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EH2750 Computer Applications in Power Systems, Advanced Course.

Lecture 4

Professor Lars Nordström, Ph.D.
Dept of Industrial Information & Control systems, KTH
larsn@ics.kth.se

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Outline of the Lecture

- Repeating where we are right now
  - Intelligent Agents of various types
  - How does this appear in JACK?
- Searching for solutions (AI book - Ch 3)
- Informed Searches (Excerpt)
- Planning

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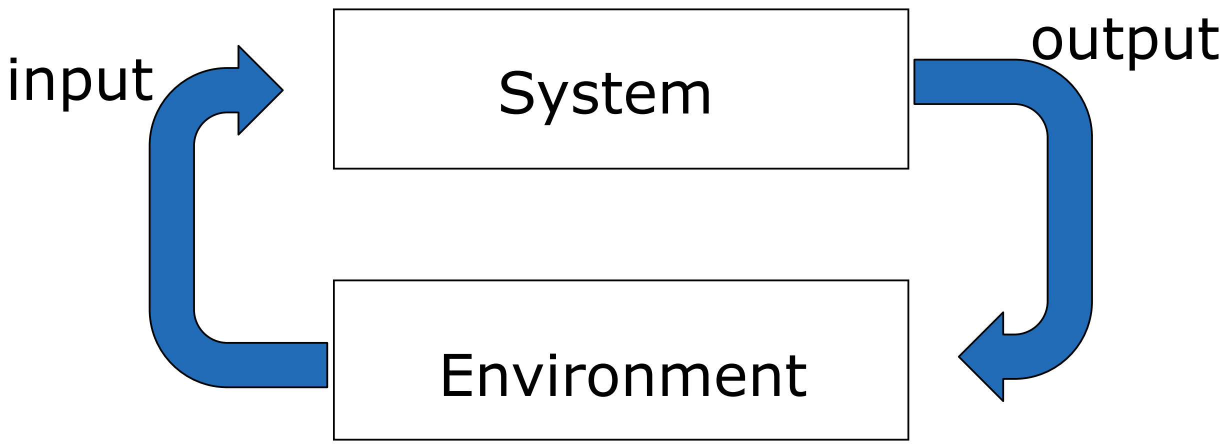
What is an Intelligent Agent?

- The main point about agents is they are *autonomous*: capable of acting independently, exhibiting control over their internal state
- Thus: *an intelligent agent is a computer system capable of flexible autonomous action in some environment in order to meet its design objectives*



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The discussion so far

- Chapter 2 describes the idea of agents that perform tasks in an environment and sets some definitions

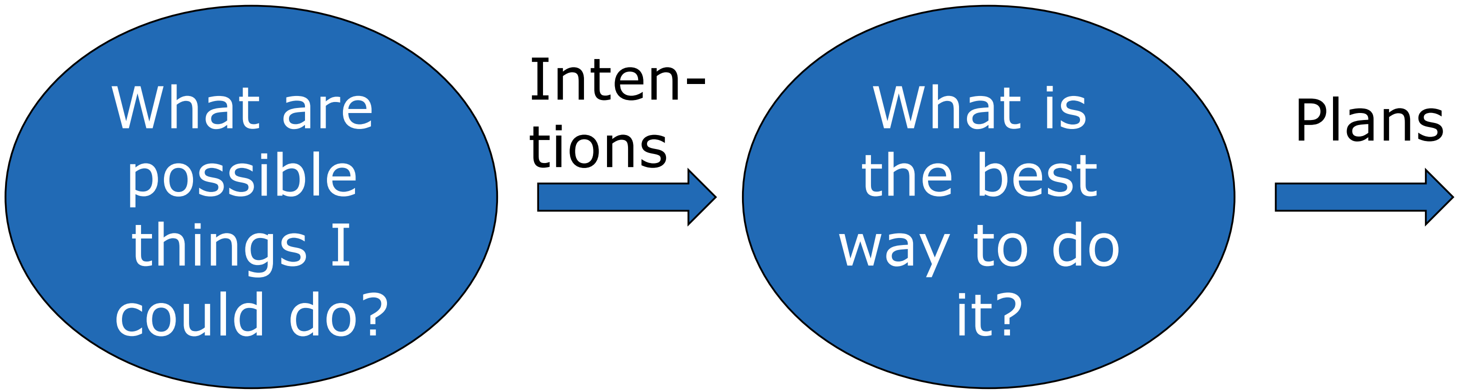
- Chapters 3, 4, & 5 describe three different approaches to describing and developing the apparent Intelligence in the agents.

  - Chapter 3 – Deductive Reasoning Agents
  - Chapter 4 – Practical Reasoning Agents
  - Chapter 5 - Reactive (and Hybrid Agents)

- Today, we take a deeper look at searching & planning

Practical Reasoning

- Human practical reasoning consists of two activities:
  - *deliberation*
    deciding *what* state of affairs we want to achieve
  - *means-ends reasoning*
    deciding *how* to achieve these states of affairs
- The outputs of deliberation are *intentions*



