CSCE 580: Introduction to AI
CSCE 581: Trusted AI

Lecture 11: Constraints and Optimization

PROF. BIPLAV SRIVASTAVA, AI INSTITUTE

28TH SEP 2023

Carolinian Creed: "I will practice personal and academic integrity."

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Organization of Lecture 11

- Introduction Segment
  - Recap of Lecture 10
- Main Segment
  - Constraint Satisfaction Problem
  - Optimization Problems
- Concluding Segment
  - Course Project Discussion
  - About Next Lecture – Lecture 12
  - Ask me anything

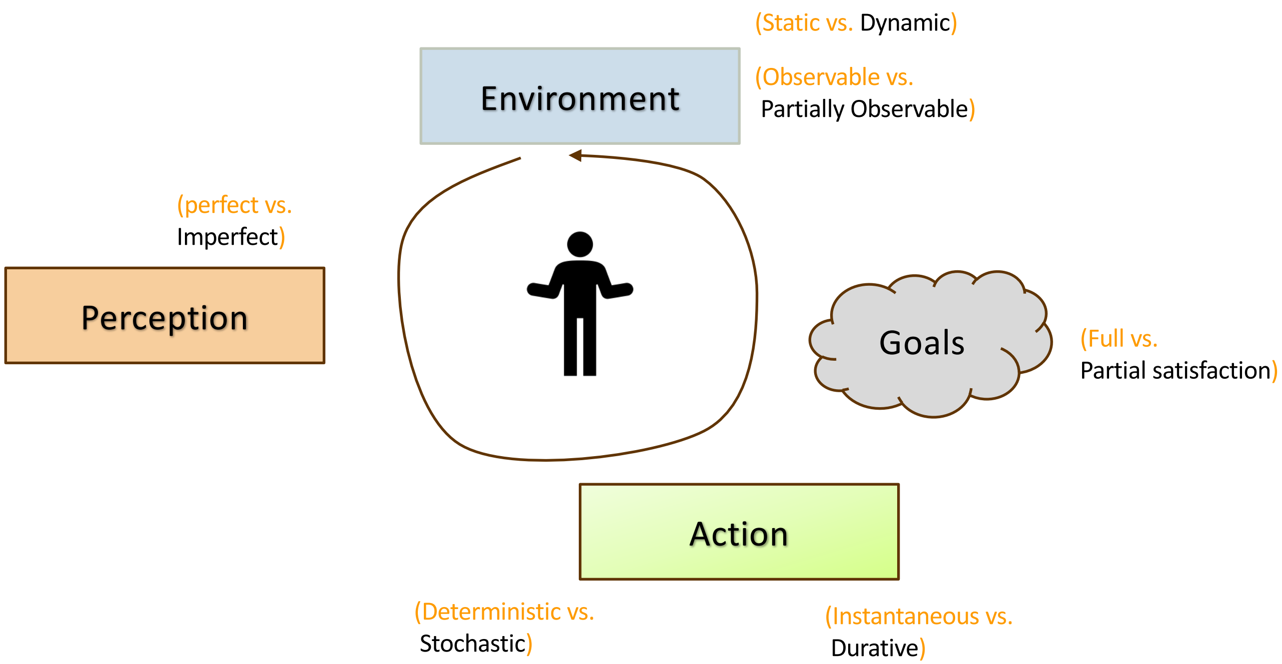
Introduction Section

Recap of Lecture 10

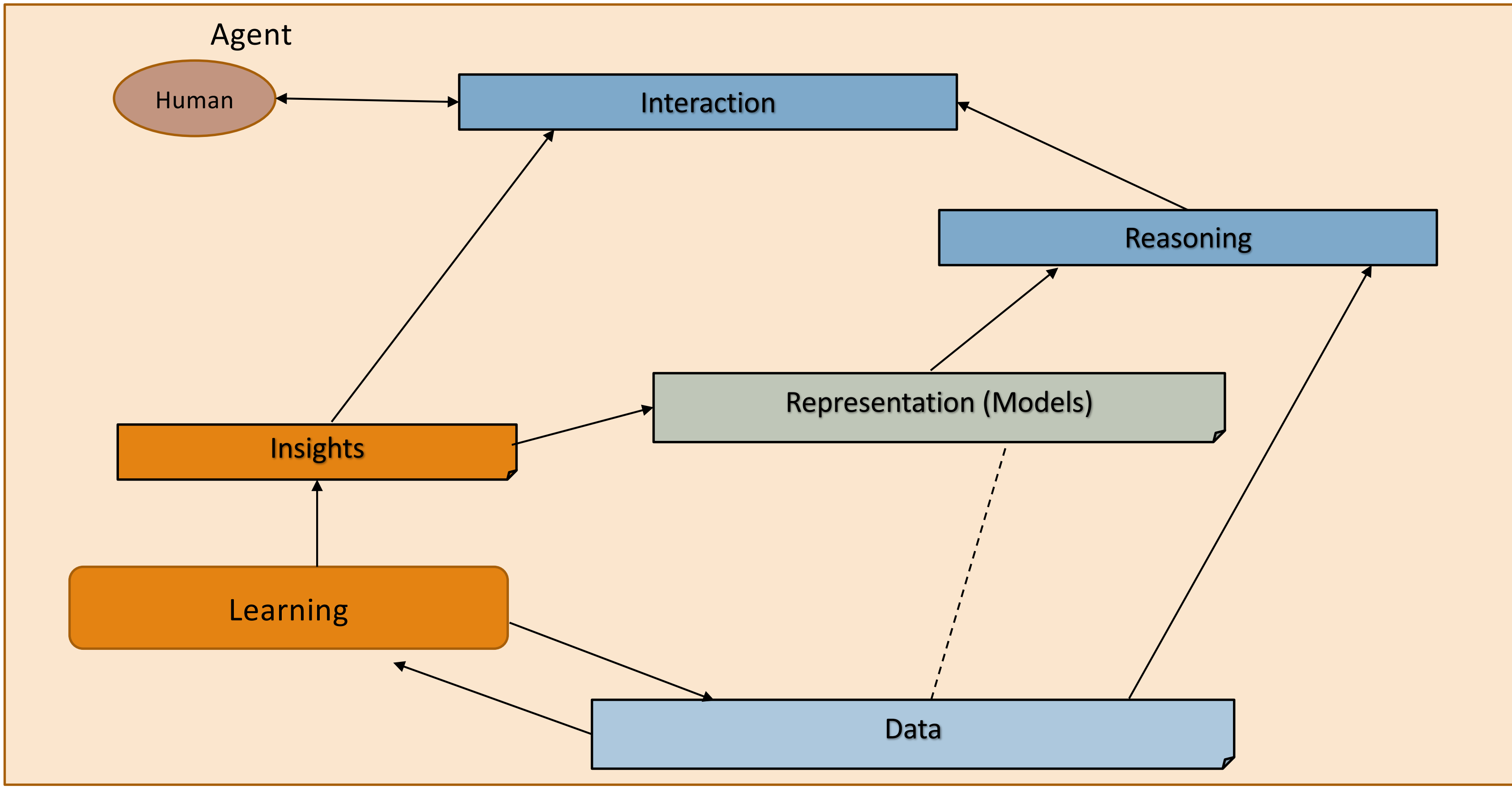
- Games and Search
