Department of Computer Science
Technical University of Cluj-Napoca

Artificial Intelligence

Laboratory activity

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Lab organisation.

1. Laboratory work is 25% from the final grade.
2. There are three deliverables in total: 1. Search, 2. Logic, 3. Planning.
3. Before each deadline, you have to send your work (latex documentation/code) at moodle.cs.utcluj.ro
4. We use Linux and Latex
5. Plagiarism: Don't be a cheater! Cheating affects your colleagues, scholarships and a lot more.

Chapter 1

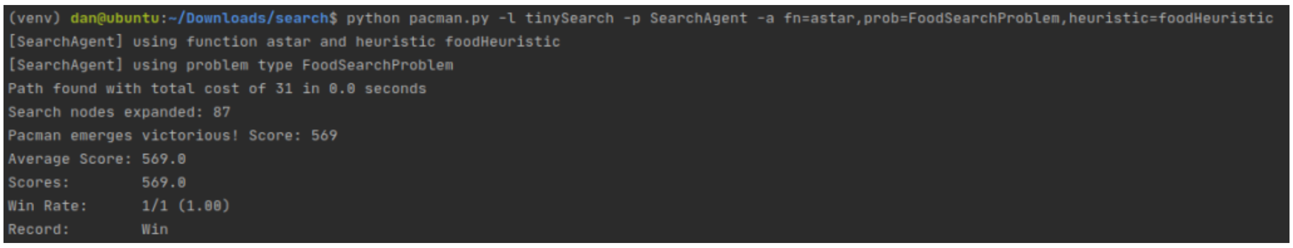
A1: Search

Weighted A^* is a bounded suboptimal search algorithm that is used to find good suboptimal solutions, because sometimes it is too expensive to search for an optimal solution.

It is similar to plain A^* with the difference that the cost from a node to the goal is computed differentely, given by the following formula: f(n) = g(n) + ε * h(n), where $\varepsilon \geq 1$ is the weight addded to the heuristic. A larger ε value results in a faster search with a greater cost.

The weight added to the heuristic makes that nodes which are further away from the goal will be affected significantly more by the added weight and will have very low priority when the algorithm performs its job, thus giving nodes that are closer to the goal a better chance of beign expanded.

During the tests performed on the algorithm I have found out that a weight of around 10 is the upper bound to how fast the algorithm gets (for our specific problem). Anything past that value returned similar values for the speed but an increase in cost. Thus, a value of 5 for the weight seems to strike a good balance between speed and cost.

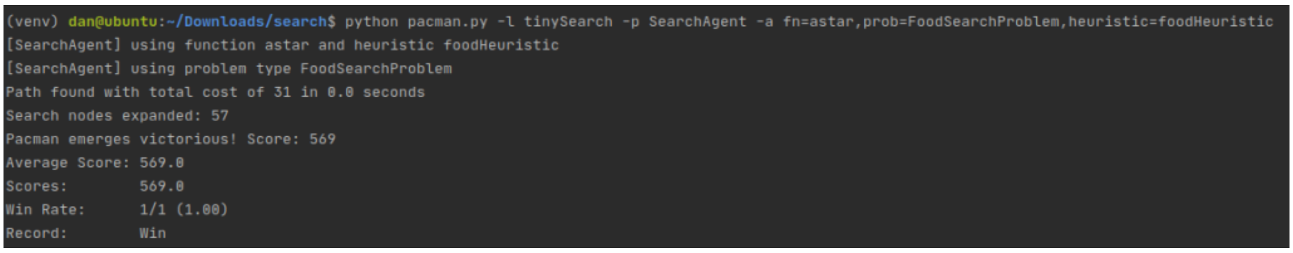


```
(venv) dan@ubuntu:~/Downloads/search$ python pacman.py -l tinySearch -p SearchAgent -a fn=astar,prob=FoodSearchProblem,heuristic=foodHeuristic
[SearchAgent] using function astar and heuristic foodHeuristic
[SearchAgent] using problem type FoodSearchProblem
Path found with total cost of 31 in 0.0 seconds
Search nodes expanded: 87
Pacman emerges victorious! Score: 569
Average Score: 569.0
Scores:        569.0
Win Rate:      1/1 (1.00)
Record:        Win
```

Fringe search is a path finding algorithm that represent the middle ground between plain A^* and iterative deepening A^*. Fringe search aims to improve on IDA^* by improving the following, repeating steps when there are multiple path to a goal node which is solved by introducing a cache of the visited states.

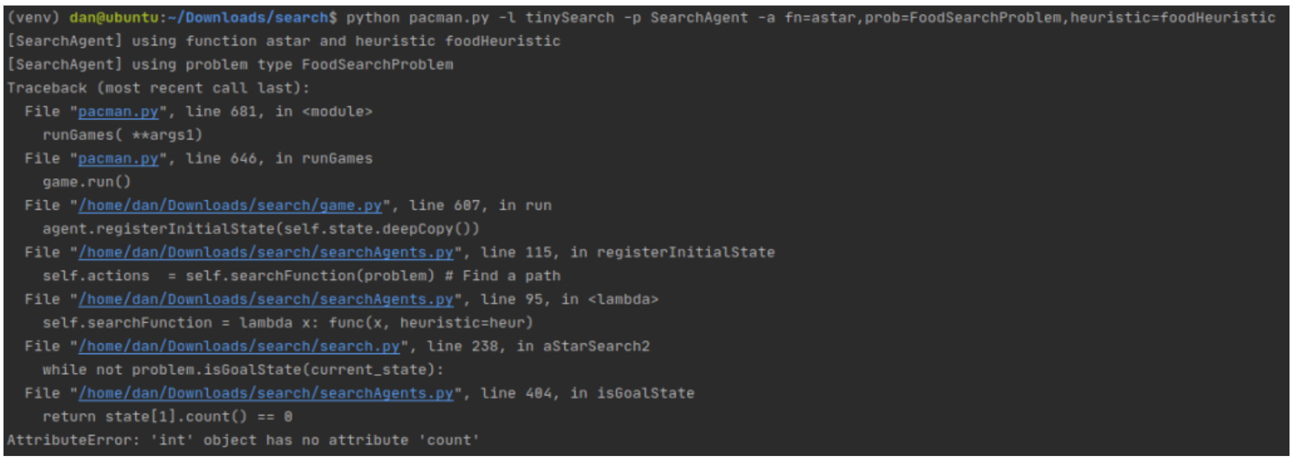
This code is a modification of the plain A^* by introducing some more lists that can hold nodes. This algorithm seems to perform better than A^* by needing to expand less nodes.

It is tested on the food problem, tinyMaze layout and with an heuristic that returns the number of remaining food on the map:



```
(venv) dan@ubuntu:~/Downloads/search$ python pacman.py -l tinySearch -p SearchAgent -a fn=astar,prob=FoodSearchProblem,heuristic=foodHeuristic
[SearchAgent] using function astar and heuristic foodHeuristic
[SearchAgent] using problem type FoodSearchProblem
Path found with total cost of 31 in 0.0 seconds
Search nodes expanded: 57
Pacman emerges victorious! Score: 569
Average Score: 569.0
Scores:        569.0
Win Rate:      1/1 (1.00)
Record:        Win
```

