AI INSTITUTE #AIISC
UNIVERSITY OF SOUTH CAROLINA

UNIVERSITY OF SOUTH CAROLINA

*CSCE 580: Introduction to AI*
*CSCE 581: Trusted AI*

# Lecture 8: Search – Informed, Heuristics

PROF. BIPLAV SRIVASTAVA, AI INSTITUTE

19TH SEP 2023

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

**Credits**: **Copyrights of all material reused acknowledged**

# Organization of Lecture 8

- Introduction Segment
  - Recap of Lecture 7
  - Review of Quiz1
- Main Segment
  - Informed Search
  - Heuristics and Properties
  - Designing Heuristics
- Concluding Segment
  - Course Project Discussion
  - About Next Lecture – Lecture 8
  - Ask me anything

# Introduction Section

# Announcement: Modified Office Timing

Instructor's new timing for office hour - available at Room 515 of the AI Institute, 1112 Greene St (5th Floor):

* 1-2pm (Mondays)

* 3-4pm (Tuesdays)

If this does not work, we can schedule a separate mutually convenient time.

# Recap of Lecture 7

- Goal-directed problem solving agents
- How to formulate problem formulations
- Search concepts
  - Problems of controlled robot navigation, 8-tile, N-queens
- Search strategies
- Quiz 1

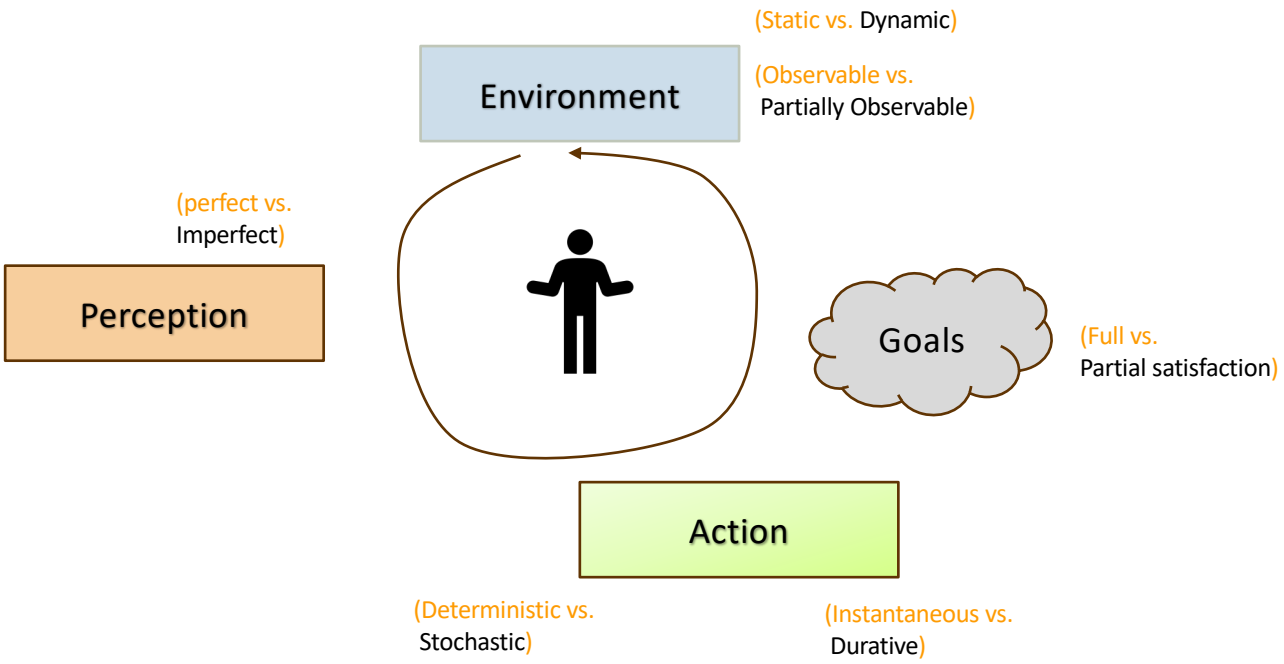
# Review of Quiz 1

| | |
|---|---|
| States<br>• Initial state<br>• Goal state | |
| Actions<br>• Transition model<br>• Action cost | |

