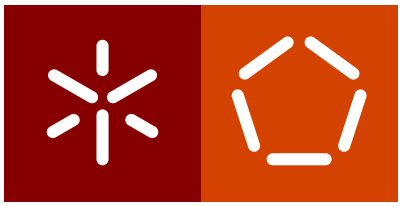
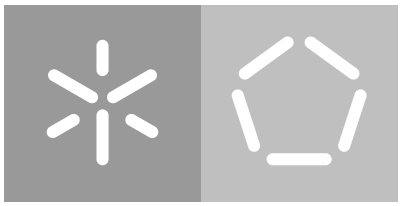


Universidade do Minho
Escola de Engenharia
Departamento de Informática

Rui Miranda

Intelligence on Nutrition in Healthcare and Continuous Care

July 2019



Universidade do Minho
Escola de Engenharia
Departamento de Informática

Rui Miranda

Intelligence on Nutrition in Healthcare and Continuous Care

Master dissertation
Integrated Master's in Informatics Engineering

Dissertation supervised by
José Machado

July 2019

DECLARATION

Name: Rui Pedro Mesquita Miranda

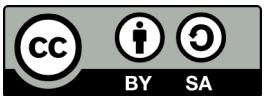
Civil ID Number: 15144008 5 ZY6

Dissertation Title: Intelligence on Nutrition in Healthcare and Continuous Care

Mentor: José Manuel Ferreira Machado

Completion Year: 2019

Course: Integrated Master's in Informatics Engineering



Universidade do Minho, _____/_____/_____

Signature: _____

ACKNOWLEDGEMENTS

This thesis is the culmination of hundreds of hours of designing a software system, programming, reading articles, and writing this dissertation. Without the help of family and friends, I would not be able to overcome many challenges and difficulties I faced throughout this process. I'm grateful for the help of these amazing people who supported me along my journey.

First, I would like to thank my mentor, José Machado, for offering me this opportunity, and for his patience and support during the development of this dissertation. In addition, I'm grateful for Professor António Abelha's help and dedication.

I want to offer my gratitude to the *Santa Casa da Miserdicórdia de Vila Verde* for allowing me to do this project in their facilities. Furthermore, I would like to thank Ana Miranda for her help and support, and the interns at the Social Cafeteria for testing the applications and for their valuable feedback.

This year I worked alongside my colleagues at the Knowledge Engineering Group (KEG). They do so many amazing things, and I'm proud to work alongside them. Their help and presence was invaluable for the development of this dissertation.

During these past five years, I have met some of the best people I could ever have met. I would like to offer my sincere thanks to my friends for standing beside me. In particular, I would like to thank Joana Miguel and Lúcia Abreu for always supporting me, as well as Raquel Rainha, my neighbour and best friend.

Finally, I would like to thank my family from the bottom of my heart, namely my mother, father, and brother. They always gave me encouragement to fight hard and achieve my goals. I must also include my aunt, my uncle, and my cousin for their presence and motivation.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

ABSTRACT

In the healthcare industry, the patient's nutrition is a key factor in their treatment process, as every user has their own specific nutritional needs and requirements. For example, after a major surgery, a patient should eat products with high fiber while avoiding processed foods and dairy. An appropriate nutrition policy can therefore complement the patient's recovery process, alleviating possible symptoms.

Food recommender systems are platforms that offer personalised suggestions of recipes to users. These systems are often implemented in food recipe websites, offering similar suggestions. They are also used for improving the user's health and recommending healthier recipes while keeping their preferences in consideration. However, there is an absence of usage of recipe recommendation systems in the healthcare sector. Multiple challenges in representing the domain of food, coupled with the patient's needs, make it complicated to implement these systems in healthcare services and continuous care.

In the context of this master's dissertation, the aim was to design, develop, and explore a new generation platform for the provision, planning, and reservation of food plans, comprised of web and mobile tools. A key feature of this platform is the suggestion of meal plans to each department, taking into account the patient's nutritional requirements.

Data regarding the user's nutritional requirements were collected and analysed, as well as feedback from health professionals and users from the social cafeteria. The collected information supported the development of a food recommendation system. These tools will help nutrition professionals at the *Santa Casa da Misericórdia of Vila Verde* in their work, namely with the making of meal plans for multiple departments, each with their specific nutritional requirements.

Keyworks: Machine learning, recommender systems, meal planning, decision support systems

RESUMO

Na área da saúde, a nutrição do paciente é um fator principal no seu processo de recuperação, onde cada utente tem as suas necessidades e requisitos nutricionais específicos. Assim, após uma cirurgia, um paciente deve comer alimentos com alto teor de fibra, evitando alimentos processados e lacticínios. Ora, uma política de nutrição apropriada pode ajudar e complementar a terapia do paciente, aliviando potenciais efeitos secundários.

Sistemas de recomendação de alimentos (*food recommender systems*) são plataformas que oferecem sugestões personalizadas de receitas a utilizadores. Estes sistemas são frequentemente implementados em páginas *web* de receitas, oferecendo sugestões similares. São, também, utilizados para melhorar a alimentação dos utilizadores, ao recomendar receitas mais saudáveis, tendo em consideração as suas preferências. Contudo, existe uma lacuna na implementação destes sistemas em cuidados de saúde. Há múltiplos desafios em representar o domínio dos alimentos, bem como as necessidades médicas dos pacientes dificultam a implementação em cuidados de saúde e cuidados continuados.

No âmbito deste projeto de dissertação, foi desenhada, desenvolvida e explorada uma plataforma de nova geração para o aprovisionamento, planeamento e reserva de planos alimentares, composta por ferramentas web e móveis. Uma funcionalidade chave desta plataforma é a sugestão de ementas a cada valência, tendo em consideração os requisitos nutricionais dos pacientes.

Dados relativos às necessidades nutricionais dos utilizadores foram recolhidos e analisados, tal como as opiniões *feedback* de profissionais de saúde e dos utilizadores da cantina social. As informações recolhidas serviram de suporte para o desenvolvimento de um sistema de recomendação ao apoio à decisão. Estas ferramentas vão auxiliar o trabalho dos profissionais de nutrição da Santa Casa de Misericórdia de Vila Verde, nomeadamente no planeamento de refeições a múltiplas valências, cada uma com os seus requisitos nutricionais específicos.

Palavras Chave: Machine learning, sistemas de recomendação, planeamento de ementas, sistemas de suporte à decisão

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

API Application Programming Interface. 1, 4, 27, 28, 34, 54

BI Business Intelligence. 1

CART Classification and Regression Tree. 1, 12, 14
CRISP-DM CRoss Industry Standard Process for Data Mining. 1, 13
CRUD Create, Read, Update, Delete. 1, 25, 36

DBMS Database Management System. 1, 24, 28, 36, 37, 39
DDL Data Definition Language. 1, 28
DML Data Manipulation Language. 1, 28
DOM Document Object Model. 1, 26
DSR Design Science Research. 1, 22, 24
DSS Decision Support System. 1
DW Data Warehouse. 1

ETL Extract, Transform and Load. 1

GDPR General Data Protection Regulation. 1, 62

HACCP Hazard Analysis and Critical Control Point. 1, 42, 61, 62
HTTP HyperText Transfer Protocol. 1, 24, 25

ID3 Iterative Dichotomiser 3. 1, 12
IDE Integrated Development Environment. 1, 25
IT Information Technology. 1, 3, 22, 23, 29, 60, 64, 66

JSON JavaScript Object Notation. 1, 25
JSX JavaScript XML. 1, 26, 27
JWT JSON Web Token. 1, 37, 39

LTS Long Term Service. 1, 37

NCC2 Naive Credal Classifier 2 (NCC2). 1, 14

ODANB One Dependency Augmented Naive Bayes. 1, 14
ORM Object-Relational Mapping. 1, 24, 36, 37, 39

PoC Proof of Concept. 1, 22, 29, 60, 65

RDBMS Relational Database Management System. 1
REST REpresentational State Transfer. 1, 25
RQ Research Question. 1

SARSA State-Action-Reward-State-Action. 1, 10
SDK Software Development Kit. 1, 4
SOAP Simple Object Access Protocol. 1, 25
SPA Single Page Application. 1, 26, 40
SQL Structured Query Language. 1, 28, 39
SWOT Strengths Weaknesses Opportunities Threats. 1, 6, 22, 29–31, 59–63, 65

URI Uniform Resource Identifier. 1, 25
URL Uniform Resource Locator. 1, 27

XML Extensible Markup Language. 1, 25

YAML YAML Ain't Markup Language. 1, 39

1

INTRODUCTION

The present document describes the research and analysis for the development and exploration of a platform for meal planning and provision, as well as a meal planner module for decision support in the healthcare industry. The project arose within the scope of the master's dissertation of the Integrated Master's in Informatics Engineering at Minho University.

This introductory chapter is divided in four sections. A brief contextualisation of this project is presented, including references to key topics of discussion (Section 1.1), as well as the main motivation that led to its realisation (Section 1.2). This chapter also includes the main aims proposed for the development of this master's thesis, thereby offering a description of the work performed (Section 1.3). Lastly, this chapter ends with the presentation of the document's structure in order to simplify its reading (Section 1.4).

1.1 CONTEXT AND FRAMING

One of the biggest hurdles in healthcare is decision-making, as every option has its advantages and possible complications, which may jeopardise a human life. A recent solution to this problem is the implementation of Decision Support Systems (DSSs). When applied to healthcare, these systems can improve the patient's quality of life, offering personalised and patient-focused suggestions (Neves et al., 2018; Esteves et al., 2019).

The patient's nutrition is a key component in their treatment and recovery process. Medical nutrition therapy, also called nutrition therapy, uses nutrition as a treatment process. A person's nutrition status is checked, and they are then given the right foods or nutrients to treat their conditions, such as those caused by diabetes, heart disease, and cancer (NCI Dictionary of Cancer Terms, 2018; Morris and Wylie-Rosett, 2010). A medical nutrition therapy policy may also help patients recover more quickly, spending less time in the hospital (Ferreira et al., 2018).

Machine learning is a scientific field of algorithms and methods that explores how computer systems can "learn" based on data (Han et al., 2012, 61). Learning algorithms are known for their ability of using past experience to improve a model's performance. This

experience refers to past information available to the learner, commonly taking the form of data collected for analysis (Mohri, 2012; Mitchell, 1997). Over the past years, machine learning systems have been successfully deployed in a variety of applications, including natural language processing, speech recognition, and medical diagnosis, and recommender systems (Esteves et al., 2019). Furthermore, since the success of a learning algorithm depends on the data used, machine learning is intrinsically related to data analysis and statistics, as well as enabling the process of Data Mining to discover patterns and extract knowledge in large data sets (Mohri, 2012, 14).

Recommender systems are tools and approaches that provide personalised and relevant suggestions for items that are most likely of interest to a particular user (Rubens (Rubens et al., 2015, 1). These systems are one of the most powerful and popular information discovery tools on the web, supporting users in their decision-making progress. Applications of recommender systems include the entertainment domain, from music to movies and TV shows, news articles, books, and online shopping (Aggarwal, 2016). Furthermore, machine learning and data mining algorithms allow for the development and implementation of advanced recommender systems, deducing common patterns and behaviours between users and items.

In this context, this project has emerged, consisting of the development and exploration of a new platform for meal planning, incorporating machine learning algorithms for decision support, helping the health professionals in the Social Cafeteria of Vila Verde. In particular, this system encompasses a web application, where all meals at the *Santa Casa da Misericórdia de Vila Verde* and at the hospital of Vila Verde can be planned and reserved for later preparation, and a mobile app, where individuals at the cafeteria can order their meals, see the menu of the week, and offer feedback regarding a dish. These tools will modernise the social cafeteria, by introducing a new ingredient repository, an intuitive dish and preparation creation system, integration with the *Primavera* provisioning system, and an overview of the cafeteria's operations, number of reservations, feedback from users, and any other possible indicators of service.

A key feature in this platform is the suggestion of food menus to each department, taking into consideration the patient's nutritional needs. Data regarding the user's nutritional requirements was collected and analysed, as well as feedback from health professionals and users from the social cafeteria. This collected information was used to support the development of a meal planner module, incorporating a food recommendation system for decision support. Thereby, these tools will help nutrition professionals at the *Santa Casa da Misericórdia of Vila Verde* in their daily work, namely on the making of meal plans for several departments, each with their specific nutritional requirements.

Hence, both web and mobile applications were designed, developed, and explored, adopting a set of methodologies and technologies available and viable for the conception of the

solutions—also called IT artefacts. The developed platform will support users and patients in fragile conditions. A carefully planned meal plan can thus help and complement their quality of life, alleviating possible symptoms.

1.2 MOTIVATION

Accordingly, the main motivation for this dissertation project focuses on developing and exploring a new generation of tools in the field of Information Technologies (ITs) (ITs) in order to help with the meal planning and management for the multiple departments offered to the community by the *Santa Casa da Misericórdia de Vila Verde*. Therefore, both web and mobile applications were developed, using several methodologies and technologies currently available and viable for the conception of the defined IT solutions, also called IT artefacts. A data retrieval of the cafeteria's operations has enabled the creation of machine learning models for the food plan recommendation system.

As a first case study (**Case Study nº 1**), a new platform for meal provisioning and management was developed, comprised of a web and mobile application. The web application will support the social cafeteria's operation, with its main feature being a revamped ingredient repository, comprised of over 600 ingredients with nutritional information and allergens, and an upgraded recipe system, where ingredients can be specified for a target age group and preparations can be reused for multiple dishes. Additional features include an improved meal reservation system, where all coordinators can easily order meals for their departments, as well as integration with the hospital's acquisition system, allowing an easier food ordering process. This application was developed using React by adopting modern technologies and frameworks and allowing the implementation of additional features and modules. A mobile app will additionally be developed for the cafeteria's users, allowing them to interact with the social cafeteria. The user is able to obtain the menu and its nutritional information, and can easily order a reservation thought their smartphone. As it was developed using React Native, this application supports the two most used mobile operating systems–Android and iOS–using the same code-base, saving time and resources.

For the second case study (**Case Study nº 2**), a meal planner module will be implemented on the web platform. This module should allow an easy creation of weekly food menus for multiple departments. Each department has their own specific menu guideline. For example, the nursery only operates on weekdays, and does not serve dinners. All of these guidelines can be easily tweaked so that the platform can adapt with the social cafeteria's future expansions. In addition, a data mining study was performed, creating knowledge about the cafeteria's functioning, nutritional requirements for the departments, and the user's feedback regarding food plans. A recommender system using machine learning approaches was thus developed for the automatic creation of food menus, keeping in consideration the

patient's nutritional needs and requirements. This module will greatly simplify the nutrition specialist's work of creating food menus for several departments, thus increasing their productivity.

1.3 OBJECTIVES

As stated previously, the present iteration of the dissertation has being the development and exploration of a new generation of software tools to help with the meal planning and management of the Social Cafeteria as its main objective:

a A tool for simplifying the Social Cafeteria's operations, namely a web platform for the reservation of meal plans, and a mobile application to the cafeteria's users

b A tool for decision support of the food plans, that is, a food recommender module that incorporates machine learning algorithms.

Therefore, in the context of this dissertation project, the following Research Questions have arisen:

- **Research Question 1:** What are the Social Cafeteria's main necessities and obstacles, and how can the implementation of IT systems help optimise its workflow and reduce costs?

To answer this question, the following objectives were highlighted:

- Case Study 1: development of a new software platform for meal planning and management, comprised of a web application and a mobile app:
  - Requirements elicitation in the design and development of the platform
  - Analysis of available methodologies and technologies involved in the design and development of the system
  - Development of a web app using the React framework, including multiple modules for administration and platform maintenance
  - Development of a mobile app using the React Native Software Development Kit (SDK) for planning the user's meals, as well as sending notifications about the cafeteria's menus
  - Development of Application Programming Interfaces (APIs) and Web Services to give support both web and mobile applications
  - Implementation and deployment of said platform in the Social Cafeteria of Vila Verde

  - Ensuring the proposed software platform is compatible with the current systems in place at the Social Cafeteria of Vila Verde

- **Research Question 2:** How can the data obtained by the developed platform be used for intelligent planning of meal plans, improving the patient's quality of life, as well as optimising the hospital's resources?

In order to answer this question, the following objectives were proposed:

- Case Study 2: data mining study of the platform's recipe and user information, and implementation of a food recommender system using machine learning algorithms:
  - Revision of literature regarding machine learning, recommender systems, and their applicability in healthcare and nutrition
  - Requirements elicitation in the design and development of a food recommender system tool
  - Analysis of tools and methodologies for data mining and development of machine learning models
  - Creation of machine learning models based on literature
  - Development of a food recommender module, suggesting food plans by the user's preferences and their healthiness
  - Deployment and testing at the Social Cafeteria of Vila Verde

Therefore, the objectives that determine the project are seen as Research Questions, serving as a guide for solving the studies presented, and thus, which ones will be searched for solutions.

1.4 Document Organization

The following document is structured in 7 chapters: Introduction, State of The Art, Research Methodologies & Tools, Platform for Meal Provision and Management, Meal Planner Module, Proof of Concept, and Conclusion and Future Work.

- **Chapter I - Introduction:** This Chapter's goal is to present a contextualisation and framing of the work, the main motivation, main objectives, and the document's structure

- **Chapter II - State of The Art:** In Chapter 2 all theoretical and scientific concepts of interest for this study in ITs are presented and documented, namely machine learning, and how it can be applied to healthcare and nutrition, and recommender systems, with a focus on food recommender systems

- **Chapter III - Research Methodologies & Tools:** This Chapter's goal is to present the Design Science Research investigation methodology for the development of all study cases. In addition, the tools and technologies planned for usage are documented
- **Chapter IV - Platform for Meal Provision and Management:** In Chapter 4 the platform for meal provision and management is introduced. The problem and its motivation are described, in addition to the platform's main objectives and requirements elicited during its development. A comprehensive documentation of all steps taken during the platform's design and development process is described. Therefore, the platform's architecture, database models, and technologies adopted are documented. This chapter concludes with an analysis and discussion of the results obtained, as well as a brief conclusion and an insight into future work
- **Chapter V - Meal Planner Module:** In Chapter 5, the meal planner module for the web application is presented. The problem and its motivation are shown, as well as the module's key objectives brought out during its development. A comprehensive documentation of all steps taken during the platform's design and development process are illustrated. In addition, all steps taken for the implementation of machine learning algorithms are exposed. This chapter ends with an analysis and discussion of the results, as well as a conclusion and an insight into future work
- **Chapter VI - Proof of Concept:** In this chapter, the proof of concept made for the developed project is presented. A Strengths Weaknesses Opportunities Threats (SWOT) analysis was performed in the web and mobile applications, as well as the meal planner module
- **Chapter VII - Conclusion and Future Work:** The last chapter of this document aims to summarise and present the main conclusions and contributions obtained through the development of this platform. In addition, proposals for future work in order to improve the platform and its applications are presented
- **Appendix A - Publications:** All scientific contributions, namely, the publications elaborated on throughout this dissertation project are described

2

STATE OF THE ART

2.1 INTRODUCTION

In this chapter, several topics of discussion relating to this dissertation are studied and documented. A careful analysis of past papers and articles allows for an understanding of what others have previously done, what challenges they had to face, and how they were able to overcome these challenges.

An introduction to machine learning is given, which describes its main concepts, shows multiple paradigms, categories of tasks, and machine learning systems—in particular, Decision Tree Learning. Several healthcare and nutrition projects that have implemented machine learning systems in literature are also discussed.

An introduction to recommender systems is presented, as well as how they can be used in various domains. For example, they can offer music recommendations, movie suggestions, or similar products. The most common approaches for recommender systems are explained, along with how they predict the utility of a recommendation. Multiple food recommender systems are also compared by how they take into account the user's preferences and/or their nutritional needs, and how the system generates those suggestions.

2.2 THEORETICAL BACKGROUND ON MACHINE LEARNING

Machine learning is a field of study that focuses on the ability of computer systems to "learn" from data and identify patterns with minimal human intervention (Wikipedia contributors, 2018; Kohavi and Provost, 1998; Institute, 2018).

Mitchell (1997) has used the following definition to explain the ability of computer software to learn from data: "A computer program is said to learn from experience E with respect to some class of tasks T and performance measure P, if its performance at tasks in T, as measured by P, improves with experience E" (Mitchell, 1997, 2). Machine learning uses advanced statistical techniques and algorithms to improve the performance measure, allowing computer systems to learn from experience.

