

# Notes for AI

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# 1 Week 5 February - Introduction

## 1.1 Basics

The course is an introduction to the basics of Artificial Intelligence. We will get an overview of the base of the artificial intelligence methods. We will use python as a programming language. Labs and support will be done in python. Prerequisite to the exam is to complete the homework of the lectures. [1]

You should help each other, but coding should be done individually.

- Thinking humanly
- Acting humanly

The Turing test is used to test this. The longer a human can be fooled into thing that the human is talking to a human, and not a bot. This could be chatbots acting humanly. You have to test for:

- Natural language processing
- Knowledge representation
- Automated reasoning
- Machine learning

Success depends on deception. Chatbot can use cheap tricks. Mitzuku has recently won for the 5th time. Computers have a had time with multiple choice questions. Eg the "The large ball crashed right through the table because it was made of styrofoam". If you replace "styrofoam" with "steel", then the answer is totally different.

**A better test?** A better Turing test, would be one that can be administed and graded by a machine, and more objectivity in the it would not depend of subjectivity of humans.

- Thinking rationally

It is about the idealized or "right" way of thinking. It is hard to describe the world using logical notation. The procedure of applying these local statements and deducing them. We also have a though time dealing with uncertainty, representing the gray areas.

- Acting rationally

Acting rationally is acting with the goal of achieving the goal, that has been set. Utility is about the goal that has been set, whether it is about, shortest route, least time or fewest changes in a public transit system.

## 1.2 Successes of AI

- IBM Watson is an AI created by IBM. IBM is one of the companies that has been investing in AI for the longest times.
- Self driving cars is one of the successes of AI. This is an example of a rational acting.
- Natural language processing is also a great improvement, with speech technologies and machine translation.
- Vision, OCR, handwriting recognition and face detection and recognition.
- Mathematics, program solved unsolved conjecture. Also wolfram alpha.
- Games

Chess(champion beaten in 1997), checkers(solved in 2007), Go (beaten for the first time by a Google AI), Google AI beat top StarCraft players.

- Logistics, scheduling, planning.

A lot of the advancement are done by the military. In the 1991 Gulf War an AI planned and scheduled for 50,000 vehicles and such.

- Robotics

Mars rovers, self driving cars, drones, robot soccer, personal robotics.

Exercises will start at 10:20.

**Basics** Python code is fairly simple and readable. Beginning and ending of blocks is done purely by indentation. We will use the Python Console for trying out examples. Variables can change types throughout the program. A variable can start as a string end as float. We can use + for string concatenation. We can use triples quotes for strings containing both ' and ".

Variables in Python do not have intrinsic types. But assignment does not create copies, but references. References are deleted by the garbage collector, when the reference has passed out of scope. Names cannot start with numbers.

We can have multiple assignments. And swapping vars is easy.

```
>>> x, y = 2, 3
>>> y
3
>>> x, y = y, x
>>> y
2
>>> x
3
```

**Sequence types** Sequence types are tuples, strings and lists. In a tuple we can have multiple types of variables. Tuples are immutable, such that they cannot be changed after it has been created. Strings are also immutable. Lists are mutable, they can also have mixed types. These sequence types have much syntax in common. If we have to change elements in an immutable tuple or string a new copy has to be created. Lists can be shrunk or expanded as you go. We assign some different variables:

```
>>> tu = (23, 'abc', 4.56, (2,3), 'def')
>>> tu
(23, 'abc', 4.56, (2, 3), 'def')
>>> li = ['abc', 34, 4.34, 23]
>>> st = "Hello World"
>>> st
'Hello World'
>>> st = Hellllo wordl'
  File "<stdin>", line 1
    st=Hellllo wordl'
    ^
SyntaxError: invalid syntax
>>> st = 'Hellllo wordl'
>>> st
'Hellllo wordl'
>>> st = """This is a multiple line
... string that uses triple quotes"""
>>> st
'This is a multiple line\nstring that uses triple quotes'
```

We can also have negative indexes, such that -1 is the last character:

```
>>> st[-1]
's'
```

```
>>> st[-2]
'e'
```

