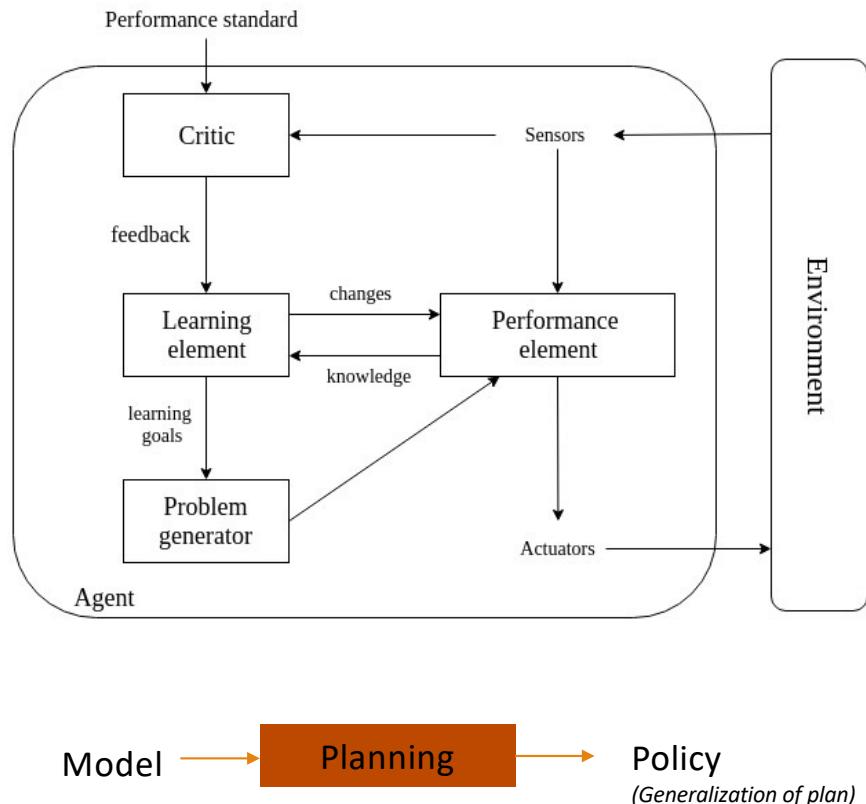


Goal- and Utility-based Intelligent Agent



RL as a Learning-Based Agent

A general, alternative way of solving goal-based problems from just execution traces

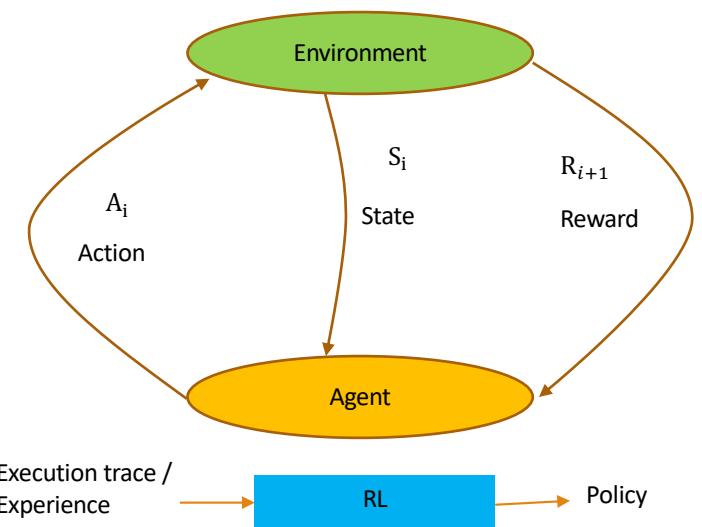


Model → **Planning** → Policy
(Generalization of plan)

