Rui Pedro Matias Ferreira Baptista

Licenciatura em Ciências da Engenharia Electrotécnica e de Computadores

Agent-based simulation of consumer occupancy distribution in shopping centers

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Orientador: Doutor Rui Alexandre Nunes Neves da Silva

Júri:

Presidente: Doutora Anikó Katalin Horváth da Costa

Arguente: Doutor Bruno João Nogueira Guerreiro

Vogal: Doutor Rui Alexandre Nunes Neves da Silva

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Resumo

Quais são as áreas mais frequentadas dentro de um centro comercial? A resposta para esta pergunta pode-nos ajudar a encontrar os sítios óptimos para se colocar publicidade, definir o seu custo, e até ajudar a optimizar a localização das lojas. Esta dissertação estuda a aplicabilidade de técnicas de simulação à circulação de clientes dentro de um centro comercial. Para isso é construído um software que seja capaz de integrar as várias técnicas e apresentar os resultados no final das simulações. É usada a simulação baseada por agentes onde os consumidores serão emulados por entidades autónomas chamadas de agentes que possuem um conjunto de características e comportamentos que suportam as suas decisões. A navegação dos agentes dentro dos corredores e a procura do melhor caminho para circular é realizada pelo algoritmo A*. Para apresentar a distribuição de ocupação dos consumidores dentro do centro comercial são usados heat maps com uma escala de cores que vai do amarelo, significando zonas menos frequentadas, ao vermelho, significando as zonas mais frequentadas. Este software não só se provou capaz de encontrar as áreas mais frequentadas, como foi capaz de as encontrar para vários segmentos da população, o que nos permite saber qual a população alvo a publicidade deve ter nas diversas áreas do centro comercial.

Palavras-chave: *Simulação baseada por agentes, comportamento do consumidor, centro comercial, heat maps.*

Abstract

Where are the most frequented areas inside a shopping center? The answer to this question can help us find the optimal places to put advertisement, set its price, or even optimize the locations of the stores. This dissertation studies the applicability of simulation techniques to the clients' circulation inside a shopping center. For that a software capable of integrating the various techniques and showing the results of the simulations is built. We use the agent-based simulations where the consumers will be emulated by autonomous entities called agents who have a set of characteristics and behaviors that support their decisions. The navigation of the agents inside the shopping center and the search for the best path is done by the A* algorithm. To show the distribution of the occupancy of the consumers within the shopping center, heat maps are used with a color scale ranging from yellow, meaning less frequented areas, to red, meaning the most frequented areas. This software not only proved to be able to find the most frequented areas, but also find them for the various segments of the population, which allow us to know what segment of the population should the advertisement, of the different areas of the shopping center, target.

Keywords: *Agent-based simulation, consumer behavior, A* algorithm, shopping center, heat-maps*

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Introduction

In this chapter we will do a brief introduction to this project. We will talk about why this work is interesting and to whom it might interest in the section **Motivation.** In the section **Approach** we will talk about what will be our approach to this problem. Finally we have the section **Document Structure** where we do a preview of the chapters that are part of this dissertation.

1.1 Motivation

Shopping centers are a big part of our economic and social life. They offer a variety of shopping possibilities as well as various types of entertainment. In [1] the author states “shopping centers of the latest generation are currently under intensive development. These multifunctional, integrated premises are becoming not only a shopping destination, but also a place in which it is possible to satisfy other needs: social and cultural needs, the need for entertainment, recreation, sport or relaxation.” Shopping centers are always looking for ways to maximize the number of visitors they receive and the time they spend inside.

In [2] is stated that most of the shopping center consumers go with the intent of spending money, and that being able to influence consumers in a location where the intention is to spend money is every marketers dream. That influence can come through the advertisement put inside the shopping center.

But how do we know where are the best places to put the advertisement? The aim of this dissertation is answering that question by use of simulation to find the most frequented areas of the shopping center. The place where an advertisement can make the most impact is in an area that has great affluence of costumers. The more people see the advertisement, the more revenue it brings.

In this dissertation, we intend to build a software that is capable of showing the most frequented areas inside a shopping center in a simulated scenario so that we can draw conclusions about the optimal places to put the advertisement.

1.2 Approach

This problem requires that we can simulate entities that can emulate the behavior of consumers and observe and analyze the spaces they navigate through. To accomplish that we have three major fields that can address these requirements.

Agent-based modeling and simulation is perfect for the simulation of complex systems. With agent-based modeling and simulation we can create these entities called agents and give them rules and behaviors that try emulate the behaviors a real individual would have.

But how do we know what behaviors to emulate? That is where consumer behavior enters the scene. This field studies the factors that influence the consumers purchase decision-making. It’s the consumer behavior that will tell us what rules and behaviors should we provide our agents.

Lastly the spatial analysis appears as the technique that allows the agents to navigate through their surroundings and give us an analysis of the most frequented places.

Our approach will be to combine these three fields to create our application.

1.3 Document structure

This document is divided in six chapters:

1. **Introduction** – Where we give a brief introduction about the problem, objectives and approach of this project.
2. **State of the art** – Where we look into the main topics of this project and what has been done in the past in each of those topics.
3. **Methodology** – Here we will explain what were the main methodologies used in this work.

4. **Development** – In this chapter we will explain a little bit how the project is structured and give a little overview of the software.
5. **Simulations results and analysis** – Here we will show some simulations on different scenarios and the conclusions drawn from them.
6. **Conclusion** – Here we give the overall conclusion of the work and what can be improved in future works.

2

State of the art

In this chapter we will look at what has been done by the research community in the field of agent based simulation and consumer behavior inside commercial infrastructures. The section Bibliography will be divided between the two topics with a section for each one and a section were we will see works that have been done using the two topics. In the section beyond the state of the art we will see what are the objectives of this work and how does it connect to the topics seen in the state of the art.

2.1 Literature review

In this section we will talk about the individual themes that are the foundation of this project.

Agent-based modelling and simulation - A technique that is used in a variety of applications that need to model or simulate complex real-world problems. How, when, and why it is used are some of the questions answered in here.

Consumer behavior – What drives the consumers to buy? What factors are behind the behaviors consumers display? Consumer behavior is the field that tries to answer those questions studying the emotional, mental and behavioral responses that influence the decisions that the consumers make.

Agent-based social simulation – The combination of agent-based simulation and the social sciences. How agent-based simulation can be a helpful tool in the study and research of fields like consumer behavior.

Spatial analysis – A type of analysis that studies location and distribution of the spatial phenomena. Where are the locations of the stores? What is the best route to the store(s)? Where is the most frequented area of the shopping center? Spatial analysis will answer these questions.

2.1.1 Agent-based modelling and simulation

Agent-based modelling and simulation (ABMS) is a computational technique used to model and simulate complex real-world systems comprised by autonomous entities called agents. Each agent has a set of characteristics and rules that they follow giving them the ability to make decisions and interact with each other and the environment that surrounds them. ABMS can be described as a set of microscopic simulations all interacting with each other.

Where has ABMS been seen?

ABMS gained its popularity in the last two decades and has been used in a broad spectrum of areas, such as anthropology [3], crime analysis [4], energy analysis [5], epidemiology [6], social behavior and consumer market [7], urban development and land use [8].

These are just a few examples of the wide use that ABMS has seen in the past years. This speaks of the importance modellers are giving ABMS when choosing what technique to use to model their systems. But why is that?

Why use ABMS

One of the most important factors is the easy to implement approach. With an ever increasing complexity of the systems we want to model the conventional model techniques start to get too complex and the difficulty of the implementation rises. That is where ABMS enters. This technique allows us to relax some of the complexities with its capacity to focus on micro-simulations that give macro-level results. In its simplest level, agent-based modelling and simulation is nothing more than several individual agent simulations that together, through their interactions, decisions, and behaviors, create a model that emulates the dynamics of a complex real-world system.

Also the advances on computational power and data gathering allows us to create larger and more accurate micro-simulations that were impossible a few years back.

But what exactly is an agent?

There has been much discussion around what can be described as an “agent”. Different authors have different opinions of what should be considered an “agent”. There are three key properties that according to [9] are sufficient to describe an agent:

- *Individuality* - An agent is an *autonomous* and *self-centred* unit functioning independently of its environment and other agents.
- *Interactivity -* An agent needs to be *social and interactive* with other agents and with the environment that surrounds it.
- *Identity -* An agent needs to be *modular* and *self-contained, an identifiable individual with* a set of characteristics, rules and behaviors that defines its actions and decisions.

Additionally they can have the ability to learn and adapt from its experiences. For this it would be necessary for an agent to have memory and, if we really want to step it up, have some type of artificial intelligence to enhance the learning capability, as can be seen in [10].

When to use ABMS?

As seen above ABMS can be very useful in a variety of different areas, especially human social dynamics and behaviors, which is the focus of this project. In [11] Axtell says that there exist three different uses of agent modelling techniques. The first is when models can be formulated and completely solved, in which the agent model is merely a tool for presenting results. The second is when it is not possible to completely solve a mathematical model completely, therefore the agents are complementary to the mathematical theorizing. The third is when writing down equations is not a useful activity for the problems we want to solve.

In conclusion ABMS is useful when:

- The agents need to be individuals potentially different from one another.
- The agents need to exhibit behaviors and decision making capabilities that reflect how real-world individuals would behave.
- There is a need of agents’ interaction and formation of complex relationships dynamics.
- There is a need of agents interacting with their environment.
- There is a spatial component and the agents’ position isn’t fixed.

- There is a learning component and the agents can learn and adapt according to its experiences.

With this in mind, we can now try to create the properties of our agents that best emulate the consumer behavior, topic that we will visit in the next section.

2.1.1 Consumer behavior

Consumer behavior is the field that studies all the aspects of the consumption process, involving how emotional, behavioral and mental responses of the consumers influence their decisions in the selection, consumption, and purchase of products and services. This is a field of interest for the marketers because with it they can understand what is behind consumers' buying behavior. However, it is a very complex field and research has shown that it is hard to predict [12].

The importance of consumer behavior.

Companies are always trying to maximize the sales of their current products, or the success of a brand new product. Therefore they need to understand their customers. That is why researchers turned to the study of consumer behavior. Understanding how a consumer behaves and what influences their choices is what differentiates success from failure.

Consumer behavior is not a static phenomenon, it is constantly changing, due to the changes in a variety of areas, such as technology, life style, fashion, and trends. There are other factors that also can influence the behavior of a consumer that is why it's important to understand them.

What are the factors that influence the consumer behavior?

In [12] the factors are divided in four main groups:

- Personal factors
- Psychological factors
- Social factors
- Cultural factors

All of these main groups play a part in the consumer behaviour, and in [13] a study was made to know how the different factors affected the consumer behavior and decision making in the choosing of a coffee brand.