The need to analyse vast amounts of information requires advanced and sophisticated methods (Institute, 2018). Data Mining can be defined as the process of discovering interesting patterns and knowledge from large amounts of data (Han et al., 2012, 24). Machine learning enables the process of Data Mining by using multiple methods and algorithms to discover patterns and extract knowledge in large data sets (Mitchell, 1997; Pereira et al., 2015).

Machine learning methods are used on "where humans might not have the knowledge needed to develop effective algorithms", or "where the program must dynamically adapt to changing conditions" (Mitchell, 1997, 17).

Some examples of machine learning applications include self-driving vehicles, fraud detection systems, and speech recognition algorithms (Dechant, 2018; Institute, 2018; Google Cloud, 2018).

To properly implement machine learning systems, multiple key decisions have to be made. Depending on the data set and the main objectives, different paradigms are recommended. How the system should learn from experience, what tasks could be performed, and several other important machine learning systems are discussed in the following chapters.

2.2.1 *Machine Learning Paradigms*

Machine learning is a fast-growing field that powers cutting-edge applications (Han et al., 2012). This subsection will illustrate classic paradigms in machine learning, and will describe their learning process and feedback available (Hoffman and Bhattacharya, 2016):

Supervised Learning

In supervised learning, the algorithm trains from labeled data, and makes predictions for all unseen cases (Mohri, 2012, 7). Each case for training consists of input variables and a desired output value. The algorithm will train from a learning data set given by a "teacher" and will discover the relationships between the input attributes and the target variable (Hoffman and Bhattacharya, 2016).

This paradigm is commonly used in classification, regression, and ranking tasks (Mohri, 2012, 7). Popular algorithms and learning systems that use supervised learning include artificial neural networks, support vector machines, and linear regression algorithms (Hoffman and Bhattacharya, 2016).

Unsupervised Learning

In unsupervised learning, no labels are given to the learning system. The main intent is to "explore the data to find some structure within" (Institute, 2018). A disadvantage with this type of system is "since the data are not labeled, the model cannot tell the performance of a learner." (Han et al., 2012, 25)

Clustering and segmentation systems are examples of unsupervised learning problems, identifying segments or groups with similar attributes (Han et al., 2012). Popular unsupervised learning algorithms include self-organising maps, nearest-neighbour mapping, k-means clustering, and singular value decomposition (Institute, 2018).

Semi-Supervised Learning

Semi-supervised learning is an approach between supervised and unsupervised learning (Chapelle et al., 2006, 4). The learner receives a training set consisting of both labeled and unlabeled data, which predicts unexpected situations (Mohri, 2012).

The labeling process can sometimes be time-consuming or expensive. One main advantage of using semi-supervised learning is having more accurate models by using the unlabeled points in the learning process (Chapelle et al., 2006, 4). A key element for accuracy with semi-supervised models is the distribution between labeled and unlabeled data, " which the unlabeled data will help elucidate, be relevant for the classification problem" (Chapelle et al., 2006).

The area of semi-supervised algorithms and the conditions for the best prediction models are a current topic of modern theoretical and applied research (Mohri, 2012, 7). Semi-supervised learning can be used with classification, regression, and prediction tasks (Institute, 2018).

Active Learning

In active learning, the user plays an active role in the learning process. The learner can interact with the user/teacher, querying for labels for new points (Han et al., 2012). By choosing which data to learn from, the model quality can be optimised with fewer labeled examples (Mohri, 2012; Hosein, 2018).

Current research in active learning is in determining the best method for choosing which cases to query. Support vector machine models show promise with active learning systems by exploiting the fact that they perform better with fewer data than with all of the data available (Hoi and Lyu, 2005; Schohn and Cohn, 2000).

Reinforcement Learning

With reinforcement learning, the training and testing phases are intermixed. The "teacher" does not provide a correct answer. Instead, by interacting with an environment, the learner receives a "reward" or a "punishment". This information can be supplied either as a result after an action has been done or after a set of actions have been done (Mohri, 2012; Rocha et al., 2009). Some reinforcement algorithms include Monte Carlo algorithms, State-Action-Reward-State-Action (SARSA), and Q-learning.

Reinforcement learning systems are versatile, since an agent would learn more from its own experiences rather than from a knowledgeable teacher. However, a challenge in reinforcement learning is the trade-off between exploration versus exploitation. To attempt to maximise the reward/obtain maximum reward, an agent must prefer taking actions that it has tried before and found to be effective. However, to find out these actions, it has to select new actions it has not yet tried. The agent has to *"exploit what it already knows in order to obtain reward, while it also has to explore in order to make better action selections in the future"* (Sutton and Barto, 1998, 4-5)

2.2.2 *Machine Learning Tasks*

The machine learning field has a set of distinct objectives for data analysis. Multiple categories of tasks can be identified, depending on their desired output Rocha et al. (2009). These categories are: classification, regression, clustering, and pattern recognition and outlier analysis.

Classification

In these types of problems, one or more classes are assigned to each item. The learner must correctly assign the item's classes to a set of values for the input variables. This is a task used with supervised learning algorithms, and it has a wide range of applications. Classifiers are used in numerous fields; for example, economics, health sciences, and engineering (Mohri, 2012; Rocha et al., 2009).

Regression

Regression is similar to classification; however, the objective is to predict a real value for each item by approximating an unknown function with a real codomain. The outputs are continuous, with the models being built based on mathematical expressions (Rocha et al., 2009). Regression is also considered a supervised problem, estimating the relationship between attributes.

Cluetering

The main objective of clustering is to identify groups of instances with similar features. Because the groups are not known beforehand, clustering is typically an unsupervised task. A common use for clustering tasks is in the marketing and ad industries to identify possible subgroups of clients with similar behaviours (Rocha et al., 2009). The main clustering methods are connectivity-based or hierarchical, centroid-based or hierarchical, as well as density and distribution-based modeling.

Pattern Recognition & Outlier Analysis

Machine learning algorithms can be used to detect patterns, associations, correlations, or occasional structures within data. For example, association analysis algorithms are used to identify items that are purchased together, helping businesses on how to market their products Agrawal et al. (1993).

A data set may contain outliers, *"that do not comply with the general behaviour or model of the data"* (Han et al., 2012, 20-21). Many machine learning algorithms can discard these outliers as noise or anomalies. However, depending on the situation, these exceptions can be more important than regular data. The study and identification of outliers is referred to as outlier analysis or anomaly mining.

2.2.3 *Machine Learning Systems*

Depending on the task at hand and the data available, multiple machine learning approaches are possible, each with their own advantages and limitations. A food recommender system was developed for decision support, helping the Social Cafeteria's planning. This recommendation system uses machine learning models and data regarding the patient's nutritional requirements, as well as feedback from users for the suggestion of food menus to each department. Commonly used machine learning systems include:

1. **Decision Tree Learning**, representing a flowchart-like tree structure, where each internal node (non-leaf node) denotes a test on an attribute, each branch represents an outcome of the test, and each leaf node (or terminal node) holds a class label (Han et al., 2012)

2. **Association Rule Learning**, where each rule is composed by an antecedent and a consequent, enabling the discovery of frequent patterns or association structures among sets of items (Agrawal et al., 1993)

3. **Artificial Neural Networks** inspired by biological neural networks, comprised of basic processing units called neurons, their connections, and their intensity. During

the learning process, the connection's weight update over time by a backpropagation algorithm (Rocha et al., 2009; Cortez et al., 1996, 2004)

4. **Support Vector Machines** are learning models used for classification and regression. Given a set with multiple attributes that belong in one of two categories, Support Vector Machines create a model that classifies new cases to one of the two groups (Han et al., 2012, 445)

5. **Genetic Algorithms** view learning in terms of competition among a population of evolving, alternative concepts. A genetic algorithm maintains a population of candidate problem solutions. According to their performance, only the fittest of these solutions survive and exchange information with other candidates to form new solutions (Luger and Stubblefield, 1993, 558)

To suggest menus for each department, the food recommender system employs decision trees to determine if a dish is nutritionally appropriate. Using information obtained for each dish, and feedback from nutrition experts, the models will classify if a meal is healthy for a target group. As a result, this approach is thoroughly documented, showcasing its key principles and algorithms.

Decision Tree Learning

Han et al. (2012) have defined decision trees as a flowchart-like tree structure, where each internal node (non-leaf node) denotes a test on an attribute, each branch represents an outcome of the test, and each leaf node (or terminal node) holds a class label.

Decision tree induction algorithms can create powerful classification models. When given a tuple for which the associated class label is unknown, the attributes of the tuple are tested against the decision tree. A path from the root to a leaf node can be traced, holding the class prediction for that tuple.

These classifiers are commonly applied, as they can be used for exploratory knowledge discovery, can handle multidimensional data, their representation in tree form is easy to understand, and the learning and classification steps are simple and fast while still having good accuracy.

The best-known decision tree algorithms include the Iterative Dichotomiser 3 (ID3) algorithm, C4.5 (a successor of ID3), and Classification and Regression Tree (CART). These algorithms adopt a greedy approach in which decision trees are constructed in a top-down recursive divide-and-conquer manner. Most algorithms also follow a top-down approach, which starts with a training set of tuples and their associated class labels. The training set is recursively partitioned into smaller subsets at the tree is being built (Han et al., 2012, 369).

A simplified decision tree for credit risk assessment was generated by Luger and Stubblefield in figure 1.

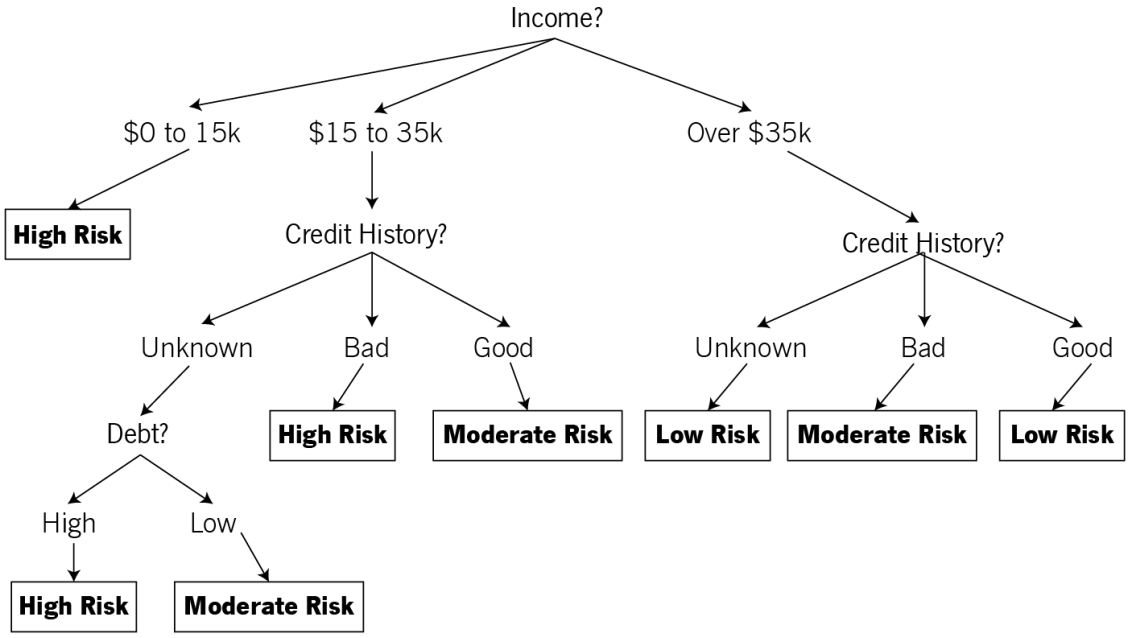


Figure 1.: Simplified Decision Tree for Credit Risk Assessment (Luger and Stubblefield, 1993, 15)

2.3 Machine Learning on Healthcare & Nutrition

Machine learning systems can be applied to an extensive range of domains, learning and extracting patterns from data. Countless articles and theses are based on machine learning systems, making an impact in computation, prediction, and automation. In addition, data mining studies employ the same methods as machine learning for extracting knowledge. In literature, several healthcare and nutrition projects have implemented machine learning systems, employing a diverse cast of algorithms.

Reis et al. (2017) have implemented a data mining study by combining a nutritional dataset with machine learning techniques. The main objective was to predict if a patient would need to be followed by a nutrition specialist. The CRoss Industry Standard Process for Data Mining (CRISP-DM) methodology was used, as well as data extracted from a Portuguese hospital. Five machine learning models were included, namely Decision Trees, Support Vector Machines, Bayesian Networks, Decision Rules, and Nearest Neighbours. They were able to create multiple models, discovering which attributes were able to predict the need for a nutrition specialist, helping decision-makers to make the best decision and predicting events before their occurrence.

Zeevi et al. (2015) have devised a machine learning algorithm for prediction of personalised postprandial (post-meal) glycemic responses. The system integrates blood parameters, dietary habits, anthropometrics, physical activity, and gut microbiota, for a total of 137 attributes. A cohort of 800 participants was used to gather data, validating the model with another cohort of 100 participants. This study has also performed a blinded randomised controlled dietary intervention based on this algorithm, resulting in lower postprandial responses and alterations to gut microbiota.

Aravind and Sweetlin (2018) have developed a system for nutrient facts analysis using machine learning systems. To make the nutrition facts more accessible and easier to understand, they applied supervised learning approaches to classify food products by their level of healthiness. Multiple models were tested and compared, including K-Nearest Neighbours, Support Vector Machines, Classification and Regression Trees (CARTs), with a maximum accuracy of 73%.

Pouladzadeh et al. (2015) has created a platform for food intake, estimating from images acquired by a mobile device. To identify the food consumed at a meal, the solution uses Support Vector Machines for image recognition. Clustering algorithms were also used to extract segments of the food portion, namely colour segmentation, k-means clustering, and texture segmentation tools. The solution is cloud-based, allowing for a distributed system, encouraging mobile users to use the platform remotely.

Srinivas et al. (2010) have implemented another data mining study, this time in a healthcare environment. Their main goal was to apply data mining techniques for the prediction of heart attacks using medical profiles such as age, sex, blood pressure, and sugar levels. By using One Dependency Augmented Naive Bayes (ODANB) classifiers and Naive Credal Classifier 2 (NCC2) (NCC2), they were successfully able to create models that predict the risk of heart attacks.

2.4 RECOMMENDER SYSTEMS

Recommender Systems are defined as *"software tools and techniques that provide suggestions for items that are most likely of interest to a particular user."* (Rubens et al., 2015, 1).

Their main ability is providing personalised and relevant recommendations to users. Recommender systems focus on a specific domain of items (for example, movies, books, or music), the user's graphical interface, and the recommendation techniques used to generate useful suggestions for that type of item (Rubens et al., 2015, 1). Recommendation systems store multiple kinds of data to build its suggestions—namely items, users, and transactions (Rubens et al., 2015, 8).

The items being recommended can be described by their complexity and utility for the user. Its value and cost to the user has to be taken into consideration when choosing the

most appropriate recommendation technique, as multiple domains—for instance, economic investments or vehicles—require carefully chosen suggestions.

Users of a recommender system have their specific needs and requirements. To personalise the recommendations, these systems gather and exploit a range of information about the users This data *"is said to constitute the user model."* (Rubens et al., 2015, 9), profiling the user's preferences. The user model plays a key role in the recommendation process, enabling personalised and useful suggestions.

Transactions are referred to as the interactions between the users and a recommender system. They are data recorded during the human-computer interaction, which is useful for the recommendation algorithm. For example, a transaction may contain a reference to an item selected by a user, the context for that recommendation, and feedback for the suggestion.

Machine learning and data mining algorithms enable the development and implementation of recommender systems, powering a wide variety of domains from entertainment to e-commerce and social networking.

2.4.1 *Recommendation Techniques*

A recommender system must be able to predict if an item is worth recommending. The system has to predict or compare the utility of some items and then decide which items to recommend for a user (Rubens et al., 2015, 10).

There are multiple approaches for the design of recommender systems. The most commonly used recommendation algorithms, and how they predict the utility of a recommendation, are described in the following subsections.

Content-Based Filtering

In content-based recommender systems, the descriptive attributes of items are used to make recommendations. The content information of the items are combined with the ratings and buying behaviour of users. That way, the system learns to recommend items that are similar to the ones the user liked in the past (Rubens et al., 2015; Aggarwal, 2016).

Content-based recommendation techniques*"aim at matching the attributes of the user profile against the attributes of the items."* (Rubens et al., 2015, 12) The item's descriptions, labelled with ratings, are *"used as training data to create a user-specific classification or regression modelling problem"* (Aggarwal, 2016, 15). For each user, the training set consists of descriptions of the items a user has rated, while the class attribute corresponds to a rating or a user's behaviour. The training data set is used to create a classification or regression model specific to each user. This model is then used to predict if that user will like a new item.

These approaches have their advantages and disadvantages. They perform better in making recommendations for new items when rating information is not available yet, as other items with similar attributes may already been rated by the user. The model can then use these ratings, along with the item's attributes, to make suggestions with no history of ratings for that item. However, they aren't effective at providing recommendations for the users, as the model needs a history of ratings to provide good suggestions.

Collaborative Filtering

Collaborative filtering models *"use the collaborative power of the ratings provided by multiple users to make recommendations."* (Aggarwal, 2016, 8). The recommender system makes suggestions to a user based on what others have liked in the past. This similarity is calculated based on the rating history of the users.

The principle of collaborative models is predicting a user's missing ratings as they can be correlated across various users and items. Users with the same tastes often have a similar rating of items. The algorithm calculates the similarity between these users, being likely that the ratings only one of them has specified are likely to be similar.

Two methods are commonly used on collaborative filtering systems, namely neighbourhood-based methods and model-based methods. Neighbourhood-based methods, also referred as memory-based methods, *"focus on relationships between items or, alternatively, between users"* (Rubens et al., 2015, 12), while model-based methods use machine learning and data mining algorithms *"in the context of predictive models."*(Rubens et al., 2015).

Knowledge-Based Recommenders

Knowledge-based recommenders pursue a knowledge-based approach to generating recommendations by using information about users and products to deduce which products meet the user's requirements (Burke, 2000, 1).

These systems are useful in domains where items are not frequently bought such as real estate or automobiles. As the items are rarely bought and also require different types of detailed options, it makes the acquisition of ratings a difficult process.

Knowledge-based recommenders don't use ratings for making suggestions. Instead, *"the recommendation process is performed on the basis of similarities between customer requirements and item descriptions, or the use of constraints specifying user requirements"*(Aggarwal, 2016, 16). They also allow for the user to explicitly specify what they want and what their requirements are, allowing for users to have greater control over the recommendation process.

Knowledge-based systems are related to content-based filtering recommenders, depending on the item's attributes. They share some disadvantages, like the fact that they don't explore the relationships between users. Whereas content-based filtering learns from the

user's past behaviour, knowledge-based recommenders make suggestions based on an active specification of the user's needs and requirements (Aggarwal, 2016, 18). Knowledge-based systems can be classified on the user interface used to achieve the recommendations, either as constraint-based or case-based.

Hybrid Recommenders

The previously mentioned recommender techniques exploit different types of information, allowing them to perform well in different scenarios. Content-based filtering uses the item's attributes and the user's ratings while collaborative-based filtering relies on community ratings and knowledge-based recommenders rely on interactions with the user. These systems all use different types of input, each with their advantages and disadvantages (Aggarwal, 2016, 19).

Hybrid systems combine multiple recommendation techniques, using the advantages of one technique to overcome the downsides of another (Rubens et al., 2015, 14). If a wider variety of information is available, *"one has the flexibility of using different types of recommender systems for the same task"* (Aggarwal, 2016, 19).

2.5 Food Recommender Systems

Food recommender systems offer suggestions for recipes/food items to users, keeping in consideration their wishes and needs. Nowadays, modern food recommenders not only recommend recipes suiting user's preferences, but they also suggest healthier choices. Food recommenders can also keep track of eating behaviour and help a user understand the impact of nutrition in their health, persuading a user's eating behaviour.

