The NFC-enabled routing game

A hands-on approach to learning Dijkstra's algorithm

Jonathan BOCKELIE[1], Marcel HÖRNER[2],
Sara IONESCU[2] and Lars Erik Midtsundstad STORBUKÅS[1]
[1] University of Oslo [2] University of Mannheim
Supervisor: Philip Mildner, Department of Computer Science IV, University of Mannheim

***Abstract*—A learning game created for mobile devices and based on NFC functionality provides a number of advantages that are able to support and enhance the process of acquiring new information. In order to facilitate the understanding of routing algorithms, this implementation allows the user to physically scan NFC tags that represent network nodes. The result is an interactive, functional NFC learning game that follows in the first steps of game-assisted teaching and presents a new perspective to the user.**

***Index Terms*—NFC, Learning game, Dijkstra, Mobile gaming.**

I. Introduction

When the writers of the science-fiction film 'Back to the Future' imagined life in 2015, they thought of flying cars, self-lacing shoes and the oddly specific pizza hydrators. Some of the ideas they had may seem absurd nowadays, but it is easy to overlook the successful predictions that were made. In the technologically advanced place they imagined the future to be, one could pay for taxi rides with a single touch (i.e. Uber and contactless payment) and doors would be unlocked without an old-fashioned key (electronic identity validation). If they would have also predicted the ability to travel a metro network by swiping a smartwatch to pay and check in the stations, they would have been completely accurate [1]. We are indeed able to experience amazing technology in the present and an important part of these innovations are powered by NFC.

Within the past years NFC (Near-Field Communication) has experienced such massive development and growth that the number of NFC-enabled devices is estimated to reach 1,9 billion phones worldwide by 2019 [2]. The NFC Forum was established in 2004 with the goal of ensuring interoperability and concrete specifications for NFC technologies and promoting their use and development. Amongst its members we find the biggest players in the IT industry and international business, with names like Google, Apple and Microsoft, but also VISA, Daimler AG and Accenture [3]. The trend seems to indicate a continuously increasing prevalence and points towards a future where NFC has become a mainstream device feature and a common presence in our daily lives.

In order to analyse the potential and versatility of NFC it is necessary to understand its capacities, what it brings to the table and what sets it apart from previous technologies. NFC can be fundamentally defined as a set of wireless communication and technology standards that allow devices to establish a simple and contactless information transfer. Specifically, NFC technology consists of two elements: an Initiator which begins and controls the information exchange, and a Target that replies to these requests [4]. The communication channel is established through a 13,56 MHz radio field and offers transfer rates ranging from 106 kbit/s to 424 kbit/s. The actual standards ISO 14443 and ECMA 352 (NFC IP2) define data rates up to 848 kbit/s [5], [6], although higher transfer rates have been demonstrated and recorded in lab prototypes [7].

The main advantage and selling point of NFC is, however, its remarkable setting up speed - connection between two NFC devices is established in less than a tenth of a second, with no pairing or manual configurations necessary [8]. NFC can be therefore used to bootstrap other wireless connections with higher transfer rates - the devices would use NFC to instantly exchange the connection details and leave the concrete data transfer to a wireless network or bluetooth connection. The swift transfer process and its relative low power requirements [9] have made NFC a spearhead in the mobile payment revolution [10] and have enabled its various uses in fields such as in transportation [15], ticketing [17], entertainment , human and animal medicine [13], [14], advertising [19], [16] and more [20].

NFC protocol distinguishes between an active (the connection of two self-powered NFC-enabled devices) and a passive mode. In the active mode, both devices communicate by alternately generating and then deactivating their own fields to receive data. The scope of this paper focuses on the passive mode, represented by communication between an NFC device and a passive antenna, entity or tag. The principle behind it is magnetic induction - the target device does not need a power source of its own since it can draw its operating power from the Initiator [25]. This then enables it to generate a radio frequency and be recognised by the NFC reader.

Originally, NFC is built upon RFID (Radio frequency identification) functionality and provides backward compatibility to passive ISO 18000-3 RFID tags. The RFID maximum read distance depends on the frequency the signal is emmited on, its size, the configuration of the reader and the surrounding conditions. A typical example of RFID functionality is found in modern toll/ticketing systems such as the AutoPass.[11] A car displaying an RFID tag is scanned by a high-power reader located a few metres above the ground, which allows the system to retrieve information about the car and the owner's subscription, quickly launching the billing process. As opposed to RFID, NFC provides a physical layer of security because NFC devices must be in close proximity to each other, usually no more than a few centimetres. This ensures the secure communication between consumer devices such as smartphones and when transferring sensitive personal information. NFC furthermore creates a wider data exchange platform by using the NDEF standard to format data on tags. Scanning an NFC tag with a smartphone can transfer anything from simple strings to commands for the OS, external URLs and signatures to certify the origin of data [24]. Current NFC tags are relatively inexpensive and the most commonly used chips start at a memory space of 64 or 168 bytes, which is enough to store short URLs. This makes them ideal for inserting additional functionality in other mediums, such as smart posters that provide information when scanned [12].