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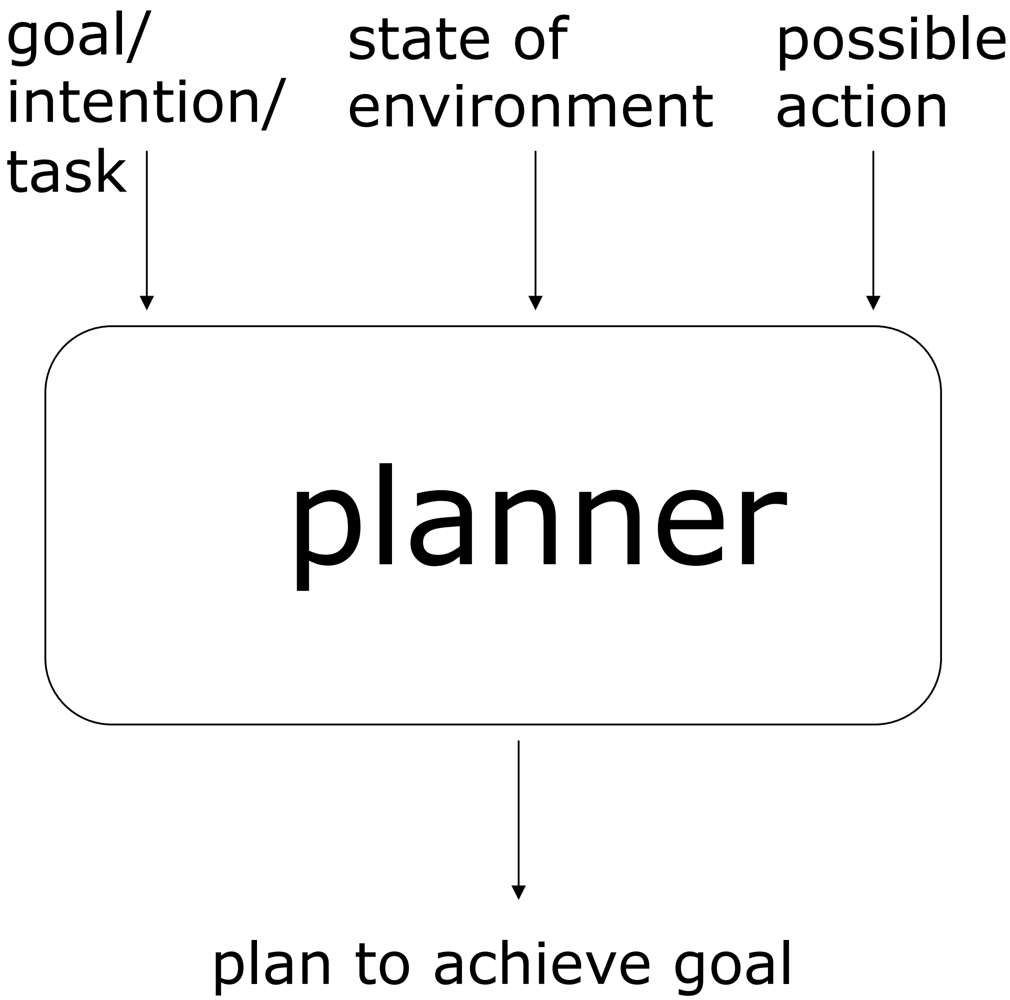
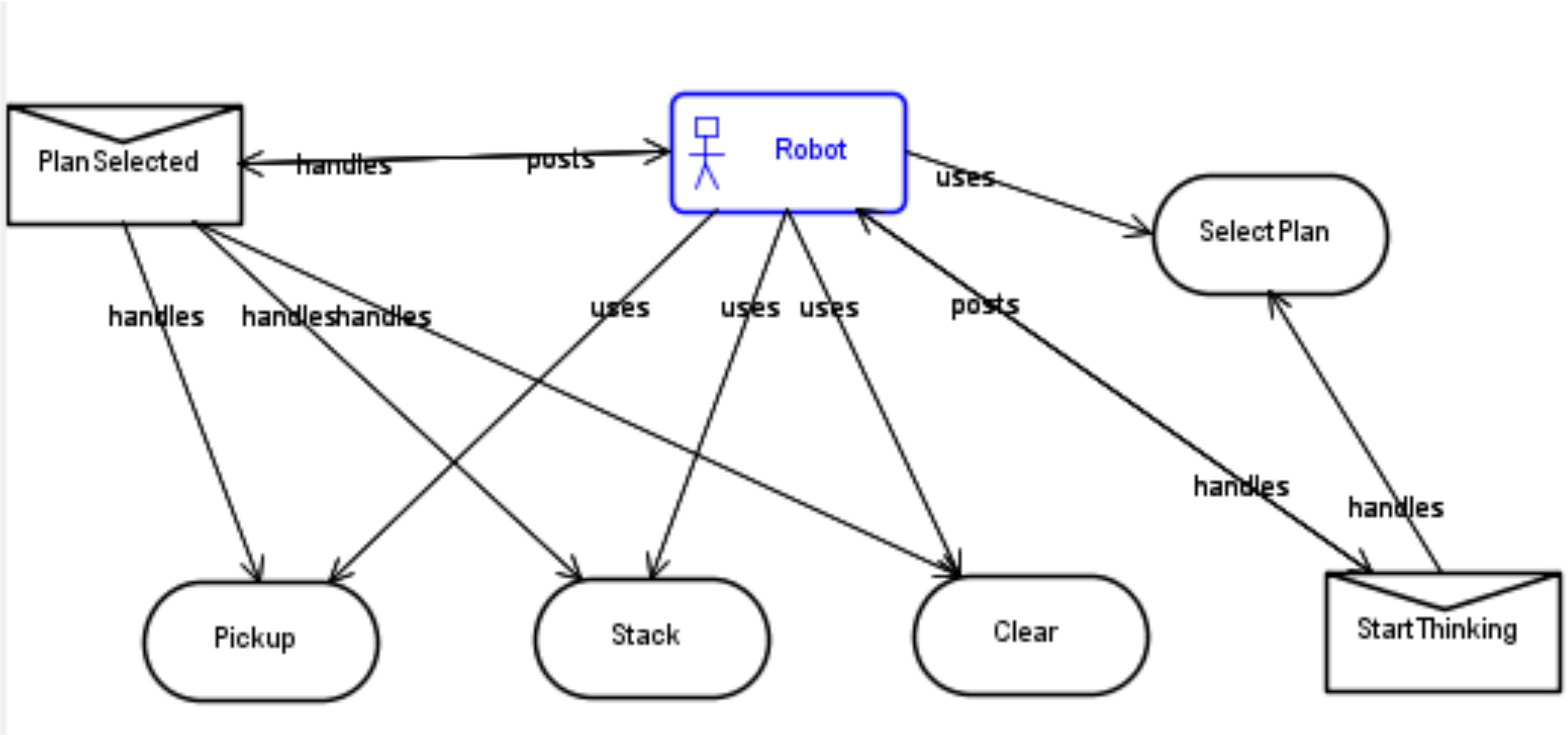
Planning is a big thing in AI



How this can look in JACK



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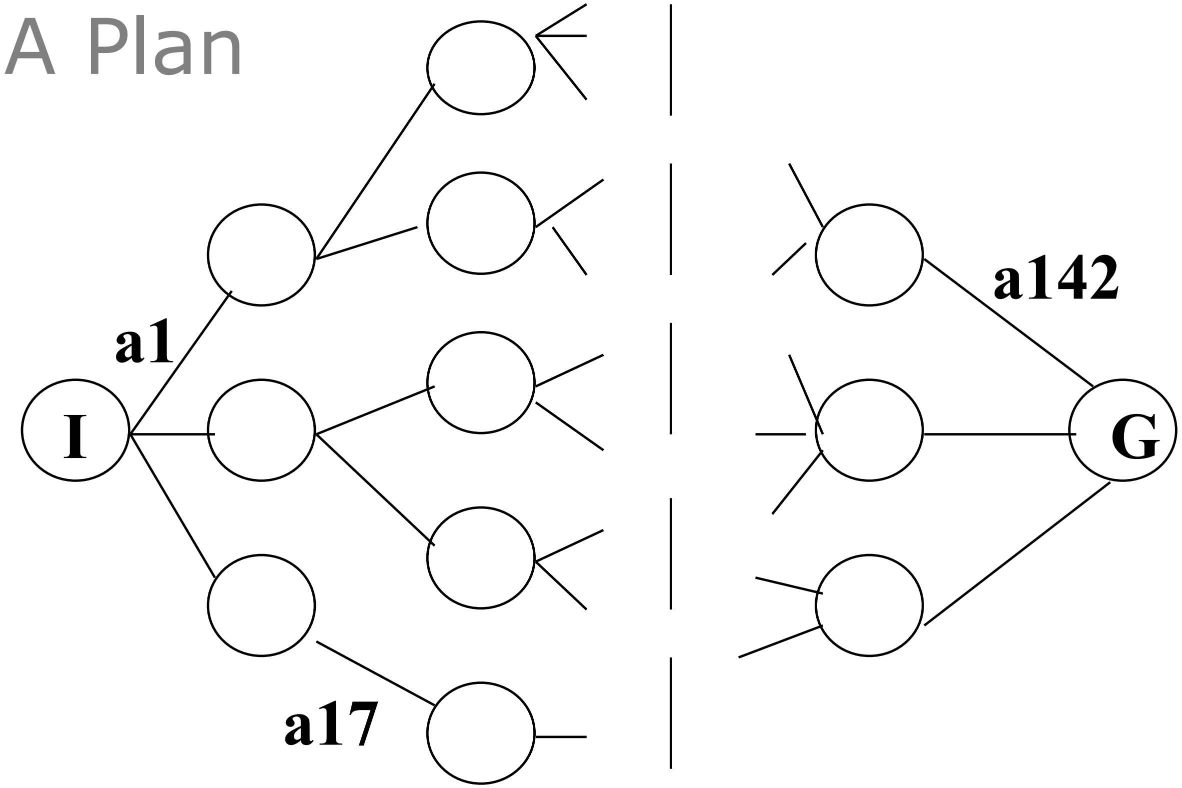
Tree Search Algorithms

- Tree searching is a classic structure for finding solutions to a problem.
- The program searches through a Tree (graph) to find a solutions
- States are the **nodes** in the tree and actions are the **edges**
- Nodes are expanded into sucessor nodes using a successor function
- Which nodes to expand are determined by which search strategy the program has implemented.