Personal factors

The personal factors that differ from consumer to consumer can influence their behavior. In [14] the study confirms that three personal factors affect the consumer buying decision, they are:

- *Age* – This is a major factor when it comes to influencing the behavior of the consumers. The choices and behaviors of the youth are different from those of an adult or a senior consumer. As seen in a study that was made to see the influence of age on the choice of activities in a tourist destination [15].
- *Economic power* – This has a great influence in the consumer behaviour. A consumer with a high economic power has a broader range of products it can buy, and usually spends more in their products. While the choices of products of a consumer with a medium to low income will tend more to the basic needs, and will try to buy affordable products.
- *Gender* – Studies show that gender is another factor that influences consumers in their buying decisions. Males and females generally have different personal preferences that reflects in their purchases.

Psychological factors

The psychological factors are harder to measure, but they play an important role when it comes to the consumers and their decisions. There are four important factors:

- *Perception* – This is the consumers' ability to collect and process information about a product, and form an opinion about it. Hence it is a major influence on the consumer behavior. This perception is formed through advertisement, customer review, social media, etc.
- *Motivation* – Every person has a many different needs that it want satisfied. Be it social, be it biological, be it psychological. Some needs are more pressing than others and so, those, have the power to motivate the consumer to buy products and services.
- *Learning* – This is a factor that influences through experience. The knowledge that a consumer will get from its past purchases helps them to

have better responses about what products and services best satisfies them.

- *Attitudes and Beliefs* – Every consumer has a set of attitudes and beliefs that influence their purchase behavior. These attitudes and beliefs make up brand image that will influence consumers towards it, or against it.

Social factors

Consumers are influenced by those around them, and naturally that reflects on their buying behavior. There are three factors to take in account:

- *Family* – A consumer is heavily influenced by their family members. For example a married person would be more interested in buying products that secures the safety of its family, while a single person is more inclined to spend on itself.
- *Reference groups* – These are the groups of people that the consumers associates themselves with, and that influence their behavior. Normally the reference groups have similar buying behavior.
- *Roles and status* – Every consumer is influenced by the roles and status it holds in society. For example the buying behavior of with high a position, therefore high status, in society will be significantly different from one with low status.

Cultural factors

Consumers come from different cultures and communities and their behavior is deeply influenced by it. The three factors are:

- *Culture* – Culture plays an important part in the consumers' wants, needs, basic values and behaviors.
- *Subculture* – Within cultures are formed various subcultures that share the same beliefs and values. These groups can be of different nationalities, race, religion, etc.
- *Social class* – Every society has some form of social class. The social class of a consumer is not only defined by income, but by occupation,

background and education. Consumers in the same social class have similar buying behavior.

Next we will see how using ABMS will aid us to create models that simulate how consumers behave and the possible decisions they make.

2.1.2 Agent-base social simulation

Agent-based social simulation (ABSS) is the area that connects the social sciences with the agent-based modelling and simulation. By social sciences we mean all of the sciences that study human beings and their societies. The European Science Foundation [16] give us a good definition – "*The social sciences examine and explain human beings on different levels, from neural foundations to individual behavior, group processes and the functioning of entire societies.*"

Consumer behaviour is one of the many different areas that are encompassed in the social sciences. With the knowledge we extract from it we can create agents with rules and behaviours that are a better approximation to how real individuals will behave in those situations.

This strategy is used in various works where the focus is to study different consumer behaviors. In [17] the author uses the knowledge of consumer behavior in a motivation function, and uses a multi-agent system to exhibit the emergent decoy effect. In [7] the author uses those exact same concepts applied in a Chinese wine market to study the consumers' purchase behavior for wine consumption.

In [18] and [19] the authors study the consumers and their choices using an agent-based approach and introducing a new spatial component that we will talk in the next section.

2.1.4 Spatial analysis

Spatial analysis is a technique all of us are used to, whether we are aware of it or not. The ability to understand and navigate through our surroundings is an ability we gain in our young ages. In [20] we can find a good definition – "*Spatial analysis is how we understand our world, mapping where things are, how they relate, what it all means, and what actions to take.*"

Spatial analysis is something we are constantly doing. When we want to go from home to work we understand where we are, we know the best route to take, and we know how to adapt to different obstacles in our path. Even when we navigate through a room we use spatial analysis to form the optimum path from point A to B avoiding obstacles.

This type of analysis is done by our brain on a daily basis. But with the technological advances we can now reach other levels in terms of spatial analysis. Not only can we answer some complex spatial problems, but also we have technologies help and upgrade the analysis our brains do, such as the global positioning system (GPS) that finds the best, and quickest, route from home to the beach, for example.

There are six categories in spatial analysis, as described in [20]:

- Understanding where
- Measuring size, shape, and distribution
- Determining how places are related
- Finding the best locations and paths
- Detecting and quantifying patterns
- Making predictions

Spatial analysis is also an important component to add to the agent-based approach. We can see various examples of ABMS used in spatial analysis in areas like urban land use and transportation [21], land-use and land-cover change [22], and geographic retailing [23], [24], and consumer mobility [25].

In consumer spatial behavior we have [18] that analyses the potential consumer choices of shopping locations on a regional level. They apply this to two different sectors, clothing and grocery, that are located in two different regions. They sort their stores by distance from workplace or home for each agent, and rate the stores using the distance sorting as a spatial attribute.

A* pathfinding algorithm

*A** is a pathfinding algorithm that searches for a path with the lowest traversal cost. This algorithm works on a collection of nodes that are connected between them. Each node is connected up to eight other nodes, each one with a value **F**. *A** searches through all of the nodes and selects the one with the lowest **F**. It does this repeatedly until it finds the path with the lowest cost. The value of **F** is calculated through the following formula [26], [25]:

$$F = G + H$$

Where **F** is the estimate final traversal cost the current node to the goal, **G** is the traversal cost from one node to another, and **H** is the estimated remaining distance from the current node to the goal. The guarantee of the shortest path will only be successful if the remaining distance **H** is an underestimate.

The *A** pathfinding algorithm will be more thoroughly explained in the next chapter.

2.2 Beyond the state of the art

In this project our aim is to simulate the clients' circulation inside a shopping center to discover the most frequented areas, or "hotspots". To reach that objective we will use all of the techniques talked in the previous sections.

ABMS will be the heart of the simulation. With it we will create our agents, called clients, and give them a set of personal characteristics that define them, a set of needs they need satisfied, and a set of rules that they follow. The clients will interact with an environment comprised of stores that also have a set of characteristics that make them different from one another.

The personal characteristics of the agents are some of the factors that influence consumer behavior. The ones covered in this project are, age, gender, and economic power (personal factors), advertisement influence and quality sensitivity (psychological factors). Also each of the agents has a set of needs, or desires, they want to satisfy in their trip to the mall, and those come from a motivation factor.

The age, gender, and economic power factors are generated through a binomial distribution probability mass function. The quality sensitivity factor is generated given the first three factors. The advertisement influence is generated randomly.

The agent will then look for the store that will best satisfy each of its needs. To move to the stores the agents will need to analyze their surroundings and find the best path to their goals. They will need to have some type of spatial behavior to accomplish that.

*A** is a pathfinding algorithm that searches for the shortest path between point A and B. This algorithm will be responsible for the selection of the best route that the agents have to take to the desired store.

Finally when the simulation is over we want to analyze all of the zones that the agents passed and create a heat map showing exactly what the “hotspots” are, the zones with bigger affluence.

In the next chapter we will talk about the main methodologies that helped us complete these objectives.

3

Methodology

In this chapter we will talk about the main methodologies used in the completion of the project.

We can single out five main methods:

- **Agent based simulation** is responsible for all the agents, their characteristics, behaviours, and interactions with the environment.
- ***Match*** will evaluate the compatibility between clients and stores.
- **Client Path** defines which stores are going to be visited by the clients.
- ***A**** **pathfinding algorithm** selects the best route to the desired store.
- **Heat maps** show the most frequented areas by the clients of the shopping center.

3.1 Agent-based simulation

The agent based simulation is the principal method of this project. This is the method that creates and manages all of our agents and their interactions with the environment.

The simulation is therefore divided in two parts:

- The agents - *Clients*
- The environment - *Stores* and areas of circulation

The clients are the agents that represent the clients of the mall, as the name suggests. The stores are a block of space that represents the stores of the mall.

All of the space that is not a store is a circulation area. Both clients and stores will have a set of parameters that describe them.

This simulation is all about the interactions between clients and the environment around them. They will circulate in the circulation areas towards the desired stores, and their movement will be stored and showed in the end of the simulation.

3.1.1 Clients

The first type of agents that we will cover are the clients. Each client is an individual agent with its own set of parameters and methods. The clients have six personal characteristics:

- Age – The age represents the age group of the agent. The decision to divide this parameter in groups instead of the real age of the agent was merely for simplicity sake. The groups are: *young, adult,* and *senior.*
- Gender – The gender represents the gender of the agent. The genders are: *male,* and *female.*
- Economic power – This represents the economic power of the agent, on other words its buying capacity. This parameter only affects the type of stores the agent visits and not the number of stores it can visit. The three groups of this parameter are: *low, medium,* and *high*.
- Quality sensitivity – This represents how much importance the client gives to the brands and products it buys. As for the economic power the quality sensitivity is also divided in *low, medium* and *high* groups.
- Advertisement influence – The susceptibility of the client to the advertisement of the brands. This parameter is also divided in the *low, medium* and *high* groups.
- Velocity – The pace of the client inside of the mall. This is directly tied to the age group.
- Desires – This is the intentions of the clients. What they want to satisfy in their trip to the mall.

When creating the clients' population the user defines various probabilities regarding the age, gender and economic power of the clients. These probabilities don’t define the population, rather the individual client. For example for a population of n clients with a 38% probability of being young means that every client, when it’s created has a 38% chance of being young.

The advertisement influence personal characteristic is randomly generated because we didn’t find any correlation between this characteristic and the age, gender and economic power characteristics.

The desires are also randomly generated because, again, we didn’t find any correlation between this characteristic and the age, gender and economic power characteristics. Each client has between 1 and 5 desires to satisfy in their trip to the mall.

The quality sensitivity personal characteristic is defined through the age and economic power of the agent. Figure 3.1, where we based ourselves to do our formula.