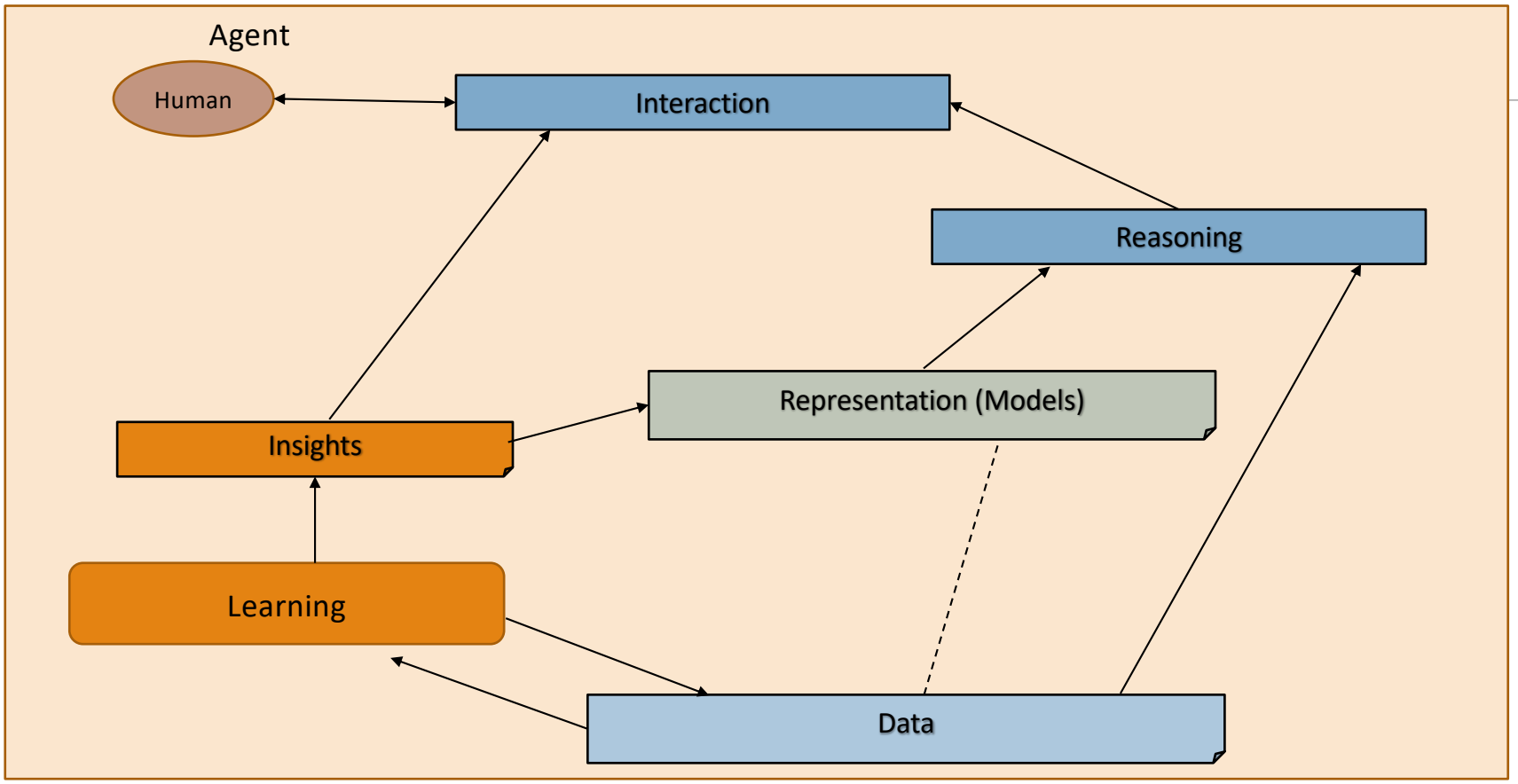
- Transition model: tells what it means to take actions -- how to move from one state to another.

So, you will have to come up with a state representation, then decide on actions, and then define function(s) to state what it means to take actions.