- Minimax
- Alphabeta
- Monte Carlo Tree Search

- Overall - search topics covered
  - Formulating search problems
  - Uninformed search
  - Informed search
  - Local search
  - Game search

Intelligent Agent Model



Relationship Between Main AI Topics



Where We Are in the Course

CSCE 580/ 581 – In This Course

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

Main Section

Constraint Satisfaction Problems (CSPs)

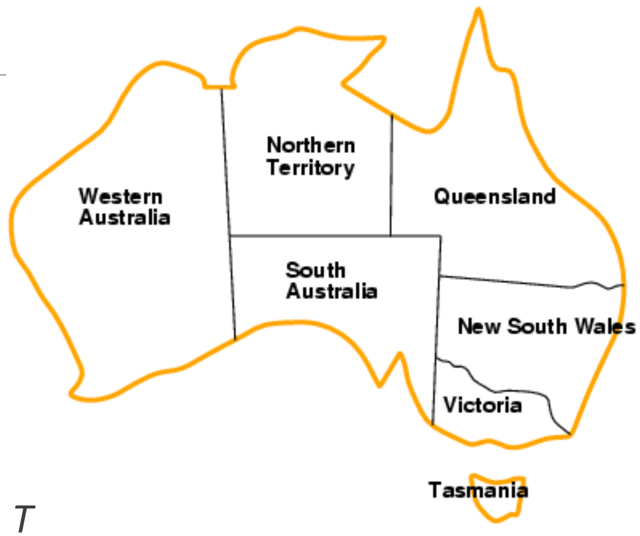
- X - A set of variables $\{X_1, \ldots, X_n\}$
- D - A set of domains $\{D_1, \ldots, D_n\}$, for each variable
- C – set of constraints specifying allowed combinations of values for variables