If want to get the 3 middle elements of the tuple we defined:

```
>>> tu[1:4]
('abc', 4.56, (2, 3))
```

From this we get a copy of the selected part of the tuple. If we do not specify where in the tuple to start, we start from the beginning.

```
>>> tu[:3]
(23, 'abc', 4.56)
```

We can do a copy like this:

```
>>> tu[:]
(23, 'abc', 4.56, (2, 3), 'def')
```

In this example there is a big difference between line 3 and 4.

```
>>> l3 = ['4', '5']
>>> l4 = ['6', '7']
>>> l3 = l4
>>> l3 = l4[:]
```

In line 3 we assign l3 we assign to the reference to l4. In the 4th line we assign l3 to a copy of l4, such that changes in l4 will not be reflected in l3.

We can use the `in` operator to check if we have a substring. We can concat tuples:

```
>>> tu[:] + tu2[:]
(23, 'abc', 4.56, (2, 3), 'def', 12, 'yeet')
>>> tu + tu2
(23, 'abc', 4.56, (2, 3), 'def', 12, 'yeet')
```

**Dictionaries** Dictionaries can store a mapping between a set of keys and values. We can create a dictionary with:

```
>>> d = {'user' : 'bozo', 'pswd' : 1234}
```

The values can be anything. We can get the value of a key like this:

```
>>> d['user']
'bozo'
```

We can delete a key:value pair like this:

```
>>> del d['pswd']
>>> d
{'user': 'bozo'}
```

## 2 Week 7 - Intelligent Agents

An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators. We can say that an agent's behaviour is described by its **agent function**. This maps any sequence to an action. This is a mathematical abstraction, the *actual program* is called the **agent program**. [2, p. 3]

We can have many types of agents, these can perceive in many ways: here are some examples.

- Human agent  
Eyes, ears, nose
- Robotic agent  
Cameras, and infrared range finders
- Software agent  
Keystrokes, file contents & network packets.

### 2.1 Vacuum-cleaner world

A vacuum-cleaner has two locations to take care of: A and B. It has four actions: left, right, suck and NoOp. We can have a simple programme for cleaning with this vacuum:

```
if status = Dirty then return Suck
else if Location = A then return Right
else if Location = B then return Left
```

The vacuum-cleaner is a rational agent, it tries to optimize on a performance measure. The choice of performance measure is a critical one. "Doing the right thing" is to always act according to the performance measure. We also call the performance measure the utility function, it is an objective criteria for the success of an agent's behaviour.

An example of potential performance measures for the vacuum agent.

- amount of dirt cleaned up
- amount of time taken,
- amount of electricity consumed
- amount of noise generated

It would be desirable to have the agent take as little time as possible, but if we only consider this, then it would stand still. But if combined, with eg the amount of dirt cleaned up, then we could have better operation.

### 2.2 Autonomy

An autonomous agent always has the ability to learn and adapt, it can always say "no", it also needs enough built-in knowledge to survive.

**Task Environment Specification** Problem specification:

- Performance measure
- Environment
- Actuators
- Sensors

For an autonomous taxi

- Performance measure  
Safe, fast, legal
- Environment  
Roads
- Actuators  
Steering wheel
- Sensors  
Cameras, speedometer

For an email spam filter:

- Performance measure  
Minimizing false positives
- Environment  
User email account
- Actuators  
Mark as spam, let mail through
- Sensors  
Incoming messages

## 2.3 Environment types

**Fully observable vs partially observable** In a game, such as FIFA or any game, it is possible to observe everything, and perceive all options. If a robot is playing football in the real world, then the perception of the environment is constrained by the input of the sensors eg eyes (you do not know what happens behind your back).

**Deterministic vs stochastic** A deterministic environment is when the coming events in time are only defined by the current state, and the agent's future actions. Versus when the game is dependent on some type of randomness, whether it be a deck of cards or dice. This is very hard to predict.

