UNIVERSIDAD POLITÉCNICA DE MADRID

ESCUELA TÉCNICA SUPERIOR
DE INGENIEROS DE TELECOMUNICACIÓN


GRADO EN INGENIERÍA DE TECNOLOGÍAS Y SERVICIOS DE TELECOMUNICACIÓN

TRABAJO FIN DE GRADO

# DEVELOPMENT OF AN AGENT-BASED MODEL OF THE RADICALIZATION PROCESS


LEANDRO SANTIAGO CAMPOS HERNÁEZ


JUNIO 2023

## TRABAJO DE FIN DE GRADO

| | |
|---|---|
| **Título:** | Desarrollo de un modelo basado en agentes del proceso de radicalización |
| **Título (inglés):** | Development of an Agent-Based Model Of The Radicalization Process |
| **Autor:** | Leandro Santiago Campos Hernáez |
| **Tutor:** | Carlos Ángel Iglesias Fernández |
| **Departamento:** | Departamento de Ingeniería de Sistemas Telemáticos |

## MIEMBROS DEL TRIBUNAL CALIFICADOR

| | |
|---|---|
| **Presidente:** | — |
| **Vocal:** | — |
| **Secretario:** | — |
| **Suplente:** | — |

## FECHA DE LECTURA:

## CALIFICACIÓN:

**UNIVERSIDAD POLITÉCNICA DE MADRID**

ESCUELA TÉCNICA SUPERIOR DE
INGENIEROS DE TELECOMUNICACIÓN

Departamento de Ingeniería de Sistemas Telemáticos
Grupo de Sistemas Inteligentes

TRABAJO FIN DE GRADO

# DEVELOPMENT OF AN AGENT-BASED MODEL OF THE RADICALIZATION PROCESS

**Leandro Santiago Campos Hernáez**

Junio 2023

# Resumen

El terrorismo es una gran preocupación en la sociedad contemporánea debido a la destrucción que supone y a su capacidad de minar la moral de la población. Debido a ello, es uno de los principales puntos de mira de los gobiernos en la actualidad. Se ha manifestado de diversas formas, siendo el más conocido el ataque a las Torres Gemelas del 11 de Septiembre de 2001. Para estudiar y entender el terrorismo, es necesario conocer las causas que llevan a un individuo a cometer un acto terrorista, llamado proceso de radicalización. El proceso por el que las personas se radicalizan es muy complejo. Por ello, es necesaria una gran investigación social y psicológica para poder sacar conclusiones que sean útiles y entender cuales son los factores que más afectan al proceso

El proposito de este proyecto es crear una simulación basada en agentes para poder investigar el proceso de radicalización. Estas simulaciones son útiles para analizar procesos y patrones de la sociedad. Permiten modelar los diferentes factores que influyen en los individuos, pudiendo observar cómo estos producen efectos sobre el resto. Los investigadores pueden estudiar cómo se desarrolla un proceso en diferentes escenarios sin necesidad de que estos ocurran realmente, y obtener así una primera idea del impacto que tendrá para poder tomar medidas y prepararse en caso de que ocurra. En el caso del proceso de radicalización, esta simulación puede ayudar a entender cómo un individuo puede acabar cometiendo un acto terrorista, teniendo en cuenta tanto sus propias características como los entornos con los que interactúa.

El diseño del modelo se ha implementado con el lenguaje de programación Python. Para la parte de agentes se ha utilizado la biblioteca SOIL, que permite desarrollar simulaciones basadas en agentes enfocadas en redes sociales. La arquitectura está basada en una máquina de estados, similar a un proceso de infección, en el cual los principales actores son las Personas y los Entornos en los que se encuentran. El resultado de la simulación consta de datos y gráficas de las que se podrán sacar las conclusiones del estudio.

**Palabras clave: Terrorismo, Radicalización, Proceso de radicalización, Simulación, Agentes**

# Abstract

Terrorism is a major concern in contemporary society due to its destructive nature and its ability to undermine the morale of the population. It is one of the main targets of today's governments. Terrorism has manifested itself in various forms. The best known case was the Twin Towers attack on September 11, 2001. To study and understand terrorism, it is necessary to know the causes that lead a person to commit a terrorist act, which is called the radicalisation process. The process by which people become radicalised is very complex. Therefore, a great deal of social and psychological research is necessary to draw useful conclusions and understand which factors have the greatest influence on the process.

The purpose of this project is to create an agent-based simulation to investigate the radicalisation process. These simulations are useful for analysing processes and patterns in society. They allow modelling the different factors that influence people, to be able to observe the effects on each other. Researchers can study the development of a process in different scenarios without the need to occur, being able to get a first idea of the impact it will have and to take measures and prepare in case it happens. In the case of the radicalisation process, this simulation can help to understand how a person can end up committing a terrorist act, taking into account both his own characteristics and the environments with which he interacts.

Regarding the design of the model, it is implemented with the Python programming language. The SOIL library is used for the agent part, which is used to develop agent-based simulations focused on Social Networks. The architecture is based on a state machine, similar to an infection process, in which the main actors is the People and the Environments where people spend their time. The output of the simulation consists of data and graphs from which conclusions can be drawn from the study.

**Keywords: Terrorism, Radicalisation, Radicalisation Process, Simulation, Agents**

# Agradecimientos

Quiero mostrar mi gratitud a todas las personas e instituciones que han dado su apoyo y han contribuido de alguna forma en la realización de esta tesis, y a todas aquellas personas que me han ayudado a llegar a donde estoy ahora mismo.

Empezando por todos los profesores que he tenido, tanto en el colegio, como en el instituto y en la universidad. Gracias por haberme motivado a seguir superándome cada día. Sus comentarios, enseñanzas y su apoyo tienen un valor incalculable.

A todos los amigos que he hecho a lo largo de mi vida, quienes han estado a mi lado durante el camino, dando su apoyo, consejos y compañía. En especial quiero citar a Sergio, Ander y Jorge, quienes hoy en día siguen siendo las personas a las que puedo recurrir en busca de apoyo.

A mi familia, quien siempre ha estado ahí para darme amor y comprensión en los momentos difíciles, quienes se han sacrificado siempre por mí, y a quien les debo todo. En especial quiero citar a mis padres Carmen y Antonio, a mi hermano Antonio, y a mi abuela Valentina.

A todo el Grupo de Sistemas Inteligentes por haberme ayudado con este proyecto, en especial a mi tutor Carlos Iglesias por haberme guiado en el proceso y a Fernando Sánchez que me ha ayudado siempre que he tenido algún problema en el desarrollo del trabajo.

A todo el resto de personas de las que haya podido aprender algo y me han ayudado a lo largo de mi vida.

# Contents

# List of Figures

CHAPTER 1

# Introduction

## 1.1 Context

Since the 1950s, people have been trying to emulate human cognitive functions in machines. There existed the idea that machines can simulate human intelligence. That was the beginning of the concept of Artificial Intelligence and other research fields. At the beggining, the first machines were unable to learn and adapt to new situations. Now machines can use data and very complex algorithms to come to conclusions and give a response.

One of the goals of scientists is to try to understand complex social processes. there exist many challenging domains because of the complexity of studying them. One of these processes is terrorism, and more specifically the radicalisation process. To solve it, some researchers began to create models that simulate artificial beings. These models could interact with the environment and provide an answer to the information they have. One of the most popular approaches is Agent-Based Models (ABMs). Nowadays, those models can learn autonomously and be proactive. In addition, many new technologies can be added to make them more sophisticated, such as deep learning.

Regarding terrorism, it is defined as the use of violence to achieve political or ideological goals [33]. It has been affecting the world in recent years. Some terrorists seek change in

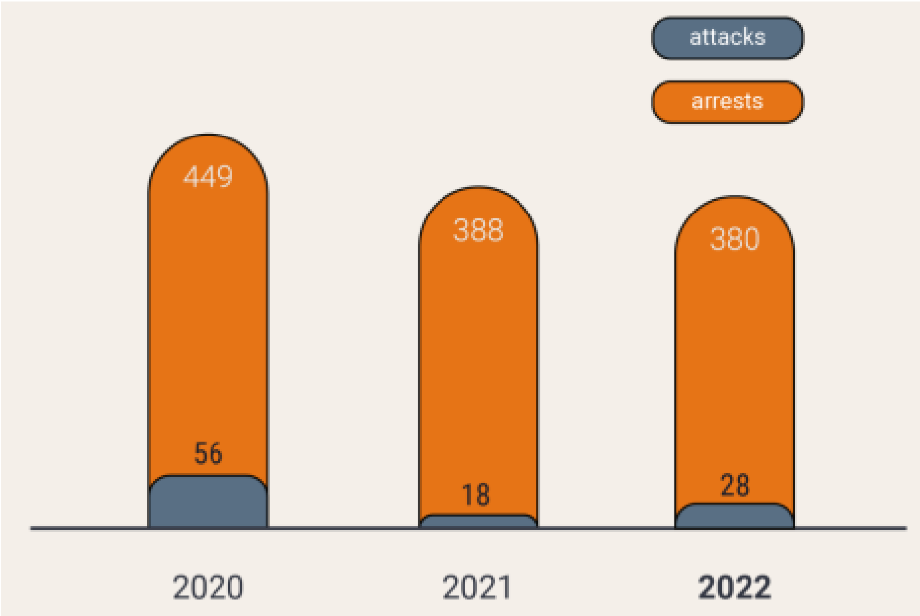


Figure 1.1: Terrorist attacks and arrest on suspicion of terrorism in European Union in 2022 [7].

governments, social changes, or the imposing of their beliefs. There exist many examples with very different incentives. They can be for political, religious, or social causes, for example. Terrorism aims to generate fear, tension, and division in society and institutions. All this causes social disorder, death, and destruction. Very little data can be found on this phenomenon. Fortunately, because that means that terrorism is not common. But it exists.

To illustrate this, the attack on the Twin Towers on September 11, 2001, changed the way people see the world. This situation filled society with terror, and unfortunately, this was not an isolated case. Many other attacks have been carried out by radicals since then. For example, only in 2022 there were 28 terrorist attacks and 380 arrested on suspicion in Europe [7]. In Fig. 1.2 you can see a map with all the cases.

For this reason, many politicians, researchers, and security professionals have been concerned about this in recent years. They are working on many prevention steps, laws, and security programmes to counter-terrorism. Due to this work, the trend for terrorism has been falling over the last year, but in 2022 there was a rise in attacks again, as you can see in Fig. 1.1. 41 people were arrested for planning an attack, 95 for membership in a terrorist organisation, 18 for radical propaganda, and 14 for financing terrorism; for the rest the cause is not specified. Another fact is that most of the arrested were men [7].

Therefore, to carry out all these security projects and help in the investigation, it is necessary to understand the factors that influence people in the radicalisation process. This

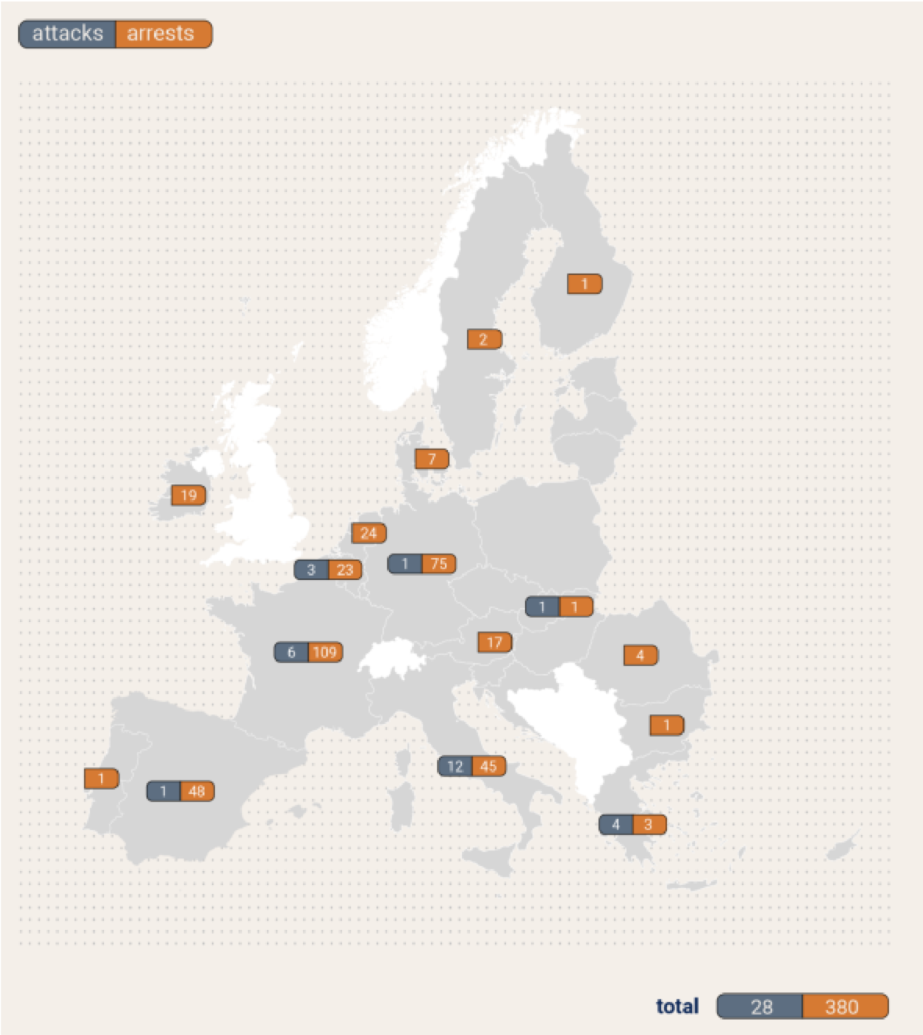


Figure 1.2: Terrorist attacks and arrests on suspicion of terrorism in the EU, 2020-2022 [7].

threat requires a global and coordinated response. Governments are working to increase security. Intelligence agencies are trying to combat terrorism in the world in many ways. With regard to technology advances, they are very useful for this goal, but, at the same time, they are useful for the terrorist. There exists many terrorist propaganda on the Internet. Social networks facilitate this online radicalisation process. A new type of terrorism has appeared: cybernetic attacks now have computers and information as the main goal. This makes the counter-terrorist more difficult.

