1 handout: slides
Are We Done?

- EOLQs
- Are We Done?

Beyond A*
Suboptimal Search
Anytime Search
Real-time Search
EOLQs

**ALPHAGO**
00:10:29

**AlphaGo**
Google DeepMind

**LEE SEDOL**
00:01:00
Beyond A*
Greedy Best-first Search (GBFS)

\[ Q \leftarrow \text{an ordered list containing just the initial state.} \]

\textbf{Loop}

\textbf{If} \( Q \) is empty,

\textbf{then return failure.}

\textbf{Node} \( \leftarrow \text{Pop}(Q) \).

\textbf{If} \textbf{Node} is a goal,

\textbf{then return} \textbf{Node} (or path to it)

\textbf{else}

\textbf{Children} \( \leftarrow \text{Expand} \ ( \textbf{Node} ) \).

\textbf{Merge} \textbf{Children} into \( Q \), keeping \textbf{sorted by heuristic}.
GBFS on the 8-puzzle

\[ h(n) = \text{number of tiles out of place. (The blank is not a tile.)} \]

\[
\begin{array}{ccc}
2 & 8 & 3 \\
1 & 2 & 3 \\
\end{array}
\]

Start state: \[\begin{array}{ccc}
1 & 6 & 4 \\
7 & \Box & 5 \\
\end{array}\]

Goal state: \[\begin{array}{ccc}
8 & \Box & 4 \\
7 & 6 & 5 \\
\end{array}\]

Please draw the tree resulting from the first two node expansions.
Assume branching factor $b$ and solution at depth $d$. 

Completeness:
Time:
Space:
Admissibility:
Beam Search

Truncate queue to hold the most promising $k$ nodes. $k$ is the beam width.
Works best with breadth-first search!
Suboptimal Search

- EOLQs
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- **Suboptimal Search**
  - Problem Settings
  - wA*
  - wA* Behavior
  - Distance-to-go
  - RR-\(d\)
- Anytime Search
- Real-time Search
- EOLQs
Problem Settings

optimal: minimize solution cost
suffer all with \( f(n) = g(n) + h(n) < f^* \)

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greedy: minimize solving time

bounded suboptimal: minimize time subject to relative cost bound (factor of optimal)

bounded cost: minimize time subject to absolute cost bound

contract: minimize cost subject to absolute time bound

anytime: iteratively converge to optimal

utility: maximize given function of cost and time
\[ f'(n) = g(n) + w \cdot h(n) \]

- nodes with high \( h(n) \) look even worse
- no infinite rabbit holes
- suboptimality bounded: within a factor of \( w \) of optimal!
optimal: uniform-cost search
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optimal: A*
bounded suboptimal: Weighted A*
For Speed: Distance-to-go, Not Cost-to-go

how to minimize solving time?
how to minimize solving time?
how to minimize number of expansions?
how to minimize solving time?
how to minimize number of expansions?
take the shortest path to a goal
For Speed: Distance-to-go, Not Cost-to-go

how to minimize solving time?
how to minimize number of expansions?
take the shortest path to a goal
for domains with costs, this is not $h(n)$

new information source: distance-to-go $= d(n)$
For Speed: Distance-to-go, Not Cost-to-go

how to minimize solving time?
how to minimize number of expansions?
take the shortest path to a goal
for domains with costs, this is not \( h(n) \)

new information source: distance-to-go = \( d(n) \)

Speedy: best-first search on \( d \)
bounded-suboptimal using $h, \hat{h}, d$

optimal: uniform-cost
bounded-suboptimal using $h$, $\hat{h}$, $d$

optimal: $A^*$
bounded-suboptimal using $h, \hat{h}, d$

bounded suboptimal: Weighted A*
bounded-suboptimal using $h, \hat{h}, d$

bounded suboptimal: Optimistic Search (ICAPS, 2008)
bounded-suboptimal using $h, \hat{h}, d$
Anytime Search
1. run weighted A*
2. keep going after finding a goal
3. keep best goal found (can test at generation)
4. prune anything with $f(n) > incumbent$

Anytime Restarting A* (ARA*): lower weight after finding each solution

Anytime EES
Break

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Beyond A*

Suboptimal Search

Anytime Search
- Anytime A*
- Break

Real-time Search

EOLQs

- asst2 (asst8), asst 3
- scores and grades
Real-time Search
keep hash table of $h$ values for visited states

1. for each neighbor of current state $s$
2. either find $h$ in table or do some lookahead
3. add edge cost to get $f$
4. update $h(s)$ to second-best $f$ value
5. move to best neighbor
1. single A* lookahead (LSS)
2. update all $h$ values in LSS
3. move to frontier
Search Algorithms

Uninformed: DFS, UCS
Admissible: A*
Limited memory: iterative deepening (IDDFS, IDA*)
Satisficing: GBFS, Speedy, Beam
Bounded suboptimal: wA*, RR-\(d\)
Real-time: RTA*, LSS-LRTA*

Wheeler Ruml (UNH)
Other Shortest-path Algorithms

- SMA*, IE
- RBFS
- Bugsy
- Rectangle Search
- any-angle pathfinding, Euclidean pathfinding
- multiobjective search
- multi-level planning: TAMP, MAPF

Course projects!
EOLQs

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EOLQs
Please write down the most pressing question you have about the course material covered so far and put it in the box on your way out.

*Thanks!*