A VR based solution for informing cycling fans

TU Delft

Delft University of Technology
Industrial design engineering
Msc Integrated Product Design

Graduation Thesis

Nov 2019

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Acknowledgements

Now that I have finished this report and that I am close to the moment of graduating, I look back a project that had ups and downs. But the most important point is that I did it, I did my graduation project. And I could not have done this on my own. First of all there was my supervisors, Imre Horvath and Doris Aschenbrenner, that were patient in supporting me. I want to that both of you for the time you took to give me feedback and to help me learn new things. Rado Dukalski was also a great support for me during my project by our inspiring ideation sessions and talks.
Other people that I want to show my gratitude are:
The cyclists that enthusiastically helped me with recording the footage I needed for my prototype
Nathalie and Suzanne For being very supportive friends who I could always talk with when I got stuck in my project. I also really appreciate your help with recruiting participants for my testing.
Yoon, for the delicious Korean cuisine you prepared for me to celebrate small achievements. Korean food always helps me to get over my homesick feelings towards Korea.
Bryan, you are always very supportive and understanding. We are both graduating at the same time, which makes that both of us are very busy. I love it how we can enjoy small things together in the little time we have next to graduating
I want to thank Lina a lot for proofreading my report, providing supportive feedback and giving me mini pep-talks at the last moments of finishing this report.
Lastly I want to thank my family for supporting me through this project, and for supporting me to follow my dreams. This graduation means more than just finishing a project. It is more than receiving the ‘Master of Science’ title and certificate. It is the finalisation of building a bridge from being a student to starting a career. Who knows me, also knows that I am going to find my happiness in South-Korea. With the finalisation of this thesis, it also means that a lot of things are going to change. I am happy that my family and friends are so much understanding and supportive, as they know I am a little bit Korean.

Abstract

This graduation project is an explorative project to the opportunities of the third dimension in Virtual Reality (VR) and the role that Informing Cyber Physical System (ICPS) principles can play in a service for providing more information to cycle fans who want to learn more while watching the Tour the France. The Tour de France implemented in 2015 live tracking data of every cyclist, and uses since 2017 machine learning to make predictions with this data. This amount of data makes this specific race interesting for the design of an information provisioning service for the cycling fans.

This project is done in collaboration with the TU Delft Sports Engineering Institute. The TU Delft Sports Engineering Institute is an interdisciplinary research institute that researches how the performances of top-athletes can be improved. One of their research topics is 'Sports Infrastructure and Facilities', which includes creating an ultimate viewing experience by augmenting the spectators' experience by giving the spectator real time information on the athlete's performance.

In six phases, this report describes the design process of the service in VR. The first phase is the orientation where the scope and context of the project and the assignment are described. Then, in the research and analysis phase, four knowledge domains are analysed, resulting in a list of requirements for the service. The Ideation and conceptualisation phase shows several ideas for functions, working the system and interactions and the VE lay-out. This resulted in three concepts of a service, of which one is selected and further detailed. Next, a digital demonstrative prototype of a few features is created using 'Unity' and a HTC Vive. This prototype is used in a user test to evaluate the concept and compare the learning effect to the traditional broadcasts.

The result of this design project is a service design for watching the Tour de France in VR with informing elements. It is an application that can be used on a VR Head mounted Display (HMD) by the users at home. In the Virtual Environment (VE) of the application the user sees a screen for video footage, a 3D map of the route of the race and several informing elements. The usage of VR will help the users to get a better overview of the race and a better perception of depth about the routes. By providing information that is tailored to individual informational needs, this service can help the users to learn more about the sport in an interactive and entertaining manner.

List of abbreviations

CPS	Cyber Physical System
CPC	Cyber-physical computing
HMD	Head-Mounted Display
IoT	Internet of Things
FOV	Field Of View
HUD	Head Up Display
IS	Interactive Storytelling
IV	Information Visualisation
TdF	Tour de France
VE	Virtual Environment
VR	Virtual Reality
XR	Extended Reality

List of definitions

System: different elements that work together.

Function: a goal or task that the service or system should fulfil.

Feature: a part of the system that fulfils a specific function.

Component concept: an idea of which the functions, components and usage are specified. It is documented using diagrams or sketches.

Demonstrative prototype: an incomplete version of the designed system, that is created with less focus in details with the purpose of testing the functionality, the feasibility and new combination of technologies.

Contents

1 Orientation

1.1 Introduction and process of the orientation

This thesis is a self-initiated project with as subject cycling. The topic is informing the cycling fans about cycling races. This subject cycling is chosen as the domain of this project because of two reasons. Firstly, the cycling sport is currently innovating their way of broadcasting using data to give the viewers real time information. This fits to one of the research subjects of the Sports Engineering Institute. Secondly, the project of the company mentor is about cycling and has data and sensors ready to use.

The objective of this orientation chapter is to introduce and describe the scope and context of the project and to describe the expected outcome of the project. This chapter first provides an introduction to the project scope, stakeholders and design challenge (section 1.2), followed by a section with background information on the context (section 1.3) and ends with a description of the project (section 1.4). Figure 1.1 shows the process of this phase.

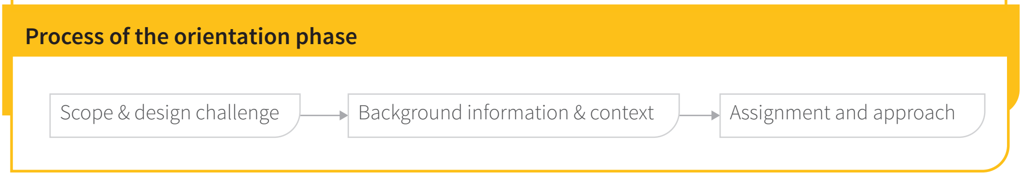


Figure 1.1: Process of the orientation phase

1.2 Scope

A scope can be defined by describing the stakeholders. Assumptions and exclusions, limitations and risks, objectives, and high level requirements. An overview of the scope is shown in figure 1.2. The key-stakeholders of this project are the Sports Engineering institute and the users. If the project outcome would be realised other stakeholders, like broadcasting stations, cycling teams, etc., would play a role as well, but this is left out of the scope. Also the business aspect is also left out of the scope. Based on the trends described in the next section, the assumption is made that the use of Virtual Reality Head Mounted Displays (VR HMDs) at home will be more common in the future. Limitations of this being an individual project are that there is only the time to make one detailed prototype. The integration of Cyber Physical Systems (CPSs) is limited to the use of only the principles. To make this a successful project the following two objectives have to be fulfilled: i) informing cycling fans about cycling races, like the Tour de France, and ii) creating an experience that fits a new and younger audience of the race. For this a list of requirements will be defined in the analysis phase, but high-level requirements are here defined as: providing educative value, design for high-end VR HMDs, using the advantages that VR offers and using the ICPS principles to give the service more value.
This section will continue with an explanation about the stakeholders and the definition of the design challenge.

To make this a successful project the following two objectives have to be fulfilled: i) informing cycling fans about cycling races, like the Tour de France, and ii) creating an experience that fits a new and younger audience of the race.

1.2.1 Stakeholders

This project is done in collaboration with the TU Delft Sports Engineering Institute. They are, together with the target group, the main stakeholders of the project.
The TU Delft Sports Engineering Institute is an interdisciplinary research institute that researches how the performances of top-athletes can be improved. But their research is not limited to only the performance of athletes. Their research topics are spread over various domains in the sport sector. Cycling is one of the sports they include as one of the research domains. One of the five research subjects of the Sports Engineering Institute is 'Sports Infrastructure and Facilities'. This subject includes "… a challenge to offer the spectators the ultimate viewing experience, which can be brought about … by augmenting the spectators' experience by giving the spectator real time information on the athlete's performance. The latter is closely linked to the research direction 'Measuring, feedback and simulation', only now the performance data is used to add an extra dimension for the spectator." (TU Delft Sports Engineering Institute, n.d.)
This thesis is linked to the research conducted by a researcher from the Citius Altius

Sanius project, Rado Dukalski, who is focussing on the use of Augmented Reality (AR). The Citius Altius Sanius project is a large project about injury prevention with several research projects on different topics. One of these researches is about injury prevention and safety of top-athletes in the cycling sport. The research of Rado Dukalski is about displaying relevant geospatial information (information that has a geographic component) in the sports domain, in context of massive-venue sports such as road cycling. This thesis relates to the displaying of information, by providing the spectator with real time information on the athletes performance and providing information about the race, a cycling race.

Key stakeholders

- TU Delft Sports Engineering Institute
- User: cycling fan

Objectives

- Informing cycling fans about cycling races
- Creating an ultimate viewer experience

Assumptions and exclusions

- In the future the use of VR HMDs at home will be more common.
- Since this is an IPD project, the business aspect is left out of the scope

High level requirements

- The service should give the user more educative value by: satisfying personal curiousity, providing educational content and intuitive interaction.
- The application is designed for high-end VR HMDs like the HTC Vive.
- The advantage of VR will be used to achieve this.
- The use of the ICPS principles is used to give the content of the service more value.

Limitations and risks

- Regarding the ICPS, only the principles will be used, but the ICPS itself will not be designed
- Users are not very known yet with the use of VR
- There is only time to make one detailed prototype during this project, using the Vive that is avalibale

Figure 1.2: scope of the project

"… there lies a challenge to offer the spectators the ultimate viewing experience …" (TU Delft Sports Engineering Institute, n.d.)

As the quote above states, the challenge is to create an ultimate viewing experience for the spectators. These spectators are defined as the second stakeholder of this project: the target group, who are younger cycling fans (aged 18 – 35 years old) who watch cycling races. This target group matches with the aim of the Tour de France organizer (A.S.O.) to attract a new younger audience. The target group is specified more specifically later in section 2.1.
The outcome of this project could increase the quality of the relationship with the fans, when fans understand better what they are watching, they can enjoy it even more and will become more valuable fans and result in a growing followership. Even though this the target group of this thesis are cycling fans, the knowledge that is obtained lays the foundation for the use of VR in cycling in a much broader range of applications. For example the use of VR by cycling team coaches or professional cycling athletes themselves for pre-race debriefing or post-race analysis.

1.2.2 Design challenge

As explained, there is a need for more information and/or explanation about the sport to keep the audience interested. To create more insights in the data, and to create content that fits the personal interest of the viewers, data technologies and ICPS principles can be used. Another technology that is currently used for the broadcasting of other sports is Virtual Reality, so it is the question if this is a good next step for the cycling sport as well.
The goal of this project is to design a service that provides the spectators with information, not only to offer the ultimate viewer experience, but also that the viewers can learn about the sport (to prepare themselves for a quiz about the Tour de France). To achieve this goal three design challenges are formulated:
1- How to create an educative experience that fulfils the needs of the viewers?
2- How to benefit from the advantages that VR offers?
3- How to create valuable content from the data using ICPS principles?

1.3 Background information

The broadcasting of the 'Tour de France' is changing substantially last couple of years. This section first introduces the main technological trends for sports broadcasting in general, and then follows with an explanation about the changes of the Tour de France broadcasting specifically. The current state of the broadcasting of this specific race and the future imagined scenario with the outcome of this project will be described.

1.3.1 Technological trends for sports broadcasting

Sports broadcasting is about providing an audio-visual report of a sports competition or race to a large audience via mass media. The development of new technologies provide opportunities to create a more unique or intriguing viewer experience. Three technological trends that influenced sports broadcasting are showed in this section.

First of all, the younger audience is used to video (live) streaming and on-demand watching of videos. Out of all 18 to 25 year-olds in the Netherlands 99,8% has access to internet. This is even more for the 25-35 year-olds, of which 100% has access to internet in 2019ds. In 2019 around 75% of the Dutch population between 18 and 35 years old watches TV via internet. (CBS, 2019)

In the U.S. research showed that people in 27% of the people are 'cord nevers' or 'cord cutters', which is increased by 50% in the past two years (Nielsen, 2018). Even tough millennials watch less TV in the traditional way, they are still interested in sport but are consuming it in different ways (McCaskill, 2019). Because of this trend there is a need to find new methods to reach this audience. An example of an innovation that is possible because of TV via internet is a the 'F1 TV App' where while watching races the viewers are immersed by features like selecting on-board cameras to watch from and live statistics.

Secondly, Augmented Reality (AR) and Virtual Reality (VR) technologies are used to immerse fans in games and races that they are watching (McCaskill, 2019). Since 2014 the NBA (National Basketball Association) started experimenting with VR broadcasts of the games, and from the 2016-2017 season up until nowadays the NBA weekly broadcasts games in VR (Welch, 2016). There is a large increase in the consumer VR (software and hardware) market expected, which is expected to grow double the current (2019) market size by 2021 (Statista, 2019). These trends show that in the near future more VR devices will be available, and that more content will be developed for these devices, which makes it more attractive to use these devices. In this project, VR is used to apply the possibilities that it provides for digital representation, for informing the user with additional context and information about the 'Tour de France'.

Thirdly, there is the trend to provide data and statistical insights to sports fans. This increases the knowledge of the fans about the sport, which also increases their interest in, and creates a stronger relationship to the sport. One technology used for the data provision is the Internet of Things (IoT) that makes use of intelligent sports equipment, player tracking and other devices. (McCaskill, 2019) IoT consists of 'things', which are physical or virtual entities with sensors. These 'things' are connected with other 'things' to share information without the help of humans, creating a network of smart devices. IoT can be seen as a subset of Cyber physical Systems (CPSs) that includes, beside the physical and/or virtual elements and data, also computational power (Camarinha-Matos, Goes, Gomes, & Martins, 2013). The next step of the usage of data in cycling broadcasts would be the use of CPS principles, that provide enablers for computing the recorded data. A technology related to this, which is currently used at the 'Tour de France' is machine learning. Using the available data predictions can be made about for example the outcome of the race. In 1.1.2 more about the data innovations at the 'Tour de France' are described.

These trends show that the use of new technologies for sports broadcasting is promising and needed to keep the fans engaged. The three trends together form the backbone this project. More information about and examples of these trends can be found in appendix A.

1.3.2 Context: Tour de France - current and the imagined future situation

The 'Tour de France' is chosen as the context in this project, because it is the "most famous multi-stage race in the world and one of the three European Grand Tours" (Prasad, 2019). This section explains first what the 'Tour de France' is and how the broadcasting of this race has evolved during the last years, the current situation and the imagined future situation.

This cycling race, the 'Tour de France', is described as "the world's most popular, not to mention prestigious, cycling race" (Koch P. , 2015). It is one of the biggest road cycling races which is held every year, organised by Amaury Sport Organisation (A.S.O.). The 'Tour de France' is a race that consists of 21 day-long stages over the course of 23 days, in which 20 to 22 teams of 8 cyclists each participate.

15 to 20 years ago there were issues with doping and after that the viewer-ship declined. Since 2016 the complete race is covered live on TV which helped the viewer-ship increase (Robinson, 2017). A.S.O. wants to attract a younger audience for the 'Tour de France' with the use of data and technologies (NTT Limited, 2019). Last years, A.S.O. collaborated with 'Dimension Data' to innovate the broadcasting of the race using technologies. Since 2015 live tracking and data analytics are used, in 2017 machine learning was added to the usage of data and this year improvements were made on integrating the data for a richer fan experience (NTT, 2019). Appendix B1 shows a detailed time-line with the developments of the 'Tour de France'. The collaboration with the company 'Dimension Data' (since July 2019 NTT Ltd.) has brought these technological innovations to the 'Tour de France'.

"Demand for data: Growing demand for accessible, real-time sport info" (Dimension Data, 2019)

To make these developments possible, every bike has currently a transmitter that tracks and sends data about the cyclist (e.g. speed and position) to data trucks. Figure 1.3 shows how this data is currently used and what the future imagined situation looks like.

Currently, at the 'Tour de France', people work to display this data as a live broadcast or to publish on their website, application and other (social media) platforms. Also machine learning is currently used to get more insights from the data.

In the future scenario the viewers will be able to follow the race via an integrated VR application. Because of large amount of available data, it is interesting to explore opportunities for implementing ICPS, that can use the existing data in more innovative ways for content creation. For this extra information or sensors might be needed.

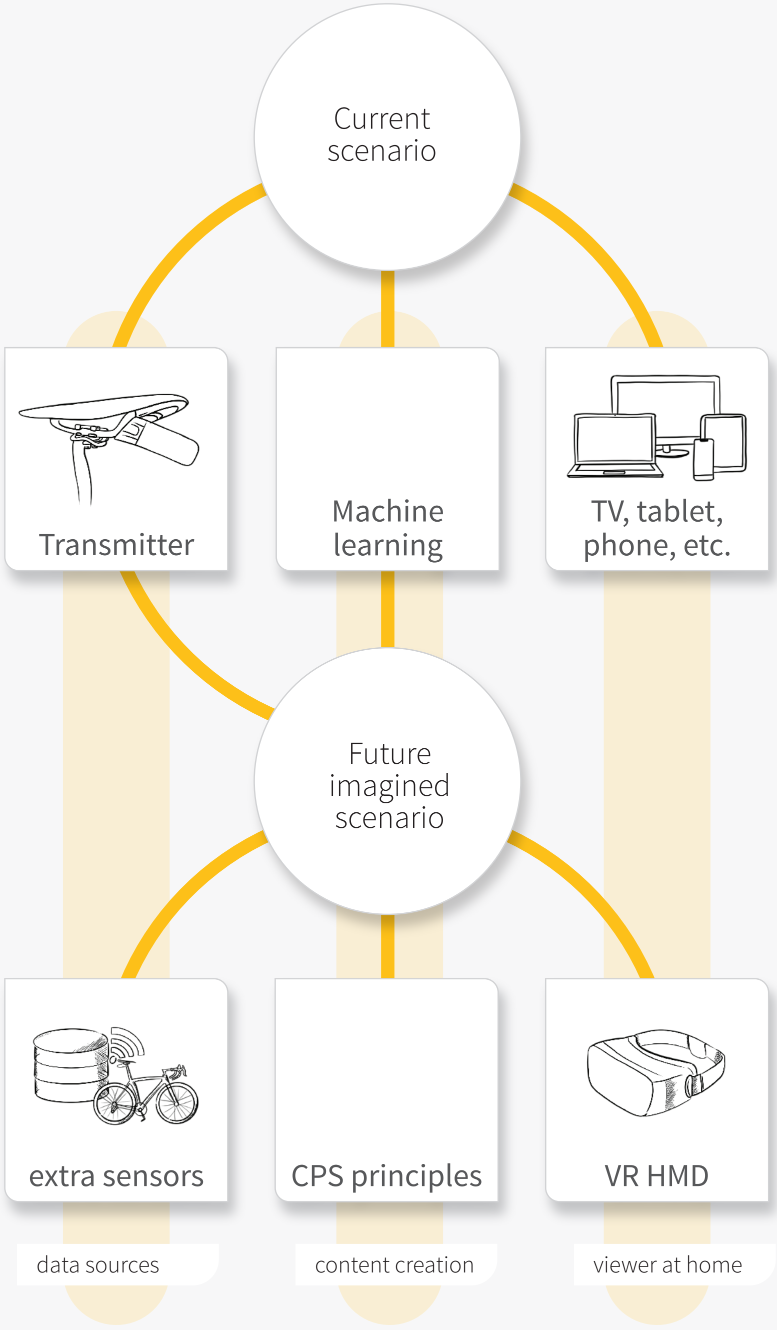


Figure 1.3: Current and future imagined scenario

1.4 Project

When analysing the search results for research articles about "Virtual Reality", there is a vast increase shown the last years, from 2005 to 2018 an increase in double the yearly amount, with the total amount of documents since 2009 being 116,409 with (Scopus, 2019). Since Virtual Reality is a field that is gaining more attention and some products are being developed for the use of this technology, it is an interesting research topic. The idea to combine VR with CPS comes from the use of data for informing the fans during a broadcast. The more data is available, the more complicated and time consuming it gets for the current situation to use it for broadcasts. Computing is needed to process the data fast enough and it can give the data more informational value, which creates a more promising service for the VR broadcasting of the cycling sport.

1.4.1 Assignment

The domain of interest of this project is the enrichment of the viewing experience by educative information while viewing the Tour de France. As a means for displaying the content a VR HMD (head mounted display) is supposed. To create the educative informational content, the principles of an informing CPS will be used. These principles are working dominantly in the cyberware domain. The original project brief of this graduation project can be found in appendix C.

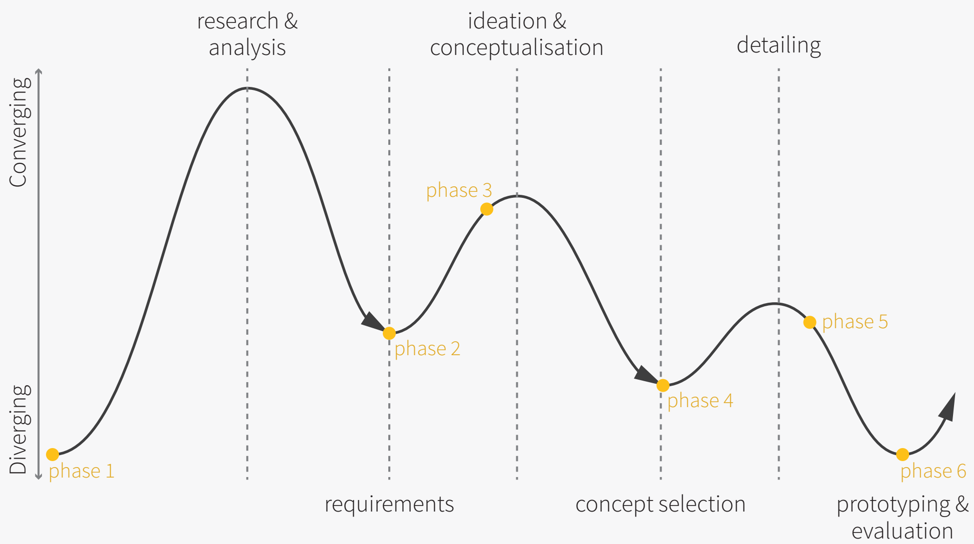
" This graduation project is an explorative project to the opportunities of the third dimension in VR and the role that ICPS principles can play in a service for providing more information to cycle fans who want to learn more while watching the Tour the France. "

1.4.2 Design process and approach

An illustration of the design process is depicted in Figure 1.4. It shows the six phases of this project and indicates when each phase started in the process of diverging and converging. Although the figure is illustrated as a linear process, the design process in reality is an iterative process with multiple cycles. The six phases are 1.orientation, 2.research & analysis, 3.ideation & conceptualisation, 4.detailing, 5.prototyping and 6.evaluation & conclusion. These phases are the chapters of this report as well.