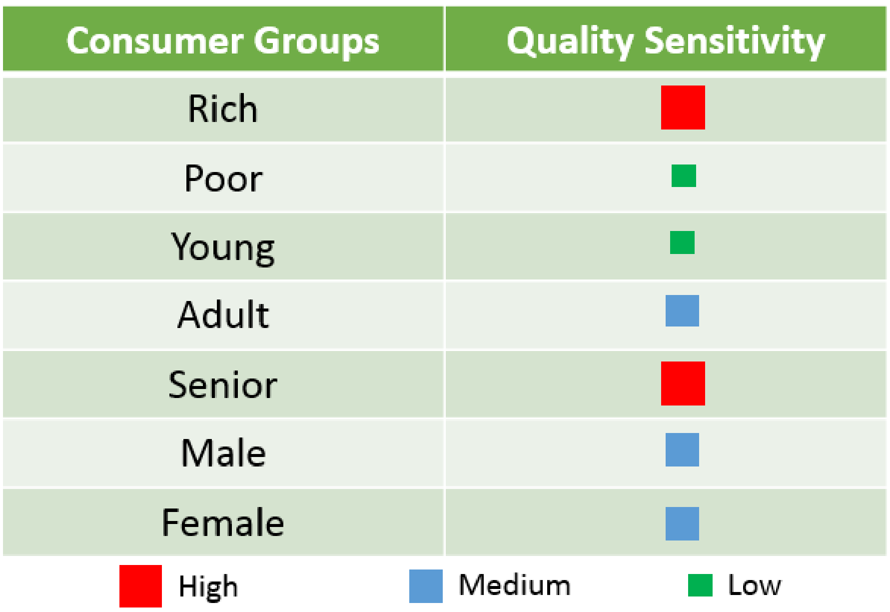


Figure 3.1 Shopping preferences taken from [18]

We assigned a value of 0 to the Low value, 1 for the Medium value, and 2 to the High value. Then we use the following equation:

$$qualitySum = \frac{qualityAge + qualityEP}{2}$$

This $qualitySum$ returns 0.0; 0.5; 1.0; 1.5; and 2.0 as possible values. With these values we use the following table to choose the quality sensitivity of our client:

$qualitySum$	Quality
0.0	*Low*
0.5	*Low*
1.0	*Medium*
1.5	*High*
2.0	*High*

Although *Medium* appears just one time, with all the possible combinations that give those results each of the Quality possibilities has 3 combinations that would select them.

As we can see in the Figure 3.1 the gender is unimportant to the quality sensitivity, given that both of them have medium sensitivity to it, and therefore don't influence the calculations.

The last field shown in the panel is the *Plant disposition* field. This field does not concern the client creation but the way the layout of the stores it will be displayed. In the next section we will cover that.

3.1.2 Stores

Stores are one of the major parts of the environment that the clients can interact with. They have their own parameters and characteristics that define them. We differ between store characteristics and parameters. The characteristics describe the store, in other words what differentiates them from the other stores, and are important in a visual way. The characteristics include:

- Entrance position – The position from where the clients can access the store. There are four option *North, East, South, West.*
- Type – The type of store, if it is a restaurant, a clothing store, a technology store, etc.
- Brand – The brand of the store.

The parameters are the stores' characteristics on which the clients will act upon. These parameters not only describe the store but also describe the demographic that it's a more common client of that store. Unlike the characteristics the parameters are important in the interaction with the clients, and which client visit which store. This is done through a method called *Match* that we will cover in the next section.

The parameters are:

- Target age
- Target gender
- Price
- Quality
- Advertisement

All of the parameters and characteristics of a store are defined when the store is created. The stores are created individually through a panel shown in Figure 3.2.

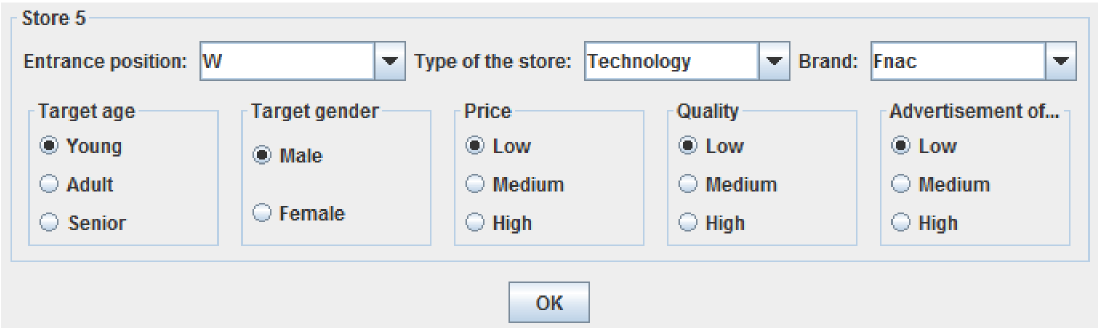


Figure 3.2 Store edit panel

This figure shows the fields that the user can adjust in a stores creation. After that the user presses the OK button and a store is created with the set of parameters and characteristics that the user selected.

These parameters will be a key factor to be used in the next method to be covered, the *Match* method. This method will take the stores parameters and compares them with the clients' personal characteristics.

3.2 Match

Match is the method developed by us to evaluate the compatibility between *Clients* and *Stores*. To do this, the *Match* method takes the clients personal characteristics and compares them with the stores parameters. The result values vary between 0 and 1, with 1 being a perfect match and 0 being no match.

Different type of stores satisfy different clients' desires. The type of store that the client needs to visit is chosen accordingly to the desire it needs to satisfy. Then the client will call the *Match* method to decide between stores of the same type, choosing the one with the highest match value, the one that best suits to the client's personal characteristics.

The *Match* method uses the *Jaccard Index* to compare the two sets of characteristics of the *Clients* and *Stores*.

3.2.1 Jaccard Index

The *Jaccard Index*, also known as Jaccard Similarity coefficient, is a similarity measurement that compares two finite sample sets A and B by dividing the size of the intersection by the size of the union of the two sets.

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|}$$

Where $|A|$ and $|B|$ are the cardinalities of the sets A and B, respectively, or in other words the complete sets.

3.3 ClientPath

We developed the method *ClientPath* that defines which stores are going to be visited by the clients. Using the *Match* method and the desires characteristic of the clients the *ClientPath* method builds a list of the stores that best satisfy the clients' desires, according to the client's personal characteristics.

This method takes the client's desires list and searches all of the stores of the type that satisfies said desire. To decide between the stores of the same type the *ClientPath* method uses the match method to see which store is the best choice for that client. When that store is found it's stored in a path list, and removed from the list of stores to take in account in the future. The match corresponding to that store is also removed. Next the method moves to the next desire in the list and repeats the same process. When all of the desires are satisfied, the exit is added to the path list. This process is illustrated in Figure 3.3.

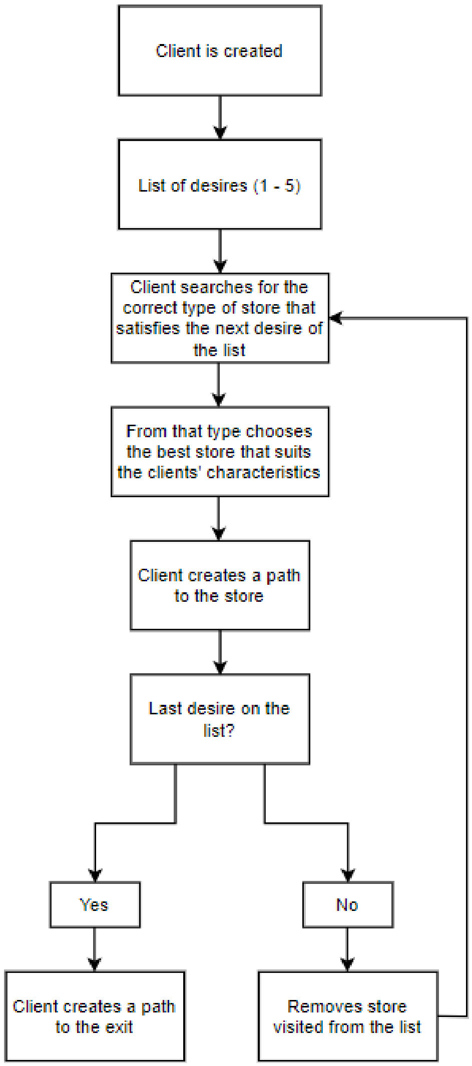


Figure 3.3 Path creation diagram

After the list of the stores to visit by the clients is completed, we need a way to build a path to and between them. For this we were aided by the *A** pathfinding algorithm, explained in the next section.

3.4 A* pathfinding algorithm

*A** is the algorithm responsible for the path selection of the clients, iteratively searching for the shortest path from a given initial node to a given goal node.

Usually the *A** algorithm searches through all possible paths, then back-tracks to the initial goal, choosing the nodes that will build the shortest path. We decided not to do that. The human brain is different from a computer and cannot always build the shortest path. For that reason we decided to build our path through step decisions, letting our client at each node decide what the best node to move to next is.

3.4.1 Path searching

The first thing to consider is the search area. Considering our search area, shown in Figure 3.4, we divided it into a set of nodes connected to each other, as shown in Figure 3.5.

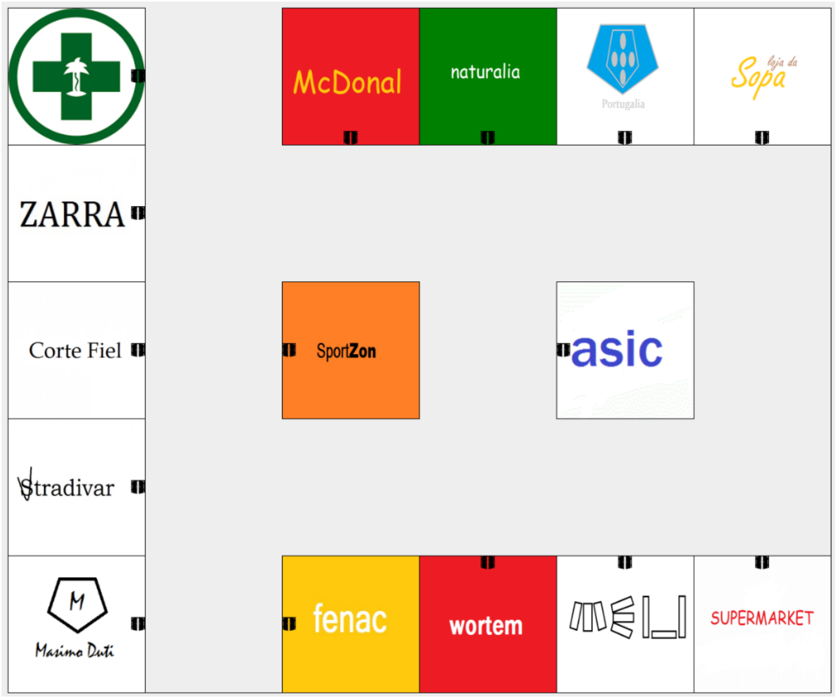


Figure 3.4 Search area

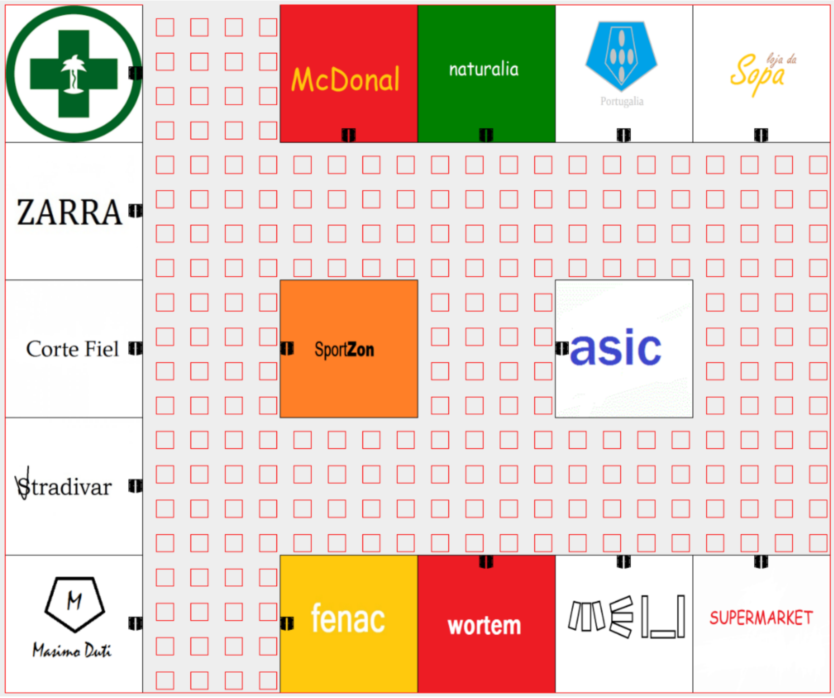


Figure 3.5 Search area with the navigation nodes

After we have our set of nodes we select one initial node, and one goal node, Figure 3.6. The initial node represents the initial position of the agent when starting to build a new path. The goal node is the nearest node to the store that the agent wants to visit.