**Episodic vs sequential** Is every step of the agent independent? Or does it depend on a previous sequence? A sequence could be a game, where current decisions depend on a previous sequence of decisions. In a spam filter the sequence of spam mail does not matter. This is a matter of definition, it is how you see your environment in terms of your decisions. A game could be episodic, if you choose to look upon it as a snapshot.

**Static vs dynamic** Is the world changing while the agent is thinking. Solving a Rubik's cube or chess is static. However self-driving is very dynamic, here things are changing all the time. This is a very challenging

**Discrete vs continuous** Does the environment provide a fixed number of distinct number of states (can they be enumerated)? Where time is a factor, then time is always continuous, if you do not choose to look at time in buckets of seconds or minutes.

**Single-agent vs multiagent** Is the agent operating by itself?

## 2.4 Hierarchy of agent types

- Table-driven agents, it's just like a big lookup table.

The table sizes can become huge. Designing such a table is challenging. We need to think about every single case.

- Simple reflex agent

This is the vacuum cleaner. For every state given the rules, we find the rule applying to the current state. It selects its action from the current percept only. Implemented through condition-action rules. Example of if-then algorithms. For this to work, then the environment must be fully observable. This won't then work for a self-driving car.

- Agents with memory, internal state to keep track of past states of the world

We can call this a model-based reflex agent. Internal state: aspects of the environment that cannot be currently observed. This is useful for partially observable environments. In addition to the rule we have a model, a description of how the next state depends on current state and action. We also have a state, a description of the current world state the action, is the most recent action.

We update the state, according to the state, action, percept and the model. When matching a rule, then we take into account the state and the rules.

- Agents with goals

- Utility



## 3 Week 8 - Uninformed Search

### 3.1 Formulating search problems

Many problems can be solved through search. Which sequence of actions can get us to the goal state? This can be solved through search. We might also have a performance measure of minimizing time. For an example a GPS is a search problem, which sequence of places gets us to the goal? [3, p. 2]

There can be many different examples of using search as a solution to a problem. Examples are getting somewhere, we can formulate the problem as:

- Start: home
- Goal: destination
- operators: move one block, turn

We can also formulate getting settled in a new apartment as a search problem.

- start: item randomly distributed over the place
- goal: satisfactory arrangement of items
- operators: select item, move item

#### 3.1.1 Searching

A search algorithm will tell us the exact sequence to get us from the start to the goal. Search strategies are important methods for many approaches to problem-solving. Search algorithms is a basis for many optimization and planning methods.

We will consider the problem of designing goal based agent in observable (the agent always knows the current state), deterministic (that each action we take has exactly one outcome), discrete (that we have finite number of actions to choose from), known (such that the agent knows which states are reached by each action) environments[1, p. 66].

**State Space** Is the initial state, actions and the successor function (or transition model) defines the state space of the problem. The set of all states reachable from initial state by any sequence of actions. This can be represented as a directed graph (nodes are states and the edge between nodes are actions).

**Building a goal based agent** To build a goal based agent, we must answer the questions[3, p. 15]:

- How to we represent the state of the world?
- What is the goal and how can we recognize it?
- What *relevant* information do we encode to describe states, action and their effects aand thereby solve the problem.

### 3.2 Examples of search problems

How we solve a comic-book maze.

- solution fixed sequence of actions
- Search: process of looking for the sequence of of actions that reaches the goal
- Agent can ignore percepts during execution.

**The maze problem** To solve a maze by searching we examine the components of a search problem. [3, p. 8]

- Initial state  
Entry
- Successor Function  
Is the result of the doing an action in a state
- Goal state  
Goal state is the exit.
- Path cost  
Assume that it is a sum of nonnegative *step costs*.
- Optimal solution: sequence of actions with the lowest path cost.

The optimal solution is the sequence of actions with the *lowest path cost* for reaching the goal.

**Vacation in Romania** We are on vacation in Romania, currently we are placed in Arad. However our flight leaves Bucharest tomorrow. Now we want to find the best way to get to Bucharest.

- Initial state  
Arad
- Successor function  
These are the possible states we can move to  $S(\text{Arad}) = \{\text{Zerind, Timisoara, Sibiu}\}$
- Goal state  
Bucharest
- Path cost  
The cost of the path from the start to the goal, is the sum of edge costs.

