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

1.1 Introduction

Artificial Intelligence (AI) has revolutionized the way machines perceive and interact with their environment, enabling them to make intelligent decisions and solve complex problems. Search algorithms play a fundamental role in AI, helping systems navigate vast decision spaces to find optimal solutions. To illustrate the power and versatility of search algorithms, we can turn to the world of gaming, and specifically, the iconic Pac-Man game.

1.2 Algorithms

Search algorithms in artificial intelligence are computational techniques used to find optimal or near-optimal solutions to complex problems by systematically exploring a search space. These algorithms are a fundamental component of AI and have applications in various domains, including route planning, game playing, robotics, natural language processing, and more.

1.2.1 A* Search

The A* algorithm is a widely used and highly effective graph search algorithm. It is commonly employed for pathfinding and graph traversal in various domains, including artificial intelligence, robotics, video games, and more. A* is renowned for its ability to find the shortest path from a starting point to a goal while efficiently exploring a search space.

The algorithm operates in a loop, continuing until the open_list is empty or a goal state is found. The loop has the following steps:

- Pop the node with the lowest f-value from the open_list. This node represents the most promising state to explore next.
- Check if the current state is the goal state using `problem.isGoalState(state)`. If it is, a solution has been found, and the algorithm returns the list of actions, which is the path to the goal state.
- If the current state has not been visited, mark it as visited by adding it to the visited set.
- Generate successors of the current state using `problem.getSuccessors(state)`. These successors are states that can be reached from the current state, along with the corresponding actions and step costs.

  For each successor:

- Calculate the new cost (new_cost) by adding the step cost to the cost of the current state.
- Calculate the f-value (f_value) of the successor using the formula $f\_value = new\_cost +$ `heuristic(successor, problem)`. The heuristic function estimates the cost to reach the goal state from the successor.
- Push the successor onto the open_list with the new actions (the current actions plus the new action) and the new cost.

1.2.2 A* Weighted Search

Weighted A* is a variation of the A* algorithm that allows you to control the trade-off between the heuristic component (h-cost) and the actual cost to reach a node (g-cost) when determining the priority of nodes in the open set. In standard A*, the priority is based on the sum of g-cost and h-cost. In weighted A*, you introduce a weight factor which is used to adjust the relative importance of g-cost and h-cost in determining the priority.

The weight factor in weighted A* determines how much emphasis is placed on the heuristic estimate. By increasing its value you make the algorithm more greedy, meaning it focuses more on the heuristic estimate and is more likely to explore fewer nodes but may not guarantee an optimal path. Conversely, by decreasing it, you make the algorithm more similar to standard A*, where it explores more nodes but has a higher chance of finding the optimal path.

- When the weight is set to 1, the algorithm behaves like traditional A*. It balances the actual cost and heuristic estimate equally. This usually results in an optimal solution, assuming the heuristic is admissible and consistent.
- Setting the weight to 0 essentially eliminates the heuristic component, making it equivalent to uniform cost search (Dijkstra's algorithm).
- When you increase the weight, the algorithm gives more importance to the heuristic estimate (h(n)) relative to the actual cost (g(n)). This means the algorithm prioritizes exploring paths that seem more promising according to the heuristic.
- Conversely, when you decrease the weight, the algorithm places more emphasis on the actual cost of the path (g(n)) compared to the heuristic estimate (h(n)). Lower weights make the algorithm focus on exploring paths that are cheaper in terms of the actual path cost.