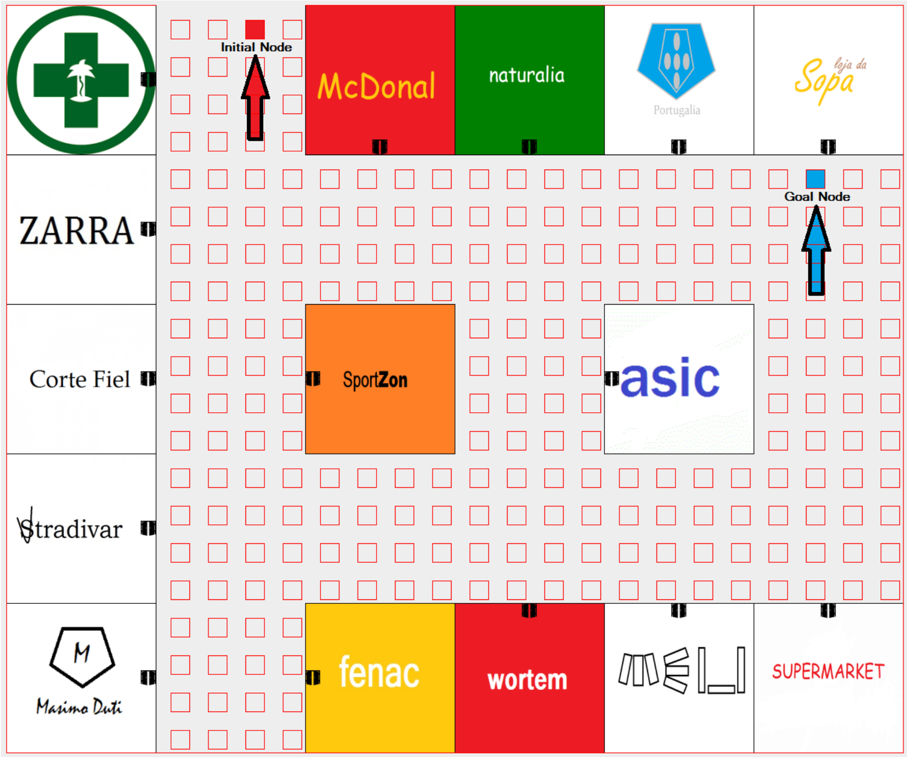


Figure 3.6 Initial node and goal node

Now that we have our two nodes, initial and goal, we start our search for the path. We do this search by completing a few steps:

1. Add the current position node to a route list.
2. Add all of the adjacent nodes, to the current node, to an open list. This open list is a list of all of the possible options that our agent has to move.
3. Give an F value to all of the nodes in the open list, and store those values in a score list.
4. Next we search on the score list for the node with the lowest F value and change the current position to that node.
5. Finally we clear the open list.

We repeat this process until the current position node is the same as the goal node. At that point the agent moves into the store. When it comes out it builds a new path, being the initial node the node nearest to the store. Figure 3.7.

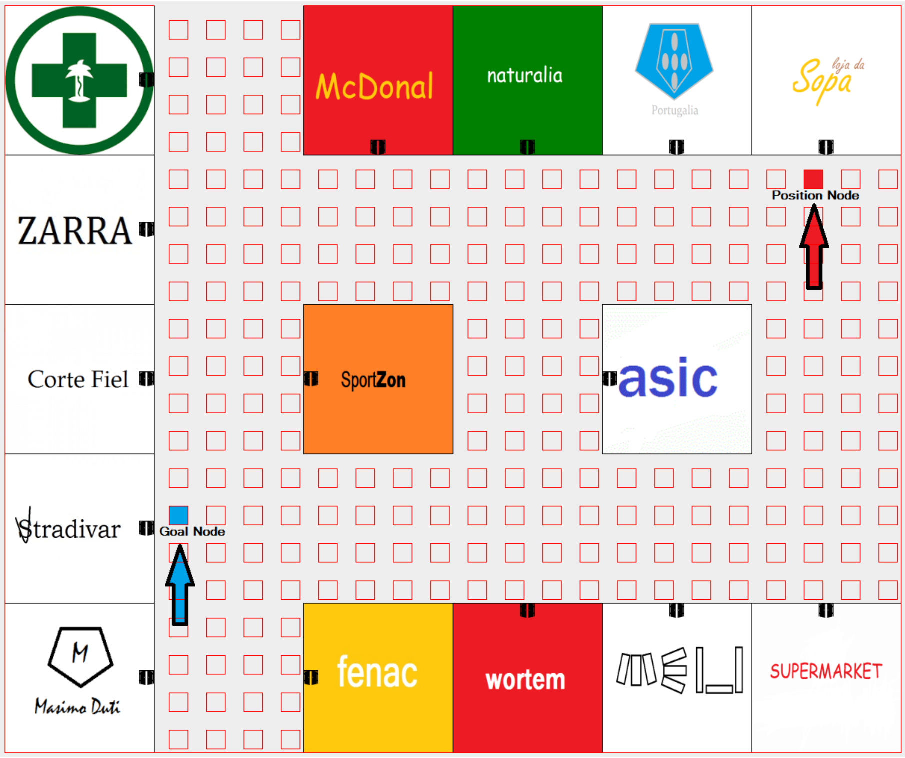


Figure 3.7 Current position node and new goal node

When the agent reaches the last store it wants to visit, the agent build a path to the exit door.

3.4.2 Node value

At each step the *A** algorithm will choose the node with the lowest value **F.** This value is the sum of other two parameters, **G** and **H**: [26], [27]

$$F = G + H$$

- F is the value by which a node will be considered. The node with the lowest F value is the node that will be chosen to build the agent path.
- G is the movement cost. The cost that it takes the agent to move from the current position node to one of its adjacent nodes. In this project we will use a value of 1 for every horizontal or vertical move, and $\sqrt{2}$ for every diagonal move. We use these values because the cost of a diagonal move is the $\sqrt{2}$ times the cost of a vertical or horizontal move.
- H is the estimated remaining distance from the current position node to the final destination, or the goal node. This is called a *heuristic* because it is a guess, the real distance will only be known when the path is found.

3.4.3 Heuristics

The *heuristics* are a very important part of the *A** algorithm. They are an estimate of the remaining distance from the current position node to the goal node. There are many different *heuristics* that can be used. For this project we decided to use the Euclidean distance. The Euclidean distance, in simple words, is the straight line between two points, shown in Figure 3.8. [27]

$$H = \sqrt{(x_{position} - x_{goal})^2 + (y_{position} - y_{goal})^2}$$

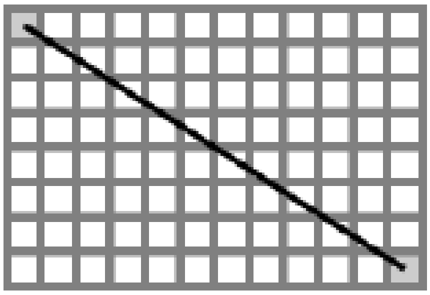


Figure 3.8 Euclidean distance

Where $(x_{position}, y_{position})$ and (x_{goal}, y_{goal}) are the coordinates of the current position node and the goal node respectively.

Given that the shortest distance between two points is always a straight line, this *heuristic* will always underestimate the remaining distance between the current position node and the goal node.

3.5 Heat Map

Heat maps are a tool for data visualization that use color to indicate values of magnitude. We will use heat maps to analyze the most frequented zones of the mall, the “hotspots”.

To show a heat map first we need to know all the points the clients passed through. To know that we store all the nodes that were in the clients’ routes. We also store an integer representing the number of times each node was stepped by the clients. This includes the multiple times a client can step on the same node in their simulation. For example if a client steps three times in the same node we increment the integer three times.

After storing all the nodes for all the agents we use a simple equation to know what the percentage of occupancy of every node is:

$$Occupancy = \frac{Number\ of\ times\ a\ node\ was\ stepped}{Total\ number\ of\ agents} \times 100$$

We divide by the total number of agents because we assume that represents the 100% occupancy.

This equation will give us the percentage of affluence every used node has. Than the $Colour$ value will be used to set the colour of the node, following the color scheme shown in the Figure 3.9.

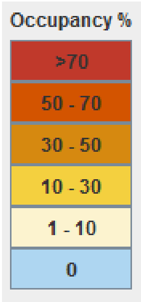


Figure 3.9 Colour scheme of the heat map

Finally we will paint the nodes with its $Occupancy$ value.

4

Development

This chapter will do a description of the software and its functionalities.

First we will talk about its **Architecture.** Then we will do an **Application overview** explaining how it works. Finally we will show the **Class diagram** of this project.

4.1Architecture

In this section we will talk about the architecture of the application. We used the Model-View-Controller design pattern to organize our code. In the next subsections we will talk about what it is and what is the purpose of each component.

4.1.1 Model-View-Contreller

Model-View-Controller (MVC) is an architectural pattern that organizes the code in three distinct components: the **model**, the **view**, the **controller**. The idea behind it is to distinguish between the different aspects of development of an application and organize them in their individual boxes.

The **model** is responsible for the data manipulation and the logic of the application. It's the core of the application, what happens behind the scenes, hidden from the user.

The **view** is the visual representation and user interaction of the applications. Everything related to user interface, what is displayed to the user visually, and user input is handled by the view.

The **controller** is the bridge between the model and the view. It takes requests form the view and asks the model for the correct data. The model then answers with the requested data and the controller updates the view.

Figure 4.1 illustrates the basic interactions of the components of the MVC.