## Example: Romania

- On vacation in Romania; currently in Arad
- Flight leaves tomorrow from Bucharest

- **Initial state**  
– E.g. Arad
- **Successor Function**  
–  $S(\text{Arad}) = \{\text{Zerind, Timisoara, Sibiu}\}$
- **Goal state**  
– Bucharest
- **Path Cost**  
– Sum of edge costs

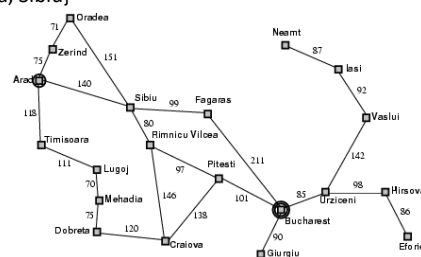


Figure 1: The Romania problem [3, p. 9]

**Vacuum-cleaner world** We can define a state for the vacuum world:

- Initial state  
Dirty
- Goal state  
All clean

- State space:

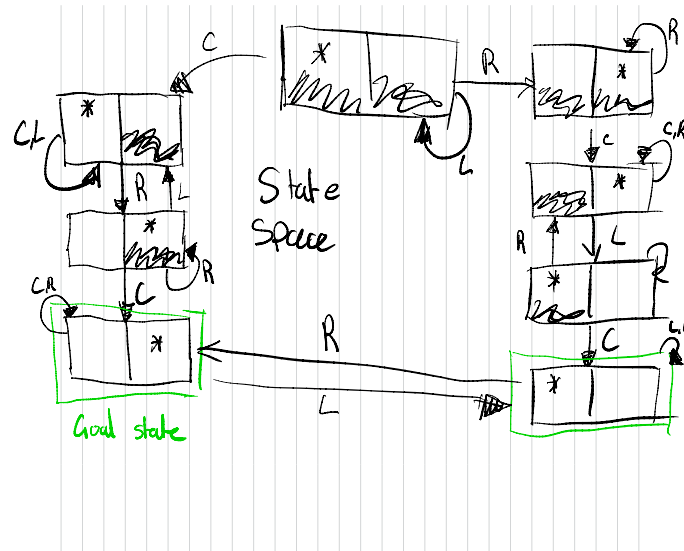


Figure 2: The state space of the vacuum cleaner world

- Path cost  
Could be the sum of the amount of electricity used, or any other type of utility function.

**Example: The 8-puzzle** The state space of the 8-puzzle has a size of 181440 states. The successor function is the actions of move blank left, right, up, down. The optimal solution is NP-hard[3, p. 17].

**Example: The 8-queens problem** On chessboard 8 queens are placed. We must place the queens, such that no other queen can attack each other.

- State space: Is the chessboard
- Successor function: depends on how you want to formalize it. It could be moving one piece in a direction, such that you have a different configuration.
- Goal state: Check if any queen is on the same row, column or diagonal.

**Example: Remove 5 sticks** Remove exactly 5 of the 17 stick such that the result forms 3 squares [3, p. 18].

- States:
- Initial state: The initial state is the state presented with all the sticks laid out, and having the 6 squares.
- Successor function: Picking up any stick from the board.
- Goal test: Check if the remaining sticks form the 3 squares, we need to have a function for that.
- Path cost: It cost one to remove a stick.

### 3.3 Tree search

We expand at the root node(which is the starting state). As we go about expanding the tree of the search, we maintain a list of unexpanded nodes. This we call the fringe. For each iteration we expand a node we pick from the fringe. We keep expanding until we reach the goal state. Our **goal** is to expand as few states as possible. This is the case as it takes time and can fill up the memory of the computer.

An important point is to that *nodes and states* are not the same. A state is a representation of a physical configuration, while a node is a data structure that is part of the search tree[3, p. 19]

A tree search algorithm works in the following way:

1. Initialize the fringe with the starting state
2. As long as the fringe is not empty:
  - (a) Choose a fringe node to expand
  - (b) If the node contains the goal state, then return that solution
  - (c) If not, expand the node and add the children of this node to the fringe.
3. If we reach the end, terminate having found no solution.

