Search Strategies

- *Aim of this lesson:*
  1. Assess the comprehension of the search strategies saw in classrooms
  2. Learn to exploit existing libraries, in particular the AIMA implementation available on the net

- *Content:*
  1. Short recap of main search strategies
  2. Few considerations on how to represent a state
  3. Short introduction to the Java library aima.core.search
  4. Short introduction to the AIMA python library
  5. Short example

Requirements – Java

- (At least v8) JDK (correctly installed)
- IDE for Java (e.g., Eclipse/Netbeans)

- Recently, the AIMA java library has undergone some refactoring…
- https://github.com/aimacode
- In the third and fourth editions of the textbook "Artificial Intelligence: a Modern Approach", few minor changes have been done to the search algorithms. As a consequence, the AIMA library has been partly rewritten to reflect these changes. The official way to import such library is through a Maven project or a git pull.

For your convenience:

- AIMA Library version 3.0.0 and a solution proposed by Prof. Chesani
- AIMA Library version 0.95 and a solution proposed by Prof. Chesani

Requirements – Python

- Python 3 (correctly installed)
- Editor for Python (e.g., Jupyter Notebook or Pycharm CE)

- (git-)clone the AIMA repository:
  https://github.com/aimacode/aima-python
  - If you don't have git installed, then it's time to install it!!!

- Prepare a new Python project
  - Virtual Env is suggested, but not mandatory
- Install module "numpy"
- You do not need the whole library… copy in your project the following files:
  - search.py
  - utils.py

- Install Jupyter, there are some notebook already prepared in the AIMA repository
  BEWARE: sometimes the notebooks are inconsistent with the code… sigh!

Looking for Solutions

Few concepts:

- *Expansion:* given a state, one or more actions are applied, and new states are generated.
- *Search strategy:* at every step, let us choose which will be the next state to be expanded.
- *Search Tree:* the expansion of the states, starting form the initial state, linked to the root node of the tree.
- The leaves of the tree (the *frontier*) represent the set of states/nodes to be expanded.

Search Strategies

- **NON-INFORMED** search strategies:
  - breadth-first (uniform cost);
  - depth-first;
  - limited depth-first;
  - iterative deepening.

Search Strategies

- **INFORMED** search strategies:
  - Best first
    1. Greedy
    2. A*
    3. IDA*
    4. SMA*

See the Russel Norvig textbook for a complete introduction to search strategies

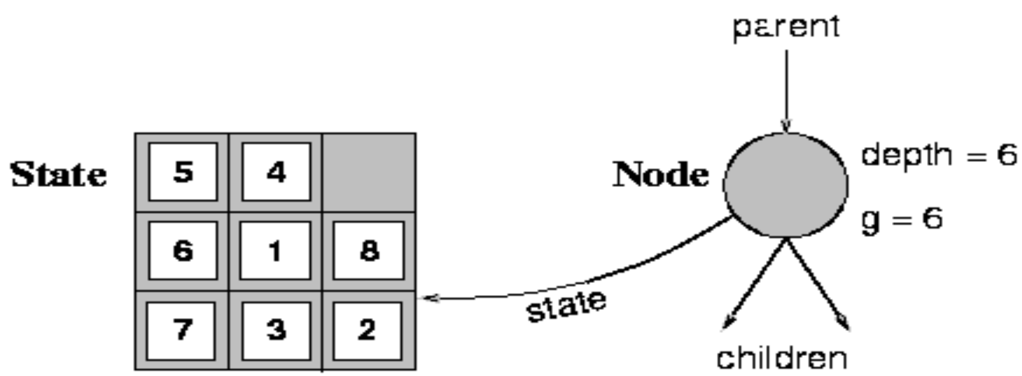
Data structure for the search tree (structure of a Node)

•The state (in the state space) to which this Node corresponds.

•The parent Node.

•The action applied to get this node.