Layout	Weight=0	Weight=1	Weight=3	Weight=100	A*
expanded nodes-medium	269	221	211	78	221
expanded nodes-big	620	549	510	466	549

Table 1.1: Results for A* weighted depending on the value of the weight

1.2.3 Iterative Deepening A*

Iterative deepening A* is a graph traversal and path search algorithm that can find the shortest path between a start node and a goal node in a weighted graph. Since it is a depth-first search algorithm, its memory usage is lower than in A*, but unlike ordinary iterative deepening search, it concentrates on exploring the most promising nodes and thus does not go to the same depth everywhere in the search tree. Unlike A*, IDA* does not utilize dynamic programming and therefore often ends up exploring the same nodes many times. The code consists of two functions:

iterativeDeepeningAStar:

It starts with a depth limit of 1. It enters a while loop that continues indefinitely (until a solution is found). In each iteration, it calls the `aStarSearchLimited` function with the current depth limit. If the result of the limited A* search is not None (i.e., a solution is found), it returns the result. If no solution is found at the current depth limit, it increments the depth limit by 1 and continues to the next iteration.

aStarSearchLimited:

- It uses a priority queue (min-heap) called `open_list` to manage the nodes to be explored. It starts by pushing the start state onto the `open_list` with an empty list of actions and a cost of 0. The priority is set to 0 because it's the initial depth. It maintains a set called `visited` to keep track of explored states. It enters a loop that continues until the `open_list` is empty. In each iteration, it pops the state, actions, and cost with the lowest priority (min f-value) from the `open_list`. If the popped state is the goal state, it returns the list of actions, which is the solution. If the state is not the goal state and has not been visited, it adds it to the `visited` set and explores its successors. It calculates the new cost and f-value for each successor and pushes the successor onto the `open_list` only if the length of the actions is less than or equal to the current depth limit.

1.3 Algorithm Comparison

Algorithm	Layout	Expanded nodes	Cost	Score
A*	small maze	53	19	491
A* weighted	small maze	39	29	481
Iterative Deepening A*	small maze	907	19	491
A*	medium maze	221	68	442
A* weighted	medium maze	78	74	436
Iterative Deepening A*	medium maze	8481	68	442
A*	big maze	549	210	300
A* weighted	big maze	466	210	300
Iterative Deepening A*	big maze	61014	210	300

Table 1.2: Comparison between algorithms

Chapter 2

A2: Logics

2.1 Logic Equation

In this 8x8 Logic Equation you have to find unique integer values for the variables [raging from 1 to 8] such that all the statements are true.

```
E + F = C + H
A  + G = C + D
F + H = B + E
A != 3
B + F = C + G
G != 2
F != 3
B != 7
G != 8
C != 1
A != 8
```

To run the logiceq.in we use the following command:

```
mace4 -f logiceq.in | interpformat standard > logiceq.out.
```

The solution to the equation is stored in logiceq.out.

```
interpretation( 9, [number = 1,seconds = 0], [
function(A, [4]),
function(B, [6]),
function(C, [8]),
function(D, [1]),
function(E, [3]),
function(F, [7]),
function(G, [5]),
function(H, [2])]).
```

2.2 Einstein's Riddle

There are five houses of different colors(blue,green,red,white,yellow) next to each other. In each house lives a man. Each man has a unique nationality(Brit,Dane,German,Norwegian,Swede), an exclusive favorite drink(beer,coffee,milk,tea,water), a distinct favorite brand of cigarettes (Blends,Blue Master,Dunhill,Pall Mall,Prince) and keeps specific pets (birds,cats,dogs,horses,fish). Use all the clues below to fill the grid and answer the question: "Who owns the fish?"

```
The Brit lives in the Red house.
The Swede keeps Dogs as pets.
The Dane drinks Tea.
The Green house is exactly to the left of the White house.
The owner of the Green house drinks Coffee.
The person who smokes Pall Mall rears Birds.
The owner of the Yellow house smokes Dunhill.
The man living in the centre house drinks Milk.
The Norwegian lives in the first house.
The man who smokes Blends lives next to the one who keeps Cats.
The man who keeps Horses lives next to the man who smokes Dunhill.
The man who smokes Blue Master drinks Beer.
The German smokes Prince.
The Norwegian lives next to the Blue house.
The man who smokes Blends has a neighbour who drinks Water.
```