RL as a Learning-Based Agent

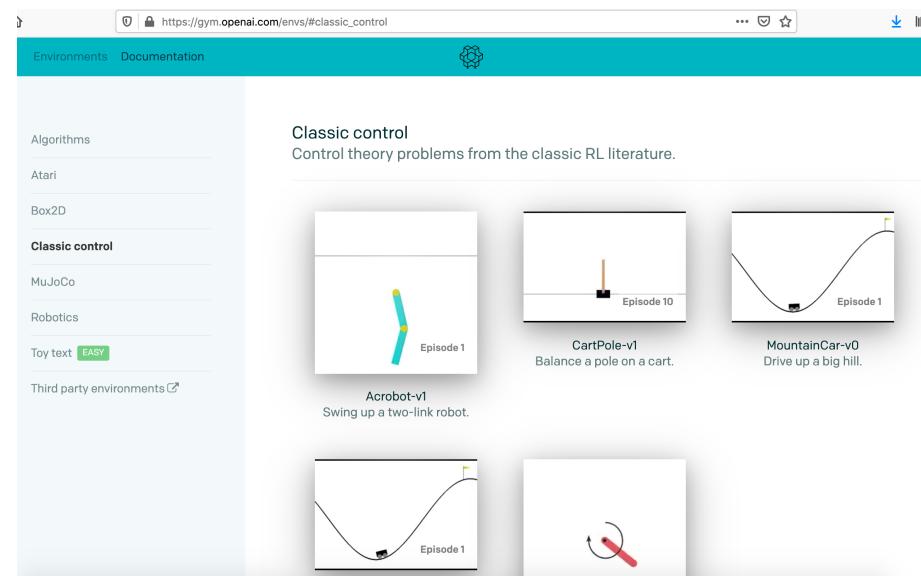
A general, alternative way of solving goal-based problems from just execution traces

Goal- and Utility-based Intelligent Agent



Exercise and Code – Gym RL

- RL using Open AI's Gym
 - <https://gymnasium.farama.org/> (Old: <https://gym.openai.com/>)
 - Environments: https://gym.openai.com/envs/#classic_control
- Exercise (5 mins):
 - Look at the various categories
 - Explore the videos



Exercise and Code – Gym RL

- RL using Open AI's Gym
 - <https://gymnasium.farama.org/>
 - Old: <https://gym.openai.com/>
- Code:
 - Latest: <https://github.com/biplav-s/course-ai-f24/blob/main/sample-code/I25-rl/RL%20with%20Gym.ipynb>
 - Old: <https://github.com/biplav-s/course-d2d-ai/blob/main/sample-code/I18-learning-agent/RL%20using%20Gym.ipynb>

Source: Russell & Norvig, AI: A Modern Approach

Diversity in RL Problems

- Environment - accessible or inaccessible
 - Accessible: states can be identified with percepts
 - Inaccessible environment: agent has to learn and maintain representation of state to track environment
- Knowledge of effects of action and utility, or learn
- Rewards
 - Available for all states or only terminal states
 - Actual utility or hints of increase/ decrease
- Ability to execute actions - Active learner or passive learner
 - A passive learner simply watches the world going by, and tries to learn the utility of being in various states
 - An active learner can actions to explore unknown environment

Source: Russell & Norvig, AI - A Modern Approach

Passive RL

- **Input**
 - policy: π_i
 - // Has no knowledge Reward $R(s)$ and Transition function $P(s' | s, a)$
- **Output**
 - Expected utility for each state, $U(s)$
- **Procedure:**
 - Execute a sequence of runs
 - At any instant, the agent knows only its current state and current reward, and the action it must take next. This action may lead it to more than one state, with different probabilities.
- **Expected Utility**