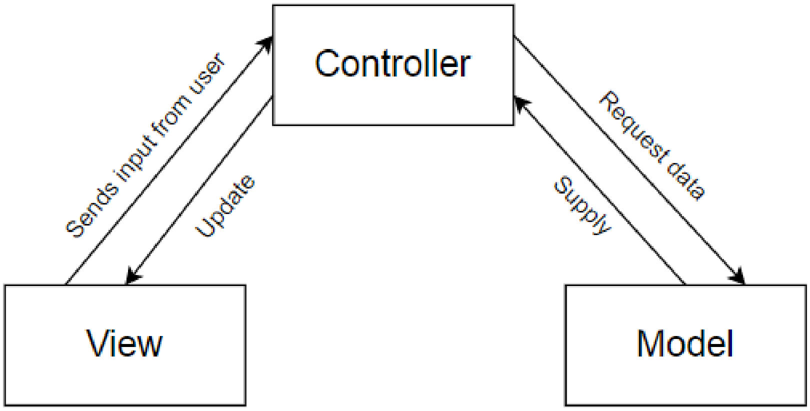


Figure 4.1 MVC simple diagram of interactions between components

Model

The *Model* in this project is responsible for creating, storing and managing all the data related to the agents and environment. Its purpose is to receive requests from the controller and produce the desired answers for those requests. All the logic of the application it's also defined by the model. For example what stores an agent needs to visit, and what path to take to each store. For this to happen the model has several classes, the main ones being: the **Database**; the **Client**; the **Store**; the **ClientPath**; the **AStar**; and the **Match**.

The **Database** is the core of the model. We can call it the controller of the model. It's the only class that receives requests from the *Controller* and it's the one that responds to them. It is the class that knows what methods of what classes to call to correctly address a request. For example if the *Controller* requests the *Database* to set the client path, in other words what stores it needs to visit, it is the *Database*'s task to communicate that request with the *ClientPath*, call the appropriate method to do it and tells the *Client* to set the path.

The **Client** is the class that is responsible for all of the data and methods of the agents. Each *Client* object is one distinct agent, with its own attributes and methods. All of those attributes are related to the personal characteristics of the agents. This class has some methods, such as the getDesires method, and the getRoute method. The list of the several *Clients* created is stored in the *Database*.

The **Store** is a class very similar to the *Clients* class but related to the stores. This class has all of the data of the attributes of the stores and all of the getters and setters that allow to get and set each of those attributes.

The **ClientPath** is the class that sets up what are the stores the client needs to visit. It does that by analyzing the desires of the client and finding the best stores that satisfy those desires for that specific client.

The **AStar** is the class responsible for the *A** pathfinding algorithm. It's in this class that the clients build their paths form one store to another. This class is called by the *Client*'s class when it needs a route build.

The **Match** class does the match between the clients and stores. Uses the *Jaccard Index* to compare the two sets of data corresponding to the personal characteristics of the clients and the characteristics of the stores.

This is all done hidden from the user. The part that is shown and interacted with by the user is the **View**, which we will see next.

View

The *View* is the visual component of the application. What the user can see and interacted with, in other words the graphical user interface (GUI), is handled by the view. To build our GUI we chose to use the Java Swing framework. With a large set of components the Java Swing allows us to customize our windows and provide them with a myriad of functionalities.

We have three components that are essential for this project:

- **JFrame** - A *JFrame* class can be defined as a base container where we can put all of the components we need. It is what provides a window on the screen, all of the other graphical components only show on screen if they are in a *JFrame*.
- **JPanel** – A *JPanel* class is another type of container. Their main purpose is to organize the components with different layouts that can be applied. A *JPanel* can contain the majority of the graphical components, including other *JPanels*. Although they are a container, much like the *JFrame* class, they can only be shown on screen if they are contained within a *JFrame*, being only *JFrames* can provide windows.

- **JLabel** – A *JLabel* class that is used to display text or image icons. *JLabels* are inactive and the user cannot interact with them.

All of the main classes represent one of those three classes:

The **MainFrame** is the heart of the view, a *JFrame* class. As the name implies it's the main *JFrame* of the application. This class holds and manages three *JPanels*, the **MainPanel**, the **SimulationPanel,** and the **HeatMapPanel**, deciding which to show and what information it passes to each one. This is also the class that is in communication with the *Controller*. It receives requests and data from the two *JPanels* that it communicates to the *Controller* and sends the responses to the respective *JPanel*.

The **MainPanel** is the first *JPanel* that appears to the user. In this panel the user creates the population of clients, by defining the number of clients to be simulated and their demography, and selects the mall plant they want for their simulation. Figure 4.2 shows the graphic visualization of the *MainPanel*.

The **SimulationPanel** is the panel where the simulation takes place. It's here that the labels representing clients will roam through the space and interact with the labels representing the stores. Figure 4.3 shows the *SimulationPanel*.

The **HeatMapPanel** is the panel responsible of showing the heat map. Its layout is the same as the **SimulationPanel** but paint's a heat map on top of it.

The **ClientIcon** is a label representing the clients. This class attributes an icon, a red dot, to each client, and manages the location and movement of that icon.

The **StoreSettings** is the panel where the user sets the attributes of the stores. This panel is nested within a second *JFrame* called **EditFrame**.

The **Controller** is what connects everything. We will see how it does that in the next sub-section.

Controller

The *Controller* is like a bridge that connects the *View* and the *Model*, through two of their classes, the *MainFrame* and the *Database*, respectively. The *Controller* only has one class, with the same name. This class receives requests and data from the *MainFrame* when some event occurs in one of its panels. Then the *Controller* delivers that request and that to the *Database* to work with.

One example is in the clients' creation. The *MainFrame* sends the request for the creation of the clients' population, with it goes all the necessary for the creation that was defined by the user. The *Controller* takes that request and data and calls the appropriate methods of the *Database* to create the clients with the information provided. When the *MainFrame* wants the list of clients created it requests the *Controller* for it. The *Controller* then asks the *Database* for the list and passes it on to the *MainFrame*.

In the next section we will have a better look and explanation of how this application works.

4.2 Application overview

Our application starts with the *MainPanel*. In this panel we have four main components, highlighted in Figure 4.2.

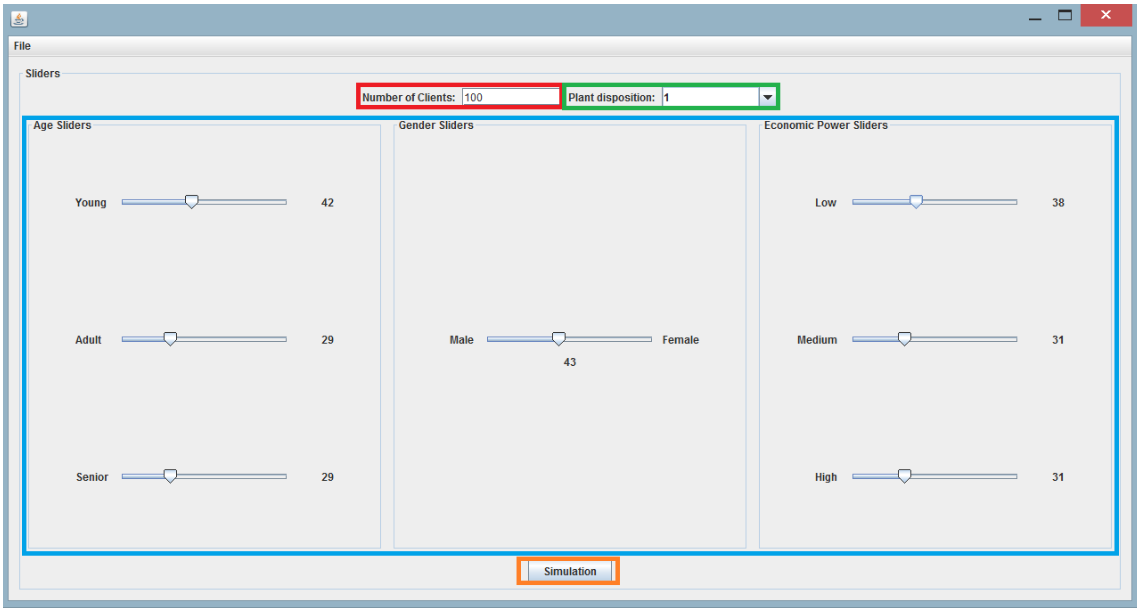


Figure 4.2 Main Panel

In red we have a *JTextField* where the user can put the number of clients they desire to simulate. The text saying "Number of Clients" is a *JLabel*. In green a *JComboBox* with the *JLabel* "Plant disposition" where the user selects the layout of the mall. In blue are all the *JSliders* related with demographics of the clients, all of them identified by *JLabels*. In orange is the *JButton* that the user presses when it's satisfied with the parameters. This button will lead us to the next panel, the *SimulationPanel*, shown in Figure 4.3.

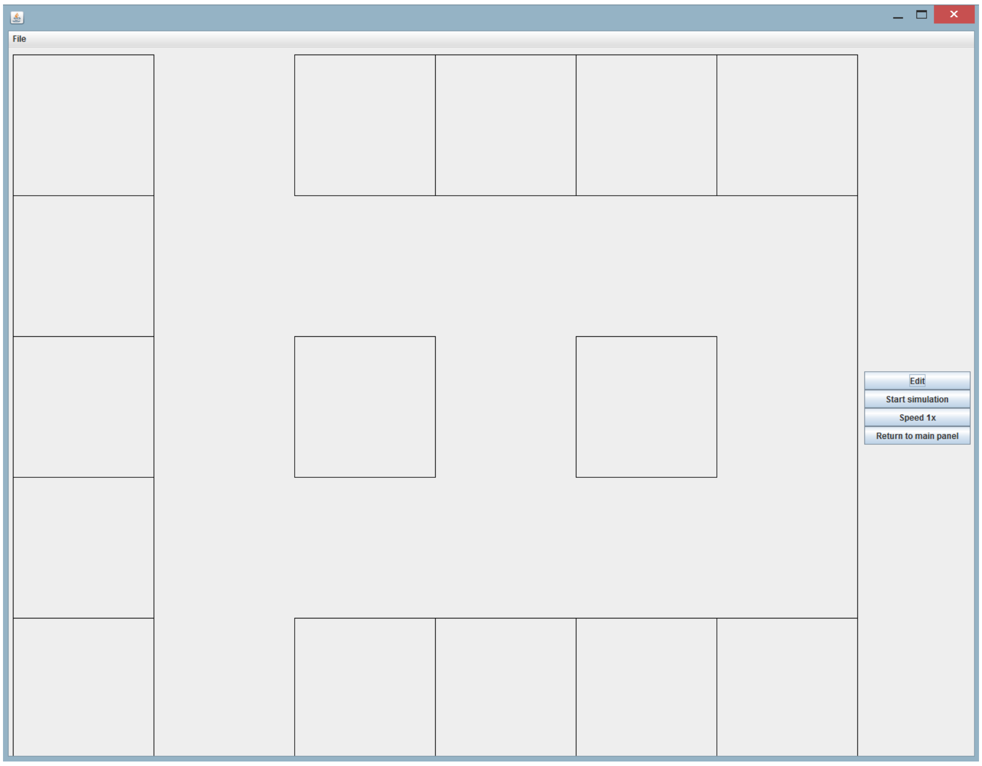


Figure 4.3 SimulationPanel

In the right section of the *SimulationPanel* we have four buttons. In the left we have the mall layout. Each square represents a possible space for a store.

The first thing we want to do is press the **Edit** button. When the user presses it several buttons appear in the center of each store space. Illustrated in Figure 4.4.