To run einstein.in we use the command:

```
mace4 -f einstein.in | interpformat standard > einstein.out
```

The only solution generated is:

```
interpretation( 5, [number = 1,seconds = 0], [
function(Beer, [4]),
function(Birds, [2]),
function(Blends, [1]),
function(Blue, [1]),
function(BlueMaster, [4]),
function(Brit, [2]),
function(Cats, [0]),
function(Coffee, [3]),
function(Dane, [1]),
function(Dogs, [4]),
function(Dunhill, [0]),
function(German, [3]),
function(Green, [3]),
function(Horses, [1]),
function(Milk, [2]),
function(Norwegian, [0]),
function(PallMall, [2]),
function(Prince, [3]),
function(Red, [2]),
function(Swede, [4]),
function(Tea, [1]),
function(Water, [0]),
function(White, [4]),
function(Yellow, [0]),
relation(first(_), [1,0,0,0,0]),
relation(middle(_), [0,0,1,0,0]),
relation(left_neighbour(_,_), [0,0,0,0,0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,1,0]),
relation(neighbour(_,_), [0,1,0,0,0,1,0,1,0,0,0,1,0,1,0,0,0,1,0,1,0,0,0,1,0]),
```

```
relation(right_neighbour(_,_), [0,1,0,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,0,1,0,0,0,0,0]),
function(Fish, [3])]).
```

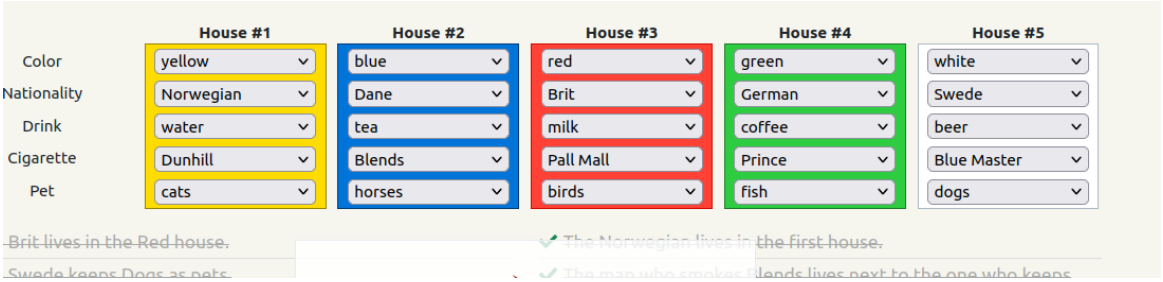

Figure 2.1: Einstein puzzle solution.

2.3 Black Friday Riddle

Five friends are side by side drinking juice and talking about the deals they got during the Black Friday sales. Follow the clues to find out who bought the laptop.

```
The man drinking the Orange juice is exactly to the right of the man who got the
70% discount.
Keith is 45 years old.
The man who bought the TV is exactly to the left of the man wearing the Red shirt.
At the third position is the man who got the 50% discount.
Keith is next to the man wearing the White shirt.
The 25-year-old man is somewhere between the 35-year-old man and the 40-year-old man,
in that order.
The man drinking Apple juice bought the Smartphone.
The 30-year-old man is exactly to the left of the man that bought the Beard trimmer.
Sean is the youngest.
The man that got the 40% discount is exactly to the right of the man who bought the
Beard trimmer.
Keith is next to the 35-year-old man.
Eugene is 40 years old.
Sean is wearing the Black shirt.
At the fourth position is the man who got the biggest discount.
Dustin got 60% off.
The man drinking the Lemon juice is exactly to the right of the man drinking the
Grape juice.
Keith bought a Game console.
The man who got the 80% discount is exactly to the left of the man who is wearing
the Blue shirt.
The man drinking Grape juice bought the Beard trimmer.
The man wearing the Black shirt is somewhere to the right of Keith.
The man that bought the Smartphone is next to the man wearing the Black shirt.
```