A Plan



- What is a plan?
  A sequence (list) of actions, with variables replaced by constants.

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Practical Reasoning Agent

```
function SIMPLE-PROBLEM-SOLVING-AGENT(percept) returns an action
   inputs: percept, a percept
   static: seq, an action sequence, initially empty
           state, some description of the current world state
           goal, a goal, initially null
           problem, a problem formulation

   state ← UPDATE-STATE(state, percept)
   if seq is empty then do
       goal ← FORMULATE-GOAL(state)
       problem ← FORMULATE-PROBLEM(state, goal)
       seq ← SEARCH(problem)
   action ← FIRST(seq)
   seq ← REST(seq)
   return action
```

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First some assumptions:

The agent and the environment

- In Lecture 2, we discussed the characteristics of the environment the agent exists within
  - Accessible vs Inaccessible
  - Deterministic vs non-deterministic
  - Static vs Dynamic
  - Continuous vs Discrete
- For the searching & planning discussion we assume:
  - Accessible, Deterministic, Static & Discrete

Environments
Accessible vs. *inaccessible*

- An accessible environment is one in which the agent can obtain complete, accurate, up-to-date information about the environment's state
- Most moderately complex environments (including, for example, the everyday physical world and the Internet) are inaccessible
  - Subsets of the real-world can of course be made accessible
  - Measurements in a Power grid (U,I,P,Q, states, φ etc)
- The more accessible an environment is, the simpler it is to build agents to operate in it

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Environments – *Deterministic* vs. *non-deterministic*

- A deterministic environment is one in which any action has a single guaranteed effect — there is no uncertainty about the state that will result from performing an action
- The physical world can to all intents and purposes be regarded as non-deterministic
  - Again, subsets of the real world can appear deterministic
- Non-deterministic environments present greater problems for the agent designer

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Environments
Static vs. *dynamic*

- A static environment is one that can be assumed to remain unchanged except by the performance of actions by the agent

- A dynamic environment is one that has other processes operating on it, and which hence changes in ways beyond the agent's control

- Other processes can interfere with the agent's

- The real world is obviously a highly dynamic environment
  - But is a distribution grid a highly dynamic environment?

Environments
Discrete vs. *continuous*

- An environment is discrete if there are a fixed, finite number of actions and percepts in it

- A chess game is an example of a discrete environment, and taxi driving an example of a continuous one

- Continuous environments have a certain level of mismatch with computer systems

- Discrete environments could *in principle* be handled by a kind of “lookup table”

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Problem Formulation

- Before starting the search for a solution, we need to define the problem we are trying to solve

- A Problem formulation has the following parts:
  - An initial state
  - Actions possible in terms of **successor** function, that is a list of tuples:
    - `(Action, Successor)`
  - A goal state and a test if we are at the goal
  - A path cost related to the cost of a path/action*

*It is easy to think of the steps along the path as separate actions, this is OK, but formally not correct at this stage.

Example - Searching in Romania

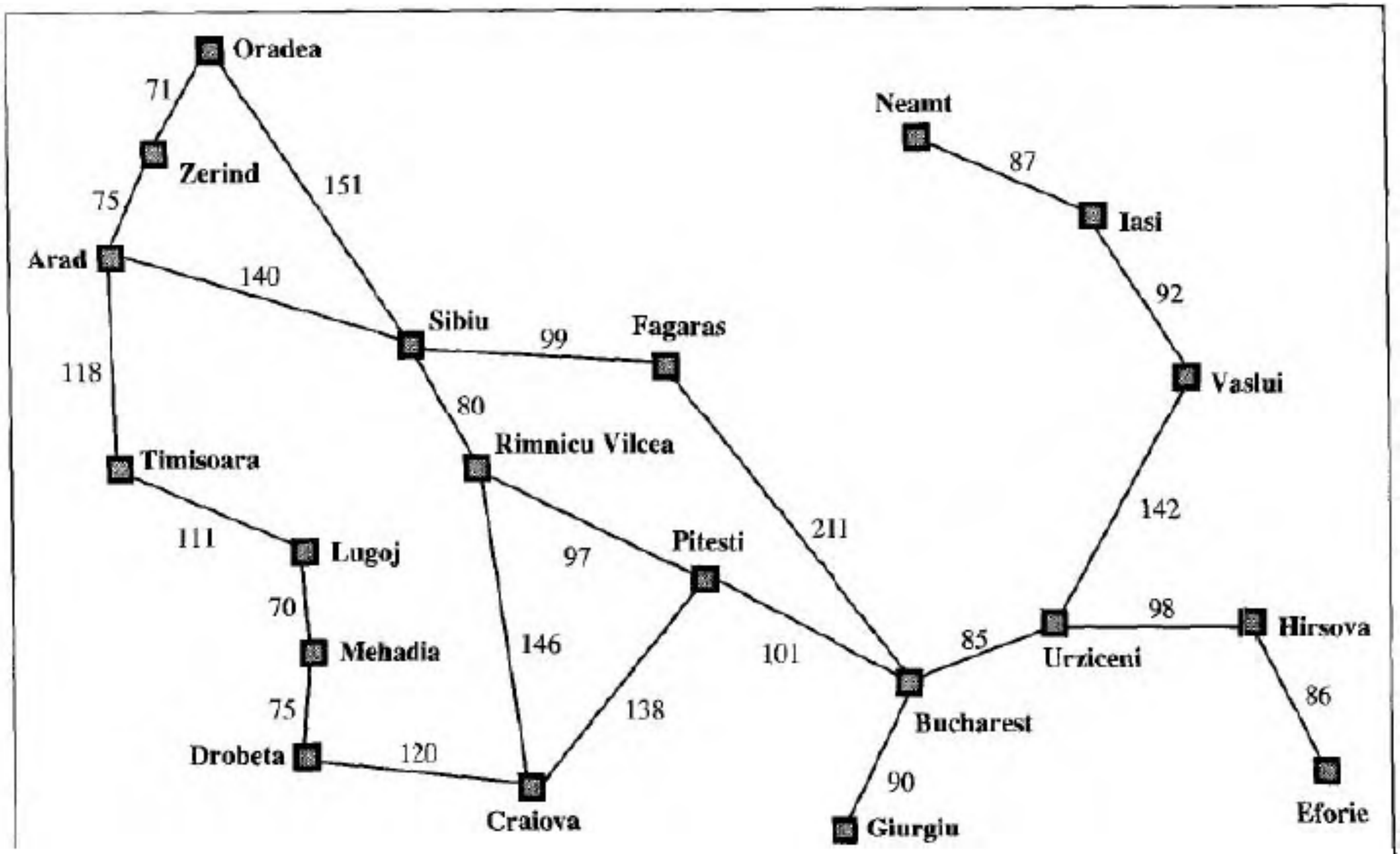

Figure 3.2 A simplified road map of part of Romania.