We keep an explored set of the node we already have visited, a node is added to this everytime we expand it. When we add a node to the fringe, then we check if it exists, with a higher path cost. If this is the case, then replace it.

### 3.4 Search strategies

A search strategy is defined by the order in which we pick which node to expand from the fringe. We have some different parameters by which to judge a search strategy:

- Completeness  
Does it find a solution if it exists?
- Optimality  
Does it find the cheapest solution?
- Time complexity  
This represents the number of the node generated aka the time it takes to run.
- Space complexity  
How many nodes are in memory?

We can measure the time and space complexity in terms of:

- $b$ : maximum branching factor of the search tree
- $d$ : depth of the least cost (cheapest) solution.
- $m$ : maximum length of any path in the state space (could be unbounded).

#### 3.4.1 Breadth-first search

We expand the shallowest node, such that we search in the breadth of the tree. This is done by the fringe being made as a first in-first out queue. Such each node that we expand, goes to the end of the fringe list.

**Completeness** Yes

**Optimality** Yes - if the cost is 1 for each step.

**Time complexity** Number of node in a  $b$ -ary tree of depth  $d$ : the complexity is  $O(b^d)$ .  
Where  $d$  is the depth of the optimal solution.

**Space complexity**  $O(b^d)$

### 3.4.2 Depth-first search

We expand the deepest node first, such that we traverse the depth of the tree, before visiting node higher up. This is done as a last-in-first-out queue.

**Completeness** Cannot deal with infinite depths, and space with loops. We be complete in finite space, if repeats are excluded from the list of visited nodes.

**Optimality** No - it returns the first solution that it finds.

**Time complexity** At depth  $m$ :  $O(b^m)$ .

**Space complexity**  $O(bm)$

### 3.4.3 Iterative deepening search

This is a mix of depth first, and breadth-first. We first examine the tree in a depth-first with the depth of 1 (we cut off node on level 2 and below). If we do not find out solution we run again with a depth of 2. We again search in a depth first-fashion. It is like having a depth-first approach, but find an optimal solution. This way we cannot fall into infinite loops.

### 3.4.4 Uniform-cost search

We organise the fringe such that all node are sorted according to the cost. Such that when we expand the root node, then its children B (cost 5) and D (cost 3) are sorted in the order D, B. We then go on to expand D.

Note that [3, p. 33] says that we should keep expanding nodes in the fringe until we are about to expand the goal node, and we should **not** stop when encountering it. Because there might a hidden better solution in the last unexpanded nodes.

## 4 Week 9 - Informed Search

The idea of informed search is to give the algorithm hints about the desirability of different states. Here we can use an evaluation function to rank node and select the most promising one for expansion. In this way can find the solution (goal) more efficiently, than just using uninformed search[1, p. 92].

We remember from the uniform-cost search, picking the best node (or the most promising node) to expand first. This we call best-first search, where use a evaluation function  $f(n)$ .

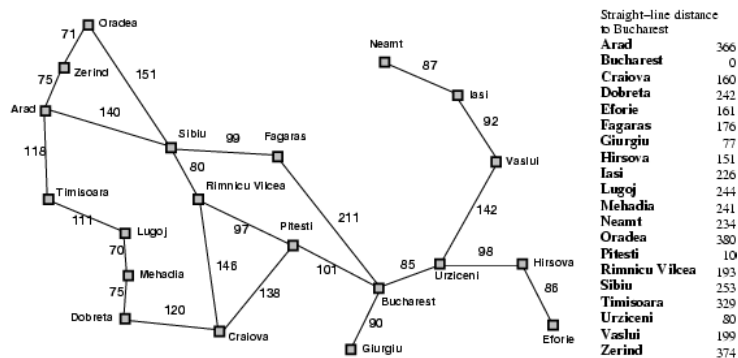
**Definition 4.1** An *evaluation function* is a cost estimate, the evaluation function defines our search strategy (which node we pick first).