Example

- $X_1 = \{1,2,3\}$, $X_2 = \{1,2,3\}$
  - Here, $D_1 = D_2 = \{1,2,3\}$
- $C = < (X_1 , X_2), X_1 > X_2 >$

Solutions = Assignments to (X_1 , X_2) = $\{(3,1), (3,2), (2,1)\}$

Example: Map-Coloring



Variables *WA, NT, Q, NSW, V, SA, T*

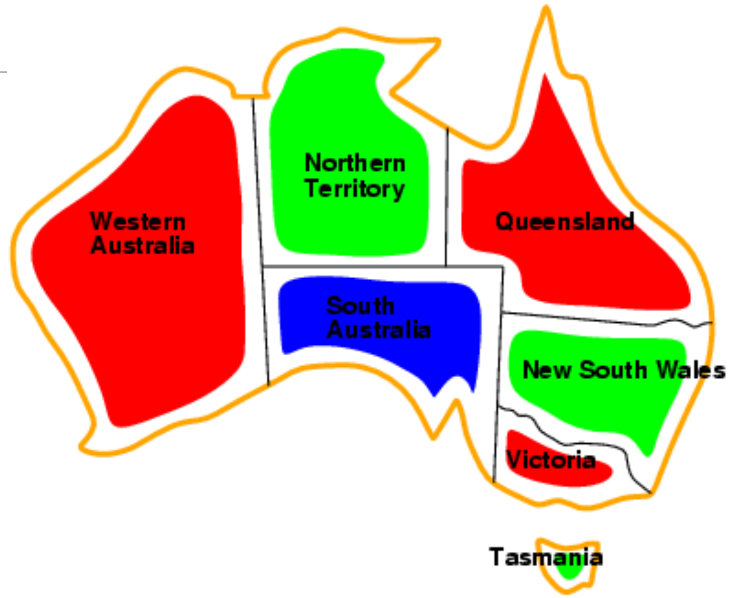
Domains D_i = {red,green,blue}

Constraints: adjacent regions must have different colors

e.g., WA ≠ NT, or (WA,NT) in {(red,green),(red,blue),(green,red),(green,blue),(blue,red),(blue,green)}

Adapted from:
Tuomas Sandholm's CSP Lecture
Russell & Norvig, AI: A Modern Approach

Example: Map-Coloring



Solutions are complete and consistent assignments

e.g., WA = red, NT = green, Q = red, NSW = green, V = red, SA = blue,T = green

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Varieties of CSPs

Discrete variables

- finite domains:
  - n variables, domain size d → $O(d^n)$ complete assignments
  - e.g., Boolean CSPs, incl. Boolean satisfiability (NP-complete)
- infinite domains:
  - integers, strings, etc.
  - e.g., job scheduling, variables are start/end days for each job
  - need a constraint language, e.g., $StartJob_1 + 5 \leq StartJob_3$

Continuous variables

- e.g., start/end times for Hubble Space Telescope observations
- linear constraints solvable in polynomial time by LP

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Varieties of constraints

Unary constraints involve a single variable,
- e.g., SA ≠ green

Binary constraints involve pairs of variables,
- e.g., SA ≠ WA

Higher-order constraints involve 3 or more variables,
- e.g., cryptarithmetic column constraints

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Constraint Propagation

- **Node Consistency**: a variable (node in CSP graph) is node—consistent of all the values in the variable's domain satisfy variable's unary constraints
- **Arc Consistency**: every variable in its domain satisfies binary constraints

function AC-3(csp) **returns** false if an inconsistency is found and true otherwise
  $queue \leftarrow$ a queue of arcs, initially all the arcs in csp

  while $queue$ is not empty **do**
    $(X_i,\ X_j) \leftarrow$ POP($queue$)
    if REVISE(csp, X_i, X_j) **then**
      if size of $D_i = 0$ **then return** $false$
      for each X_k **in** X_i.NEIGHBORS - $\{X_j\}$ **do**
        add $(X_k,\ X_i)$ to $queue$
  return $true$

function REVISE(csp, X_i, X_j) **returns** true iff we revise the domain of X_i
  $revised \leftarrow false$
  for each x **in** D_i **do**
    if no value y in D_j allows (x,y) to satisfy the constraint between X_i and X_j **then**
      delete x from D_i
      $revised \leftarrow true$
  return $revised$

Adapted from:
Russell & Norvig, AI: A Modern Approach

Constraint Propagation

- **Path Consistency**: A two variables set $\{X_i , X_j\}$ is path-consistent with respect to a third variable X_m if, for every assignment $\{X_i = a_i, X_j = a_j\}$ consistent with constraints on $\{X_i , X_j\}$, there is an assignment to X_m which is consistent with $\{X_i , X_m\}$ and $\{X_m , X_j\}$

- **k-consistency**: A CSP is k-consistent if for any set of (k-1) variables and their consistent assignments, a consistent value can always be assigned for the k^{th} variable.