Problem Formulation - Romania

- Initial State `In(Arad)`
- Actions possible Successor function `F(state)`

`For example:`

  - `F(Arad) = ((Go(Sibiu),In(Sibiu)), (Go Timisoara),In (Timisoara)), (Go(Zerind),In(Zerind))`

- The Goal test `In(Bucharest)`
- Path cost `Distances in Kilomters.`

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General Idea of Search algorithm

function TREE-SEARCH(*problem*, *strategy*) **returns** a solution, or failure
  initialize the search tree using the initial state of *problem*
  loop do
    if there are no candidates for expansion **then return** failure
    choose a leaf node for expansion according to *strategy*
    if the node contains a goal state **then return** the corresponding solution
    else expand the node and add the resulting nodes to the search tree

Figure 3.7 An informal description of the general tree-search algorithm.

So, which search strategy should we use?

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Quality of Problem Solutions Strategies

- How do we rate one strategy over another

- Completeness
  - Is the strategy guaranteed to find a solution?
- Optimality
  - Does the strategy find the solution with the lowest path cost?
- Space complexity
  - How much memory is needed bythe strategy
- Time complexity
  - How long time does it take to find the goal using the strategy

Measuring Complexity

- The complexity of the solution in time & space represents the CPU processing time, and memory needs for the algorith.

- Measurement (indices for complexity) are:
  - `b` – branchingfactor, maximum number of sucessors to any node.
  - `d` – depth, number of layers to reach the first optimal solution
  - `m` – maximum length that a path can have.

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Some typical (uninformed) strategies

- Breadth First Search
- Uniform cost (breadth first) Search
- Depth First Search
- Backtracking Search
- Depth Limited Depth First Search
- Iterative Deepening search

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General tree search algorithm

```
function TREE-SEARCH(problem, fringe) returns a solution, or failure

  fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
  loop do
      if EMPTY?(fringe) then return failure
      node ← REMOVE-FIRST(fringe)
      if GOAL-TEST[problem] applied to STATE[node] succeeds
          then return SOLUTION(node)
      fringe ← INSERT-ALL(EXPAND(node, problem), fringe)
```

```
function EXPAND(node, problem) returns a set of nodes

  successors ← the empty set
  for each (action, result) in SUCCESSOR-FN[problem](STATE[node]) do
      s ← a new NODE
      STATE[s] ← result
      PARENT-NODE[s] ← node
      ACTION[s] ← action
      PATH-COST[s] ← PATH-COST[node] + STEP-COST(STATE[node], action, result)
      DEPTH[s] ← DEPTH[node] + 1
      add s to successors
  return successors
```

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Where….

- We implement the nodes in the tree as a `queue`.
- And implement the following functions to work on the queue.

- MAKE-QUEUE(*element*, …) creates a queue with the given element(s).
- EMPTY?(*queue*) returns true only if there are no more elements in the queue.
- FIRST(*queue*) returns the first element of the queue.
- REMOVE-FIRST(*queue*) returns FIRST(*queue*) and removes it from the queue.
- INSERT(*element*, queue) inserts an element into the queue and returns the resulting queue. (We will see that different types of queues insert elements in different orders.)
- INSERT-ALL(*elements*, queue) inserts a set of elements into the queue and returns the resulting queue.

Breadth First Search

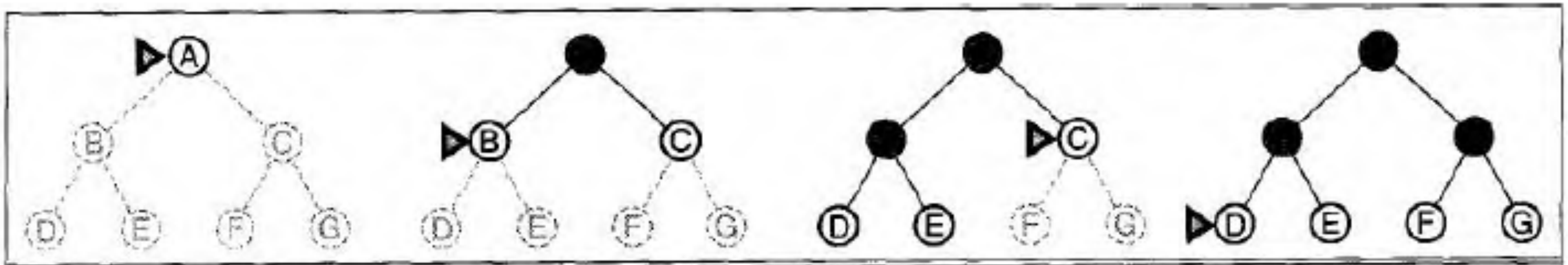


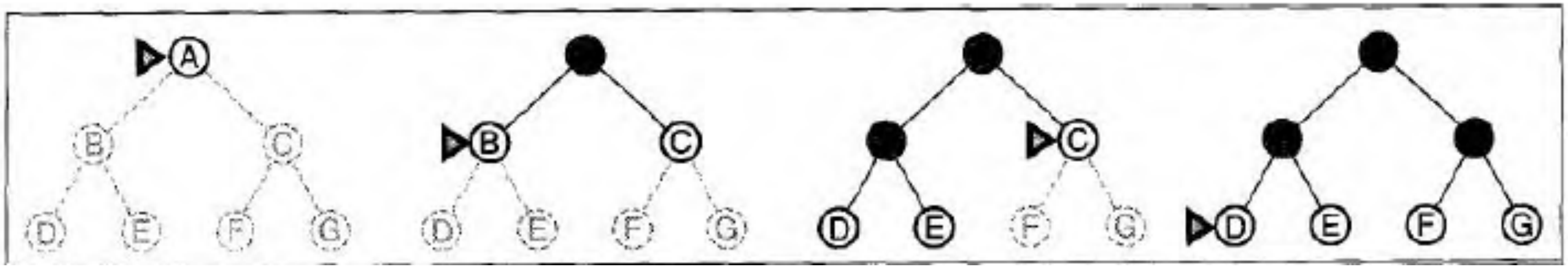
Figure 3.10 Breadth-first search on a simple binary tree. At each stage, the node to be expanded next is indicated by a marker.

- The queue of Nodes is a FIFO queue (First in First Out)
- If `d` and `b` are limited, then BFS is Complete
- Optimal only if all Path costs are similar at same level.
- Unfortunately very memory and time-consuming, i.e. Complex
  - Number of nodes generated (memory need)