# 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

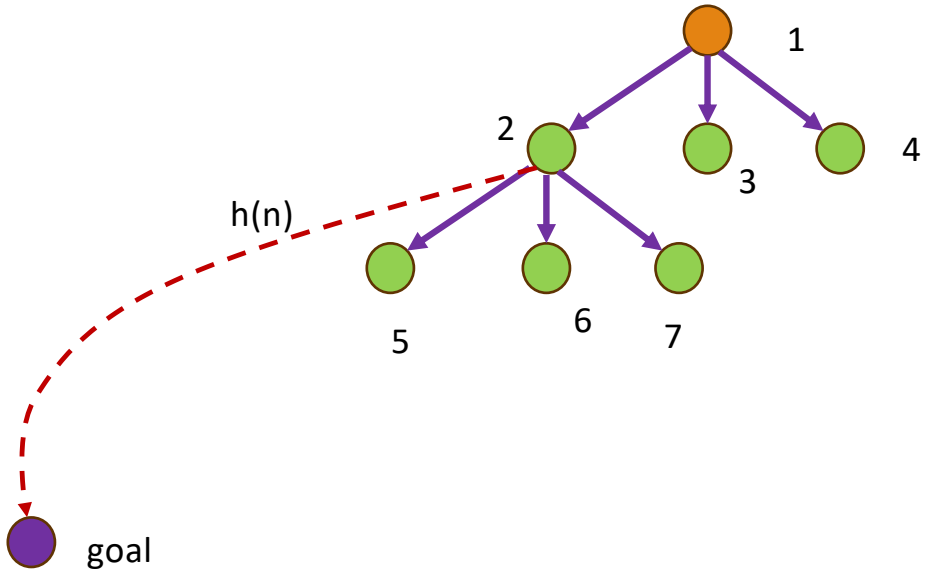
# Main Section

# Informed Search – Greedy best-first

Uses domain/problem specific hints to guide search

f(n) = h(n)

- f: estimated cost of best path via n to goal
- h: estimated cost to goal from n // h is also called heuristic function

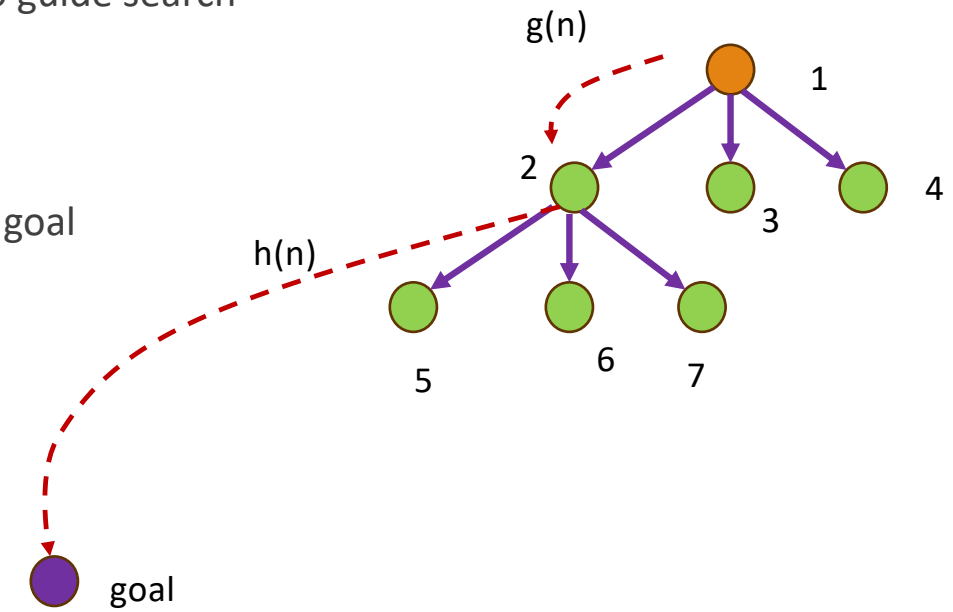


# Informed Search – A* search

Uses domain/problem specific hints to guide search

f(n) = g(n) + h(n)