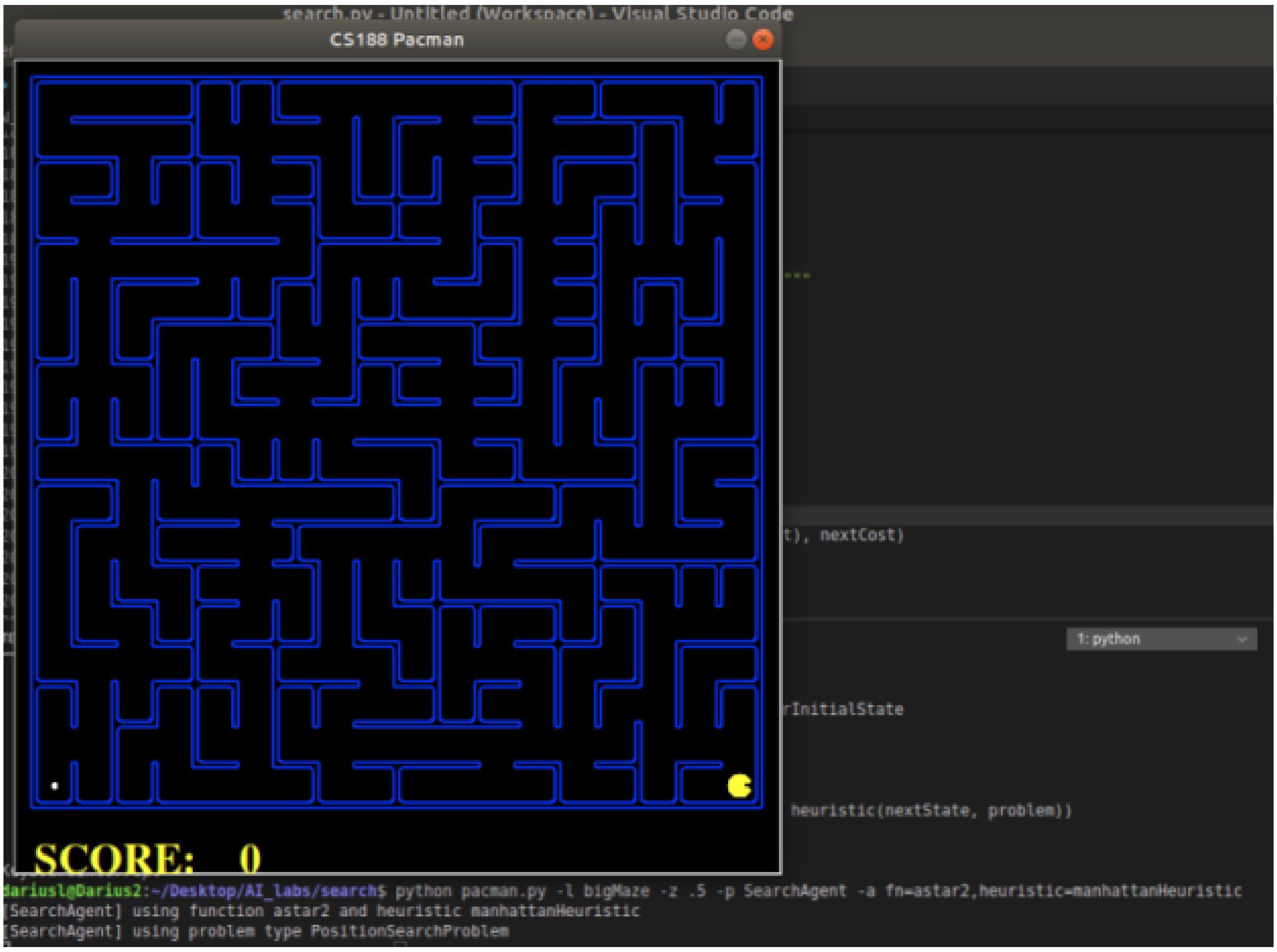
It would seem that it is necessary to enque and pop the starting node before entering the main loop of the program, otherwise the program crashes:



```
(venv) dan@ubuntu:~/Downloads/search$ python pacman.py -l tinySearch -p SearchAgent -a fn=astar,prob=FoodSearchProblem,heuristic=foodHeuristic
[SearchAgent] using function astar and heuristic foodHeuristic
[SearchAgent] using problem type FoodSearchProblem
Traceback (most recent call last):
  File "pacman.py", line 681, in <module>
    runGames( **args1)
  File "pacman.py", line 646, in runGames
    game.run()
  File "/home/dan/Downloads/search/game.py", line 607, in run
    agent.registerInitialState(self.state.deepCopy())
  File "/home/dan/Downloads/search/searchAgents.py", line 115, in registerInitialState
    self.actions  = self.searchFunction(problem) # Find a path
  File "/home/dan/Downloads/search/searchAgents.py", line 95, in <lambda>
    self.searchFunction = lambda x: func(x, heuristic=heur)
  File "/home/dan/Downloads/search/search.py", line 238, in aStarSearch2
    while not problem.isGoalState(current_state):
  File "/home/dan/Downloads/search/searchAgents.py", line 404, in isGoalState
    return state[1].count() == 0
AttributeError: 'int' object has no attribute 'count'
```

We saw online that one variation for A^* is similar to a Dijkstra based algorithm, closely related to Uniformed Cost Search algorithm where we have a directed weighted space that starts from a node and reaches the goal with the minimum cost. We figured out, from the comment's text, that the UCS and A^* are somehow related. We, first, searched for a pseudocode online resembling the UCS algorithm and try to modify it so we can adapt it to our PacMan problem.

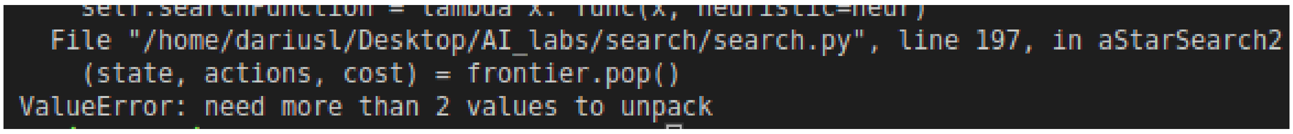
On the wikipedia page, referenced in the Bibliography chapter, we found the pseudocode for the UCS algorithm and had an idea that we can adapt the BFS algorithm, implemented in one lab session, to compute the UCS, implemented only on one of our search.py file, and then adapt it to obtain the desired variation of A^*. We saw that the priority queue has one parameter for setting the priority, so we could choose to have the cost as a parameter for that later in the push() function. We tried our best not to have problems compiling the code, and, luckily, we managed to have no obvious errors. We tested the algorithm on the bigMaze layout and found out that the PacMan is not doing anything just like in the image below:



```
t), nextCost)
rInitialState
heuristic(nextState, problem))
dariusl@Darius2:~/Desktop/AI_labs/search$ python pacman.py -l bigMaze -z .5 -p SearchAgent -a fn=astar2,heuristic=manhattanHeuristic
[SearchAgent] using function astar2 and heuristic manhattanHeuristic
[SearchAgent] using problem type PositionSearchProblem
```

Figure 1.1: The PacMan is unable to move

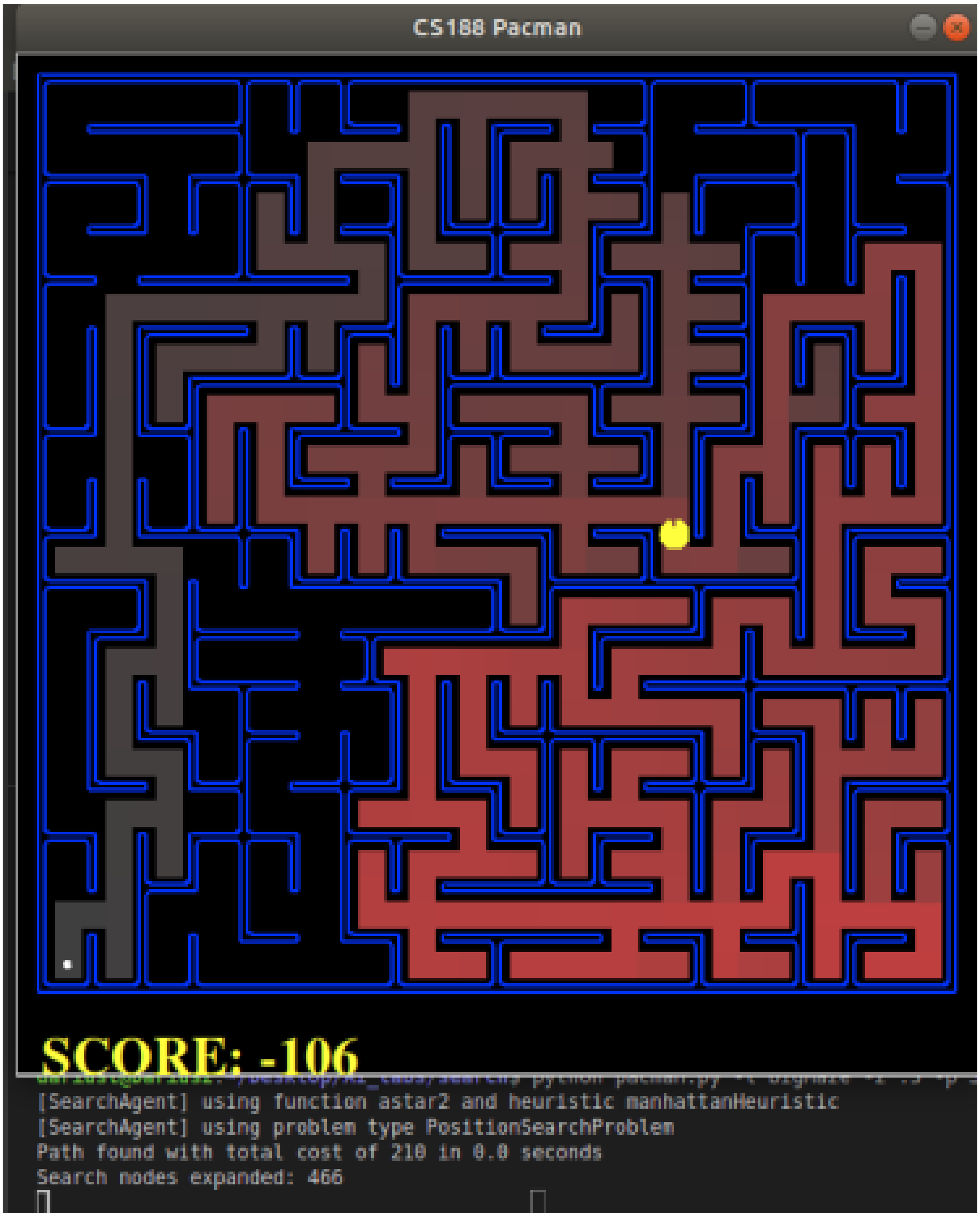
We tested the above variant without any heuristic to the algorithm because we did not know exactly where we should add the heuristic, but, again, it was in front of our eyes, just in the comment text ”combined cost and heuristic”. We added there the heuristic, but no difference. The logic was good, but we were unconscious on what to change next and tried to modify the items in the push() and pop() functions, maybe there is the problem. We took out the last parameter of the first declaration of push() and got the error shown:



```
    self.searchFunction = lambda x: func(x, heuristic=heur)
  File "/home/dariusl/Desktop/AI_labs/search/search.py", line 197, in aStarSearch2
    (state, actions, cost) = frontier.pop()
ValueError: need more than 2 values to unpack
```