Coding Example

- CSP code notebook
  - https://github.com/aimacode/aima-python/blob/master/csp.ipynb/

Making Optimal Decisions

Optimal Decision

- What is it? There is no absolute answer. In AI, there is the concept of a **rational** agent.
- Acting rationally: acting such that one ca achieve one's goals given one's beliefs (and information)
  - But what are one's goals
  - Are the always of achievement?
- Some options
  - Perfect rationality: maximize expected utility at every time instant
    - Given the available information; can be computationally expensive
    - "Doing the right thing"
  - Bounded optimality: do as well as possible given computational resources
    - Expected utility as high as any other agent with similar resources
  - Calculative rationality: *eventually* returns what would have been the rational choice

What Is It?

- As a working principle
  - Bounded or Calculative Rationality
- In observable and deterministic scenarios
  - Maximize utility: (benefit – cost)
- In scenarios with uncertainty and/ or unobservable
  - Maximize ***expected*** utility: (benefit – cost)

Example Situation – Course Selection

- A person wants to pass an academic program in two majors: A and B
- There are three subjects: A, B and C, each with three levels (*1, *2, *3). There are thus 9 courses: A1, A2, A3, B1, B2, B3, C1, C2, C3
- To graduate, at least one course at beginner (*1) level is needed in major(s) of choice(s), and two courses at intermediate levels (*2) are needed
- **Optimality considerations** in the problem
  - Least courses, fastest time to graduate, class size, friends attending together, …
- Answer questions
  - Q1: How many <u>minimum</u> courses does the person have to take ?
  - Q2: Can a person graduate in 2 majors studying 3 courses only?
  - …

Algorithms for Optimality

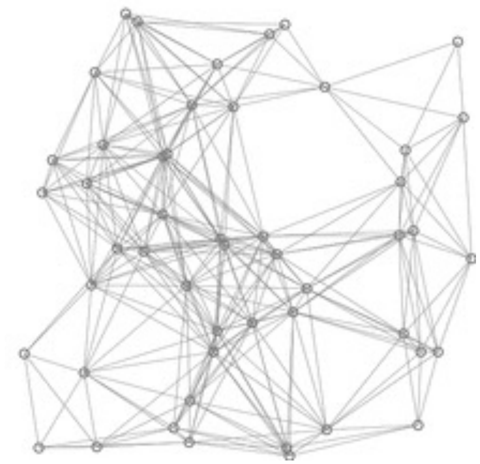
- Problem specific methods
  - Path finding
  - Linear programming
  - Constraint satisfaction and optimization

- General-purpose methods for optimality using search

Optimality: Example - Path Finding

Main steps

1. Mark all nodes unvisited. Create a set of all the unvisited nodes called the *unvisited set*.
2. Assign to every node a tentative distance value: set it to zero for our initial node and to infinity for all other nodes. Set the initial node as current.
3. For the current node, consider all of its unvisited neighbors and calculate their *tentative* distances through the current node. Compare the newly calculated *tentative* distance to the current assigned value and assign the smaller one.
4. When we are done considering all of the unvisited neighbors of the current node, mark the current node as visited and remove it from the *unvisited set*. A visited node will never be checked again.
5. If the destination node has been marked visited or if the smallest tentative distance among the nodes in the *unvisited set* is infinity, then stop. The algorithm has finished.
6. Otherwise, select the unvisited node that is marked with the smallest tentative distance, set it as the new "current node", and go back to step 3.



A demo of Dijkstra's algorithm based on Euclidean distance

Djikstra's Algorithm with positive numbers or labels that are [monotonically](#) non-decreasing.

Source: https://en.wikipedia.org/wiki/Dijkstra%27s_algorithm

Exercise and Code

- Linear Programming Methods
  - Link - https://github.com/biplav-s/course-d2d-ai/blob/main/sample-code/l16-optimal/Optimization.ipynb

Course Project

Project Discussion: What Problem Fascinates You ?