•The path cost for reaching this Node



The general search algorithm

function GENERAL-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
  end

The general search algorithm

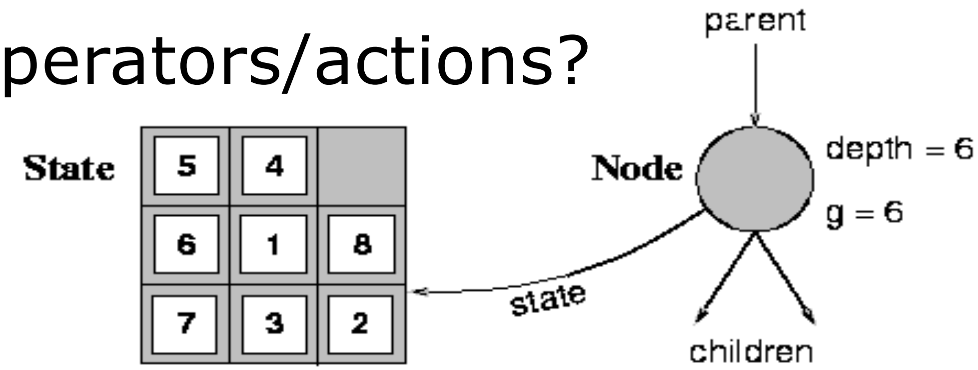
```
function GENERAL-SEARCH(problem, QUEUING-FN) returns a solution, or failure

  nodes ← MAKE-QUEUE(MAKE-NODE(INITIAL-STATE[problem]))
  loop do
     if nodes is empty then return failure
     node ← REMOVE-FRONT(nodes)
     if GOAL-TEST[problem] applied to STATE(node) succeeds then return node
     nodes ← QUEUING-FN(nodes, EXPAND(node, OPERATORS[problem]))
  end
```

Tramite l’argomento **Queuing-Fn** viene passata una funzione per accodare i nodi ottenuti dall’espansione

First Step: the Problem definition

- How to represent a “problem”?
  1. Usually, represented by means of “states”, together with state operators (aka actions)
  2. there is a initial state
  3. a goal to reach (a property that should hold, i.e. a state for which the property holds)
- How to represent a state?
  - through data structures… which ones?
- What about the state operators/actions?



In Java...

- An object-oriented approach: states are represented through (instances of) a user-defined class.
- State operators are represented thorugh methods of the same class.
- Other methods?
  - boolean **`isGoalTest(…)`** → returns true if Goal has been reached, false otherwise
    Interfaces **`aima.search.framework.GoalTest`** or **`aima.core.search.framework.problem.GoalTest`**

No other constraints on the class used to represent the state (a part from being instance of Object…)

In Python…

- The AIMA LIBRARY provides two classes:
  - class Problem: our problem instance will extend this class
  - class Node: we will just access it…
- The class Problem is abstract (i.e., you must implement some methods)

- **`def __init__(self, initial, goal=None):`**

```
    """The constructor specifies the initial state, and possibly a goal
state, if there is a unique goal. Your subclass's constructor can add
other arguments."""
```

- However, **the state must be a tuple** (why? Graph search, the possibility of computing the hash…)

In Python…

- ***def actions(self, state):***

  ```
   """Return the actions that can be executed in the given
  state. The result would typically be a list, but if there are
  many actions, consider yielding them one at a time in an
  iterator, rather than building them all at once."""
  ```

- ***def result(self, state, action):***

  ```
   """Return the state that results from executing the given
  action in the given state. The action must be one of
  self.actions(state)."""
  ```

- ***def goal_test(self, state):***

  ```
  """Return True if the state is a goal. The default method compares the
  state to self.goal or checks for state in self.goal if it is a
  list, as specified in the constructor. Override this method if
  checking against a single self.goal is not enough."""
  ```

…let's implement these methods…

- Which are the search strategies that I can apply?

  1. Breadth-first
  2. Depth-first
  3. Depth-bounded
  4. Iterated Deepening

- What about the path of a solution?
- I might be interested to know if a solution exists…
- … but I might be interested also to know how to reach that solution (e.g., think about a labyrinth problem)

In Java: the concept of Successor

- Successor is a data structure that keep track of:
  1. The state
  2. The operator applied in order to reach such state
- `aima.core.search.framework` already provides the class `Successor.java`
- list_of_successors `getSuccessors()` → returns a list of possible successors obtained by appyling the operators (interface `aima.search.framework.SuccessorFunction`)

- Interface `aima.core.search.framework.problem.ActionsFunction` Returns the list of actions that can be applied to the current state
- Interface `aima.core.search.framework.problem.ResultFunction` Returns the state generated/reachable by applying a specified action
- Mind it! Do not mix the Successor concept with the Node of the search tree…

In Python…

- What about the path of a solution?
- The Node class keeps track of the path!!! But… it will require some code trick to access it…

What about the Uniform Cost Strategy?

We nee to keep into account also **the cost of the operators/actions** that we applied to reach the goal…

To this end, there exists the interface:
`aima.core.search.framework.problem.StepCostFunction`

With the method:

```
public double c(Object fromState, Action a, Object toState)
```

What about the Uniform Cost Strategy?