To compile the code we use the following command:

```
mace4 -f blackFriday.in | interpformat standard > blackFriday.out
```

The blackFriday.out file will contain the only solution.

```
interpretation( 5, [number = 1,seconds = 0], [
function(A25, [3]),
function(A30, [2]),
function(A35, [1]),
function(A40, [4]),
function(A45, [0]),
function(Apple, [2]),
function(BeardTrimmer, [3]),
function(Black, [3]),
function(Blue, [4]),
function(D40, [4]),
function(D50, [2]),
function(D60, [1]),
function(D70, [0]),
function(D80, [3]),
function(Dustin, [1]),
function(Eugene, [4]),
function(GameConsole, [0]),
function(Grape, [3]),
function(Keith, [0]),
function(Lemon, [4]),
function(Orange, [1]),
function(Red, [2]),
function(Sean, [3]),
function(Smartphone, [2]),
function(TV, [1]),
function(White, [1]),
relation(fourth(_), [0,0,0,1,0]),
relation(middle(_), [0,0,1,0,0]),
relation(left_neighbour(_,_), [0,0,0,0,0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,1,0]),
relation(neighbour(_,_), [0,1,0,0,0,0,1,0,1,0,0,0,0,1,0,1,0,0,0,0,1,0,1,0,0,0,0,1,0]),
relation(on_left(_,_), [0,1,1,1,1,1,0,0,1,1,1,1,0,0,0,0,1,1,0,0,0,0,0,1,0,0,0,0,0,0]),
relation(on_right(_,_), [0,0,0,0,0,0,1,0,0,0,0,0,1,1,0,0,0,0,1,1,1,0,0,0,1,1,1,1,1,0]),
relation(right_neighbour(_,_), [0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,1,0,0,0,0,0,0,0,1,0,0,0,0,0,0]),
function(Cranberry, [0]),
function(Green, [0]),
function(Hank, [2]),
function(Laptop, [4])]).
```

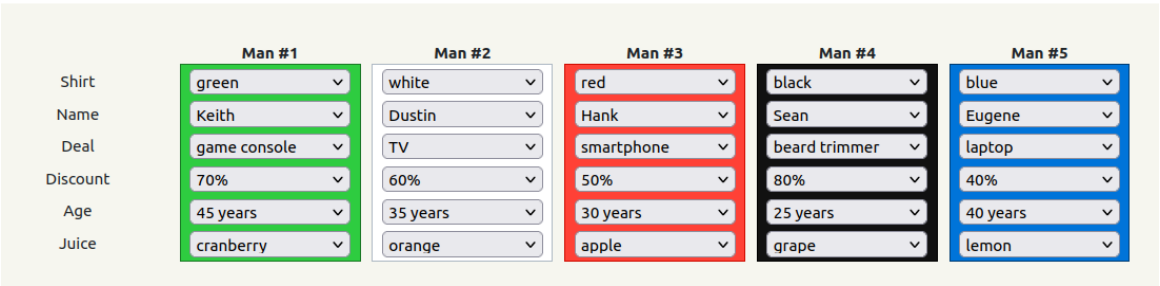

Figure 2.2: Black Friday puzzle solution.

2.4 Greek Logic Puzzle

We have a 4x4 grid. The first row and another cell are already filled. Fill the empty cells such that each row, column and main diagonals contain the given Greek letters without repetitions.

The command used is:

```
mace4 -f greek_logic.in | interpformat standard > greek_logic.out
```

The only solutin is :

```
interpretation( 4, [number = 1,seconds = 0], [
function(Delta, [0]),
function(Lambda, [2]),
function(Pi, [3]),
function(Theta, [1]),
function(f(_,_), [0,1,2,3,
                  2,3,0,1,
                  3,2,1,0,
                  1,0,3,2])]).
```

2.5 Mainarizumu Puzzle

Mainarizumu (also called Minarism) is a puzzle game with numbers to be placed onto a grid.