$$b + b^2 + b^3 + \cdots + b^d + (b^{d+1} - b) = O(b^{d+1}) .$$

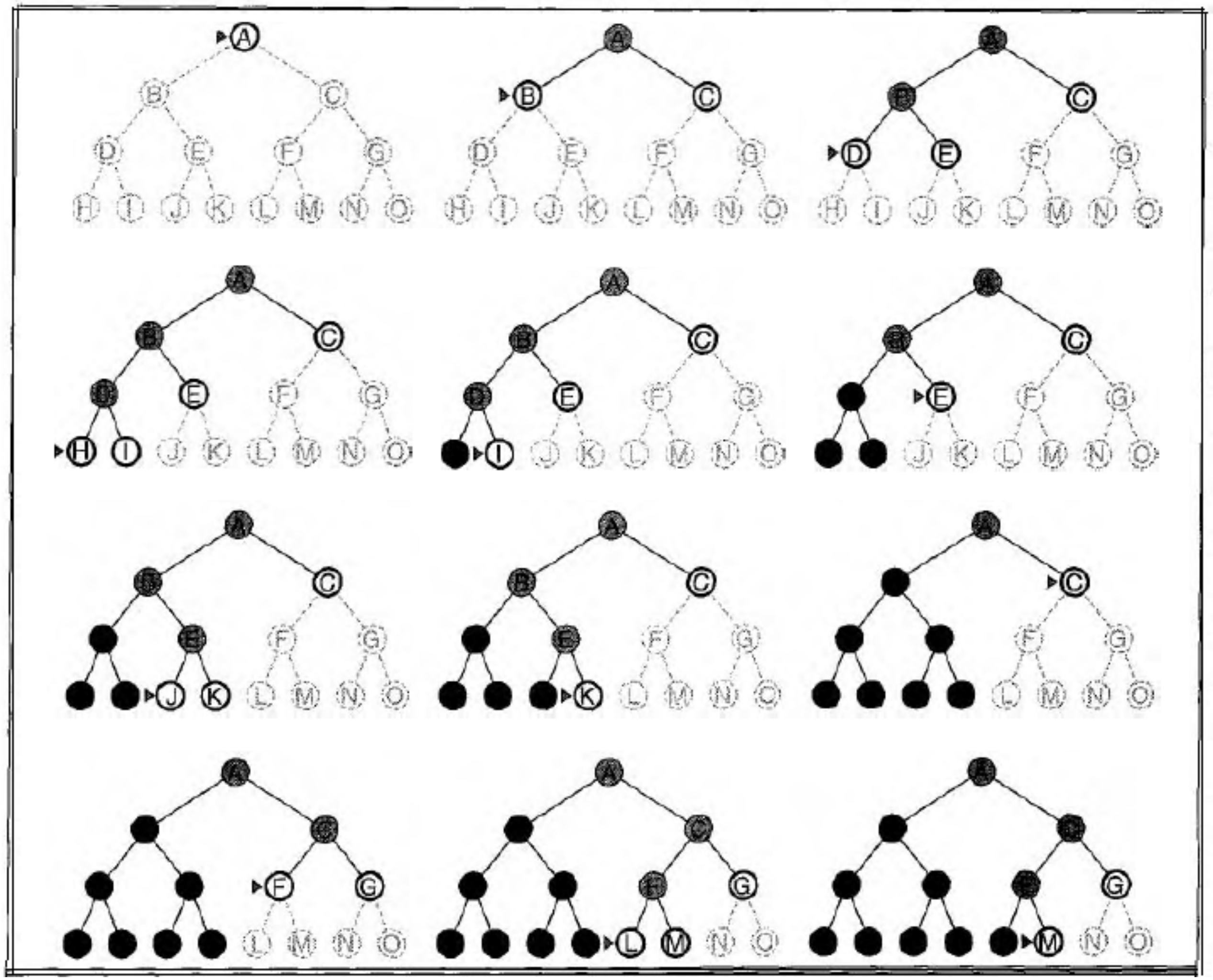
Uniform Cost Search

- Utilising the information about Path cost to select which path to follow.



- If all Path costs are equal, this is equal to Breadth First Search

Depth First Search - I



Depth First Search - II

- The fringe is implemented as a LIFO (Last in First Out) or commonly known as stack.
- Very modest memory requirements, only one path needs to be stored, since paths can be discarded after search to end.
  - Memory need is $b*m+1 \ll \mathbf{O}(b^{d+1})$

- DFS is **not complete**, since it can get stuck in loops
- DFS is **not optimal**, since it can find a solution, deep down one part of the tree, even if optimal solution is higher.

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Backtracking Search

- Variant of Depth First Search, where **only one** of a nodes successors is generated before moving on to that successor.
- Additionally, we do not keep the pre-decessor states in memory either, they are regenerated as we go back.
- This leaves un-expanded Nodes higher up, that must be recorded.
- Even less memory requirements – **O**(m)

Depth limited search

- By setting an `l (length)`, that limits the maximum depth that a DFS can go.
- Basically, when the path length reaches `l`, we do not expand further successors
- Basic DFS can be considered as having infinite `l`

- Basing `l` on some knowledge about the problem can be useful, this is an example of heuristics

Iterative Deepening DFS

function ITERATIVE-DEEPENING-SEARCH(*problem*) **returns** a solution, or failure
  inputs: *problem*, a problem

  for *depth* ← 0 **to** ∞ **do**
    result ← DEPTH-LIMITED-SEARCH(*problem*, *depth*)
    if *result* ≠ cutoff **then return** *result*

Figure 3.14 The iterative deepening search algorithm, which repeatedly applies depth-limited search with increasing limits. It terminates when a solution is found or if the depth-limited search returns *failure*, meaning that no solution exists.

- Do a DFS with l =1
- If No solution found, set l=2 do same thing again.
- Repeated creation of states at higher levels in the tree is a small cost compared to the benefits gained by combining DFS and BFS.

- Preferred uninformed method, if state space is unknown

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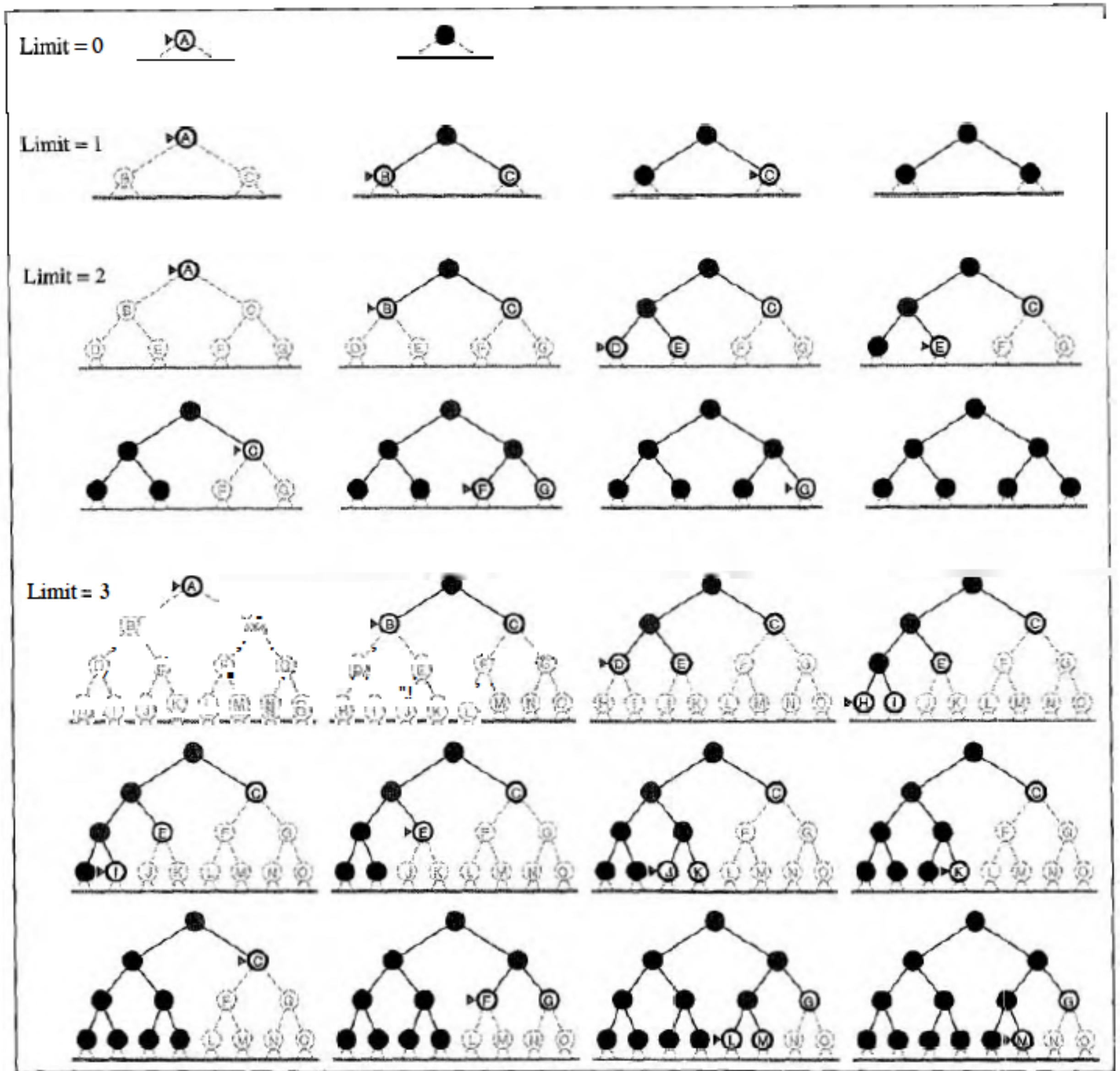

Figure 3.15 Four iterations of iterative deepening search on a binary tree.