Implementing a food recommender system is, however, a challenging task. The food domain is complex and extensive, with thousands of recipes, ingredients, and nutritional information to collect. The ingredients are also usually combined with each other in a recipe instead of being consumed separately, increasing the complexity of a recommender system. Additional challenges in food recommender systems include how to gather user information and preferences, especially when the system is being used for the first time; how many recipes should the system have, and ensuring their nutritional information is accurate; improving the quality of suggestions; changing user's eating behaviours in positive ways; explanations on why a decision outcome is created; and how to suggest food items to groups (Trang Tran et al., 2018, 502).

2.5.1 *Comparison of Food Recommenders*

Food recommender systems can be developed for multiple target audiences and goals. They can be classified in several types: considering the user's preferences, recommending healthier recipes or food items that are most similar to the ones the user liked in the past; considering the nutritional needs of users, recommending to users those items which have been identified beforehand by health care providers; striking a balance between preferences and nutritional needs; recommending food for groups, in which food items are consumed by groups of users rather than by individuals (Trang Tran et al., 2018, 507).

Existing research on food recommender systems is summarised and compared in how they take into account the user's preferences and/or their nutritional needs, and how the system generates those suggestions.

De Pessemier et al. (2013) have proposed a food recommender for patients in a care facility. As many of those patients cannot express their personal preferences, a recommender system can assist in the selection of the menu items that match a patient's taste. A framework was also developed to store data about preferences, activities, and behaviours of patients regarding meals.

Their recommendation strategy involved the development of a hybrid recommender system using implicit and explicit feedback, as well as collaborative filtering based on ingredients. Implicit feedback can be estimated by the patient's eating behaviour and the amount of food eaten. This behaviour can be registered by the caregivers using their mobile devices. Explicit preferences can be specified by the patient, caregivers, as well as family members. A collaborative approach was also implemented, where personal preferences for new ingredients are inferred from the preferences of neighbouring patients. The patient's preferences for the ingredients are extrapolated by decomposing the menu items into high-level ingredients.

In addition, the framework developed can also monitor the amount of food eaten by every patient over time, detecting irregularities in eating behaviour. This information can be of use to the caregivers to keep track of the patient's health condition.

Agapito et al. (2014) have presented a recommender system for the adaptive delivery of nutrition contents, improving the quality of life of both healthy subjects and patients with diet-related chronic diseases. The system also contains catalogues of typical regional foods from Calabria, Italy, characterised by their nutraceutical properties.

Individualised nutritional recommendations are provided according to the user's health profile through the administration of medical questionnaires provided by nutrition specialists and nephrologists. The system has the ability to profile healthy users, as well as patients

affected by chronic kidney disease, hypertension, and/or diabetes. Patients with chronic kidney disease are also provided with glomerular filtration rate estimations for disease staging.

To give users dietary advice, the system adopts a user's health status, disease data, and food nutritional information. The system evaluates whether a food item is compatible with the user's health status, and sorts the items according to how appropriate they are. However, the system does not suggest food items based on the user's preferences, instead, it uses a knowledge-based approach for food recommendation.

van Pinxteren et al. (2011) have developed a recipe recommender system, aiming for a strategy to provide healthier variations to routine recipes, by taking a user-centred approach.

To identify the most important aspects that contribute to the recognition of the similarities between recipes, a card-sorting task was designed. Using two recipe sets, one comprising of popular recipes, and another comprised of twenty Italian pasta dishes, they were able to represent the dishes in 55 features, divided over 13 characteristics. A feature extraction algorithm was also used, converting recipes into a feature-vector representation.

A recipe similarity measure was also derived, similar to the current state of the art in an evaluation with potential users. This measure was explored in a small scale at-home study, analysing if the recipes suggested by the system were similar to the user's eating patterns. Unfortunately, the challenge of assessing the healthiness of a recipe is beyond the scope of this paper.

Teng et al. (2012) seek to distil the collective knowledge and preferences about cooking using data mining algorithms on a popular recipe-sharing website. To extract information, the unstructured text of recipes and the accompanying user reviews are parsed.

Two types of networks were constructed, reflecting different relationships between ingredients and capturing the user's knowledge on how to combine ingredients. A complement network captured which ingredients tend to co-occur frequently, while the substitute network, derived from user-generated suggestions for modifications, can be decomposed into many communities of functionally equivalent ingredients, as well as capturing the user's preferences for healthier alternatives.

With this information, they performed a prediction task, where given a pair of similar recipes, the algorithm should determine which one has a higher average rating than the other. Discriminative machine learning algorithms such as support vector machines and stochastic gradient boosting trees were used for this prediction problem. The ingredient networks had better performance metrics than a full ingredient list, showing that the rela-

tionship between ingredients can be used to predict users' preferences about recipes.

Freyne and Berkovsky (2010) have presented an investigation on the design of a food recommender, aimed at educating and sustaining user participation, which makes tailored recommendations of healthy recipes. Two data gathering strategies were applied: a fine-grained food item strategy that gathers ratings on individual food items, and an approach that gathers ratings on recipes.

To relate ingredients to recipes and vice versa, the authors have developed a relationship strategy, where all food items are equally weighted within a recipe. As such, ratings gathered on recipes are transferred to food items, and vice versa from food items to recipes. Multiple recommendation strategies were also used, namely content-based algorithms, community filtering algorithms, and hybrid approaches of both content-based and collaborative strategies. The recommenders are categorised according to the item types (food items or recipe items) on which their input is based and what recommendation strategies they use.

The best results were from strategies whose input ratings were recipe-based, where the best performer was the hybrid approach. Thus, the decomposition of recipes into food items was beneficial for the purposes of generating recommendations, even with a naive break-down and reconstruction applied, avoiding the need of a user to rate food items for recipe recommendations.

Ge et al. (2015) have proposed a mobile food recommender system that provides high quality and personalised recipe suggestions. A user can use their Android device to access the recommender system, and get suggestions on what to cook at home.

A mobile app allows for two preference elicitation processes; one where the user rates and tags recipes, and another where the user defines important ingredients to them, and should therefore be included in the recommended recipes. The recommendation employs a hybrid approach, building upon a matrix factorisation method by using both ratings and recipe features in the form of tags.

Zhang et al. (2008) have presented a knowledge-based food recommender system, leveraging multiple machine learning algorithms. This system was part of the *Case Based Cookery Challenge*, offering a new approach for Case Based Reasoning recipe systems.

For the design of a structured case representation, the provided recipes were in a semi-structured textual format. A framework for case description was developed, replacing the list of text-based ingredients with a structured ingredient representation. To identify all food products from the ingredient text, the WordNet lexical database of English was used. The recipe information was parsed using regular expressions, and potential food

products were identified, ensuring each one is a node in one of a number of food related sub-hierarchies in WordNet.

An active learning system was built to label each recipe, its appropriate course type, its cuisine types. Multiple two-class active learning labellers were built, where each labels recipes as either belonging to a target class or not. That way, the recipe case can be easily labeled with a large number of tags, minimising the labeling effort required by human experts.

A user can access the system by querying a list of ingredients that should be included or excluded in any recommender recipe, and by optionally selecting a specific type of course and/or cuisine. Each ingredient is validated as a food concept in WordNet in the same way as the system identifies the ingredient food products in a recipe case. The system then retrieves recipes from the case that best match the query. A weighted measure of similarities between the query requirements and the case base is used for comparing each recipe with the request. By using any valid WordNet food concept as a requirement, some generalisation in the querying process is allowed. For example, certain requirements such as salads or soups can be added as a requirement or as an exclusion.

2.6 CONCLUSION

This chapter has presented several topics of interest to the project, specifically machine learning and recommender systems. To develop a next-generation platform for meal planning and provisioning, a comprehensive study on theoretical concepts and past works is an important process.

A theoretical background on machine learning was offered, introducing its main concepts and presenting multiple paradigms, categories of tasks, and machine learning systems, with an added focus on Decision Tree Learning. Several healthcare and nutrition projects that have implemented machine learning systems in literature were also discussed.

An introduction to recommender systems was presented, as well as how they can be used in a wide variety of domains. The most commonly implemented recommendation techniques were analysed and compared, describing how they predict the utility of a recommendation. Multiple food recommender systems were compared in how they take into account the user's preferences and/or their nutritional needs, and how the system generates those suggestions.

In the next chapter, the Design Science research investigation methodology as well as the tools and technologies used for developing solutions are explored and reviewed.

3

RESEARCH METHODOLOGIES & TOOLS

3.1 INTRODUCTION

A research project requires the adoption of methodologies to define its phases, processes, and methods. As such, every IT study must carefully research and analyse multiple methodologies and technologies that are both available and viable for the conception of a solution (**?**). The final decision should be based upon their main advantages and limitations, as well as their compliance and security requirements.

Thereby, the development of this dissertation project was based upon the Design Science Research (DSR) investigation methodology used on the construction and evaluation of reliable and rigorous IT solutions. Additionally, in every phase during the creation of this system, from the data mining process to the development of the project, multiple methodologies, technologies, and toolkits that are appropriate for the definition and implementation of each component of the final solution were adopted and implemented.

SWOT analysis is a planning technique used to identify the strengths and weaknesses (internal factors), in addition to opportunities and threats (external factors), of a business or project plan (Mitchell, 2019). A SWOT analysis can help reveal opportunities to exploit, explain potential weaknesses, and develop strong strategic plans (Wikipedia contributors, 2019; Mind Tools Content Team, 2019).

In the following sections, the Design Science Research methodology is presented, describing the phases and techniques for the creation of knowledge, as well as how SWOT analysis was used to evaluate the platform's Proof of Concepts (PoCs). In addition, tools and technologies used for developing the solution are showcased and discussed, along with main reasons for adoption.

3.2 DESIGN SCIENCE RESEARCH METHODOLOGY

To answer all proposed Research Questions, a Research Design applied to engineering and sciences was formulated, leading to the adoption of the Design Science Research method-

ology. This methodology is used for the development of solutions and approaches in ITs, creating knowledge than can be shared and discussed.

Design Science Research can be described as a *"research paradigm in which a designer answers questions relevant to human problems via the creation of innovative artefacts, thereby contributing new knowledge to the body of scientific evidence"* (Hevner and Chatterjee, 2010, 5). Two primary activities improve and elaborate on the behaviour of aspects in Information Systems, namely the *"creation of new knowledge through design of novel or innovative artefacts (things or processes) and the analysis of the artefact's use and/or performance with reflection and abstraction."* (Kuechler and Petter, 2017, 1).

The initial phase for a Design Science Research methodology is an **Awareness of Problem**: defining a problem and it's importance and outputting a proposal for a new research effort.

Afterwards, a **solution** must be presented with a proper foundation, where new functionalities are envisioned based on a novel configuration of either existing or new and existing elements, and what this new artefact would accomplish.

The new artefact is then **developed** and **evaluated** according to implicit criteria made explicit in the proposal. If the artefact confirms a hypothesis, it can be considered as a final solution that may be shared or published.

This methodology uses an iterative approach, allowing it to have the freedom to adapt the structure and evaluation of the developed artefact until an ideal solution is found (Kuechler and Petter, 2017, 8-10).

The Design Science Research methodology was represented by (Peffers et al., 2007) in Figure 2.

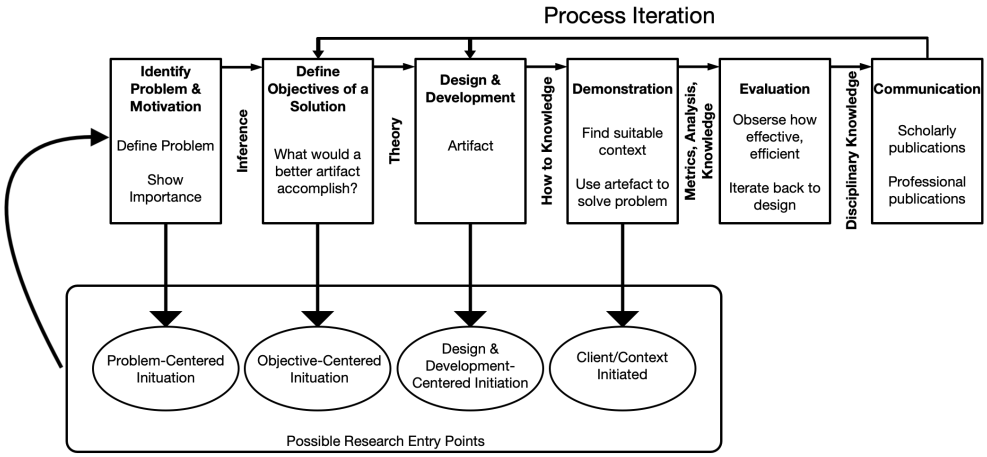


Figure 2.: Design Science Research Methodology (Peffers et al., 2007, 15)

For this dissertation project, the DSR methodology is used to ensure the solution to the problem accomplishes all needs and requirements of the professionals in the Social Canteen of Vila Verde.

This way, the health institution is provided with an appropriate and well-founded solution, based on methodologies and technologies already explored and proven suitable for the solution to the problem in question, while elucidating new knowledge both to the institution and to the scientific community.

3.3 Programming Languages and Frameworks

For a successful development of the system, multiple tools and technologies were used. In this section the adopted frameworks and programming languages for the development of the proposed platform are presented. In particular, the frameworks and languages used were: *Node.js*, a JavaScript run-time environment used in the creation of Web services; *R*, an environment for statistical computing deployed for the creation of machine learning models; *React*, a JavaScript library applied for building the web app's interface; *React Native*, a software developer kit used to develop the Android and iOS applications with the same code base; *MySQL* Database Management System (DBMS), storing all information regarding users and business requirements.

3.3.1 *Node.js Run-Time*

Node.js is an open-source JavaScript run-time environment, enabling JavaScript code to run on the server uncoupled from a browser (Brown, 2014). It is not by itself a web server, but rather it contains a built HTTP server library, allowing for greater control at the cost of increased complexity in configuration and preparation. By being single-threaded, Node.js web servers are faster and make very efficient use of system resources, serving more customers with fewer resources (Holmes and Herbert, 2019, 30).

Express.js is self described as *"a minimal and flexible Node.js web application framework that provides a robust set of features for web and mobile applications."* (Node.js Foundation, 2019). Express.js sets up a web server to incoming requests and return results while offering an interface for routing an incoming URL to a piece of code, HTML responses for server-side rendering, and session support for user identification. Thus, Express.js abstracts multiple complexities and repeatable tasks, allowing for faster, more efficient and more maintainable web applications (Holmes and Herbert, 2019, 36).

For the development of the platform's RESTful Web services, Node.js at version 12.1.0 was used, along with Express at version 4.16.4, the Sequelize Object-Relational Mapping (ORM) at version 5.8.6, and Passport.js, an authentication middleware, at version 0.4.0.

RESTful Web Services

REpresentational State Transfer (REST) is an architectural style which serves as a model on how to build Web services. Web services that satisfy the principles of REST, also called RESTful Web services, provide uniform interface semantics between agents. REST interactions are stateless, meaning that the interpretation of a message does not depend on the state of the conversation (Booth et al., 2004).

RESTful Web services use Uniform Resource Identifiers (URIs) to identify resources, Web protocols, for example, HyperText Transfer Protocol (HTTP) and Simple Object Access Protocol (SOAP), and data formats for messaging.

For the development of the Web services, HyperText Transfer Protocol (HTTP) methods are used to operate Create, Read, Update, Delete (CRUD) operations. *POST* requests are used to create resources, *GET* to read resources, *PATCH* to update resources, and *DELETE* to delete resources (Holmes and Herbert, 2019, 187). RESTful Web services should return a consistent data format. Commonly used data formats are Extensible Markup Language (XML) and JavaScript Object Notation (JSON). The developed Web services use JSON as they are JavaScript-friendly, and they are also simpler and more compact than XML.

The OpenAPI Specification is used to specify the available endpoints, using Swagger Tools to design, document, and test the developed Web services.

3.3.2 *R Programming Language*

R is a language and software environment for statistical computing and graphics. The R environment provides a wide variety of statistical, graphical techniques, and has extensible thought functions and packages. Therefore, R is used by statisticians, data analysts, researchers, and marketers to retrieve, clean, analyse, visualise, and present data (R Core Team, 2019).

R includes a suite of facilities for data manipulation, calculation, and graphical display. It includes a data handling and storage facility, a collection of operators for calculations on arrays in particular matrices, graphical facilities for data analysis and displays, and a simple and effective programming language (The R Foundation, 2019). Multiple statistical and graphical techniques have been implemented in R, including linear and nonlinear modelling, classical statistical tests, time-series analysis, classification, clustering, and others. The R developer community contributes by developing and sharing packages, enhancing R's features, and introducing new techniques and algorithms.

To design, develop, and explore a food recommender system using machine learning algorithms, the R programming language and software environment at version 3.6.0 (2019-04-26) was adopted, along with the RStudio Integrated Development Environment (IDE). Several third-party packages were also used, for example, the *ggplot2* system for the cre-

ation of graphics, the *rminer* set of data mining methods in classification and regression tasks, and the *e1071* collection of functions for latent class analysis, short time Fourier transformations, fuzzy clustering, support vector machines, and others (Wickham, 2016) (Cortez, 2016) (Meyer et al., 2019).

3.3.3 *React Library*

React is a JavaScript library built and maintained by Facebook to address some of the challenges associated with large-scale, data-driven websites (Banks and Porcello, 2017). React allows the construction of components that manage their own state, then composes them to create complex and interactive user interfaces (Facebook Inc., 2019).

These components implement a render method that takes input data and returns a display to the browser. Components use an XML-like syntax extension to JavaScript called JSX, and are later transformed to raw JavaScript code. Components can also maintain internal state data. When the state of a component changes, the component renders a new interface that reflects those changes (Facebook Inc., 2019).

The React library greatly simplifies the process of building Single Page Applications (SPAs) by automatically updating the browser's DOM. Developers don't have to deal with the complexities of maintaining the DOM, allowing them to create optimised Web applications (Banks and Porcello, 2017, 76).

To tackle the multiple challenges in maintaining an ever-growing state and how data changes flow thought the application, the Redux library was developed. Redux was inspired by Facebook's Flux architecture for building user interfaces. Both make developers focus their model update logic in a certain layer of their applications, and describe every mutation as an object (Abramov and Redux Documentation Authors, 2015b).

Redux's main concepts are actions, reducers, and the store. Actions are payloads of information that send data about what should change in the application state, along with the necessary data to make those changes. They are the only source of information for the store, being sent through dispatches (Banks and Porcello, 2017, 201). Reducers specify how the application's state changes in response to actions sent to the store. They are functions that take the current state along with an action and use them to create and return a new state. The state of the whole application is stored in a object tree within a single Store (Abramov and Redux Documentation Authors, 2015a).

The architecture of a React application implementing Redux was represented by Pini in Figure 3.

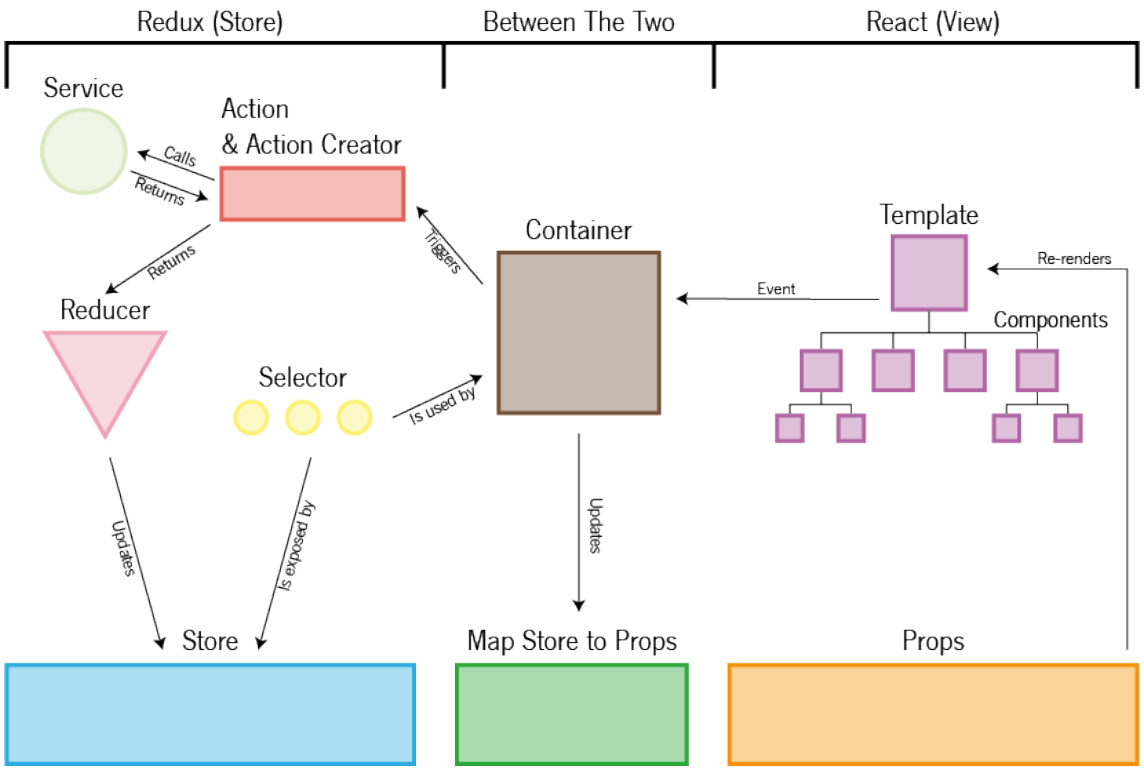


Figure 3.: Architecture and data flow of a React application implementing Redux (Pini, 2016)

The developed solution uses the React Router package, offering a collection of navigational components that allow for declarative routing. This package allows for the routing of Single Page Applications according to the browser's URL, having a similar behaviour as regular web pages. Additionally, the solution employs Redux for state managment, Formik to easily build forms, and the Semantic UI component framework. The *create-react-app* toolchain was used at version 3.0.1, offering a modern build setup with no configuration.