One of my personal ambitions for this project was to find out if I want to continue in the field of research after my graduation or not. So, this project is chosen with the focus on research and design. This results in an emphasis on the analysis (phase 1), design (phase 2, 3, 4 and 5) and evaluation (phase 6), where the analysis formed a base for the design cycles.

For the prototyping and testing, the available materials and resources are the HTC Vive (available in the TU Delft Applied Labs), a recorded dataset and a bike with sensors attached (to possibly record extra data when needed, both are available via the Sports Engineering Institute). The prototype is a demonstrative prototype rather than a prototype of the complete working system. A demonstrative prototype is an incomplete version of the designed system, that is created with less focus in details with the purpose of testing the functionality, the feasibility and new combination of technologies. At the beginning of each new phase (chapter) the detailed diagram of the process of the tasks performed in that phase is shown. Appendix D shows these diagrams in one figure and the relations between them.



Phase 1: Orientation
Phase 2: Research and analysis
Phase 3: Ideation & Conceptualisation
Phase 4: Detailing
Phase 5: Prototyping
Phase 6: Evaluation & Conclusion

Figure 1.4: an overview of the phases of the project

2 Analysis

2.1 Introduction and process of the analysis

The objective of the analysis phase is to get an overview of, and more insights in the four knowledge domains of this project, namely the user, sources of information about the 'Tour de France', technologies (this is split up in CPS and VR), and content of the service. Figure 2.2 shows these four domains and how they relate to each other, which is further explained in the next section. The results of the analysis are used to compose a list of requirements for the concept. Figure 2.1 shows the process of this phase, and indicates which analysis methods are used. These include literature research, internet research (products (and manuals), images, videos, etc.), user interview and questionnaire, expert articles, and white papers.

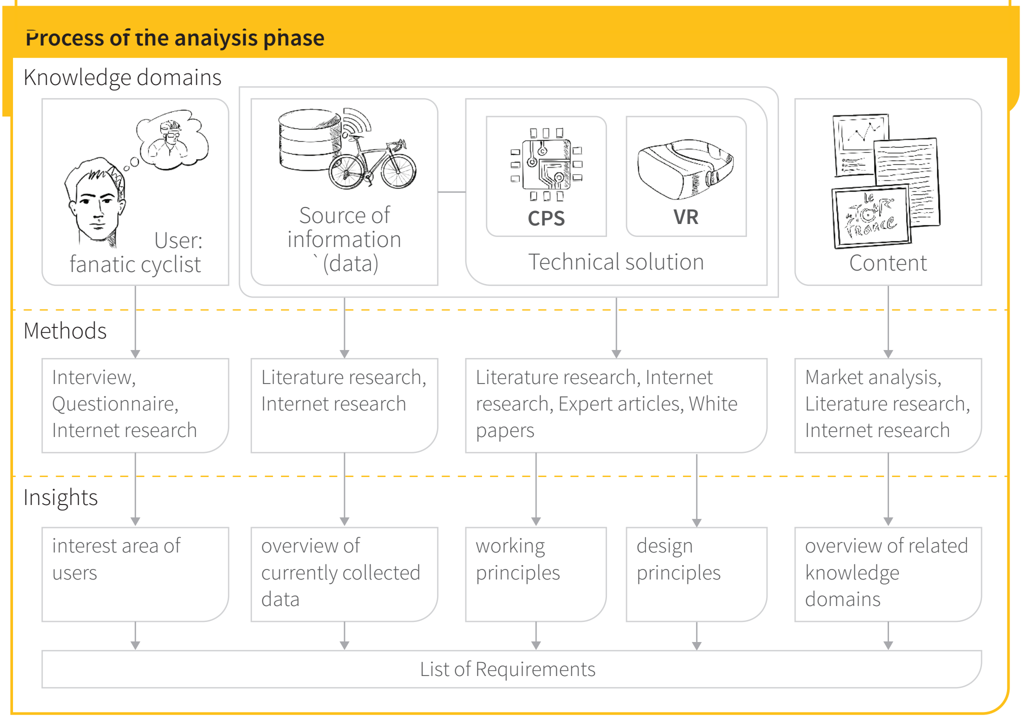


Figure 2.1: Process of the analysis phase

2.2 Knowledge domains

When specifying the future imagined scenario, which was presented in the previous chapter, four relevant domains can be defined. Knowledge about these domains is needed to design the imagined service. This section explains the how the knowledge domains relate to each other in the system.
In the centre of figure 2.2 the knowledge domain 'content' is placed, which is about the content of the service. This includes what is shown to the users; what information, what type of elements, in what kind of structure, and so forth. The content is useful for the preparation for a quiz about the cycling races.
Above the 'content' the knowledge domain of the 'user' is placed. The user is the person who watches the cycling race at home and interacts with the content via the user interface.
At the left side of the 'content' the 'source of information' is located, which provides the data and information that is used to create the content. One aspect of the data is that data about the user (e.g. user profile or usage of the application) can be collected to use for providing a more personal service.
Lastly, at the right side of the figure is the 'technical solution' which includes two technologies, namely VR and CPS (of the latter only the principles are analysed and used). These technologies are integrated, using each other's in- and output. The user input to the system is sensed by the VR set (how this works is explained is section 2.5.3), and then used for direct interaction with the application or indirectly used to improve the creation of (personalised) content. This content is then showed in the VR HMD to the user. Besides the selection of the content, the CPS principles are also used to process the data into valuable content.

The following sections of this chapter will each analyse different these knowledge domains (user in 2.3, data sources, VR and ICPS in 2.4 and content in 2.5). To answer the first question that was defined in the design challenge (see 1.2.2): 'design challenge 1- how to create an educative experience that fulfils the needs of the viewers?' first the user and their needs are analysed. To create the content using the proposed technologies the following two questions will be answered: 'design challenge 2- how to create valuable content from the data using ICPS principles?' and 'design challenge 3- how to benefit from the advantages that VR offers?'. After analysing the technologies, the second part of the first question can be answered in the last section about content creation. This section explains how the three previously explained knowledge domains come together, and what additional knowledge is needed to create the content for the service.

2.3 User analysis

The objective of the user analysis is to create a clear image of who the target group is, to know how the users currently experience the Tour de France and gain insight in the needs of the user. This section first gives an explanation about the target group, and then their current experience of the 'Tour de France' is given. This will answer the user-needs part of the first design challenge (see 1.2.2 and 2.2).

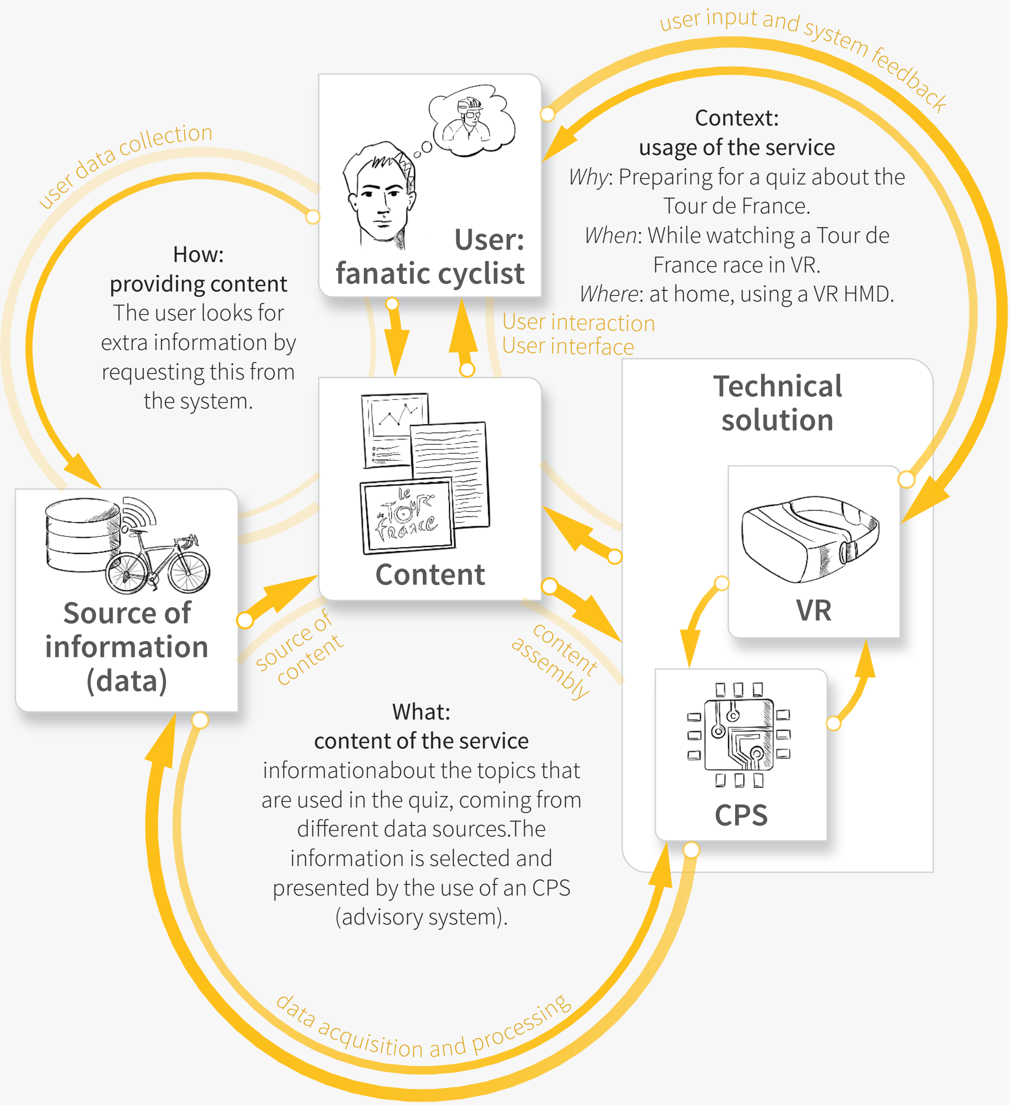


Figure 2.2: an overview of the imagined outcome of the project, illustrated by the four knowledge domains and their relationship

2.3.1 Target group information

To find out more about the who target group the following research methods are used: interview, observation and questionnaire. In addition, the report of a research conducted by the Royal Dutch Cycling Union (KNWU), named 'Wielersportmonitor' is used. n the 'Wielersportmonitor', a research on the Dutch cycling market, there are 4 types of cyclists described: adventurous-, fanatic-, enjoying- and free cyclists (NTFU, Bike MOTION Benelux, KNWU, 2018). The size of each group in the Dutch cycling market is shown in the inner circle of figure 2.3. The Fanatic cyclists are chosen as the target group of this project because they will be most eager to learn more about cycling.

The vision of A.S.O. (organizer of the 'Tour de France') is to use the digital transformation of the 'Tour de France' to create contents that will engage existing fans and attract new and younger viewers (Dimension Data, 2018). Different social media and other online platforms are used nowadays to attract this younger audience. In 2018 73% of the Tour de France's 6.5-million-strong social media audience were in the age group between 18 and 35 years old (Dimension Data, 2018). To fit the goal and vision of A.S.O, the age of the target group is chosen to be 18-35 years old.

During a visit to one of the weekly cycling races at the cycling association 'De Spartaan', I interviewed two people, one was a cyclist who was participating in the race and the other person was in the board of the association, organising the race (See appendix E1 for the interviews). What was standing out the most is that the cyclists are very competitive, even outside the competition, but in a convivial manner. The short interviews served as an inspiration for the questionnaire.

The questionnaire was held under 40 cyclists (see appendix E2 for all results). In this questionnaire the participants were asked to select the type of cyclist, as defined in the 'Wielersportmonitor', that fits them best and 55% categorised themselves as fanatic cyclists (see the outer circle of figure 2.3). 87.5% of the respondents watches cycling races, and all of the fanatic cyclists watch cycling races. Figure 2.3 shows at the right side the results of the questionnaire on the questions about the watching behaviour of cycling races. The results are shows for all the respondents (n=36) in the white bars. The results specified for the 'fanatic cyclists' specifically are highlighted in in orange. The results for all respondents are that they watch the races mostly alone (77.8%), with family (61.1%) or with cycling buddies (44.4%) and the location is mostly at home (97.2%). For the fanatic cyclists specifically the outcomes for watching alone, with family and with friends do not differ much. The story of the race is the most selected reason to watch by all respondents. The story of the race are the events that happen during a single race that together create the story. In comparison to all respondents, fanatic cyclists are more interested in the strategy of cycling. Two other reasons to watch cycling races that are only selected by fanatic cyclists are the in the atmosphere with fans, good quality of images, but these are still the least selected reasons.

Story of the race: the events that happen during a single race that together create the story.

From this user research can be concluded that the target group needs information about the story of the race and the used cycling tactics when watching a cycling race broadcast. The product should also fit for the use at home and can either be for the use alone of together with others.

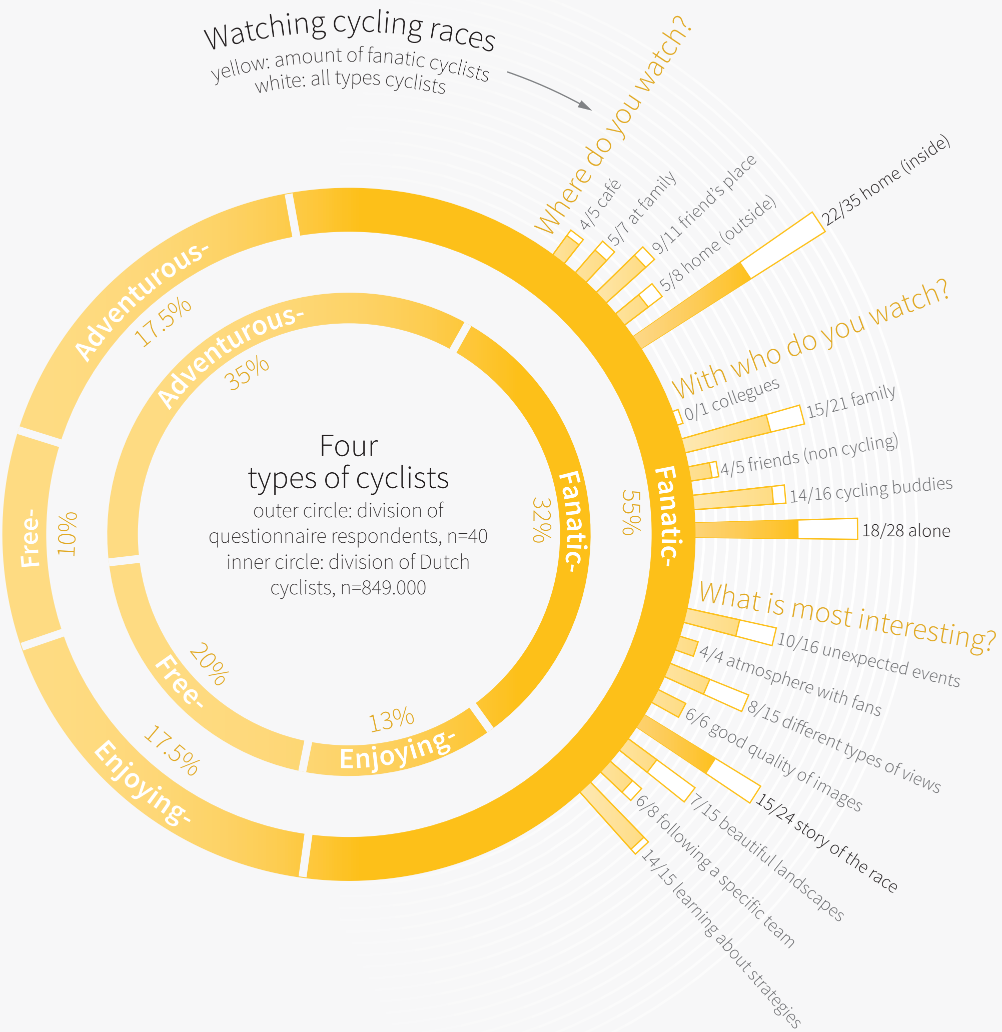


Figure 2.3: results of the conducted questionnaire (n=40), specified for fanatic cyclists. The four types of cyclists are categorised in the same way as the 'Wielersportmonitor' (NTFU, Bike MOTION Benelux, KNWU, 2018)

2.3.2 Current viewer experience of the TdF

As told in the introduction, the 'Tour de France' is innovating each year with new technologies. Figure 2.4 shows a concise time-line of the developments and innovations in the viewer engagement of the 'Tour de France', the complete time-line is shown in appendix B1. The most important developments were the integration of data into the broadcasts and availability of statistics with live updates. The trend is that data and the use of advanced technologies to present

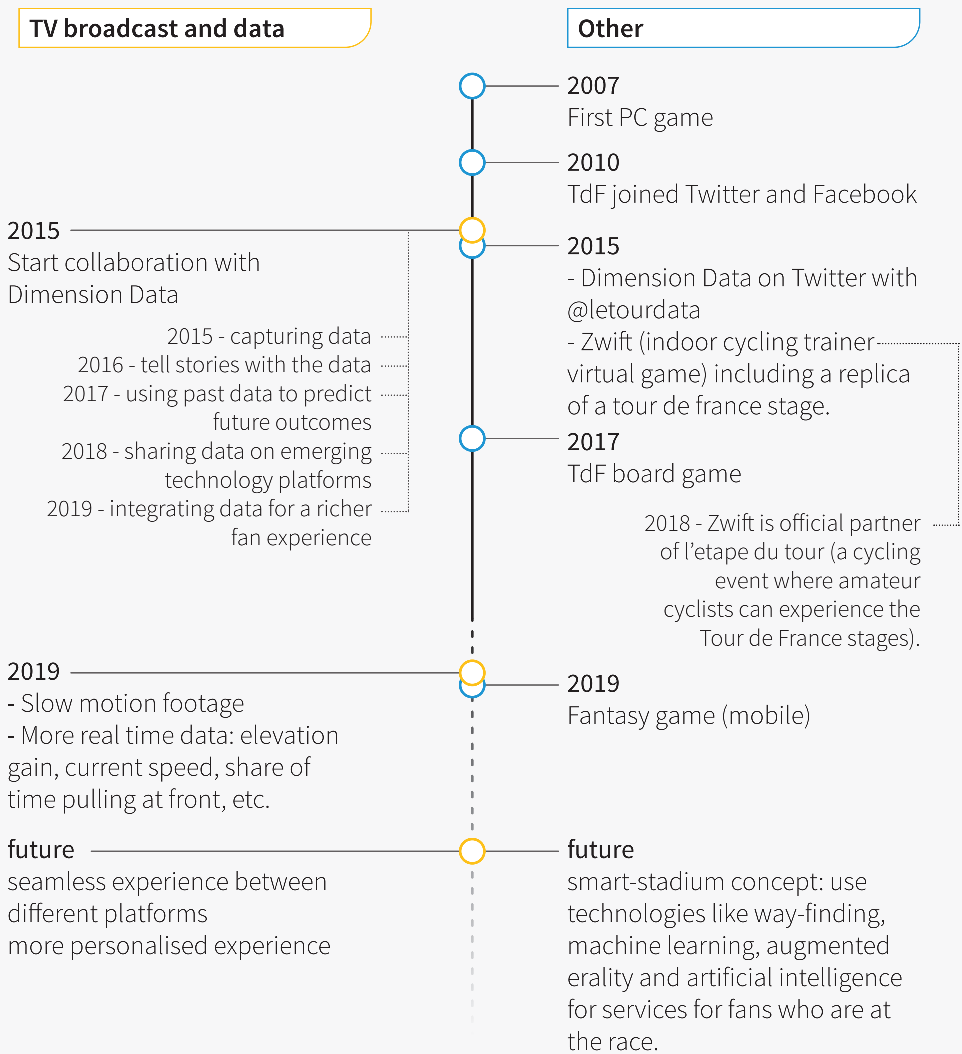


Figure 2.4: a concise time-line of the Tour de France fan engagement innovations. Sources: (Tour de France, 2018), (Rogers, 2018), (Discovery, 2017), (Harris & Maxwell, 2016), (Heil, 2019), (Jacobs, 2017) and (NTT, 2019)

this data to the fans, is getting more important in today's viewer engagement of the 'Tour de France'.

"Fans want to be able to follow their favourite player throughout a tournament, get detailed coverage of the teams they are supporting, and view competitive events on any number of platforms." (NTT, 2019) This paragraph gives an overview of these different platforms, there are many more options aside from following the tour on television (live and on demand). First there are online broadcasts (live and on demand) and web sites, for example on the 'Tour de France'-site and via several different applications live data can be tracked. Other web sites that can be used to follow the tour are blogs, news sites, Youtube (e.g. inCycle), etc. Also, social media plays a huge role in engaging the audience with the race, the participants of the race and even to engage fans with each other. Examples are official pages of the 'Tour de France' and 'Dimension Data' as well as the pages of the tour riders on Instagram, Twitter, Facebook, Instagram, Strava, etc. Lastly, it is of course also possible to follow the race in real at the side-line of the stages. Additional to the named experiences, there are more ways to engage with the 'Tour de France', including games (board game, mobile fantasy game, PC and console games), Indoor cycling trainer application where you can experience the stages yourself while training, magazines (e.g. 'Tour de France' special), literature/ biographies, etc.)

Viewers can have different motivations to follow mediated sports, and these can differ for e.g. different ages, moods, genders, time of the day, etc. The 3 main categories of motivators are emotional, cognitive, and behavioural or social needs (see appendix B2). This project is targeting mostly the cognitive needs, but to create an appealing experience, the other needs cannot be ignored. One of the most common cognitive motivations for viewing sports on television is the learning motivation. This motivation can be about learning about the viewer's favourite cyclists and teams, but or about knowing as much as possible about the sport and to stay up to date with their facts. (Raney, 2009)

"Several scholars have noted how sports fans take pride in being walking encyclopaedias of sports knowledge and trivia." (Raney, 2009)

2.3.3 Conclusions User Analysis

1A The target group are young fanatic cyclists (of the age 18 – 35), who found their passion in knowing more about cycling and want to participate in a quiz about the Tour de France.

1B Informational needs are learning about the 'story of the race' and the 'strategy of cycling'.

1C The product should also fit for the use at home and can either be for the use alone of together with others.

2.4 Technologies

As explained in section '2.2 knowledge domains', CPS principles are used to create content for the service in VR using data. The objective of this section is to acquire knowledge about the technologies that are relevant to this project with regards to the working principles, characteristics and usage. There are three categories of technologies in this project, namely technologies that have to do with acquiring data, processing data, and displaying the content of the service.
First an explanation is given about what data is available and how it is recorded. Then, what the working principles of Informative Cyber physical Systems (ICPSs) are and how they can be used for this service are described. And lastly, the technology for displaying in- and design principles for VR are described.