### Heuristic function

**Definition 4.2** A *heuristic function*  $h(n)$  estimates the cost of reaching a goal from node  $n$ . The heuristic function is a type of evaluation function, that is often used in best-first search.

As an example we can use the heuristic function in the Romania problem. Presented here with the heuristics:

### Heuristic for the Romania problem



4

Figure 3: Heuristics for the Romania problem

Figure 3 shows the straight line distance from the town to Bucharest. This is not equal to the shortest distance on the graph. The heuristic is merely to inform our descisions in the heuristic function  $h(n)$ , when deciding which node to expand.

### 4.1 Informed Search Algorithms

There multiple types for informed search algorithms. In this section we outline these search algorithms.

#### 4.1.1 Greedy best-first search

Using the greedy best-first search algorithm we expand the node, which has the *lowest value* of the heuristic function  $h(n)$ .

**Properties** The greedy-best first search has some properties and pitfalls. The greedy best-first is **not complete** as it can get stuck in loops, where it jumps between two nodes, with a lower value than the two it jumps between. It is **not optimal** as it can make some not optimal descisions. As an example it will make the journey to Bucharest in the order: Arad, Sibiu, Fagaras, Bucharest, while the more optimal solution is: Arad, Sibiu, Rummucu Vilcea, Pitesti, Bucharest. The **time complexity** the worst case is:  $O(b^m)$ , and best case is  $O(bd)$  is the heuristic function is 100% accurate[4, p. 12].

#### 4.1.2 A\* search

As the greedy best-first search is flawed, we can change the *evaluation function*  $f(n)$ . We want to change the evaluation function  $f(n)$  to more accurately represent the estimated total cost of the path from the node  $n$  to the goal.

**Definition 4.3** We define  $A^*$  where:

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

- $g(n)$ : cost of getting to  $n$ , the path cost.
- $h(n)$ : estimated cost from  $n$  to the goal, this is our heuristic.

The algorithm is identical to uniform-cost, it just uses  $g(n) + h(n)$  instead of just  $g(n)$ [1, p. 93].

**Definition 4.4** An *admissible heuristic* never overestimates the cost to reach the goal (it is optimistic).

An example of an admissible heuristic is using the straight line distance from  $n$  to the goal. This is the case because the straight line distance is always *less* than the true distance to get somewhere. If  $h(n)$  is admissible, then **A\* is optimal**[4, p. 21]. A\* is optimally efficient, no other tree-based algorithm that use the same heuristic can expand fewer nodes and still be guaranteed to find the optimal solution.

## 4.2 Designing a Heuristic Function

We look at getting a heuristic function for the 8-puzzle.

- $h_1(n)$ : number of misplaced tiles.
- $h_2(n)$ : total Manhattan distance of the tiles form their goal positions

We now want to determine if the heuristics  $h_1$  and  $h_2$  are admissible. The results of this is for a goal state:

- $h_1(start) = 8$
- $h_2(start) = 3 + 1 + 2 + 2 + 2 + 3 + 3 + 2 = 18$

The results of the two heuristics is less than the actual cost, thus the heuristics are optimistic, and this they are admissible.

**Definition 4.5** A *dominant heuristic* the heuristic which dominates the other in  $A^*$  search. This is the case if  $h_2(n) \geq h_1(n)$  for all  $n$ .

### Heuristics from relaxed problems

**Definition 4.6** A *relaxed problem* is a problem with fewer restrictions on the actions.

The optimal cost to nodes in the relaxed problem is an admissible heuristic for the original problem. An example of a relaxed heuristic is the 8-puzzle is relaxed such that a tile can move anywhere on the board, then  $h_1(n)$  gives the shortest solution (a tile's shortest path to its right place). We can also relax the rules of the game, such that a tile can move to any adjacent squares, then  $h_2(n)$  give the shortest solution.

Looking at the typical search cost for the 8-puzzle (average number of nodes expanded for different solution depths).