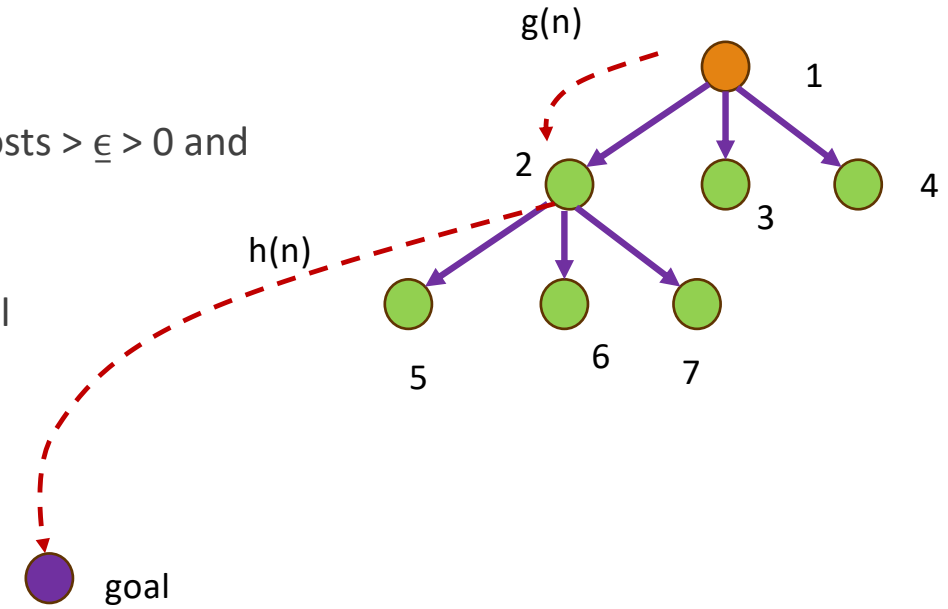
- f: estimated cost of best path via n to goal
- g: cost of best path to n
- h: estimated cost to goal from n



# Properties of A* search

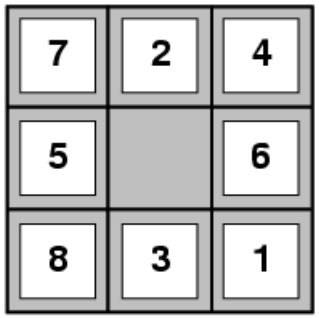
f(n) = g(n) + h(n)

- **A* is complete**, assuming actions costs > $\epsilon$ > 0 and state space has solution or is finite
- **h(n) is admissible**, i.e., never overestimates true cost to reach goal

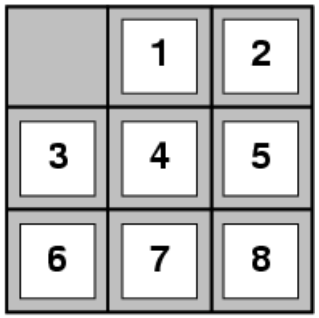


# Finding Heuristics Function

- h1: number of misplaced tiles (excluding blank)
  - H1(start) = 8
- h2: sum of the distance of tiles from goal (excluding blank)
  - h2(start) = (3 + 1 + 2) + (2 + 3) + (2 + 2 + 3) = 18
- True cost: 26