In addition to the previously mentioned fields, NFC has tremendous potential for user interaction in games, especially mobile play. This paper aims to present the capacities of NFC-enabled gaming, with emphasis on serious games and the advantages and applications of NFC in a learning context.

In what follows we will showcase existing research, analyse past attempts and examples of NFC applications and present the concept of our own NFC-enabled game. The concrete implementation will be described, as well as the technology behind the process. Finally, we will evaluate the results and propose ideas for future implementation and outlook.

II. Related Work

A. NFC in gaming

The technological advances of the past decades have reduced the necessary physical space many games need to an absolute minimum. If a chess player deploying a piece needs to be physically present and move his arm, playing online Scrabble against your friends requires nothing more than a few finger taps on your smartphone. A development in the opposite direction can be noticed recently with the popularity of active play controllers and games such as the Nintendo Wii series[21].

The disadvantage of any physical game is the need for specific objects and equipment, which constraints the ease of access and availability of a game and reduces the spontaneity element. Traditional arcade games have often been translated and transposed in a digital mobile environment, even though the input and output restrictions of a smartphone lack the depth of the three-dimensional analog game [22]. An experimental Whack-a-mole implementation by the Domoco euro labs in Munich demonstrates just how easy it is to recreate the swift gameplay and the physical challenge of the original game using NFC technology [27]. In this case, the grid user interface of the game is projected on a dynamic NFC display and the players use their phones to tap the grid and catch the "moles" or targets. There are multiple arguments in favour of this implementation. The NFC tags can be reused for a number of games that require a grid layout (and not only) and the characteristic NFC quick set-up enables players to get started immediately. Transferring the game from a tiny screen (in this situation on an enlarged wall display) allows more people to be involved in the gameplay and is therefore a social experience. Additionally, players can learn the rules of the game by observation. Finally, the novelty of the installation makes for an engaging, active and interesting experience.[27]

Not surprisingly, the physical NFC element increases the interactivity of the game and provides easy and more intuitive [23] controls for the players. An even more social approach to NFC gaming has been deployed and tested at the University of Lancaster, with the goal of demonstrating the improved peer-to-peer contact and interaction NFC can provide [28]. Two originally parlor games centered around the idea of passing around a bomb or a message from player to player were implemented on NFC-able mobile phones and tested in a group setting. The players were using their phones to play, but stated that the focus of their attention was rather the content itself and the other players. Over 70 percent reported they preferred the physical nature of the NFC game as it allowed them to more intimately and actively interact with each other. The experiment also suggests a general openness and interest for using mobile phones as bussines cards or public transport passes, as reported by the interviewed players.

Current research shows that combining NFC and mobile gaming results in positive user experiences even without the social or group aspect. Sarmenta [29] presents a series of NFC games that were developed for the general public, specifically aiming to attract the category of casual, spontaneous gamer. The games were made available for download and the users were instructed to play the game using any NFC tags they had available. The underlying concept of these games revolves around the tags containing 'hidden' information that the player would reveal on the phone upon scanning the tag. The creators implemented simple games with well known rules, for instance a card game with the goal to find matching pairs by uncovering them two by two, or a Simon says example where a given beat or drum pattern must be repeated. The paper concludes with positive reports regarding NFC functionality. The largest impairment for the user experience was the difficulty of acquiring NFC chips, as some players did not possess the necessary amount of cards or tags. However, most players had found it very easy to start and play the games and were pleasantly surprised with the technology.

B. Serious games

The topic of games and their effect on the development of the individual and the society is an incredibly vast subject with roots not only in game design and development, but also in phychology, behavioural sciences and chemistry. Even the act of merely defining what a game is leads to a large number of different attempts and points of view. Juul [31] summarises some of these past attempts and names six criteria that can be used to describe and define a game. He proposes a classic game model that is broad enough to define the concept of a game in various mediums and throughout history, but narrow enough to apply to any specific examples.