Figure 1.2: Removing one parameter

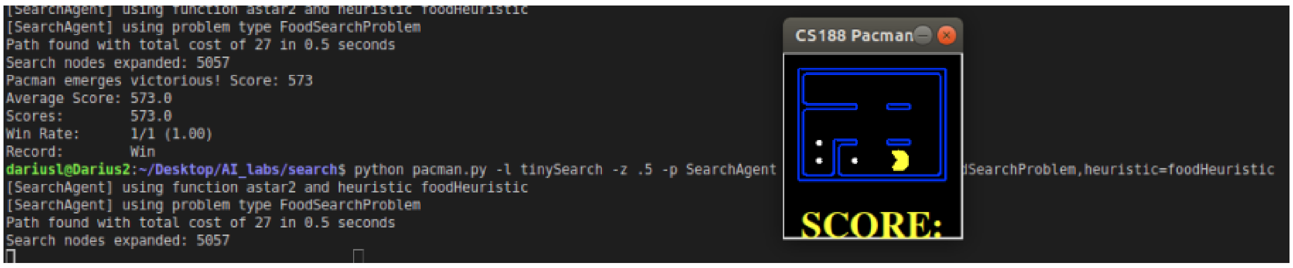
We quickly figured out that we also needed to modify what we wanted to pop(), obvious error, but not so on the spot and also from the push() in the for loop. Removing one parameter still has not resolved the problem. We thought that we might indent further away one tab and, indeed, it was because each statement below the first ”if” should have been one tab away. After all of that errors, the algorithm worked as intended, and below is an image of the test on the bigMaze layout:



```
[illegible]
[SearchAgent] using function astar2 and heuristic manhattanHeuristic
[SearchAgent] using problem type PositionSearchProblem
Path found with total cost of 210 in 0.0 seconds
Search nodes expanded: 466
```

Figure 1.3: The PacMan is able to move and performs the task

We also took a test, just in case something would not run in normal terms, for the food-Heuristic on the tinySearch layout and it was also a success, as you can see from the image underneath:



```
[SearchAgent] using function astar2 and heuristic foodHeuristic
[SearchAgent] using problem type FoodSearchProblem
Path found with total cost of 27 in 0.5 seconds
Search nodes expanded: 5057
Pacman emerges victorious! Score: 573
Average Score: 573.0
Scores:        573.0
Win Rate:      1/1 (1.00)
Record:        Win
dariusl@Darius2:~/Desktop/AI_labs/search$ python pacman.py -l tinySearch -z .5 -p SearchAgent dSearchProblem,heuristic=foodHeuristic
[SearchAgent] using function astar2 and heuristic foodHeuristic
[SearchAgent] using problem type FoodSearchProblem
Path found with total cost of 27 in 0.5 seconds
Search nodes expanded: 5057
```

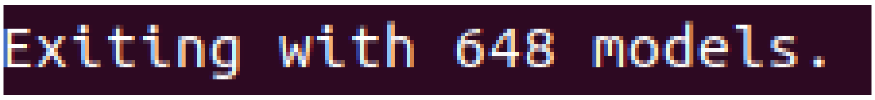
Figure 1.4: The test for the foodHeuristic

Chapter 2

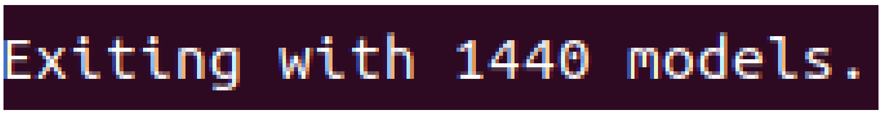
A2: Logics

For this assignment, we wanted to implement as much polyominoes puzzles as we could.

We started from a PNG file and a site, provided by our teacher, both will be referenced in the Bibliography section, with many example to inspire us in making our own puzzles or, maybe, try to replicate some of them. We tested the example provided in the PNG file and saw that there were quite some models for that grid, it was similar to the first puzzle from the site, were only 6 solutions were found. Further investigation led us to find that the domain size being quite high, 9, generated more possible values for the distinct list's members, so for, let's say, one or two possible arrangements of the pieces in that grid, mace4 found 30 to 40 possible models for them. That is exacly what we ecountered in our testing phase, we found a lot more models for some possible arrangements of those pieces than the actual computation, on paper, for a small grid (3x3, 4x4). This event is more visible for the irregular form, that we have implemented, where the models skyrocketed for a larger grid (5x5 or bigger). Below we will put two screenshots with the number of models obtain after the computation of some assumptions for two grids:



```
Exiting with 648 models.
```



```
Exiting with 1440 models.
```

Figure 2.1: The first number is for the tetromino irregular grid and the other one for the 4x4 irregular grid puzzle

We tried to construct 8 puzzles with different grids, regular or irregular and of different sizes, similar to the ones shown on the provided site or custom, entirely made by us. Underneath, we will show one pack of two images for each puzzle in which we show the pieces and the grid and in the second image the first model that came into our minds when we designed the puzzle or replicated from the site and some screenshots, when possible, to show different ordering of the chunks into each grid. Those arrangements were added into an array to have a nicer view of the segments and to see at which model they interchange. We did not implement any rotation of the pieces, they remain in the same position when mace4 tries to find models to fit in those grids.