2.4.1 Sources of information about the Tour de France

Critical functionalities of database system technology are data collection and database creation, data management and advanced data analysis (Han, Kamber, & Pei, 2012). This section focusses on the data collection and data management, the data analysis is addressed in section 2.4.3. This section ends with a description about the regulations regarding the usage of data.

2.4.1.1 Data collection

Currently data of every cyclist at the 'Tour de France' is recorded using rider-tracking devices that are attached to the bikes (see figure 2.5). These record the following data: time-stamp, latitude, longitude and speed (Wade, 2018). From this data the following can be calculated: speed of individual riders, distance between riders, relative position of riders in the peloton and saddle time of individual riders. Information that is used to give the data more context are the gradient, wind speed and wind direction. Other recorded data which is available from a selection of riders are the power and heart rate. See Appendix B4 for the complete architecture of the data recording and processing of 'Dimension Data' at the 'Tour de France'.
Figure 2.6 shows an overview of the available data (grey and black outline) and optional additional data (yellow outline). The data variables are grouped by their

Figure 2.5: rider-tracking devices attached to bikes used at the 'Tour de France.' Image source: (NTT Ltd., 2017)

sources (see the first column). The most right column in the figure shows the data that can be derived from the primary data variables in the column in the middle. The data that is currently not used, but that could be used for designing this service (yellow outline), are the data that the bike of the 'Sports Engineering Institute' can record and data that was indicated as interesting in the questionnaire that is conducted under cyclists (see appendix E2).

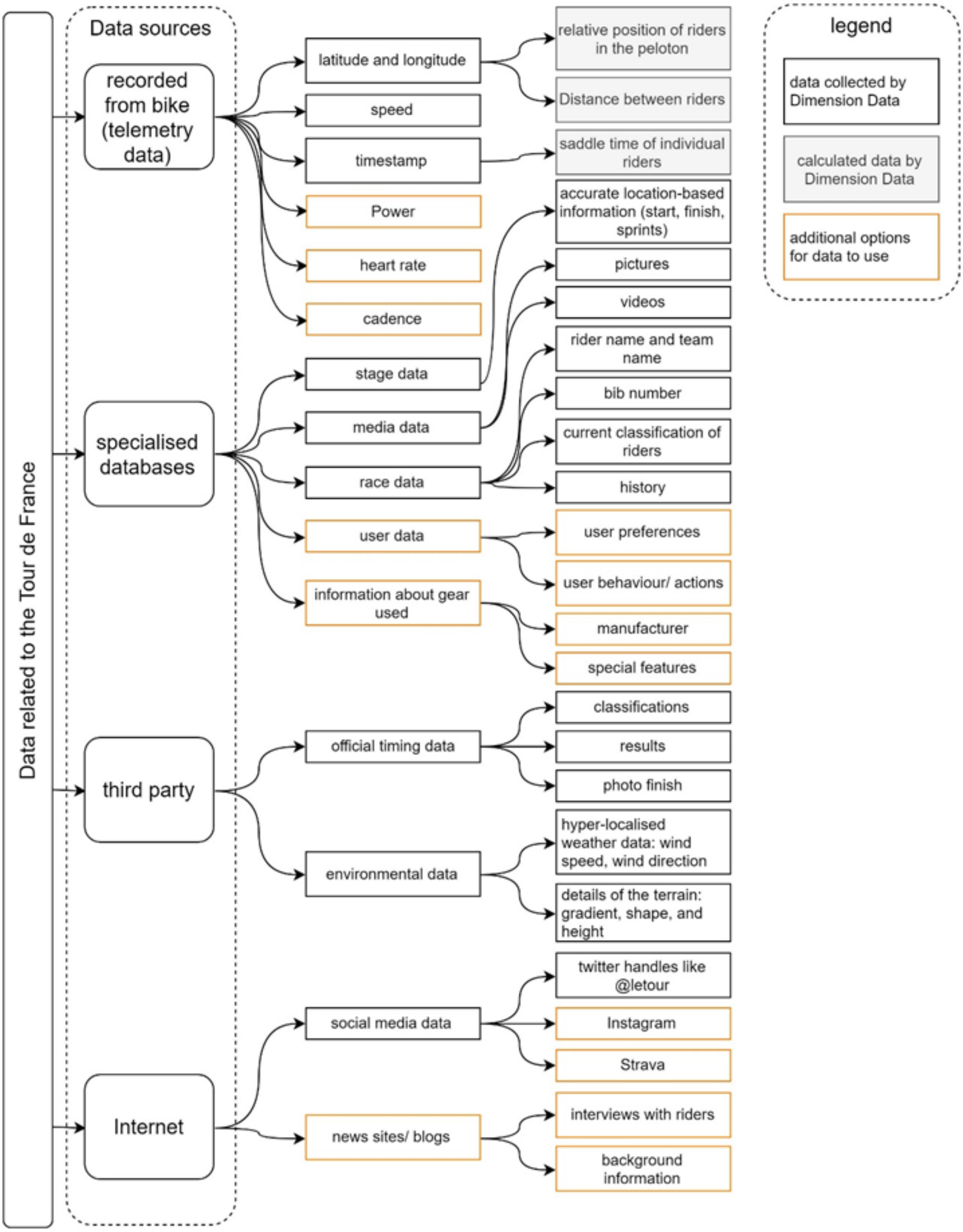


Figure 2.6: the different data sources to use for content creation of the 'Tour de France' VR experience.

2.4.1.2 Data management: storage, retrieval and transaction

Data management includes data storage, data retrieval and database transaction processing (Han, Kamber, & Pei, 2012). There are two types of storage: local and cloud storage. Compared to remote storage, local storage can be accessed faster. The advantages of cloud storage are that this type is easily expandable and can be accessed from anywhere using an internet connection. The security of data is more complicated for cloud storage. To ensure that the data in the database is consistently organised and easily accessible, a database management systems (DBMS) can be used. There are four main types of DBMSs: 1-hierarchical databases, 2-network databases, 3-relational databases and 4-object oriented databases. The relational database management system (RDBMS) is the most used type, it stores data in a tabular format using rows and columns. Structured Query Language (SQL) is the language used to perform queries on this database, like searching or editing specific data.

For the retrieval of a simple textual or numerical database a query can be compared to the data in the database to locate it. Beside a query-interaction with a database, it is also possible to use context aware computing for finding data that the user might be interesting in, without the user requesting specific data. To realise this, the computing uses data about the context. Contextual data is for example the time of the day or the location of the user. An example of an context aware application is the development of the mobile-visitor-App of the 'Tour de France' that gives live information to the users that is relevant to them based on their location, e.g. when a certain rider will pass, where the closest place is to buy merchandise or navigation instructions from their current position to the finish line (NTT, 2019).

Because multiple databases are used, aggregation and filtering of the data is needed. This can be done using a multi-database management system (MDBS), which can resolve issues that arise when implementing queries that require information from more than one database. These problems include: resolving discrepancies between the databases, such as differences in representation and naming conflicts, resolving inconsistencies between copies of the same information stored in different databases, and transforming a query from the user's language into a set of queries expressed in the different retrieval languages supported at the different sites. (Dayal & Hwang, 1984)

The retrieval of media data is more complicated than numerical or textual databases, because the digitized representation does not contain the semantics a viewer perceives (Yoshitaka & Ichikawa, 1999). Nowadays, many video retrieval problems are still challenging. "Work on interactive video search builds on the automatic methods, and focuses on topics such as making effective use of the selections of the human user and on intuitive and efficient user interfaces" (Lokoc, Bailer, Schoeffmann, Muenzer, & Awad, 2018).

Transactions are units of related operations that can only succeed or fail as a whole, resulting in a better error recovery. A transaction is an interactive application, while the other type of network application is a batch processing application, also called streaming. Streaming is the transfer of data, often used for video data (video streaming). The performance of data transmission is influenced by several aspects. For multimedia experiences the performance of the transmission can be measured by for example delay, bandwidth, jitter, etc. For 360-degree videos the transmission is challenging for because of the high resolution and high bandwidth requirements. Solutions are proposed by several researches, for example a layered encoding (TaghaviNasrabadi, Mahzari, Beshay, & Prakash, 2017) and a viewport-adaptive streaming system (Corbillon, Simon, Devlic, & Chakareski, 2017).

To make the streaming faster, scalable and more reliable a Content Delivery Network (CDN) is commonly used. A CDN has two elements, servers and clients. A client is a machine (laptop/ pc/ phone/ etc) or program (browser/ application/ etc.) that makes a request through the web. A server responds to these requests. In a CDN, many servers with a fast internet connection are located around the world. When a client sends a request, the server that is most close to that client will response.

Individual sensor data streams that are collected on separate hardware are often poorly synchronised (Fridman, et al., 2016). There are three types of synchronisation: 1. time-, 2. destination-, and 3. context synchronisation (Santos & Mendos, 2014). When we want to recreate the race based on the data in the virtual environment, the data needs to be precisely synchronised in time. When the system has to be able to find related content to specific moments, like context aware computing, the data needs context synchronisation as well. Finding a solution for this challenge is left out of the scope of this thesis.

2.4.1.3 Data and privacy regulations

Lastly, there is recently a new privacy law adopted, the General Data Protection Regulation (GDPR). This means that by law it is not allowed to collect and further utilise more personal data than absolutely necessary (Netherlands Enterprise Agency, n.d.). This is important when collecting and using data about the user of the to be designed service. The user has to give permission before personal data can be collected and used. Personal data (PD) is defined by “any information relating to an identified or identifiable natural person (‘data subject’)” (Koch, 2019). If the experience will use functions that rely on the availability of personal data, mostly used for personalisation purposes, people have to accept this, otherwise the application cannot be used.

2.4.2 Conclusions Information sources Analysis

- 2A ‘Dimension Data’ currently collects different data about individual riders, teams, the stages of the tour and other related data. This data is not open access, but I assume that when the service that is designed in this project would be implemented their data can be used.
- 2B Technological challenges regarding data are the retrieval of media data and the transmission of 360-video material. The solutions for these challenges fall out of the scope of this project.
- 2C Context aware computing can be used to create a more personalised experience.

2.4.3 ICPS

In this part information needed to answer the second design challenge will be provided 'design challenge 2- how to create valuable content from the data using ICPS principles?'. The goals of this part are to i) gain knowledge about the how the technology works on a basic level and ii) to get an overview of the working principles and how they can be implemented in this project. The goal of this project, as described in 1.4.1 (see page 16), is to provide information to the viewers for educative purposes. So the focus of the CPS analysis is how CPS principles can be applied for information provisioning for supporting specific learning.

2.4.3.1 CPS fundamentals

There are many different definitions of a CPS. In their paper Horváth, Rusák and Li, describe five most fundamental characteristics of CPSs (Horváth, Ruzák, & Li, 2017):

1. Penetration into real-life processes: enabled by the paradigm of cyber-physical computing (CPC) involving SRAE-cycles (see figure 2.7). Needs amongst others in-process (run-time) intervention and run-time acquired data.
2. Diversity of functional semantics: CPSs are multifunctional systems, which simultaneously reflect a stereotype higher level functionality and a tailored lower level functionality.
3. Aggregate complexity: Increase of complexity often means increase of uncertainty and unpredictability, but also increasing 'intelligence', adaptability and autonomy.
4. Cognitive capabilities: CPSs are equipped with various forms (and levels) of cognitive capabilities (such as inferring, reasoning, planning, learning, decision-making, etc.)
5. Runtime variation: the operational circumstances as a whole may vary in a short term, but more certainly in a long term.

Most of the characteristics of CPSs rely on cyber-physical computing (CPC) (Horváth, Ruzák, & Li, 2017). CPC complements or replaces predefined flows of computation with run-time devised flows, and appends run-time learned algorithms to the pre-programmed algorithms. This type of computing involves recurrent cycles of sensing-reasoning-learning-adapting cycles (see figure 2.7) (Horvath, 2019). Sensing can be performed by hardware sensors, software sensors, mixed sensor networks, etc. Technologies for reasoning are system-level models, inferring/ reasoning mechanisms, databases, etc. Examples of learned algorithms are patterned data structures, situated computing strategies, and context-driven reasoning mechanisms. Technologies for adapting can be for example programmable actuators (for example vibration in controllers)

2.4.3.2 Supporting technologies for CPSs

The needed cyber components are a computing element (for CPC) and a database (mainly for sensing). This section presents technologies, related to these two components, that enable the realisation of a CPS.

The computing element can be a local server or personal computer, or a network of remote servers hosted on the internet (cloud computing). Since last year (2018) 'Dimension Data' runs everything in the cloud for their 'Tour de France' data service since it is widely accessible (Grey, 2018). Two tasks that can be performed by cloud computing are data processing and data analysis.

The database is where the information is stored in a specific structure, see section 2.4.1.2 for an explanation about the management of a database. One of the important functionalities of the database and data management industry is advanced data analysis (involving data warehousing and data mining, see figure 2.8) (Han, Kamber, & Pei, 2012). "Data mining is the knowledge discovery process by analysing the large volumes of data from various perspectives and summarizing it into useful information." (Shazmeen, Baig, & Pawar, 2013)

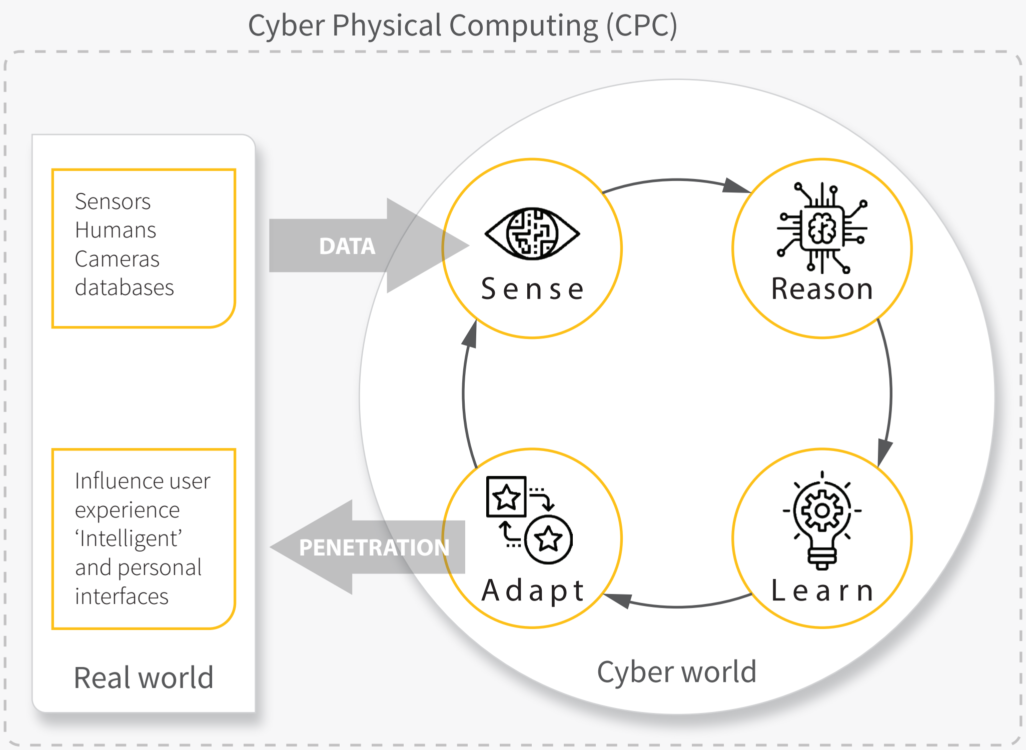


Figure 2.7: Four clusters of smart enablers for smart cyber-physical systems: sense, reason, learn and adapt (Horvath, 2019)

Figure 2.8 shows that in the process of knowledge discovery data mining is used to find patterns in the data. The following concepts are used to achieve the two primary goals of data mining (prediction and description): classification, regression, clustering, dependency, data summarization, and change and deviation detection. (Suresh & Selvakumar, 2014)
Where data mining is about extracting knowledge from big data, like finding patterns, machine learning is about improving an algorithm based on experiences with data. Machine learning could use data mining techniques as well. Currently at the 'Tour de France' machine learning is used to make real-time predictions (effort index and catch predictor) and overnight batch predictions (Performance profile and stage favourites) (Wade, 2018). (see section 2.4 for the architecture of the current data processing at the 'Tour de France')

2.4.3.3 Examples for implementation

The focus of this section is to give examples of how CPS principles can be applied for information provisioning for supporting specific learning. The following three working principles to use for the service are defined:
CPS working principle 1: penetration in real life processes.
CPS working principle 2: cognitive capabilities (reason, learn)
CPS working principle 3: functions adaptive to the environment

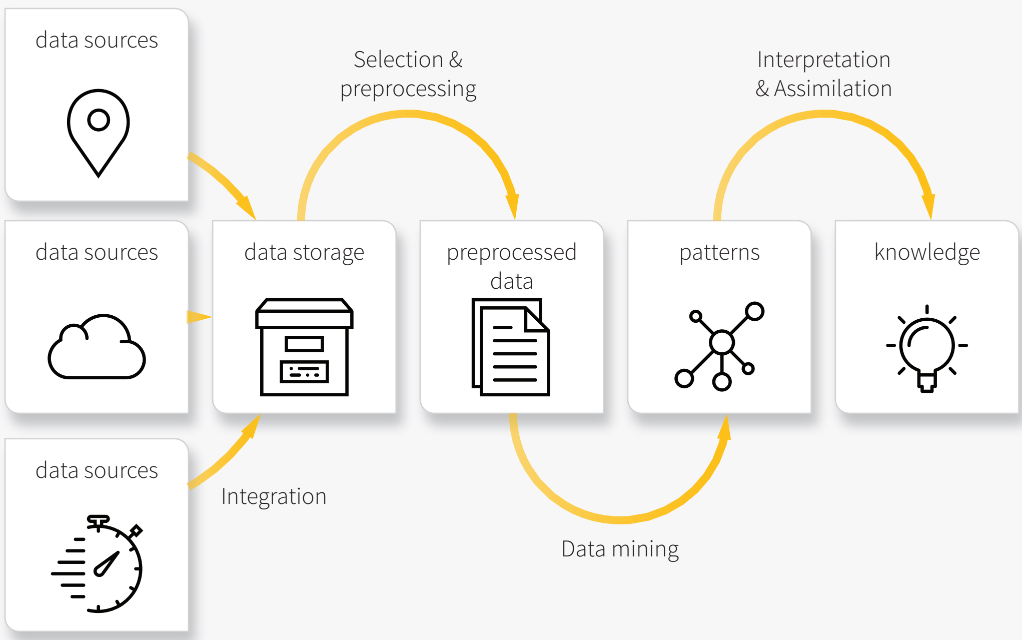


Figure 2.8: the steps for knowledge discovery from data (Bramer, 2007)

The examples are given after defining the context of the system. The service design is based on the following situation: A user at home has a PC with the service on it. The data is saved in the could and computation takes place at both the users device and in the cloud. A displaying device (VR HMD) is connected to the desktop and used with a set of two controllers. Figure 2.9 illustrates an overview of the basic architecture of the to be designed system (based on the four knowledge domains). related to the following description of a cyber-physical system: a CPS has three components, namely cyber, physical and application, and includes the 3C paradigm of Control, Computing and Communication (Xiong, et al., 2015). The cyber-component is mostly about the management of the data and creation and assembly of the content of the service. This component includes the displaying and computing element, internet, and databases. The source of information is partly physical (the transmitters attached to the bikes) and partly cyber (data

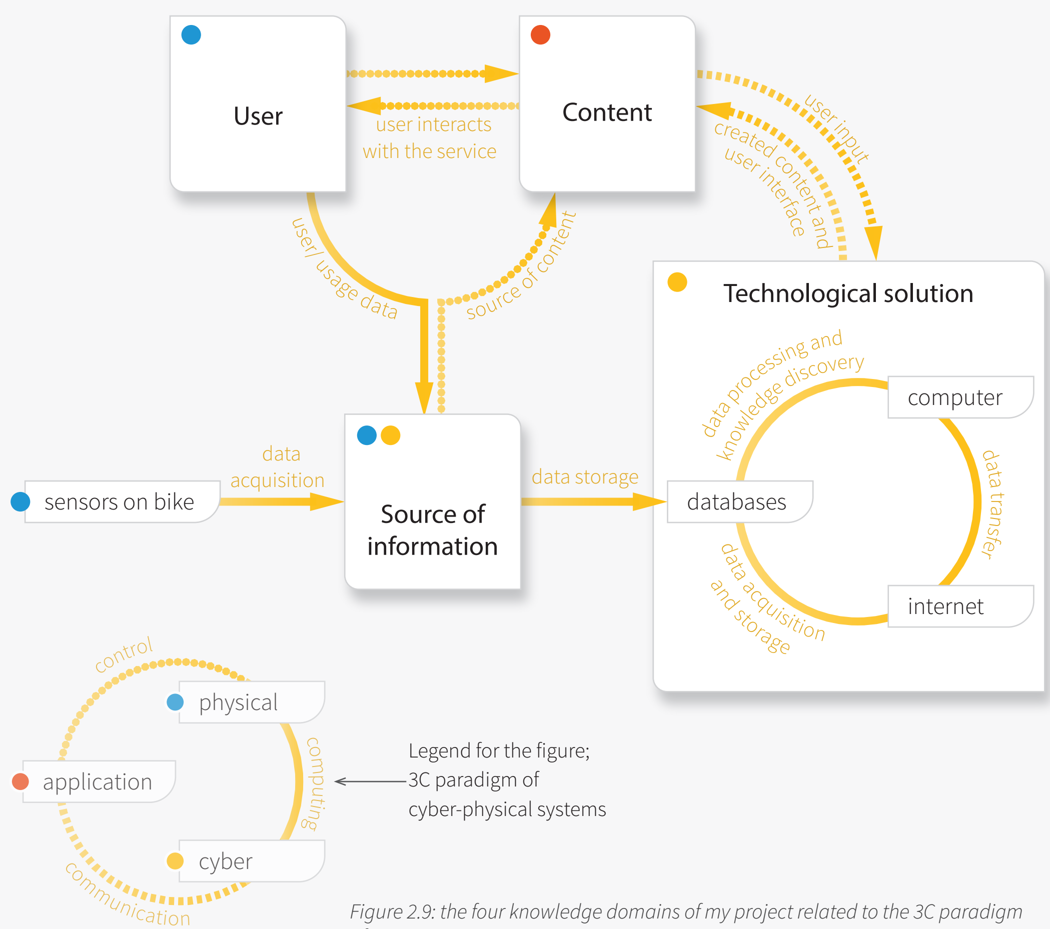


Figure 2.9: the four knowledge domains of my project related to the 3C paradigm of CPSs.

retrieved by the means of computing). The remaining physical element is the user who can physically interact with the system using the controllers. The application is the content that is being presented to the user via the service. The three types of interactions (3C) are indicated in the figure using different types of arrows.