We nee to keep into account also **the cost of the operators/actions** that we applied to reach the goal…

You should implement the method:

```
def path_cost(self, c, state1, action, state2):
    """Return the cost of a solution path that arrives at state2 from
    state1 via action, assuming cost c to get up to state1. If the problem
    is such that the path doesn't matter, this function will only look at
    state2.  If the path does matter, it will consider c and maybe state1
    and action. The default method costs 1 for every step in the path."""
```

A default method is provided, which considers the constant cost 1 for every action

Informed Strategies… in Java

- Remember the notion of heuristic: a function that estimates (with a certain error) the distance of a state from the goal… admissible? consistent?
- Interface `aima.core.search.framework.evalfunc.HeuristicFunction` defines a method:

```
public double getHeuristicValue(Object state)
```

Informed Strategies… in Python

- Remember the notion of heuristic: a function that estimates (with a certain error) the distance of a state from the goal… admissible? consistent?
- You should implement the method:

```
def h(self, node):
        """Returns the heuristic applied to the Node node"""
```

Summing up… in Java:

1. Breadth-first
2. Depth-first
3. Depth-bounded
4. Iterated Deepening
5. Uniform Cost
6. Greedy
7. A*

StepCostFunction

HeuristicFunction

GoalTest, ActionsFunction, ResultFunction

Notice: Applying intelligent strategies means a cost in terms of the knowledge you should provide…

Summing up… in Python:

```
def actions(self, state)
def result(self, state, action)
def goal_test(self, state)
```

1. Breadth-first
2. Depth-first
3. Depth-bounded
4. Iterated Deepening
5. Uniform Cost
6. Greedy
7. A*

```
def path_cost(self, c, state1, action, state2)
```

```
def h(self, node)
```

Notice: Applying intelligent strategies means a cost in terms of the knowledge you should provide…

AIMA AND JAVA…

How it is made the package `aima.search`

Starting point, the class:

- `aima.core.search.framework.problem.Problem`

It models the problem, to which it is possible to provide the initial state, and the implemented interfaces (on the basis also of the chosen interfaces):

- `GoalTest`
- `ActionsFunction`
- `ResultFunction`
- `StepCostFunction`
- `HeuristicFunction`

How it is made the package `aima.search`

Provides an implementation of the nodes of a search tree (a search graph) through the classes:

- `aima.core.search.framework.Node`,
- in `aima.core.search.uninformed`:
  - `BreadthFirstSearch`
  - `DepthFirstSearch`
  - `DepthLimitedSearch`
  - `UniformCostSearch`
  - `IterativeDeepeningSearch`
- in `aima.core.search.informed:`
  - `GreedyBestFirstSearch`
  - `AStarSearch`
- in `aima.core.search.informed:`
  - `SimulatedAnnealingSearch`
  - `HillClimbingSearch`

The general search algorithm

function GENERAL-SEARCH(*problem*, QUEUING-FN) **returns** a solution, or failure

```
nodes ← MAKE-QUEUE(MAKE-NODE(INITIAL-STATE[problem]))
loop do
    if nodes is empty then return failure
    node ← REMOVE-FRONT(nodes)
    if GOAL-TEST[problem] applied to STATE(node) succeeds then return node
    nodes ← QUEUING-FN(nodes, EXPAND(node, OPERATORS[problem]))
end
```

Through the parameter **Queuing-Fn** it is specified the enqueuing function for the nodes generated in the expansion

How it is made the package `aima.search`

You can specify to QueueSearch (to its subclasses) if you are searching over a tree or over a graph:

- `aima.core.search.framework.qsearch.TreeSearch`
- `aima.core.search.framework.qsearch.GraphSearch`

How it is made the package
`aima.search`

Finally, it provides the class:

`aima.core.search.framework.SearchAgent`

That search a solution in the state space.

It gets as parameters a problem (an instance of the class `Problem`), and a search strategy.

AIMA AND PYTHON…

The library `search.py`

Given an implementation of the problem, provides the following functions:

- **`def breadth_first_tree_search(problem):`**
```
"""Search the shallowest nodes in the search tree first.
    Search through the successors of a problem to find a goal.
    The argument frontier should be an empty queue.
    Repeats infinitely in case of loops."""
```
- **`def breadth_first_graph_search(problem):`**
```
"""... """
```
- **`def depth_first_tree_search(problem):`**
```
"""Search the deepest nodes in the search tree first.
    Search through the successors of a problem to find a goal.
    The argument frontier should be an empty queue.
    Repeats infinitely in case of loops. [Figure 3.7]"""
```
- **`def depth_first_graph_search(problem):`**
```
"""Search the deepest nodes in the search tree first.
    Search through the successors of a problem to find a goal.
    The argument frontier should be an empty queue.
    Does not get trapped by loops.
    If two paths reach a state, only use the first one."""
```

The library `search.py`

Given an implementation of the problem, provides the following functions:

- `def uniform_cost_search(problem):`
- `def depth_limited_search(problem, limit=50):`
- `def iterative_deepening_search(problem):`
- `def astar_search(problem, h=None):`
- `def hill_climbing(problem):`
- `def simulated_annealing(problem, schedule=exp_schedule()):`
- `def genetic_search(problem, fitness_fn, ngen=1000, pmut=0.1, n=20):`

The library `search.py`

How to use it?