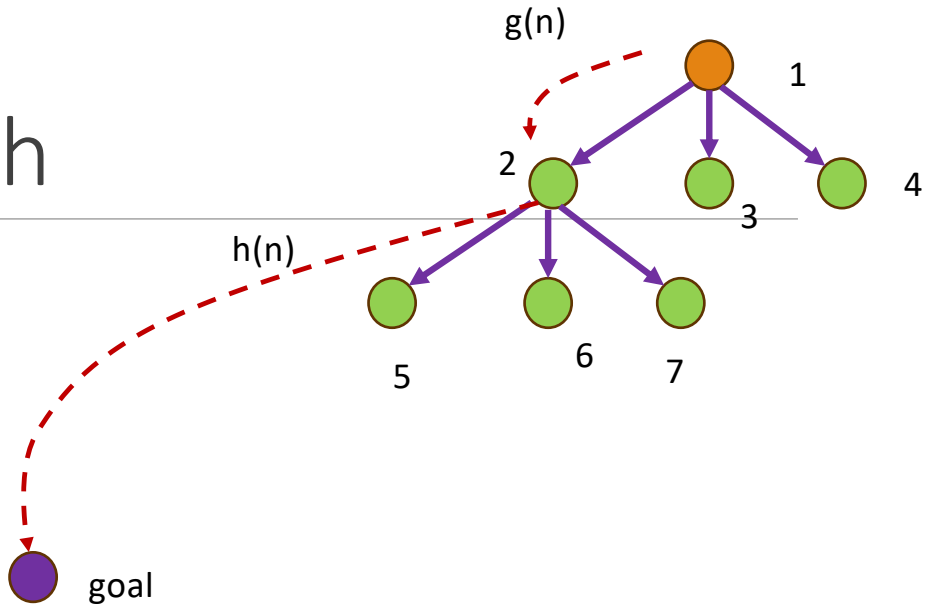
Start State



Goal State

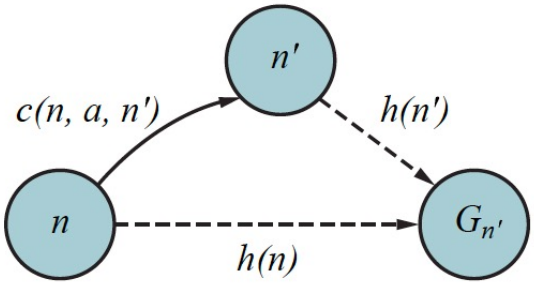
Adapted from:
Russell & Norvig, AI: A Modern Approach

# Properties of A* search




f(n) = g(n) + h(n)

- A **heuristic is consistent** if
  h(n) <= c(n, a, n') + h(n')



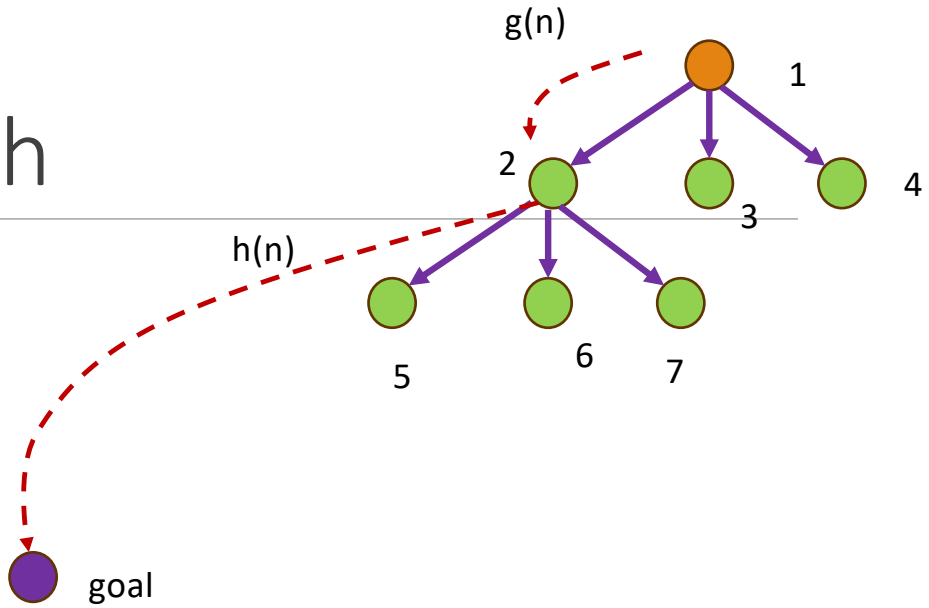

Adapted from:
Russell & Norvig, AI: A Modern Approach

# Properties of A* search

f(n) = g(n) + h(n)

- A* with consistent heuristic is **optimally efficient**

- A*
  - Any algo using search path and same heuristics at A* will atleast expand these nodes
  - Prunes (removes) search nodes that are not necessary for finding optimal solution