From these six points, two of them are suitable to introduce the concept of serious or learning games. First of all, a characteristic of a game is the **valorisation of the outcome**. This means that a game, which can have a number of different outcomes, assigns values to these distinct outcomes - some are better than others. In a concrete setting this can be done implicitly in the game set-up, through instructions or by assigning scores and points. The player then would aim to influence the game state and achieve a positive outcome by investing energy and time. This is the second characteristic, **player effort**.

In a learning game, the positive outcome is not only reaching the declared goal of the game, but more importantly acquiring certain knowledge or a set of skills. An example of learning games with real-life consequences are flight and combat simulators used in an Army setting. These games are different from leisurely played games because the knowledge is gained consciously and the game is played with the specific purpose in mind, as shown in [32]. The article analyses the role and place of games in an educational context and reports in detail three different game scenarios that pass on knowledge to the player without the explicit declared purpose of doing so. Such games achieve a learning outcome through role-playing, repetition and because memorising certain knowledge is required to achieve a good output of the game. The important factors for the success of a game seem to be the quality of the game itself, the immersiveness and, decisive in order to motivate the player to play the game, the enjoyment it provides. The authors refer to some learning games used in an educational context as nothing more than boring digital flash cards, compared to their counterparts in entertainment.

Some of the recent attempts at providing satisfactory learning games were presented within the 2014 International Conference for Serious Games. The University of Vienna presents a case study for the design of learning games based on a concrete and tested implementation[33]. The game itself aims to convey content about the safe usage of the internet to school children in an exploratory, first-person approach. The main character of 'Internet Hero' is transported in a fictional world representing the Internet, where the player is taught decision-making in different contexts, such as recognising spam mail and malicious software. The findings of the study show that the game was overall interesting to the target audience and was well received. The authors of the game explain that the biggest challenge in the design of learning games is conveying and abstracting the learning contents with accuracy while at the same time creating an interesting and fun gameplay. The ideal learning game would be as enjoyable as it is worthwhile and valuable, so that the player voluntarily plays it for recreation while still appropriating the knowledge. The risk therefore is falling short on either side and not achieving the fragile balance.

Moving towards the mobile gaming environment, a successful example in the world of science gamification is the SYNMOD learning game, which attempts to stimulate the interest in synthetic biology, explain the synthesis of biologically active molecules and provide a tool to learn about standard aminoacids[38]. The game is available for download [36] and runs both on Android and Apple devices. Using a mobile platform for a learning game provides many advantages, starting with the high availability, portability and constantly increasing processing speed of mobile devices[37]. The need to improve public perception on emerging research fields in general and the possible methods of approaching this task have been outlined by Ruotolo [39]. An argument he provides for games in a learning environment is the fact that they provide real time feedback, which allows the user to accurately assess their status and improve future performance. A major selling point is also the possibility to easily scale and add further content and functionality.

As can be seen in [32], role-playing games have the ability to convey information easily due to their immersive nature. However, this must not be embraced as an inevitable criteria for the success of a learning game, as demonstrated by a 2014 study [40]. To test the hypothesis that the learning gain of the students depends on the immersiveness of the game, two games with identical underlying game rules were compared regarding their ability to convey concepts from Newtonian physics. One of the games was a 2D educational game, developed by a teacher to improve understanding of the physics course. The other game was based on a 3D Unreal Tournament modification and was customised to fit the learning environment and provide the same rules as the 2D game. An important factor measured during this experiment was the flow state, which is defined by Kiili as the optimal state, when the user is fully engaged and absorbed in an activity[42]. The group of students playing the 3D game did indeed seem more enthusiastic during the experiment, but reported flow levels identical to the students playing the 2D game. Furthermore, testing the students on the respective topics showed that the 2D educational game had comparatively better results, with marks improving significantly even for students who had previously produced mediocre output. The 3D perspective, although adding to the reality of the experience, does not necessarily imply a higher level of receptiveness or clarity. These findings point towards the importance of didactics and of fully understanding the taught mechanisms when designing a learning game. An considerable factor is, to a degree, limiting the player's in-game freedom and environment, so that the stimuli do not distract the students from recognising and concentrating on the concept.

C. NFC in the University

Around the world different approaches were made to implement and benefit from NFC functionality in a higher education context. The University of Taiwan has conducted an 18 week study to analyse the way NFC-enabled classrooms affect the organisation and management of courses[43]. A so called smart classroom was equipped with individual NFC readers for each desk, in addition to the teacher-operated computer and the displays used to show course content. The students were able to use their NFC-able phones or NFC cards to register their presence at the desktop NFC readers, which reduced paperwork and conserved time by instantly storing attendance records in the provided database. An additional advantage was the ability to oversee the students' seat positioning, in order to assist the teacher in familiarising themselves with the students and their learning progress in large classes.