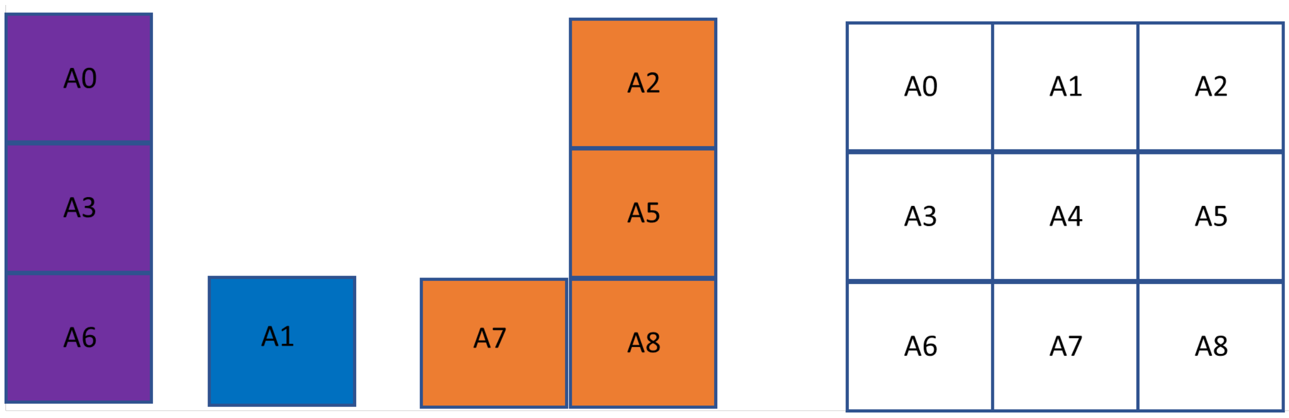


Figure 2.2: Custom 3x3 grid puzzle

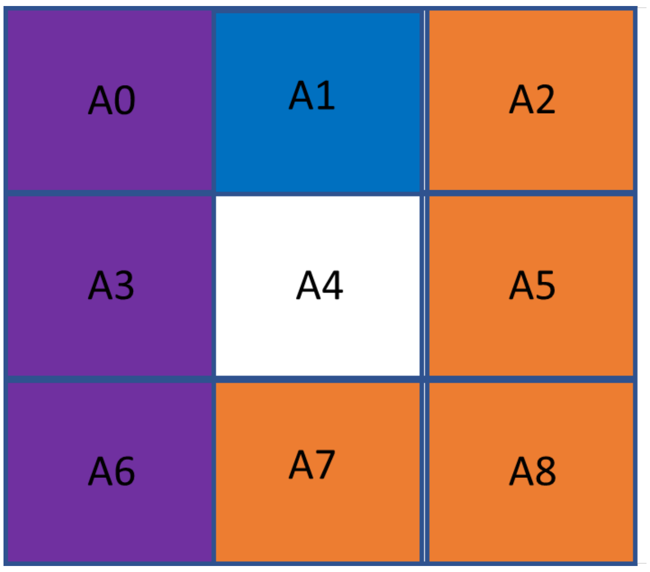


Figure 2.3: First representation with a hole in the middle

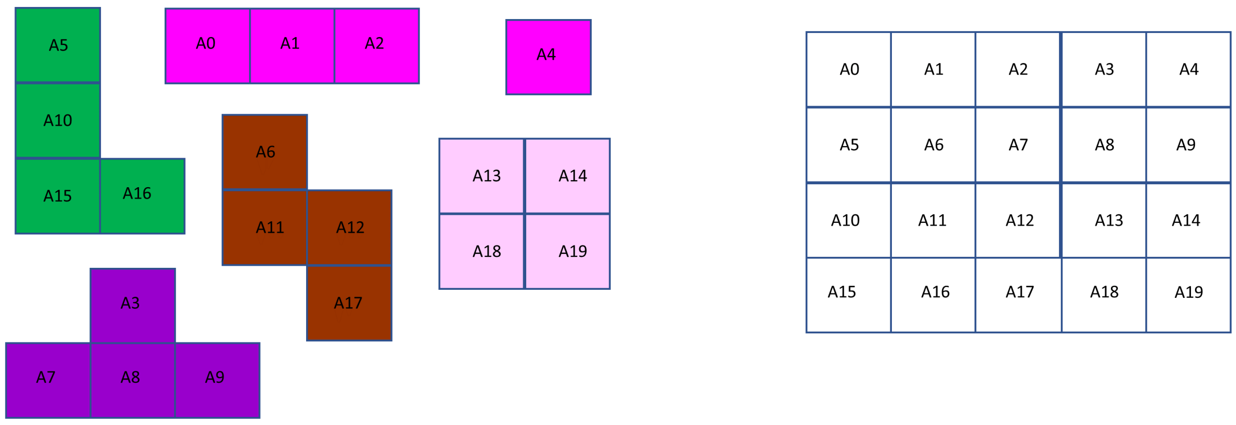


Figure 2.4: First tetromino from the site

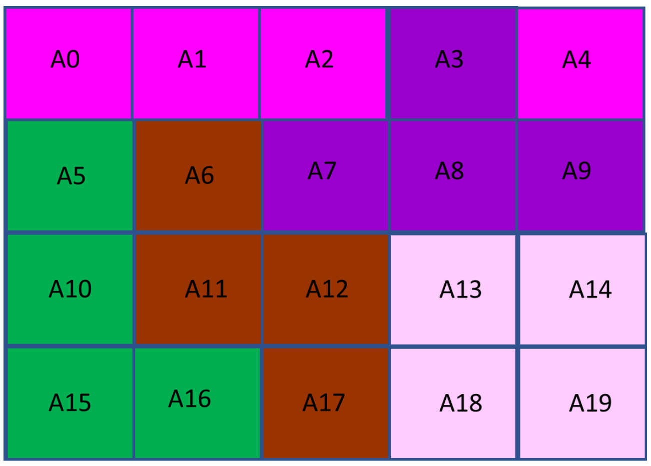


Figure 2.5: First representation of this form on this grid

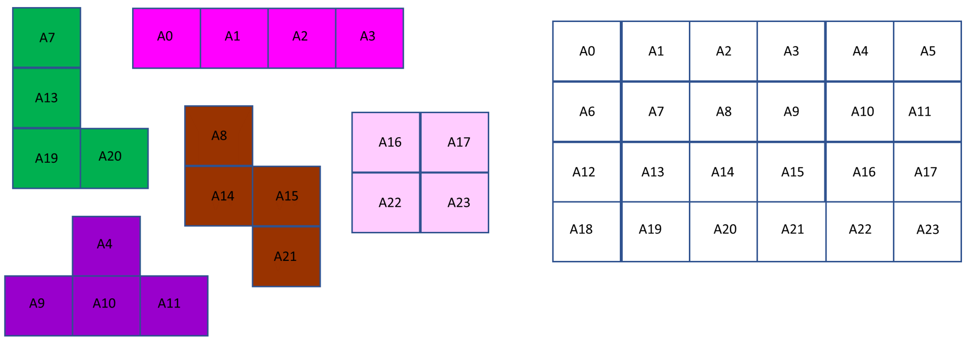


Figure 2.6: First irregular tetromino from the site

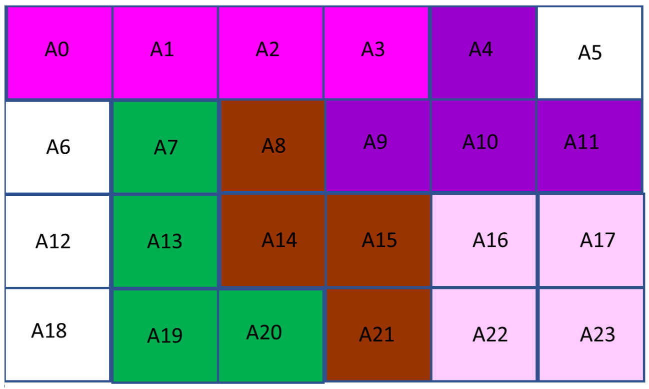


Figure 2.7: First representation of this form on this grid

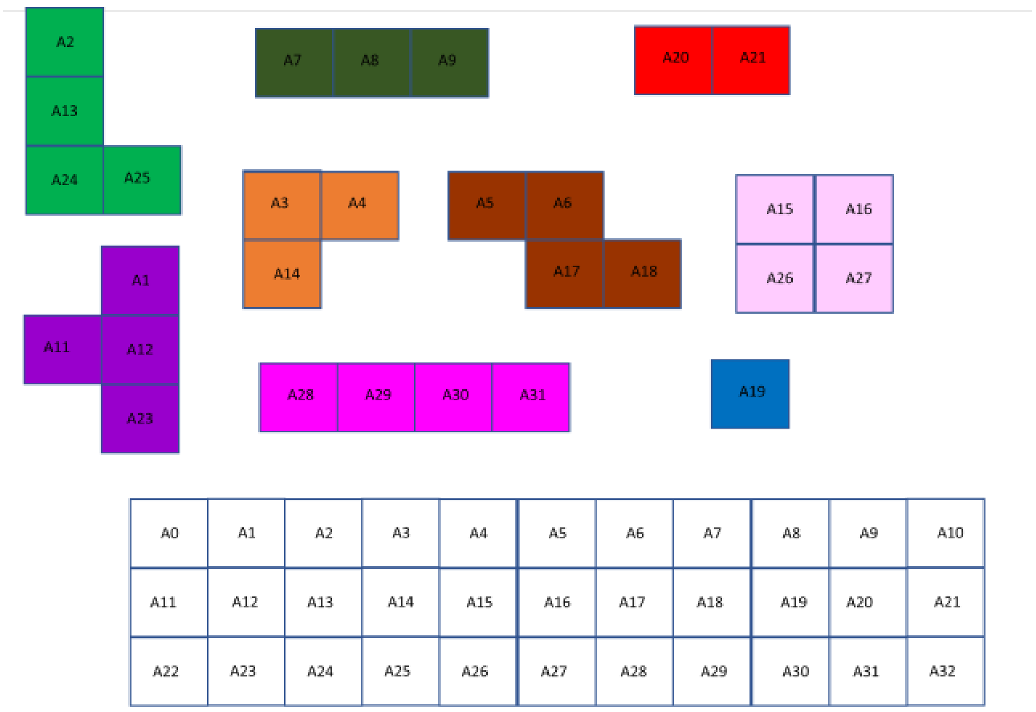

A2 A13 A24 A25
A7 A8 A9
A20 A21
A3 A4 A14
A5 A6 A17 A18
A15 A16 A26 A27
A1 A11 A12 A23
A28 A29 A30 A31
A19
A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 A10
A11 A12 A13 A14 A15 A16 A17 A18 A19 A20 A21
A22 A23 A24 A25 A26 A27 A28 A29 A30 A31 A32

Figure 2.8: Custom 11x3 grid

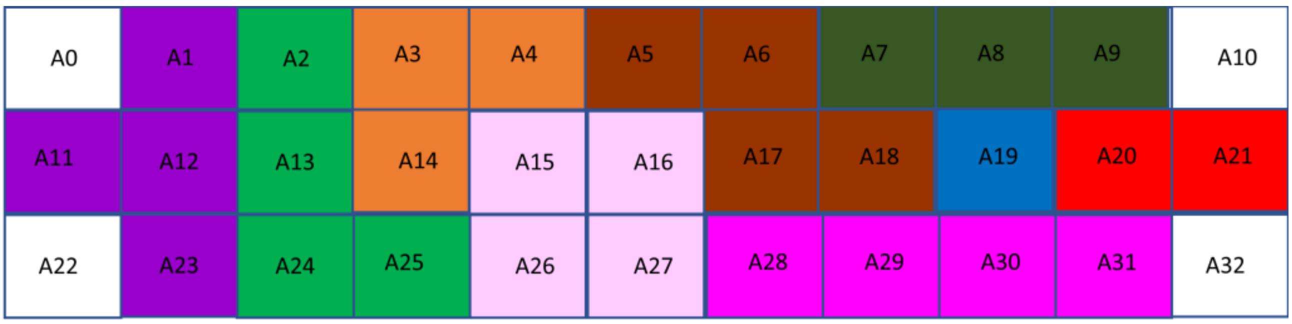

A0 A1 A2 A3 A4 A5 A6 A7 A8 A9 A10
A11 A12 A13 A14 A15 A16 A17 A18 A19 A20 A21
A22 A23 A24 A25 A26 A27 A28 A29 A30 A31 A32