Comparison of Search Strategies

Criterion	Breadth-First	Uniform-Cost	Depth-First	Depth-Limited	Iterative Deepening	Bidirectional (if applicable)
Complete?	Yes[a]	Yes[a,b]	No	No	Yes[a]	Yes[a,d]
Time	$O(b^{d+1})$	$O(b^{1+\lfloor C^*/\epsilon \rfloor})$	$O(b^m)$	$O(b^\ell)$	$O(b^d)$	$O(b^{d/2})$
Space	$O(b^{d+1})$	$O(b^{1+\lfloor C^*/\epsilon \rfloor})$	$O(bm)$	$O(b\ell)$	$O(bd)$	$O(b^{d/2})$
Optimal?	Yes[c]	Yes	No	No	Yes[c]	Yes[c,d]

Figure 3.17 Evaluation of search strategies. b is the branching factor; d is the depth of the shallowest solution; m is the maximum depth of the search tree; l is the depth limit. Superscript caveats are as follows: [a] complete if b is finite; [b] complete if step costs $\geq \epsilon$ for positive ϵ; [c] optimal if step costs are all identical; [d] if both directions use breadth-first search.

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How to avoid repeated states?

"If an algorithm forgets its past, it is doomed to repeate it"

- Simple answer is, keep track if a state has been expanded previously.

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Graph Search algorithm

function GRAPH-SEARCH(*problem*, *fringe*) **returns** a solution, or failure

closed ← an empty set
fringe ← INSERT(MAKE-NODE(INITIAL-STATE[*problem*]), *fringe*)
loop do
  if EMPTY?(*fringe*) **then return** failure
  node ← REMOVE-FIRST(*fringe*)
  if GOAL-TEST[*problem*](STATE[*node*]) **then return** SOLUTION(*node*)
  if STATE[*node*] is not in *closed* **then**
    add STATE[*node*] to *closed*
    fringe ← INSERT-ALL(EXPAND(*node*, *problem*), *fringe*)

Figure 3.19 The general graph-search algorithm. The set *closed* can be implemented with a hash table to allow efficient checking for repeated states. This algorithm assumes that the first path to a state *s* is the cheapest (see text).

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Heuristics

- Often, we (the programmer) has **some knowledge about** the problem we are asking the agent (the computer) to solve.
- We can add different sorts of clever *heuristics* to our algorithm.
- Essentially, we use an evaluation function `f(n)` to select which successor node to expand, creating a priority queue, where `f(state)` is the ranking of the nodes.
- Normally node the lowest value (distance to goal) is expanded first.

Greedy First

- GFS always selects the node with apparent cheapest solution to reach goal.
- In Romania, we set for example:
- h_{SLD}=shortest line distance
- Always expand node with lowest h_{SLD}

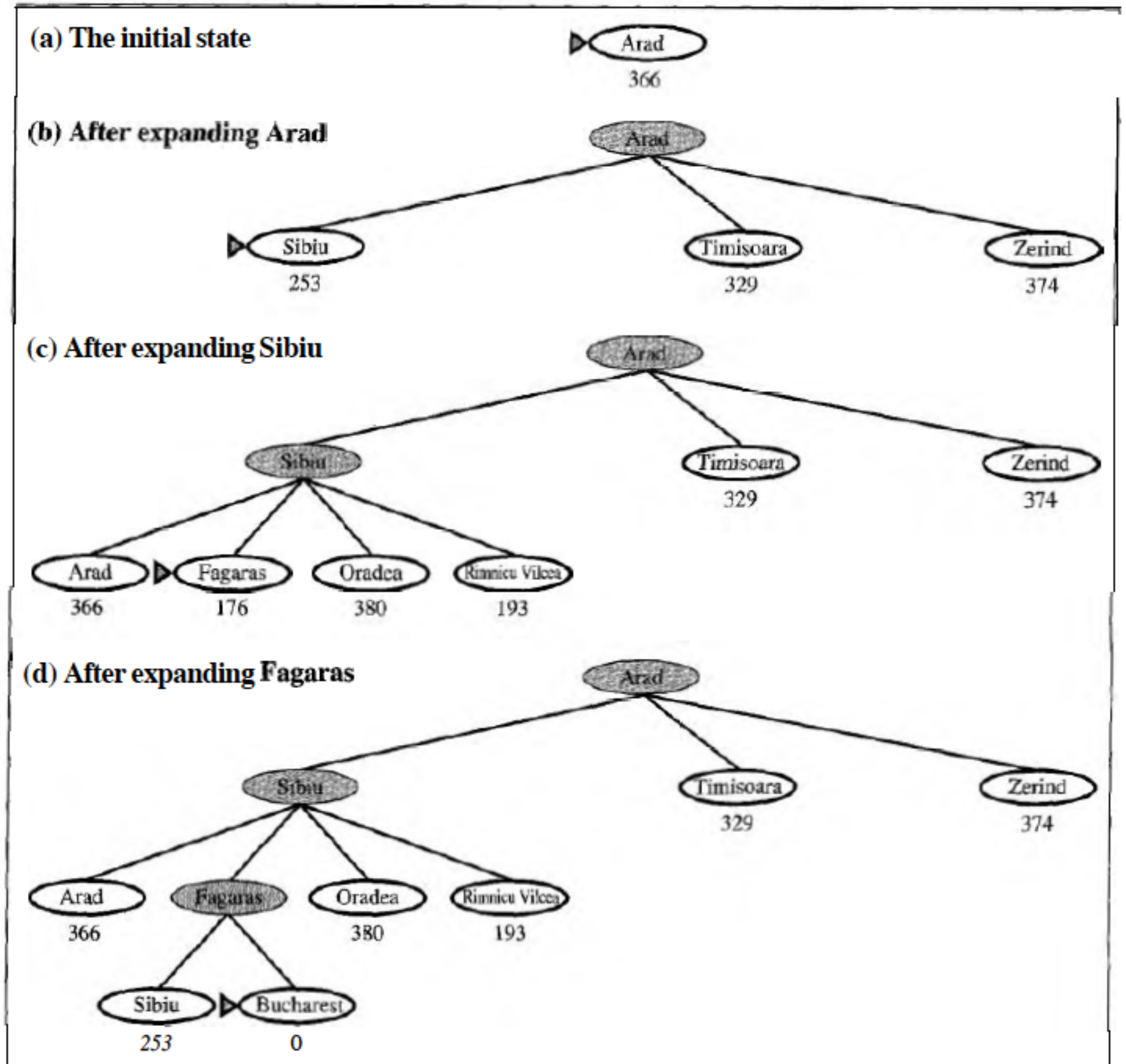

Figure 4.2 Stages in a greedy best-first search for Bucharest using the straight-line distance heuristic h_{SLD}. Nodes are labeled with their h-values.