At the end of the course, the advantage of using NFC was obvious in what concerns the possibility of real time student feedback and management of student presence and seating. Furthermore, the researchers were able to measure a change in the students' approach and enthusiasm towards Computer Science and technology. The class in question was an introductory course to Computer Science, with students originally reporting varied levels of interest in an academic context, outside of school and regarding future participation and career goals. The results show a notable positive increase in the students' attitude and interest towards Computer Science in general, regardless of their marks and performance in the subject. Students were more likely to find CS fun and anticipate the lesson after this experiment. It is apparent that increasing the presence of interactive, intelligent Computer Science-related systems in University life helps students recognise its importance in day to day life. The decision to use NFC for this project was based on the fact that no supplemental configurations had to be made on the students' side for NFC connectivity and the option of integrating the readers into the existing campus system.

A similar concept was the NFC attendance control pilot project carried out at the University in Madrid in 2011/2012[44]. The basic idea is the same as in [43], with the exception that the NFC system was implemented in every classroom and for all courses, making it the first of its kind. In addition to recording daily presence, a portal offered the students the possibility to monitor their attendance and access information about the courses, whereas teachers had added functionality like managing classes, verifying attendance by subject or student and eventually condoning absences and delays. NFC was selected as an ideal wireless transfer technology due to its level of security and extensive support by technology companies. The average time needed for attendance control dropped drastically during this experiment and everyone involved had access to more information and improved statistics. Surveys clearly showed a high level of general satisfaction with the project and its usefulness.

A possible future use for NFC in the university is proposed in [45]. In this concept, NFC would play an important role in assisting the examination system. The prototype requires an already existing system that allows students to sit their exams fully digitally on university terminals. In this environment, the students would use NFC cards to identify themselves before the examination, which saves time by instantly assessing presence. After the student's identity is validated, an individual key is saved and encoded on the card. This allows the student to sign in at the terminal and receive his individual exam questions, which are automatically forwarded in the system at the end of the allocated time.

Finally, we found an example of an NFC implementation where the goals of gaming, learning and a high education context all converge, with the addition of a spacial augmented reality aspect. This project has been implemented in [46] and has the goal to encourage student learning and motivation. Two university courses benefited from the experiment and a third one was used as a control group. The NFC game in this case was a strategy-based game taking place across the campus, with locations that students scanned with their phone. Once an objective had been located, players could read the tag and a question extracted from the course material would be displayed on their phone. By answering correctly, they would receive points in the game. Throughout the semester, the level of knowledge was monitored by constant testing and the students who participated in the game were were randomly selected without previous notice (this means they were not able to prepare in advance or skew the previous marks). The results showed that the students' qualifications increased not only after the game session took place, but already when the teachers announced the existence of this part of the course.

This could mean that the students became more interested in the subject once they were aware of the game interactive element.

The results of the game session were not counted in the grades, but after the experiment the students answered positively, noticing they were motivated to study the teaching material of the subject because of the competitive aspect of the game, the new technology, and the development and results of the game being available to their course mates.

III. Concept

Understanding previous research and successes in this field was an additional motivation to proceed with confidence in our project and has helped us clarify which aspects to take into consideration when designing and implementing the app. The goal of our project was to successfully create an NFC-based learning game presenting a new approach to the learning of computer network algorithms. Due to the nature of this topic which is usually taught in University introductory CS courses, the ulterior motive was to conceive a game that would act as a course learning tool. We have identified two key goals:

Firstly, fulfilling the concrete technical requirements of building a tool that efficiently utilises and evaluates NFC capabilities. The app should work with Android 2.2.3 and successfully use NFC technology to read and write data on tags. It should be able to reveal NFC functionality to players who were previously not aware of it and it should raise their interest in computer science in general, similar to the results of previous attempts.

Secondly, the learning aspect of the game plays a crucial role. Given the topic of this project we have identified a similarity to training games, since teaching a routing algorithm (by presenting information from a course) implies consequences in the player's real life and the intrinsic goal of is presumed to be voluntarily learning. This has enabled us to focus on conveying the concept rather than the presentation.