Figure 2.9: First representation of this form on this custom grid

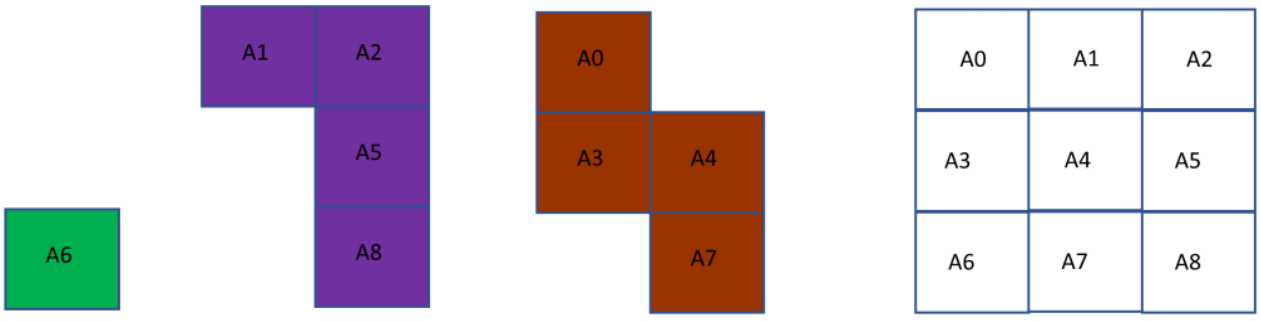


Figure 2.10: Custom 3x3 regular grid

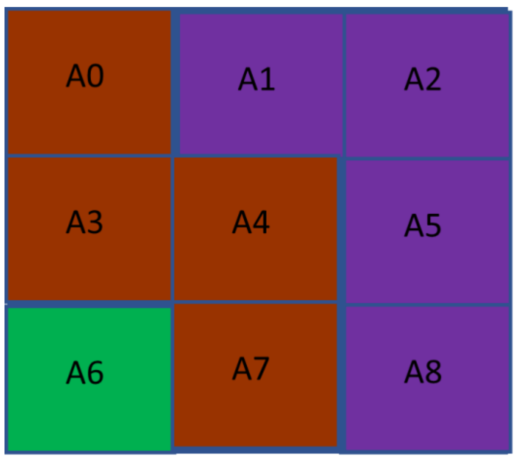


Figure 2.11: First representation of this form on this grid

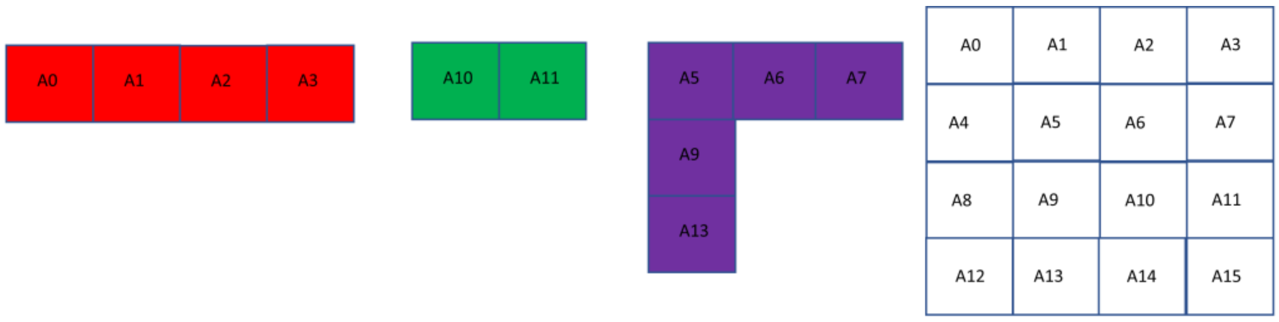


Figure 2.12: Custom 4x4 irregular grid

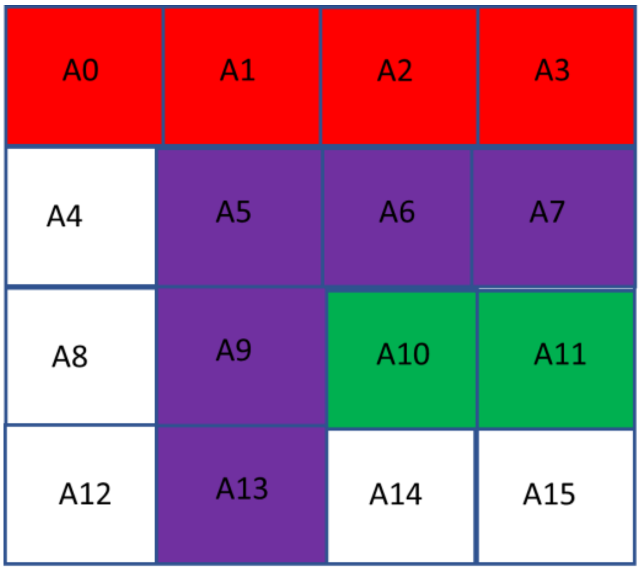


Figure 2.13: First representation of this form on this grid

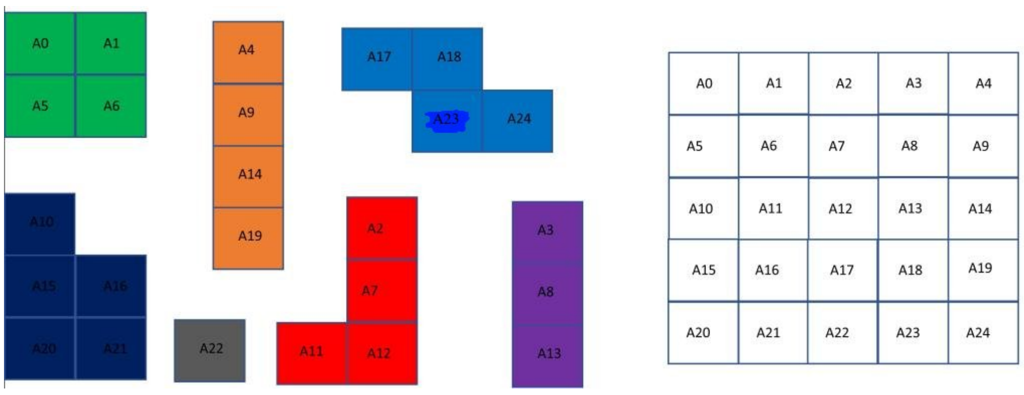


Figure 2.14: Custom 5x5 regular grid

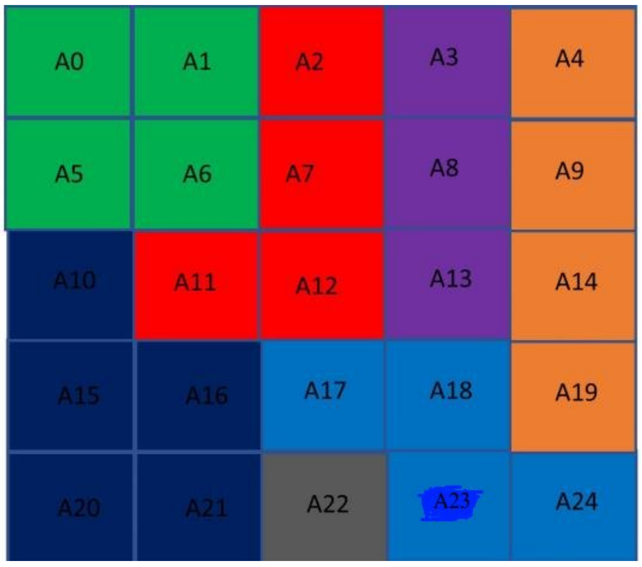


Figure 2.15: First representation of this form on this grid

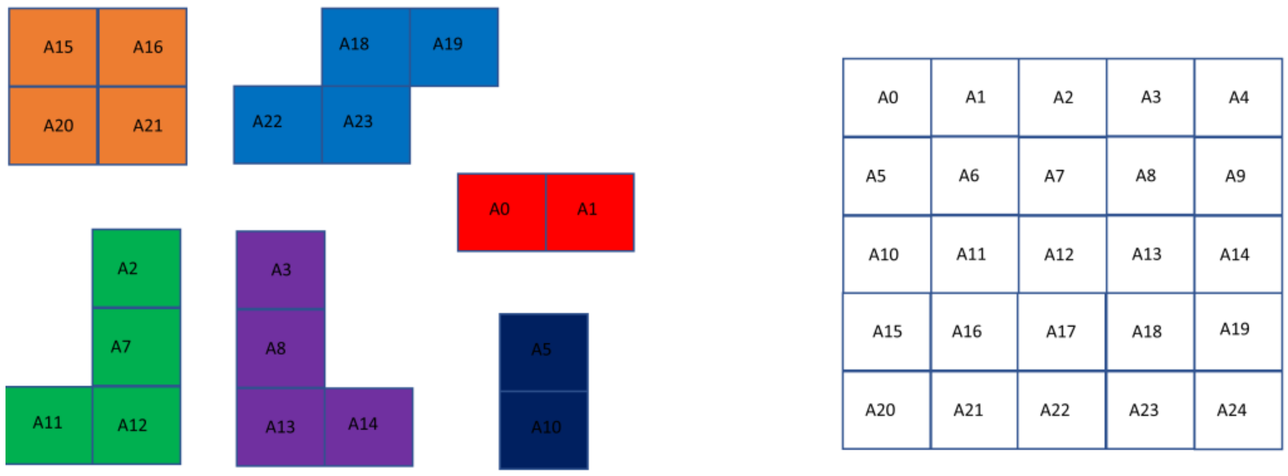


Figure 2.16: Custom 5x5 irregular grid

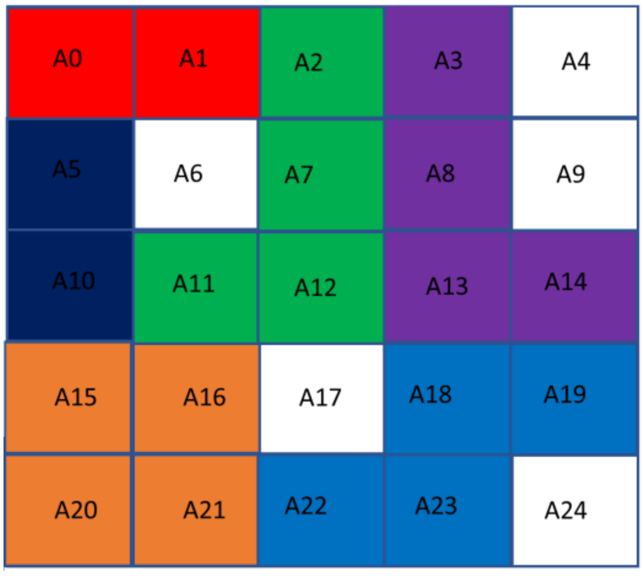
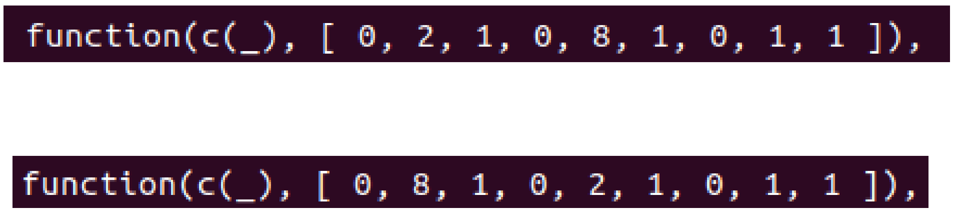


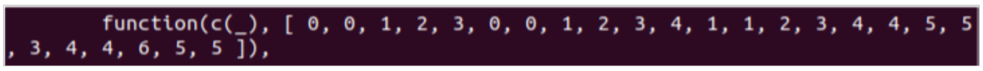
Figure 2.17: First representation of this form on this grid



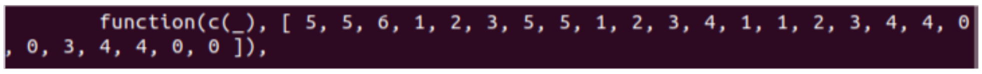
```
function(c(_), [ 0, 2, 1, 0, 8, 1, 0, 1, 1 ]),
```

```
function(c(_), [ 0, 8, 1, 0, 2, 1, 0, 1, 1 ]),
```

Figure 2.18: Differnet arrays with position - colours for the "hole" grid



```
        function(c(_), [ 0, 0, 1, 2, 3, 0, 0, 1, 2, 3, 4, 1, 1, 2, 3, 4, 4, 5, 5
, 3, 4, 4, 6, 5, 5 ]),
```



```
        function(c(_), [ 5, 5, 6, 1, 2, 3, 5, 5, 1, 2, 3, 4, 1, 1, 2, 3, 4, 4, 0
, 0, 3, 4, 4, 0, 0 ]),
```

Figure 2.19: Differnet arrays with position - colours for the 5x5 regular grid

From those implementations, we obtained that there are 2 models for the hole puzzle, also 2 models for the regular tetromino, 648 for the iregular tetromino and tens of thousands for the 11x3 grid, we had to interrupt the computation at a certain point because too many models were generated. Also, for the 3x3 puzzle we had one model, for the 4x4 grid, 1440, 5x5, 26 and the same outcome as for the 11x3 we had with this 5x5 iregular puzzle. Comments are in the source code with the colours of the pieces and which are the values fot the empty spaces for the irregular forms.