## 1.2 Project goals

The project aims to create an agent-based model that can explain the radicalisation process. This is hardly verifiable with empirical evidence, because there is not much information on this process.

As the model cannot be checked with real data, our main goals are the following:

- Simulating an agent-based model that can explain the radicalisation phenomenon in society, trying to improve previous models.
- Study the psychological and sociological theory related to the process and identify the most important factors that lead people to radicalisation.
- Identifying areas that require more research.
- Explore some scenarios to compare the results and draw a conclusion about the influence of factors on the environment.

## 1.3 Structure of this document

In this section, we provide a brief overview of the chapters included in this document. The structure is as follows:

***Chapter 1*** **Introduction:** provides a background of the matter and defines the goals of the project.

***Chapter 2*** **Enabling Technologies:** introduces all the technologies that are used in the project.

***Chapter 3*** **Model Description:** provides a general description of the model, explaining all the psychological theories used.

***Chapter 4*** **Simulation:** explains the work of the simulation and all the functions and classes used in the project.

***Chapter 5*** **Results:** provides the results of the simulations to be studied.

***Chapter 6*** **Conclusions and future work:** tries to explain the results and provide a global vision of the work done.

***Appendix A*** **Impact of this project:** shows the possible impact of this project.

***Appendix B*** **Economic budget:** provides an explanation of the minimum budget necessary to develop the project.

# CHAPTER 2

# Enabling Technologies

In this chapter, the technologies used in this project are described.

## 2.1 Technologies

### 2.1.1 Python

Python [25] is an open-source programming language developed in 1991. Because it is versatile, powerful, and very easy to understand, it has gained a lot of popularity in recent years. Due to its very simple and readable syntax, it is expected to be the most popular programming language in 2023, according to Forbes [5].

One of the keys to Python's adoption is the very large library ecosystem. There exist many open-source libraries that allow developers to easily integrate existing solutions into their programmes. For example, there are many frameworks such as Django [6] or Flask [22] and many libraries such as Numpy [13], Pandas [19] or MathPlotLib [14]. In our case, we use the SOIL [30] framework developed by GSI-UPM [10] to develop agent-based social simulations.

### 2.1.2 Pandas

Pandas [19] is a powerful Python library that is used to manipulate data. It has been under development since 2008 by Wes McKinney. Because it has many functions and data structures, it is very popular among data scientists and analysts. With Pandas, we can handle structured data, such as databases, through dataframes, which are its data structure. In addition, it allows data to be filtered and sorted for efficient data analysis. Pandas offers many tools for data cleaning and preprocessing. For these reasons and for its ease of use, it is the favourite among developers.

### 2.1.3 MatPlotLib

Matplotlib [14] is a Python library that is used for data visualisation. It was developed by John D. Hunter in 2003. It is capable of creating high-quality graphs and charts. With this library, you can generate many types of visualization, such as line graphs, scatter graphs, bar graphs, or histograms. Moreover, you can customise the interface and change aspects of the graphs, such as colours, labels, and annotations. In this project, some graphs are created with Matplotlib, where the results are represented.

### 2.1.4 Jupyter

Jupyter [16] is an open source web tool that allows programmers to create documents with code and visualisations. It was developed in 2011 by Fernando Pérez with the name IPython Notebook. This name was later changed to Jupyter. Jupyter notebooks enable users to write code and put multimedia content, making it easier to create dynamic presentations. In this project, Jupyter is used to present the data to be analysed.

### 2.1.5 SOIL

SOIL [30] is an Agent-Based Social Simulator that focuses on modelling and simulating social networks. It has been developed by GSI-UPM [10]. It can be used in many different scenarios, such as rumour propagation, emotion propagation, and information propagation. It offers many tools for developing models and analysing the results.

There are three different parts to a simulation, which are the network topology, the agents, and the environment.

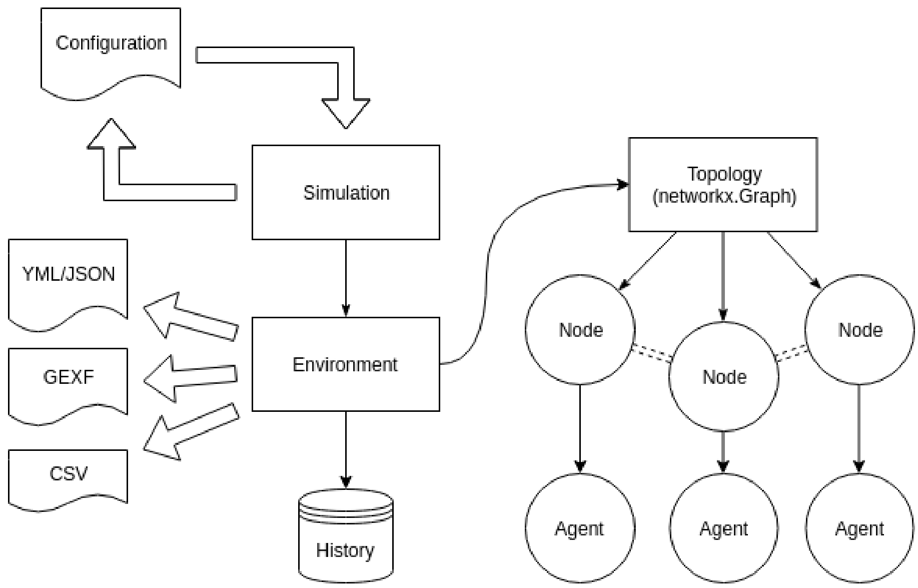


Figure 2.1: SOIL relations for simulations

1. **Network topology**: This Python framework utilises NetworkX [11]. It is possible to generate a new network topology or use an existing one.

2. **Agents**: Regarding the agents, there are two types, network agents and environmental agents.

   (a) **Network agents** are linked to a node in the topology. They have many methods to interact with other agents in the simulation. In the latest version of SOIL, a general network agent class is inherited from Finite State Machine (FSM) agents and Evented agents. FSM agents are defined in terms of states (one state is the default) and change stage with transitions. Evented agents are an actor-based model of agents that can communicate with message passing.

   (b) **Environment agents**, which are not connected to a node. Environment agents interact with the environment, but are invisible to other agents. They are useful for modelling the behaviour of the scenario.

3. **The environment** saves the state of the simulation and the variables. All agents can access the environment.

In Fig. 2.1, the relations of the original version of the SOIL are shown. In the latest version, the configuration file is not necessary. The configuration is now in the same file as the simulation. It is possible to export files with the simulation result, but it is recommended to inspect the environments made by the return method directly. All the necessary parameters for the simulation are defined at the beginning of the project. It is shown that, for each node in the topology, an agent is linked with the node. The nodes may be linked to each other or not.

## 2.2 Model

Modelling helps us to understand the functioning of specific phenomena, using data obtained through observational learning, in order to be able to represent the entire system for analysis later. Today, there are many social processes that are very complex, and simulations can help us obtain responses.

### 2.2.1 Modeling Behaviour in SOIL

For earlier versions of SOIL, a SOIL agent needs to implement a run(self) method or use a Finite State Machine agent. On the other hand, the last version has redesigned the framework so that agents are derived from Network, FSM and Evented superclasses. Thus, agent behaviour is described using FSMs.

Agents have two main characteristics: agent type and agent state. Every step is defined as a state which is a function that represents what the agent is at that moment. To change its state, the state function must return the new state.

All agents have access to the model parameters using *self.model* and to their own state using *self.state*. There exist many methods to access the state of other agents, such as, for example, *self.iter_neighbours*.

## 2.3 Simulation

Simulation is the process of executing the model to obtain results. The model can be executed in many different ways and may iterate more than one execution to check if the results are stable or variable. At the end of the simulation, you will obtain the state of all agents for the analysis. The most important variables in a simulation are the agent model, the environment, the network topology, and its algorithm for generation, events, and time steps.

### 2.3.1 Simulating in SOIL

In earlier versions of SOIL, a configuration file was needed, but since the latest version, it is not necessary. All the configuration is in the same file as the model.

All network agents must be linked to a node. It is possible to add more agent types to the same network. And all agents have an initial state.

However, in the case of the environment agents, it is not necessary that they are linked to a node.

To run the simulation, you must specify the number of time steps and the number of iterations. Every of these iterations is independent. Therefore, this is useful to check if there exist changes because of random behaviour or something else.

SOIL can save the results in a CSV file, GEFX, or SQLITE. But sometimes it is useful to analyse directly the environment of the simulation.

CHAPTER 3

# Model Description

In this chapter, the agent-based model is explained. This model is based on the theory of Wikström [34] and on the ideas of the model by Pepys et al. [23]. This chapter starts with a description of what really is the radicalisation process. This is defined in Sect. 3.1 Then there is an explanation in Sect. 3.2 of the psychological concepts that are used in the model. This is to provide a background of the theory that is used in the model. Next, the principal functions of the model are explained in Sect. 3.3. These functions are very important because they represent the transitions from a person or a setting (the place where people spend their time) who is not radicalised to a radicalised one.

This model is expected to help the research by simulating the process in practise. The main goal is to create a simulation in SOIL (Sect. 2.1.5) that simulates this process. SOIL is able to make an optimised and powerful simulation that can be useful for making a very realistic model. The SOIL library offers a large set of tools that allow one to create a more accurate agent-based model of the radicalisation process. This model aims to be realistic that can help professionals counter-radicalisation to implement an effective preventive plan.

First, we need to define what a good model is. Gilbert's study [9] pointed out that to create a simulation model, data from three stages are necessary: It is necessary to create hypotheses about the relationships between system components, then quantify the relationships, and then validate the model with real-world results. Because the model cannot be checked with real data, the Ormerod and Rosewell [21] theory is used, in which they say that if the model output can explain the phenomena, it is a good model.

## 3.1 Radicalisation Process

Radicalization is the process in which an individual adopts extremist beliefs and is ready to use violence to defend its ideology. It involves individuals from various backgrounds, religious groups, nationalities, and socioeconomic positions. This process has many stages, it is not a lineal process [23]. Nevertheless, certain trends may exist among some terrorist's background. However, these trends alone do not explain the change in the propensity to commit an act of terrorism. Consequently, this process is very complex and very difficult to study.

For these reasons, there is little information about the radicalisation process. The main reason for the few data is that it is very difficult to identify when a person becomes radicalised. This is because situational factors can cause a person not to commit an act, even if they are very radicalised [23]. Therefore, it is very difficult to understand this process using traditional scientific methods. However, even though there are very few data on the radicalisation process, reliable data are needed to develop a realistic simulation. Despite the complexity of the process, this project aims to understand the origin of radicalism and try to counter it.

Although data on the radicalisation process are limited, some research suggests that there exists a relationship between radicalisation and general criminal propensity [26]. There is empirical evidence to suggest that the propensity to commit a terrorist act is similar to the propensity to commit ordinary crimes. There exist many similar patterns and factors between ordinary criminals and terrorists [23]. Therefore, radicalisation in this project is considered similar to ordinary crime.

More background on the radicalisation process can be found in Pepys et al.'s article [23].

## 3.2 Psychological Analysis

In this section, some necessary psychological concepts are defined.

**Individual vulnerability** refers to an individual's susceptibility to undergo a change in their propensity to engage in a terrorist act. It is a complex concept that can be influenced by the social environment of a person. It can be determined by many other factors, such as personal experiences, psychological factors, and exposure to certain ideologies or radical propaganda [23].

**Propensity** is an important part of Wikström's situational action theory [34]. It tries to explain why people choose to break the moral rules included in the law. An individual can be involved in a situation with many options and one of them may be to commit a crime at a particular moment. If they choose to commit the act, a priori, it can be said that this person had a higher propensity to terrorism. Additionally, the development of an individual's propensity has two parts: the process of moral education of a person and the process of the development of the cognitive skills relevant to self-control.

**Situational factors** are the circumstances at some time that allow an individual to commit a crime [23]. There exist many factors, such as an easy opportunity to steal, a lack of security in a place, or a vulnerable target. For example, a person who goes into a store and in one moment there is no vigilance.

**Sense of morality** is the ability of an individual to be aware of whether an act is morally wrong. It represents the capacity to discern and evaluate moral implications of their actions, keeping in mind the commonly accepted moral rules. It includes individual values, beliefs, and empathy. It is very important for an individual to have the ability to consider the potential consequences of its acts.

In addition, many factors, such as education, cultural and social influences, and personal experiences, can influence the development of a sense of morality. These factors influence their ability to make ethical decisions [18]. There exists an article by Fumagalli and Priori [8] in which they say that biological factors can influence the cognitive susceptibility to moral change.

**Self-control** is the ability of an individual to control their emotions and choose not to commit an act. It refers to the cognitive capacity to manage emotions, impulses, and actions [23]. It includes the effort to ignore desires by thinking of long-term goals. It requires self-awareness to make good choices aligned with moral principles. The prefrontal cortex is very important in some cognitive processes such as decision making or impulse control. [17]. Genetic factors, socialisation, and early experiences can influence the development of self-control.