3.3.4 *React Native Framework*

React Native is a JavaScript framework for building native rendering applications for iOS and Android. It is based on React, but targets mobile applications instead of web browsers. Thus, React Native enables web developers to write applications using declarative components. Additionally, as most of the code can be shared between platforms, React Native allows to simultaneously develop for iOS and Android (Eisenman, 2017, 16).

Similarly to React, React Native applications use JSX to construct and compose components. Under the hood, the React Native "bridge" invokes the native APIs in Objective-C (for iOS) or Java (for Android). Consequently, applications will render using real UI components, and will look and feel like native mobile applications. React Native also exposes

JavaScript interfaces for platform APIs, allowing apps to access platform features like the phone's camera or the user's location (Eisenman, 2017, 16).

An alternative to React Native is Flutter from Google. Like React Native, Flutter enables developers to write mobile, web, and desktop applications from a single code-base. Flutter applications are written using Dart and employ reactive-style views. Flutter is still too young to be adopted for a long-term project, but it shows great progress, with a growing developer community, and new features being introduced (Flutter Team, 2019).

For the development of the platform's mobile application, the React Native application framework at version 0.59 was adopted. React Native empowers developers to use the concepts learned from developing React web applications to write a mobile application. Hence, the developed solution reuses multiple packages from React, namely Redux for state managment, React Router, and Formik to build forms. Additionally, the Ant Design Mobile UI component library was adopted, ensuring an attractive user interface for both Android and iOS.

3.3.5 *MySQL Database*

MySQL is a relational Database Management System (DBMS), allowing users to define, create, support, and control access to the database (Connolly and Begg, 2015, 16). A MySQL database was developed and implemented in order to store and maintain all relevant data in regard to the platform's usage.

Relational Database Management Systems (DBMSs) are based on the relational data model proposed by E. F. Codd (1970), in which all data is logically structured within relations/tables. Each relation has a name and a set of attributes/columns of data. Every row contains one value per attribute, as well as a unique key identifier. Relationships allow for connections between tuples of two or more relations (Connolly and Begg, 2015, 69).

MySQL uses the Structured Query Language (SQL) to create databases, perform data management tasks, and execute queries. SQL is comprised of two main components, namely a Data Definition Language (DDL) for defining the database structure and controlling access to the data (*CREATE, ALTER, DROP* statements), and a Data Manipulation Language (DML) for retrieving and updating data (*SELECT, INSERT, UPDATE, DELETE* statements). Extensions are features provided on top of the standard by the vendors, including new data types and control-of-flow procedures (Connolly and Begg, 2015; Dyer, 2015).

MySQL at version 8.0.16 was adopted due to its compatibility with multiple operating systems, its versatility, and a wide variety of third-party integrations and utilities. In addition, JetBrains' DataGrip and MySQL Workbench were used for data manipulation. Other relational DBMSs include Oracle SQL, PostgreSQL, and Microsoft SQL Server.

3.4 PROOF OF CONCEPT METHODOLOGY

A Proof of Concept (PoC) is a demonstration to confirm whether a concept or theory is feasible for real-world applications (Singaram and Jain, 2018; Techopedia, 2019). A methodology is made up of practical models that can prove or validate a concept through analysis and development. Proof of concept research *"presents a discovery about our knowledge of the world and the structure of existence"* (Kendig, 2016).

A Proof of Concept is considered a key procedure in the process of design, development, implementation, and proposal of software solutions in the field of ITs. They validate whether a project fulfils its main features and defined objectives, as well as identifies potential flaws or mistakes in the developed solution. In addition, the concept of proof in research aims to answer a question whose answer has wide applicability in areas beyond those tested for (Kendig, 2016).

In this dissertation project, the viability and functionality discussion of the developed tools for decision support was corroborated by the application of a Proof of Concept methodology. As such, two Strengths Weaknesses Opportunities Threats (SWOT) studies were performed on both web and mobile applications, as well as on the meal planner module.

The proof of concept of this work, and all steps taken into account towards its creation, is described in chapter 6 of this document.

3.4.1 *SWOT Analysis*

The Strengths Weaknesses Opportunities Threats (SWOT) analysis planning technique is used to develop strong strategic plans by analysing the strengths and weaknesses (internal factors), in addition to opportunities and threats (external factors), of a business or project plan (Mind Tools Content Team, 2019). A SWOT analysis promotes a fact-based and data-driven analysis of the internal and external factors that are advantageous or detrimental, helping reveal prospective opportunities to exploit and understand potential weaknesses (Mitchell, 2019; Wikipedia contributors, 2019).

SWOT analysis groups key data into two main categories: internal and external. Internal factors are the present strengths and weaknesses of an organisation while external factors are the opportunities and treats [?] offered by the environment, out of control of the organisation. SWOTs can be used as inputs for the creation of strong, well-calculated strategies (Hay and Castilla, 2006).

In the context of applying a SWOT analysis to the developed platform and the food recommender module, each study can thus be based on four main components:

- Strengths: internal attributes of the platform that are helpful towards its successful development and integration;
- Weaknesses: internal attributes of the platform that are harmful towards its successful development and integration;
- Opportunities: external attributes of the platform that are helpful towards its successful development and integration;
- Threats: external attributes of the platform that are harmful towards its successful development and integration.

A carefully thought out SWOT analysis can produce valuable information that helps in decision making. When the potential implications of this information on the organisation are fully assessed, meaningful analysis emerges (Hay and Castilla, 2006).

The SWOT matrix was represented by (Mitchell, 2019) in Figure 4, where each characteristic is made up in one quadrant, providing a quick overview of a project's position.

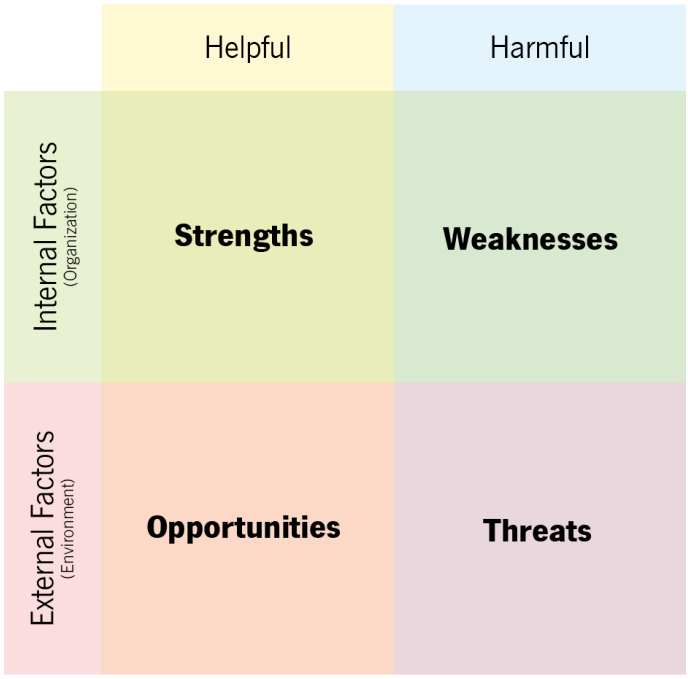


Figure 4.: SWOT Matrix (Mitchell, 2019)

In subsection 6.2.1 and subsection 6.2.2, the SWOT analysis technique will be performed on the developed platform for meal provision and management, as well as the meal planner module.

3.5 CONCLUSION

This chapter has presented the Design Science Research methodology, all tools and technologies that were adopted, as well as the Proof of Concept methodology and the SWOT analysis technique, ensuring that the solution to the problem accomplishes all needs and requirements of the professionals, while elucidating new knowledge both for the institution and the scientific community.

For the developed platform, *React* and *Reach Native* were used to implement the platform's front-end, while *Node.js*, *R*, and *MySQL* were used to store and query all relevant data, as well as to create machine learning models for the food recommender module.

In the next chapter, each of the case studies in this dissertation project will be displayed, as well as their respective phases and main results obtained during the development of this work.

4

PLATFORM FOR MEAL PROVISION AND MANAGEMENT

4.1 INTRODUCTION

In this chapter, the platform for meal provision and management is introduced and discussed. This platform is composed of a web and a mobile application supporting the Social Cafeteria's operation. Key features include an improved ingredient repository, an upgraded recipe system, an easier approach for all coordinators to order meals for their departments, and a mobile application for users of the Social Cafeteria.

In the following sections, the problem and its motivations are described, as well as the platform's main objectives and requirements elicited during its development. All steps taken during the platform's design and development process are described. Thus, the platform's architecture, database models, and the usage of Node.js and React are analysed and documented. This chapter concludes with a discussion of the results obtained, as well as a brief conclusion and an insight into future work.

4.2 CONTEXT AND MOTIVATION

The Social Cafeteria of the *Santa Casa da Miserdicórida de Vila Verde* is responsible for the preparation and distribution of dishes to all departments of the health institution. This division serves over 100 dishes per day, including short and long stay units, a convalescence unit, a nursery, a kindergarten, a nursing home, and a cafeteria, each with their own specific nutritional requirements and schedules.

To support this volume of requests, a system for the provision of meals was implemented where each department can reserve how many dishes are expected for the following week because the number of users is stable and predictable. In the cafeteria, the reservation system is slightly different, as the users can order their meals for the day only until 10 AM.

However, the current version in the social cafeteria is completely archaic. The previous platform was developed using Microsoft Access in 2015, therefore hosting critical security vulnerabilities. In addition, the platform is confusing to use and unappealing, and the

reservation system is considered restrictive by the nutrition specialists. As no one has the original source code and the database is encrypted by a password [1], the application cannot be fixed or improved.

The cafeteria's reservation system is chaotic and disruptive, since the social cafeteria spends their mornings picking up calls regarding reservations. To add insult to injury, multiple people make their reservations and fail to show up, and some arrive without making reservations at all. This approach is extremely costly and stressful to the nutrition specialists in the social cafeteria, whose main job is to maintain the social cafeteria's operations.

This master's dissertation was thus proposed, consisting of the design, development, and exploration of a new platform for meal provision and management, incorporating machine learning algorithms for decision support, and helping nutrition specialists at the *Santa Casa da Miserdicória de Vila Verde* on their work, namely in the making of meal plans for multiple departments, each with their nutritional requirements.

Thus, in the first case study of the development of this dissertation project, a new platform for meal provisioning and management was designed and developed, comprised of a web and mobile application. This new solution is comprised of a suite of tools and modules designed to help nutrition specialists on their work, as well as a mobile application for the cafeteria's users. The decisions of all modules, components, and features developed in the platform were based on meetings with health and nutrition specialists at the social cafeteria in order to bring about the main objectives to fulfil the development of the solution, specifically the necessary business and technical requirements.

4.3 Platform Objectives

The platform for meal provision and management was designed to help nutrition specialists at the *Santa Casa da Miserdicórdia de Vila Verde* in their daily work. In particular, the design aids with the making of meal plans for multiple departments, each with their specific nutritional requirements.

The aim of this case study is to design, develop, and implement a new software platform, comprised of a web and a mobile application. This system must provide answers to the social cafeteria's main necessities and obstacles in order to help optimise its workflow and reduce costs.

Thus, the main objectives to fulfil with the development of the platform are the following:

- Researching requirements of the design and development of the platform thought meetings with health and nutrition specialists at the *Santa Casa da Miserdicórdia de Vila Verde*

1 By reverse-engineering the application, the database's password was eventually retrieved. This database was useful to recover a repository of registered recipes.

- Development of database models that store all relevant information such as dishes, ingredients, users, food plans, and reservations
- Development of APIs and Web Services to give support both to web and mobile applications
- Development of a web app using the React library, including multiple modules, components, and features for administration
- Development of an *Overview* module which provides a summary of the cafeteria's operations, the number of reservations by the departments and in the cafeteria, feedback from users, and any other possible indicators of service
- Development of an *Ingredient* module, allowing for interactions with the ingredient repository
- Development of a *Data Sheet* module for the creation and manipulation of dishes and their preparations
- Implementation and deployment of said platform in the Social Cafeteria of Vila Verde
- Ensuring the proposed software platform is compatible with the current systems in place at the Social Cafeteria of Vila Verde

4.4 Business Requirements

To assess the platform's main objectives and requirements, multiple meetings and brainstorm sessions with the nutrition specialists at the social cafeteria were prepared. The social cafeteria's main problems and challenges were identified, along with how the proposed platform can help their daily work in making meal plans for all departments. Multiple use cases for the system were established, as well as writing definitions of terms used in the social cafeteria. The platform's main components, features, and constraints were analysed and discussed, including their technical feasibility and priorities.

Several key requirements for the multiple system modules and components include:

- **Web Application**
  - The web application should only be accessed by the nutrition specialists and health professionals at the *Santa Casa da Miserdicórdia de Vila Verde*
  - The application must be compatible with all commonly used web browsers, as well as responsive to desktops and tablets

  - The application's main components are the planning and reservation of meals for all divisions, the creation of recipes and their preparations, and the administration of the platform's users and divisions
  - The application should have an intuitive user interface, adopting a simple and clear design language
  - The application must allow for future integration and expansions

- **Ingredient Module**
  - This module must allow for the creating, manipulation, and removal of ingredients for future usage
  - The ingredient repository is based on *PortFIR*, a database composed of ingredients and their complete nutritional information
  - An ingredient is categorised by their basic information, their allergens, and their nutritional information
  - Multiple nutritional components are required in order to accurately calculate a dish's nutritional information

- **Data Sheet Module**
  - This module is responsible for the manipulation of dishes and their preparations
  - A preparation is made from the item's basic information, multiple ingredients, and instructions of confection, allowing for the preparation to be reused for multiple dishes
  - The module must allow for the creation, manipulation, removal, and printing of preparations
  - A dish is composed of their basic information and a set of preparations
  - The module must allow for the creation, manipulation, removal, and printing of dishes

- **Mobile Application**
  - The mobile application's main goal is to allow the cafeteria's users to interact with the platform
  - The user must be able to see the menu for the week, their past dishes, and their nutritional information
  - The user must be able to order and cancel their meals thought their mobile devices
  - The user should receive notifications of changes in the food menu

4.5 PLATFORM'S ARCHITECTURE AND DEVELOPMENT

To successfully develop the system, multiple tools and technologies were studied and the most appropriate were chosen to create the solution. The chosen technologies are:

1. **Node.js**, an open-source, cross-platform JavaScript run-time environment used to create the web server. In addition, the **Express** framework is used to build the system's web services and **Passport.js** to ensure a secure authentication process
2. **MySQL** is the Database Management System (DBMS), storing all information regarding users and business requirements
3. **R** is a language and software environment used to develop and a explore a food recommender using machine learning algorithms
4. **React** is a JavaScript library used to build the interface of the web application
5. **React Native** is a software developer kit used to develop an Android and iOS application using the same code-base

In the following subsections, the platform's architecture is presented, as well as the database tables modelled with the Sequelize Object-Relational Mapping (ORM), how the web services were developed using Node.js, the web application's modules, and the mobile application's main features.

4.5.1 *Platform Architecture*

The application is comprised of two main types of users, namely the health and nutrition specialists at the Social Cafeteria and the cafeteria's users. Each type of user is able to use a specific application of the platform. While the social cafeteria uses the web application to plan and reserve meals at the *Santa Casa da Miserdicódia de Vila Verde* and at the hospital of Vila Verde, the cafeteria users can make use of the mobile application to obtain the menu and its nutritional information, and can easily make their reservations thought their smartphones.

The web application was developed with the React library, whereas the mobile app was developed with the React Native framework. Both applications allow for the construction of components that manage their own state, then compose them to create complex and interactive user interfaces (Facebook Inc., 2019).

Both applications communicate with a back-end server via CRUD RESTful web services. These web services were developed using Node.js together with the Express framework. To ensure a secure authentication process, the Passport.js library was implemented using

JSON Web Tokens (JWTs) for authorisation, allowing users to access routes and resources. To design, develop, and explore a food recommender using machine learning algorithms for decision support, the R language and software environment was used. All information regarding all users and business requirements are stored on a MySQL database.

The developed platform is currently implemented on an Ubuntu production machine (Ubuntu 18.04.2 LTS) at the *Santa Casa da Miserdicódia de Vila Verde*. Although it has already been deployed and installed on a machine, it is still in testing and evaluation phases.

Figure 5 represents the platform's architecture, its main components, and its interactions.

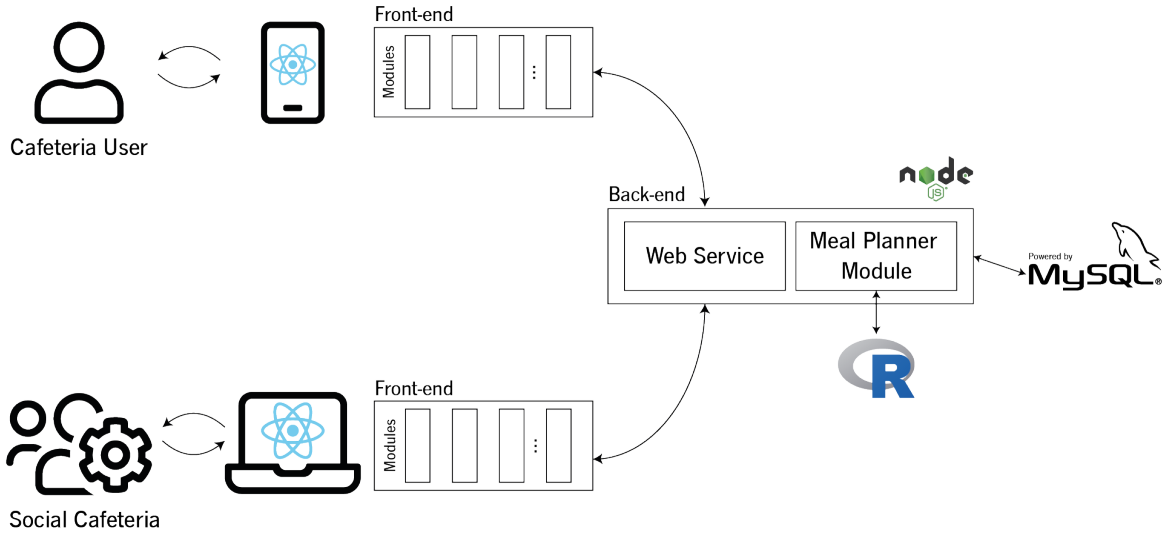


Figure 5.: System Architecture and Tools.

4.5.2 *Database Models*

This platform requires the storage of information concerning the users, menus, dishes, ingredients, and their nutritional information. The MySQL Database Management System (DBMS) stores all tables and relationships, while the **Sequelize** Object-Relational Mapping (ORM) is used to define all models and interact with the database.