Chapter 3

A3: Planning

Chapter 4

Bibliography

https://inst.eecs.berkeley.edu/~cs188/fa18/assets/sections/final_review_solutions.pdf
https://webdocs.cs.ualberta.ca/~holte/Publications/fringe.pdf
https://en.wikipedia.org/wiki/Fringe_search
https://en.wikipedia.org/wiki/A*_search_algorithm#Relations_to_other_algorithms
Dijkstra Wikipedia
Poly.png
Site with polyominoes
Own laboratory's work

Appendix A

Your original code

A.1 Code for A1

```
# Weighted A*
def aStarSearch1(problem, heuristic=nullHeuristic):
    """Search the node that has the lowest combined cost and heuristic first."""
    priority_queue = util.PriorityQueue()
    visited = []
    start_state = (problem.getStartState(), [], 0)
    priority_queue.push(start_state, 0)
    while not priority_queue.isEmpty():
        state = priority_queue.pop()
        if problem.isGoalState(state[0]):
            return state[1]
        if not state[0] in visited:
            visited.append(state[0])
            successors = problem.getSuccessors(state[0])
            for successor in successors:
                if not successor[0] in visited:
                    cost = state[2] + successor[2]
                    total_cost = cost + 5 * heuristic(successor[0], problem)
                    new_state = (successor[0], state[1] + [successor[1]], cost)
                    priority_queue.push(new_state, total_cost)
    return nullHeuristic(problem)
# Fringe search
def aStarSearch2(problem, heuristic=nullHeuristic):
    fringe = util.PriorityQueue()
    visited = []
    temp = []
    later = []
    now = util.PriorityQueue()
    fringe.push(problem.getStartState(), 0)
    current_state = fringe.pop()
    while not problem.isGoalState(current_state):
        if current_state not in visited:
            visited.append(current_state)
            successors = problem.getSuccessors(current_state)
            for successor in successors:
                temp = later + [successor[1]]
                total_cost = problem.getCostOfActions(temp) + heuristic(successor[0], problem)
                if successor[0] not in visited:
                    fringe.push(successor[0], total_cost)
                    now.push(temp, total_cost)
        current_state = fringe.pop()
        later = now.pop()
    return later
#Variation of Dijkstra’s algorithm using heuristic
def aStarSearch3(problem, heuristic=nullHeuristic):
    """Search the node that has the lowest combined cost and heuristic first."""
    frontier = util.PriorityQueue()
    frontier.push((problem.getStartState(), []), 0)
    explored = set()
    while not frontier.isEmpty():
        (state, actions) = frontier.pop()
        if state not in explored:
            explored.add(state)
            if problem.isGoalState(state):
                return actions
            for nextState, nextActions, nextCost in problem.getSuccessors(state):
                frontier.push((nextState, actions + [nextActions]), nextCost + heuristic(nextState, problem))
    return []
```