**Susceptibility to selection** refers to the tendency of a person to choose to go to an environment with a radicalising context, which makes it possible to increase his propensity

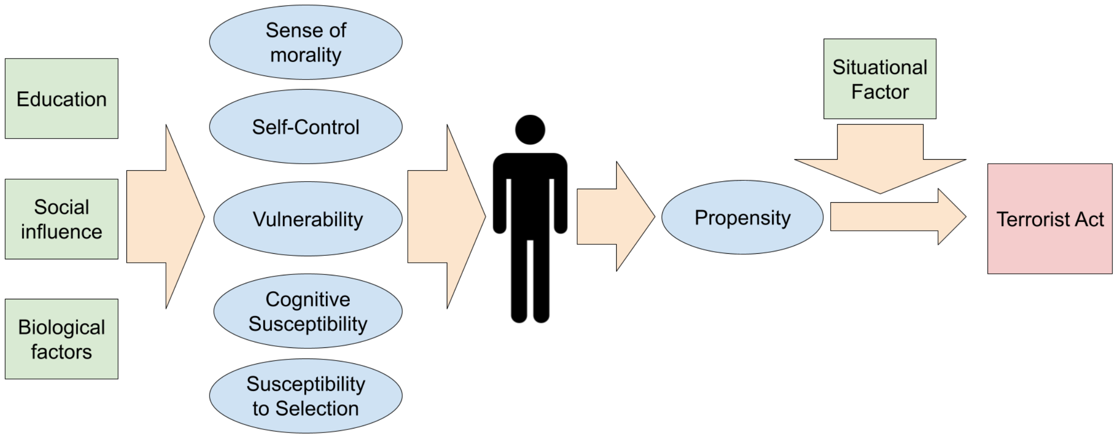


Figure 3.1: Psychological factors of the radicalization process [3].

to be influenced by extremist ideologies or beliefs [23].

**Cognitive susceptibility** refers to the vulnerability of an individual to be easily influenced by persuasive messages, propaganda, or manipulation [23]. This affects critical thinking and reduces the ability to exercise self-control. Loss of cognitive skills can result in an inability to exercise self-control [3]. Some studies suggest that the individual ease to be influenced by radicalising moral context may be due in part to biological factors [8].

In particular, for radicalisation, people must be susceptible to selection to go to a radical setting (the place where people spend their time) and cognitively susceptible to being influenced by it [23].

All these factors are summarised in a diagram in Fig. 3.1.

## 3.3 Main Functions of the Model

In this section, the model used in this project is described, focussing on the main functions of it. The Radicalisation Model of Bouhana & Wikström 2011 [3] has been chosen for this project. This model attempts to explain how the radicalisation process happens in society. All this by taking into account many of the factors explained in Sect. 3.2. This model uses the concept of vulnerability of a person to a moral change and the exposition (defined in Sect. 3.3.1) to explain the changes in the propensity of a person. It also uses the concept of emergence (defined in Sect. 3.3.2) to explain the radicalisation of some settings. A setting represents the place where people spend their time.

### 3.3.1 Exposure

Wikström's article [35] provides a definition of an activity field, which can be understood as the different settings in which a person spends its time. According to this research, an individual with many radicalising settings in his field of activity has a higher probability of committing a crime. Radicalising settings refer to environments or places in which extremist ideologies are promoted and may recruit people. If an individual frequently visits a radicalising setting, for example, an extremist group, the exposure to radical messages and ideologies increases. Because of that, the probability of radicalisation increases [23].

Anyone can meet anywhere at any time, but due to social relationships, it is more likely, for example, that a teenager will find more similar groups at school than in an office. This phenomenon is attributable to social selection [23]. Social selection determines the settings in which an individual probably stays. Due to social selection, self-selection are less relevant. As an illustration of this, a person can prefer to stay in another setting, but because he is a student, for example, he will spend more time at the university than in other places, and he will stay in settings with more university students.

Additionally, radicalising environments can be very different and can be physical (such as an office or a cinema) or virtual (an online chat, for example). Emergence (Sect. 3.3.2) explains this.

An article by Caitlin Clemmow [4] points out that there exist four types of person exposure patterns:

1. **Solitary** seems to have no clear indicators of a propensity to commit a terrorist act.
2. **Susceptible** reveals a cognitive susceptibility. It manifests itself as a mental illness.
3. **Situational** proves how how situational factors can accelerate the commitment to a violent act.
4. **Selection** has remarkably more frequent antecedent violent behaviours.

This would be very useful for future intelligence investigations.

### 3.3.2 Emergence

Some environments that are radicalised provide people a place out of vigilance that makes it easier to engage in illegal actions. Consequently, it is more attractive to individuals with a high propensity to terrorism. There are settings that have a higher probability of radicalisation than others [23]. For example, it is more likely to recruit people in a temple than in an office. In addition, radicalisation narratives play an important role in the recruitment process. Therefore, in some places, it is more common to find interested people than in others.

Furthermore, online radicalisation settings, such as social networks, are powerful tools for radicalisation. The anonymity of online spaces makes them very attractive to vulnerable individuals who want validation or a sense of belonging. As a result, it is easy to recruit people with similar beliefs on the Internet.

Due to privacy, there are not many data on radicalising settings. However, the theory of social disorganization [29] explains that some variables in a community, such as socioeconomic level or multiculturalism, are first directly related to social disorganisation, and social disorganisation increases the level of crime rate. On the other hand, there exists a newer study [27] that replaces the social disorganisation one by introducing the concept of collective efficacy. It is defined as social cohesion in a community and the will to do the common good. In this project, this theory is used to explain that some locations are more likely to be radicalised than others.

Fig. 3.2 shows a summary of the model thought by Wikström and Bouhana [3]. All of the main characteristics of the process are shown in this figure. There are three zones: the upper part is focused on the social environment of the individual. It is related to where they choose to stay and where they are because of demographic characteristics. The bottom-left part is focused on the psychological characteristics of the individual. Psychological characteristics are related to their education, environment, and biological characteristics. The bottom-right part focusses more on the environments and their process of radicalisation.

A division by colour in Fig. 3.2 was performed. External factors are green. The characteristics of the individual or the setting are coloured blue. The key of the diagram, which is the vulnerability to have a change in moral, is in its centre, coloured orange. In red is the result of the diagram, the propensity. The two main functions of the model are shown in yellow: exposure to a radicalising setting and the emergence of radicalism in a setting.

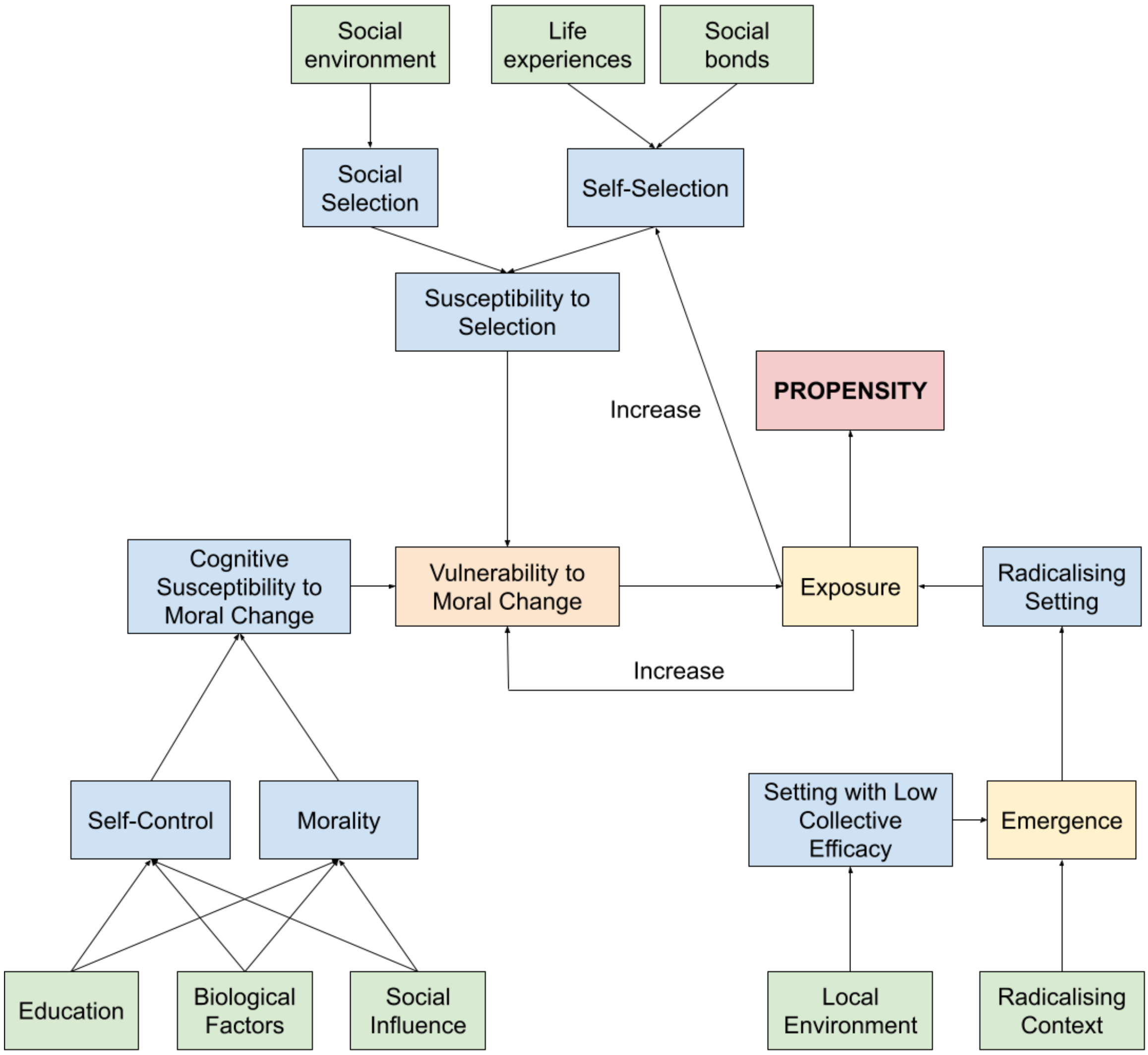


Figure 3.2: Radicalisation Model, Bouhana & Wikström 2011 [3]

CHAPTER 4

# Simulation

An agent-based simulations is a system that runs a model of agents and their environment, which is the context in which the agents develop their actions. Each agent has his own characteristics and behaviour. Agents can make decisions depending on the situation. They can respond to a stimulus of any kind, using available information and checking changes in the environment. These responses can result in a change in their own state. Therefore, agent-based simulations are useful for understanding complex social processes. For this simulation, the library of Python SOIL is used (for more information, see Sect. 2.1.5).

The main goal in this chapter is to simulate the model explained in Chapter 3. This model is based on the Radicalisation Model of Bouhana & Wikström 2011 [3] and some ideas of the article [23]. The chapter starts with a description of the concepts of “Person” and “Setting”. Then, there is an explanation in depth in Sect. 4.2 of the simulation environment and the most important functions. Finally, there is a complete diagram in Sect. 4.3 to better understand how the simulation works.

## 4.1 Person and Setting

To understand this project, it is necessary to explain the concepts of “Person”, and “Setting”, which are the main entities of the model:

- **Person**: It is the most important entity in the model. It represents a person in a society. People have different characteristics, mentioned in Sect. 4.2. The main characteristic of a person is its level of propensity. Indicates the propensity of a person to commit a terrorist attack. The propensity changes due to the effect of the exposure function, explained in Sect. 4.2.2.
- **Setting**: A setting represents a place where people spend their time. It can be a school, a university, an office, a church, a mosque, a high street, a leisure centre, or a youth club. Setting also has different characteristics, mentioned in Sect. 4.3. The level of radicalisation is the most important characteristic of a setting. It changes due to the effect of the emergence function, explained in Sect. 4.2.2.

Hence, the only class that has been implemented as an agent is “Person”. This is because the settings can be seen as the spaces where the agents stay, and they can be designed as a characteristic of the environment in the simulation. “Person” inherits from *soil.Agent*, which is the class for making agents in SOIL.

In Fig. 4.1, there is a very simple diagram of the states and the transitions of the agents. A person is an agent that can be in two states: “Neutral” and “Radicalised”. These Person agents are defined in Sect. 4.1.1. The Setting class is only an object, not an agent, and is defined in Sect. 4.1.2.

### 4.1.1 Agents: Person Class

The Person class is the only one that is considered an agent in this project. The Person class inherits from the *soil.Agent* class, which is a SOIL class 2.1.5 that represents the agents. It has network and event capabilities. In addition, it has many functions to interact with other agents and the environment. This class has many attributes that represent the characteristics of people. For the initial values of these attributes, there is a CSV file with 800 agents and some values of each. These are the attributes:

- **Age**, which is between 14 and 30 years. It increases each year or 52 steps. This value is initialised with the CSV file.