Multiple key tables have been defined and modelled:

- **Dish (*Prato*)**: represents all information regarding dishes. A dish is made up of multiple recipes, allowing for the reuse of common preparations which simplifies the process of creating dishes

- **Preparation (*Preparação*)**: represents all information regarding preparations. A recipe is comprised of several ingredients and cooking instructions
- **Ingredient (*Ingrediente*)**: represents all information regarding ingredients. An ingredient is made up of nutritional components per portion, potential allergens, and an edible part percentage. The ingredient's nutritional information was obtained from *PortFIR*, a Portuguese food information platform, containing 1206 food products Instituto Nacional de Saúde Dr. Ricardo Jorge (2016)
- **Menu (*Ementa*)**: stores all menus, the dishes chosen for each division, and how many users are expected
- **User (*Utilizador*)**: represents all registered users, user types, and interactions with the platform
- **Division (*Valência*)**: represents all departments at the *Santa Casa da Miserdicódia de Vila Verde* and stores all configurations for the meal planner module

Figure 6 represents the relational model of the platform's database, showcasing the relationships between the tables.

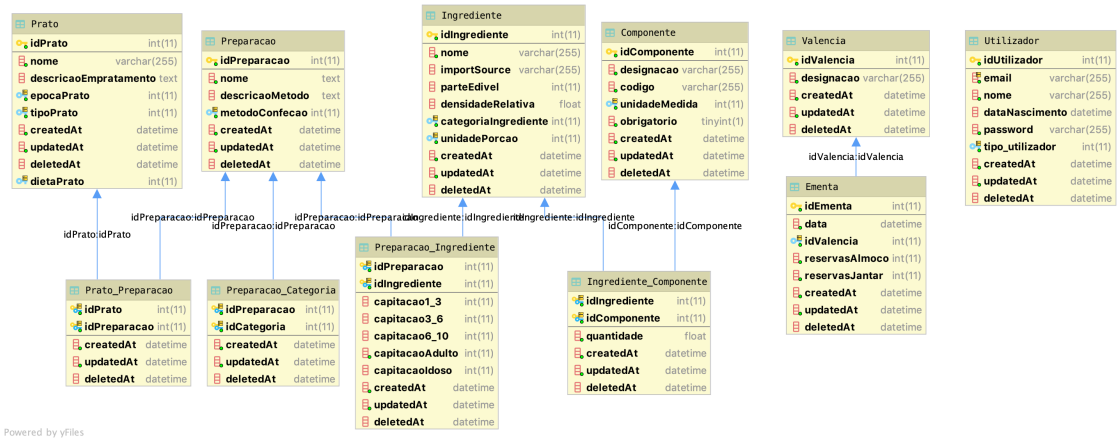


Figure 6.: Relational Model of the Platform's Database

4.5.3 *Web Services using Node.js*

To develop the platform's RESTful web services, the Node.js run-time environment was adopted. Multiple packages and libraries were used, providing a set of features for routing, authentication, interaction with databases, and documentation.

Express.js is a web application framework for Node.js. Express.js offers a collection of HTTP utility methods and middleware, making the creation of robust APIs quick and easy.

When a request is sent to the server, Express.js employs routing mechanisms for serving the client the content that they have asked for.

As the application is deployed at the *Santa Casa da Miserdicódia de Vila Verde*, where sensitive data regarding patients are held and multiple security and data protection features are employed. To ensure that only authorised users can access the platform's resources, the Passport.js authorisation middleware was employed. Passport.js is designed to authenticate requests and supports a variety of authentication mechanisms, also known as strategies. For this platform the JSON Web Token (JWT) strategy was adopted. During login, the server signs in and sends an authentication token as a response. This token identifies a specific user and cannot be tampered with, as it is digitally signed. Every subsequent request will include the JWT, allowing the user to access routes, services, and resources that are permitted with that token.

In addition, the Sequelize ORM was used to define all models and interact with the database. Object-Relational Mapping (ORM) can be defined as a technique that lets users query and manipulate data from a database using an object-oriented paradigm. Therefore, an ORM tool like Sequelize enables users to interact with and manipulate the data in the same programming language without writing in SQL. Additionally, developers can easily switch between DBMSs, as they are based on the relational data model to represent information.

The OpenAPI specification, formerly known as the Swagger specification, was used to document the developed endpoints. The OpenAPI specification is defined using YAML, allowing for the delineation of the platform's methods, parameters, and models. Additionally, by using the Swagger framework, the platform's endpoint documentation can be automatically generated, helping keep the documentation, clients, and source code in sync. Figure 7 presents the Swagger Web UI of the developed platform, allowing for a living document of the system's web services.

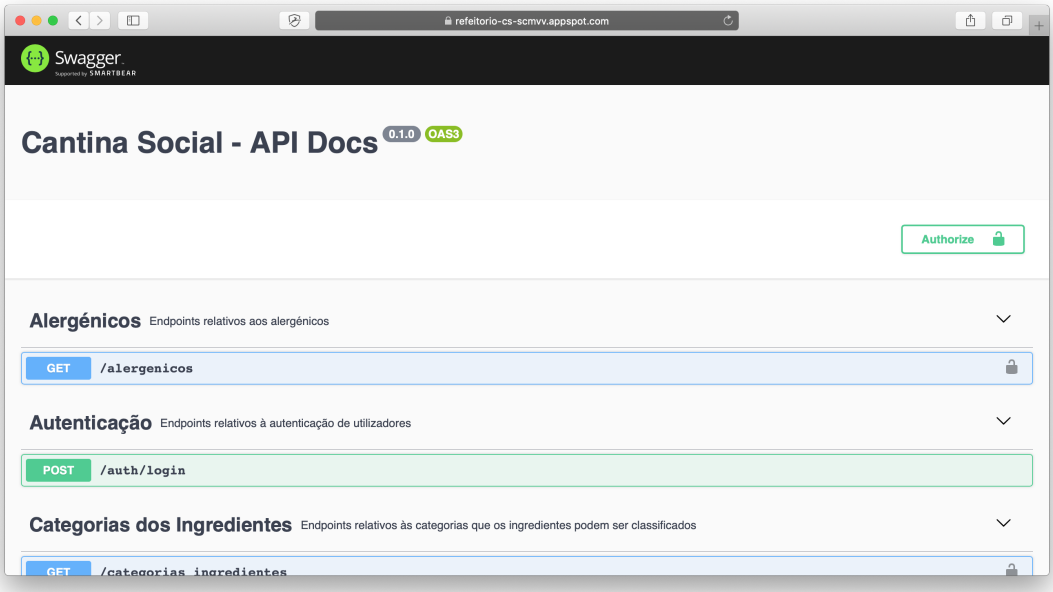


Figure 7.: Web API Documentation using Swagger

4.5.4 *Web Application*

The developed web application will support the social cafeteria's operation, offering a set of tools and modules for meal planning and management. Multiple features include a revamped ingredient repository, an upgraded recipe system, an enhanced meal reservation system, and integration with the hospital's acquisition platform.

To develop a Single Page Application (SPA) that loads a single HTML page and dynamically updates that page as the user interacts with the app, the React JavaScript library was employed (Wasson, 2013). By adopting modern technologies and frameworks, additional features and modules can easily be implemented. Key packages include Axios for making HTTP requests to the server, Formik to easily build forms, React Router for declarative routing, and Redux for state management. The Semantic UI component framework and its React integration was also used to build an appealing and responsive application. Additionally, the *create-react-app* toolchain was used, offering a modern build setup with no configuration.

The web application is comprised of multiple modules, namely an overview module, a reservation module, an ingredient module, a data sheet module, an administration module, a capitation module, and a meal planner. Each module is stored as a container, keeping their states separate. Several of these modules will be presented, along with their main features and objectives.

a **Overview Module**

The Overview Module presents a summary of the cafeteria's operations, the number of reservations made by the departments and in the cafeteria, feedback from users, and any other possible indicators of service. This information is presented with simple to understand statistics and graphs, thus highlighting and providing a visualisation of the indicators of greatest interest to the platform's users.

Figure 8 presents the Overview Module, enabling the nutrition professionals at the Social Cafeteria to make fast, informed decisions.

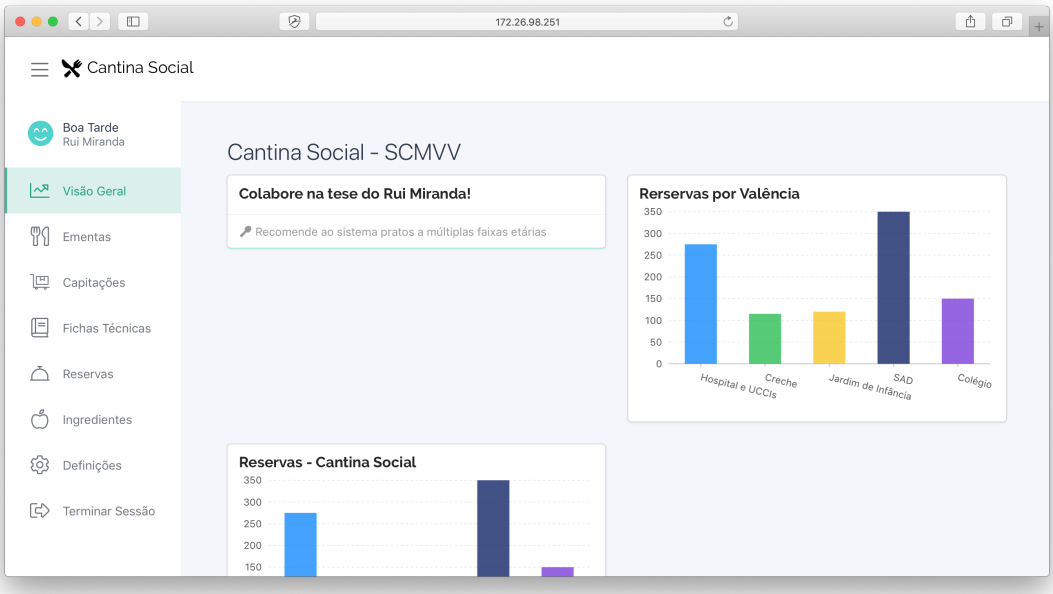


Figure 8.: Interface of the Overview Module

b **Ingredient Module**

The Ingredient Module is responsible for enabling the nutrition and health professionals to interact with the ingredient repository. This ingredient repository holds over 500 ingredients, along with their basic information, allergens, and nutritional information. Using data provided from *PortFIR*, a Portuguese food information platform, the repository is able to store and represent more than fifty nutritional components Instituto Nacional de Saúde Dr. Ricardo Jorge (2016).

The Ingredient Module is subdivided into different submodules, namely the Ingredient List and the Ingredient Form. The Ingredient List lets users view the ingredient repository, filter according to their name and category, and create or edit ingredients, while the Ingredient Form gives users a simple and intuitive way to add, edit, and remove ingredients.

Figure 9 presents the Ingredient List submodule, including the developed repository and its respective information.

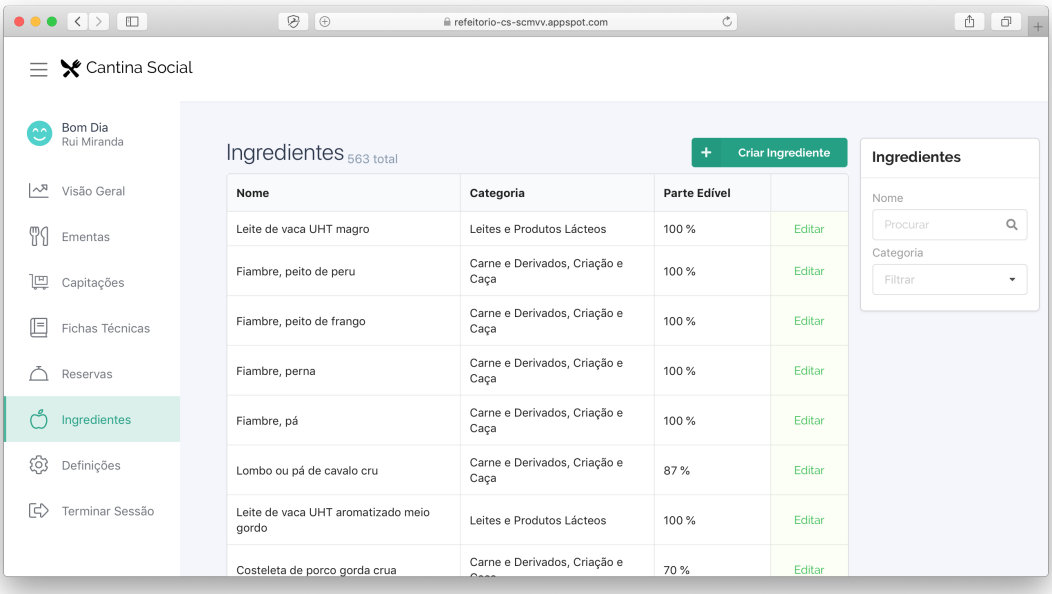


Figure 9.: Interface of the Ingredient List Submodule

To create an ingredient, the nutrition professional has to input the ingredient's basic information, including its category, editable portion and unit of portion, its allergens, and its nutritional components. To comply with HACCP policies, the platform requires all ingredients to include their nutritional information regarding carbohydrates, calories, fat, protein, and salt.

Figures 10 and 11 show the Ingredient Form submodule and how users add nutritional components to an ingredient.

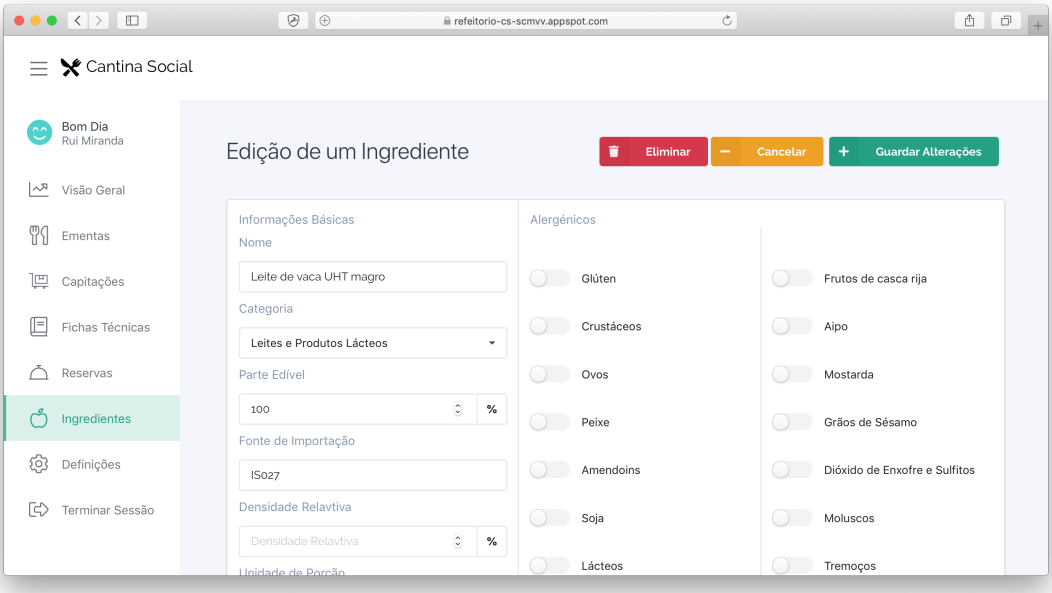


Figure 10.: Interface of the Ingredient Form Submodule

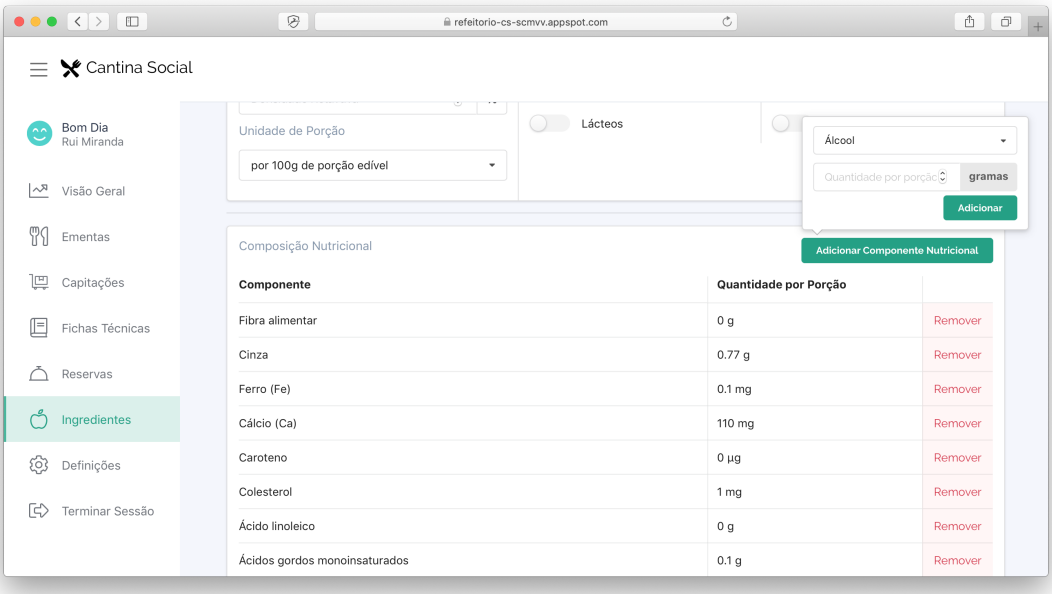


Figure 11.: Interface of the Nutritional Composition Table

c Data Sheet Module

The Data Sheet Module is divided into two submodules, namely the Preparation submodule and the Dish submodule. The Preparation submodule includes a listing of

the created preparations and a preparation form, where users can build, edit, remove, and print recipes. This listing is made up of the name of each preparation, as well as their categories and cooking method. The Dish submodule includes a list of the created dishes and the dish form, which enables users to create, update, remove, and print dishes.

Figure 12 presents the Data Sheet module's interface, including the preparation and dish listings.

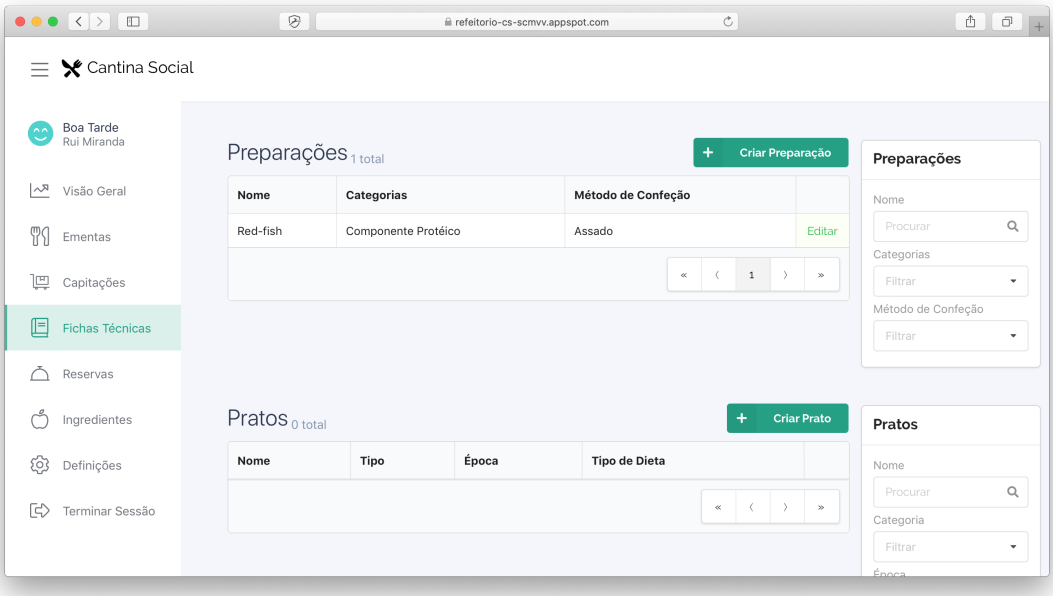


Figure 12.: Interface of the Data Sheet Module

To create a recipe, the nutrition professional has to input the ingredient's name, its categories, cooking method, cooking instructions, and ingredients, along with their capitations for each age group.

Figure 13 shows the preparation form, namely how users insert the preparation's basic information.

Figure 13.: Interface of the Preparation Form

The dish form enables users to build, update, remove, and print dishes. A dish is made up of its name and category, as well as a main season, diet, presentation instructions, associated preparations, and an image. When a user adds a recipe, the dish's nutritional information is automatically calculated, combining the ingredients' nutritional components. This information will be presented using a traffic light label system, showing at a glance whether a dish is high or low in carbohydrates, calories, fat, protein, and salt.