A*

- A variant of Greedy First Search is A*

- Uses the evaluation function `f(n) = h(n)+g(n)`
- Where `g(n)` is the cost to get to where we are
- And `h(n)` is the estimated cost to reach goal.

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A* example

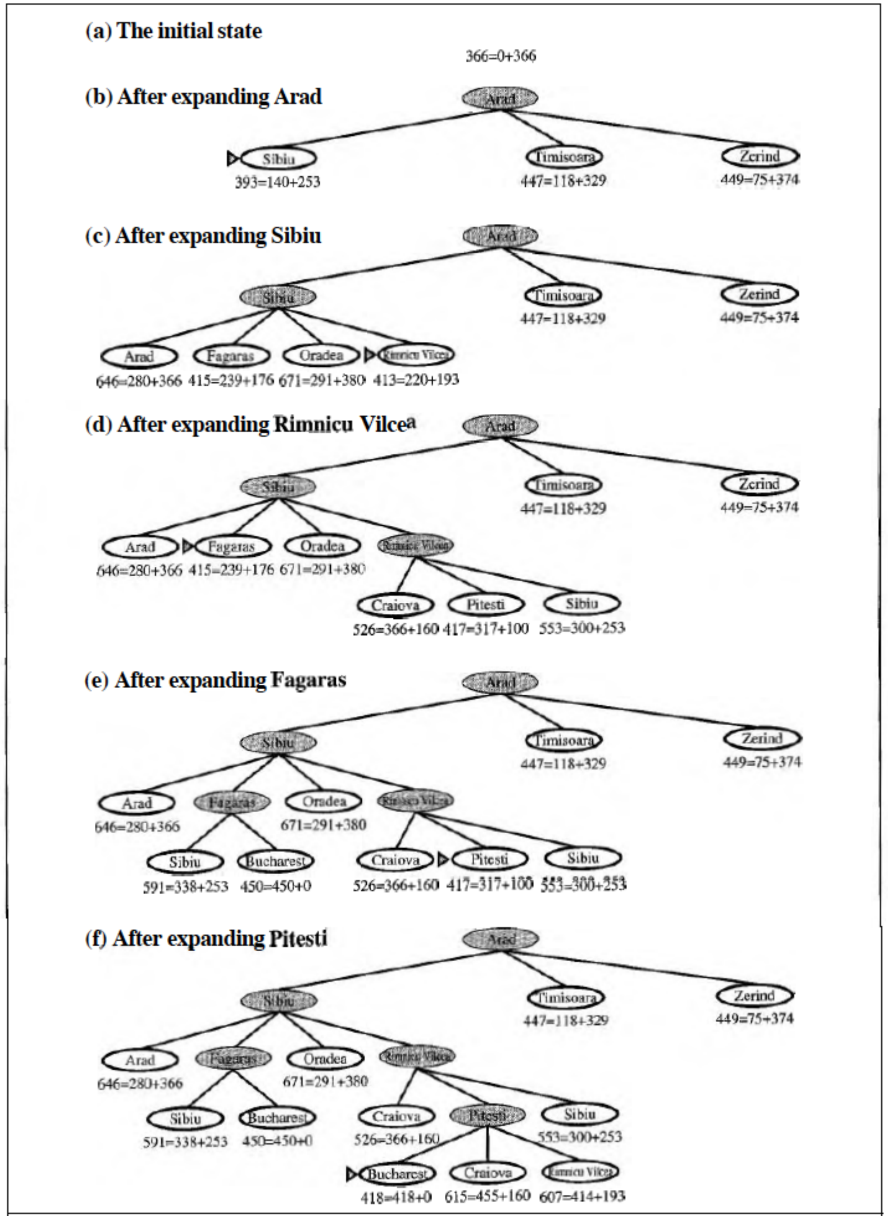

Figure 4.3 Stages in an A* search for Bucharest. Nodes are labeled with $f = g + h$. The h values are the straight-line distances to Bucharest taken from Figure 4.1.

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Planning approaches

- STRIPS based effort at a switching problem
- We need a problem definition

Problem Formulation

- Before starting the search for a solution, we need to define the problem we are trying to solve

- A Problem formulation has the following parts:
  - An initial state
  - Actions possible in terms of **successor** function, that is a list of tuples:
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*It is easy to think of the steps along the path as separate actions, this is OK, but formally not correct at this stage.

The Switching Ontology

- To represent this environment, need an *ontology*

Conducting(x)	Circuit Breaker x is conducting
Breaking(x)	CB x is breaking
LightsOn(y)	Load y is on

- *The closed world assumption is implicitly valid.*

Representing Actions

- *Actions* are represented using a technique that was developed in the STRIPS planner
- Each action has:
  - a *name*
    which may have arguments
  - a *pre-condition list*
    list of facts which must be true for action to be executed
  - a *delete list*
    list of facts that are no longer true after action is performed
  - an *add list*
    list of facts made true by executing the action

Each of these may contain *variables*

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Actions in the problem

- Using STRIPS notation
- Closing Breaker x description is:
  - Name: `Close (x)`
  - Pre: `Breaking(x)`
  - Add: `Conducting (x)`
  - Del: `Breaking (x)`

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So lets try this!

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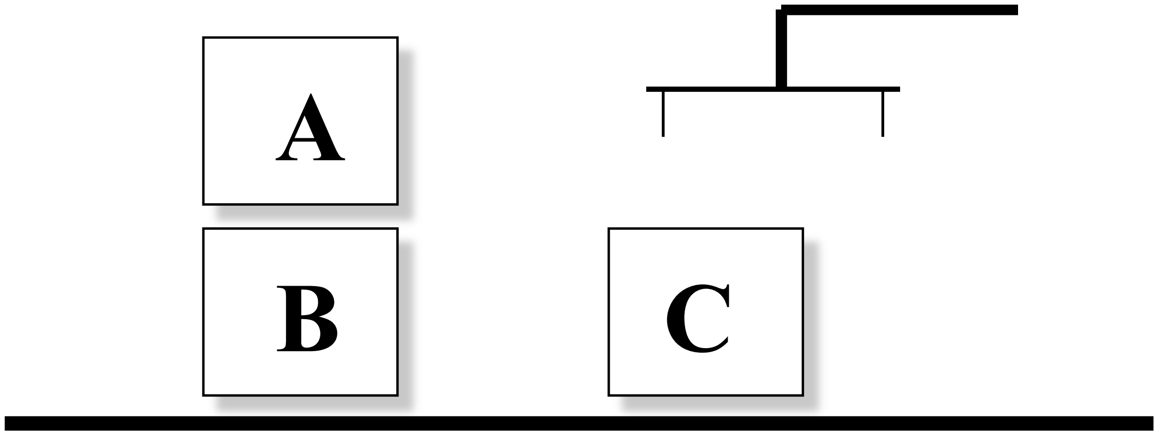
Backup slides

The Blocks World



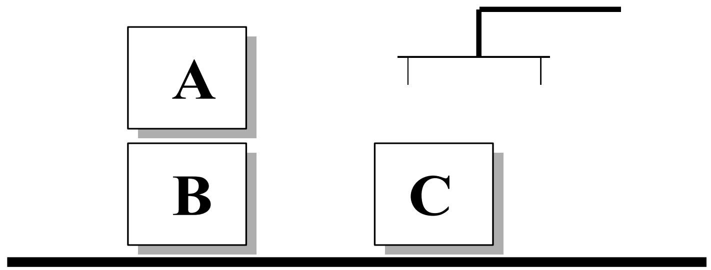
- We'll illustrate the techniques with reference to the *blocks world* Contains a robot arm, 3 blocks (A, B, and C) of equal size, and a table-top