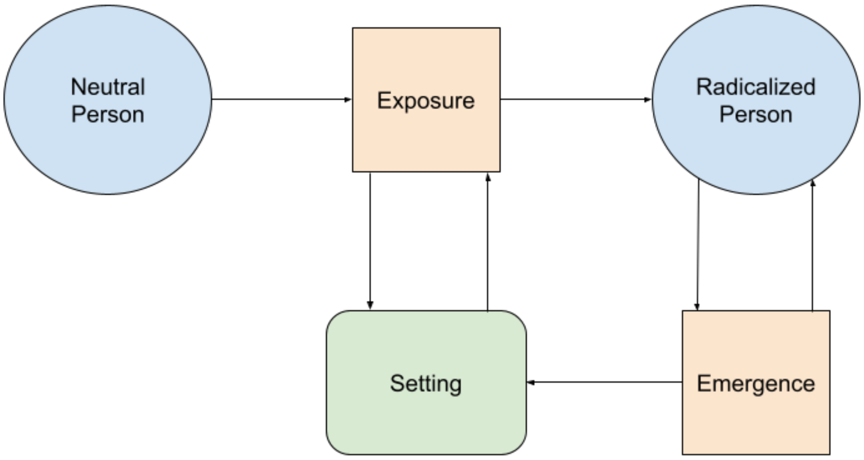


Figure 4.1: Diagram of the agents states

- **Religion**, which can only be between “Christian”, “Muslim”, or “None”. These are the only ones considered because they are the most widely regarded religions in the world. This value is initialised with the CSV file and it does not change.

- **Employment**, which is between “Student”, “Employed” or “Unemployed”. All people under the age of 16 are students and go to school. Furthermore, if a person is a student and is older than 18 years, he goes to the university. This value is initialised with the CSV file and can change due to the increase in age.

- **Gender**, which can be women or men. This value is initialised with the CSV file and it does not change.

- **Location of its home**, which are two values, one for the x-axis and the other for the y-axis. This is useful for calculating the settings that are near the home of an individual. This value is initialised with the CSV file, and it does not change.

- **Propensity**. This concept is explained in Sect. 3.2. At the beginning of the simulation, it is very low and equal for all people. Because of that, all people have the same probability of becoming radicalised.

- **Self Control**, which is explained in Sect. 4.2.2. It represents the ability of a person to control its impulses.

- **Susceptibility to Peer Influence (SPI)**, which is explained in Sect. 4.2.2. It represents if a person is easily influenced. Furthermore, to force the exposure to start, one agent SPI is manually increased.

- **Activity Field**, which is explained in Sect. 4.2.2. The activity fields represent where people spend their time with percentages.

- **Quotient** $Q_i$, which is explained in Sect. 4.2.2. It represents how much time people spend in a type of setting. It is used to calculate activity fields.

- **Variable** *exp*, which is explained in Sect. 4.2.2. It is peer delinquency. It can be shown as the number of exposures to a radicalising setting of a person. It is used to calculate the exposure function (Sect. 4.2.2).

- **Best Friend**, which represents who the person most similar to another person is. A person spends the same time in his own home as in the home of his best friend.

The agent class inherits from the FSM class. This is important because the Person agent has two states, which are the "Neutral" state and the "Radicalised" state. To model a good transition between both states, we need to define what a person radicalised is and what is not. For this task, the heterogeneity parameter, defined in the article [23], is used. It indicates the number of opportunities missed to commit a terrorist act before carrying out one. A person has an average of 8.14 opportunities missed before doing it [23]. Because of that, the inverse of 8.14, 0.1228 is used as a threshold. This means that the transition from one state to another occurs when an agent has more than 0.1228 propensity. For example, a person with a propensity of 0.2 will miss 5 (inverse of 0.2) opportunities before committing a terrorist act.

The behaviour of the agents is very simple. First, all of them are in the "Neutral" state. The emergence (Sect. 4.2.1) and exposure (Sect. 4.2.2) functions are executed at every time step. Then, if there is any agent with a propensity level greater than 0.1228, its state will change to "Radicalised". Agents in radicalised state will increase the radicalisation level of the settings where they spend its time. This radicalisation level of a setting also affect the people that spend their time in the setting.

In Fig. 4.2 there is an UML diagram of the Person class. All attributes of the class are there. It is not draw, but the fact that soil.Agent also inherits from FSM, EventedAgent, and NetworkAgent classes is important.

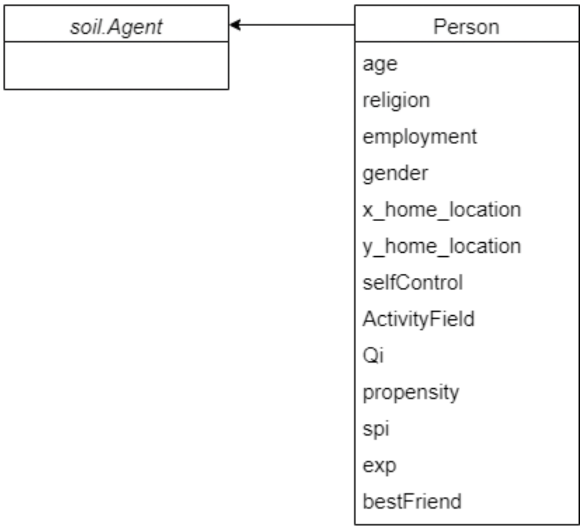


Figure 4.2: UML Diagram of the Person Class

### 4.1.2 Setting Class

The Setting Class is very simple. Note that this is not an agent class. It is an object with some attributes, and many of them are initialised with the values of a CSV file. This CSV file has 55 settings. To save all the settings, a list of Setting objects is defined in the environment. These are the attributes:

- **Name**, which is the name of the setting. It is useful to find out which setting is radicalising. This value is initialised with the CSV file. It never changes.
- **Type**, which can be “School”, “University”, “Office”, “Mosque”, “Church”, “High-Street”, “LeisureCentre”, or “YouthClub”. This value is initialised with the CSV file. It never changes.
- **Location**, which are two values, one for the x axis and the other for the y axis. This value is initialised with the CSV file. It never changes.
- **Size of the setting**, it is important for the calculation of the Activity Field (Sect. 4.2.2). This value is initialised with the CSV file. It never changes.
- **Radicalisation Level**, which is calculated in the emergence function (Sect. 4.2.1). Its initial value is 0 for all settings.
- **Collective Efficacy**, which is explained in Sect. 3.3.2. It can be chosen manually, but for this project, all settings have the same collective efficacy, except schools and universities, which have a little more, and offices, which have some more.

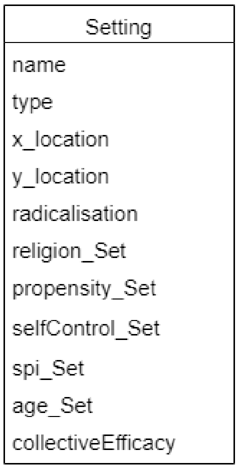


Figure 4.3: UML diagram of the Setting Class

- **Mean Religion**, which is defined as religion_Set. It represents the mean value of the religion of all people who spend their time in the setting. It is initialised with a neutral value.

- **Mean Propensity**, which is defined as propensity_Set. It represents the mean value of the propensity of all people who spend their time in the setting. It is initialised with a neutral value.

- **Mean Self Control**, which is defined as selfControl_Set. It represents the mean value of the self control of all people who spend their time in the setting. It is initialised with a neutral value.

- **Mean SPI**, which is defined as spi_Set. It represents the mean value of the SPI (mentioned in Sect. 4.2) of all people who spend their time in the setting. It is initialised with a neutral value.

- **Mean Age**, which is defined as age_Set. It represents the mean value of the age of all people who spend their time in the setting. It is initialised with a neutral value.

In Fig. 4.3 there is an UML diagram of the Setting class. All attributes of the class are there. The attributes finished on "_Set" are the means of all people who go to the setting. For example, propensity_Set refers to the mean of all propensities of people who spend time on that setting.

## 4.2 Environment

In the environment, all the common features of all agents are defined. For the first time, both the Setting and People files are opened, and all Person agents and Setting objects are created. Setting objects are saved in a list for faster access. All the initial values of the settings and people are put. One person is set to have a higher propensity to force the exposure to happen. In SOIL (Sect. 2.1.5), all agent reporters to save data to be deposited in dataframes are defined here. The network of the agents is also defined here (see Sect. 4.2.3).

For optimising the simulation, a redefinition of the step method of the SOIL environment is needed. Usually, the step method only checks the state functions of all agents. But in this method, we now call both the emergence and the exposure functions. This is because SOIL have a random behaviour, and in our project, some variables need to be calculated in order.

### 4.2.1 Emergence Function

Settings with low collective efficacy are easily radicalised (for more information, see Sect. 3.3.2). There are two ways of emergence: radicalised people prefer to go to settings with low collective efficacy, and settings with low collective efficacy enhance the influence of radicalised people [23].

To do all the processes necessary in this function, firstly, it is necessary to calculate the means of the features of each setting, like the mean age, mean religion, etc., keeping in mind all people who spend time in the setting. Then, a person needs to have a minimum propensity to influence the setting and he needs to spend a minimum of time in that setting. Consequently, the minimum propensity threshold is 10% of the collective efficacy of the setting [23]. And the minimum time that a person needs to spend in a setting to influence it is one hour a week.

In addition, to express the power that a low collective efficacy has in a radicalised person, the level of radicalisation of a setting is calculated like the mean of the propensity of all people in the setting multiplied by the inverse of the collective efficacy (a higher value results in a lower level of radicalisation, and vice versa). This transition is defined with the formula (Listing 4.1) [23]:

$$r_j(t) = \frac{1}{n\sqrt{w_j}} \sum_{t>1,p>0.1w} p_i(t) \tag{4.1}$$

Where $r_j(t)$ is the radicalisation of the setting $j$ at time $t$, $w_j$ is the collective efficacy of the setting $j$, and $p_i$ is the propensity of the person $i$.

For more information on the emergence function, see this article [23].

### 4.2.2 Exposure Function

For exposure (more information in SubSect. 3.3.1), it is necessary to explain the cognitive susceptibility to radicalisation, which is determined by morality and self-control [23]:

1. **Self-control**: Wikström points out in his study [34] that the development of self-control is finished in childhood and is distributed in the population as a normal distribution. For these reasons, in our model self-control is constant and normally distributed.

2. **Susceptibility to Peer Influence**: Due to the fact that it is more difficult to model morality, we use a concept developed by Steinberg and Monahan [31] that is the Resistance to Peer Influence, or its opposite, the SPI. This measure is accepted by many studies. It represents the tendency of a person to be influenced by people. It can influence individual decisions, leading a person to adopt behaviours similar to those of their peers. Therefore, it is good at predicting criminal behaviour. Steinberg and Monahan concluded that SPI depends on age and is linear between 14 and 18 years of age. An article by Berndt [2] pointed out that women are less susceptible to pressure from people than men.

Moreover, to model the activity field, the concept of homophily [15] is used. That is, people usually go to settings with people similar to them. Harris and Wilson identified in their study [12] the importance of the size of a setting and the proximity to the home of a person. They developed a formula (Listing 4.2) [23]. Although this formula is for the flow of money from one location to another, it is used for our model.

$$f_{ij} = A_i Q_i W_j^a e^{-bc_{ij}} \tag{4.2}$$

Where $A_i = \frac{1}{\sum_k W_k^a e^{-bc_{ij}}}$.

In our project, $c_{ij}$ is the distance between person i and setting j. $W$ is the size (number of people who usually spend time in the setting) multiplied by the similarity between the person and the people who spend time in the setting. $a$ and $b$ are parameters of their study [12] [23]. $Qi$ represents the time a person spends in a type of setting (for example, 40 hours at the university or 2 hours at the church).

Next, a Meldrum model [20] gives a formula to calculate the probability that a person commits a crime in the next year. This formula is very useful, but it is necessary to fit it into the radicalisation model. The formula (Listing 4.3) [23] represents the propensity to commit a terrorist attack.

$$p_i(t) = 1 - \left( \frac{1}{1 + 0.1228 e^{b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 + b_3 x_3}} \right)^{8.14} \tag{4.3}$$

Where $x_1$ is SPI, $x_2$ is self-control and $x_3$ is peer delinquency.

Because a terrorist attack is a deliberate crime and not only a leak of self-control, the morality factor must have a very important weight in the equation. For this reason, the factor $b1$ should be greater than $b2$ and $b12$. SPI increases propensity and self-control reduces it, so $b1$ and $b3$ must be positive and $b2$ negative.

In equation 4.4, the values have been fitted with the trial-and-error method. In the original article [23] of the formula, different values are calculated. But for our model, these values work better.

$$p_i(t) = 1 - \left( \frac{1}{1 + 0.1228 e^{-7.2 + 0.95 x_1 - 0.45 x_2 + 0.1 x_1 x_2 + 0.03 x_3}} \right)^{8.14} \tag{4.4}$$

In addition, in this project, there exists a previous function that calculates the number of exposures that a person has to a radicalising setting. The result of this function is passed to the value $x_3$ in the formula (Listing 4.3). Likewise, there is another function to calculate the value of quotients $Q$ for the formula (Listing 4.2).

For more information on the exposure function, the reader can consult [23].

### 4.2.3 Network

The SOIL networks are made with NetworkX (see Sect. 2.1.5). For this project, a Complete-Graph topology is used. A complete graph is a graph in which all nodes are connected, that is, all pairs of nodes are linked between them. Each node represents an agent, and each link represents a relationship between two agents. The election of a complete graph is because all agents can spend time in the same setting along the simulation, and all can interact with the rest. Agents interact between them through activity fields (see Sect. 4.2.2). In Fig. 4.4 there is an example of a complete graph with seven nodes.