Figure 14 presents a portion of the dish form, specifically how users insert the dish's main information, as well as how they can upload a picture.

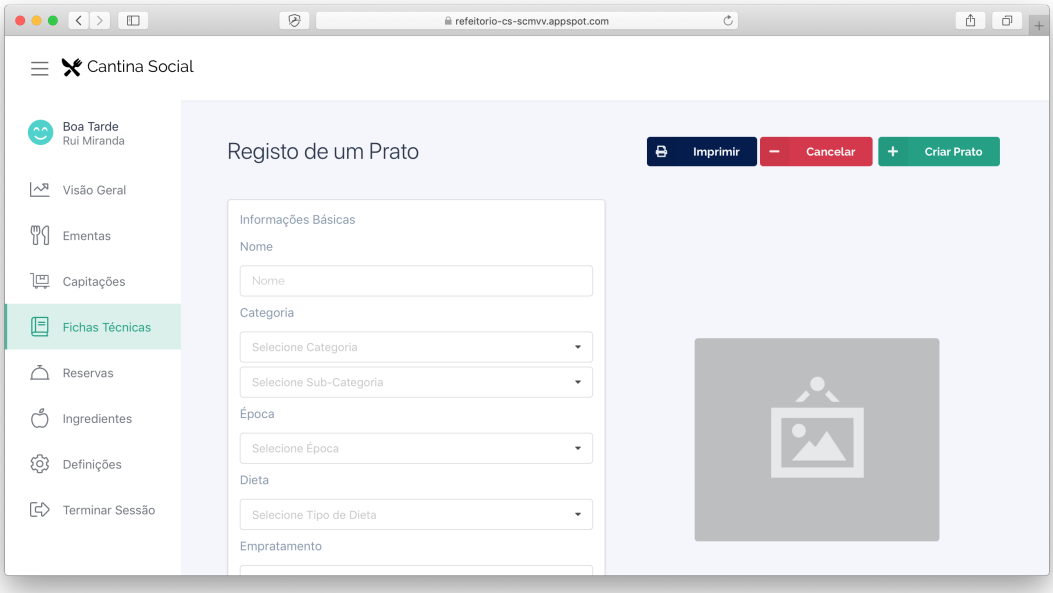


Figure 14.: Interface of the Ingredient Form

d **Administration Module**

The Administration Module is divided into three segments, namely the Update User, Users, and Division segments. From the Administration Module, administrators can easily change the platform's settings and preferences. In the Update User segment, the user can update their name, date of birth, email address, and password. The Users segment lets administrators add, remove, and update users, while the Division segment enables the health professionals to create, remove, and change a division's preferences for meal planning.

Figure 15 presents the Administration Module, as well as the aforementioned segments.

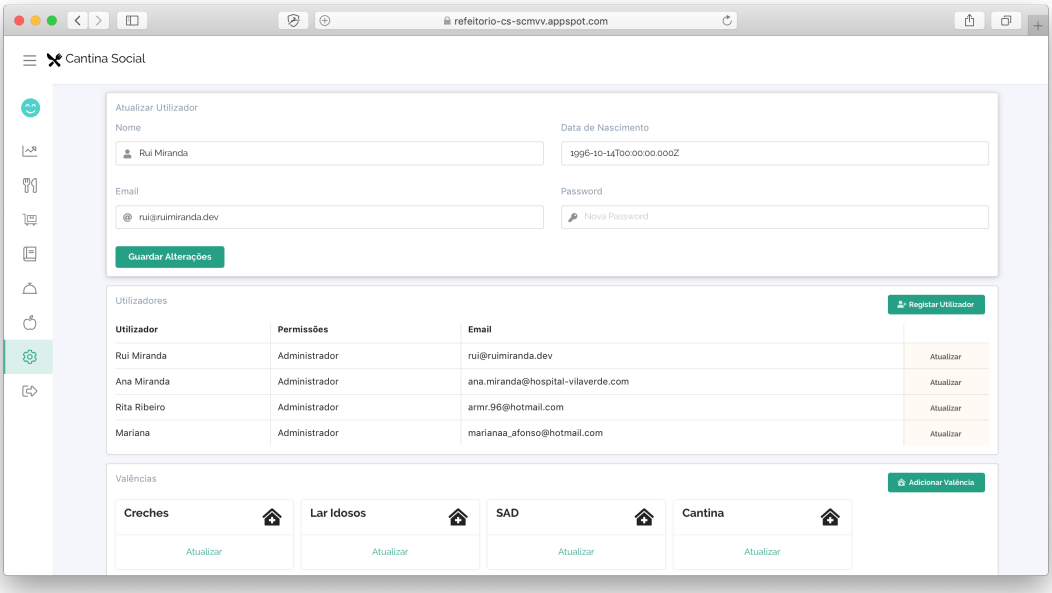


Figure 15.: Interface of the Administration Module

4.5.5 *Mobile Application*

The designed mobile application allows the cafeteria's users to interact with the social cafeteria. The user is able to obtain the menu and its nutritional information and can easily make a reservation thought their smartphone. As it will be developed using React Native, this application supports the two most used mobile operating systems—Android and iOS—using the same code-base, which saves time and resources.

To develop the mobile application's prototypes, the InVision Studio screen design tool was adopted. This tool enables teams to design, prototype, and animate in the same application while using the InVision platform to share and collaborate with each other.

The mobile application is divided in multiple components, namely Login, Main Screen, Feedback, History, Reservations, and Preferences. The Login component allows the cafeteria users to identity their email addresses and passwords. After the authentication procedure is complete, the users are greeted with the main screen. This dashboard presents the cafeteria's menu for the day and the following day, as well as easy access to the application's main features. The Feedback component enables users to give commentary regarding past menus. This information can be used for additional indicators of service, as well as future usage on the meal planner module. The Reservation component lets the cafeteria users order and cancel their meals for the week. The menus will have their nutritional information presented using a traffic light label system, showing at a glance whether a dish

is high or low in carbohydrates, calories, fat, protein, and salt. To conclude, the Preferences component lets the user update their personal information and preferences.

Figures 16, 17, and 18 present the mobile application interface prototypes, and how the cafeteria's users can interact with the platform.

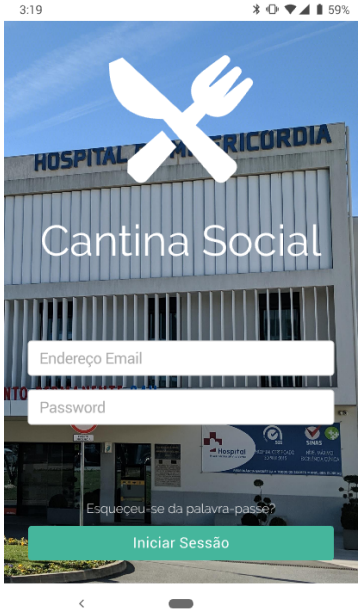


Figure 16.: Prototype for the Login Component

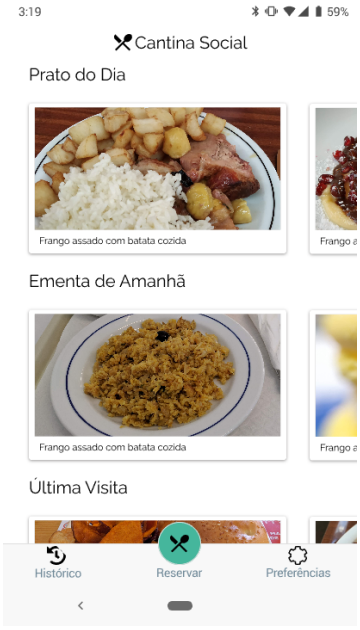


Figure 17.: Prototype for the Main Screen Component

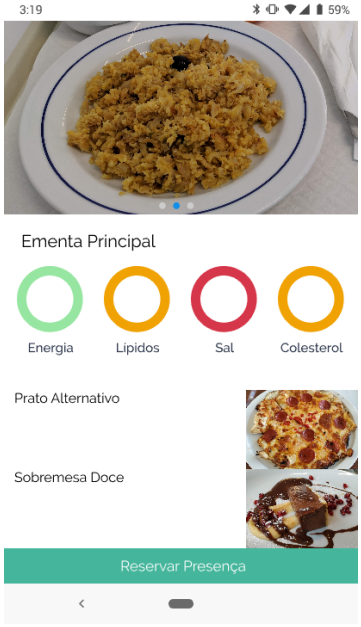


Figure 18.: Prototype for the Reservation Component

4.6 DISCUSSION

This first case study has consisted of the development of a new software platform for meal provision, planning, and management comprised of a suite of tools and modules designed to help nutrition specialists with their work, as well as a mobile application for the cafeteria's users. These tools allow for modernising the Social Cafeteria at the *Santa Casa da Miserdicórdia de Vila Verde*, using the combination of thoughtful design and the latest technologies to provide a user-friendly experience, as well as a modular architecture that can be easily improved to suit the institution's future needs.

The developed platform greatly simplifies the nutrition specialist's daily work, supporting the present and future needs at the *Santa Casa da Miserdicórdia de Vila Verde*. The web application's key objectives are the administration, provision, and creation of dishes and meal plans on computers and tablets. The developed repositories allow for a wide range of culinary dishes, with their nutritional information calculated for multiple age groups. Furthermore, the mobile application empowers a new way of engagement between the Social Cafeteria and its users. Through this application, the cafeteria users can inform themselves about the weekly menu and its nutritional information, reserve their meals by themselves, and contribute with feedback.

In addition, the developed solution introduces new, innovative features that are addressed directly or indirectly in this chapter and throughout this dissertation. Thus, its main innovative features, as well as a brief description, are presented and described in Table 1.

Innovative Characteristic	Description
Modular Architecture	The platform's architecture is easy to maintain and new features can be quickly introduced
User-Friendly	Both web and mobile applications were designed to be intuitive and easy to use
Multiplatform	The web application runs on all devices that have a browser with no installation required. The platform is installed in a production machine, thus distributed to the nutrition specialists through the health institution's private network. In addition, the mobile application is compatible with Android and iOS, the two most used mobile operating systems
Inter-operable Web Services	The applications communicate to the server using a RESTful Web Service, enabling other services to access the platform's data
Reuse of Preparations	A preparation can be used in multiple dishes simultaneously, saving time and ensuring consistency within the Social Cafeteria. Preparations can have specific ingredients and capitations for a target age group
Nutritional Information Calculation	A dish's nutritional information is accurately calculated for each age group, taking the ingredients' portion into consideration.
Installation of Libraries	The adopted technologies, namely Node.js, React, and React Native, can use the npm package manager to install, update, and remove packages. By using these technologies, new features can be added by installing packages
Mobile Application	The developed mobile application lets the cafeteria's users interact with the platform and be aware of their nutritional intake. The user is able to obtain the menu and its nutritional information and can easily make a reservation through their smartphone

Table 1.: Main Innovative Characteristics of the Platform for Meal Provision and Management

4.7 Conclusion and Future Work

In this chapter the platform for meal provision and management was introduced and discussed, as well as the solution's main objectives and the requirements elicited during its development. This first case study carried out within the scope of this dissertation project is composed of a web and a mobile application that have both been presented and documented during this chapter. Furthermore, the results obtained and how the developed solution will help nutrition professionals at the *Santa Casa da Miserdicórdia de Vila Verde* in their work are also explored.

The main motives that led to the development of this case study were the need of a platform that fulfils the present and future needs of a growing health institution. The previous tool was unequipped to adapt to an ever-changing world of technology where security and data protection are more important than ever. Users now interact with software systems from multiple devices, expecting a clean and intuitive interface. Thus, the requirements elicitation process began by identifying key points that would justify the design, development, and implementation of a next generation platform for the provision, planning, and reservation of food plans.

As future work, it is expected to finalise the implementation and configuration of additional modules. These modules include an interface where the multiple departments at the health institution can reserve their meals and offer feedback, and integration with the Primavera logistics suite, offering a seamless provision process, as well as the ability to notify the nutrition professionals of any events of interest via email. In addition, the mobile application shall be developed and implemented, providing cafeteria users with a new way to order their meals.

In the next chapter, the meal planner module will be introduced and showcased, as well as the main results obtained during the development of this case study.

5

MEAL PLANNER MODULE

5.1 INTRODUCTION

The second case study of this dissertation project refers to the development and implementation of a meal planner module. This module's aim is to simplify the process of creating weekly food menus for multiple departments, each having their specific guidelines and nutritional requirements. To create knowledge about the cafeteria's functioning as well as nutritional requirements for the departments, an additional data mining study was performed. This module will greatly simplify the nutrition specialist's work of creating food menus for several departments, thus increasing their productivity.

In the following sections the problem and its motivations are described, as well as the module's main objectives and elicitation during its development. All steps taken during the platform's design and development process are described. The module's main components are also analysed and documented. Data regarding the user's nutritional requirements was collected and analysed, as well as feedback from health professionals. This collected information was used to support the development of a meal planner module, incorporating a food recommendation system for decision support. This chapter concludes with a discussion of the results obtained, as well as a brief conclusion and an insight into future work.

5.2 CONTEXT AND MOTIVATION

At the Social Cafeteria of the *Santa Casa da Miserdicórdia de Vila Verde*, the responsibility of preparing and distributing dozens of dishes daily is at times overwhelming. Currently, the Social Cafeteria serves dishes to eight departments, each with their own schedules and necessities. For example, the nursing homes serve breakfast, lunch, dinner, and supper throughout Monday to Sunday, while the kindergarten serves only lunch and a snack from Monday to Friday. In addition, the nutrition professionals plan weekly meal plans for all departments at the health institution.

Although the *Santa Casa da Miserdicória de Vila Verde* continued expanding, the previous platform was not able to keep up with the Social Cafeteria's needs. No new departments could be added to the previous solution, forcing the nutrition specialists to manually create their weekly menus on a word processor. The platform also fails to take the children's different capitations to adults into consideration. The weekly capitation is often incorrect, as the solution treats children as adults.

In this context, this case study has emerged, consisting of the development and exploration of a meal planner module for the next-generation platform. This module should allow for an easy creation of weekly food menus for all departments at the health institution. At the same time, the module has to be flexible enough to support future departments at *Santa Casa da Miserdicória de Vila Verde*, as well as their respective menu guidelines.

To further support the nutrition professionals, a feature in this module is the suggestion of food menus to each department, which takes the patient's nutritional needs into consideration. In addition, a data mining study was performed, creating knowledge about the cafeteria's functions, nutritional requirements for the departments, and the user's feedback regarding food plans. A recommender system for the suggestion using machine learning approaches was thus developed for the automatic creation of food menus. This module will greatly simplify the nutrition specialist's work of creating food menus for several departments, thus increasing their productivity. Furthermore, the adoption of a carefully planned meal plan can complement the patient's recovery process, alleviating possible symptoms.

5.3 Module Objectives

The aim of this case study is to design, develop, and implement a meal planner module for the introduced platform at the Social Cafeteria at the *Santa Casa da Miserdicórdia de Vila Verde*. To introduce additional value to the platform, this module should support the ability to automatically suggest new meal plans for each department, taking into account the patient's nutritional requirements. Thus, a data mining study was performed, extracting valuable knowledge regarding the cafeteria's functioning and nutritional requirements of the departments for the design and development of a food recommender system using machine learning algorithms.

This module will greatly simplify the nutrition specialist's work of creating food menus for several departments, increasing their productivity. In addition, the data obtained by the developed platform will be used for an intelligent planning of meal plans, improving the patient's quality of life, as well as optimising the health institution's use of resources.

Hence, the main objectives to fulfil with the development of the meal planner module are the following:

- Requirements elicitation in the design and development of the meal platform thought meetings with health and nutrition specialists at the *Santa Casa da Miserdicórdia de Vila Verde*
- Revision of literature regarding machine learning, recommender systems, and their applicability in healthcare and nutrition
- Development of a *Dish Classification* module for the creation of knowledge regarding the dishes and their healthiness to multiple age groups
- Data mining study for the creation of knowledge about the cafeteria's functions, nutritional requirements for the departments, and the user's feedback regarding food plans
- Design and creation of machine learning models to determine if a dish is nutritionally appropriate
- Development of a *Meal Plan* module, allowing users to create and update meal plans for all departments at the health institution
- Design and development of a food recommender system for the automatic creation of food menus
- Development of APIs and Web Services to give support to the meal planner module
- Implementation and deployment of said module in the Social Cafeteria of Vila Verde
- Ensuring the proposed module is compatible with the current systems in place at the Social Cafeteria of Vila Verde

5.4 Design and Development

To build a next-generation platform for meal planning that incorporates machine learning algorithms for decision support, several modules were designed and developed. These modules were incorporated to the developed web application using the React library. A Dish Classification module will allow the nutrition specialists to create knowledge regarding the dishes and their healthiness to multiple age groups. This knowledge will be used for the creation of machine learning models, powering a food recommender system. The Meal Plan module enables users to create, update, and print meal plans for all departments at the health institution. In addition, several tables were defined and modelled, as well as the development of web services to support the developed modules.

In the following subsections, the Dish Classification and Meal Plan modules are presented. Their main features are described, as well as how they work well with a food recommender system for decision support.

5.4.1 *Dish Classification Module*

The extensive variety of recipes, ingredients, and nutritional information to collect and analyse make the extraction, exploration, and exploitation of knowledge in the food domain a challenging task. In addition, the ingredients are also combined with each other in a recipe instead of being consumed separately, increasing the complexity of designing and developing a food recommender system.

To support a food recommender system for decision support and to extract knowledge for the nutrition professionals at the Social Cafeteria, a Dish Classification module was designed and developed. The main objective of this module is the classification of dishes according to their healthiness. With this module, the nutritionists at the *Santa Casa da Miserdicória de Vila Verde* can classify the dishes previously submitted to the platform. For each dish added, the user will classify whether or not it's appropriate or recommended for the age groups to which the Social Cafeteria offers their services.

Figure 19 presents the Dish Classification Module, and how users can create knowledge by answering a survey-like form.

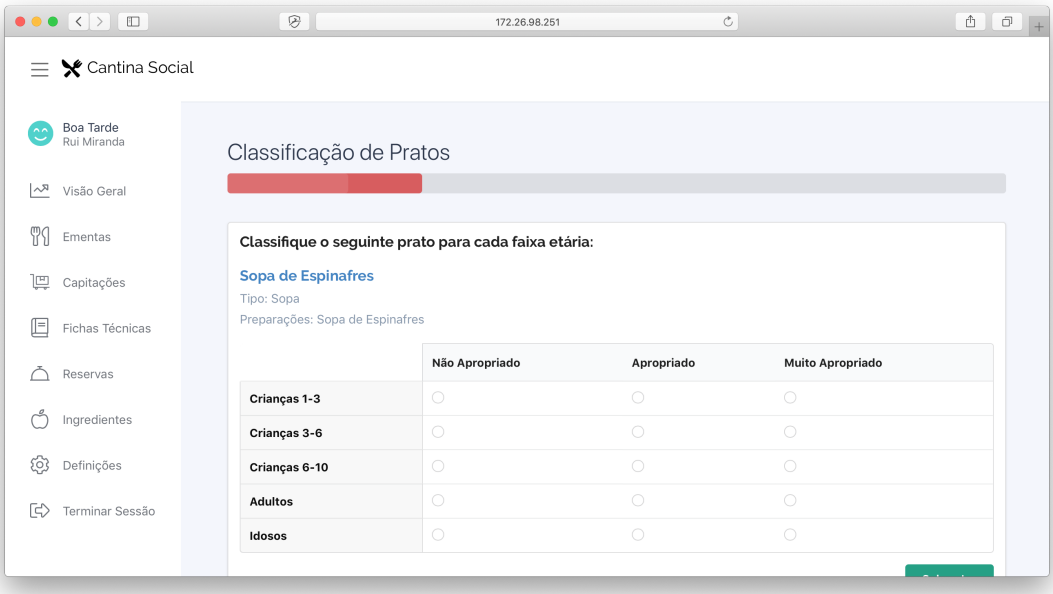


Figure 19.: Interface of the Dish Classification Module

This module is expected to extract relevant knowledge regarding the Social Cafeteria and their served dishes. This data is vital for the development of a food recommender system, where decision tree algorithms will be employed to determine if a meal is nutritionally appropriate for a target group.