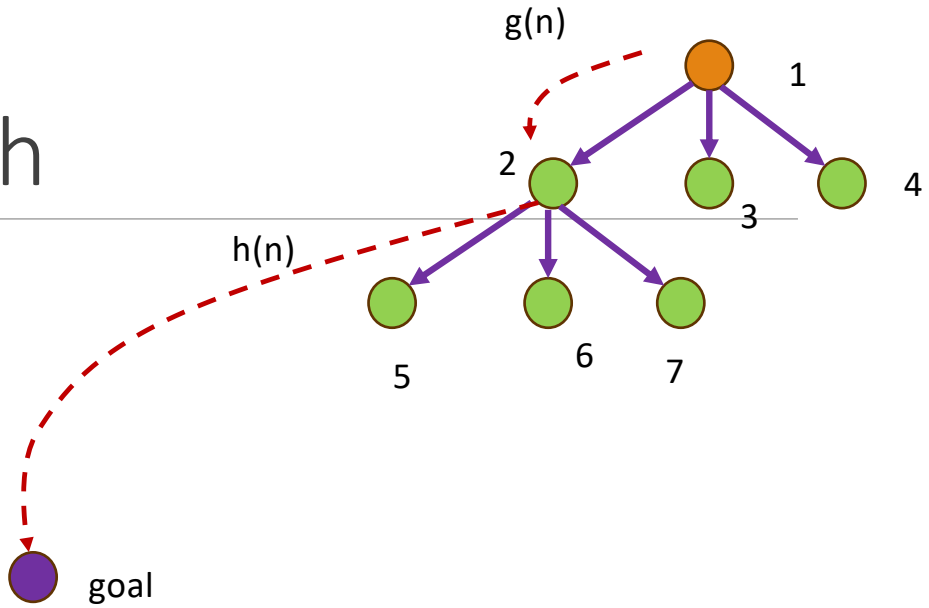



Adapted from:
Russell & Norvig, AI: A Modern Approach

# Type: Satisficing Search

f(n) = g(n) + W * h(n)