Due to the entertainment aspect of this project, we have decided to avoid the oversimplification of a more complex algorithm and instead realistically represent the Dijkstra algorithm as it is used in network routing protocols to determine the shortest path between two nodes. A network will therefore be represented by a weighted graph connecting an arbitrary number of nodes, and the application will calculate the distances between all the points of the graph. In order for the user to win the game, he or she must understand and follow the Dijkstra algorithm to find the shortest distance between the starting node and the end node.

The game should be competitive and engaging so we plan to achieve this by allocating scores for speed and accuracy. We have resolved to create a single player mode because the focus in the beginning is to evaluate how well the game is able to deliver the knowledge to an individual. However, a function to save high scores under different names is offered.

IV. Implementation

To express the functionality of our app, the following use case diagram summarises the actions the player is able to execute.

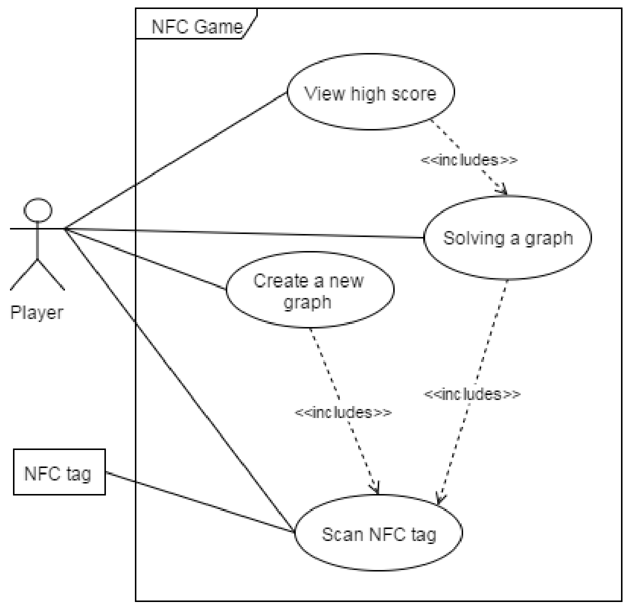

Fig. 1: Use case diagram

There are many different types of NFC tags, and what sets them apart is often storage size and whether they are read-only. Our application works with most modern NFC tags, and the one which is most likely to encounter is the NXP MiFare Ultralight, which has a memory size of 68 bytes. Our application can at most use 60 bytes, but should need considerably less space under normal circumstances. The application runs on Android versions starting 2.3.3.

In the following the three composing parts of our implementation are presented in detail.

A. NFC Interface

The NFC part of our application takes care of all reading and writing of text to and from the NFC-tags.

To be able to store information on these tags, a certain structure for reading and writing needs to be followed. As defined by NFC standards, the data is stored within an NDEF-message, which is a container (or wrapper object) used to store one or more NDEF-records, which then contain the payload (text, image, music and so on). This is necessary to ensure content is understandable to other NFC devices regardless of their individual specifications and formatting standards.

In order to fully showcase the NFC capabilities, we have decided that our app should not be limited to only reading the tags. Because a write operation also includes reading the tag, it is more elaborate than a read operation. However, using tags preloaded with data would have greatly reduced the app's range of use and flexibility. Therefore, the application is able to write on tags not only during the configuration process, but also whenever information needs to be appended to a tag in-game (for example, to record or increment game statistics).

The first encountered challenge was the fact that a typical smartphone has, at any given time, multiple applications utilising or listening for events from the NFC technology. In essence, this means that when the Android environment processes a NFC tag it needs to decide what app to use and which action is required. As soon as the device is within range of an NFC-tag, it broadcasts an Android Intent, which lets the existing applications know that a tag has been scanned. The necessary action is not something Android chooses at random, and thus it prompts the user to provide a preference for an application to be launched. Evidently, this is a very cumbersome process for the user and would break the flow in any gameplay.

Therefore, we have added a listener for NFC tags in the class onNewIntent()-an intent is just an abstract description of an action to be performed. For the next step, we had to create most of the needed methods for creating and interpreting NDEF records ourselves. This turned out to be an advantage, as we were able to control exactly how the text should be stored on the tag.

As our NFC actions do not rely on objects (NFC tag objects), and instead receive all necessary information directly from the tags, the NFC methods are static and are all located in a separate file. Using the read message would therefore require typing NFC.getMessage(). It is debatable whether this is the best solution for future versions of the app, but at the moment it proves to be a very simple way of reading and writing to tags. The only exception is that methods for NFC actions that need to be added have to be "caught" by the activity (onNewIntent, onResume, onPause), but the guidelines for this action are described within the NFC class. Our reasoning for making the methods static is because it is rather unpredictable when and which NFC-tags will be scanned at any time. This also makes the tags easier to share among multiple devices and applications and requires less set-up (creating objects).