5.4.2 *Meal Plan Module*

The Meal Plan Module is a key component in the developed platform for the provision, planning, and reservation of food plans, with its main objective being the creation and updating of meal plans for all departments at the *Santa Casa da Miserdicória de Vila Verde*. Hence, this module is a starting point for the development of a food recommender system, suggesting food plans by the user's preferences and their healthiness.

This module is subdivided into different submodules, namely the Meal Plan List and the Meal Plan Form. The Meal Plan submodule includes a listing of the current, past, and following week's meal plans for all departments at the health institution. Furthermore, the submodule lets users build and update meal plans for a department, as well as create a main meal plan. The main meal plan is comprised of the appropriate dishes for a target age group. For example, the food tastes of children are different than that of adults, and the soups children normally eat are pureed. When a user submits a main meal plan, the platform will automatically create the food plan for all departments.

Figure 9 presents the Meal Plan List submodule, including the current/active meal plans for all departments, and how users can build or update meal plans.

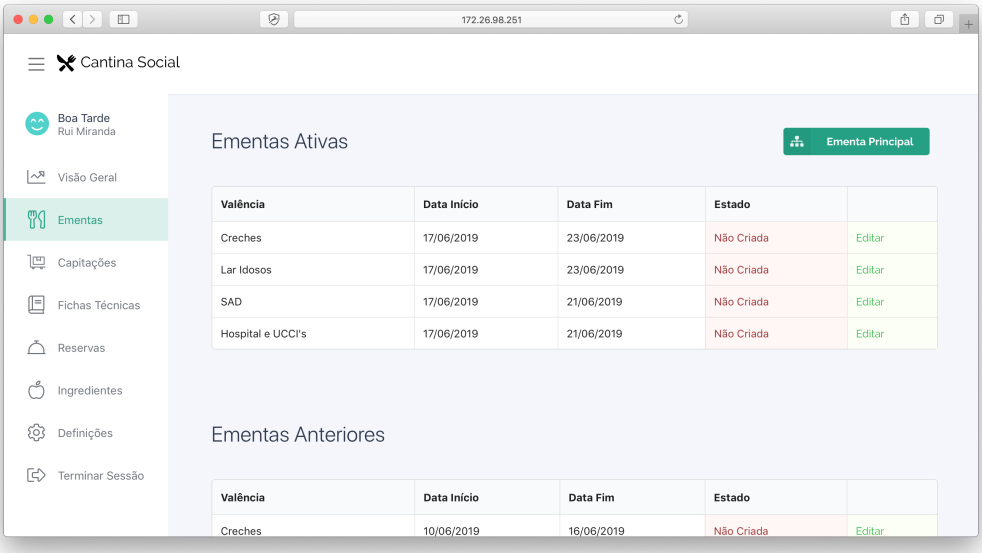


Figure 20.: Interface of the Meal Plan List Submodule

The Meal Plan Form submodule enables the nutrition professionals to build, update, and print food plans for either a department or for a main meal plan. The user is required to select a soup, main course, salad, and dessert for lunch and dinner. The form automatically changes according to whether it's for a selected department or for a user building a main meal plan. Furthermore, the user can access the food recommender system, automatically generating a meal plan for each department, complying with their specific nutritional requirements.

Figure 21 presents the Meal Plan Form submodule, and how the users build a meal plan by selecting dishes from the developed repository.

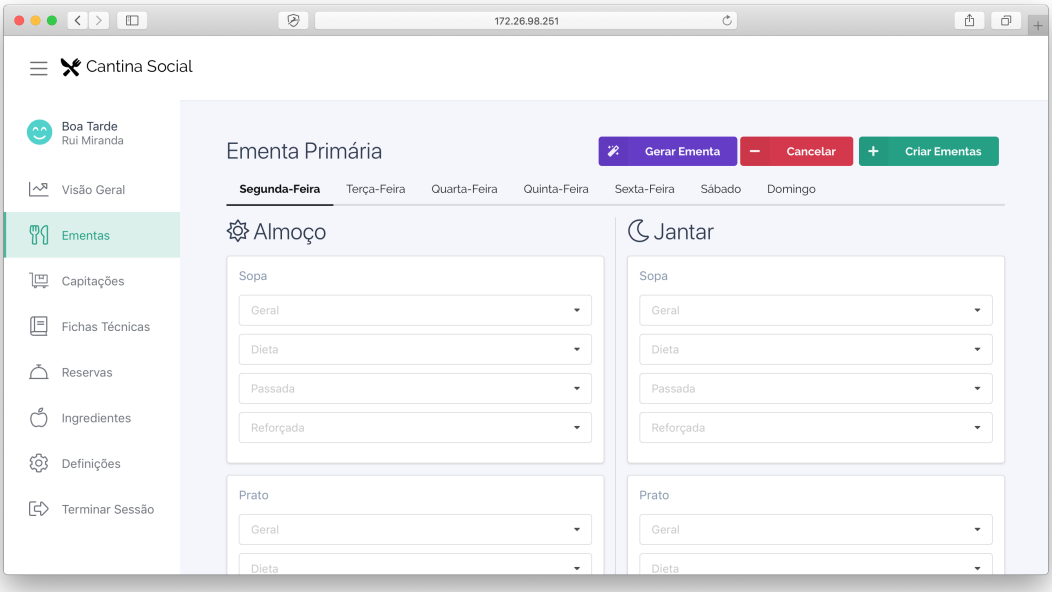


Figure 21.: Interface of the Meal Plan Form Submodule

This module will help with the nutrition specialist's work of creating food menus for several departments, which will increase their productivity. In addition, the food recommender system should suggest appropriate food menus for all departments at the health institution, incorporating machine learning algorithms for decision support. By adopting an appropriate nutrition policy, it is expected to improve the patient's quality of care, alleviating possible symptoms.

5.5 DISCUSSION

This second case study has consisted of the design and development of a next-generation meal planner module, incorporating a food recommendation system for decision support.

Two modules for the web application were developed, as well as their web services and database models. These components are implemented into the platform for provision, planning, and reservation of food plans, and is currently used by the nutrition specialists at the *Santa Casa da Miserdicórdia de Vila Verde*.

The Meal Classification Module enables the creation of knowledge regarding the Social Cafeteria and the served dishes. By classifying the added dishes according to their healthiness, it is expected to extract valuable information about what makes a dish healthy for multiple age groups. This data is key for the development and exploration of a food recommender system for decision support, and can be used for future work regarding nutrition.

The Meal Plan Module offers a simple and intuitive way to create weekly food menus for all departments at the heath institution. Furthermore, this module is able to support additional departments and their specific menu guidelines, and can be easily upgraded for any future requirements. A key feature in this module is the automatic suggestion of meal plans for each department, using machine leaning algorithms and knowledge extracted from the nutrition professionals. This module will not only increase the nutrition professional's productivity, but also improve the patient's quality of care , and drive more users to the Social Cafeteria.

5.6 Conclusion and Future Work

In this chapter, the meal planner module was introduced and discussed, as well as the solution's main objectives and requirements elicited during its development. This case study is composed of two modules for the developed web application. A Dish Classification module was designed and developed to extract knowledge regarding the Social Cafeteria's dishes and their healthiness for multiple age groups, while a Meal Plan module will simplify the process of creating weekly food menus for multiple departments. These module have been presented and documented during this chapter. Furthermore, the results obtained and how the developed modules will help nutrition professionals at the *Santa Casa da Miserdicórdia de Vila Verde* in their work are also explored.

The motivation that led to the development of this case study was to evaluate the application of machine learning algorithms on nutrition in healthcare and continuous care. The healthcare industry is one of the world's fastest growing fields, with large volumes of data being collected daily (Reis et al., 2017, 1). Despite this, it is regarded as being "information rich" yet "knowledge poor". The usage of data mining tools to extract relationships and knowledge in healthcare organisations is increasing, responding to the needs of doctors in their decision-making process (Duarte et al., 2010; **?**). Hence, a study on machine learning approaches and food recommender systems in nutrition was performed, identifying the Social Cafeteria's needs and how can these algorithms can overcome them.

As for future work, it is expected to finalise the development and testing of the Meal Plan module. In addition, a food recommender system for decision support shall be developed and implemented, suggesting nutritionally appropriate meals for all departments at the health institution.

In the next chapter, the proof of concept made for the developed project is presented. A Strengths Weaknesses Opportunities Threats (SWOT) analysis was performed in the web and mobile applications, as well as in the meal planner module.

6

PROOF OF CONCEPT

6.1 INTRODUCTION

A Proof of Concept is considered a key procedure in the process of the design, development, implementation, and proposal of software solutions in the field of ITs. It validates whether a project fulfils its main features and defined objectives, as well as identifies potential flaws or mistakes in the developed solution. In addition, the proof of concept in research aims to engage with a question whose answer has wide applicability in areas beyond those tested for (Kendig, 2016).

Hence, a Proof of Concept (PoC) is a demonstration to confirm whether a concept or theory is feasible for real-world applications (Singaram and Jain, 2018; Techopedia, 2019). A methodology is made up of practical models that can prove or validate a concept through analysis and development. Proof of concept research *"presents a discovery about our knowledge of the world and the structure of existence"* (Kendig, 2016).

In this chapter, two Strengths Weaknesses Opportunities Threats (SWOT) studies were performed on both web and mobile applications, as well as on the meal planner module. As discussed on subsection 3.4.1, a SWOT analysis promotes a fact-based and data-driven analysis of the internal and external factors that are advantageous or detrimental, helping reveal prospective opportunities to exploit and understand potential weaknesses (Mitchell, 2019; Wikipedia contributors, 2019).

6.2 SWOT ANALYSIS

In the following subsections, the Strengths Weaknesses Opportunities Threats (SWOT) analysis of the platform for meal provision and management and the meal planner are presented. The Strengths Weaknesses Opportunities Threats (SWOT) analysis planning technique is used to develop strong strategic plans by analysing the strengths and weaknesses (internal factors), in addition to opportunities and threats (external factors), of a business or project plan (Mind Tools Content Team, 2019). A SWOT analysis can help reveal oppor-

tunities to exploit and understand potential weaknesses, and also develop strong strategic plans (Wikipedia contributors, 2019; Mind Tools Content Team, 2019).

6.2.1 *Platform for Meal Planning and Management*

The first case study of this dissertation project—namely the design, development, and implementation of a platform for meal planning and management—was subject to a SWOT analysis. Thus, the solution's strengths, weaknesses, opportunities, and threats were extracted and identified.

The following strengths of the platform were identified:

- Development of a high quality, easy to use platform
- Support for all devices that have a web browser, and a mobile application that is compatible with Android and iOS
- Increased efficiency and compliance with the Hazard Analysis and Critical Control Point (HACCP) system
- New interactions with the social cafeteria and its customers and patients
- Sophisticated nutritional information calculation system, evaluating a dish accurately for each age group
- Easy to maintain architecture, where new features can be quickly introduced

However, the platform's internal attributes that are harmful towards its successful development and integration (weaknesses) were also identified:

- Constant internet connection is required
- Unwillingness to transition to a new platform from the nutrition professionals
- Migration of hundreds of dishes and recipes from the old platform

In addition, the platform's opportunities, namely the external attributes to the platform that are helpful towards its successful development and integration, were extracted:

- New departments within the *Santa Casa da Miserdicória de Vila Verde* may offer new possibilities
- Mobile app allows for the exploration of new interactive features
- Recent trends to boost the user's health and nutrition awareness

On the other hand, several possible external threats to the system were identified:

- Complicated laws and regulations (GDPR, HACCP, ...)
- Complex architecture, requiring the maintenance of one back-end and two front-end applications
- Competition from external companies and competitiveness of other platforms

6.2.2 *Meal Planner Module*

The meal planner module and the food recommender system for decision support were also the subjects of a Strengths Weaknesses Opportunities Threats (SWOT) analysis. Hence the module's strengths, weaknesses, opportunities, and threats were extracted and identified.

The following strengths of the module were identified:

- Usage of machine learning approaches for nutrition therapy
- Simple process of creating weekly food menus for multiple departments
- Support for additional departments and their specific menu guidelines

The platform's weaknesses, namely the external attributes to the platform that are harmful towards its successful development and integration, were extracted:

- Machine learning algorithms may suggest ill-suited dishes
- Transition to a new interface may require training

In addition, the platform's opportunities, namely the external attributes to the platform that are helpful towards its successful development and integration, were collected:

- Possible collaboration with external health institutes and nutrition associations
- Introduction of more advanced features and machine learning models
- Extraction of knowledge regarding the Social Cafeteria's dishes and their healthiness

Finally, several possible external threats to the system were identified:

- New data may require the development of a new machine learning based approach
- Competition from external companies and competitiveness of other platforms

6.3 CONCLUSION

In this chapter the proof of concept of the designed, developed, and integrated cases studies during this dissertation project was presented and defended. Strengths Weaknesses Opportunities Threats (SWOT) analyses were performed on the platform for meal provision and management, as well as on the module for meal planning, identifying their main strengths, weaknesses, opportunities, and threats.

Hence, this chapter has presented the platform's viability, usefulness, and usability. Key points taken during the SWOT analyses were the platform's modules, enabling its easy maintainability and expansion for the health institution. Furthermore, all features developed are user-friendly and easy to use, while satisfying all requirements at the Social Cafeteria. This is thanks to a thought requirements elicitation process and a carefully thought-out design. The meal planner module, which incorporates a food recommender system for decision support, will greatly help with the nutrition professional's daily work, as well as enabling the extraction of knowledge in nutrition and nutrition therapy.

The next and last chapter aims to summarise and present the main conclusions and contributions obtained through the development of this platform. In addition, proposals for future work in order to improve the platform and its applications are presented.

7

CONCLUSIONS

7.1 INTRODUCTION

The final chapter of this dissertation aims to summarise and present the main conclusions and contributions obtained through the development of a new generation platform for the provision, planning, and reservation of food plans, comprised of web and mobile tools. In addition, proposals for future work in order to improve the platform and its applications are presented.

In section 1.3 of this document, multiple Research Questions were presented as the platform's objectives, serving as a guide for exploring the case studies presented. Hence, in the following sections, the answers to the questions proposed are presented, summarising the main contributions of this dissertation project, as well as including some suggestions for future work.

7.2 MAIN CONTRIBUTIONS

Information technology systems are changing the healthcare sector, from the discovery of cures for diseases and the development of new treatment techniques to the improvement of patients' diagnoses and the enhancement of effective health care delivery (Brito et al., 2019). From health centres to large-scale hospitals, the increased use of IT approaches in clinical procedures is improving the patients' quality of care, as well as optimising the health institution's resources (Cardoso et al., 2014; Neves et al., 2008; Duarte et al., 2011).

The nutrition status of the patient is crucial for his/her treatment process. Food recommender systems provide personalised recommendations of food items and/or recipes to the users and may take into consideration the health status of the user. Although there are several food recommender systems in literature, health institutions fail to implement and use such systems. The present dissertation aims to analyse the specific needs of a health institution in order to understand what functionalities and requirements a nutritional recommendation system must have in order to be successfully implemented and used by a health

institution. This project is a result of the collaboration of the Department of Informatics of the Minho University in Braga with a Portuguese hospital, the *Santa Casa da Misericórdia de Vila Verde*. Currently, the project counts on the collaboration of a work team made up of programmers and health professionals, with the ability to intervene and participate in the multiple phases of the project.

Through the methodologies and investigation strategies chosen, it was possible to delineate a valid strategy starting from topics and key ideas that, with the revision of the literature, became more solid and justified. Accordingly, the end result of this project is the creation of a new approach for meal planning, using the patient's preferences and nutritional needs for decision support. Thus, a new intelligent system on nutrition in healthcare and continuous care was developed based on machine learning algorithms, and using data mining to identify patterns and improve the patient's quality of care.

In order to answer to the first research question, a case study was proposed, consisting of the development of a new software platform for meal planning and management. This platform is comprised of a web application and a mobile app, each with their own specific objectives and features. The web application, developed using the React library, will support the social cafeteria's operations, including multiple modules for administration and platform maintenance. In addition, a mobile application was designed for planning the user's meals, as well as sending notifications about the cafeteria's menus.

Afterwards, the second case study was introduced in a data mining study of the platform's recipe and user information, and implementation of a food recommender system using machine learning algorithms. To accomplish this objective, a meal planner module was designed, greatly simplifying the nutrition specialist's work of creating food menus for several departments, thus increasing their productivity. This module will incorporate the recommender system for the automatic creation of food menus, keeping in consideration the patient's nutritional needs and requirements.

To give support and validation to both case studies, a Proof of Concept (PoC) methodology was carried out, consisting of Strengths Weaknesses Opportunities Threats (SWOT) analyses on the platform for meal provision and management, including the meal planner module. This study has confirmed the platform's viability and effectiveness based on its feature set, its modular architecture, and its user-friendly interface. Furthermore, incorporating machine learning algorithms for decision support along with the design, development, and implementation of a food recommender system will enable the creation, extraction, and exploitation of nutritional knowledge that can be used in future projects.

7.3 FUTURE WORK

This dissertation project has created multiple solutions—also called Information Technology (IT) artefacts. These artefacts will not only make the nutrition professional's work easier, but will also support users and patients in fragile health conditions. It is expected that the food recommender system will suggest carefully planned meal plans, thus helping and complementing their quality of life, alleviating possible symptoms. To further answer the Research Questions and its case studies, additional features and modules will be developed and integrated in the near future.

The initial case study—namely the design and development of a platform for meal planning and provision—is expected to finalise the implementation and configuration of additional modules. These modules include an interface where the multiple departments at the health institution can reserve their meals and offer feedback. The interface also includes integration with the Primavera logistics suite, offering a seamless provision process, as well as the ability to notify the nutrition professionals of any events of interest via email. In addition, the mobile application shall be developed and implemented, providing cafeteria users with a new way to order their meals.

The second case study is expected to finalise the development and testing of the Meal Plan module. In addition, a food recommender system for decision support shall be developed and implemented, suggesting nutritionally appropriate meals for all departments at the health institution.

Therefore, all of the previously defined Research Questions in section 1.3 and its objectives were successfully accomplished.

BIBLIOGRAPHY

Dan Abramov and Redux Documentation Authors. Basic Tutorial: Intro · Redux, 2015a. URL https://redux.js.org/basics/basic-tutorial.

Dan Abramov and Redux Documentation Authors. Prior Art · Redux, 2015b. URL https://redux.js.org/introduction/prior-art.

Giuseppe Agapito, Mariadelina Simeoni, Barbara Calabrese, Ilaria Caré, Theodora Lamprinoudi, Pietro H. Guzzi, Arturo Pujia, Giorgio Fuiano, and Mario Cannataro. DIETOS: A dietary recommender system for chronic diseases monitoring and management. *Computer Methods and Programs in Biomedicine*, 153:93–104, 2014. ISSN 18727565. doi: 10.1016/j.cmpb.2017.10.014. URL https://doi.org/10.1016/j.cmpb.2017.10.014.

Charu C. Aggarwal. *Recommender Systems*, volume 40. Springer International Publishing, Cham, 2016. ISBN 978-3-319-29657-9. doi: 10.1007/978-3-319-29659-3. URL http://link.springer.com/10.1007/978-3-319-29659-3.

R. Agrawal, T. Imielinski, and A. Swami. Mining Association in Large Databases. *ACM SIGMOD Record*, 22:207–216, 1993. ISSN 01635808. doi: 10.1145/170036.170072.

J. Aravind and J. Dhalia Sweetlin. Nutrient facts analysis using supervised learning approaches. In *2017 Conference on Information and Communication Technology, CICT 2017*, volume 2018-April, pages 1–6, 2018. ISBN 9781538618660. doi: 10.1109/INFOCOMTECH.2017.8340604.

A Banks and E Porcello. *Learning React: Functional Web Development with React and Redux*. O'Reilly Media, 2017. ISBN 9781491954621. URL https://books.google.pt/books?id=6bVZjwEACAAJ.

David Booth, Hugo Haas, Francis McCabe, Eric Newcomer, Michael Champion, Chris Ferris, and David Orchard. Web Services Architecture. *W3C*, page 7, 2004. URL https://www.w3.org/TR/ws-arch/#whatis%0Ahttps://www.w3.org/TR/ws-arch/wsa.pdf.