- Data
  - Water
  - Finance
  - …
- Analytics
  - Search, Optimization, Learning, Planning, …
- Application
  - Building chatbot
- Users
  - Diverse demographics
  - Diverse abilities
  - Multiple human languages

Project execution in sprints

- Sprint 1: (Sep 12 – Oct 5)
  - Solving: Choose a decision problem, identify data, work on solution methods
  - Human interaction: Develop a basic chatbot (no AI), no problem focus
- Sprint 2: (Oct 10 – Nov 9)
  - Solving: Evaluate your solution on problem
  - Human interaction: Integrated your choice of chatbot (rule-based or learning-based) and methods
- Sprint 3: (Nov 14 – 30)
  - **Evaluation:** Comparison of your solver chatbot with an LLM-based alternative, like ChatGPT

Project Discussion: Dates and Deliverables

Project execution in sprints

- Sprint 1: (Sep 12 – Oct 5)
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- Sprint 3: (Nov 14 – 30)
  - **Evaluation:** Comparison of your solver chatbot with an LLM-based alternative, like ChatGPT

- Oct 12, 2023
  - Project checkpoint
  - In-class presentation
- Nov 30, 2023
  - Project report due
- Dec 5 / 7, 2023
  - In-class presentation

Skeleton: A Basic Chatbot

- Run in an infinite loop until the user wants to quit
- Handle any user response
  - User can quit by typing "Quit" or "quit" or just "q"
  - User can enter any other text and the program has to handle it. The program should write back what the user entered and say – "I do not know this information".
- Handle known user query types // Depends on your project
  - "Tell me about N-queens", "What is N ?"
  - "Solve for N=4?"
  - "Why is this a solution? "
- Handle chitchat // Support at least 5, extensible from a file
  - "Hi" => **"Hello"**
  - …
- ***Store session details in a file***

Illustrative Project

1. **Title**: Solve and explain solving of n-queens puzzle
2. **Key idea**: Show students how a course project will look like
3. **Who will care when done**: students of the course, prospective AI students and teachers
4. **Data need**: n: the size of game; interaction
5. **Methods**: search
6. **Evaluation**: correctness of solution, quality of explanation, appropriateness of chat
7. **Users**: with and without AI background; with and without chess background
8. **Trust issue**: user may not believe in the solution, may find interaction offensive (why queens, not kings? …)

Project Discussion: Illustration

1. Create a private Github repository called “CSCE58x-Fall2023-<studentname>-Repo”. Share with Instructor (biplav-s) and TA (kausik-l)
2. Create Google folder called “CSCE58x-Fall2023-<studentname>-SharedInfo”. Share with Instructor (prof.biplav@gmail.com) and TA (lakkarajukausik90@gmail.com)
3. Create a Google doc in your Google repo called “Project Plan” and have the following by next class (Sep 5, 2023)

1. **Title**: Solve and explain solving of n-queens puzzle
2. **Key idea**: Show students how a course project will look like
3. **Who will care when done**: students of the course, prospective AI students and teachers
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Project Illustration: N-Queens

- Sprint 1: (Sep 12 – Oct 5)
  - Solving: Choose a decision problem, identify data, work on solution methods
    - Method 1: Random solution
    - Method 2: Search – BFS
    - Method 3: Search - …
  - Human interaction: Develop a basic chatbot (no AI) as outlined
  - Deliverable
    - Code structure in Github
      - ./data
      - ./code
      - ./docs
      - ./test
    - Presentation: Make sprint presentation on Oct 12, 2023

Reference: Project Rubric

- **Project results** – 60%
  - Working system ? – 30%
  - Evaluation with results superior to baseline? – 20%
  - Considered related work? – 10%
- **Project efforts** – 40%
  - Project report – 20%
  - Project presentation (updates, final) – 20%

- **Bonus**
  - Challenge level of problem – 10%
  - Instructor discretion – 10%
- **Penalty**
  - Lack of timeliness as per announced policy (right) - up to 30%

Milestones and **Penalties**

- Oct 12, 2023
  - Project checkpoint
  - In-class presentation
  - **Penalty: presentation not ready by Oct 10, 2023 [-10%]**
- Nov 30, 2023
  - Project report due
  - **Project report not ready by date [-10%]**
- Dec 5 / 7, 2023
  - In-class presentation
  - **Project presentations not ready by Dec 4, 2023 [-10%]**

Lecture 10: Summary

- We talked about
  - Constraint Satisfaction Problem
  - Optimization Problems

Concluding Section

About Next Lecture – Lecture 11

Lecture 11: Machine Learning

- Problem Settings
- Data preparation and feature engineering
- Solving classification problems