Each of those buttons will open a separate frame, the **EditFrame**, as can be seen in Figure 4.5. This is where we can edit our stores, or create new ones, selecting the location of the entrance, the type of store, the brand of the store, and the demographics that the store attracts. After all of that is set to the user preferences they can press the ok button and the store will appear in the store space with the settings that the user chose. Figure 4.6.

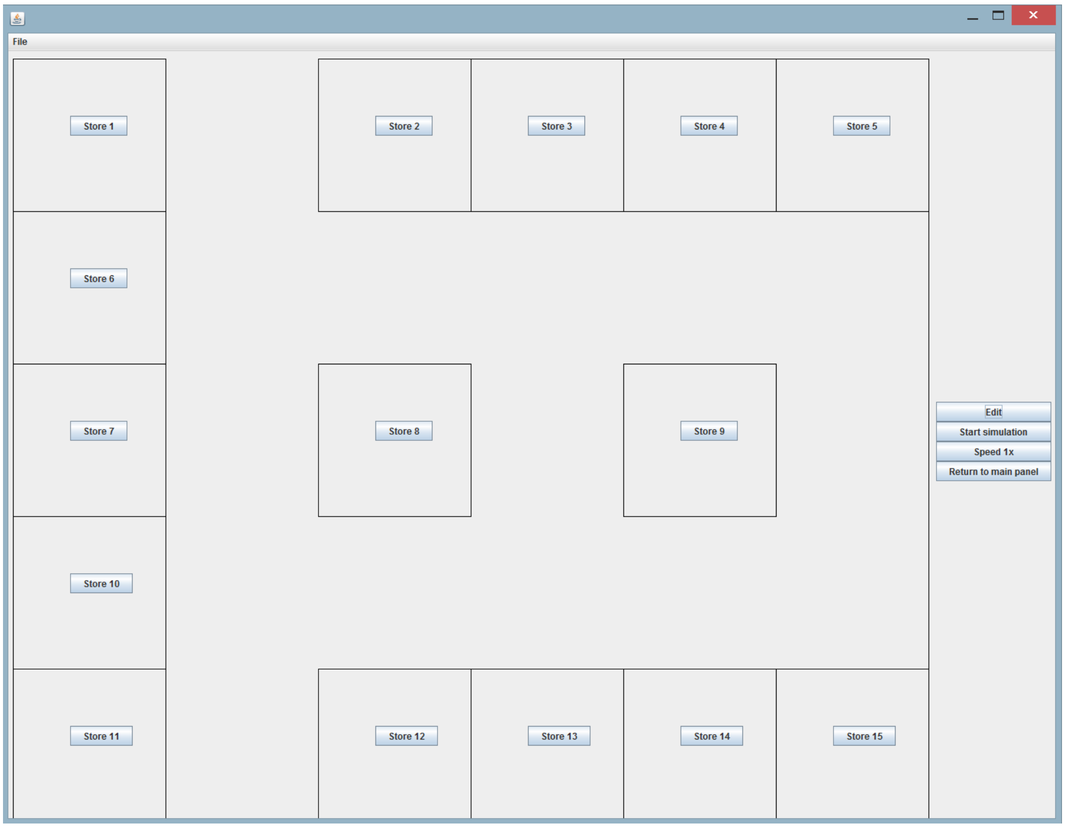


Figure 4.4 Edit buttons on SimulationPanel

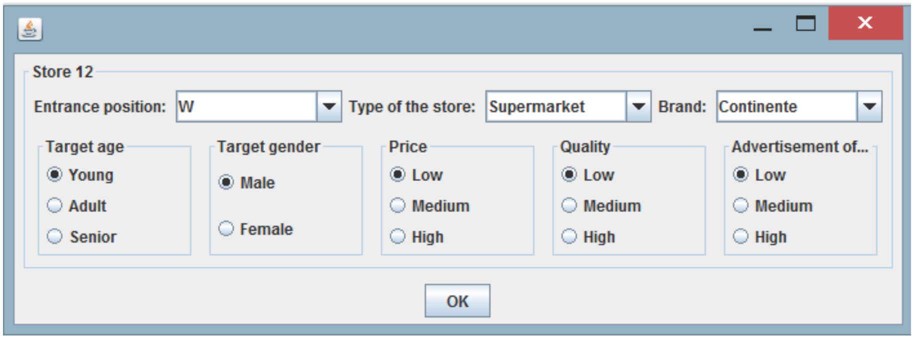


Figure 4.5 EditFrame

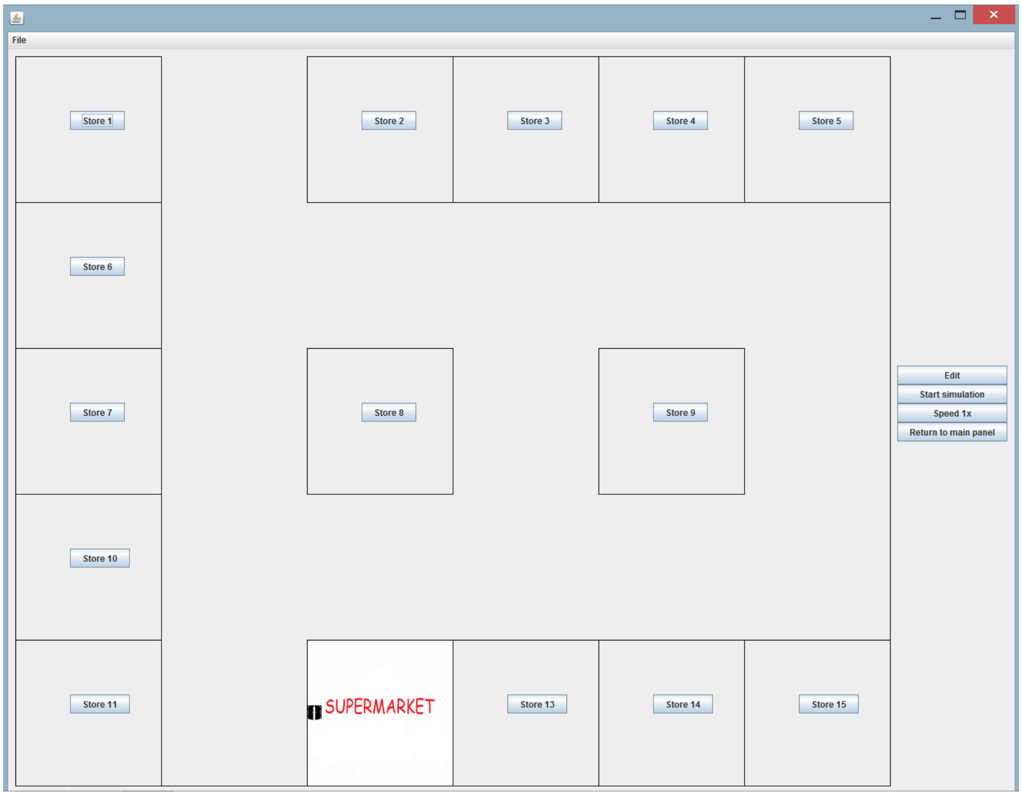


Figure 4.6 SimulationPanel with one store edited

The user then repeats this process and fills the mall with all the stores they want in the simulation. After all the stores are edited the user can start the simulation by pressing the "Start simulation" button. The clients will start to enter the mall by the entrance located between *Store* 1 and *Store* 2. The clients will roam through the mall, visit the stores they need to visit and exit the mall in the same entrance they came in. Figure 4.8 shows one simulation with clients.

The user instead of editing the stores one by one can import files with previously edited layouts. They can also export files and save them for later simulations. For that they only need to click in the menu item "File". Illustrated in Figure 4.7.

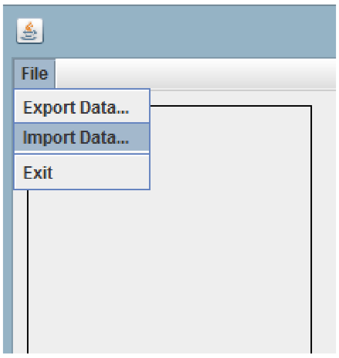


Figure 4.7 Menu item to import or export data

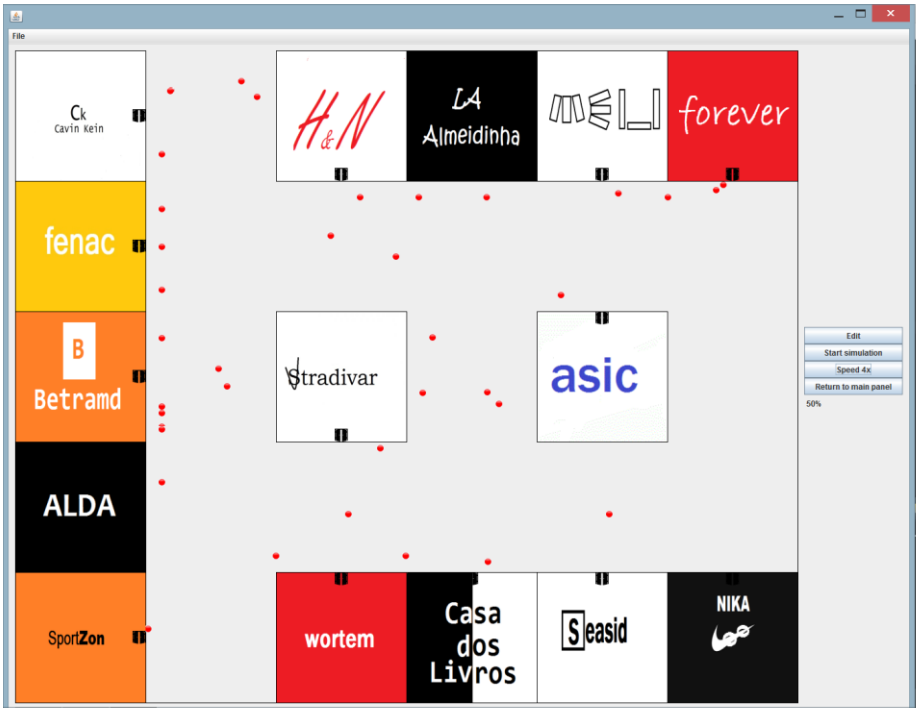


Figure 4.8 Simulation

After the simulation is finished the *MainFrame* switches to the *HeatMap-Panel* where the user can see what are the most frequented zones of the mall. Figure 4.9 shows the heat map.