A.2 Code for A2

```
%Regular 3x3 puzzle with a hole in the middle (custom)

assign(domain_size, 9).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2,
    a3, a4, a5,
    a6, a7, a8
 ].
end_of_list.

formulas(assumptions).
    (x != 6 & x != 7 & x != 8 & x != 4) -> (on(x,y) <-> y = x + 3).
    %x on y (will be used for each puzzle)
   -(x != 6 & x != 7 & x != 8 & x != 4) -> -on(x,y).
   %for the grid (will be used for each puzzle)

    (x != 2 & x != 5 & x != 8 & x != 4) -> (left(x,y) <-> y = x + 1).
    %x left of y (will be used for each puzzle)
   -(x != 2 & x != 5 & x != 8 & x != 4) -> -left(x,y).
   %for the grid (will be used for each puzzle)

    on(a0, a3) & on(a3, a6).              %purple
    on(a2, a5) & on(a5, a8) & left(a7, a8). %orange
end_of_list.

formulas(pretty_print).
    c(a0) = 0. c(a3) = 0. c(a6) = 0.         %purple
    c(a2) = 1. c(a5) = 1. c(a7) = 1. c(a8) = 1. %orange
    c(a1) = 2.   %blue
    c(a4) = 8.  %empty
end_of_list.


%Regular tetro puzzle from site

assign(domain_size, 20).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2, a3, a4,
    a5, a6, a7, a8, a9,
    a10, a11, a12, a13, a14,
    a15, a16, a17, a18, a19
 ].
end_of_list.

formulas(assumptions).
(x != 19 & x != 18 & x != 17 & x != 16 & x != 15) -> (on(x,y) <-> y = x + 5).
   -(x != 19 & x != 18 & x != 17 & x != 16 & x != 15) -> -on(x,y).

(x != 4 & x != 9 & x != 14 & x != 19) -> (left(x,y) <-> y = x + 1).
   -(x != 4 & x != 9 & x != 14 & x != 19) -> -left(x,y).

    left(a0, a1) & left(a1, a2).     %pink
    on(a3, a8) & left(a7, a8) & left(a8, a9).     %purple
    on(a5, a10) & on(a10, a15) & left(a15, a16).     %green
    on(a6, a11) & left(a11, a12) & on(a12, a17).     %brown
    on(a13, a18) & left(a13, a14) & on(a14, a19) & left(a18, a19). %blueberry yoghurt
end_of_list.

formulas(pretty_print).
    c(a0) = 0. c(a1) = 0. c(a2) = 0.  %pink
    c(a3) = 1. c(a7) = 1. c(a8) = 1. c(a9) = 1.  %purple
    c(a5) = 2. c(a10) = 2. c(a15) = 2. c(a16) = 2.  %green
    c(a6) = 3. c(a11) = 3. c(a12) = 3. c(a17) = 3.  %brown
    c(a13) = 4. c(a14) = 4. c(a18) = 4. c(a19) = 4. %blueberry yoghurt
    c(a4) = 5.  %the last bit of pink
end_of_list.
```

```
%Irregular tetro puzzle from site

assign(domain_size, 24).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2, a3, a4, a5,
    a6, a7, a8, a9, a10, a11,
    a12, a13, a14, a15, a16, a17,
    a18, a19, a20, a21, a22, a23
 ].
end_of_list.

formulas(assumptions).
    (x != 23 & x != 22 & x != 21 & x != 20 & x != 19 & x != 18) -> (on(x,y) <-> y = x + 6).
    -(x != 23 & x != 22 & x != 21 & x != 20 & x != 19 & x != 18) -> -on(x,y).

    (x != 5 & x != 11 & x != 17 & x != 23) -> (left(x,y) <-> y = x + 1).
    -(x != 5 & x != 11 & x != 17 & x != 23) -> -left(x,y).

    left(a0, a1) & left(a1, a2) & left(a2, a3).  %pink
    on(a4, a10) & left(a9, a10) & left(a10, a11).  %purple
    on(a7, a13) & on(a13, a19) & left(a19, a20).  %green
    on(a8, a14) & left(a14, a15) & on(a15, a21).  %brown
    on(a16, a22) & left(a16, a17) & on(a17, a23) & left(a22, a23).  %blueberry yoghurt
end_of_list.

formulas(pretty_print).
    c(a0) = 0. c(a1) = 0. c(a2) = 0. c(a3) = 0. %pink
    c(a4) = 1. c(a9) = 1. c(a10) = 1. c(a11) = 1.  %purple
    c(a7) = 2. c(a13) = 2. c(a19) = 2. c(a20) = 2.  %green
    c(a8) = 3. c(a14) = 3. c(a15) = 3. c(a21) = 3. %brown
    c(a16) = 4. c(a17) = 4. c(a22) = 4. c(a23) = 4. %blueberry yoghurt
    c(a5) = 9. c(a6) = 9. c(a12) = 9. c(a18) = 9.  %empty
end_of_list.


%Puzzle 11x3 grid custom

assign(domain_size, 33).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2, a3, a4, a5, a6, a7, a8, a9, a10,
    a11, a12, a13, a14, a15, a16, a17, a18, a19, a20, a21,
    a22, a23, a24, a25, a26, a27, a28, a29, a30, a31, a32
 ].
end_of_list.

formulas(assumptions).
    (x != 32 & x != 31 & x != 22 & x != 23 & x != 24 & x != 25 & x != 26 & x != 27
    & x != 28 & x != 29 & x != 30 & x != 0) -> (on(x,y) <-> y = x + 11).
   -(x != 32 & x != 31 & x != 22 & x != 23 & x != 24 & x != 25 & x != 26 & x != 27
    & x != 28 & x != 29 & x != 30 & x != 0) -> -on(x,y).

(x != 10 & x != 21 & x != 32) -> (left(x,y) <-> y = x + 1).
   -(x != 10 & x != 21 & x != 32) -> -left(x,y).

    on(a1, a12) & left(a11, a12) & on(a12, a23).     %purple
    on(a2, a13) & on(a13, a24) & left(a24, a25).     %lime
    left(a3, a4) & on(a3, a14).    %orange
    on(a15, a26) & left(a15, a16) & on(a16, a27) & left(a26, a27). %blueberry yoghurt
    left(a5, a6) & on(a6, a17) & left(a17, a18).     %brown
    left(a28, a29) & left(a29, a30) & left(a30, a31).     %pink
    left(a7, a8) & left(a8, a9).     %green
    left(a20, a21).     %red
end_of_list.

formulas(pretty_print).
    c(a1) = 0. c(a12) = 0. c(a11) = 0. c(a23) = 0.  %purple
    c(a2) = 1. c(a13) = 1. c(a24) = 1. c(a25) = 1.  %lime