Example 1: penetration in real life processes and cognitive capabilities

- Data mining: determine the important moments of the race
- Adapt: the information shown is adapted with a focus on the important moments
- Helps learning by: creating explanations

Currently stage predictions are done, using machine learning, where historical data combined with data about the stage are used to predict who could win that stage. A similar mechanism can be used to find out how, or which moments, made that the winning cyclist won. This information can already be shown in the live broadcast while the race is going on by pointing out the moments that are expected to have a large influence on the progress of the race. For example when the cyclists are biking against the wind for a longer time and one of the cyclists is known to be better at that compared to other cyclists (the currently generated performance profiles can help with this), it can be indicated on the broadcast. After the race the information can be aggregated into an explanation about the winning cyclist.

Example 2: penetration in real life processes and adaptation to the environment

- Context aware computing: the context in this example is the physical context of the selected cyclist, as if the viewer is that cyclist in the race.
- Adapt: the information shown is adapted to the context of the chosen cyclist.
- Helps learning by: immersing the viewer in the experience of a specific cyclist for better understanding of cycling tactics in a team.

The 'context' in context aware computing can be a computing environment (e.g. devices accessible for user input and display, network capacity, etc.), User environment (e.g. location, collection of nearby people, etc.) or a physical environment (lighting, noise level, etc.). In this example the context is similar to a user environment, but different in a way that a virtual representation of the cyclist environment is used. The context conditions taken into account are the position on the route, nearby cyclists, team-members, goal of that cyclist and his team, gradient, etc. The information that is shown has the goal to explain the situation of that cyclist. This consists of the route with the location of the cyclist indicated, a section of the route with the relative positions of the team members, speed compared to the average, distance to go, distance to the first rider, effort of the cyclist and his team.

Besides these two examples, the used technologies can help self-initiated learning of the user also by:

- Provide information that suits the interest of the viewer: based on the time that the viewer spend attention on specific information can be used to predict what the user interests.

- Keep track of what the viewer knows and doesn't know and adjust the provided information to that. In example when the user wants to get more information about a cyclist, the system can find information about that cyclist (using data mining) and select the articles that the viewer did not sea earlier, or a long time ago.
- Motivate to learn more by using for example mini quizzes or games (with leader boards), prompts with teasers of information, etc.
- Provide information that suits the knowledge level of the viewer: more details/ explanations on specific items when the viewer needs that.
- And many more

2.4.4 Conclusions CPS technology Analysis

3A Cyber Physical Systems rely on Cyber-physical computing (CPC) which involves recurrent sense, reason, learn and adapt cycles.

3B Cognitive capabilities are used to get more insights from the data:

- 3Ba data mining can be used for extracting knowledge from big data, like finding patterns (prediction and description).
- 3Bb machine learning can be used for improving an algorithm based on experiences with data.

3C Three working principles of CPSs:
CPS working principle 1: penetration in real life processes.
CPS working principle 2: cognitive capabilities (reason, learn)
CPS working principle 3: functions adaptive to the environment

2.4.5 VR

The third design challenge will be addressed in this section: 'design challenge 3- how to benefit from the advantages that VR offers?' Information needed to provide an answer on this question is first of all a definition of VR. Then a description of the working principles of the used system are described. This section ends with the characteristics of VR that can be used and how to benefit from those in the shape of design guidelines.

2.4.5.1 Definition of VR

Virtual reality belongs to the realm of extended reality (XR) (North of 41, 2018). On the scale from real world, to a fully virtual environment (VE), VR is an utmost where the 'world' is completely virtual. The perception of the virtual world is called telepresence: "presence refers to the natural perception of an environment, and telepresence refers to the perception of mediation of an environment". (Nimbol, Thomas, & Paul, 2018). Highly presence-inducing experiences can be ranked on different continua, the VR fidelity continua. Three of these continua are representational fidelity (photo realistic – abstract), interaction fidelity, and

experiential fidelity (storyline – free-roaming world). The decision on what to use depends on the vision and goal of the project (Jerald, 2016).
VR is a broad term that can be used from different perspectives (see figure 2.10): VR as an environment (an alternate world filled with computer-generated images), VR as a form of interaction (a unique interaction space where users can perceive a different reality) and VR as immersion (users feel like they are somewhere else) (Cisneros, et al., 2019). Different aspects or technologies can be used to achieve these aspects of VR (see the connected elements at the right side of figure 2.10).

2.4.5.2 HTC Vive

Using a VR Head Mounted Display (VR HMD) the user can be 'present' in the Virtual Environment (VE). The VR HMD that is used for creating prototypes this thesis is the HTC Vive (see figure 2.11). The set consists of three main components: a tethered headset, two base stations and two controllers. The headset is places on the user's head and connected to a PC. The position of the headset and the two controllers are detected using the 'Lighthouse' position tracking system. The 'Lighthouse' system uses two base stations (the black cubes in figure 2.11) which are placed in a room at two corners of the use-area (see figure 2.12). These base stations emit infrared pulses (60 per second) that can be 'seen' by the multiple IR sensors in the headset and the controllers. This results in a position tracking system with sub-millimetre precision (Poppr, n.d.). Two base stations are used so there is less chance that the tracked devices are occluded from the IR pulses. The controllers of the HTC Vive have the following buttons: menu button, track-pad, trigger button and grip buttons. Navigating or moving in a virtual scene using VR can be done in different ways (like teleporting or floating), but they use the

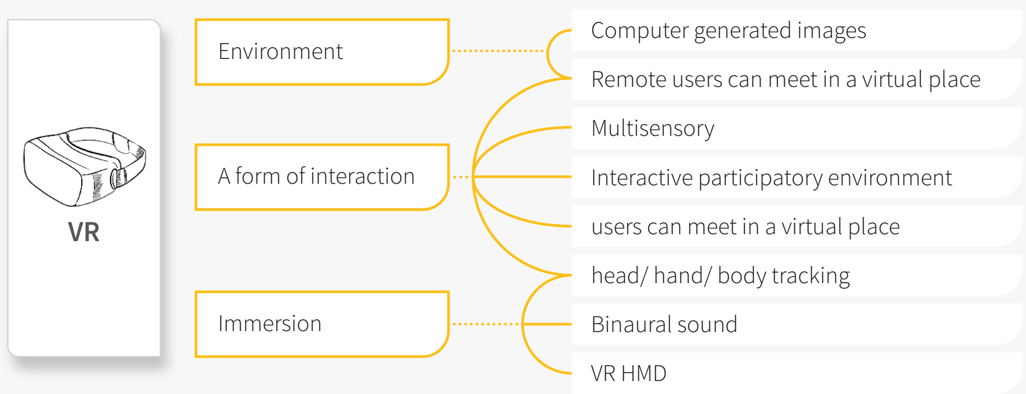


Figure 2.10: a combination of the characteristics of VR described by (Gigante, M. 1993) and sorted them in the 3 categories of the research of Cisneros et al. (Cisneros, et al., 2019).

Figure 2.11: HTC Vive; image source: (PB Tech, n.d.)

same principles. Figure 2.12 illustrates the tracking of the position and the virtual camera that is in the virtual scene. When using a VR HMD, the user's movement is limited to a virtual bounding box (see blue area in figure 2.12). When the VR HMD and controllers are inside this area, their position and orientation can be tracked (see the 6 degreed of freedom (DOF) in figure 2.12). The virtual scene has a virtual camera, of which the position is adjusted to the position and orientation of the VR HMD. The same counts for the controllers. What the virtual camera records is presented on the display inside the VR HMD. The exact way of how the virtual representations of the VR HMD and controllers react on the movements in reality depends on the design of the application that is viewed in the VR HMD. When watching a 360 video footage, the system can only adjust the view based on rotation and not on position, because there is no real 3D media available.

2.4.5.3 Design guidelines for VR experiences

This section presents five VR design guidelines, which are points that have to be taken into account when designing a VR experience. These guidelines are divided into two categories: ergonomics and health, and technological opportunities and limitations.

Category 1 - Ergonomics and health:

1. Design for natural interaction. Users have real world habits, so the users will expect events to happen like they will in the real world. To prevent negative emotions (like frustration or confusion), there should not be a difference in what the user expects and what happens in VR, or at least this difference should be minimal. (Stepherd, Carter, Pepping, & Potter, 2018)

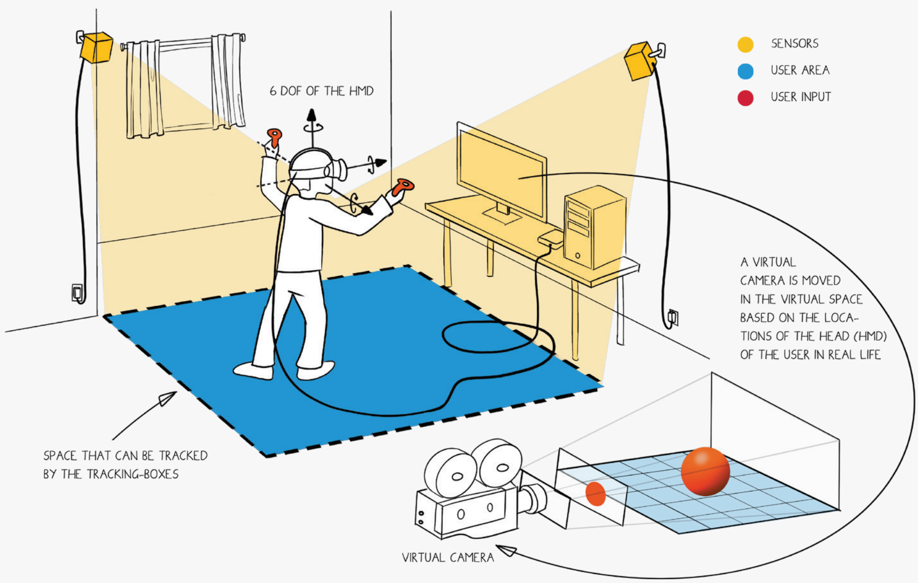


Figure 2.12: navigating through a virtual scene using a VR HMD and controllers.

2. Design interactions that fit the user scenario. For a seated experience the options, in example for moving around in the scene, will be different compared to a standing experience.
3. Decrease the chance on cyber sickness. Users could suffer from cyber-sickness when using VR, and a poor designed experience can strengthen this, in example interactions that control the viewpoint can cause motion sickness (Jerald, 2016). Also high latency (time difference between the physical movement and the movement in VR) can cause motion sickness. Other factors that play a role in causing cyber-sickness are: sensory conflicts (caused by sudden motions), level of experience with VR and the type of graphics (Katsigiannis, Willis, & Ramzan, 2018). The change on cyber sickness also increases with the duration of the experience (Jerald, 2016).

Category 2 - Technological opportunities and limitations:

4. Use the third dimension in advantage of the experience. The opportunities of the third dimension that VR offers are a large canvas to draw on, immersion and perception of depth.
5. Different types of elements can be used in the VE. Examples of these elements are 360 recorded video footage, digital created 3D models, 3 scanned models which are converted to 3D models and 2D elements in the 3D space (like a panel).

2.4.6 Conclusion VR Technology Analysis

4A When designing a VR experience, the ergonomics and health of the user, and technological limitations have to be considered.

4B The several VR fidelity continua (representational fidelity, Interaction fidelity, and experiential fidelity) influence the experience. The decision on what to use depends on the vision and goal of the project.

4C A seated or standing experience requires a different interaction design compared to a standing experience.

2.5 Content of the service

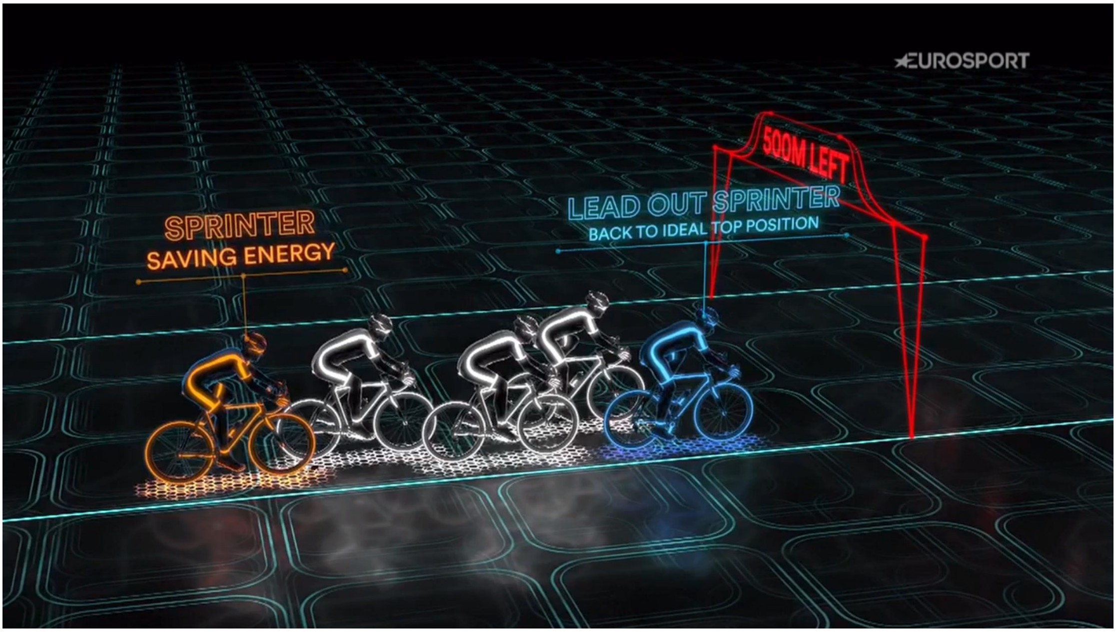
In the section 2.3 the needs of the users were discussed, which answers the second part of the following question: 'design challenge 3 - how to create an educative experience that fulfils the needs of the viewers?' Now we have more knowledge about the data sources and technologies, this section combines the knowledge into providing an answer to the question. The objective of this section is to i) create an overview of content that has an educative value that is currently used in cycling broadcasts, and ii) get insight in the expertise that is needed to create a cycling broadcast by using data and VR.

2.5.1 Current informative broadcasting content

The purpose of broadcasting is informing (includes explaining) and entertaining. 'Tour de France' broadcasts contain a vast amount of informative data representations which are often presented on top of video content (different types: race, interview, helicopter, etc.). The visualisations can be supported by a commentator voice or stand on themselves. These data representations can be data visualisations, animations, etc. Examples of data visualisations that are used during cycling broadcasts are described in the table 2.1. More visual examples of these types of visualisations used during broadcasts can be found in appendix B3, figure 2.13 shows two examples of visualisations.

Table 2.1: data visualisations used in 'Tour de France' broadcasts

Type of visualisation	Information presented
Profile of the route heights (see figure 2.13)/ (semi-3D) map	Length of the stage, highest points, elevation gain, difficulty of stage, challenges on the route, start and finish
Information shown for a longer time as overlay on the video (similar to a game head up display (HUD))	Time, distance, time gap between peloton/ first rider and chasing group, positions of the riders, logo of the tour/ race
Rankings	Position, rider name, rider team, time, stage number and name of the start and end city.
3D animation (see figure 2.13)	Explanation of a strategy
Pop-up: introduction	Stage predictions: name of rider, vest of rider illustration, points Names of commentators
Pop-up: team view	Name of team, name of rider, country (flag), illustration of the vest, time and distance
Pop-up: surrounding/ annotation	Information about the surrounding (e.g. name of a town or a historical building), location of the camera view in the race



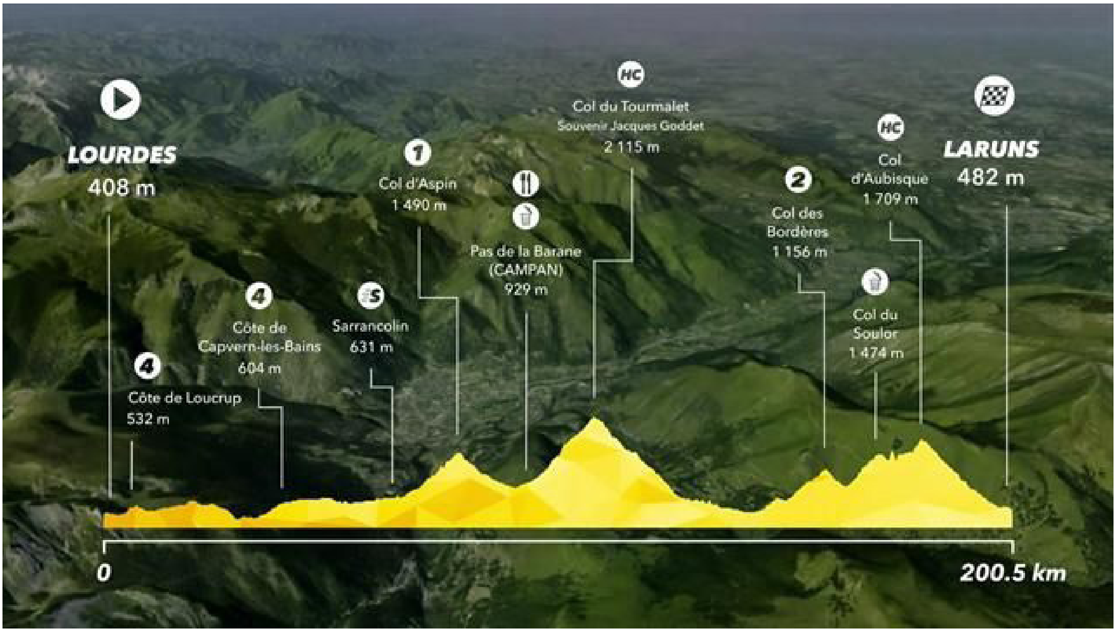


Figure 2.13: two examples of cycling broadcasting visualisations. Top: strategy explanation (from an 3D animation), bottom: stage overview. (See appendix B3 for more examples)

2.5.2 Content creation: areas of expertise

The goal of the content of the to be designed service is to let the viewers learn about the 'Tour de France' in an entertaining manner. For creating the content of the service there are three important domains, which can be related to the knowledge domains of this project that are elaborated in the previous chapters. The first domain is data: here the sources of information (section 2.4.1) and the CPS principles (section 2.4.3) come together to provide the information and insights for the visualisation. The second domain is journalism: this is about the structure of a story told to the viewer using the data. The third domain is VR (section 2.4.5): the medium can immerse the viewer in the story and provides opportunities for using the 3D space. Figure 2.14 shows in the inner ring these three domains, and in the second ring different areas of expertise that are related to these domains are presented. This section continues with an explanation and examples for these areas of expertise (examples and frameworks are indicated in outer ring in the figure).

2.5.2.1 VR broadcasting

There are several VR broadcastings available: 'Intel' has a partnerships for broadcasting sports competitions in VR with NFL, NBA, MLB, PGA, NCAA, and highlights from the Olympics in PyeongChang. For the 2018-2019 season there is a VR live broadcast of a basketball competition on a weekly basis. Many of the early VR broadcasting applications used traditional (2D) video footage (e.g. 'LiveLike'). Nowadays, most VR sporting events provide a 180- to 210-degree field of view (Nelson Jr., 2017), but 'Intel' for example uses 360 video footage for sports broadcasts. In Appendix A2 these and more examples of VR broadcasting are illustrated.

2.5.2.2 VR data visualisation

There are applications existing for visualising data in VR, e.g. 'VR DataVis' and 'Virtualitics'. In the current cycling TV broadcasting, often information about for example the speed is shown as an overlay on the video material, similar to a game Head Up Display (HUD). Excluding a game HUD is not an obstacle for engagement and enjoyment, and it could even increase the immersion for experienced gamers. Although this research was done with games, it shows that the type of UI placement for data presentation can influence the experience and should be taken into account when designing the service. (Iacovides, Cox, Kennedy, Cairns, & Jennett, 2015) Besides the placement of the data, the visualisation of the data itself is also important. In their paper Moloney et al. define 5 principles for development of VR environments for Immersive Analytics (Moloney, Spehar, Globa, & Wang, 2018): 1. Use abstraction of environments to which the human perception is attuned, 2. Natural affordance of mimetic reference overlaid with constructed affordances, 3. Utilize cross-modal mapping (e.g. sound aligned with movement), 4. Representations tuned to intermediate zone where human perception is most discerning, and 5. Granularity and distribution of data aligned with naturally occurring distribution patterns.