In order to let the device know that our app should be responsible for NFC-related actions, we had to deal with the fact that Android launches the app which is responsible for each respective intent or notification. Therefore, in the current implementation an action takes place only if the app is already open and the NFC activity listener is activated. This is why all of our activities that utilize NFC need to have an onResume, onPause and onNewIntent that is NFC-related, to avoid launching the pop-up that asks the user which application to run.

The actions needed for reading or writing to NFC tags have been split into multiple methods for simple use and modifications. In the NFC class many of the sub-operations are within private static methods, some of which include creating an NDEF-message, formatting a tag, processing NDEF messages and so on. The general overview of our application can be seen in Figure 2.

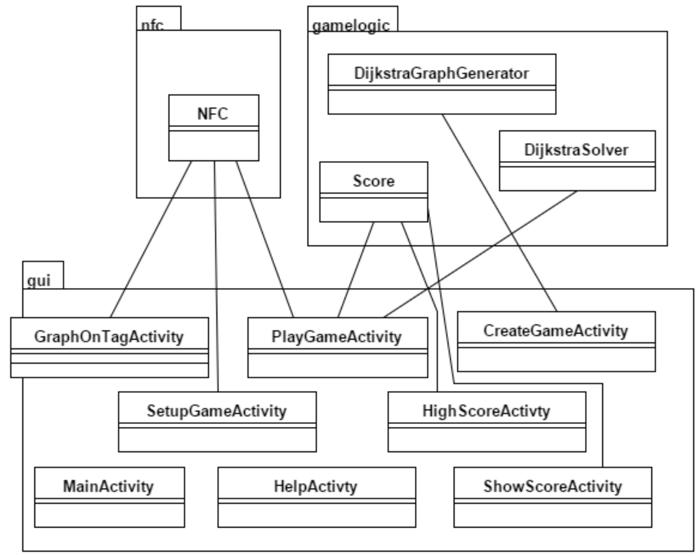

Fig. 2: Class diagram

B. Game Logic

The game logic is responsible for the evaluation of the data read from the tags, as well as the preparation of the data to be written to the tags. It follows the basic flow of the game as presented in Figure 3 and utilises a set of three libraries respectively responsible for graph generation, user input handling and score handling.

The graph generation and user input handling work hand in hand. For every new routing algorithm implemented on our application, a unique graph generation class and a user input handler class are necessary in order to adequately make use of the graph data for each given algorithm. The only requirement for these classes is that they fulfil the interfaces set for graph generation and user input handling, making it straightforward to add further functionality to the application.

The graph generation takes place in the create game mode. It is responsible for making a graph and finding a goal node. Looking at Dijkstra's algorithm as our implemented example, the result is a connected graph with a random number of weighted edges between the nodes, with the goal node being the one with the highest cost to reach from the start node. Once the graph and goal node have been generated, the app creates the data structure to be stored on the tags, which contains all

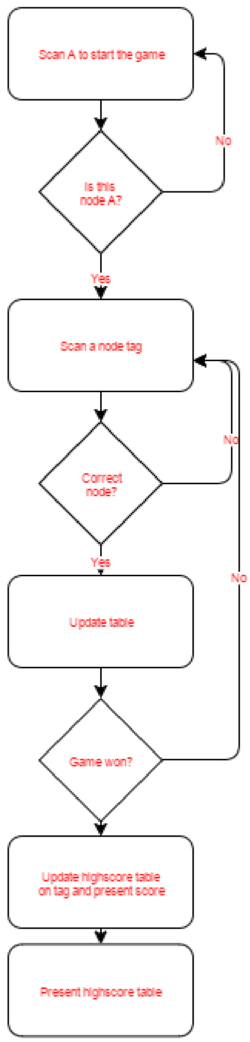

Fig. 3: Game flow chart

the graph data. This structure will vary between algorithms. For Dijkstra's algorithm, the series of bytes is divided into three sections. The first section is a 1-byte name identifier. The second section is reserved only for the start node, containing information about the total number of present nodes and the identity of the goal node. Finally, the third section encodes all the neighbours and the weight of the edges for each neighbour node.