If the solution has a depth  $d$  of  $d = 12$ . Then:

- $IDS = 3644035$  nodes
- $A * (h_1) = 227$  nodes
- $A * (h_2) = 73$  nodes

If the solution has a depth  $d$  of  $d = 24$ . Then:

- $IDS = 54,000,000,000$  nodes
- $A * (h_1) = 39,135$  nodes
- $A * (h_2) = 1,641$  nodes

So there is a clear benefit to choosing the right heuristic[4, p. 31].

However if there is no dominant heuristic and we have a collection of admissible heuristics  $h_1(n), h_2(n), \dots, h_m(n)$ . Then we can combine them with:

$$h(n) = \max\{h_1(n), h_2(n), \dots, h_m(n)\}$$

### 4.3 Weighted A\* search

The idea of weighted A\* search is to speed up the search at the expense of optimality. So we take an admissible heuristic, and inflate it by  $\alpha > 1$ , and then perform the A\* search as usual. By using this approach we expand fewer nodes, but we might not reach the solution in the most optimal way. The cost will be at most  $\alpha$ .



## 5 Week 10 - Local Search

We can formulate problems in terms of optimization. We do not care about the path to a solution. We have an objective function that us about the quality of a possible solution, and we want to find a good solution by minimizing or maximizing the value of the function.

There is three approaches to local search.

### 5.1 Hill-climbing (greedy) search

Here the crux is: keep a single "current state" and try to locally improve it. You can like it to "climbing mount Everest in thick fog with amnesia".

If we look at a puzzle, it should be 1, 2, 3, 4, 5, 6, 7, 8 going in a clockwise circle our function is

$$f(n) = -(\text{number of tiles out of place})$$

. We want to find the best solution, the one closest to what we think we want.

In each iteration we probe, for which move increases our evaluation function. It can get stuck in a local optimum.

### 5.2 Simulated annealing search

The hill-climbing will be never go down the hill of global and local maxima. The idea is to escape local maxima by allowing some "bad" moves but gradually decrease the frequency of these bad moves.

- Probability of taking downhill move decreases with number of iterations, steepness of downhill move
- Controlled by annealing schedule

Inspired by annealing process, as part of the tempering of glass, metal.

## 6 Week 11 - Adversarial Search

## 7 Week 12 - Constraint Satisfaction Problems

## 8 Week 15 - Probability

## 9 Week 16 - Bayesian Networks

## 10 Week 17 - Hidden Markov Models

## 11 Week 18 - Intro to Machine Learning

## **12 Lab 1 - Week 7**

### **12.1 TABEL-DRIVEN-AGENT**

**Run the module** The program prints:

**The percept**



## 13 Lab 2 - Week 8

1. Successor nodes are inserted at front of the fringe (successor list) as a node is expanded. Is this a breadth (FIFO) or depth-first search (LIFO)?

This is depth-first search. We put the successor node in front, and examine these first.

2. For goal J, give the fringe (successor list) after expanding each node.

The fringe list, should be empty, when we have found the goal J. However if we just expand the tree, going depth-first with LIFO then we would have:

J I H G F C E D B A

3. What is the effect of inserting successor nodes at the end of the fringe as a node is expanded? A depth or breadth-first search?

The effect of this is a breadth-first search.

4. For goal J, give the fringe (successor list) after expanding each node

A, B, C, D, E, F, G, H, I, J

## 14 Lab 3 - Week 9

## 15 Lab 4 - Week 10

## 16 Lab 5 - Week 11

## 17 Lab 6 - Week 12

## References

- [1] Stuart Russell and Peter Norvig. *Artificial Intelligence. A Modern Approach*. 2016.
- [2] Sanja Lazarova-Molnar. *Intelligent Agents*. Presentation. 2021. URL: ../presentations/w7\_lec02\_agents\_sanja\_2021.pdf. (accessed 08.04.21).
- [3] Sanja Lazarova-Molnar. *Solving Problem by Searching*. Presentation. 2021. URL: ../presentations/w8\_lec03\_search\_intro\_2021.pdf. (accessed 08.04.21).
- [4] Sanja Lazarova-Molnar. *Informed Search*. Presentation. 2021. URL: ../presentations/w9\_lec04\_informed\_search\_sanja\_2021.pdf. (accessed 08.04.21).