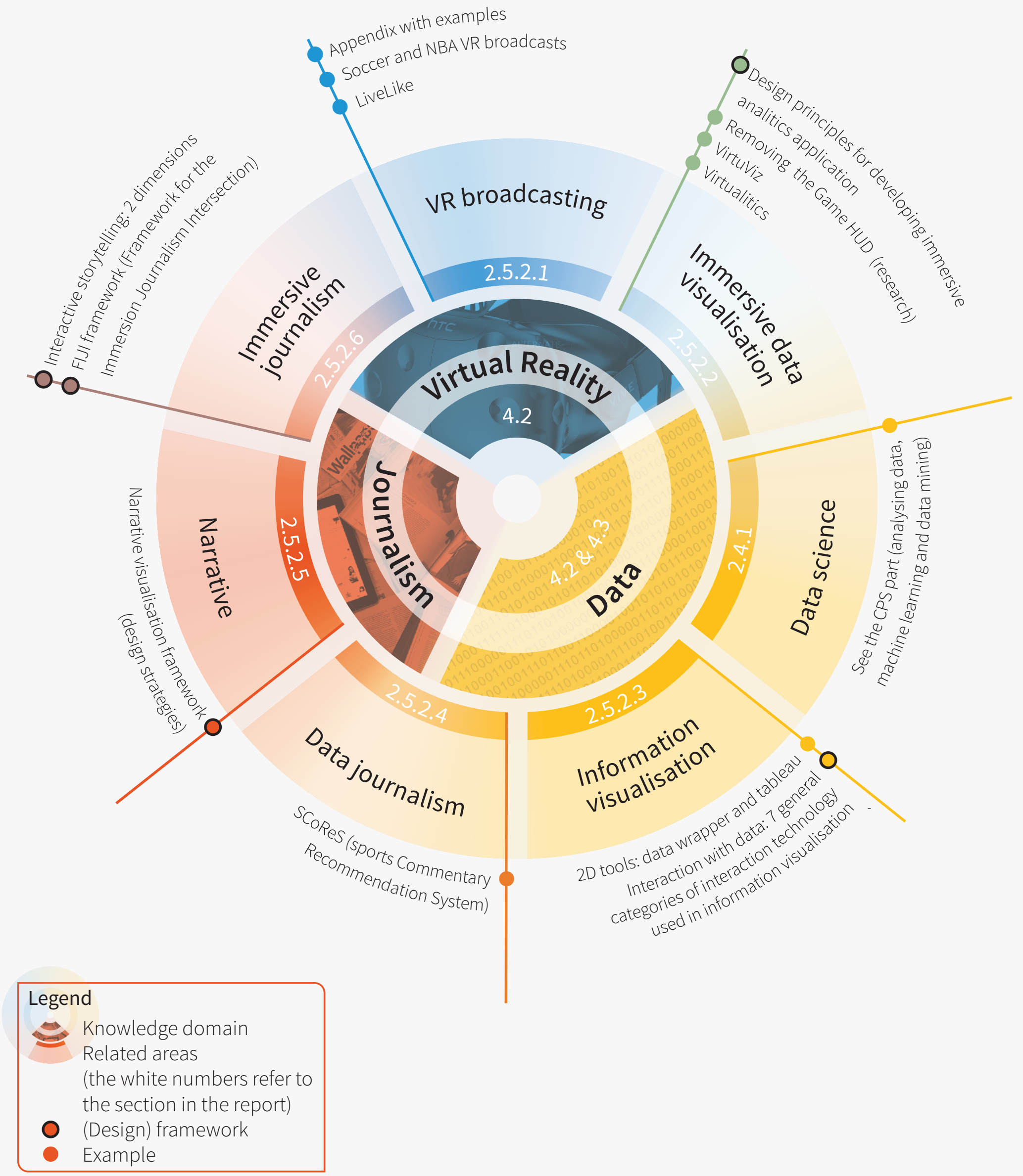


Figure 2.14: an overview of content-creation related areas of expertise and examples

2.5.2.3 Information visualisation

Examples of applications that make 2D data visualisation of big data user friendly are 'Tableau' and 'Datawrapper'. These applications use clear steps and visual interactions like drag-and-drop and micro animations to make the creation of visualisations clear and simple. An important element of information visualisation (IV) is interaction with the data. In their research Yi, Kang and Stasko propose seven general categories of interaction techniques widely used in IV: Select, Explore, Reconfigure, Encode, Abstract/Elaborate, Filter and Connect. (Yi J. , Kang, Stasko, & Jacko, 2007) More specifically for VR environments, Moloney et al. define 5 principles for development of VR environments for Immersive Analytics: (Moloney, Spehar, Globa, & Wang, 2018)

1. Use abstraction of environments to which the human perception is attuned.
2. Natural affordance of mimetic reference overlaid with constructed affordances.
3. Utilize cross-modal mapping (e.g. sound aligned with movement)
4. Representations tuned to intermediate zone where human perception is most discerning.
5. Granularity and distribution of data aligned with naturally occurring distribution patterns.

2.5.2.4 Data journalism

(SCoReS) (see figure 2.15 for the system architecture) is a system that automatically suggest stories for commentators to tell during sports games. It can be effective at selecting stories that add to the enjoyment and watchability of sports. (Lee, Bulitko, & Ludvig, 2012)

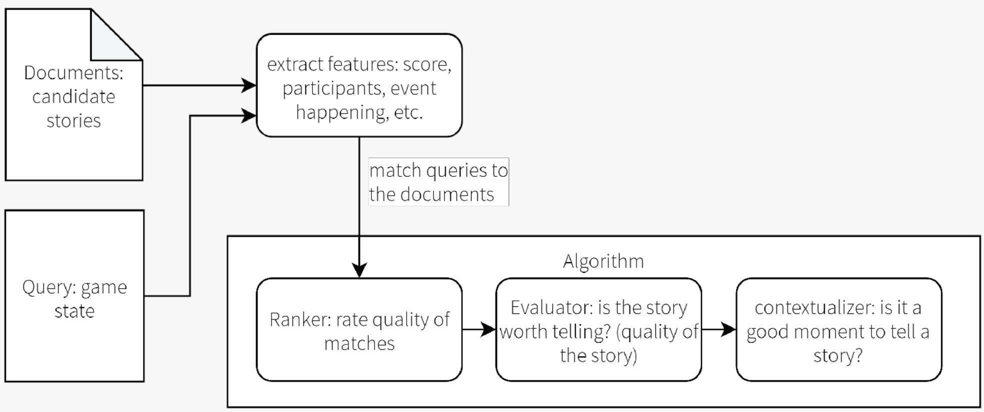


Figure 1.5: SCoReS system architecture

2.5.2.5 Narrative

The framework for narrative visualisation presented by Segel en Heer, suggests design strategies for narrative visualization. Their analysis of the design space of narrative visualisation includes three dimensions (with their own subdivisions): genre, visual narrative and narrative structure (Segel & Heer, 2010).

2.5.2.6 Immersive journalism

Key requirements of immersive journalism are defined in the 'Framework for the Immersion-Journalism Intersection' (FIJI). It defines the fundamentals of immersion, common immersive technologies, the fundamentals of journalism, and the major types of journalistic stories (Hardee & McMahan, 2017). Like describes in the VR section, an element of VR is interaction. The interaction paradigms of interactive storytelling can be classified along two main dimensions: (1) the level of involvement of the user in the story, which determines the frequency of interventions, and (2) the relation of the viewer to the visual narrative itself. There is a richness of interaction possibilities when using VR: immersive media (VR or AR) provide alternative contexts for the relationship between multi-modal interaction and narrative visualization (Cavazza & Charles, 2016).

2.5.3 Conclusion content of the service

5A There are three important domains that have to be considered for creating the content of the service: data, journalism and VR.

5B Related existing products that can inspire the ideation are: 2D data visualisation tools, VR data visualisation applications, VR broadcasting, and the 'SCoReS' recommendation system: Suggest stories based on data.

5C UI placement of the data and the manner of visualising the data itself have an influence on the experience.

2.6 Summary and requirements

For assembling a list of requirements six topics are used: General requirements, interaction requirements, visual requirements, data requirements, CPS requirements, and UI requirements. The conclusions of this phase were sorted in groups into these groups, and used to create this list of requirements.

1. General (Service goal)
    a. The story of the race should be told in an informative manner.
    b. By using this service the users will learn more about the story of a 'Tour de France' race compared to watching the TV broadcast.
2. Interaction (user experience)
    a. The interaction is intuitive, provides feedback and error recovery.
    b. Different levels of user interaction (active and passive) are integrated in the narrative of the experience.
    c. The experience must be balanced between active and passive.
    d. The interaction must fit a seated experience.
    e. The user has to understand the interaction after a short explanation
3. Visual
    a. The mapping of the data has to be clear in an intuitive way.
    b. The visualised content has good legibility (distinctness that makes perception easy)
    c. The information can be found quickly
    d. The visualised content must be easy to understand for users within the target group.
4. Data
    a. The data of the races is stored in the cloud.
    b. User data is stored on the personal computer of the user.
    c. The recording of new data (data that is not used yet) does not influence the performance of the cyclists.
5. CPS interventions include:
    a. The sense-reason-learn-adapt cycles are used to select the content of what and how it is shown to the viewer.
    b. The CPS is able to learn from the user's usage in order to provide content that fits personal interests.
6. UI (VR)
    a. The opportunities of the 3rd dimension that VR offers, being a large canvas to draw on, immersion and perception of depth are used to improve the presentation of the data.
    b. The representational fidelity, interaction fidelity and experiential fidelity are chosen so that they fit the vision and goal of the project

Beside the requirements that the service has to fulfil, there is also a list of wishes. The wishes are criteria that the product should fulfil as good as possible. The wishes are stated below sorted on importance, of which the most important criteria is on top.

1. The concept should help the user to learn as effective as possible
2. It should be as easy as possible to add other functionalities to the concept
3. The concept should be as easy to use as possible
4. The concept should be as much entertaining as possible
5. The concept should have a balance between active and passive usage as much as possible
6. The concept should make use of the values that VR offers for data visualisation as good as possible.

3 Ideation & Conceptualisation

3.1 Introduction

The objective of this phase is to use the insights of the analysis phase to create and choose one concept for the imagined service. In this phase of the project ideas are generated (chapter 3.2) for the content and lay-out of the VR scene. Then these ideas are combined into three concepts (chapter 3.3). Of these concepts, one is selected (chapter 3.4) using the requirements and wishes of the analysis phase. Figure 3.1 shows the process of the ideation and conceptualisation phase.

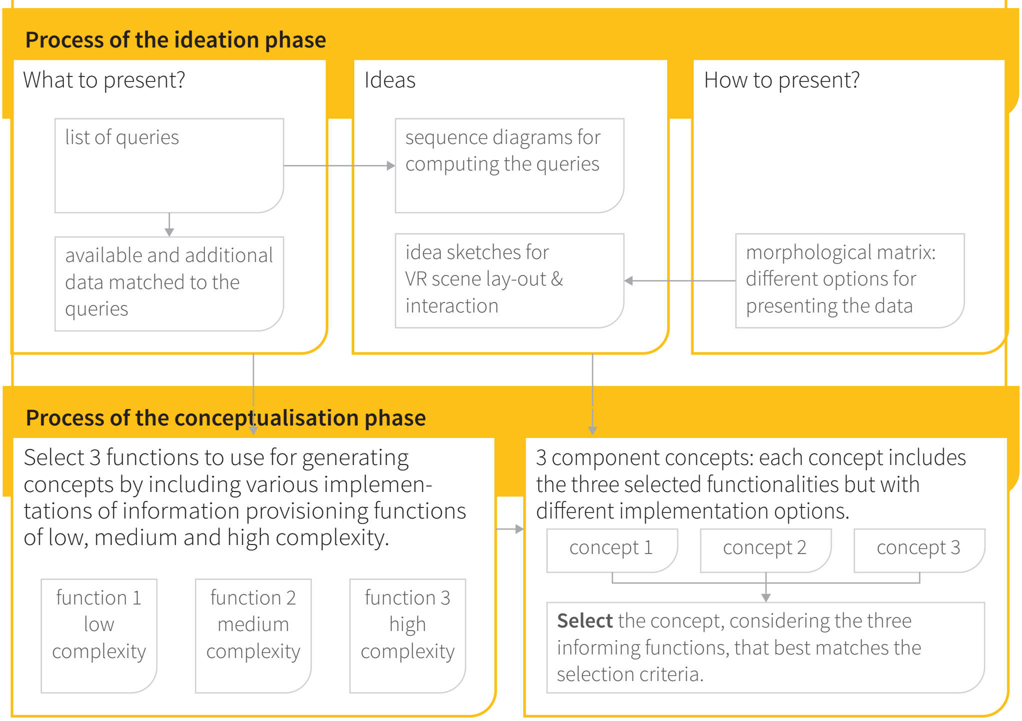


Figure 3.1: Process of the analysis phase

3.2 Ideation

The objective of the ideation is to generate a set of functions and structures to fuel the conceptualisation. This chapter describes the exploration of the 'what' and 'how' of presenting a virtual broadcast of the Tour de France. Firstly the 'what' is explored resulting in a selection of functions. Then ideas for the 'how' are generated and presented. At last the findings from small tests in a VR environment of some of the ideas are described.

3.2.1 What to present

The 'what' refers to the content of the service. This is described by the functions and the data that is needed to realise these functions. The focus of the educative element of the service is to learn more about the story of the race, which means the events that happen during a single race that together create the story.

The 'what' refers to the content of the service.

3.2.1.1 Queries

To have an overview of the information that the user is interested in, a list of queries is created (see figure 3.2 on the next page). This list is not a complete overview of everything the user might want to know, but it shows a diversity of general and more complicated queries to demonstrate the possibilities. The list consists of four elements (see the columns): type of query (indicated with a number and explained at the bottom of the figure), a query index (used to refer to the query items), the query itself (the user wants to know...) and lastly the subject of the query (a specific rider (R), a team (T), all displayed riders (D) or all riders of the stage (S)). The last column indicates to which subjects it is possible to apply the query to.

The queries in figure 3.2 with a ***-sign are clarified below:

1.02.2 A similar race in the past could be a race with a similar route (described by a combination of the height profile, the amount of curves or other properties) or with a similar result (classification).

1.03 The rider profile includes the age, name, team, performance, type of rider, etc.

1.04 The most challenging points of the race can be indicated with their location on the route and what the challenge is. Also an explanation about the challenge could be included.

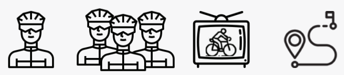
2.02 The progress of the live race can be shown using e.g. video, sports commentator, news posts, etc.

2.03.2 A specific angle to watch the race from can be achieved be using multiple cameras and let the user choose from which one to watch.

2.09 The current classification of this race or the complete Tout de France of that year.

type	index	the user wants to know ...		... of a specific rider (R), a team (T), all displayed riders (D) or all riders of the stage (S)			
1	1.01	the name		R	T	D	S
1	1.02.1	how the route of the race looks like					S
3	1.02.2	if there was a similar race in the past	***				S
1	1.03	the rider profile	***	R	T		
1	1.04	the most challenging points of the race	***				S
2	2.01	the current speed		R		D	
2	2.02	how the live race is progressing	***	R	T	D	S
2	2.03.1	where on the route the video is recorded					S
3	2.03.2	how the race looks like from a specific angle	***	R			S
2	2.04.1	why riders of a team ride in a specific formation			T	D	S
3	2.04.2	examples of other situations where the same cycling strategy was used in previous races					S
2	2.05	what the impact of the wind is on the riders		R	T	D	S
2	2.06	distance between riders		2 R	T	D	
2	2.07.1	position on the route of all riders		R	T	D	S
3	2.07.2	progress of a specific rider		R			
3	2.07.3	who the front riders are		R		D	
2	2.08	what the weather conditions are				D	S
2	2.09	the current classification	***	R	T	D	S
2	2.10	how the race was going at a specific moment		R		D	S

*** described in the report in more detail.



↑

1 Basic information about this race (predefined and does not change)
2 Story of this race and the used strategies
3 Additional/ background/ historical information

Figure 3.2: list of queries and their applicable subjects

Several insights can be concluded from creating this list of queries:

- There are numerous possible queries, this shows the large pool of functions that could be implemented in this service.
- The queries can be grouped into three main types: basic information (this is constant, it does not change during the race), information to tell story of the race (this changes during the race) and additional information (used to provide further explanation).
- The complexity of implementation of the queries differs extensively.
- The duration of relevance of the queries differs, e.g. the showing the name could be interesting the complete race to easily recognize the riders, the classification only needs to give a few updates during the race, and showing examples of past races is not relevant for every race.

3.2.1.2 Data

To provide an answer to the queries described previously (see figure 3.2) the system needs data. In chapter 2.4 figure 2.6 an overview of the currently used data was presented. Figure 3.3 has the list of queries in the middle and data variables connected at both sides. The elements at the left side are the currently used data variables and at the right side the proposed additional data variables are presented. The continuous lines in the figure are connecting the queries to the data variables that are needed to achieve the function or that can `highly improve' the answer to the query. When the line is dotted, it is possible to use for the function, but has no great influence.

The data variables that can be used for many of the queries can be found by looking at the amount of lines that connect to a single data variable. In this way the most important data variables can be determined.

These most important variables are for the proposed additional data variables:

- the camera GPS coordinates,
- the 3D elevation map of the route,
- 180/ 360 degree video recording of the race, and
- route markers for challenges

For the currently used data variables the most important ones are:

- pictures
- the rider & team name
- speed
- videos
- location data of the cyclists

Another insight from the diagram is that some data variables need others. In example when displaying a 3D elevation map, the terrain details are partly included. Or to show the location of the cyclists a map or video is needed.

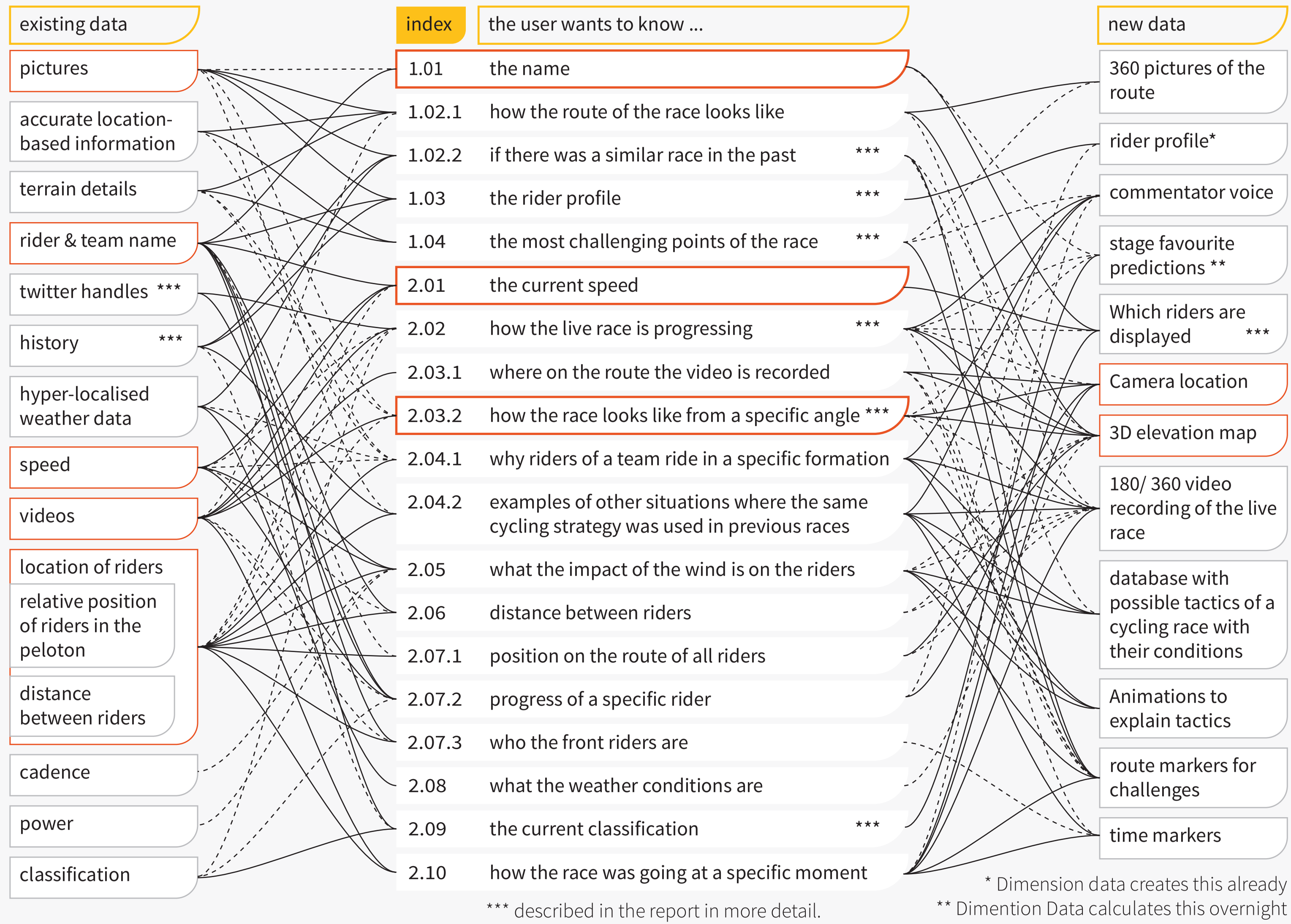
The data variables in figure 3.3 with a ***-sign are clarified below:

Twitter handles: e.g. @letour or #TDFdata

History: data like speed and classifications of previous races, or data from earlier moments in the currently broadcasted race

Hyper-localised weather data: i.e. local wind speed and direction

Which riders are displayed: can be found using the camera and rider positions or image recognition



——— data that is needed to achieve the function or that can 'highly improve' the answer to the query.

- - - - data that is possible to use for the function, but has no great influence.

Figure 3.3: data linked to queries

3.2.1.3 Interaction: sequence diagrams

To see how these queries can be implemented in an information provisioning service, sequence diagrams are constructed. These diagrams include the interaction between the user and the system. The processing of the system is described in the diagram using Input-Transformation-Output cycles (ITO cycles). See appendix F for an overview of the sequence diagrams of all queries. From making these sequence diagrams, the following findings are discovered:

- When the sequence diagram indicates that a value has to be stored in the database, a description of these databases is needed. This is only presented in the detailing phase where the chosen concept is elaborated.
- Some of the functions can be combined into one, for example showing the name and speed of a cyclist could be combined into one function.
- There are many different options to realise a user-system interaction. Figure 3.4 shows a taxonomy of selection interaction techniques. When looking for example at the indication to select one of the options is button. Of this there are again multiple options: both controllers have 3 different types of buttons. The steps of the interaction can also influence the logic of the actions of the user scenario.

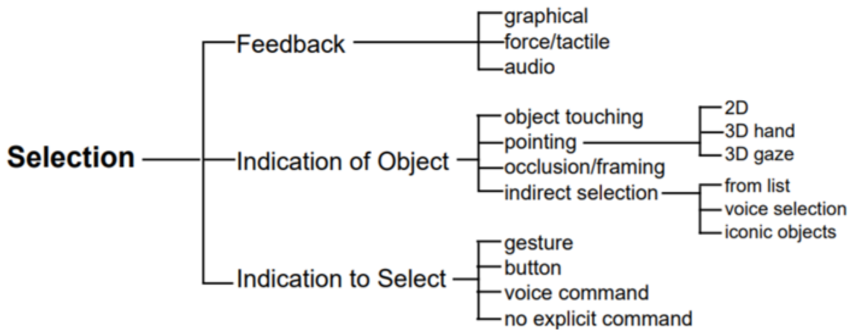


Figure 3.4: a taxonomy of selection interaction techniques (Bowman, Johnson, & Hodges, 1999)

3.2.1.4 Selection of functions

Because the service can include a vast amount of functions, a selection is made of the functions that will be explored in this thesis. Three information provisioning functions of low, medium and high complexity are selected. The set of three functions is used for generating concepts. The selected functions can represent the bubble of all possibilities, and are those that are connected to the most a selection of the most important data sources (see figure 3.3). Figure 3.5 shows the functions that are selected to use for generating concepts, which are 1) showing the name, 2) showing the current speed, and 3) show how the race looks like from a specific angle. These chosen functions are also indicated in the query-data diagram (figure 3.3) using an orange colour. Showing the name is the most basic function for learning about the 'Tour de France'. When the user knows the name of a cyclist, he is able to recognize the cyclist and follow his performance through the race. The speed gives the user more insight in the performance, especially when the speed is also used to calculate related information like the power or average speed. The last chosen function, showing the race from a specific angle, can help the viewer to become more aware of the shape of the route and where the video footage is recorded. This can help to get a better overview and sense of space.