- If heuristic is inadmissible, A* may find just any solution

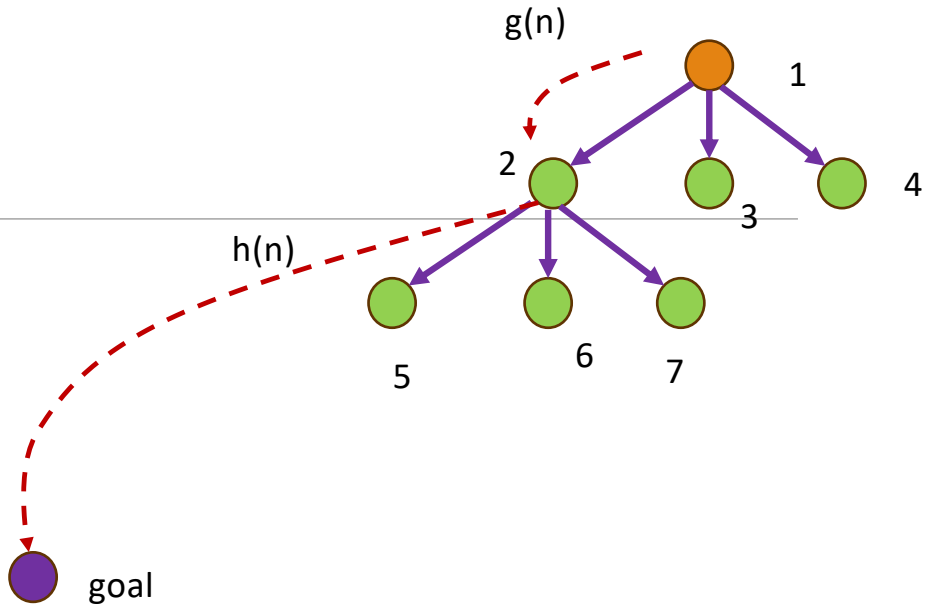



Adapted from:
Russell & Norvig, AI: A Modern Approach

# Type: Beam Search

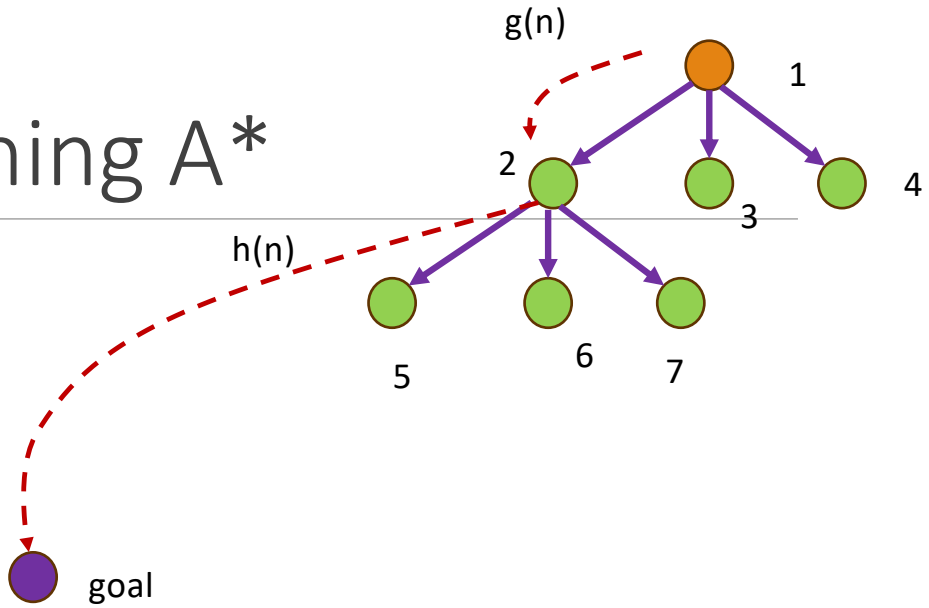
f(n) = g(n) + h(n)

- Keep only k (*a parameter*) nodes with the best f-score in frontier
- Incomplete and sub-optimal, but space efficient




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

# Type: Iterative Deepening A*




f(n) = g(n) + h(n)

- Similar to Iterative Deepening Depth search, but for f-score. Optimizes memory usage.
- In each iteration, search until find a node with f-score exceeding threshold; use the node's f-score as the new threshold
- Iterative search takes more time than A*

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

# Informed Search Types

| A* search | f(n) = g(n) + h(n) | (W = 1) |
|---|---|---|
| Uniform-cost search | f(n) = g(n) | (W = 0) |
| Greedy best-first search | f(n) = h(n) | (W = infinite) |
| Weighted A* search | f(n) = g(n) + W * h(n) | (1 < W < infinite) |

Notes:
Uniform-cost => uninformed
Weighted A* => satisficing

# Impact of Heuristics Function

| | Search Cost (nodes generated) | | | Effective Branching Factor | | |
|---|---|---|---|---|---|---|
| $d$ | BFS | A*($h_1$) | A*($h_2$) | BFS | A*($h_1$) | A*($h_2$) |
| 6 | 128 | 24 | 19 | 2.01 | 1.42 | 1.34 |
| 8 | 368 | 48 | 31 | 1.91 | 1.40 | 1.30 |
| 10 | 1033 | 116 | 48 | 1.85 | 1.43 | 1.27 |
| 12 | 2672 | 279 | 84 | 1.80 | 1.45 | 1.28 |
| 14 | 6783 | 678 | 174 | 1.77 | 1.47 | 1.31 |
| 16 | 17270 | 1683 | 364 | 1.74 | 1.48 | 1.32 |
| 18 | 41558 | 4102 | 751 | 1.72 | 1.49 | 1.34 |
| 20 | 91493 | 9905 | 1318 | 1.69 | 1.50 | 1.34 |
| 22 | 175921 | 22955 | 2548 | 1.66 | 1.50 | 1.34 |
| 24 | 290082 | 53039 | 5733 | 1.62 | 1.50 | 1.36 |
| 26 | 395355 | 110372 | 10080 | 1.58 | 1.50 | 1.35 |
| 28 | 463234 | 202565 | 22055 | 1.53 | 1.49 | 1.36 |

**Figure 3.26** Comparison of the search costs and effective branching factors for 8-puzzle problems using breadth-first search, A* with $h_1$ (misplaced tiles), and A* with $h_2$ (Manhattan distance). Data are averaged over 100 puzzles for each solution length $d$ from 6 to 28.

Reduces effective Bbranching factor!