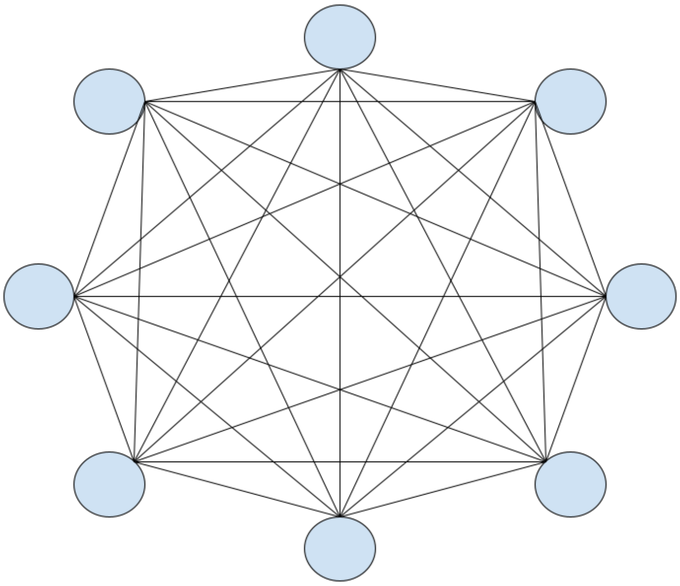

Figure 4.4: Example of a seven-node complete graph

## 4.3 Simulating the Model

Once all classes, functions, and variables used in this simulation are defined, the whole process is explained in this section. All of this is executed using Python (see Sect. 2.1.1) and the results are plotted using MatPlotLib (see Sect. 2.1.3). Regarding the time taken for the simulation to finish, it depends on two factors, which are the number of agents that are executed (maximum 800) and the number of time steps that are run. For instance, for a simulation of 800 agents and 260 time steps (each step represents a week), it takes around 10 minutes (this is the mean for a current computer).

The whole process is shown in Fig. 4.5. This is an explication step-by-step of the diagram:

1. At the beginning of the simulation, all values of the settings and people are set, reading the CSV files. Values that are not in the CSV files, like the SPI or self-control, are also calculated in this step.
2. The mean values of the setting are calculated. These values depend on the attributes of people who spend their time in the setting. For example, if there are many people with low self-control in the setting, the value "selfControl_Set" will be lower. All this was explained in Sect. 4.1.2. For the first time, there is no one person in the settings. For that reason, all of these values are set to a neutral value.

3. The emergence function is called. In this function, the level of radicalisation of a setting is calculated taking into account all the people that go to the setting. The logic of this function is divided in two parts:

   (a) Check if someone spends enough time in a setting (more than one hour), if not, exit.

   (b) If the propensity of that individual is enough (the threshold depends on collective efficacy), emergence increases the radicalisation value of the setting; if not, exit.

   This function was explained in Sect. 4.2.1.

4. The number of exposures of a person to a radicalising setting is calculated. The result of this step is used in the formula for the next.

5. The exposure function is called. The propensity level of people is calculated using the formula (Listing 4.4). It depends on the value of SPI, self-control, and the result of the previous step in this diagram. See Sect. 4.2.2.

6. The quotients "Q" of the time spent by a person in a type of setting are calculated. To calculate this quotient, there are many factors to keep in mind. For example, people younger than 18 years are students and go to school, and people who are students but are over 18 years old go to university. People younger than 20 years go to youth clubs. People who are employed go to the office. And people who are followers go to the temple.

7. Check if someone is similar to people who spend their time in a setting. The individual will go more to settings with similar people and less to settings with different people. This is explained in Sect. 4.2.2.

8. With the previous information, the activity fields of each person are calculated. The function to calculate the activity fields is explained in Sect. 4.2.2. In summary, it checks if one person is similar to the people who go to each setting. Then, if it is similar, that person will feel more attraction to this setting and will go more to it.

9. If the simulation reaches step 260 (or the maximum steps that we have set), the simulation is completed. In the other case, the next step starts. When the simulation finishes, the results are plotted and can be checked.

10. Check if the propensity of an agent is greater than the threshold (0.1228). If so, that agent changes its state to "Radicalised". If not, continue. The value of the threshold was calculated in Sect. 4.2.2.

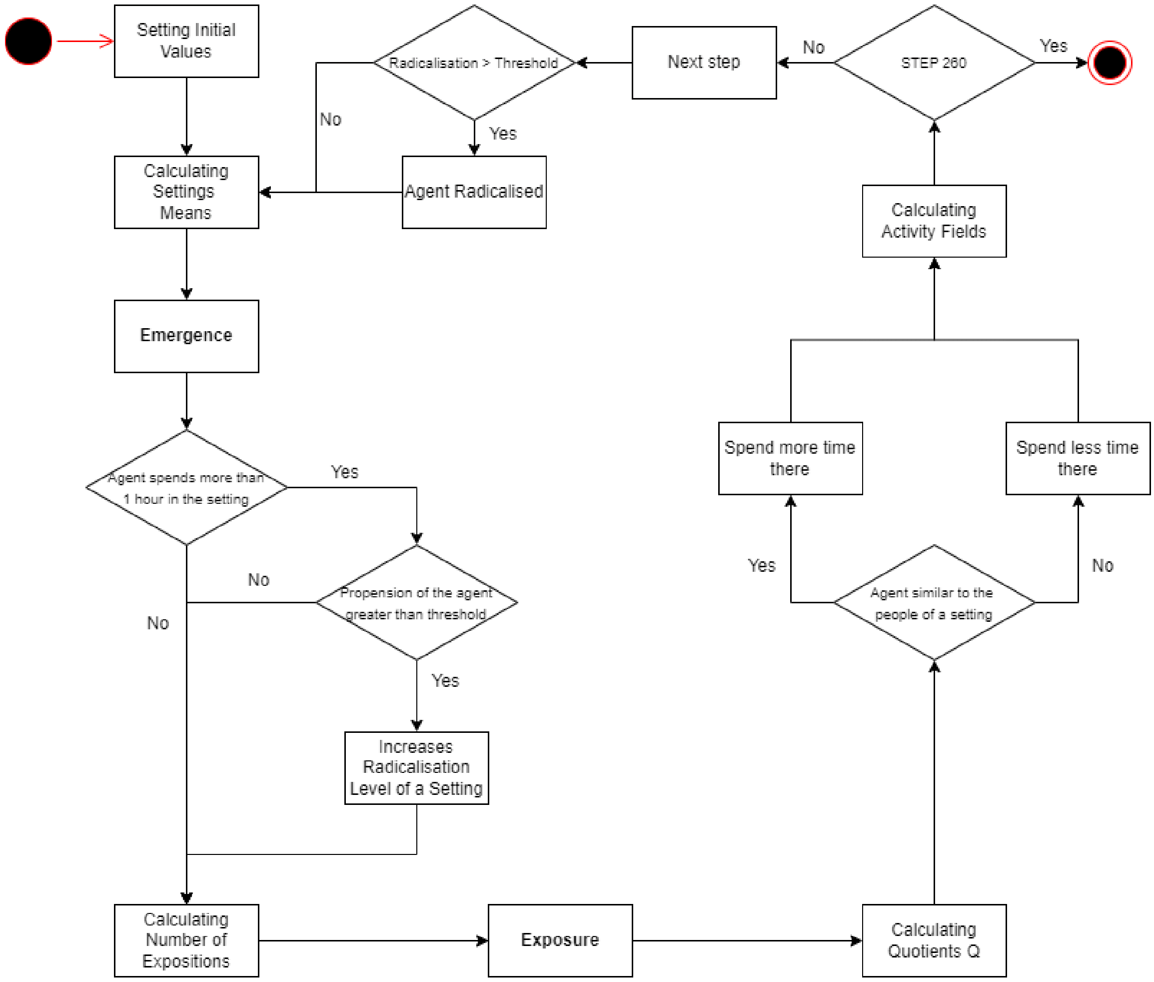


Figure 4.5: Behaviour of the simulation

11. Return to the beginning.

CHAPTER 5

# Results

In this chapter, all the results of some simulations are represented and compared. The fact that there is very little data on the radicalisation process has already been mentioned many times in the project. For this reason, the results cannot be compared with reliable and empirical data. Therefore, the theory of Ormerod and Rosewell [21] mentioned in Sect. 3.1 is used. They pointed out that if a model can explain the phenomenon, then it is a good model.

## 5.1 Expected Results

The next step is to define what features of the phenomena would be interesting to check in the model:

1. The radicalisation process is very unusual. The demographic conditions that lead to this process are not usual. In 2022, 380 people were arrested on suspicion of terrorism in the European Union [7]. There were 447,7 millions of people in the European Union in 2023 [32]. Therefore, it is expected to have few radicalised people in our simulation.
2. The level of propensity in a person is not constant; it varies over time. It is due to

situational factors and the change in activity fields.

3. The level of propensity should tend to decrease over time in an environment composed of the same people. This is because SPI of people between 14 and 18 years decreases with the passing of time (see Sect. 4.2.2).

4. Men have a higher propensity than women, in general. This is because SPI is lower for women (see Sect. 4.2.2). Furthermore, these data can be found in the Europol Annual Report [7].

## 5.2 Simulations

### 5.2.1 Simulation with 800 Agents

In this section, some simulations of 800 agents and 260 steps are presented. The goal is to try to explain some of the points mentioned in Sect. 5.1 with the results of the simulations. First, to validate our model, we have run the model without including the effect of radicalisation factors. As expected, no person has been categorised as radicalised. This is aligned with the first point in Sect. 5.1. In the next experiment, we force the emergence (see Sect. 4.2.1) to occur. An agent is set to have more SPI manually (in particular, agent number 50). After running 10 simulations with this configuration, the average simulations with at least one radicalised person are 20%. A graph of the propensity level of all agents can be seen in Fig. 5.1. With this graph, a histogram can be calculated to check the ratio of propensity levels, in Fig. 5.1. We can check that 8 people are slightly radicalised and one person is very radicalised. The rest of the people in the simulation have a lower propensity than the threshold (0.1228, calculated in Sect. 4.2.2), and most of them have a propensity level lower than 0.05.

Another simulation is run and the results are presented. For the second simulation, a graph of the propensity level of all agents can be seen in Fig. 5.3, and a histogram of the propensity is shown in Fig. 5.4. We can check that only two people are clearly radicalised, but with a low level of propensity. Again, most people have a propensity level lower than 0.05.

In addition, a third simulation is run. Now, we have added two new graphs. First, in Fig. 5.5 is the variation in propensity of the propensity level for the first agent, and in Fig. 5.6 is the same for the first 10 agents. With these graphs, it can be shown that the propensity is not constant and tends to decrease. This is due to the power of the activity

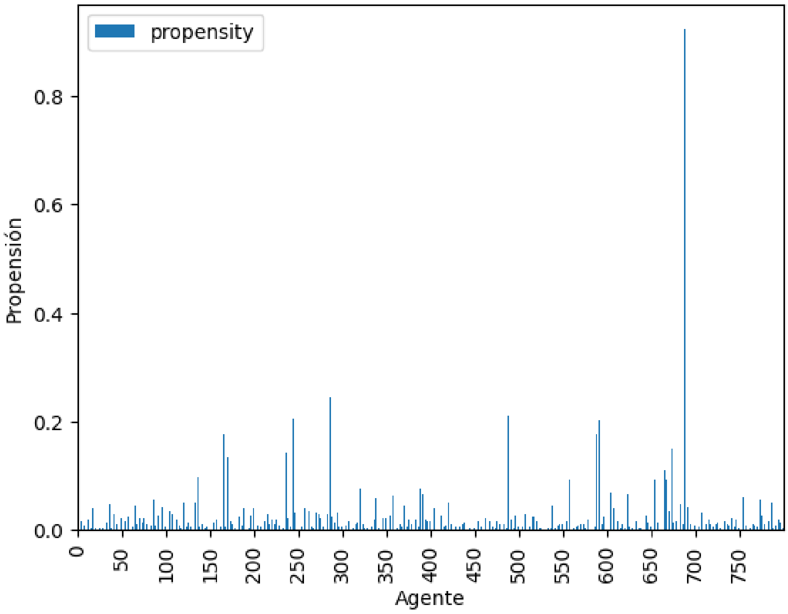


Figure 5.1: Propensity of 800 agents and 260 steps simulation. Simulation 1.

fields, explained in Sect. 4.2.2. Furthermore, the tendency of these graphs is that the propensity decreases. This can be explained with the second and third points of Sect. 5.1.

### 5.2.2 Simulation with 600 Agents

In this section, the results of a simulation of 600 agents and 260 steps are presented. The goal is to try to explain whether reducing the number of agents has any effect on the results. Like in Sect. 5.2.1, agent number 50 is forced to have more SPI. First, a graph of the propensity level of all agents can be seen in Fig. 5.7. A histogram of the propensity is shown in Fig. 5.8. In Fig. 5.9 is the variation in the propensity of the propensity level for the first agent, and in Fig. 5.10 is the same for the first 10 agents.

Apparently, nothing happens. It is very similar to the first simulation in the previous section. But there exists a slight difference in the majority of the simulations done. Usually, with 600 agents, there are fewer radicalised agents than in the 800 agents simulation case, but now the propensity level of one agent is usually higher. In the case of 800 agents, usually there are more agents radicalised, but no one has a very high level of propensity. Furthermore, like in Sect. 5.2.1, the level of propensity tends to decrease. This can be explained with the third point of Sect. 5.1.