In the play game mode, the user input handling is responsible for parsing the graph data read from the tag when scanned by the user. Reading the start node represents the initial set-up, since the start node contains the information about the used algorithm and the graph itself. After this point, it works as a brute force algorithm where the user suggests nodes by scanning them. Should a correct node be read, the table will update eventual information about unknown neighbours or shorter paths to already known neighbours. If the scanned node is incorrect, it will return a value depending on what wrong. It could be an unknown node, one that was already visited or simply not the node with shortest path yet. Once the user has scanned the goal node as a correct node, the game is marked as finished.

The score library is in use during the play game mode. It is responsible for keeping track of how well the user is playing the game and giving an evaluation in form of a score depending on the number of mistakes, correct moves on row and how much time the user has left on a timer presented during the play game mode. At the end of a game, it calculates the score and parses the highscore table from the goal tag. Should the user's score surpass any of the players on the high score board, the top three is updated and written back to the tag. The score and high score table are retrieved from this library after the game mode in order to present them.

C. *User Interface*

The graphical user interface is the part directly displayed to the user on their phone. After launching the app, the user is shown a simple start screen with little detail. This screen only contains the most important information to avoid a possible distraction. The two options displayed on this screen are creating a new graph and starting the game with an existing graph. After receiving user feedback, a Help button was added, which allows the user to find out more about the play game mode or the app in general.

When the user decides to create a new graph, the values for the graph generation need to be specified. We solved this by adding two standard Android spinners to this activity. After the user's selection the graph is generated by the application, and the user is forwarded to the next activity. To symbolise to the user that he or she is now required to scan an NFC tag, this screen displays the instruction in written form and a suggestive image of a mobile phone exchanging information. The name of the next tag that needs to be scanned changes accordingly and a small feedback window informs the user whether the tag has been scanned and written on correctly, as visible in Figure 4. After all NFC tags are scanned, the graph structure has been written on them so the user is sent back to the main menu.

In order to play the existing graph, the user can enter a name in the main activity and then tap the play button. This launches the next activity where the user is asked to scan the first tag, which contains all the relevant information for this graph. The design of this activity is very similar to the graph creating screen in order to emphasise that the same action (scanning tags) is required. Upon reading the first tag, the actual game is launched. The game activity displays relevant information like bonus timer, mistakes, chain of right paths, algorithm to use and a table. The game waits for the user to scan a path

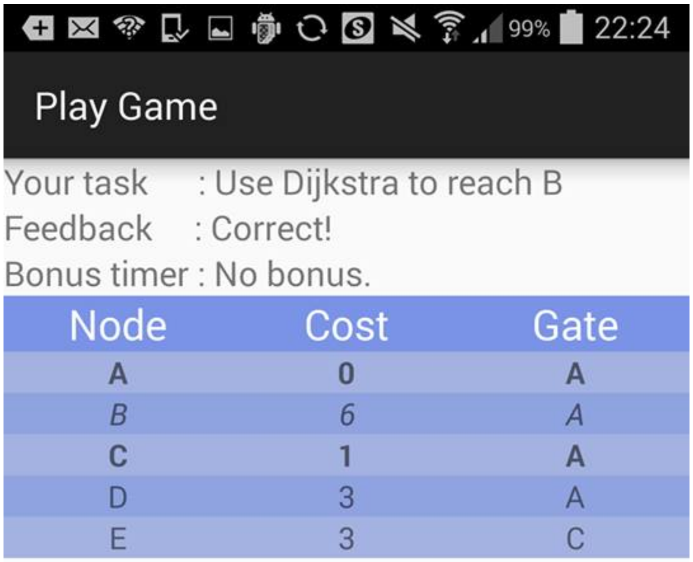

Fig. 4: Screenshot of the play mode

of NFC tags. When a path is scanned, the user gets feedback if the path was correct. If so, the respective node in the table changes its appearance to bold. When a tag is scanned the amount of mistakes with respect to this NFC tag are shown to the user. This information is displayed to the user via a small pop up text. When the last correct NFC tag is scanned the user's score is displayed. The score shows all the different game relevant values. After viewing the score the user can look at the high score. The high score shows the names and the total score of the top 3 players of the played graph. We did not include all possible values to have a clearer high score and to avoid saving unnecessary information. Values like the chain of correctly scanned paths of other players are not that important to save. At this point the game is finished and the user can return to the main menu and go on like described before.

V. Evaluation

After completing our app we were pleased to report that the NFC technical aspect worked as required. During the evaluation process, the app was tested on Nexus, Samsung Galaxy and TODO and worked smoothly on all devices without crashes or gameplay difficulties. The UI behaved accordingly and did not exhibit skewing or elements out of place. Since the used process and routing algorithm are not very resource consuming, the app was running without difficulty even with 10+ other apps open. Regarding the flow of the game itself, we found the table version we picked to be adequate because it mimics a common type of routing exercise and it was most suitable way to represent data from all the approaches we considered.