- define the class Problem, representing your problem
- import the file "**`reporting.py`**" (utilities...)
- Looking for a solution?

```
myP = MyProblem(...)
soln = breadth_first_tree_search(myP)
path = path_actions(soln)
print(path)
print("Cost: ", soln.path_cost)
path = path_states(soln)
print(path)
```

- Want to compare strategies?

```
report([
    breadth_first_tree_search,
    breadth_first_graph_search,
    # depth_first_tree_search,
    depth_first_graph_search,
    astar_search
    ],
    [myP])
```

A simple problem: Missionaries and Cannibals

- 3 missionaries and 3 cannibals are on the same shore of a river, and want to cross such river. There is a single boat (on the same initial shore), able to bring around two persons at a time.
- Should it happen that in ANY shore there are more cannibals than missionaries, the cannibals will eat the missionaries (failure states).

- Which state representation?
- State: a tuple of three numbers representing the number of missionaries, the number of cannibals, and the presence of the boat on the starting shore.

- The initial state is: (3,3,1)

A simple problem: Missionars and Cannibals

- Actions: the boat cross the river with passengers:
  - 1 missionary, 1 cannibal,
  - 2 missionaries,
  - 2 cannibals,
  - 1 missionary
  - 1 cannibal.

- Goal: state (0,0,0)

- Path cost: the number of river crossings.

A second problem: Fill a square

- A matrix of 10x10 cells is given.
- In the initial state, all the cells are empty, except the left upper corner, that is initialized to 1.
- Problem: assign a consecutive value to all the cells, starting form 1 up to 100, with the following rules:
- Starting from a cell with value x, you can assign value (x+1) to:
  - empty cells that are two cells away in vertical or horizontal direction, or
  - one cell away in diagonal direction.

A second problem:
Fill a square

- If the matrix is empty, a cell has 7 possible “next cells” to be filled → branching factor?
- hen the matrix is partially filled , the number of free cell that are reachable diminishes → branching factor lowers
- The depth of the search tree is 100…

A third problem:
The U2 Bride (exam test -- 16 December 2005)

- U2 are giving a concert in Dublin.
- There are still 17 minutes. Unfortunately, to reach the stage, the members of the band must cross a small, dark, and dangerous bridge… do not despair! They have a torch!!! (only one)
- The bridge allows the passing of two persons at a time. The torch is mandatory to cross the bridge, and should be brought back and forth (cannot be thrown…). All the members are on the wrong side of the bridge, far from the stage…
- Every member of the U2 walks at a different velocity, and they takes different time to cross the bridge:
- Bono, 1 minute
- Edge, 2 minutes
- Adam, 5 minutes
- Larry, 10 minutes

A third problem:
The U2 Bride (exam test -- 16 December 2005)

- If two members cross the bridge together, it will take them the highest time to cross it (i.e., the faster will walk at the velocity of the slower).
- For example: if Bono and Larry will cross together, it will take them 10 minutes to get over the bridge. If Larry brings back the torch, another 10 minutes will pass, and the mission will be failed.
- Think about an heuristic function for this problem, and try to solve it using A* over graphs. To limit the search space, suppose that the members move always in couple in one direction, and only one member brings back the torch.

A third problem:
The U2 Bride (exam test -- 16 Dicember 2005)

A suggestion for the heuristic function:

- At most, only two persons can move at a time. Let us group the members in couples. Sort the member in descending order on the base of the crossing time, and:
- put in the first group the two slower members
- put in the second group the remaining members
- Every group will move at the velocity of the slowest in the group. The heuristic function is the sum of the time required by each group still in the wrong side of the bridge.

- Is this heuristic function admissible? Will it find the best solution?

Today…

1. Prepare a new Java/python project
2. Choose a problem, define the state and the functions, and test the different strategies
   - Missionaries and Cannibals
   - U2
   - Fill the 10x10 matrix

Example - Java

```
MCState initState = new MCState();
Problem problem = new Problem(initState,
                        new MCActionsFunction(),
                        new MCResultFunction(),
                        initState,
                        initState);

BreadthFirstSearch search =
new BreadthFirstSearch(new TreeSearch());

SearchAgent agent =
new SearchAgent(problem, search);


// semplici metodi di stampa dei risultati…
printActions(agent.getActions());
printInstrumentation(agent.getInstrumentation());
```