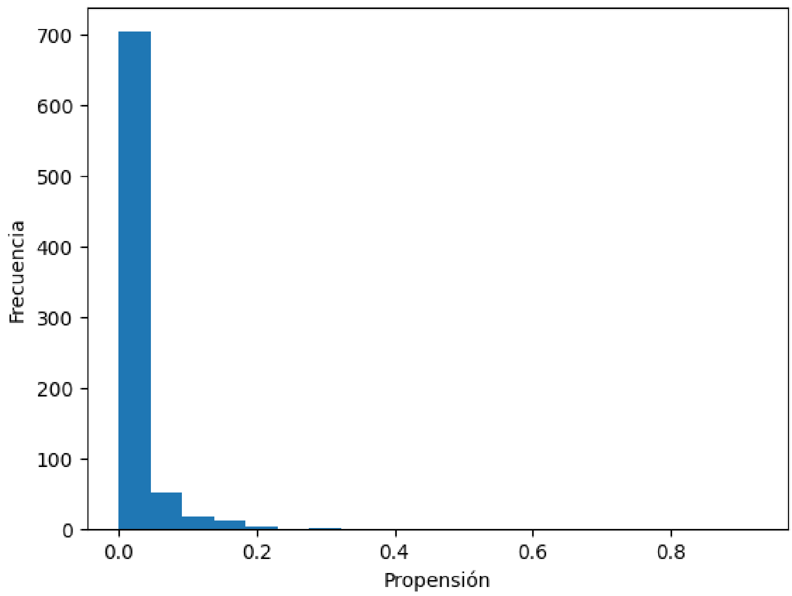


Figure 5.2: Histogram of the propensity of 800 agents and 260 steps simulation. Simulation 1.

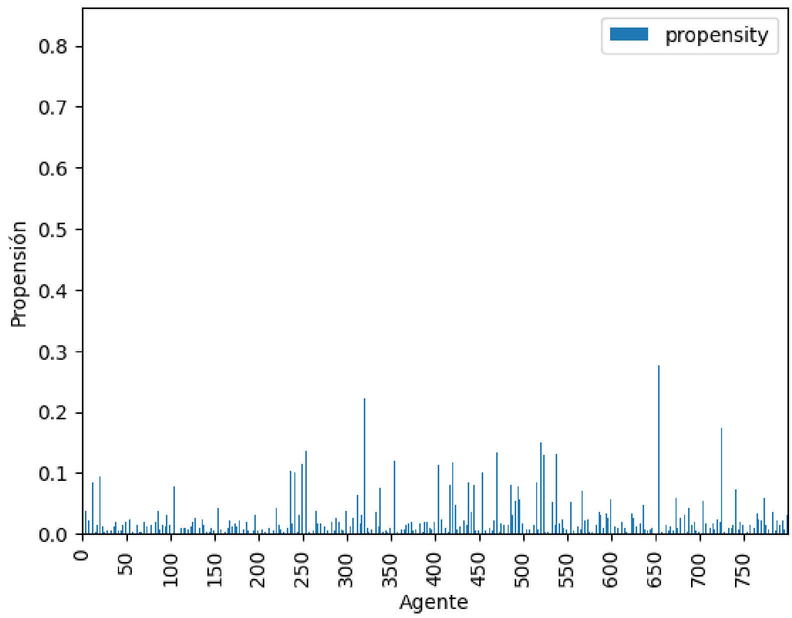


Figure 5.3: Propensity of 800 agents and 260 steps simulation. Simulation 2.

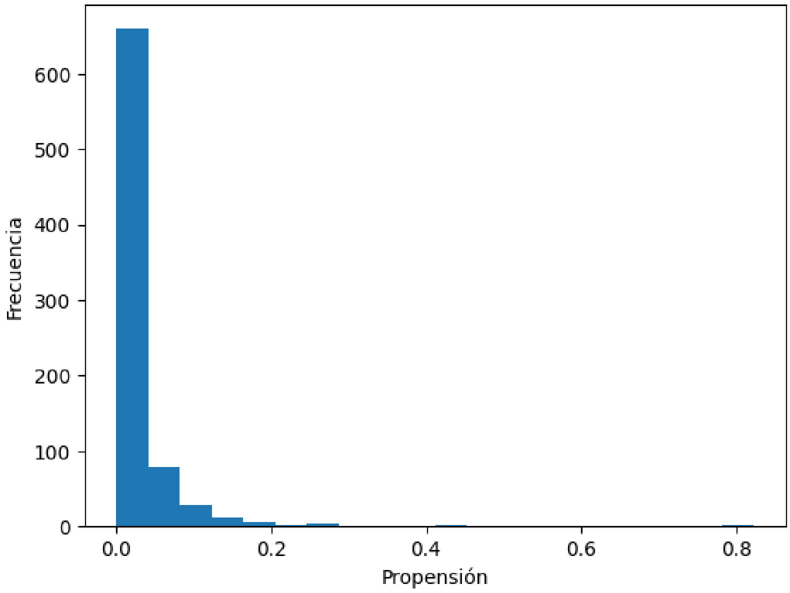


Figure 5.4: Histogram of the propensity of 800 agents and 260 steps simulation. Simulation 2.

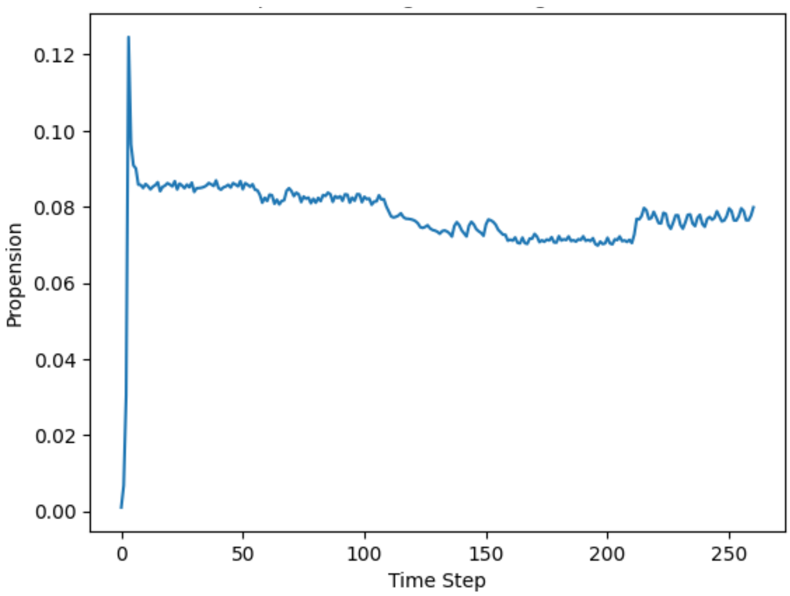


Figure 5.5: Variation in the propensity of the first agent. Simulation 3.

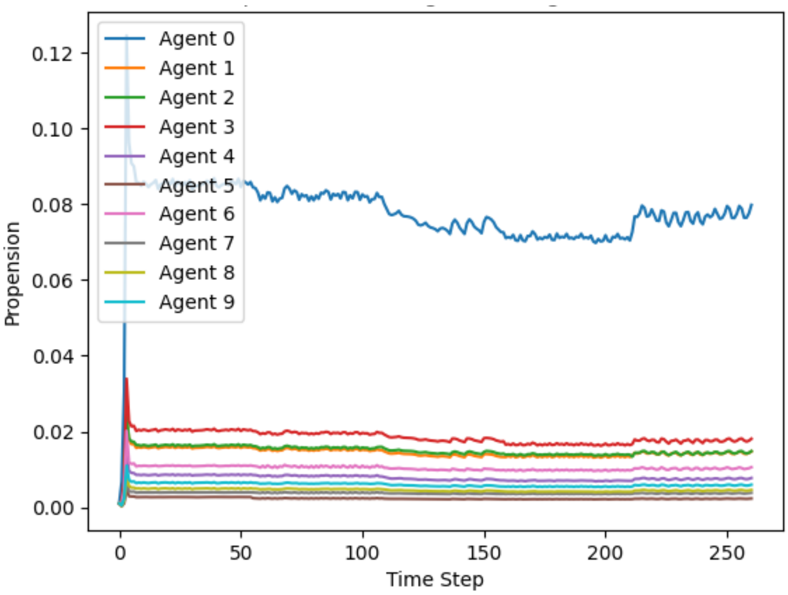


Figure 5.6: Variation in the propensity of the 10 first agents. Simulation 3.

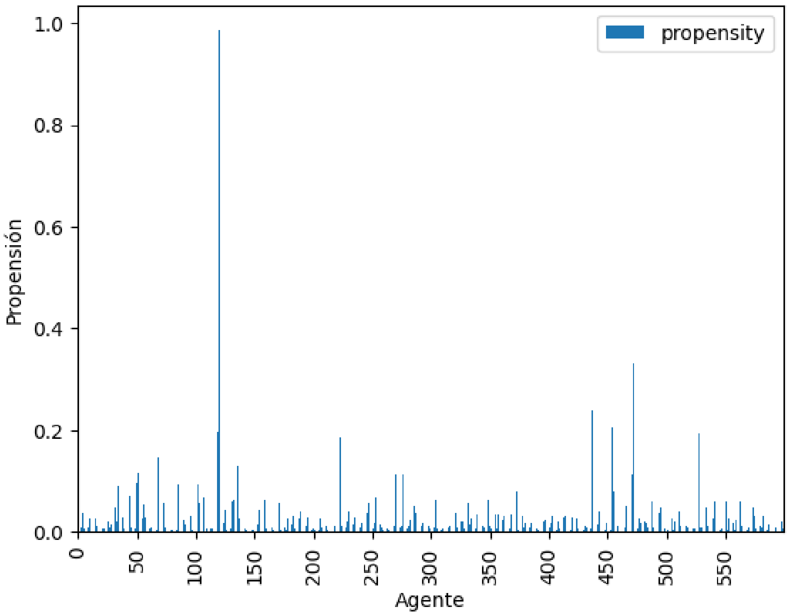


Figure 5.7: Propensity of 600 agents and 260 steps simulation. Simulation 4.

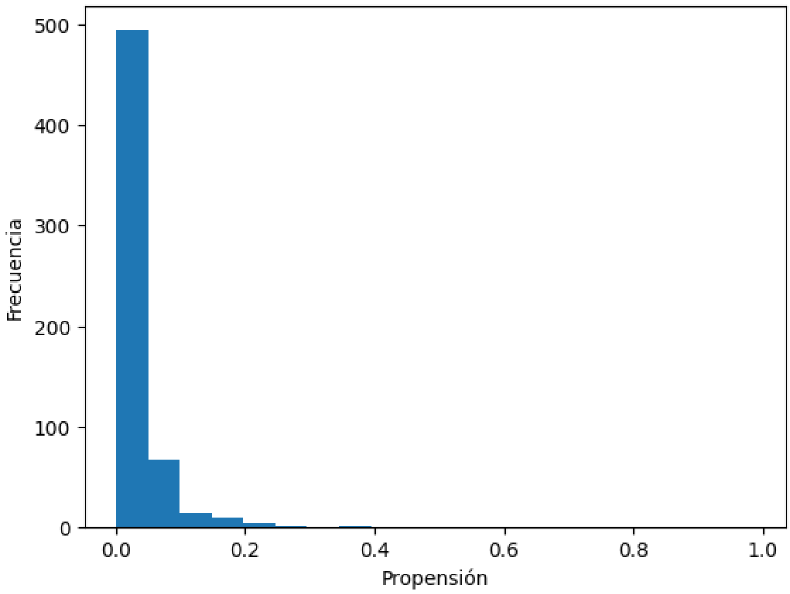


Figure 5.8: Histogram of the propensity of 600 agents and 260 steps simulation. Simulation 4.

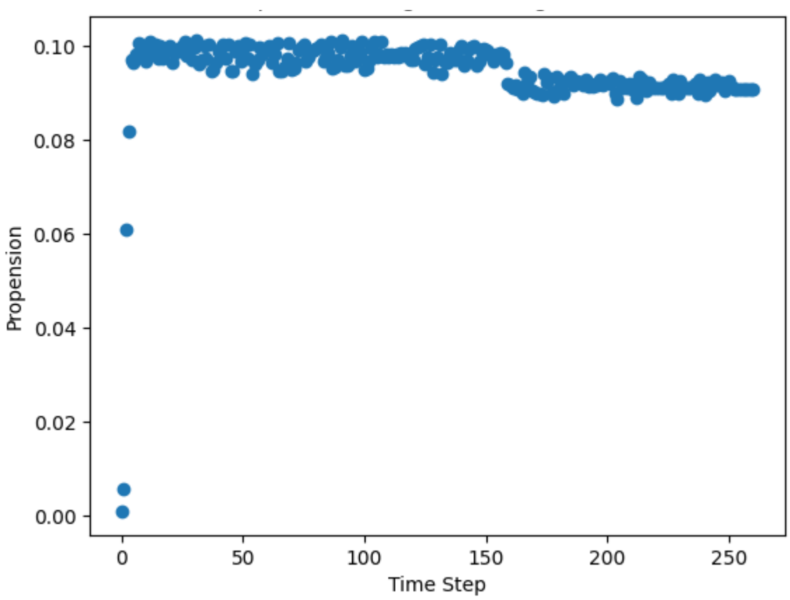


Figure 5.9: Variation in the propensity of the first agent. Simulation 4.