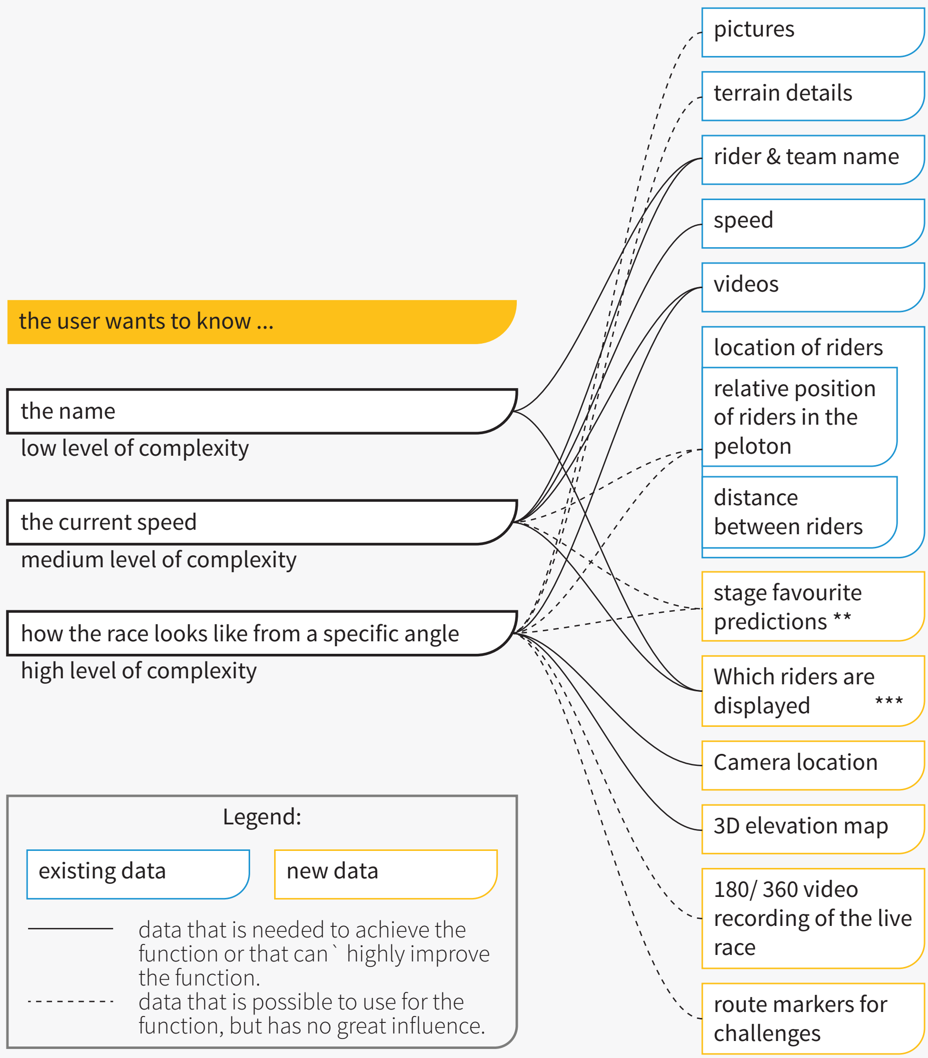


Figure 3.5: chosen queries with linked data

3.2.2 How to present

The ‘how’ refers to the manner in which the content is presented in VR. The goal of the data presentation in this thesis is to promote self-initiated learning of the user. There are various factors of the ‘how’ that can influence the learning ability of the users.

The ‘how’ refers to the manner in which the content is presented in VR.

3.2.2.1 Morphological matrix

To get an overview of the different possibilities that can make the presentation of the data in VR different, a morphological matrix is used (see figure 3.6). This matrix includes a list of functions that are included in the service. For each of these functions a set of different solutions is presented in every row of the matrix. The functions that are included in the matrix are grouped into 2 categories: general functions and case specific functions. The general functions are the functions that are applicable for all situations. Case specific functions are the functions that were chosen in the previous section (see 3.2.3). These functions can be applied to different subjects which are one cyclist, a team, the displayed riders or all riders of the stage (see figure 3.2). For different subjects, different solutions might be needed. During this phase of the project one subject is chosen, which is ‘the displayed cyclists’. Solutions for the other subjects will be addresses during the detailing of the concept.

The morphological matrix includes the following functions:

- Basis 3D environment configuration
- Showing the progress of the race
- Interaction with the data: seven general categories of interaction techniques widely used in Information visualisation. (Yi J. , Kang, Stasko, & Jacko, 2007)
    - Select: mark something as interesting
    - Explore: show something else
    - Reconfigure: show me a different arrangement
    - Encode: show me a different representation
    - Abstract/ elaborate: show me more or less detail
    - Filter: show me something conditionally
    - Connect: show me related items
- Provide feedback on the interaction(options from the feedback-branch of the taxonomy shown in figure 3.4 (Bowman, Johnson, & Hodges, 1999)).
    - Graphical (in the matrix this is divided into highlight and text)
    - Force/ tactile
    - audio
- Camera selection or movement
- VR functions for data representation: what value VR can add to data representation.

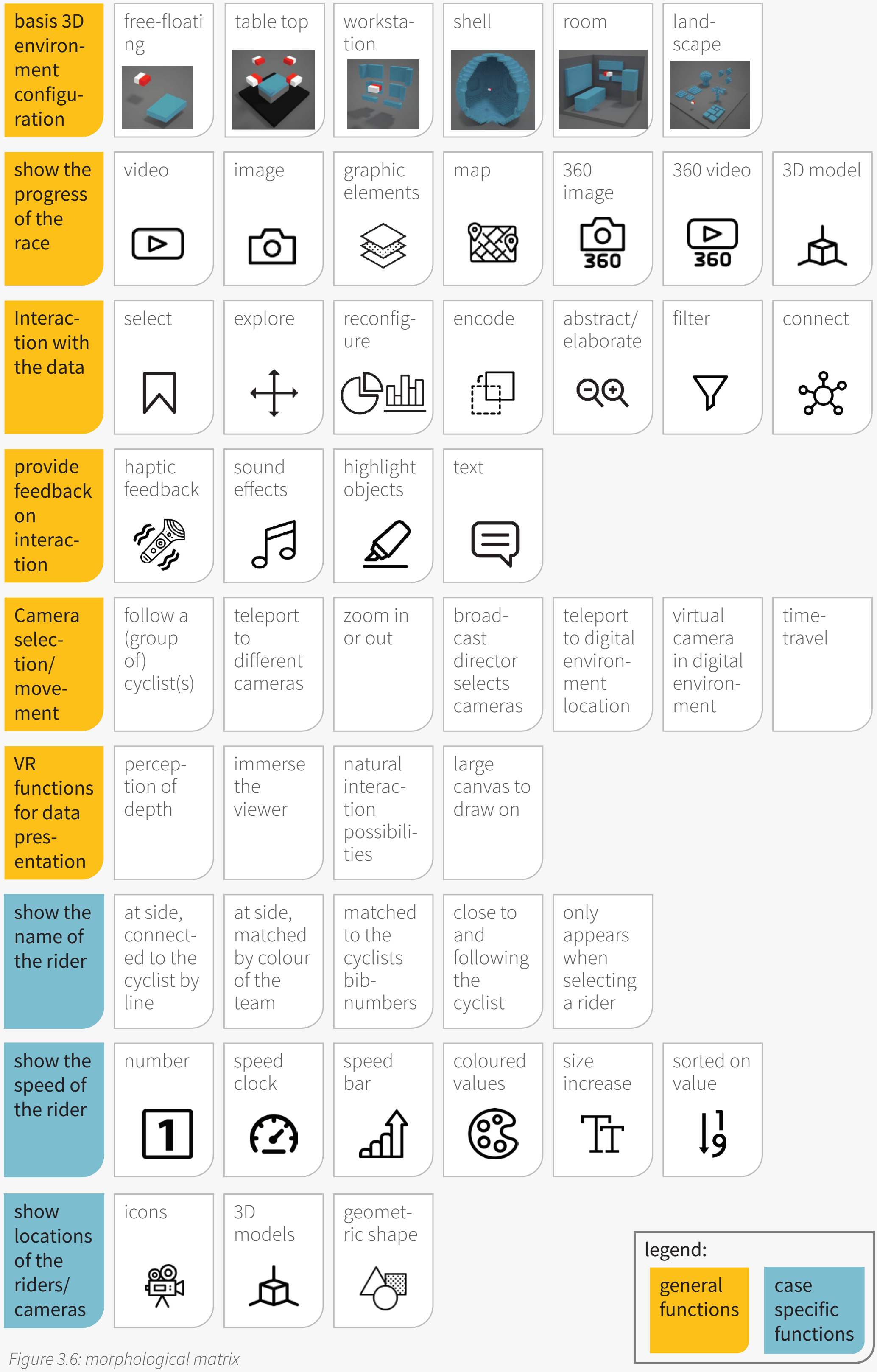


Figure 3.6: morphological matrix

- Show the name of the rider
- Show the speed of the rider
- Show the locations of the riders and cameras (The indication of the locations of the riders and the cameras have the same options so these are presented in one function in the diagram. However, for the rider and camera locations a different option can be used.)

3.2.3 Ideas: sketches

Ideas are generated by combining the elements in the morphological matrix. Appendix G2 shows the combinations of the elements of the morphological matrix for the three component concepts. Appendix G1 shows the idea sketches that are made. The component concepts presented in the next section are further developments of these idea sketches.

3.2.4 Ideas testing

Before creating the concepts, a few of the ideas are tested to get a better sense of how these work in VR. The chosen features to test are the features that are expected to be most general to use for this use case, being a map with moving cyclists, selecting these moving cyclists, showing information using a label at the moving cyclists, and showing information at the side with connections to the moving cyclists on the map. The findings and possible design solutions are as following:

Selecting

A small and fast moving object is not easy to select (see figure 3.7 right). Possible solutions are making the objects larger (e.g. use a zoom area where bikes are bigger) or to make them move more slowly (e.g. focus the zoom area on a moving object).

3D map with moving cyclists

Because a 3D map is used, the bikes can be hidden behind a mountain (see figure 3.7 right). This could be solved by using an indication that there is a bike (e.g. a label pointing at the bike), by using local transparency of the mountain, or by rotating the map.

Presenting the information

Many cyclists could ride together in a large group. When showing a label that moves with the cyclist, they are likely to overlap and only the front ones will be readable (see figure 3.7 left). To solve this a smart text placement algorithm

Figure 3.7: screen-shots of the testing in VR. left: overlapping name tags when bikes move, right: bike almost behind the mountain and hard to select.

could be introduced, or a different way of showing the information (e.g. show the information at the side and use a number to refer to the cyclists bib-number (the number that is shown on their jersey).

3.3 Component concepts

The objective of the concepts is to compose a feasible solution for the support of individual learning (for cycling fans) by creating alternate sets of functions and structures. In this chapter three component concepts are presented, which are ideas of which the functions, components and usage are specified. The component concepts are all combinations of the elements from the morphological matrix shown in figure 3.6. A version of this figure including the selection of the combinations of the concepts that are presented in this chapter is shown in appendix G2. The concepts are all services that are a virtual environment viewed in a VR HMD. In the following sections they are documented using sketches, diagrams and a textual description.
The sketches in this chapter show the virtual environments. The user sitting on a chair or couch is also presented in the sketches to show where in the environment the virtual camera will be located and to give a sense for the scale of the virtual environment. In reality the user is sitting at home using a VR HMD, and thus not visible in the VR environment.

The sketches of the concepts show how the virtual environment would look like, the user is shown to indicate the location of the virtual camera and the scale, but is in reality not visible in the VR scene.

The interactions are presented using sequence diagrams. These diagrams show the human- and computer side of the system, and the interface that connects them. This interface is shown in the sketches that are mentioned before. Figure 3.8 shows the legend for the sequence diagrams (see figure 3.11, 3.14 and 3.15 for the diagrams). This section continues with the presentation of the three component concepts. They are all named metaphorically to an experience they simulate.

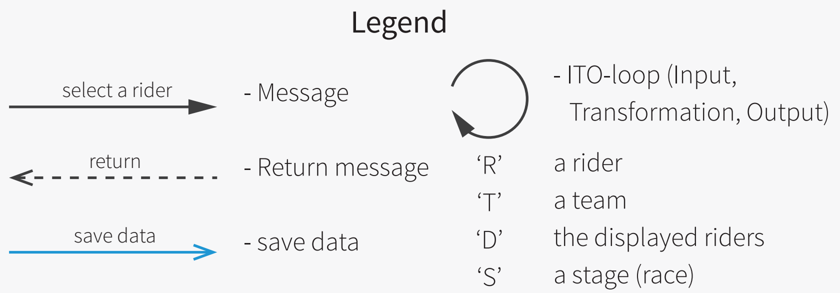


Figure 3.8: legend for sequence diagrams (see figure 3.11, 3.14 and 3.17)

3.3.1 Concept 1: Teleport map

This first concept uses a virtual environment (VE) with a screen and a 3D elevation model of the route of the race. This 3D elevation model has real-time updated locations of the cyclists and cameras. The main feature of this concept is that the user can teleport to different cameras to view the race from. Using a virtual laser-pointer from the controller, the user can select a camera that is shown on the 3D map. A camera can be a conventional 2D camera, or a 360 degree camera. When a 360 camera is selected a 2D preview of that footage is shown on the screen and the user is able to switch to the 360-viewmode. When playing 360 videos in the 360-viewmode, the VE changes to a shell-environment. The different viewing-angles on the race are combined with different information elements which are described more specifically later.
The 3D elevation map helps the user to get a better perception of depth about the route of the stage. Therefore it can lead to a better understanding of the environment and the impact it has on the cyclists. The interactive experience from different viewpoints can stimulate the viewer to emphasize more with the race from different viewpoints.

3.3.1.1 System architecture

The combination of functions selected for this concept from the morphological matrix is shown in figure 3.9. The interaction with the data is based on exploring which is explained in a paper by Yi et al. as following: "Information visualisation system users typically examine a subset of the data to gain understanding and insight, and then they move on to view some other data. Explore interactions do

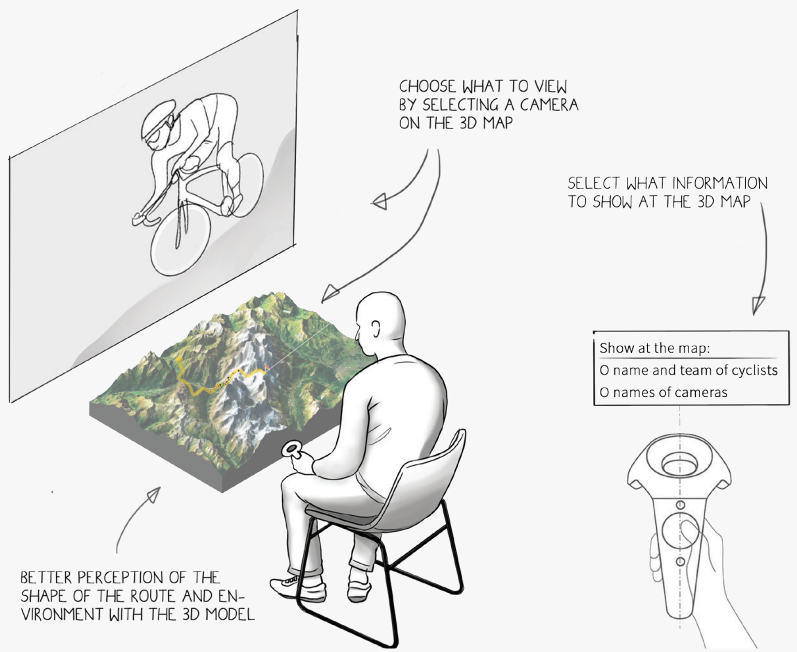


Figure 3.9: sketch of concept 1

not necessarily make complete changes in the data being viewed, however. More frequently, some new data items enter the view as others are removed" (Yi J. , Kang, Stasko, & Jacko, 2007). The exploring interaction with the data is realised in this system by connecting the showed information to the view-modes (see figure 3.10 for the details). The user can select different cameras to view from, and each view comes with different information. The second way of exploration are the two zoom-levels of the 3D map: overview and focus (see figure 3.8). The overview zoom-level shows the map of the complete route with the selected camera highlighted. The focus zoom-level shows the area that is visible on the screen with an extra margin. Besides constantly selecting the cameras manually, there is also the 'autopilot' option where the system selects different camera-views. The location of the cameras and the riders are shown on the 3D map, which is always visible, except when watching a video in 360-viewmode. The cameras are represented using geometric shapes: spheres for 360 cameras and cubes for conventional cameras.

3.3.1.2 User scenario

In figure 3.11a and 3.11b the sequence diagrams for this concept are presented. They show how the user interacts with the system. It is an example of a user scenario and not a complete experience is presented, but only the main features. These features include watching the race on the screen, see the positions on the map, selecting a different camera, changing the view-mode of the 3D elevation map and changing the view-mode to 360-viewmode.

	Stationary camera: like a fan at the side-line or a reporter	Camera on bike: like a cyclist	Camera on motor bike: lika a coach	Drone camera: like a cycling tourist
Name and team of rider	**X**			**X**
nationality of rider	X			
Speed of rider	**X**	**X**		
Ranking of riders	X		X	
Location of riders	**X**		**X**	**X**
Average speed (per team)	X		X	
Heartrate		X	X	
Power		X	X	
Distance to other cyclists	X	X		
Route information: direction and approaching challenges		X	X	
Show names of cities and landmarks				X

Figure 3.10: the information that is shown per view-mode in concept 1

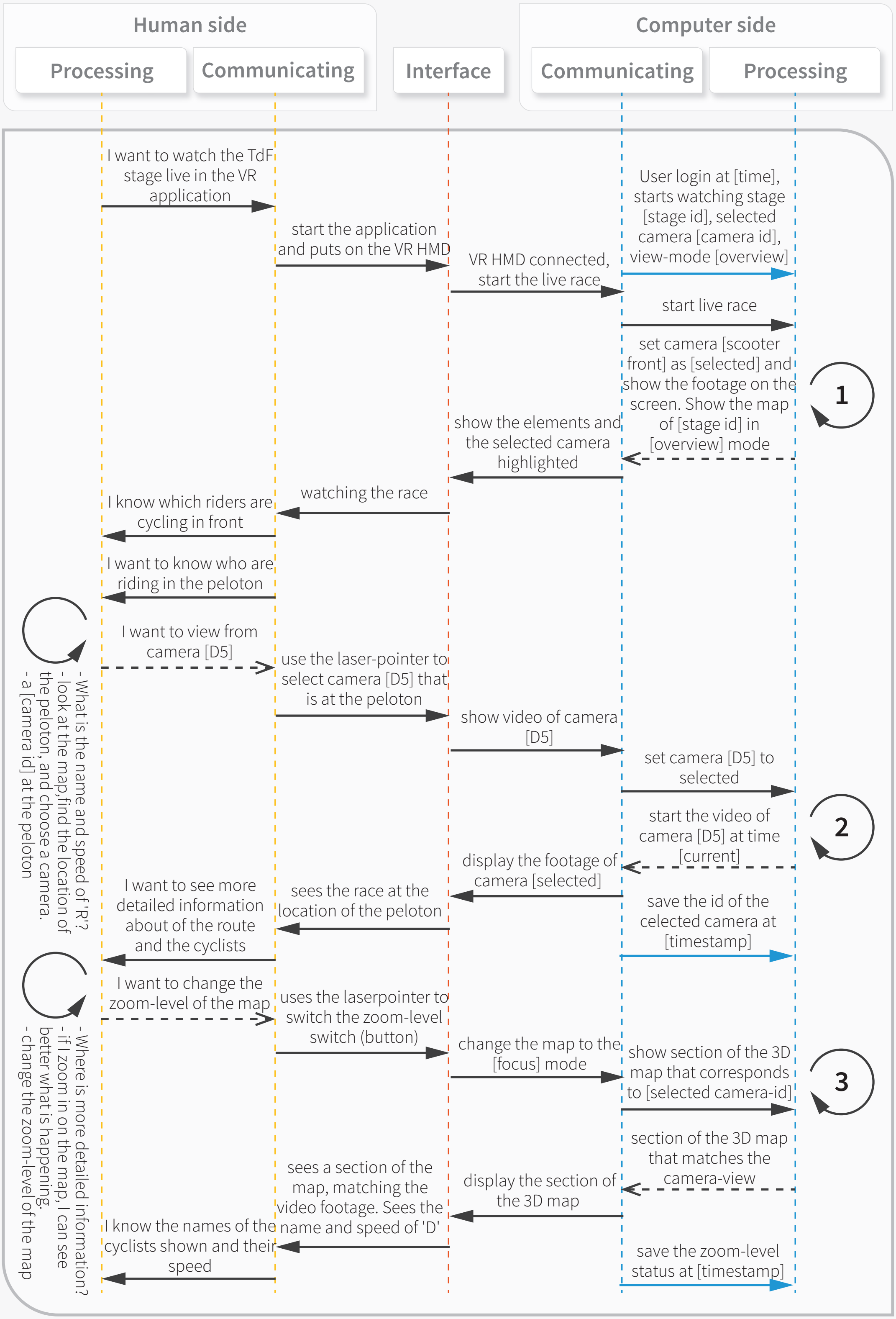
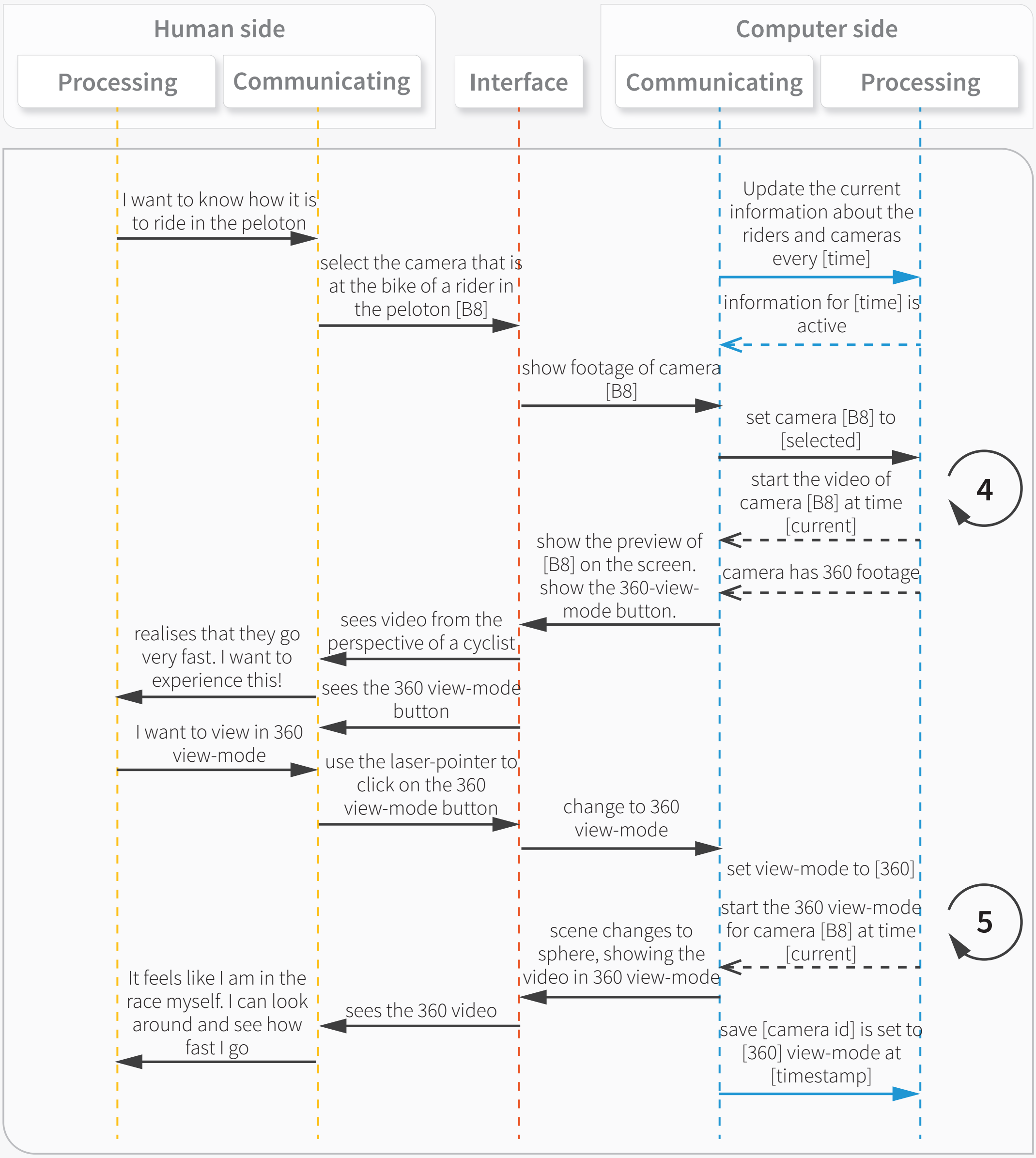


