# ARTIFICIAL INTELLIGENCE

Sonia Navas Rutete, 100472180
Jorge Rodrigo Leclercq, 100459870

# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

**This project consists in coding a Python program that works as a Markov Decision Process to control the temperature of a room through a thermostat, using the Bellman Equation to reach the desired temperature looking at different costs.**

# OBJECTIVES

**The goal of this activity is to obtain 22 degrees of temperature in the room thanks to a thermostat, modeled as an MDP and transformed into Python language. Furthermore, the idea is to also know which actions (policy) are more efficient (optimal) when obtaining this goal.**

# FORMAL DESCRIPTION OF THE MDP MODEL

**We have done a MDP MODEL where we differentiate this attributes:**

**<S,A,P,C>**

**STATES = {16, 16.5, 17, 17.5, 18, 18.5, 19, 19.5, 20, 20.5, 21, 21.5, 22, 22.5, 23, 23.5, 24, 24.5, 25}**

**ACTIONS = {TURN ON, TURN OFF}**

**P = {WHEN TURN ON: $P_{on}(S_i+1| S_i)$,**

| | 16 | 16.5 | 17 | 17.5 | 18 | 18.5 | 19 | 19.5 | 20 | 20.5 | 21 | 21.5 | 22 | 22.5 | 23 | 23.5 | 24 | 24.5 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 0.9 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.5 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.5 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.5 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| 22.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 | 0 |
| 23.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 | 0 |
| 24.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.2 | 0.1 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.3 |

**WHEN TURN OFF: $P_{off}(S_i+1|\ S_i)$}**

| | 16 | 16.5 | 17 | 17.5 | 18 | 18.5 | 19 | 19.5 | 20 | 20.5 | 21 | 21.5 | 22 | 22.5 | 23 | 23.5 | 24 | 24.5 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 0.3 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16.5 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.5 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.5 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 | 0 |
| 22.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 | 0 |
| 23.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 | 0 |
| 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.5 | 0.2 |
| 24.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.7 |
| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.9 |

In addition, to decide which will be the final bellman value for each state, we have chosen that the difference between the value of the previous cycle and the actual one should be 0.001.

# DETAILED COST MODEL ANALYSIS

## STATIC COSTS

With the aim of expanding the knowledge of every possible situation, different costs have been tested. For the first and main model, "turn on" has a cost of 2.25, since that's the price of two AA batteries, the ones used for powering up a thermostat. On the other hand, "turn off" has a cost of 1.5, as for the majority of the classes/degrees, even though 22 degrees can be hit, it will take more time as the probabilities are lower. In addition, it may be uncomfortable for it to be off.

A second model considers the kWh in Spain, which averages 0.07€ and the price of a cheap thermostat, which is around 20€. Because a day has 24 hours, 0.07*24 + 20 = 21.68 will be the cost of the turn on action. The objective of this set of costs was to observe what would happen if the turn off action was more expensive than the turn on action, and thus, 21.68 + 1 = 22.68 is the cost of "turn off".

For a third model, the cost of both actions is the same, for the curiosity of seeing what would occur. Hence, both actions have a cost of 1.

In a fourth and last model, the goal was to look at what would happen if any of the costs was 0. Therefore, "turn on" costs 2 (chosen randomly) and "turn off" costs 0. This leads to a situation where "turn off" is the optimal policy for every state.

## DYNAMIC COSTS

Another option would be to apply dynamic costs. That is, changing the costs of each action depending on the class the robot is into. For example, *cost off* could have a lower cost whenever the degree is higher than 22, as it is going to get to the final state faster. However, in the situation where the degree is lower than 22, *cost off* could have a higher cost as it is going to get to the final state slower. This plan hasn't been implemented due to time constraints.

# OPTIMAL POLICY

| COSTS | [2.25, 1.5] | [21.68, 22.68] | [1, 1] | [2, 0] |
|---|---|---|---|---|
| STATE | | | | |
| 16 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 16.5 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 17 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 17.5 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 18 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 18.5 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 19 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 19.5 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 20 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 20.5 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 21 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 21.5 | TURN ON | TURN ON | TURN ON | TURN OFF |
| 22 | FINAL STATE | FINAL STATE | FINAL STATE | FINAL STATE |
| 22.5 | TURN OFF | TURN OFF | TURN OFF | TURN OFF |
| 23 | TURN OFF | TURN OFF | TURN OFF | TURN OFF |
| 23.5 | TURN OFF | TURN OFF | TURN OFF | TURN OFF |
| 24 | TURN OFF | TURN OFF | TURN OFF | TURN OFF |
| 24.5 | TURN OFF | TURN OFF | TURN OFF | TURN OFF |
| 25 | TURN OFF | TURN OFF | TURN OFF | TURN OFF |

**Unless for the situation where any of the costs is 0 (in which case the action with the 0 cost will be the optimal policy for every state), it can be easily seen that if the state/degree is lower than 22, then the optimal policy is to turn on the thermostat, whereas if the the state/degree is greater than 22, then the optimal policy is to turn off the thermostat.**

# PROJECT PHASES

1. Examine the problem to get the states, actions, probabilities and costs according to the problem.
2. Making 2 excel files, one when having the heating on and another having the heating off with all the probabilities. For example: if the temperature is 16.5° which is the probability of having 17° in half an hour if the thermostat is ON.
3. Dividing the bellman equation by parts for coding it:
    a. Passing the probabilities of the excel to an array
    b. Declaring the costs.
    c. Function for making the summation of the bellman equation.
    d. Making the necessary cycles of the bellman equation until getting the final value.
    e. Obtaining the policy.
    f. Printing the result of each state: The temperature + bellman value + policy.
4. Adding different costs instead of fixed ones.

# BUDGET

According to different sources, the average salary of a programmer in Spain is 25,000€ per year, which is equal 25,000/(220 working days per year * 8 hours of work per day)= 14.2€ per work hour. This project has been done by 2 persons in around 6 hours, leading to a cost of personnel of 14.2*2*6 = 170.4€. In the situation of having it done in an office, prices would be higher because of infrastructure ( = 200€ for chairs and tables), light ( = 0.42€), computers ( = 1,000€). This all sums up to a total cost of 1370.82€.

# CONCLUSIONS

This project has been quite enjoyable and satisfying, as it has allowed us to apply the concepts learned in class into a real world situation and has brought up new knowledge to our minds. Artificial intelligence has always been an interesting but imposing topic for us, and being able to at least scratch its surface with this activity has been encouraging. We hope we get to do more jobs like this one soon.