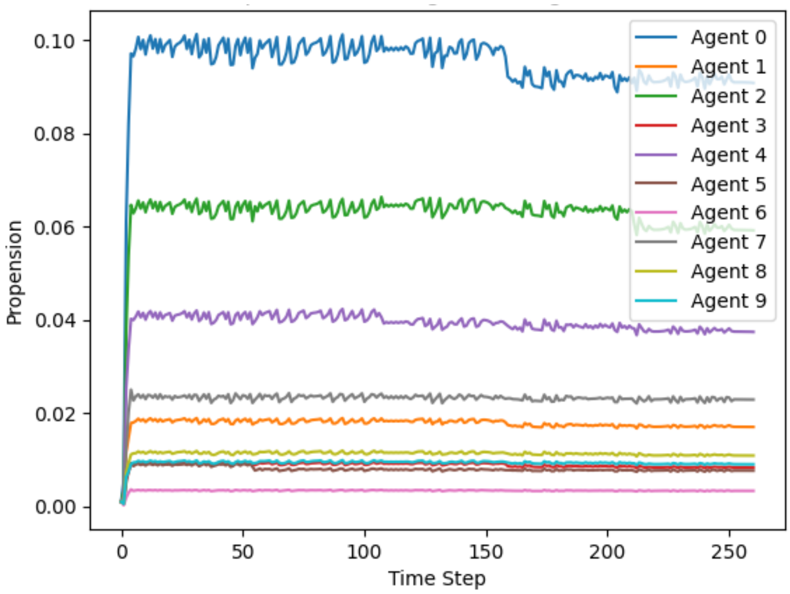


Figure 5.10: Variation in the propensity of the 10 first agents. Simulation 4

### 5.2.3 Simulation with 300 Agents

In this section, the results of a simulation of 300 agents and 260 steps are presented. Again, the goal is to try to explain whether reducing the number of agents has any effect on the results. In Sect. 5.2.2 we saw that really the reduction in the number of agents does not have any special change. Like in both previous sections, agent number 50 is forced to have more SPI. First, a graph of the propensity level of all agents can be seen in Fig. 5.11. A histogram of the propensity is shown in Fig. 5.12. The graphs of the variation of the propensity are not included now because they do not provide any relevant information.

The number of radicalised agents is again lower than in the 800 or 600 agent simulations. Moreover, one of these radicalised agents usually has a higher level of radicalisation, as in the case of 600 agents simulation.

With this information, we can make the following hypothesis: In environments with more people, it is easier to find radicalised people, but it is more difficult for those people to be very radicalised. It can be suggested that due to there being more people, some radicalise more likely, but at the same time, there are many more people who are not radicalised, and because of that, the emergence functions have less power.

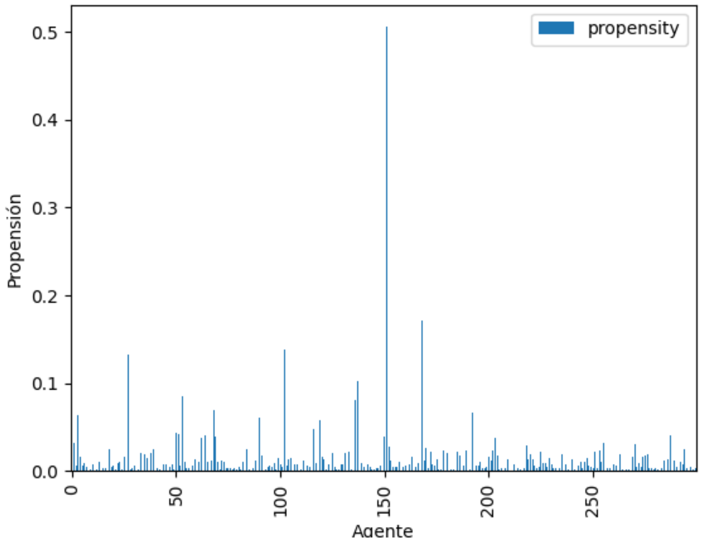


Figure 5.11: Propensity of 300 agents and 260 steps simulation. Simulation 5.

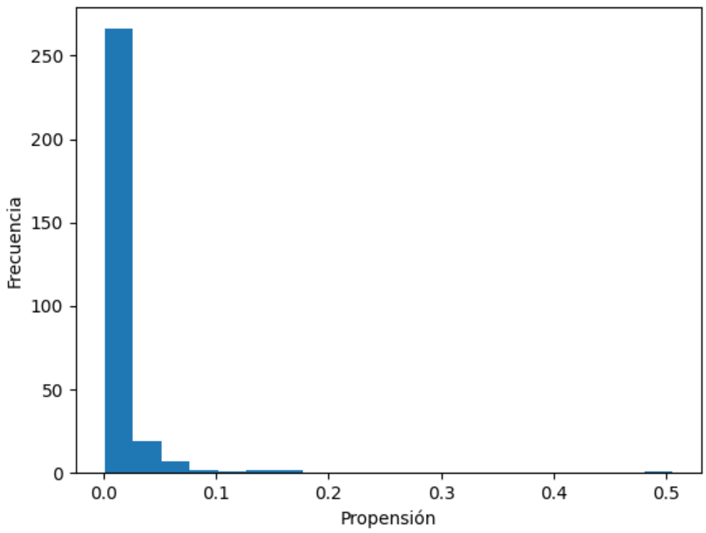


Figure 5.12: Histogram of the propensity of 300 agents and 260 steps simulation. Simulation 5.

## 5.3 Mean profile of the radicalised person

In this section, the relationships between the different attributes of a person and their propensity are studied. It is checked if gender, age, employment, or religion have any influence on the radicalisation process. With this information, the mean profile of a radicalised person is calculated. All the simulations in this section are new, trying to have a great number of radicalised people.

First, Fig. 5.13 represents the mean propensity of all agents in different simulations divided by the gender. In all the simulations, men have more propensity than women. Due to this, the mean propensity of men is 62.35% greater than the mean propensity of women. This can be explained by the fourth point in Sect. 5.1. SPI is lower for women than for men. Therefore, men are more susceptible to be influenced. This is confirmed by the Europol report [7].

Regarding age, it is divided into two graphs. In Fig. 5.14 there is a representation of the mean propensity of all people in step 51, and in Fig. 5.15 there is the same but at step 260. This is because in our simulation people increase their age each 52 steps (each step represents a week) and there are no people younger than 14. Because of that, after step 52, there are no people of 14 years of age. As a result, we have a graph with all ages and another with people older than 18 years (260 steps represent 5 years completed, but people do not increase their age in the last step). In the first graph (Fig. 5.14), we can check that younger agents have a higher propensity, and the propensity is similar from 20 years on. In the second graph (Fig. 5.15), the same result is obtained, but with a delay of 4 years. This can be explained by the theory of Steinberg and Monahan [31], in which they said that SPI decreases linearly between the ages of 14 and 18. All this explains why the propensity level tends to decrease.

Regarding religion, Fig. 5.17 represents the propensity of Christians, Muslims, and non-believers. It can be shown that the religion of the person it is not relevant in this model. All results are very similar. However, in the Europol report [7], real information on this can be found.

Regarding employment, Fig. 5.16 represents the propensity of employed, unemployed, and students. Due to the fact that in our model all people between 14 and 16 years are students, and that in Fig. 5.14 the younger people have the higher propensity, the students also have the higher propensity. Therefore, this graph a priori is not relevant.

With all of this data, we try to define the most common profile of a radicalised person.

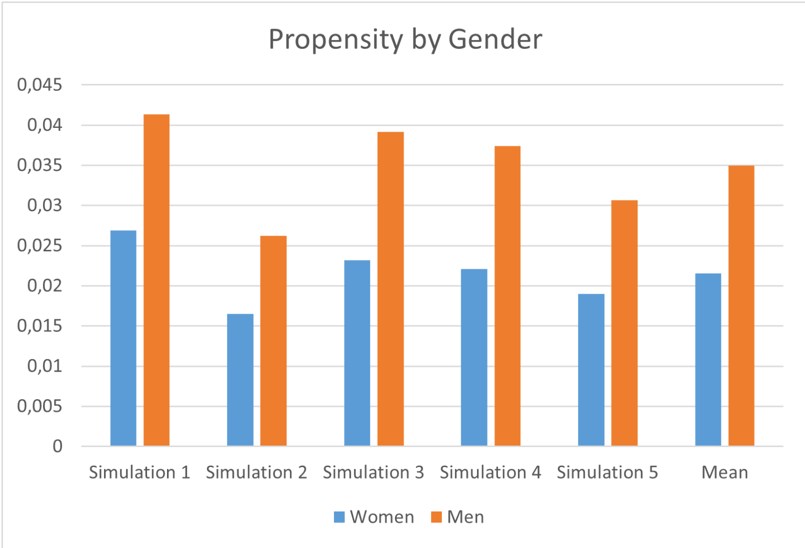


Figure 5.13: Propensity by gender.

In a Russel and Miller article [24], the most common profile of a terrorist is a man between 22 and 24 years of age with at least partial university studies (it is important that this article refers to terrorists and not to radicalised people). In our model, the common profile of a radicalised person is a student male between 14 and 18 years of age. Although there exists a difference in ages, both refer to young people. In conclusion, although our model is very limited, it can result in something similar to reality.

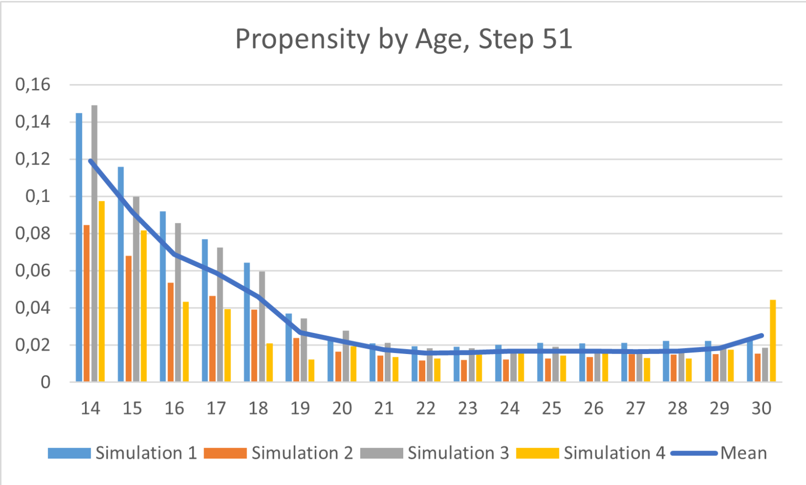


Figure 5.14: Propensity by age in step 51.

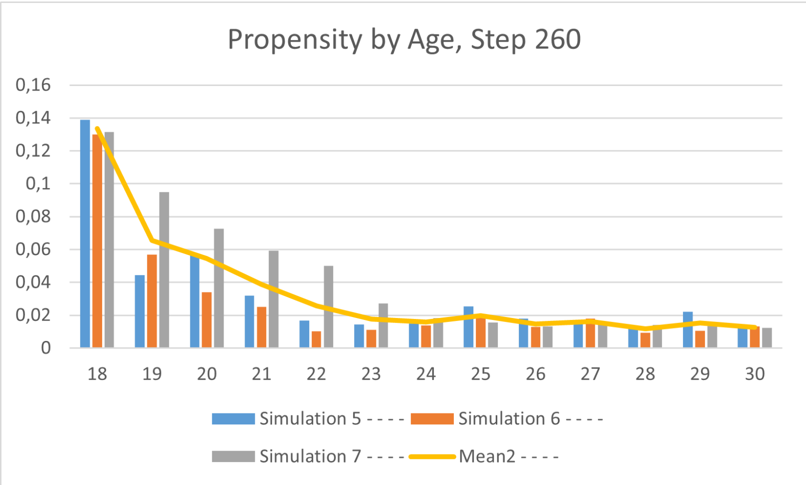


Figure 5.15: Propensity by age in step 260.

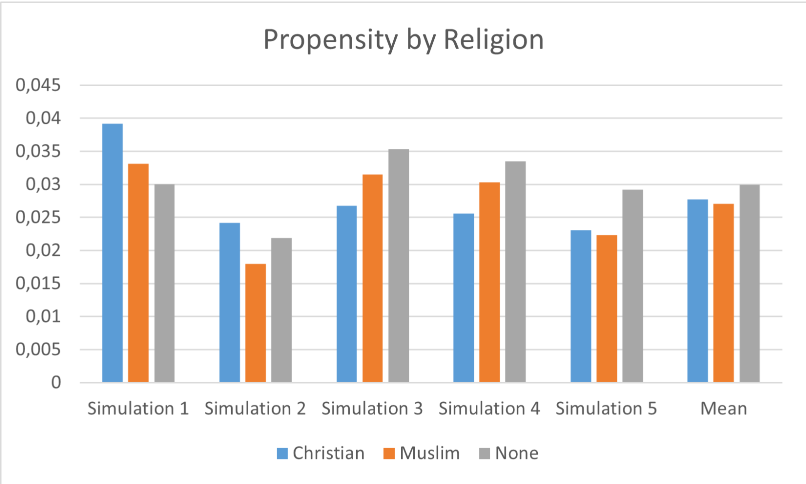


Figure 5.16: Propensity by religion.

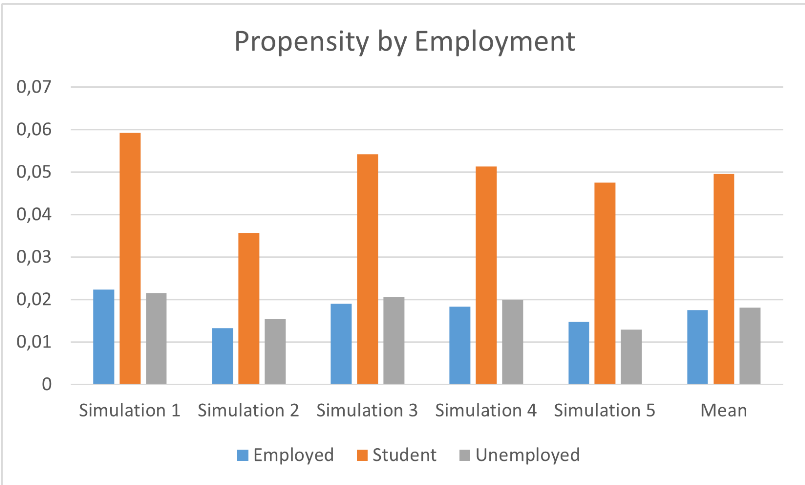


Figure 5.17: Propensity by employment.