Figure 3.11 a: sequence diagram concept 1



ITO cycles

Index	Input	Transformation	Output
1	start live race	set [camera id] as [selected]	show footage on screen, and map in [overview] mode
2	set camera [D5] to [selected]	find [camera id] of [D5] set to [selected] and current sel. to []	start the video of camera [D5] at time [current]
3	show section of the 3D map that corresponds to [camera-id]	locate [camera-id] calculate view-area and add margin	section of the 3D map that matches the camera-view
4	set camera [B8] to [selected]	find [camera id] of [B8] set to [selected] and current sel. to []	start the video of camera [B8] at time [current], camera has 360 footage
5	set view-mode to [360]	check if footage is 360, set viewmode to [360]	start the 360 view-mode for camera [B8] at time [current]

Figure 3.11 b: sequence diagram concept 1 continued

3.3.2 Concept 2: Tour time travel

Concept 2 consists of a VR environment with a three screens. The middle screen is the main video screen that displays video footage of the race (see figure 3.12). The screen on the left shows the route of the race with the location of the cyclists on it. The screen at the right is the information screen, which has two sections: a timeline and a section for additional information (section 3.3.2.1 shows more details about what information is shown). There is also a miniature elevation model of a section of the route of the race available. This can be activated using the trigger of a 'HTC Vive controller'. As the name of the concept indicates, the main feature is to time travel, which means that the user can go back or forward in time to view specific moments of the race. So when an important event happened, the viewer can go back in time to re-watch it and learn more about what exactly happened. Also when for example the viewer sees that one cyclist is far in front of the peloton, he can go back in time to see the moment where that happened, to understand it better.

3.3.2.1 System architecture

The virtual environment of concept 2 consists of a workstation configuration, build up from different elements like a map, video and graphical elements, as described in the introduction of this concept. The interaction with the data is based on an 'abstract/ elaborate' interaction, which means showing less or more detail. This is implemented by zoom levels on the map- and information screens. Figure 3.13 illustrates what information is shown at these different levels of elaboration.

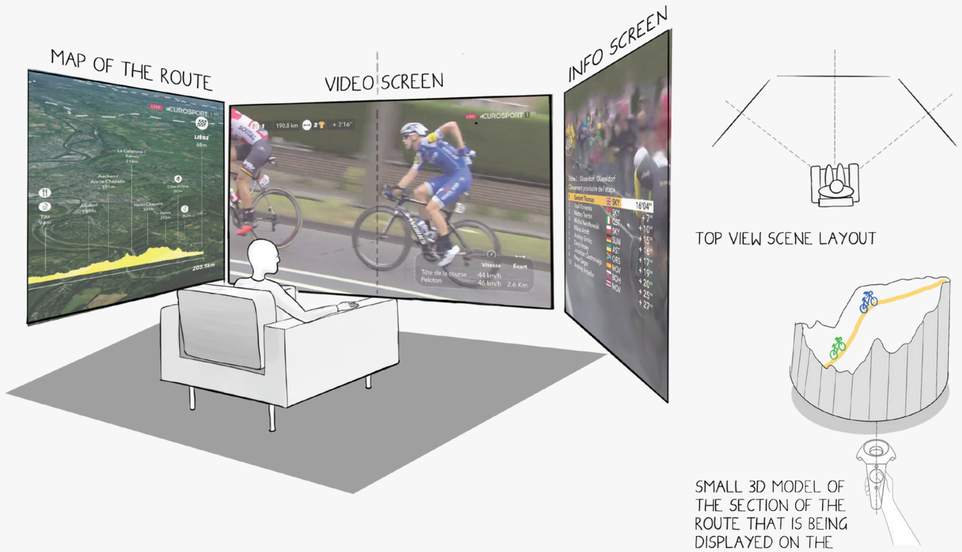


Figure 3.12: sketch of concept 2

When watching a live race there are always two buttons shown at the time-line: jump back to 10 seconds ago and go to the live moment. When watching a replay of a race, instead of the 'live moment' button a '10 seconds forward' button is shown. It is also possible to use the slider under the time-line to go to a specific moment in the race. The location of the currently shown camera is always indicated on the map. By using the time-travel feature of this concept he can also change the camera angle from which he is watching the race. The types of cameras used for the broadcast are indicated on the time-line, so by selecting a moment that is recorded using a specific type of camera the user can select the camera-angle on the race, but he does not have complete freedom on the selection of the cameras like in concept 1.

3.3.2.2 User scenario

In figure 3.14 a and b the sequence diagrams for this concept are presented. The main features of this concept that are presented in the sequence diagrams are: activating the 3D miniature of the map, jump back 10 seconds ago in the video, changing level of detail of the information screens (this is similar for the map so that is not shown separately), and watching a specific moment of the race.

Zoom levels	Map-screen	Info screen - timeline	- other info
Elaborated	• Overview of the whole route • Locations of challenges/ landmarks • Locations of the riders represented by blobs of the locations main groups • Locations of the cameras using icons	• Complete timeline overview • The moment where the progress of the is race currently at (live watching) • At what time the video is recorded • Total time of the race (prediction when watching live) • Selection of most important challenges in the race	• Name of the race • Name, nationality and team of the cyclists • Position in the race
Simple	• Height profile with slope information • Zoom section (automatically where the shown video is recorded, manual possible)	• Scrollable timeline • All moments with challenges in the race and where important events happened (are added while watching a live race) • Type of camera that recorded the video (colour coded)	• Amount of km to go • Distance to, and time behind on the lead cyclist

Figure 3.13: the information that is shown per zoom-level in concept 2

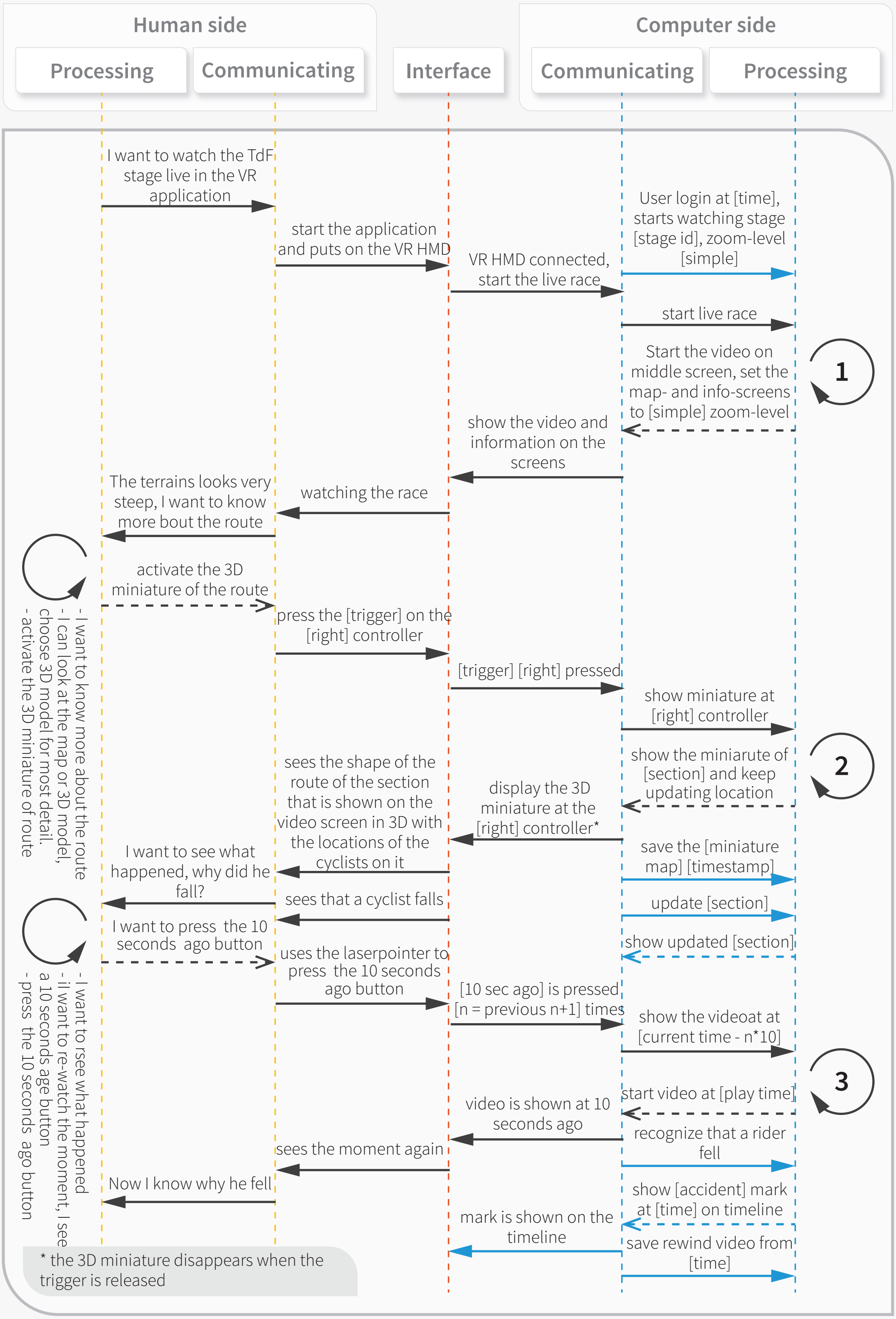
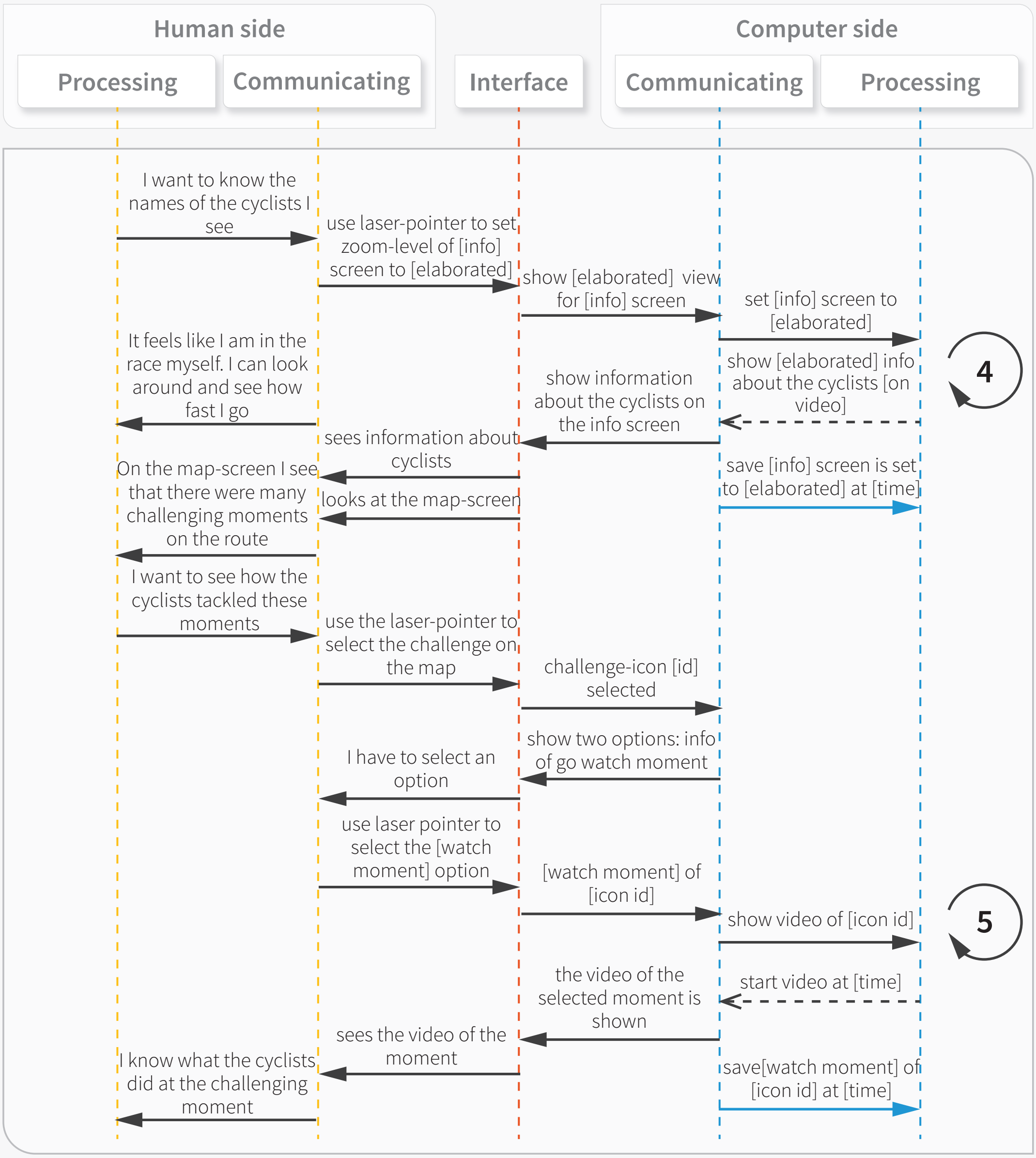


Figure 3.14 a: sequence diagram concept 2



ITO cycles

Index	Input	Transformation	Output
1	start live race	set [cuttent time], set [map] and [info] screens to [simple]	Start video on [middle] screen
2	show miniature at [right] controller	calculate view-area and add margin, create 3D miniature	show the miniarute of [section] and keep updating location
3	show the video at [current time - n*10]	calculate [play time]	start video at [play time]
4	set [info] screen to [elaborated]	find the cyclist [on video] and show info about them	show [elaborated] info about the cyclists [on video]
5	show video of [icon id]	check [time] of [icon id]	start video at [time]

Figure 3.14 b: sequence diagram concept 2 continued

3.3.3 Concept 3: Control room

The third concept is designed in a way that the interaction is like a control room where the user has the control over the screens and information shown on the screens. There are two main elements in this VR environment: a screen and a height-profile visualisation. Both elements are curved around the user. The height profile visualisation automatically rotates as the race is progressing (see figure 3.15). The interaction with the screen-elements is like a control room. The user is able to watch the race on multiple video screens at the same time. The sections on the screen-element can also be used to show information about the race, see figure 3.16 for examples of how 'Dimension Data' visualises the data currently in posts on 'Twitter'.

3.3.3.1 System architecture

The screen- and height-profile-elements of concept 3 are placed in the VR environment in a workstation configuration. The user can interact with the data that is presented on the screen-elements by using 'filter' and 'connect' interactions. By default the screens are empty, only the broadcast is shown in the middle. When the user wants to view information on those screens, the 'Filter' interaction is used wants to select what information to show (a selection of data variables and cyclists can be made). The 'connect' data interaction can be used in 2 ways: highlighting the same datapoints in different data visualisations (this also includes the height-profile) and to show more information about the data that is not shown (e.g. when a speed graph of multiple cyclists is shown and the user selects one cyclist, the specific numbers of the selected cyclist will be shown).

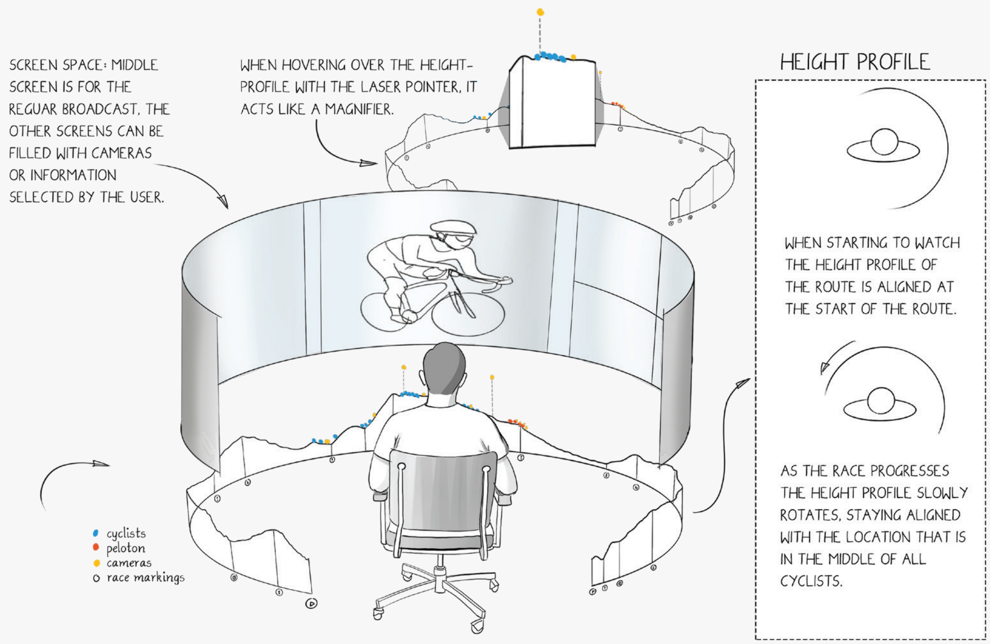


Figure 3.15: sketch of concept 3

The natural interaction value of VR is used for the large height-profile visualisation. The user can rotate his head to quickly have an overview of the whole route while he is also able to see the details. So for example when the user wants to see how much distance the cyclists still have to go, he can just rotate his head to see the endpoint of the race.
When testing the ideas, one of the conclusions was that it is difficult to select a small moving object (see section 3.2.6). Since in this concept the cyclists on the height profile could be small, the selection method will be explained here. The length of a long stage (extreme scenario) is about 220 [km] based on the length of the stages in 2019). A medium length stage is about 170 [km] and a short stage 90 [km]. The height profile in VR will have a radius of 1,5 [m] and use 2/3 of a circle part, which results in a length of the height profile of approximately 6 [m]. The scale the height profile for a long stage would be scale=(length of stage in [m])/6=220000/6=36666 → so the scale is 1:36666. This results for a person who is 1,75 m in reality and a long stage, in a height of about 0,005 cm in the virtual environment. This is too small to notice, so the cyclists have to be depicted enlarged on the height profile, not to their real scale. When using the correct scale for the section that is enlarged (by zooming in on the height profile) the person should be at least 5 cm high. This results in a scale of minimum 1:35.
Since the movement on the height profile follow a curve, the selection of a moving object is more simple compared to an object that moves in multiple directions. Also the rotation of the map, which is contrary to the movement of the bikes, makes them move slower. Another way that is used to simplify the selection is a magnifier that enlarges a section of the height profile.

Figure 3.16: examples of data visualisations posted on twitter by DimensionData #TDFdata

3.3.3.2 User scenario

In figure 3.17 a, b and c the sequence diagrams for this concept are presented. The interactions shown in the diagram are: watching a race, zoom in on the height profile and see information about a cyclist, select a cyclist for more information, follow the speed graph, add an extra video screen, and removing info screens.