A. *Challenges and problems that may occur*

As observed in previous research [29], the casual gamer may have difficulties playing this game due to the necessary requisites. A small investment in NFC cards or tags is required in the beginning, which in a learning context could be provided by the respective school or university.

The fact that some smartphones do not offer NFC functionality at the moment may constitute a challenge, but it is predicted that this issue will remedy itself in the future, given the current trends [2].

Since NFC technology is not particularly designed for a very rapid switch of tags when scanning, there is a slight possibility of the user reading from one tag, quickly moving to the next tag and writing back on the second tag by accident. In other words, this could result in an error within the game logic. Since our trials have shown this is a rather unlikely possibility, we have chosen to not squander resources on approaching this scenario.

Compatibility errors with future Android versions may also pose a challenge in the future, therefore we advise the user to play the current version of this app only on TODO.

B. *User Feedback*

The evaluation of this project was performed by randomly selecting students from the Universities in Mannheim and Oslo and allowing them to test our app. The results were recorded partly in written form, partly as oral remarks and statements. Due to time constraints between the final version of the app and the end of the project, a proper controlled study with more participants could not be carried out. However, we have received useful feedback which can help improve the app in the future.

We have found out that general public have trouble associating the terms NFC or Near-Field Communication with a definition when prompted, but recognised and were aware of NFC or RFID applications when given clear examples (such as using the student identification card to open doors or lockers on university grounds). In these cases, the students did not seem to know whether their smartphone offered NFC functionality, even when it did. One of the students was already very familiar with NFC (fidelity cards and contactless payment). One of the students that participated was eager to try the app on their phone, which gave us the chance to test it on yet another device. The other participants used smartphones provided by us with the pre-installed app.

The overall reaction to NFC functionality was surprise or an 'aha!' response. We are able to report that people were pleased to scan a card with no visible chip or communication elements and then observe an immediate change on the screen. The game functions and usability were rated positively. The addition of the Help button which includes instructions about how to play the game turned out to be a useful and utilised function.

It was possible for a player to simply start the app and play immediately. However, we found that the most learning gains appear when presenting the player with an initial short explanation of the Dijkstra algorithm, and only then allowing them to go on scanning. When trying out the app without a previous explanation, it was reported that the players completed the game through trial and error and without truly understanding what was happening. This encouraged us to think about how to make the gameplay clearer to improve the learning aspect. It may be likely that the time counter represented an additional stress to the players and encouraged them to act quickly and therefore not waste time trying to comprehend the algorithm.

VI. Outlook and future work

Some of the changes and additions that can be made to further improve the app are presented in this chapter.

To increase the player's understanding of the app functionality and learning goal, future implementations could include a short demonstration before the concrete start of the game. This would be beneficial in what concerns the execution of the routing algorithm and it may also reduce the stress at the first contact with the fully functional, timer-based graph-solving screen.

A new design for the visual representation of the graph and the node scanning process should be definitely taken into consideration. The improved layout should include the possibility to present more information during the graph solving process, in order to explain the learning concepts. It should also be able to clearly display and support a large number of nodes. For aesthetic reasons, the general UI of the game can be also improved and reshaped.

For added functionality, more routing algorithms can be added in the game logic, as well as the option of playing in a multiplayer mode, over a wireless or data network. The possibility of a try-out mode, where the player can experiment and learn about the algorithms without time pressure and

The development process itself can be improved for future versions, by involving the end users in the design and implementation stages and by rigorously testing and evaluating the app at an earlier time.

Overall, the full possibilities of NFC-enabled learning games extend greatly beyond the scope of this project. Although the basic functionality requirements for the Dijkstra learning game were fulfilled, the created app can be greatly improved given enough time and following user feedback. However, the development process was an interesting, educational and rewarding experience, and we feel that this learning game has the potential of becoming an useful learning tool in the future.

VII. Team member participation

The necessary steps to accomplish this project were literature research, concept development, app implementation, refactoring and testing, evaluation, report conception and writing. These tasks were completed as a continuous team effort, with the individual participation divided equally as follows.

Team member	Contribution
Bockelie, Jonathan	25%
Hörner, Marcel	25%
Ionescu, Sara	25%
Midtsundstad Storbukås, Lars Erik	25%

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