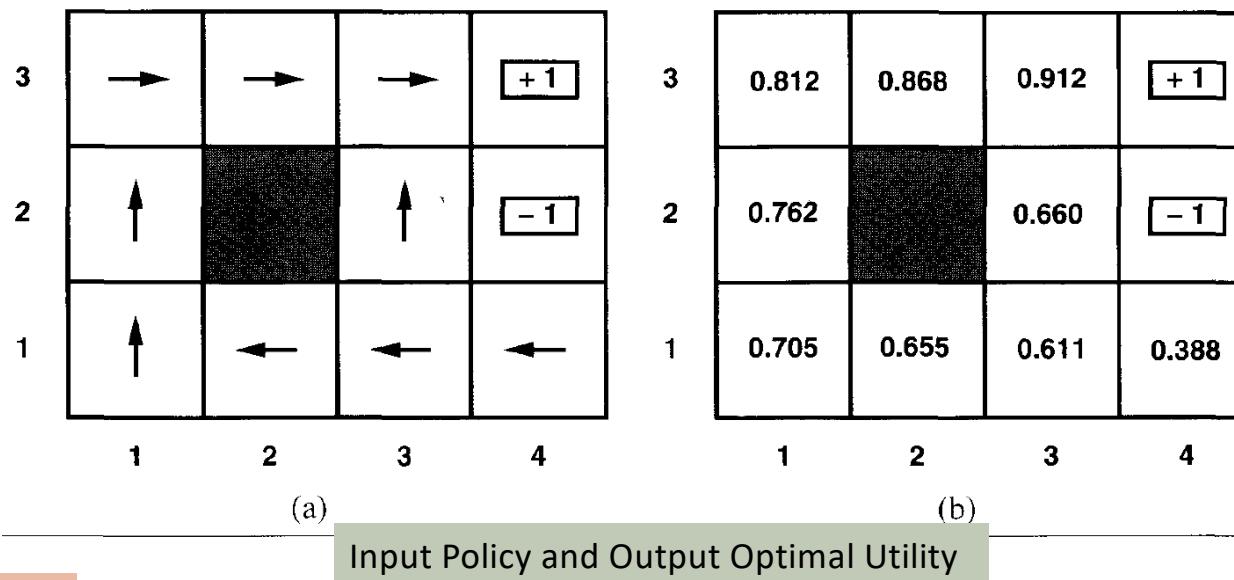
$$U^\pi(s) = E\left(\sum_{t=0}^{\infty} \gamma^t R^t(s')\right)$$

Illustration

```
# Action Directions
north = (0, 1)
south = (0, -1)
west = (-1, 0)
east = (1, 0)

policy = {
    (0, 2): east, (1, 2): east, (2, 2): east, (3, 2): None,
    (0, 1): north, (2, 1): north, (3, 1): None,
    (0, 0): north, (1, 0): west, (2, 0): west, (3, 0): west,
}
```

Policy: https://github.com/biplav-s/course-d2d-ai/blob/main/sample-code/l15-l16-l17-l18-agents/reinforcement_learning.ipynb



Source: Russell & Norvig, AI - A Modern Approach

The Markov Property – True of Many Domains

- Our policy at timepoint t is only dependent on the current state s
 - $\pi(a|s) = P(A_t = a|S_t = s)$
- Although the agent has a history up until S_t
 - $H_t = S_0, A_0, R_1 S_1, A_1, R_2 \dots S_{t-1}, A_{t-1}, R_t, S_t$
- One may assume that all relevant information about the future is contained in the current state and action
 - $P(S_{t+1} = s', R_{t+1} = r|S_t = s, A_t = a) = P(S_{t+1} = s', R_{t+1} = r|H_t = h_{t+1}, A_t = a)$
- This is a generalization of the Markov property to sequential decision problems
 - $P(S_{t+1}|S_t) = P(S_{t+1}|S_t, S_{t-1}, \dots S_0)$

Source: Forest A.'s RL Course

RL with Finite States

Solving a Finite MDP

- **States:** A discrete and finite set \mathcal{S}
- **Actions:** A discrete and finite set \mathcal{A}
- **Transition Probabilities:** $P(S_{t+1} = s', R_{t+1} = r | S_t = s, A_t = a)$
 - Defines the dynamics of the MDP
- The state-transition probabilities can be obtained from the transition probabilities
 - $p(s'|s, a) = \sum_{r \in \mathcal{R}} p(s', r | s, a)$ // Estimating state-transition by looking at reward of samples
- The **expected reward** can be obtained from the transition probabilities
 - $r(s, a) = \sum_{r \in \mathcal{R}} r \sum_{s' \in \mathcal{S}} p(s', r | s, a) = \mathbb{E}[R_{t+1} | S_t = s, A_t = a]$
// Estimating reward from transitions seen