1. In each field of the NxN grid, write numbers from 0 to N-1.
2. In each row and each column, each number must be written exactly once.
3. A comparison operator between two fields indicates which of these fields' numbers is the biggest (>) resp. smallest (<).
4. A number between two fields indicates the difference of these fields' numbers.

The output file will look like :

```
interpretation( 5, [number = 1,seconds = 0], [
function(f(_,_), [2,3,1,4,0,
                  4,1,0,3,2,
                  0,2,4,1,3,
                  1,0,3,2,4, 3,4,2,0,1])]).
```

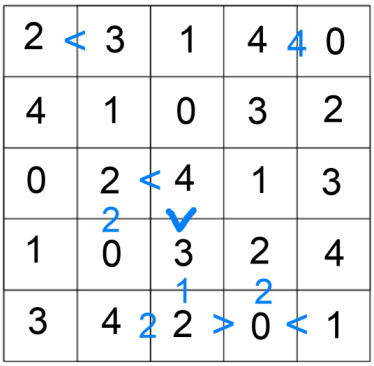

Figure 2.3: Mainarizum puzzle solution

Chapter 3

A3: Planning

Bibliography

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[6] "Greek Logic" [Online]. Available: https://www.brainzilla.com/logic/greek-logic/

[7] "Black Friday" [Online]. Available: https://www.brainzilla.com/logic/zebra/black-friday/

Appendix A

Your original code

Don't be a cheater! Cheating affects your colleagues, scholarships and a lot more. This section should contain only code developed by you, without any line re-used from other sources. This section helps me to correctly evaluate your amount of work and results obtained.

A.1 A* Search code

```
def aStarSearch(problem, heuristic=nullHeuristic):

    open_list = util.PriorityQueue()
    start = problem.getStartState()
    open_list.push((start, [], 0), 0)
    visited = set()

    while not open_list.isEmpty():
        state, actions, cost = open_list.pop()

        if problem.isGoalState(state):
            return actions

        if state not in visited:
            visited.add(state)
            successors = problem.getSuccessors(state)
            for successor, action, step_cost in successors:
                new_cost = cost + step_cost
                f_value = new_cost + heuristic(successor, problem)
                open_list.push((successor, actions + [action], new_cost), f_value)

    return None
```

A.2 A* Weighted Search code

```
def aStarWeighted(problem, heuristic=nullHeuristic, weight=0):

    open_list = util.PriorityQueue()
    start = problem.getStartState()
    open_list.push((start, [], 0), 0)
    visited = set()

    while not open_list.isEmpty():
        state, actions, cost = open_list.pop()

        if problem.isGoalState(state):
            return actions

        if state not in visited:
            visited.add(state)
            successors = problem.getSuccessors(state)
            for successor, action, step_cost in successors:
                new_cost = cost + step_cost
                f_value = new_cost + weight*heuristic(successor, problem)
                open_list.push((successor, actions + [action], new_cost), f_value)

    return None
```

A.3 Iterative Deepening A* code

```
def iterativeDeepeningAStar(problem, heuristic):
    depth_limit = 1
    while True:
        result = aStarSearchLimited(problem, heuristic, depth_limit)
        if result is not None:
            return result
        depth_limit += 1

def aStarSearchLimited(problem, heuristic, depth_limit):
    open_list = util.PriorityQueue()
    start = problem.getStartState()
    open_list.push((start, [], 0), 0)
    visited = set()

    while not open_list.isEmpty():
        state, actions, cost = open_list.pop()

        if problem.isGoalState(state):
            return actions

        if state not in visited and len(actions) <= depth_limit:
            visited.add(state)
            successors = problem.getSuccessors(state)
```

```
            for successor, action, step_cost in successors:
                new_cost = cost + step_cost
                f_value = new_cost + heuristic(successor, problem)
                if len(actions) + 1 <= depth_limit:
                    open_list.push((successor, actions + [action], new_cost), f_value)

    return None
```