Claúdia Brito, Marisa Esteves, Hugo Peixoto, António Abelha, and José Machado. A data mining approach to classify serum creatinine values in patients undergoing continuous ambulatory peritoneal dialysis. *Wireless Networks*, 4, 2019. ISSN 15728196. doi: 10.1007/s11276-018-01905-4.

E Brown. *Web Development with Node and Express: Leveraging the JavaScript Stack*. O'Reilly Media, 2014. ISBN 9781491902295. URL https://books.google.pt/books?id=HsLvAwAAQBAJ.

Robin Burke. Knowledge-Based Recommender Systems. In CRC Press, editor, *Encyclopedia of Library and Information Science*, pages 180–200. Marcel Dekker, 2000. ISBN 9780849397127.

Luciana Cardoso, Fernando Marins, Filipe Portela, Manuel Santos, António Abelha, and José Machado. The next generation of interoperability agents in healthcare. *International journal of environmental research and public health*, 11 (5):5349–71, 5 2014. ISSN 1660-4601. doi: 10.3390/ijerph110505349. URL http://www.ncbi.nlm.nih.gov/pubmed/24840351http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4053905.

Olivier Chapelle, Bernhard Schölkopf, and Alexander Zien. *A semi-supervised learning*, volume 1. MIT Press, 2006. ISBN 0262514125, 9780262514125.

Thomas Connolly and Carolyn Begg. *Database Systems: A Practical Approach to Design, Implementation, and Management*. Addison-Wesley, England, 6th editio edition, 2015. ISBN 9780132943260. URL https://www.pearson.com/us/higher-education/program/Connolly-Database-Systems-A-Practical-Approach-to-Design-Implementation-and-Managemen PGM116956.html?tab=overview.

Paulo Cortez. rminer: Data Mining Classification and Regression Methods, 2016. URL https://cran.r-project.org/package=rminer.

Paulo Cortez, J Machado, and J. Neves. An evolutionary artificial neural network time series forecasting system. *Proceedings of the IASTED International Conference on Artificial Intelligence, Expert Systems and Neural Networks*, page 278–281, 1996. URL http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.60.2551&rep=rep1&type=pdf.

Paulo Cortez, Miguel Rocha, José Machado, and José Neves. A neural network based time series forecasting. *Proceedings of ICNN'95 - International Conference on Neural Networks*, pages 329–331, 2004. doi: 10.1109/icisip.2004.1287677.

Toon De Pessemier, Simon Dooms, and Luc Martens. A food recommender for patients in a care facility. *Proceedings of the 7th ACM conference on Recommender systems - RecSys '13*, pages 209–212, 2013. doi: 10.1145/2507157.2507198. URL http://dl.acm.org/citation.cfm?doid=2507157.2507198.

Moritz Dechant. Self-driving car technology — Between man and machine, 2018. URL https://www.bosch.com/explore-and-experience/autonomous-driving-interview-with-moritz-dechant/.

Júlio Duarte, Maria Salazar, César Quintas, Manuel Santos, José Neves, António Abelha, and José Machado. Data quality evaluation of electronic health records in the hospital admission process. *Proceedings - 9th IEEE/ACIS International Conference on Computer and Information Science, ICIS 2010*, pages 201–206, 2010. doi: 10.1109/ICIS.2010.97.

Júlio Duarte, Carlos Filipe Portela, António Abelha, José Machado, and Manuel Filipe Santos. Electronic Health Record in Dermatology Service. In Maria Manuela Cruz-Cunha, João Varajão, Philip Powell, and Ricardo Martinho, editors, *ENTERprise Information Systems*, pages 156–164, Berlin, Heidelberg, 2011. Springer Berlin Heidelberg. ISBN 978-3-642-24352-3.

Russell J.T. Dyer. *Learning MySQL and MariaDB*. O'Reilly Media, Incorporated, 2015. ISBN 9781449362898. URL https://books.google.pt/books?id=hn1jAQAACAAJ.

B Eisenman. *Learning React Native, 2nd Edition*. O'Reilly Media, Incorporated, 2017. ISBN 9781491989135. URL https://books.google.pt/books?id=BJH0swEACAAJ.

Marisa Esteves, António Abelha, and José Machado. The development of a pervasive Web application to alert patients based on business intelligence clinical indicators: a case study in a health institution. *Wireless Networks*, 1 2019. ISSN 1572-8196. doi: 10.1007/s11276-018-01911-6. URL https://doi.org/10.1007/s11276-018-01911-6.

Facebook Inc. React – A JavaScript library for building user interfaces, 2019. URL https://reactjs.org/.

Diana Ferreira, Hugo Peixoto, Jose Machado, and Antonio Abelha. Predictive Data Mining in Nutrition Therapy. In *2018 13th APCA International Conference on Control and Soft Computing (CONTROLO)*, pages 137–142. IEEE, 6 2018. ISBN 978-1-5386-5346-3. doi: 10.1109/CONTROLO.2018.8516413. URL https://ieeexplore.ieee.org/document/8516413/.

Flutter Team. Flutter: a Portable UI Framework for Mobile, Web, Embedded, and Desktop, 2019. URL https://developers.googleblog.com/2019/05/Flutter-io19.html.

Jill Freyne and Shlomo Berkovsky. Intelligent food planning: Personalized recipe recommendation. In *Proceedings of the 15th international conference on Intelligent user interfaces - IUI '10*, page 321, 2010. ISBN 9781605585154. doi: 10.1145/1719970.1720021. URL http://dl.acm.org/citation.cfm?doid=1719970.1720021.

Mouzhi Ge, Mehdi Elahi, Ignacio Fernaández-Tobías, Francesco Ricci, and David Massimo. Using Tags and Latent Factors in a Food Recommender System. In *Proceedings of the 5th International Conference on Digital Health 2015 - DH '15*, pages 105–112, New York, New York, USA, 2015. ACM Press. ISBN 9781450334921. doi: 10.1145/2750511.2750528. URL http://dl.acm.org/citation.cfm?doid=2750511.2750528.

Google Cloud. Cloud Speech-to-Text - Speech Recognition — Cloud Speech-to-Text API — Google Cloud, 2018. URL https://cloud.google.com/speech-to-text/.

Jiawei Han, Micheline Kamber, and Jian Pei. *Data Mining*. Elsevier, 2012. ISBN 9780123814791. doi: 10.1016/C2009-0-61819-5. URL https://linkinghub.elsevier.com/retrieve/pii/C20090618195.

GJ Hay and Guillermo Castilla. Object-based image analysis: Strengths, weaknesses, opportunities and threats (SWOT). *Proceedings of 1st International Conference on Object-based Image Analysis (OBIA 2006)*, XXXVI-4/C4(May 2014):3, 2006. URL https://www.isprs.org/proceedings/XXXVI/4-C42/.

Alan R Hevner and Samir Chatterjee. *Design Research in Information Systems: Theory and Practice*, volume 2. Springer, New York, NY, 2010. ISBN 978-1-4419-6107-5. doi: 10.1007/978-1-4419-6108-2. URL http://link.springer.com/10.1007/978-1-4419-6108-2.

Beth Hoffman and Rupashree Bhattacharya. Machine Learning, Deep Learning 101 – IBM Developer, 2016. URL https://developer.ibm.com/articles/l-machine-learning-deep-learning-trs/.

Steven C.H. Hoi and Michael R. Lyu. A semi-supervised active learning framework for image retrieval. *Proceedings - 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, CVPR 2005*, II:302–309, 2005. ISSN 1063-6919. doi: 10.1109/CVPR.2005.44.

S Holmes and C Herbert. *Getting Mean with Mongo, Express, Angular, and Node*. Manning Publications Company, 2019. ISBN 9781617294754. URL https://books.google.pt/books?id=rfgpswEACAAJ.

Stefan Hosein. A Beginner's Guide to Active Learning (article) - DataCamp, 2018. URL https://www.datacamp.com/community/tutorials/active-learning.

SAS Institute. Machine Learning: What it is and why it matters, 2018. URL https://www.sas.com/en_gb/insights/analytics/machine-learning.html.

Instituto Nacional de Saúde Dr. Ricardo Jorge. Tabela da Composição de Alimentos, 2016. URL http://portfir.insa.pt.

Catherine Elizabeth Kendig. What is Proof of Concept Research and how does it Generate Epistemic and Ethical Categories for Future Scientific Practice? *Science and Engineering Ethics*, 22(3):735–753, 6 2016. ISSN 1353-3452. doi: 10.1007/s11948-015-9654-0. URL http://link.springer.com/10.1007/s11948-015-9654-0.

Ron Kohavi and Foster Provost. Glossary of Terms Journal of Machine Learning, 1998. URL http://ai.stanford.edu/~ronnyk/glossary.html.

Bill Kuechler and Stacie Petter. Design Science Research in Information Systems. *Design Science Research in Information Systems:*, pages 8–10, 2017. ISSN 03029743. doi: 10.1007/978-3-642-29863-9. URL http://desrist.org/desrist/content/design-science-research-in-information-systems.pdfhttp://www.desrist.org/design-research-in-information-systems/.

George F Luger and William A Stubblefield. *Artificial Intelligence: Structures and Strategies for Complex Problem-solving*. Benjamin-Cummings Publishing Co., Inc., Redwood City, CA, USA, second edi edition, 1993. ISBN 0-8053-4780-1.

David Meyer, Evgenia Dimitriadou, Kurt Hornik, Andreas Weingessel, and Friedrich Leisch. e1071: Misc Functions of the Department of Statistics, Probability Theory Group (Formerly: E1071), TU Wien, 2019. URL https://cran.r-project.org/package=e1071.

Mind Tools Content Team. SWOT Analysis (Strengths, Weaknesses Opportunities, Threats), 2019. URL https://www.mindtools.com/pages/article/newTMC_05.htm.

Grant Mitchell. SWOT Analysis Definition, 2019. URL https://www.investopedia.com/terms/s/swot.asp.

Thomas M Mitchell. *Machine Learning*. McGraw-Hill, Inc., New York, NY, USA, 1 edition, 1997. ISBN 0070428077, 9780070428072.

Mehryar Mohri. *Fundations of Machine Learning*. The MIT Press, 2012. ISBN 9780262018258.

Sara F. Morris and Judith Wylie-Rosett. Medical nutrition therapy: A key to diabetes management and prevention. *Clinical Diabetes*, 28(1):12–18, 2010. ISSN 08918929. doi: 10.2337/diaclin.28.1.12.

NCI Dictionary of Cancer Terms. Definition of medical nutrition therapy - NCI Dictionary of Cancer Terms - National Cancer Institute, 2018. URL https://www.cancer.gov/publications/dictionaries/cancer-terms/def/medical-nutrition-therapy.

Jose Neves, Manuel Santos, José Machado, António Abelha, Sollari Allegro, Maria Salazar, Centro Hospitalar Do Porto, and Epe Porto. Electronic Health Records and Decision Support Local and Global Perspectives. *WSEAS TRANSACTIONS on BIOLOGY and BIOMEDICINE*, 5(1), 2008.

José Neves, Henrique Vicente, Marisa Esteves, Filipa Ferraz, António Abelha, José Machado, Joana Machado, João Neves, Jorge Ribeiro, and Lúzia Sampaio. A Deep-Big Data Approach to Health Care in the AI Age. *Mobile Networks and Applications*, 23(4):1123–1128,

8 2018. ISSN 1383-469X. doi: 10.1007/s11036-018-1071-6. URL http://link.springer.com/10.1007/s11036-018-1071-6.

Node.js Foundation. Express - Node.js web application framework, 2019. URL https://expressjs.com/.

Ken Peffers, Tuure Tuunanen, Marcus A. Rothenberger, and Samir Chatterjee. A Design Science Research Methodology for Information Systems Research. *Journal of Management Information Systems*, 24(3):15, 12 2007. ISSN 0742-1222. doi: 10.2753/MIS0742-1222240302. URL https://www.tandfonline.com/doi/full/10.2753/MIS0742-1222240302.

Sónia Pereira, Filipe Portela, Manuel Filipe Santos, José Machado, and António Abelha. Predicting Type of Delivery by Identification of Obstetric Risk Factors through Data Mining. In *Procedia Computer Science*, 2015. doi: 10.1016/j.procs.2015.08.573.

Colt Pini. React + Redux: Architecture Overview, 2016. URL https://medium.com/mofed/react-redux-architecture-overview-7b3e52004b6e.

Parisa Pouladzadeh, Shervin Shirmohammadi, Aslan Bakirov, Ahmet Bulut, and Abdulsalam Yassine. Cloud-based SVM for food categorization. *Multimedia Tools and Applications*, 74(14):5243–5260, 7 2015. ISSN 1380-7501. doi: 10.1007/s11042-014-2116-x. URL https://link.springer.com/content/pdf/10.1007%2Fs11042-014-2116-x.pdfhttp://link.springer.com/10.1007/s11042-014-2116-x.

R Core Team. R: A Language and Environment for Statistical Computing, 2019. URL https://www.r-project.org.

Rita Reis, Hugo Peixoto, José Machado, and António Abelha. Machine Learning in Nutritional Follow-up Research. *Open Computer Science*, 7(1):41–45, 12 2017. ISSN 2299-1093. doi: 10.1515/comp-2017-0008. URL http://www.degruyter.com/view/j/comp.2017.7.issue-1/comp-2017-0008/comp-2017-0008.xml.

Miguel Rocha, Paulo Cortez, and José Maia Neves. *Análise Inteligente de Dados - Algoritmos e Implementação em Java*. FCA, Braga, 2009. ISBN 978-972-722-278-0. URL https://books.google.pt/books?id=dMTOcQAACAAJ.

Neil Rubens, Mehdi Elahi, Masashi Sugiyama, and Dain Kaplan. *Recommender Systems Handbook*. Springer US, Boston, MA, 2015. ISBN 978-1-4899-7636-9. doi: 10.1007/978-1-4899-7637-6. URL http://link.springer.com/10.1007/978-1-4899-7637-6.

G Schohn and David a Cohn. Less is more: Active learning with support vector machines. *Icml*, pages 839–846, 2000. ISSN 0029-6554. doi: http://dx.doi.org/10.1016/j.outlook.2014.08.004. URL http://citeseerx.ist.psu.

edu/viewdoc/download?doi=10.1.1.31.6090&rep=rep1&type=pdf%5Cnpapers2://publication/uuid/A19B6F5E-AE3F-4929-814C-470A6CF2AECC.

Muthu Singaram and Prathisma Jain. What is the Difference between Proof of Concept and Prototype?, 2018. URL https://www.entrepreneur.com/article/307454.

K Srinivas, BK Rani, and A Govrdhan. Applications of Data Mining Techniques in Healthcare and Prediction of Heart Attacks. *International Journal on Computer Science and Engineering*, 02(JANUARY 2010):250–255, 2010. ISSN 0975-3397. doi: 10.1.1.163.4924. URL http://www.enggjournals.com/ijcse/doc/IJCSE10-02-02-25.pdf.

Richard Sutton and Andrew Barto. Reinforcement Learning I: Introduction. *Trends in Cognitive Sciences*, 3(9):360, 9 1998. ISSN 13646613. doi: 10.1016/S1364-6613(99)01331-5. URL http://linkinghub.elsevier.com/retrieve/pii/S1364661399013315.

Techopedia. Definition - What does Proof of Concept (POC) mean?, 2019. URL https://www.techopedia.com/definition/4066/proof-of-concept-poc.

Chun-Yuen Teng, Yu-Ru Lin, and Lada A. Adamic. Recipe recommendation using ingredient networks. In *Proceedings of the 3rd Annual ACM Web Science Conference on - WebSci '12*, volume V-59-09, pages 298–307, New York, New York, USA, 2012. ACM Press. ISBN 9781450312288. doi: 10.1145/2380718.2380757. URL https://arxiv.org/pdf/1111.3919.pdf?utm_source=www.mazavr.tk&utm_medium=referralhttp://dl.acm.org/citation.cfm?doid=2380718.2380757.

The R Foundation. What is R?, 2019. URL https://www.r-project.org/about.html.

Thi Ngoc Trang Tran, Müslüm Atas, Alexander Felfernig, and Martin Stettinger. An overview of recommender systems in the healthy food domain. *Journal of Intelligent Information Systems*, 50(3):507, 6 2018. ISSN 0925-9902. doi: 10.1007/s10844-017-0469-0. URL http://link.springer.com/10.1007/s10844-017-0469-0.

Youri van Pinxteren, Gijs Geleijnse, and Paul Kamsteeg. Deriving a recipe similarity measure for recommending healthful meals. In *Proceedings of the 15th international conference on Intelligent user interfaces - IUI '11*, page 105, 2011. ISBN 9781450304191. doi: 10.1145/1943403.1943422. URL http://delivery.acm.org/10.1145/1950000/1943422/p105-vanpinxteren.pdf?ip=193.137.92.248&id=1943422&acc=ACTIVESERVICE&key=2E5699D25B4FE09E.8B0EA5264B27B16E.4D4702B0C3E38B35.4D4702B0C3E38B35&__acm__=1539078595_b0f1c810a8423fe09c6d20adb1d73d68http://portal.

Mike Wasson. Single-Page Applications: Build Modern, Responsive Web Apps with ASP.NET, 2013. URL https://msdn.microsoft.com/en-us/magazine/dn463786.aspx.

Hadley Wickham. *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York, 2016. ISBN 978-3-319-24277-4. URL https://ggplot2.tidyverse.org.

Wikipedia contributors. Machine learning - Wikipedia, The Free Encyclopedia, 2018. ISSN 0070428077. URL https://en.wikipedia.org/w/index.php?title=Machine_learning&oldid=868337401.

Wikipedia contributors. SWOT analysis, 2019. URL https://en.wikipedia.org/w/index.php?title=SWOT_analysis&oldid=885318472.

David Zeevi, Tal Korem, Niv Zmora, Zamir Halpern, Eran Elinav, Eran Segal Correspondence, David Israeli, Daphna Rothschild, Adina Weinberger, Orly Ben-Yacov, Dar Lador, Tali Avnit-Sagi, Maya Lotan-Pompan, Jotham Suez, Jemal Ali Mahdi, Elad Matot, Gal Malka, Noa Kosower, Michal Rein, Gili Zilberman-Schapira, Lenka Dohnalová, Meirav Pevsner-Fischer, Rony Bikovsky, Eran Segal, Zamir Halpern, Eran Elinav, and Eran Segal. Personalized Nutrition by Prediction of Glycemic Responses. *Cell*, 163(5):1079–1095, 2015. ISSN 10974172. doi: 10.1016/j.cell.2015.11.001. URL http://dx.doi.org/10.1016/j.cell.2015.11.001.

Qian Zhang, Rong Hu, Brian Mac Namee, and Sarah Jane Delany. Back to the future: knowledge light case base cookery. *Proceedings of the Workshop on the Computer Cooking Contest 9th European Conference on CaseBased Reasoning*, pages 239–248, 2008. URL http://arrow.dit.ie/scschcomconhttp://www.comp.dit.ie/sjdelany/publications/eccbr08.pdf.

A

PUBLICATIONS

A.1 INTELLIGENT NUTRITION IN HEALTHCARE AND CONTINUOUS CARE

Authors: Rui Miranda, Diana Ferreira, António Abelha, José Machado
Conference International Conference in Engineering Applications (ICEA19)
Book/Publisher:
Year: 2019
Abstract: In the healthcare industry, the patient's nutrition is a key factor in their treatment process. Every user has their own specific nutritional needs and requirements. An appropriate nutrition policy can therefore help the patient's recovery process and alleviate possible symptoms. Food recommender systems are platforms that offer personalised suggestions of recipes to users. However, there is a lack of usage of recipe recommendation systems in the healthcare sector. Multiple challenges in representing the domain of food and the patient's needs make it complicated to implement these systems. The present project aims to develop a platform for an intelligent planning of the user's meals, based on their clinical conditions. The application of machine learning algorithms on nutrition, in healthcare services and continuous care is thus a key topic of research. This platform will be tested and deployed at the Social Cafeteria of Vila Verde (*Cantina Social da Santa Casa da Misericórdia de Vila Verde*). The development of this project will use the Design Science Research (DSR) investigation methodology, ensuring that the solution to the problem accomplishes all needs and requirements of the professionals, while elucidating new knowledge both for the institution and the scientific community.
Keywords: Machine Learning, Recommender Systems, Meal Planning, Decision Support Systems
Status: Accepted