CHAPTER 6

# Conclusions and future work

In this chapter we describe the conclusions extracted from this project (Sect. 6.1), the achieved goals (Sec. 6.2) and the thoughts about future work (Sect. 6.3).

## 6.1 Conclusions

Throughout this project, the main goal has been to obtain a useful tool to contribute to the counter-terrorist race. Due to this, we have decided to create an agent-based model of the radicalisation process. First, we have obtained some important information on the factors that influence the radicalisation process. These factors were explained using some psychological theory in Sect. 3.2. Then, the whole model was described using these concepts. The most important thing was the description of the exposure and emergence phenomena (in Sect. 3.3), which are the key parts of this process. After the process was modelled in Chapter 3, the simulation and how it works were explained in detail in Chapter 4. Finally, the results of some simulations were presented and studied in Chapter 5.

As we have mentioned on many occasions, there is very little information on this process. Due to this, it is not possible to verify the model empirically. To solve this, the definition of a good model mentioned in the theory of Ormerod and Rosewell [21] has been used. With this definition, the project aims to explain the radicalisation process as well as possible. We have tried to explain the most important points of the radicalisation process described in Sect. 5.1 simulating the model.

Regarding the results obtained in Chapter 5, we can suggest some ideas:

1. In our model, as expected, the process does not happen in an 800 agent simulation. Due to this, we need to force it to start. This can be explained with the first point in Sect. 5.1.

2. A very small proportion of agents have a considerable propensity to commit a terrorist attack. This can also be explained with the first point in Sect. 5.1.

3. The level of propensity of a person is not constant; it was demonstrated in Sect. 5.2.1. This can be explained with the second point in Sect. 5.1.

4. The level of propensity tends to decrease by studying the tendency of the evolution in propensity charts in this Sect. 5.2.1. This can be explained with the third point in Sect. 5.1.

5. In environments with more people, it is easier to find more radicalised people, but these radicalised people usually do not have a very high level of propensity. This may be due to the importance of the activity field: Because there are more people, there are more people with a low level of radicalisation who influence the emergence function.

6. The most common profile of radicalised people is a male student between 14 and 18 years of age, as suggested in Sect. 5.3.

In an effort to make the results more interesting, we checked the profile of all agents in the simulation to suggest which is the most common profile of the agents, in Sect. 5.3. We have found that the most common profile is a male student between 14 and 18 years old. This was verified with the Europol Report [7] and with this article [24] in which it can be shown that the most common profile of a terrorist (remark that a terrorist is not the same as a radicalised person) is a man with at least partial university studies between 22 and 24 years old. Due to the fact that terrorism is a premeditated crime and the radicalisation process is very long [23], we can suggest that some years are necessary from the time when a person starts to radicalise to the time when a person commits a terrorist attack. With this information, we can see that even though our model is limited, it can explain reality.

Furthermore, it is important to note that younger people have a higher propensity. This is because they are very easily influenced. Due to this, most of the online radical propaganda is focused on young people, because they do not have a clear identity. Then, if an easily influenced teenager with low self-control capacity listens to radical messages, it could be a potential terrorist in a few years. For this reason, it is very important to check where children spend their time and help them to understand what is morally correct and what is not.

In summary, we have performed a very simple agent-based model for studying the complex process of radicalisation in society. All of this trying to keep in mind many important psychological and social characteristics of human beings. Although the model is very simple and there are only 800 agents, the results of the model are good according to the few data we have about the process. And the simulation can explain the points cited in Sect. 5.1. For all these reasons, we can conclude that the project has achieved its goals (see Sect. 6.2). It can be useful in the counter-terrorism race. Obviously, the project could be improved in many ways, as explained in Sect. 6.3.

## 6.2 Achieved goals

This Section provides a brief overview of the goals that have been achieved in the project. It is shown the progress and success of the project. This summary helps interested people to understand the work done and the positive impact of it.

**Studying the psychological and social theory** of the radicalisation process. Before creating this model, it was necessary to understand all the factors that influence it.

**Creating and agent-based model of the radicalisation process.** We have been able to create an accurate model of this complex phenomenon using the Python [25] SOIL 2.1 library. For modelling it, we had to use the previous concepts to study the relations between the different parts of the process and the variables involved.

**Obtain the results for visualisation.** Once we had the entire model, some simulations were run to obtain the DataFrames with the results. These data were filtered using different tools of Python and SOIL (more information is provided in Chapter 2).

**Visualisation of the results and conclusions.** With the output of the simulations, we plotted the data to visualise the results. Due to this, many conclusions could be drawn. Furthermore, this conclusions were verified with the few available data from this process.

## 6.3 Future work

This Section provides a brief explanation of some possible fields of future work to do in this project. This summary helps interested people to understand the future projection and the potential of this project.

- **Studying and implement more factors** that could influence the radicalisation process. To make a more accurate model, more factors must be implemented. For example, we have not implemented the probability of having mentally ill people.
- **Implementing online propaganda**. Nowadays, radical online propaganda is one of the more common ways that terrorists spread their messages. It could be interesting to add this to the model and see the influence that social networks and the Internet have in this process.
- **Studying intervention politics**. One of the most interesting things about this project is the possibility of using it for counter-terrorism. It could be very interesting to study different intervention politics and check what is the best policy. Some examples of this politics can be universal counter-narratives or targeted counter-narratives.
- **Implement Machine Learning** in the model. There are many interesting ways to implement this. For example, the model can be trained with Machine Learning to be more accurate. The intervention politics mentioned above can also be trained with Machine Learning.

APPENDIX A

# Impact of this project

This appendix reflects on the possible impact of this project in the society.

## A.1 Social impact

The development of this model has an important social impact. First, it is a useful tool to understand the radicalisation process in the society. The model can be used to identify common patterns in this process and, in the future, to know when it would be better to make an intervention. Moreover, the model can be useful to researchers to understand what profile is the most common among the radicalised people. In addition, the police and intelligence departments can use this model to understand the dynamics of the society and develop new strategies for security.

The project is very simple and limited, in part due to the very little information we have about the process. The current model is probably not interesting enough for the best security organisations. But with more investigation of the process, many new useful information can be gotten and used in the model. The model is scalable, it can be improved in many ways, and many more things can be implemented. For these reasons, if new factors of the process were implemented, the project would be much more interesting and accurate.

Artificial intelligence can also be implemented in some areas of the model.

## A.2 Ethical implications

Regarding ethical implications of this project, first, it is very important to preserve the privacy of the data of the people managed. This involves the need to obtain the consent of the people and ensure the anonymity of the data, according to the ethics principles. Indeed, all the tools that can be used to increase the security of society reduce at the same time the privacy of the population. This is in contradiction to the principles of freedom. Due to this, there are examples like the recent case of the prohibition of facial recognition cameras in the European Union. In conclusion, this model could be very powerful, but at the same time, it is necessary to preserve the privacy of the people and to ensure that the freedom principles will not be violated.

## A.3 Economic impact

This agent-based model of the radicalisation process can help security departments understand this process. They could be useful in the counter-terrorist race to improve the intervention policies. Due to this, it potentially reduces terrorist attacks. As a result, many lives, buildings, and information can be more secure, saving millions of euros.

APPENDIX B

# Economic budget

This appendix details an adequate budget to bring about this project.

## B.1 Physical resources and Software

This project has been created using only a computer of 16GB RAM and 6 Cores of 4.4 GHz. This computer is able to run the simulation in 10 minutes and to visualize all the results. Regarding the software, all software and licenses used in this project are free.

The minimum specifications of the computer are these:

- 8 GB RAM or higher.
- 4 Cores at 2.8 GHz or higher.
- At least 10GB of free space.

## B.2 Human resources

In this section we will explain the process of estimating the final price of this project taking in account the total hours spent working on it.

The estimation of the time cost for this project is around 420 hours. The average hourly salary in Spain is 15€. We will estimate that, due to the experience, our salary should be 8€ per hour. Because of that, it is estimated that this project will cost around 3360€.

## B.3 Taxes

If the product will be sold in Spain, the Value-Added Tax must be taken into account. In our country this tax is 21%. Due to this, the earnings after taxes are 2654.4€.

# Bibliography


[1] Oscar Araque. Design and Implementation of an Event Rules Web Editor. Trabajo fin de grado, Universidad Politécnica de Madrid, ETSI Telecomunicación, July 2014.

[2] Thomas J. Berndt. Developmental changes in conformity to peers and parents. *Developmental Psychology*, 15:608–616, 1979.

[3] Noemie Bouhana, Per-Olof H. Wikström, and Home Office. Al qa'ida-influenced radicalisation: A rapid evidence assessment guided by situational action theory. *Counter terrorism research and analysis*, page 113, 2011.

[4] Caitlin Clemmow, Noémie Bouhana, and Paul Gill. Analyzing person-exposure patterns in lone-actor terrorism: Implications for threat assessment and intelligence gathering. *Criminology & Public Policy*, 19(2):451–482, 2020.

[5] Forbes Tech Council. What your software partner should know: The top programming languages of 2023, December 2022.

[6] Django Software Foundation. *Django Documentation*. Django Software Foundation, Última versión consultada: 2021. https://docs.djangoproject.com.

[7] Europol. TE-SAT 2023: Evaluation of the threat of terrorism in the european union. Technical report, Europol, 2023.

[8] Manuela Fumagalli and Alberto Priori. Functional and clinical neuroanatomy of morality. *Brain*, 135(7):2006–2021, 02 2012.

[9] G. Nigel Gilbert and Klaus G. Troitzsch. Simulation for the social scientist, 1999.

[10] Grupo de Sistemas Inteligentes (GSI). GSI - Grupo de Sistemas Inteligentes. Sitio web, Fecha de acceso: 2023. Consultado el 7 de junio de 2023.

[11] Aric Hagberg, Daniel Schult, and Pieter Swart. Exploring network structure, dynamics, and function using NetworkX. *Proceedings of the 7th Python in Science Conference (SciPy2008)*, pages 11–15, 2008.

[12] B Harris and A G Wilson. Equilibrium values and dynamics of attractiveness terms in production-constrained spatial-interaction models. *Environment and Planning A: Economy and Space*, 10(4):371–388, 1978.

[13] Charles R. Harris et al. NumPy: A fundamental package for scientific computing with Python. *Nature*, 585(7825):357–362, 2020.

[14] John D. Hunter. matplotlib: Visualization with Python. *Journal of Open Source Software*, 3(86):1872, 2018.

[15] Denise B. Kandel. Homophily, selection, and socialization in adolescent friendships. *American Journal of Sociology*, 84(2):427–436, 1978.

[16] Thomas Kluyver et al. Jupyter notebooks – a publishing format for reproducible computational workflows. *ELPUB*, 87:87–90, 2018.

[17] Daria Knoch and Ernst Fehr. Resisting the power of temptations: The right prefrontal cortex and self-control. *Annals of the New York Academy of Sciences*, 1104(1):123–134, 2007.

[18] Lawrence Kohlberg and Richard H Hersh. Moral development: A review of the theory. *Theory into practice*, 16(2):53–59, 1977.

[19] Wes McKinney et al. *pandas Documentation*. pandas Development Team, Última versión consultada: 2021. https://pandas.pydata.org.

[20] Ryan C. Meldrum, Holly V. Miller, and Jamie L. Flexon. Susceptibility to peer influence, self-control, and delinquency. *Sociological Inquiry*, 83(1):106–129, 2013.

[21] Paul Ormerod and Bridget Rosewell. Validation and verification of agent-based models in the social sciences. In Flaminio Squazzoni, editor, *Epistemological Aspects of Computer Simulation in the Social Sciences*, pages 130–140, Berlin, Heidelberg, 2009. Springer Berlin Heidelberg.

[22] Pallets Projects. *Flask Documentation*. Pallets Projects, Última versión consultada: 2021. https://flask.palletsprojects.com.

[23] Rosemary Pepys, Robert Bowles, and Noémie Bouhana. A simulation model of the radicalisation process based on the ivee theoretical framework. *Journal of Artificial Societies and Social Simulation*, 23(3):12, 2020.

[24] Charles A. Russell Ph.D. and Bowman H. Miller Captain. Profile of a terrorist. *Terrorism*, 1(1):17–34, 1977.

[25] Python Software Foundation. Python documentation. https://docs.python.org, 2021.

[26] Gabrielle Rifkind and Scilla Elworthy. *Making Terrorism History*. Random House, 2011.

[27] R. J. Sampson. Neighbourhood and community: Collective efficacy and community safety. *New Economy*, 11:106–113, 2004.

[28] J. Fernando Sánchez-Rada. Design and Implementation of an Agent Architecture Based on Web Hooks. Master's thesis, ETSIT-UPM, 2012.

[29] Clifford Robe Shaw and Henry Donald McKay. Juvenile delinquency and urban areas., 1942.

[30] SoilSim Development Team. Soilsim documentation. https://soilsim.readthedocs.io, Última versión consultada: 2021.

[31] Laurence Steinberg and Kathryn C. Monahan. Age differences in resistance to peer influence. *Developmental Psychology*, 43:1531–1543, 2007.

[32] Unión Europea. Vida en la UE - Datos y cifras clave. Technical report, Unión Europea, 2023.

[33] Wikipedia. Terrorism. Wikipedia: The Free Encyclopedia, 2023.

[34] Per-Olof H. Wikström. Crime propensity, criminogenic exposure and crime involvement in early to mid adolescence. *Monatsschrift für Kriminologie und Strafrechtsreform*, 92(2-3):253–266, 2009.

[35] Per-Olof H. Wikström, Vania Ceccato, Beth Hardie, and Kyle Treiber. Activity fields and the dynamics of crime. *Journal of Quantitative Criminology*, 26(1):55–87, 2010.