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

# Choosing From a Choice of (Admissible) Heuristics

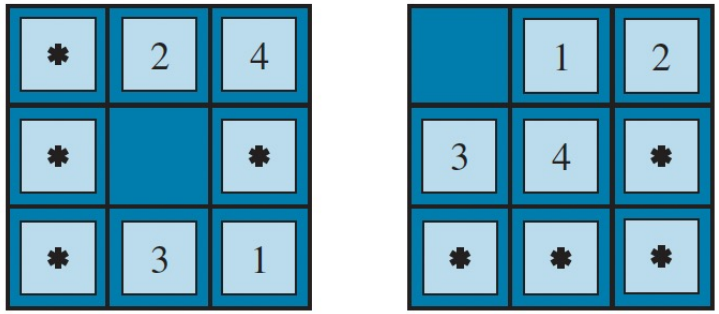
- Choose dominating heuristics
  - For n, h2(n) >= h1(n)

- If not dominating, choose maximum
  - h(n) = max {h1(n), h2(n), …, $h_k$(n)}

# Creating Heuristics Automatically

- From relaxed problems
  - Formulate a relaxed problem
  - Solve relaxed problem
  - Use solution length as heuristics for original problem (Relaxed problem heuristics)
- From sub-problems
  - Formulate a sub-problem
  - Solve relaxed sub-problem
  - Store solution of sub-problem
  - Compute admissible heuristic h_DB for each node by looking up sub-problem and its solution cost

  (Pattern databases)
- Learn heuristics
  - From data: past solutions, relaxed problems, …
  - **Predict heuristic value**



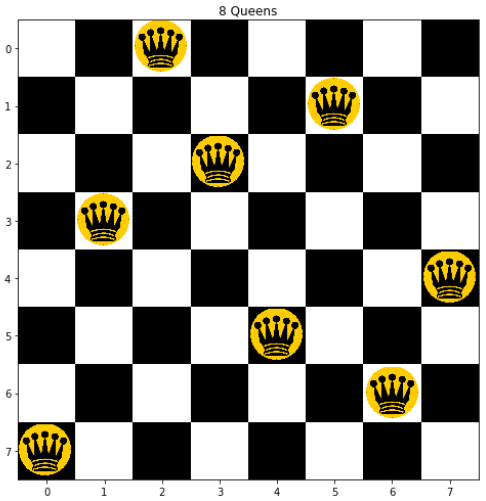

Adapted from:
Russell & Norvig, AI: A Modern Approach

# Coding Example

- 8-Puzzle – code notebook
  - https://github.com/biplav-s/course-ai-tai-f23/blob/main/sample-code/Class6-To-Class9-search.md

# Discussion: Relaxed Problems

- For N-Queens
- Pancake problem
- Many more
  https://www.movingai.com/SAS/index.html




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

# Uninformed Search Strategies

Search strategies use only the information available in the problem definition. They do not use a measure of distance to goal (*uninformed*).

- Breadth-first search
- Uniform-cost search
- Depth-first search
- Depth-limited search
- Iterative deepening search
- Bidirectional search

**Consideration:** type of queue used for the fringe of the search tree
(collection of tree nodes that have been generated but not yet expanded)

Adapted from:
1. Russell & Norvig, AI: A Modern Approach
2. Bart Selman's CS 4700 Course

# Informed Search – A* search

- Best-first
- A*
- Weighted A*
- Beam search [Incomplete]
- Iterative-deepening A* [Incomplete]

| A* search | f(n) = g(n) + h(n) | (W = 1) |
|---|---|---|
| Uniform-cost search | f(n) = g(n) | (W = 0) |
| Greedy best-first search | f(n) = h(n) | (W = infinite) |
| Weighted A* search | f(n) = g(n) + W * h(n) | (1 < W < infinite) |

# 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)
  - 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

- 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
4. **Data need**: n: the size of game; interaction
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7. **Users**: with and without AI background; with and without chess background
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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 effort**s – 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 8: Summary

- We talked about
  - Informed Search
  - Heuristics and Properties
  - Designing Heuristics

# Concluding Section

# About Next Lecture – Lecture 9

# Lecture 9: Local Search

- Searching in large spaces
  - Hill climbing
  - Simulated Annealing
  - Genetic programming

- Class 10: Adversarial games and search