The Blocks World

- Here is a representation of the blocks world described above:

  Clear(A)
  On(A, B)
  OnTable(B)
  OnTable(C)

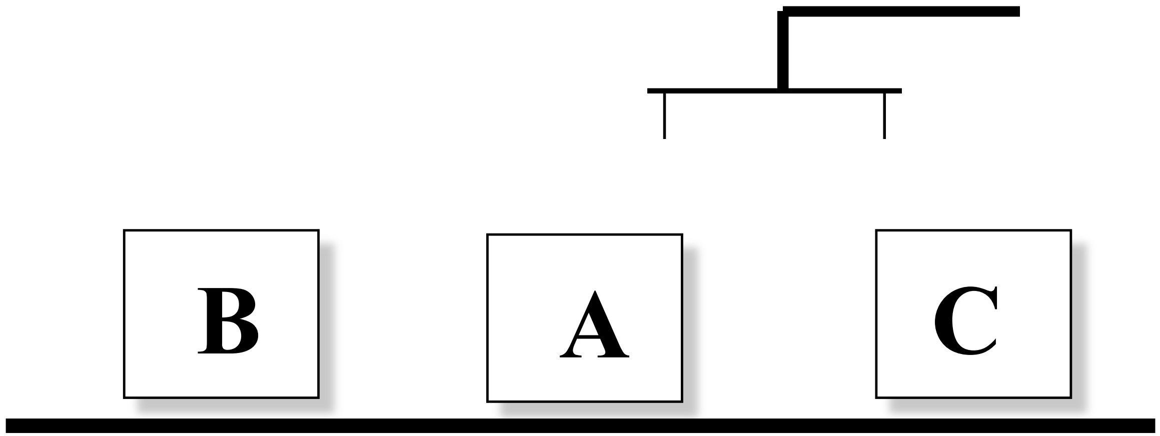
- Use the *closed world assumption*: anything not stated is assumed to be *false*



The Blocks World

- A *goal* is represented as a set of formulae
- Here is a goal:

$$OnTable(A) \wedge OnTable(B) \wedge OnTable(C)$$



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The Blocks World

- *Actions* are represented using a technique that was developed in the STRIPS planner
- Each action has:
  - a *name*
    which may have arguments
  - a *pre-condition list*
    list of facts which must be true for action to be executed
  - a *delete list*
    list of facts that are no longer true after action is performed
  - an *add list*
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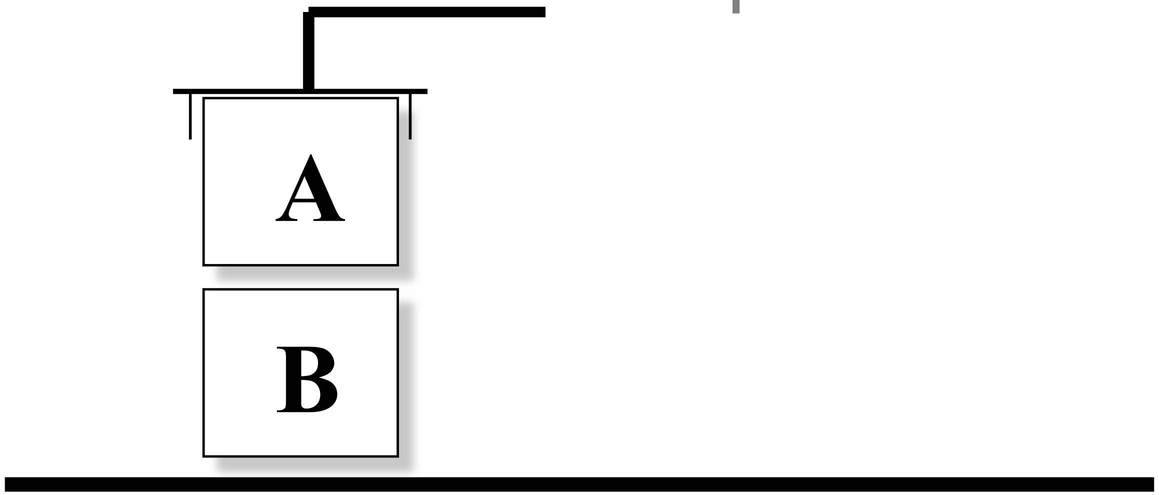
Each of these may contain *variables*

The Blocks World Operators



- Example 1:
  The *stack* action occurs when the robot arm places the object x it is holding is placed on top of object y.

	$Stack(x, y)$
pre	$Clear(y) \wedge Holding(x)$
del	$Clear(y) \wedge Holding(x)$
add	$ArmEmpty \wedge On(x, y)$

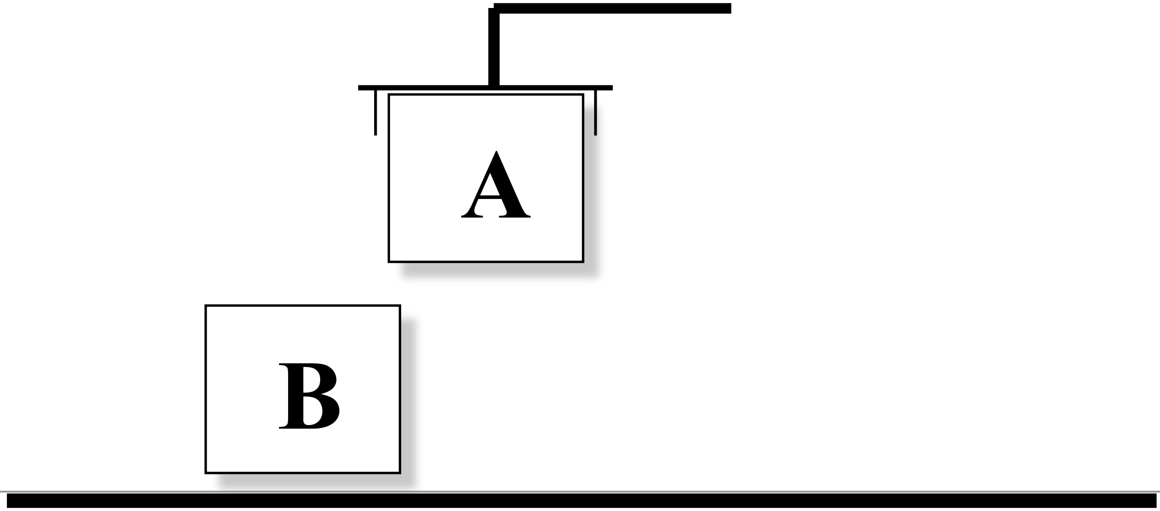
The Blocks World Operators

- Example 2:

The *unstack* action occurs when the robot arm picks an object x up from on top of another object y.

	UnStack(x, y)
pre	*On(x, y)* ∧ *Clear(x)* ∧ *ArmEmpty*
del	*On(x, y)* ∧ *ArmEmpty*
add	*Holding(x)* ∧ *Clear(y)*

Stack and UnStack are *inverses* of one-another.



The Blocks World Operators

- Example 3:
  The *pickup* action occurs when the arm picks up an object x from the table.

	Pickup(x)
pre	$Clear(x) \wedge OnTable(x) \wedge ArmEmpty$
del	$OnTable(x) \wedge ArmEmpty$
add	$Holding(x)$

- Example 4:
  The *putdown* action occurs when the arm places the object x onto the table.

	Putdown(x)
pre	$Holding(x)$
del	$Holding(x)$
add	$Clear(x) \wedge OnTable(x) \wedge ArmEmpty$