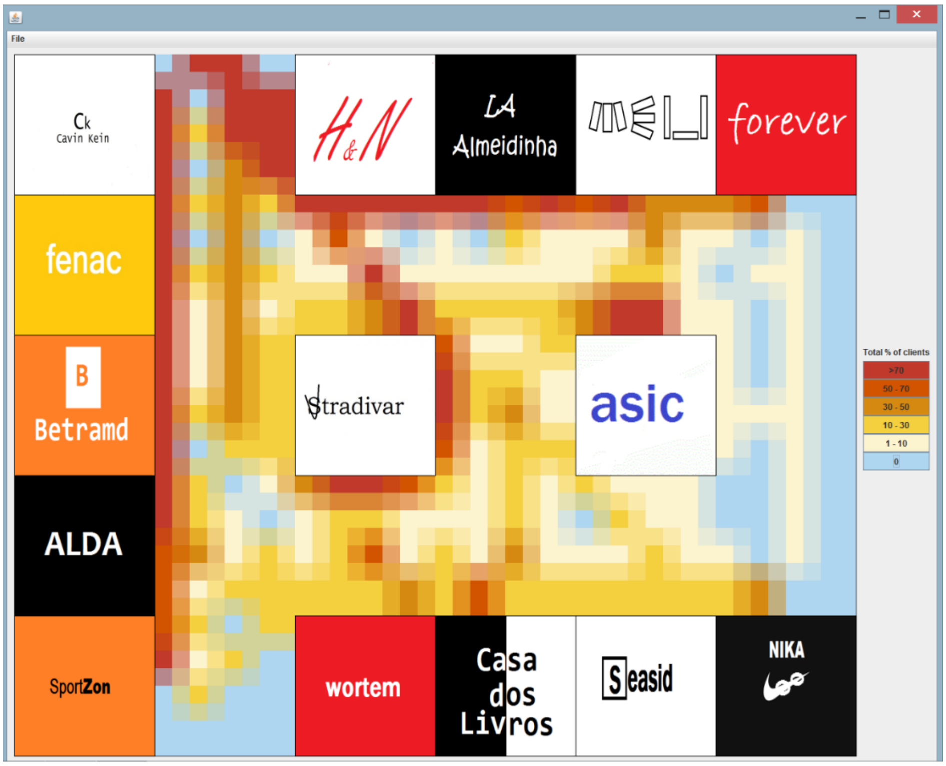


Figure 4.9 Heat Map

4.3 Class diagram

In this section we show a class diagram shown in Figure 4.10. Due to the size and number of classes of this project we had to do a simplified version of the class diagram.

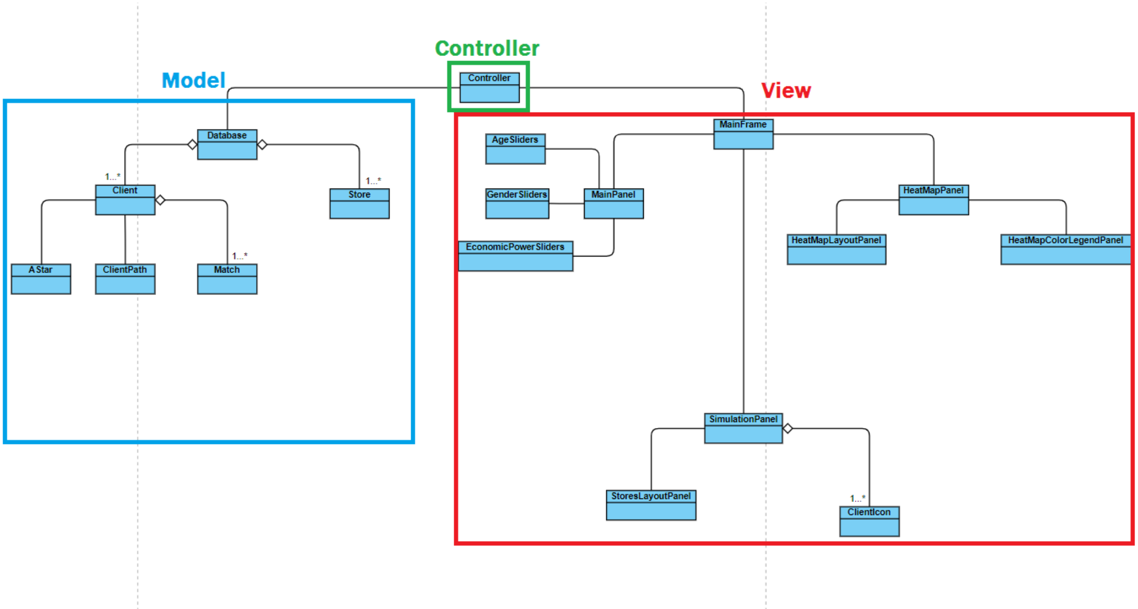


Figure 4.10 Class diagram

5

Simulation results and analysis

To analyze the behavior of the software we created four different scenarios for our simulations.

- **Scenario 1 –** The majority of the clients are *young, male,* and with a *low* economic power.
- **Scenario 2 –** The majority of clients are *adult, female,* and with *medium* economic power.
- **Scenario 3 –** The majority of clients are *senior* with *high* economic power. *Male* and *female* are distributed equally.
- **Scenario 4 –** All the clients' characteristics are distributed equally.

All of the scenarios have a client population of 1000 clients.

In the following sections we will show and analyse the results of each scenario.

5.1 Shopping center plant

We wanted a shopping center plant that would allow us to see significant changes in the results of the four scenarios. For that reason we divided the stores in three sections as can be seen in Figure 5.1. Each of the sections targets the clients' demographics of the first three scenarios.

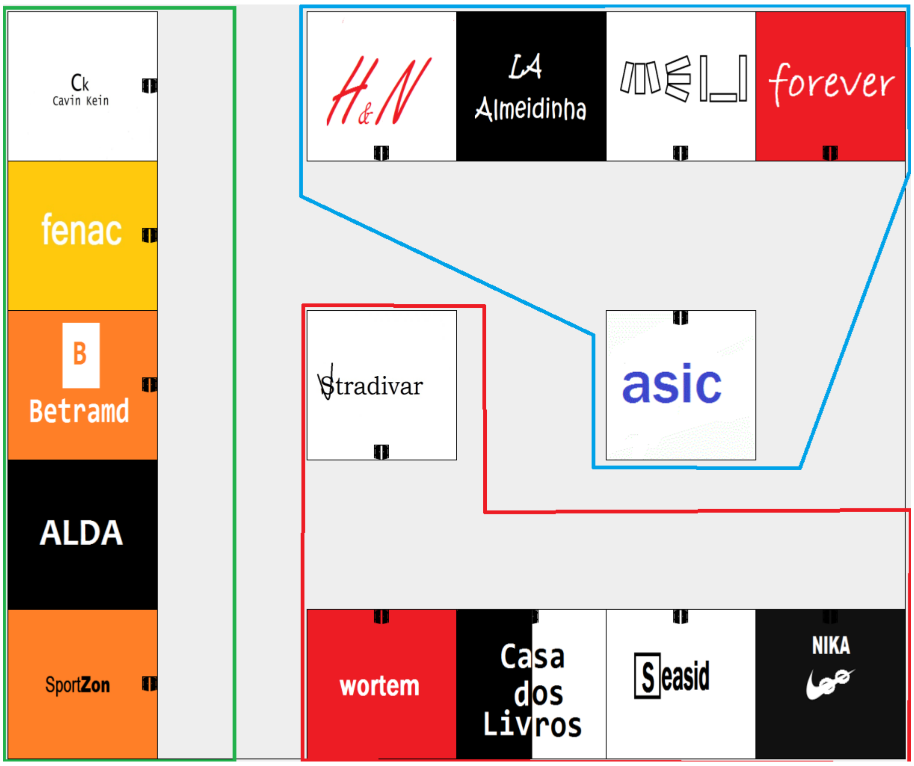


Figure 5.1 Sections of the shopping center

In the green area we have stores that target *young, male* clients with *low* economic power.

In the blue area we have stores that target *adult, female* clients with *medium* economic power.

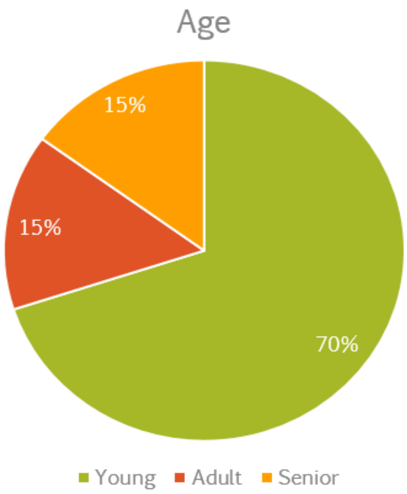
In the red area we have stores that target *senior* clients, both *male* and *female,* with high economic power.

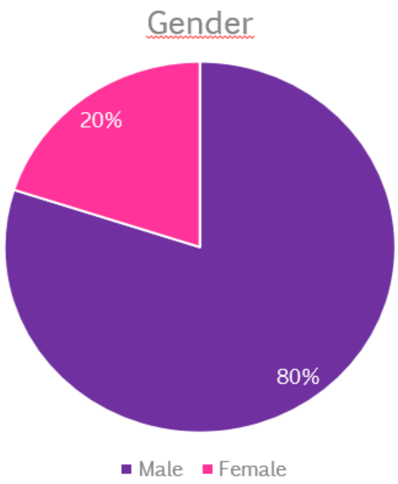
In the next sections we will look at the four scenarios individually and see the results of the each scenario's simulation, to find where the optimal place to put ads will be.

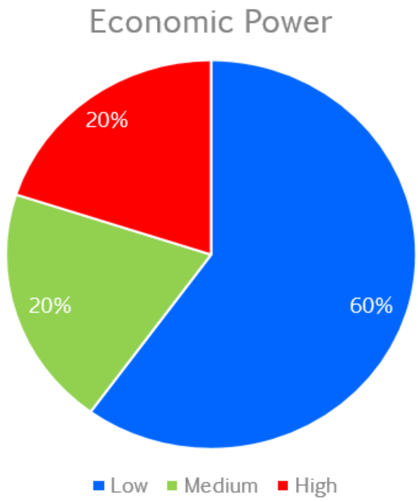
The entrance point will not be considered given that all the clients enter and exit from the same location.

5.2 Scenario 1

The first scenario is a scenario where the majority of the clients are *young, male,* with a *low* economic power. The exact distribution of the several parameters is shown in the following pie charts. The results of the simulation with this distribution are shown in Figure 5.2.