A.4 Logic Equations

logiceq.in

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

list(distinct).
  [0,A,B,C,D,E,F,G,H].
end_of_list.

formulas(assumptions).
  E+F=C+H.
  A+G=C+D.
  F+H=B+E.
  A!=3.
  B+F=C+G.
  G!=2.
  F!=3.
  B!=7.
  G!=8.
  C!=1.
  A!=8.
end_of_list.
```

logiceq.out

```
 interpretation( 9, [number = 1,seconds = 0], [
    function(A, [4]),
    function(B, [6]),
    function(C, [8]),
    function(D, [1]),
    function(E, [3]),
    function(F, [7]),
    function(G, [5]),
    function(H, [2])]).
```

A.5 Einstein's Riddle

```
The Brit lives in the Red house.
The Swede keeps Dogs as pets.
The Dane drinks Tea.
The Green house is exactly to the left of the White house.
The owner of the Green house drinks Coffee.
The person who smokes Pall Mall rears Birds.
The owner of the Yellow house smokes Dunhill.
The man living in the centre house drinks Milk.
The Norwegian lives in the first house.
The man who smokes Blends lives next to the one who keeps Cats.
The man who keeps Horses lives next to the man who smokes Dunhill.
The man who smokes Blue Master drinks Beer.
The German smokes Prince.
The Norwegian lives next to the Blue house.
The man who smokes Blends has a neighbour who drinks Water.
```

einstein.in

```
set(arithmetic).
assign(domain_size,5).
assign(max_models,-1).

list(distinct).
[Blue,Green,Red,White,Yellow].
[Brit,Dane,German,Norwegian,Swede].
[Beer,Coffee,Milk,Tea,Water].
[Blends,BlueMaster,Dunhill,PallMall,Prince].
[Birds,Cats,Dogs,Horses,Fish].
end_of_list.

formulas(utils).
right_neighbour(x,y)<->x+1=y.
left_neighbour(x,y)<->x=y+1.
neighbour(x,y)<->right_neighbour(x,y)|left_neighbour(x,y).
middle(x)<->x=2.
first(x)<->x=0.
end_of_list.

formulas(assumptions).
Brit=Red.
Swede=Dogs.
Dane=Tea.
left_neighbour(White,Green).
Green=Coffee.
PallMall=Birds.
Yellow=Dunhill.
middle(Milk).
first(Norwegian).
neighbour(Blends,Cats).
```

```
neighbour(Horses,Dunhill).
BlueMaster=Beer.
German=Prince.
neighbour(Norwegian,Blue).
neighbour(Blends,Water).
end_of_list.
```

A.6 Black Friday Riddle

The requirements:

```
The man drinking the Orange juice is exactly to the right of the man who got the
70% discount.
Keith is 45 years old.
The man who bought the TV is exactly to the left of the man wearing the Red shirt.
At the third position is the man who got the 50% discount.
Keith is next to the man wearing the White shirt.
The 25-year-old man is somewhere between the 35-year-old man and the 40-year-old man,
in that order.
The man drinking Apple juice bought the Smartphone.
The 30-year-old man is exactly to the left of the man that bought the Beard trimmer.
Sean is the youngest.
The man that got the 40% discount is exactly to the right of the man who bought the
Beard trimmer.
Keith is next to the 35-year-old man.
Eugene is 40 years old.
Sean is wearing the Black shirt.
At the fourth position is the man who got the biggest discount.
Dustin got 60% off.
The man drinking the Lemon juice is exactly to the right of the man drinking the
Grape juice.
Keith bought a Game console.
The man who got the 80% discount is exactly to the left of the man who is wearing
the Blue shirt.
The man drinking Grape juice bought the Beard trimmer.
The man wearing the Black shirt is somewhere to the right of Keith.
The man that bought the Smartphone is next to the man wearing the Black shirt.
```

blackFriday.in