    c(a3) = 2. c(a4) = 2. c(a14) = 2.  %orange
    c(a15) = 3. c(a16) = 3. c(a26) = 3. c(a27) = 3.  %blueberry yoghurt
    c(a5) = 4. c(a6) = 4. c(a17) = 4. c(a18) = 4.  %brown
    c(a28) = 5. c(a29) = 5. c(a30) = 5. c(a31) = 5.  %pink
    c(a7) = 6. c(a8) = 6. c(a9) = 6.  %green
    c(a20) = 7. c(a21) = 7. %red
    c(a19) = 8.  %blue
    c(a0) = 32. c(a10) = 32. c(a22) = 32. c(a32) = 32.  %empty
end_of_list.
```

```
%Puzzle 3x3 custom

assign(domain_size, 9).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2,
    a3, a4, a5,
    a6, a7, a8
 ].
end_of_list.

formulas(assumptions).
(x != 6 & x != 7 & x != 8) -> (on(x,y) <-> y = x + 3).
   -(x != 6 & x != 7 & x != 8) -> -on(x,y).

(x != 2 & x != 5 & x != 8) -> (left(x,y) <-> y = x + 1).
   -(x != 2 & x != 5 & x != 8) -> -left(x,y).

    left(a1, a2) & on(a2, a5) & on(a5, a8). %purple
    on(a0, a3) & left(a3, a4) & on(a4, a7). %brown
end_of_list.

formulas(pretty_print).
    c(a0) = 0. c(a3) = 0. c(a4) = 0. c(a7) = 0. %purple
    c(a1) = 1. c(a2) = 1. c(a5) = 1. c(a8) = 1. %brown
    c(a6) = 2.     %only one green box
end_of_list.

%Puzzle 4x4 irregular custom

assign(domain_size, 16).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2, a3,
    a4, a5, a6, a7,
    a8, a9, a10, a11,
    a12, a13, a14, a15
 ].
end_of_list.

formulas(assumptions).
(x != 12 & x != 13 & x != 14 & x != 15) -> (on(x,y) <-> y = x + 4).
   -(x != 12 & x != 13 & x != 14 & x != 15) -> -on(x,y).

(x != 3 & x != 7 & x != 11 & x != 15) -> (left(x,y) <-> y = x + 1).
   -(x != 3 & x != 7 & x != 11 & x != 15) -> -left(x,y).

    left(a0, a1) & left(a1, a2) & left(a2, a3).  %red
    left(a5, a6) & left(a6, a7) & on(a5, a9) & on(a9, a13). %purple
    left(a10, a11).  %green
end_of_list.

formulas(pretty_print).
    c(a0) = 0. c(a1) = 0. c(a2) = 0. c(a3) = 0.    %red
    c(a5) = 1. c(a6) = 1. c(a7) = 1. c(a9) = 1. c(a13) = 1.   %purple
    c(a10) = 2. c(a11) = 2.    %green
    c(a4) = 8. c(a8) = 8. c(a12) = 8. c(a14) = 8. c(a15) = 8. %empty
end_of_list.
```

```
%Puzzle 5x5 regular custom

assign(domain_size, 25).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2, a3, a4,
    a5, a6, a7, a8, a9,
    a10, a11, a12, a13, a14,
    a15, a16, a17, a18, a19,
    a20, a21, a22, a23, a24
 ].
end_of_list.

formulas(assumptions).
(x != 20 & x != 21 & x != 22 & x != 23 & x != 24) -> (on(x,y) <-> y = x + 5).
   -(x != 20 & x != 21 & x != 22 & x != 23 & x != 24) -> -on(x,y).

(x != 4 & x != 9 & x != 14 & x != 19 & x != 24) -> (left(x,y) <-> y = x + 1).
   -(x != 4 & x != 9 & x != 14 & x != 19 & x != 24) -> -left(x,y).

    left(a0, a1) & on(a0, a5) & left(a5, a6) & on(a1, a6).    %green
    on(a2, a7) & on(a7, a12) & left(a11, a12).    %red
    on(a3, a8) & on(a8, a13).   %purple
    on(a4, a9) & on(a9, a14) & on(a14, a19).    %orange
    on(a10, a15) & on(a15, a20) & left(a15, a16) & left(a20, a21) & on(a16, a21). %dark blue
    left(a17, a18) & on(a18, a23) & left(a23, a24).    %light blue
end_of_list.

formulas(pretty_print).
    c(a0) = 0. c(a1) = 0. c(a5) = 0. c(a6) = 0.     %green
    c(a2) = 1. c(a7) = 1. c(a7) = 1. c(a11) = 1. c(a12) = 1.   %red
    c(a3) = 2. c(a8) = 2. c(a13) = 2.     %purple
    c(a4) = 3. c(a9) = 3. c(a14) = 3. c(a19) = 3.     %orange
    c(a10) = 4. c(a15) = 4. c(a16) = 4. c(a20) = 4. c(21) = 4. %dark blue
    c(a17) = 5. c(a18) = 5. c(a23) = 5. c(a24) = 5.     %light blue
    c(a22) = 6.     %last box - grey
end_of_list.

%Puzzle 5x5 irregular custom

assign(domain_size, 25).
assign(max_models, -1).
set(arithmetic).

list(distinct).
 [
    a0, a1, a2, a3, a4,
    a5, a6, a7, a8, a9,
    a10, a11, a12, a13, a14,
    a15, a16, a17, a18, a19,
    a20, a21, a22, a23, a24
 ].
end_of_list.

formulas(assumptions).
(x != 20 & x != 21 & x != 22 & x != 23 & x != 24) -> (on(x,y) <-> y = x + 5).
   -(x != 20 & x != 21 & x != 22 & x != 23 & x != 24) -> -on(x,y).

(x != 4 & x != 9 & x != 14 & x != 19 & x != 24) -> (left(x,y) <-> y = x + 1).
   -(x != 4 & x != 9 & x != 14 & x != 19 & x != 24) -> -left(x,y).

    left(a0, a1).    %red
    on(a2, a7) & on(a7, a12) & left(a11, a12).    %green
    on(a3, a8) & on(a8, a13) & left(a13, a14).    %purple
    on(a5, a10).    %dark blue
    on(a15, a20) & left(a15, a16) & on(a16, a21) & left(a20, a21).%orange
    left(a18, a19) & on(a18, a23) & left(a22, a23).    %light blue
end_of_list.

formulas(pretty_print).
    c(a0) = 0. c(a1) = 0.   %red
    c(a2) = 1. c(a7) = 1. c(a7) = 1. c(a11) = 1. c(a12) = 1. %green
    c(a3) = 2. c(a8) = 2. c(a13) = 2. c(a14) = 2.   %purple
    c(a5) = 3. c(a10) = 3.  %dark blue
    c(a15) = 4. c(a16) = 4. c(a20) = 4. c(a21) = 4.   %orange
    c(a18) = 5. c(a19) = 5. c(a22) = 5. c(a23) = 5.   %light blue
    c(a4) = 8. c(a6) = 8. c(a9) = 8. c(17) = 8. c(24) = 8.   %empty
end_of_list.
```