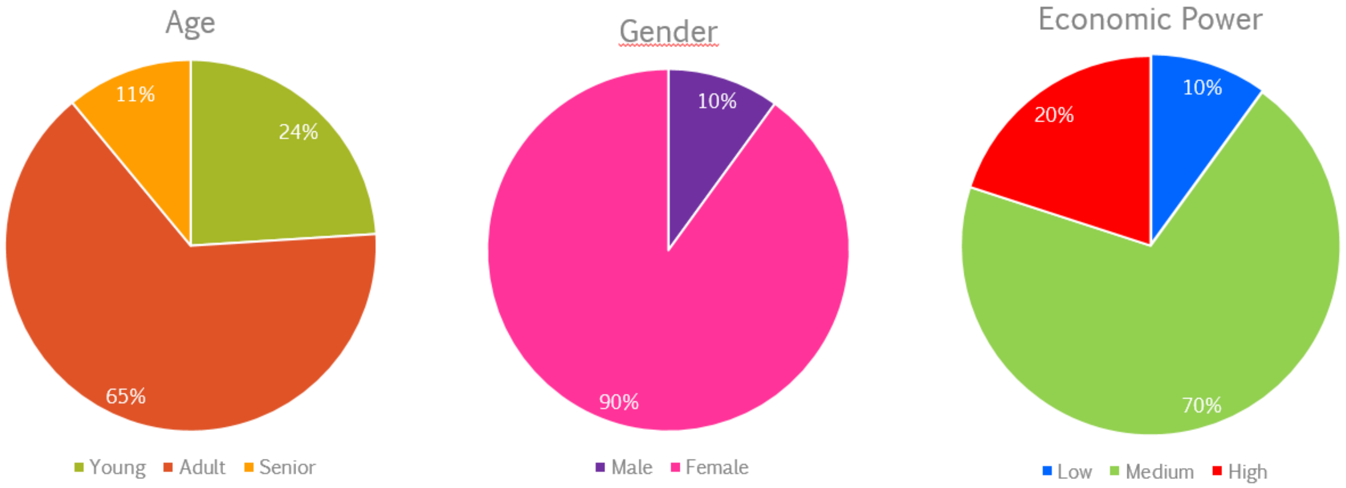
In this scenario is expected that the most frequented areas will be around the green area. The majority of clients are *young, male,* and have *low* economic power, and so it is expected that they will prefer the stores of the green area that target those three characteristics.

Figure 5.2 Simulation results of scenario 1

Analysing the results we can observe that the results are as expected. The clients had a bigger concentration on the green area. Although the left side of the blue area, and both the two center stores also attract a good amount of clients. These would be the recommended places to put advertisement, with the big emphasis being on the green area.

5.3 Scenario 2

In the second scenario we have a distribution where the majority of clients are *adults, female,* with *medium* economic power. The distributions are shown in the following pie charts. The results of the simulation are shown by Figure 5.3.



With this population distribution it is expected that most clients chose stores in the blue area, because that is the area that target the clients with the characteristics of the majority of clients of this population.

Figure 5.3 Simulation results of scenario 2

As we can see the results go accordingly to what was expected. The blue area is the most frequented area. The majority of clients being *adults, female,* with *medium* economic power chose the stores that target those same characteristics. We can also observe that the other two areas have very little affluence of clients. This would be the optimal place to put the advertisement.

5.4 Scenario 3

In the third scenario we have a population of clients where the majority are *seniors* with *high* economic power, both *male* and *female*. The distributions are shown by the following pie charts. The results of the simulation are shown by Figure 5.4.

In this scenario it is expected that the red area will be the most frequented. We also expect a big concentration of clients in the corridor between the two central stores, because that is the preferential path taken by the clients to go to the stores of the red area.

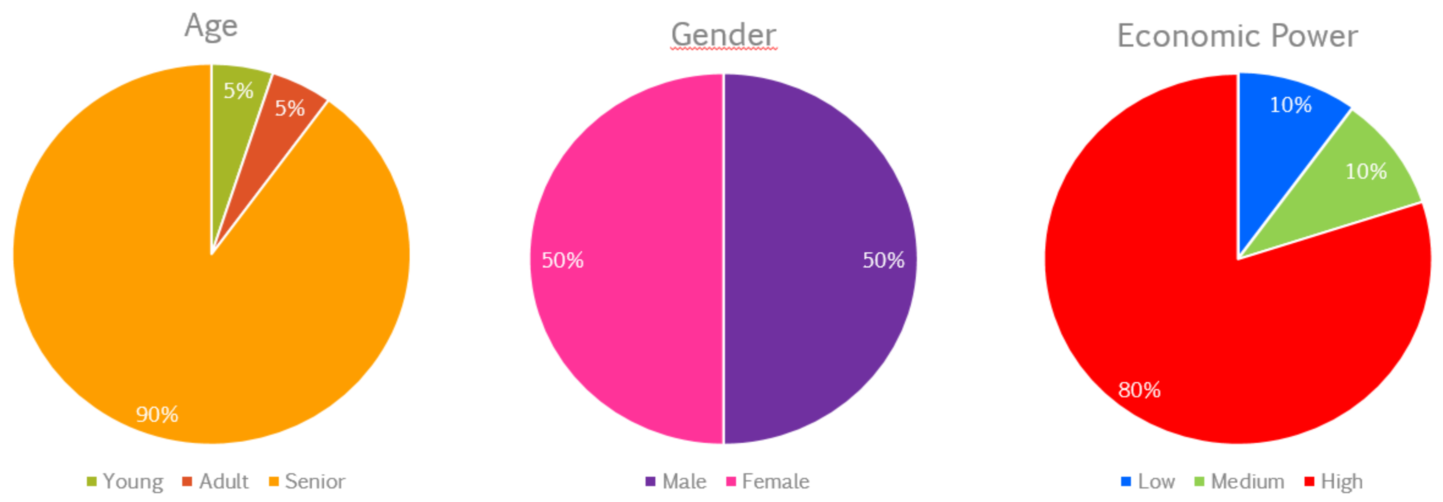
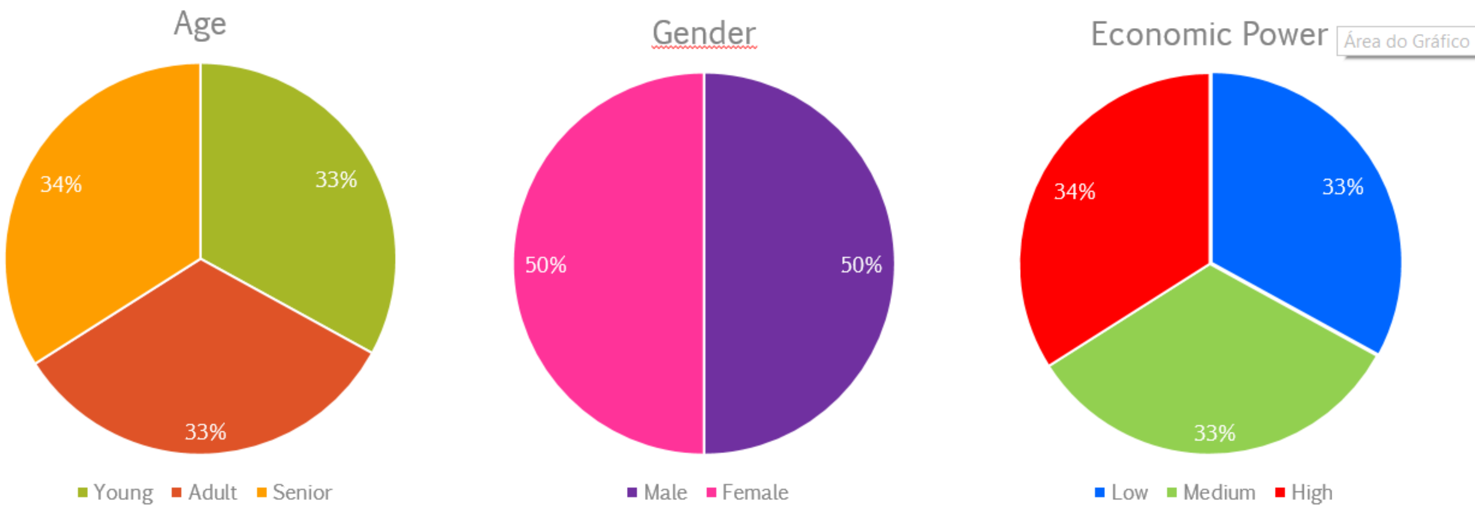


Figure 5.4 Simulation results of scenario 3

We can observe that the results are as expected. We can also see that the green and blue areas attract some clients, even though the parameters of the clients targeted by those zones are low. This led us to conclude that gender plays a big part in the choices of these clients. The results show us that we have a big concentration of clients in the stores of the red area, and in the middle of the mall plant. The first stores of the green and blue areas also attract a fairly good amount of clients. With these results the best place to put advertisement would be in the bottom and middle of the mall.

5.4 Scenario 4

The final scenario is a scenario where all of the parameters are distributed equally. This distribution can be seen in the following pie charts. The results of the simulation are shown in Figure 5.5.



In this scenario it is expected to see a more uniform heat map, with the three areas having roughly the same concentration of clients.

Figure 5.5 Simulation results of scenario 4

These results were not completely as expected. We can see that the red area had a lesser concentration of clients than the green and blue areas. That can be explained by the fact that some stores of that area target males and some target females, while the other two areas target only one specific gender. Male in the green area, and female in the blue area. As we concluded before the green area has a bigger chance of attracting more males, the blue area has a bigger chance of attracting females, and the red area is divided between the two genders. With these results we can conclude that the only place where it would not be recommended to put advertisement would be near the bottom stores of the mall plant. All of the other areas are potentially good places to put advertisement.

6

Conclusion

In this project we intended to build a software capable of simulating clients circulating inside a shopping center and then present a heat map with the most frequented areas, with the objective of showing where the optimal areas to put advertisement are.

To do that we used several techniques in the development of this software. All were important tools during the development phase, but some proved to be more indispensable than others.

The Agent-based simulation was one of the most important techniques used in this project and an indispensable one. The agents responded with individuality and their actions were a reflection of their characteristics, as the simulation showed us. Although there could have been a little more depth into their behaviors that would describe even better the human behavior they are simulating. Certain behaviors like standing in front of a store looking to the showcase window, or avoiding other agents, weren't included in this project and could be useful additions in future works.

The *A** proved to be a good pathfinding algorithm finding with success the best route from point A to B. But there are some flaws with it. We noticed this algorithm starts to get too slow when there are many agents being simulated simultaneously, roughly when the number of agents is superior to 300. We also noticed the movement of the agents could be less mechanic, not translating accurately how human movement really is.

The heat maps were a great way to show the results. The color scheme it is easy to read and easy to draw conclusions from. This is a technique that proved to be a very useful, and intuitive, way to show the results of the simulations.

We can consider the project reached the objective as it accomplish its primary goal. The results of the simulations show us that the agents respond differently in different scenarios, as we can see in the distinctions in each scenario's heat map. However these differences are not random and go accordingly to what we should expect of the agents' behaviors.

The main question of where is the optimal place to put advertisement, and set its price, was answered in each scenario, and we can also conclude that this software has the capacity to segment the clients' population to indicate not only the optimal place to put advertisement but also what is the demographics that advertisement should target.

6.1 Future work

Although the software accomplished its purpose there are several aspects that can be improved.

- Add some type of learning capabilities to the agents so that they could learn in each simulation approximating their behaviour to the human behaviour they are simulating.
- Make the stores a type of agents with their parameters adjusting throughout the simulation, and adding some other type of parameters, like sales and promotions. This could add more dynamic to the simulation and make it closer to reality.
- Make modifications in the *A** algorithm to make the agents' movement more human like. In [28] the authors show three strategies to optimize the *A** algorithm that make it close to human pathfinding behavior.
- Include behaviors like collision avoidance or stand in front of stores.
- Create a changeable shopping center layout that can be built to replicate any shopping center plant.

These are some of the many aspects that would improve the capabilities of this software. Which shows that this is not the final version, rather it is the beginning. The potential of growth is huge.

7

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