Foundations of Artificial Intelligence

17. State-Space Search: IDA*

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State-Space Search: Overview

Chapter overview: state-space search

- 5.–7. Foundations
- 8.–12. Basic Algorithms
- 13.–19. Heuristic Algorithms
  - 13. Heuristics
  - 14. Analysis of Heuristics
  - 15. Best-first Graph Search
  - 16. Greedy Best-first Search, A*, Weighted A*
  - 17. IDA*
  - 18. Properties of A*, Part I
  - 19. Properties of A*, Part II

IDA*: Idea

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Idea: use the concepts of iterative-deepening DFS

- bounded depth-first search with increasing bounds
- instead of depth we bound f
  (in this chapter $f(n) := g(n) + h(n.\text{state})$ as in A*)

$\rightsquigarrow$ IDA* (iterative-deepening A*)

- tree search, unlike the previous best-first search algorithms

IDA*: Algorithm

Remarks on the Algorithm (1)

- We describe an IDA* implementation with explicit search nodes.
- More efficient implementations leave search nodes implicit, as in the depth-first search algorithm in Chapter 12.

Remarks on the Algorithm (2)

- Our recursive function calls yield two values:
  - *f_limit*, the next useful f-bound for the subtree considered by the call (or **none** if a solution was found)
  - *solution*, the found solution (or **none**)
- More efficient implementations store these values (in instance variables of a class or in a closure) to save time for passing these values.

IDA*: Pseudo-Code (Main Procedure)

IDA*: Main Procedure

n_0 := make_root_node()
f_limit := 0
while *f_limit* $\neq \infty$:
    $\langle$*f_limit*, *solution*$\rangle$:= recursive_search(n_0, *f_limit*)
    if *solution* $\neq$ **none**:
        return *solution*
return unsolvable

IDA*: Pseudo-Code (Depth-first Search)

function recursive_search(n, f_limit):

if $f(n) > f\_limit$:
    return $\langle f(n), \textbf{none} \rangle$
if is_goal(n.state):
    return $\langle \textbf{none}, \text{extract\_path}(n) \rangle$
$next\_limit := \infty$
for each $\langle a, s' \rangle \in$ succ(n.state):
    if $h(s') < \infty$:
        $n' := \text{make\_node}(n, a, s')$
        $\langle rec\_limit, solution \rangle := \text{recursive\_search}(n', f\_limit)$
        if $solution \neq \textbf{none}$:
            return $\langle \textbf{none}, solution \rangle$
        $next\_limit := \min(next\_limit, rec\_limit)$
return $\langle next\_limit, \textbf{none} \rangle$

IDA*: Properties

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Inherits important properties of A* and depth-first search:

- semi-complete if h safe and $cost(a) > 0$ for all actions a
- optimal if h admissible
- space complexity $O(\ell b)$, where
  - ℓ: length of longest generated path
    (for unit cost problems: bounded by optimal solution cost)
  - b: branching factor

⇝ proofs?

IDA*: Discussion

- compared to A* potentially considerable overhead because no duplicates are detected
  - ⇝ exponentially slower in many state spaces
  - ⇝ often combined with partial duplicate elimination (cycle detection, transposition tables)
- overhead due to iterative increases of f bound often negligible, but not always
  - especially problematic if action costs vary a lot: then it can easily happen that each new f bound only reaches a small number of new search nodes

Summary

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- IDA* is a tree search variant of A*
  based on iterative deepening depth-first search
- main advantage: low space complexity
- disadvantage: repeated work can be significant
- most useful when there are few duplicates