```
set(arithmetic).
assign(domain_size,5).
assign(max_models,-1).

list(distinct).
[Black,Blue,Green,Red,White].
[Dustin,Eugene,Hank,Keith,Sean].
[BeardTrimmer,GameConsole,Laptop,Smartphone,TV].
[D40,D50,D60,D70,D80].
[A25,A30,A35,A40,A45].
```

```
[Apple,Cranberry,Grape,Lemon,Orange].
end_of_list.

formulas(utils).
right_neighbour(x,y)<->x+1=y.                    %y is on the right
left_neighbour(x,y)<->x=y+1.                     %y is on left
neighbour(x,y)<->right_neighbour(x,y)|left_neighbour(x,y).
middle(x)<->x=2.
fourth(x)<->x=3.
on_left(x,y)<->x<y.                          %x is on the left of y
on_right(x,y)<->x>y.                          %x is on the right of y
end_of_list.

formulas(assumptions).
right_neighbour(D70,Orange).
Keith=A45.
left_neighbour(Red,TV).
middle(D50).
neighbour(Keith,White).
on_left(A35,A25)&on_right(A40,A25).
Apple=Smartphone.
left_neighbour(BeardTrimmer,A30).
Sean=A25.
right_neighbour(BeardTrimmer,D40).
neighbour(Keith,A35).
Eugene=A40.
Sean=Black.
fourth(D80).
Dustin=D60.
right_neighbour(Grape,Lemon).
Keith=GameConsole.
left_neighbour(Blue,D80).
Grape=BeardTrimmer.
on_right(Black,Keith).
neighbour(Smartphone,Black).
end_of_list.
```

A.7 Greek Logic Puzzle

We have a 4x4 grid. The first row and another cell are already filled. Fill the empty cells such that each row, column and main diagonals contain the given Greek letters without repetitions.

greek_logic.in

```
set(arithmetic).
assign(domain_size,4).
assign(max_models,-1).

formulas(latin_square).
   all x  all y1 all y2 (f(x, y1) = f(x, y2) -> y1 = y2).
```

```
   all x1 all x2 all y  (f(x1, y) = f(x2, y) -> x1 = x2).
   all x1 all x2 (f(x1,x1)=f(x2,x2) -> x1=x2).
   all x1 all y1 all x2 all y2 (f(x1,y1)=f(x2,y2) & x1+y1=3 & x2+y2=3 -> x1=x2 & y1=y2).

end_of_list.

formulas(greek).
f(0,0)=Delta.
f(0,1)=Theta.
f(0,2)=Lambda.
f(0,3)=Pi.
f(3,1)=Delta.
Delta=0.
Theta=1.
Lambda=2.
Pi=3.
end_of_list.
```

A.8 Mainarizumu Puzzle

```
In each field of the NxN grid, write numbers from 0 to N-1.
2. In each row and each column, each number must be written exactly once.
3. A comparison operator between two fields indicates which of these fields' numbers is
4. A number between two fields indicates the difference of these fields' numbers.
```

mainarizunu.in

```
set(arithmetic).
assign(domain_size,5).
assign(max_models,-1).

formulas(latin_square).
all x all y1 all y2 (f(x,y1)=f(x,y2)->y1=y2).
all x1 all x2 all y (f(x1,y)=f(x2,y)->x1=x2).

end_of_list.

formulas(mainarizumu).
f(0,0)<f(0,1).
f(0,3) +- f(0,4)=4 | f(0,3)+-f(0,4)=-4.
f(2,1)<f(2,2).
f(2,2)>f(3,2).
f(2,1)+-f(3,1)=2 | f(2,1)+-f(3,1)=-2.
abs(f(3,2)+-f(4,2))=1.
abs(f(4,1)+-f(4,2))=2.
f(4,2)>f(4,3).
f(4,3)<f(4,4).
abs(f(3,3)+-f(4,3))=2.
end_of_list.
```