Adapted from: Forest A.'s RL Course

Model-free RL: Q-learning

- Learning action-value functions
- $Q(a,i)$: value of doing action a in state i
- Relationship between utility U of state and Q value
 - $U(i) = \max Q(a, i)$
- Finding Q value based on whether transition probability is known
 - When M (transition is known)

$$Q(a, i) = R(i) + \sum_j M_{ij}^a \max_{a'} Q(a', j)$$

- Estimating with TD method

$$Q(a, i) \leftarrow Q(a, i) + \alpha (R(i) + \max_{a'} Q(a', j) - Q(a, i))$$

Source: Russell & Norvig, AI - A Modern Approach

RL with Deep Learning

- For small problems, like games, state-value function (U), action- utility value (Q), and transition functions (M), and policy functions are represented using a table
- But for large and realistic problems, number of states are countably large/ practically infinite
- Deep learning are excellent function approximators
 - Estimate Q -value i.e., action-value
- Not covered in this class

Exercise and Code – RL

- RL settings and solution methods
- Code: <https://github.com/biplav-s/course-d2d-ai/blob/main/sample-code/l18-learning-agent/RL%20using%20Gym.ipynb>

Source: Russell & Norvig, AI: A Modern Approach

Inverse Reinforcement Learning

- Given π^* and transition function M ,
 - can we recover R
- Or, given execution traces corresponding to π^*
 - can we recover R ?
- Applications
 - Path planning
 - Automated-driving
- Reference: Pieter Abbeel's course slides: <https://people.eecs.berkeley.edu/~pabbeel/cs287-fa12/slides/inverseRL.pdf>

More RL – Multi-Arm Bandits

- A decision maker iteratively selects one of multiple fixed choices (i.e., arms or actions) when the properties of each choice are only partially known at the time of allocation, and may become better understood as time passes.
- Used for
 - Recommendations
 - clinical trials investigating the effects of different experimental treatments while minimizing patient losses
 - adaptive routing efforts for minimizing delays in a network,
 - financial portfolio design

Credits: https://en.wikipedia.org/wiki/Multi-armed_bandit

RL References

- Sutton and Barto's Book: <http://incompleteideas.net/book/the-book.html>
 - Russell and Norvig, AI – A modern Approach
 - David Silver's RL course, <https://www.davidsilver.uk/teaching/>
-
- Inverse RL
 - A Survey of Inverse Reinforcement Learning: Challenges, Methods and Progress, <https://arxiv.org/abs/1806.06877>, 2018
 - Pieter Abbeel's course slides: <https://people.eecs.berkeley.edu/~pabbeel/cs287-fa12/slides/inverseRL.pdf>

Lecture 22-25: Summary

- We talked about
 - Planning
 - Uncertainty
 - LLMs and Planning
 - Quiz 3
 - Reinforcement Learning

Weeks 12-13: Concluding Comments

We talked about

- Lecture 22: Planning
- Lecture 23: LLM and Planning
- Lecture 24: Quiz 3
- Lecture 25: RL

- Week 1: Introduction, Aim: Chatbot / Intelligence Agent
- Weeks 2-3: Data: Formats, Representation and the Trust Problem
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- Week 13: Trustworthy Decision Making: Explanation, AI testing
- Week 14: AI for Real World: Tools, Emerging Standards and Laws; Safe AI/ Chatbots

Projects B: Sep 30 – Nov 20 (7 weeks; 400 points)

- End date: **Thursday, Nov 20**
 - Remember to update spreadsheet on data/ time when finished (**Column I**)
- Choices
 - Given by instructor
 - Defined by student using project-b teamplate; reviewed and approved by instructor

Upcoming Evaluation Milestones

- Projects B: Sep 30 – Nov 20
- Quiz 2: Oct 7
- Quiz 3: Nov 11
- Paper presentation (grad students only) : Nov 18
- Finals: Dec 11

About Week 14 – Lectures 26, 27

Week 13 – Lectures 26, 27

- Lecture 26: Graduate paper presentations
- Lecture 27: AI for the Real World – Bringing All Together; Advanced Topics

- Week 1: Introduction, Aim: Chatbot / Intelligence Agent
- Weeks 2: Data: Formats, Representation, ML Basics
- Week 3: Machine Learning – Supervised (Classification)
- Week 4: Machine Learning - Unsupervised (Clustering) –
- Topic 5: Learning neural network, deep learning, Adversarial attacks
- Week 6: Large Language Models – Representation and Usage issues
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- Week 14: AI for Real World: Tools, Emerging Standards and Laws; Safe AI/ Chatbots

Note: exact schedule changes slightly to accommodate for exams and holidays.