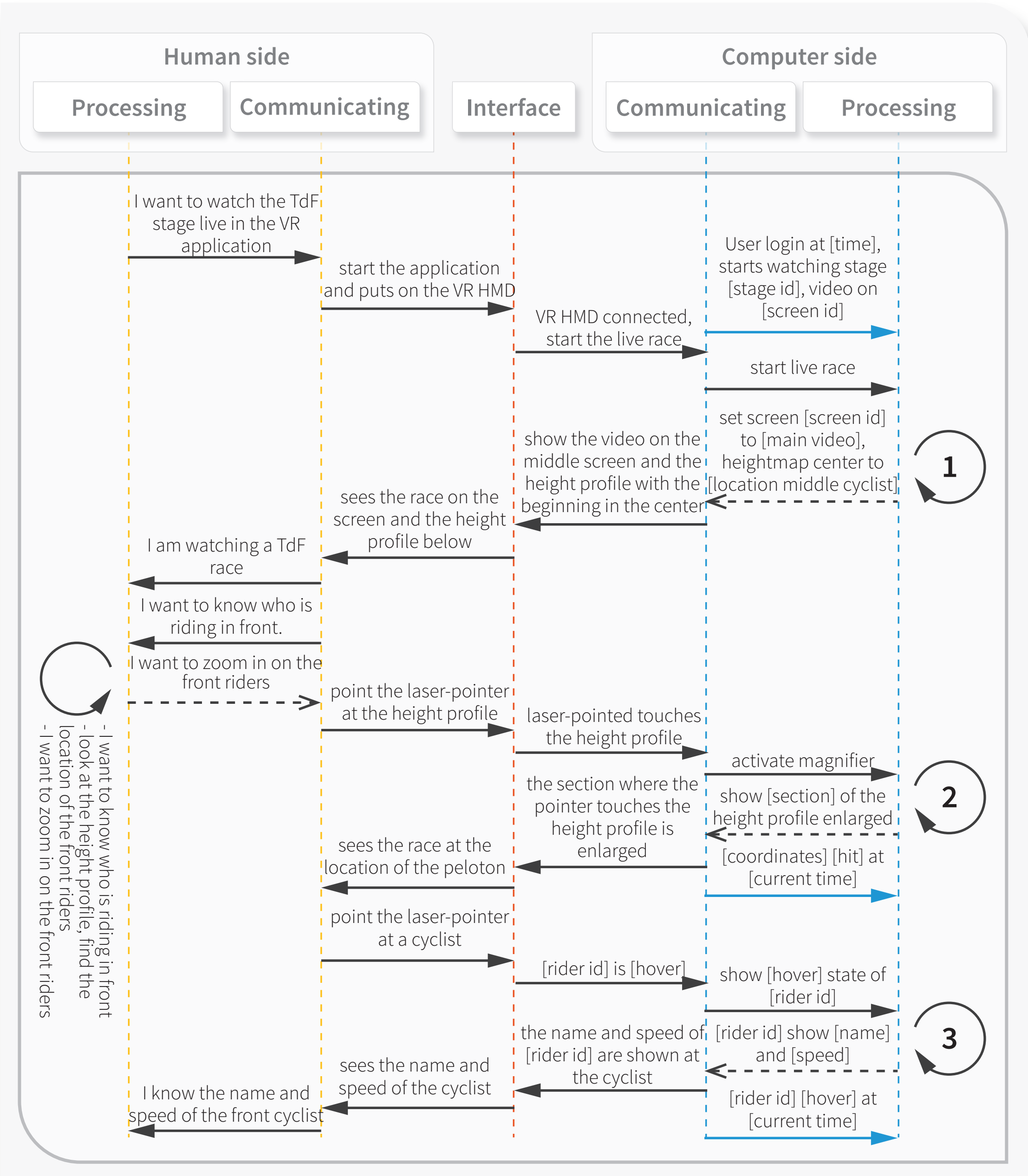


Figure 3.17 a: sequence diagram concept 3

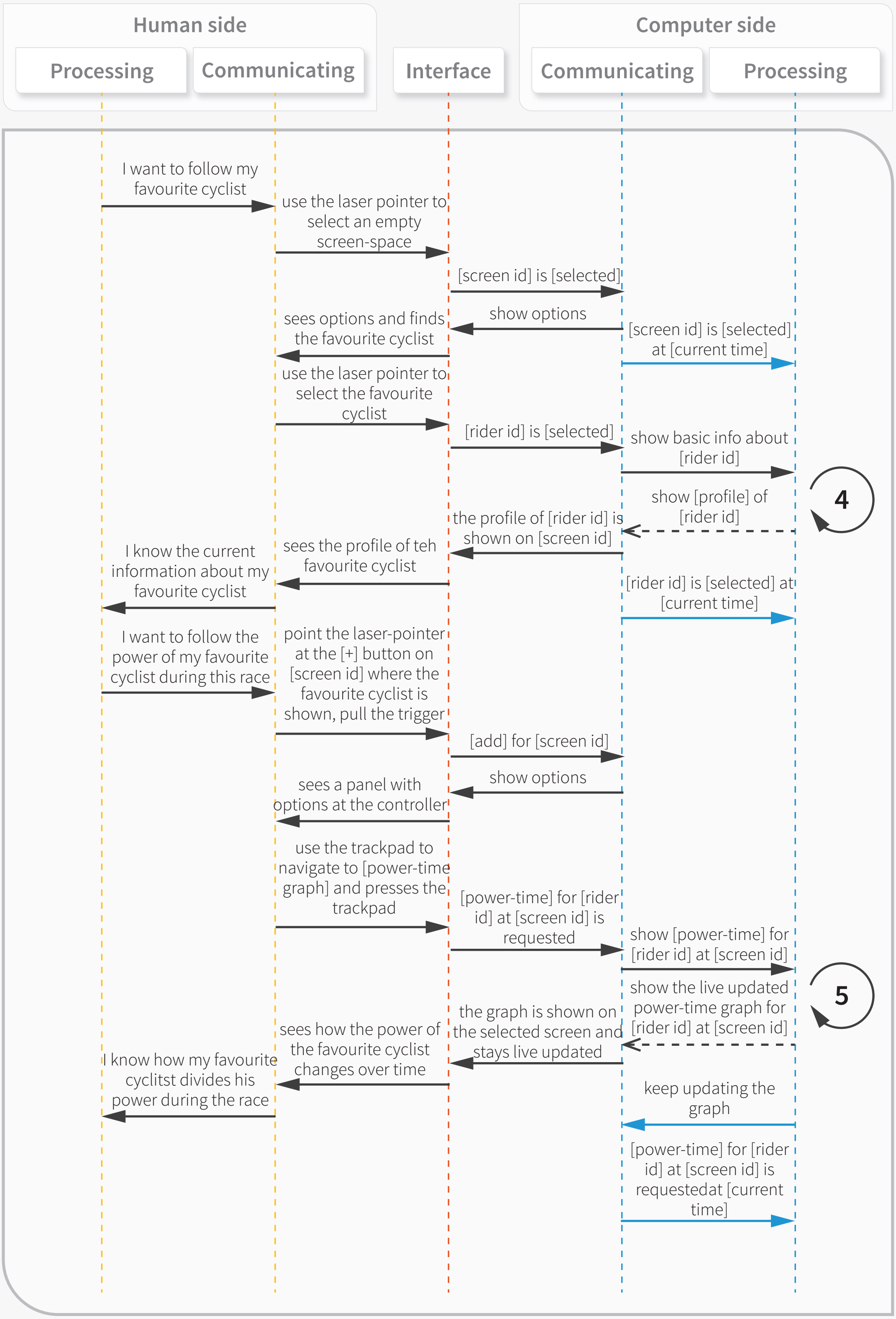
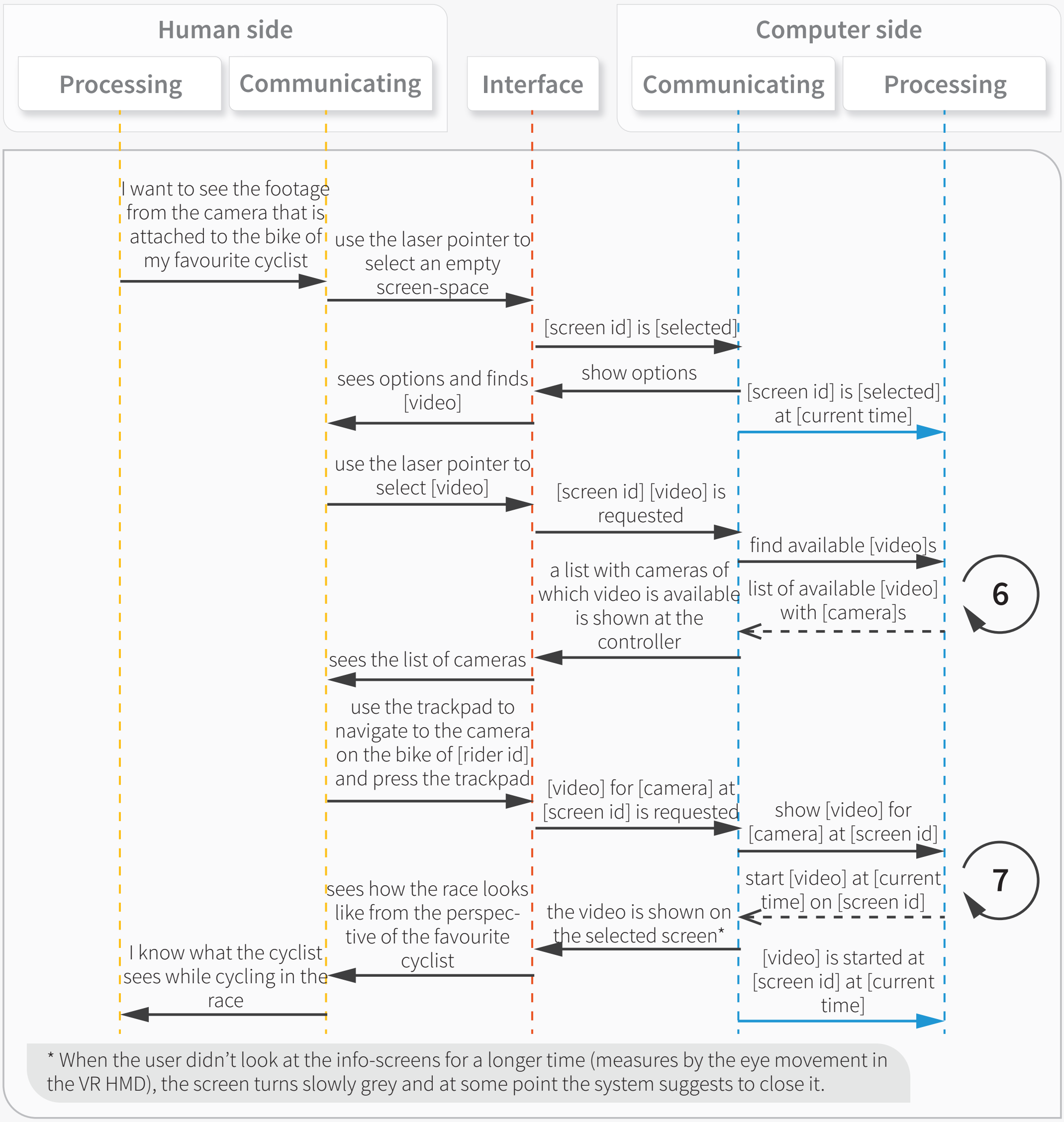


Figure 3.17 b: sequence diagram concept 3 continued



ITO cycles

Index	Input	Transformation	Output
1	start live race	start video at [time0], locate the heightmap of [race id]	set screen [screen id] to [main video], heightmap center to [loc. mid-cyclist]
2	activate magnifier	[hit-location] on the profile, transfom to [section]	show [section] of the height profile enlarged
3	show [hover] state of [rider id]	find [name] and [speed] of [rider id]	show [name] and [speed] of [rider id]
4	show basic info about [rider id]	find basic info of [rider id]	show [profile] of [rider id]
5	show [power-time] for [rider id] at [screen id]	calculate [power] using speed, generate live updated graph	show the live updated power-time graph for [rider id] at [screen id]
6	find available [video]s	locate cameras that have video footage	list of available [video] with [camera]s
7	show [video] for [camera] at [screen id]	locate [video]	show [video] for [camera] at [screen id]

Figure 3.17 c: sequence diagram concept 3 continued

3.4 Component concept selection

The objective of this chapter is to asses each concept on a comparative level, to select the concept that fits best to the criteria considering the three selected informing functions, namely showing the name and speed, and showing the race from a specific viewpoint. First the three concepts are compared to the conclusions of the analysis, and then one concept is selected using the requirements and wishes. The selected concept is further detailed and developed in the next sections.

3.4.1 Concepts compared to te analysis conclusions

A description where the three prototypes are compared to the conclusions of the analysis:

As concluded in the user analysis (see page 25) the designed service should fit the target of young fanatic cyclists (of the age 18 – 35), who found their passion in knowing more about cycling and want to participate in a quiz about the Tour de France. The informational needs that the concept should address are learning about the 'story of the race' and the 'strategy of cycling'. The service is designed for a use at home, and the three concept all focus on an individual usage.

The analysis on the technology addressed three aspect i) data, ii) ICPS principles and iii) Virtual Reality. For the data source the three concepts all use data that is currently collected at cycling races, as well as newly acquired data. All three concepts do not include much of the CPS principles that were described in the analysis phase (see page 35), but they all have the potential to include them. The implementation of the CPS principles will be described in the detailing phase for the selected concept. In all the three concepts the cognitive capabilities of the CPS principles can be used to create more personalised experiences by making the system learn about the users preferences and educational needs. This can be used together with the principle 'penetration in real life processes' where the system decides what information to present. For concept 1 the opportunity for using CPS principles lies also in the functions that are adaptive to the environment. The viewer will watch the race from different viewpoints (that are at different locations) which can be used to select information that fits to that location. The VR experience has to be designed with the type of usage in mind (see conclusions on page 39). Therefore the three concept sketches include a user that is seated, to make sure that the design fits that context. The level of fidelity of the VE is not defined for the three concepts, this will be discussed in the detailing phase for the selected concept.

The last section of the analysis addressed the content creation (see page 45). The exact description of the content creation including the specification of the UI placement of the information elements will also be described in more detail in the detailing phase for the selected concept.

3.4.2 Concept selection using requirements and wishes

The concepts all meet the requirements (see section 2.6) for the following categories: general (except 1b is unknown), data, and UI (VR). Requirement 1b 'By using this service the users will learn more about the 'Tour de France' compared to watching the TV broadcast' has to be tested to know if it is met. The exact visualisation (requirement 3a and b) and the usage of CPS principles is not specified in the concept and will be detailed in the next phase for the chosen concept.

To compare the three concepts that were described in this chapter, the wishes defined in 2.6 are used as criteria. The 'Harris profiles' in figure 3.18 show how well each concept fulfils the criteria. The criteria that are used for the assessment of the concepts are sorted on importance, of which the most important criteria is on top:

1. The concept should help the user to learn as effective as possible
2. It should be as easy as possible to add other functionalities to the concept
3. The concept should be as easy to use as possible
4. The concept should be as much entertaining as possible
5. The concept should have a balance between active and passive usage as much as possible
6. The concept should make use of the values that VR offers for data visualisation as good as possible.

Criteria 1: The difference between the concepts on the learning is the amount of information shown and the interaction possibilities with the information. The effect on learning will be influenced most by the way the data is visualised, which can still easily be adjusted for all the concepts.

Criteria 2: Different functions can be added for both concepts 1 and 2 by adjusting the data that is shown. Since the amount of screens in concept 3 can easily be increased for adding more functions this concept is the most flexible for adding functions.

Criteria 3: Concept 1 has a straight forward navigation because small amount of layers the information. The same counts for concept 2, but the user has to learn where to find what information since there are 2 screens used for the purpose of displaying information. In concept 3 there is a natural interaction for the height profile, but the user has to learn how the screens can be edited, which can get complicated. There are many different options available to choose from for the user which can be overwhelming.

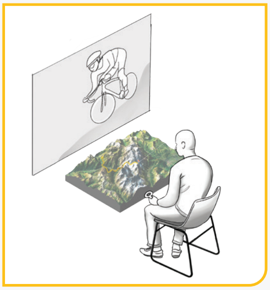
Criteria 4: In concept 1 the experience changes towards different perspectives on the race, this can make the learning more entertaining. Concept 2 is more serious, the information is simply shown on the screens, and does not tell a story by itself like the other concepts do. The elements in concept 3 appear to be more playful and less traditional compared to concept 2, but does not have the different experiences and story that is achieved in concept 1.

Criteria 5: In concept 1 the user can be very active in selecting different camera-views, but is also able to sit back and watch the race using the autopilot function. Both of concept 2 and 3 have the most active use when adjusting what is shown

on the screens. This is probably mostly done in the beginning and less during the race. Then there is only a passive usage of watching.
Criteria 6: The 3D map in concept 1 helps a lot with the perception of depth and the 360 videos increase the empathy with the cyclists. In concept 2 the 3D miniature can give a good insight in the route, but it is not a main feature and the user has to decide to use it. The large canvas is used, but this way already exists in other VR broadcast products, which makes it not very innovative. The third concept makes use of the large canvas, but the freedom that the user gets also gives them the ability to make the amount of shown information overwhelming.

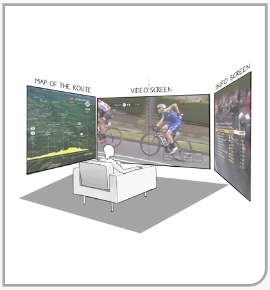
From the 'Harris profiles' it can be concluded that concept 1 is the best concept. For the next phase concept 1 will be chosen to continue with. The focus of the detailing should be on improving the learning effectiveness of the visualised information.

Concept 1: Teleport map



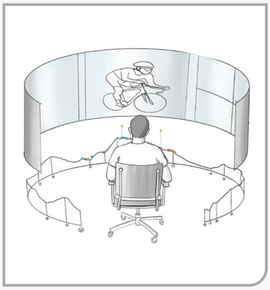
	--	-	+	++
criteria 1			■	
criteria 2			■	■
criteria 3			■	■
criteria 4			■	
criteria 5			■	■
criteria 6			■	

Concept 2: Tour time travel



	--	-	+	++
criteria 1			■	
criteria 2			■	
criteria 3			■	
criteria 4		■		
criteria 5		■		
criteria 6			■	

Concept 3: Control room



	--	-	+	++
criteria 1			■	
criteria 2			■	■
criteria 3		■		
criteria 4			■	
criteria 5		■		
criteria 6			■	

Figure 3.18: Harris profiles to compare and select a concept

4 Detailing

4.1 Introduction

The objective of the detailing phase is to improve the concept by defining the details of the features. The concept that was chosen in the previous chapter is described in more detail in this chapter. For the detailing of the graphic representation variants are compared. Also the interaction of the user with the service is detailed. The chapter ends with a description of the implementation of the concept, addressing the technical and functional requirements. Figure 4.1 shows the process of the detailing phase in the project.

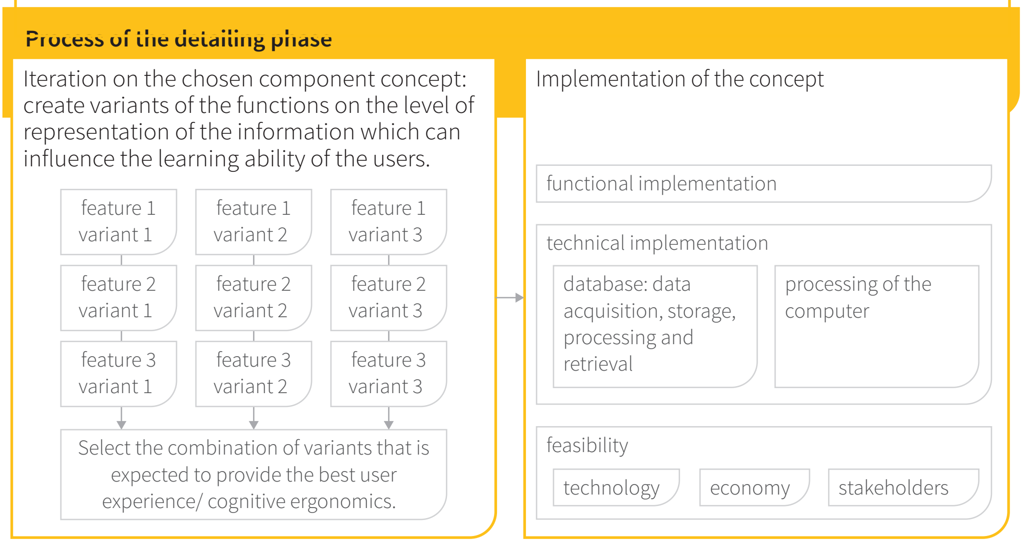


Figure 4.1: Process of the detailing phase

4.2 Iteration

In chapter 3.4, component concept 1 was chosen with the comment that the learning effectiveness of the visualised information had to be improved. To improve the learning effectiveness, a design iteration on the information representation elements is done first. Then the map and the combination of the elements with the interactions with them are presented.

4.2.1 Visualisation of the information

The goal of the concept is to achieve that the viewers can learn about the story of the cycling race. Learning is the acquisition of knowledge, it is the ability to remember information. In a research by Kirk, Kennedy and Boy five factors that affect data visualisation consumption and engagement process are defined (Sam, 2016). One of these factors is that the manner of visualising should fit with the visual literacy of the viewers, which is explored in this iteration. When the users don't understand the information, they will not remember it.

The cycling fans are used to see the current visualisations used in broadcasts, data visualisations that are posted on social media (e.g. #TDFData on 'Twitter') and their own cycling performance data presented in 'Strava' for example (see appendix B2). These data visualisations come in several types, from minimal textual representations, to graphs or even animations. Because of this it is assumed that the viewers will have a good base of visual literacy. Nevertheless the visualisations themselves should be as clear as possible.

Learning about the story of the race is also about knowing how well a specific cyclist performs in the context of the race. In this concept different levels of information are available, namely an overview of all cyclists or a focus on specific cyclists. In order to display information about a specific cyclist, it has to be clear to who the information is connected. In the concept (see section 3.3.1) only three informing functions were included. 'Presenting the name' is used in this iteration to find out how to connect the information to a specific cyclist. In the final concept can be extended with more informing functions, which can be related to the name. How this can be done is shown in this iteration using speed data. The third informing function, knowing how the race looks like from a specific angel, has several elements. Firstly, there the user has to know which video is shown on the screen. Secondly, there is the interaction that lets the user find another camera and select it. Lastly, the information about the direction of the cameras is also supportive for the viewers.

Because it is not possible for the viewers to focus on the video screen and map with information at the same time, it is helpful to present the same information at multiple locations (e.g. at the screen and on the map).

Figure 4.2 shows for the four different types of cameras what is shown per information element. These information elements are the information that is placed as an overlay on top of the video (like in current television broadcasts is done), the information shown on the 3D map in overview mode and the information shown on the 3D map in focus mode. The figure shows that displaying of these three information elements on the 3D map are the same. For each of the three informing functions, three variants will be discussed next. The best variant for each information element will be chosen using the visual-requirements in section 2.6. These requirements are:

- 3a The mapping of the data has to be clear in an intuitive way.
- 3b The visualised content has good legibility (distinctness that makes perception easy)
- 3c The information can be found quickly
- 3d The visualised content must be easy to understand for users within the target group.

Figure 4.3 shows an overview of all variants for each function. It also includes the comparison of the variants using Harris profiles. The selected variant is indicated with a yellow outline. The variants are all for presenting the information on the 3D map.

Function 1: displaying the name at the 3D map

Figure 4.3 shows three variants of the displaying of the names of the cyclists in the top row. Variant 1 presents the name of the cyclist above the cyclist with a vertical line towards the cyclist. Here the name moves with the cyclist. Variant 2 has the names on a fixed place and a line connects the name to the cyclist. Variant 3 had no lines to connect the name to the cyclist. The names are presented in the order in which the cyclists are in the race. Also pictures of the cyclists are used to make the them easily recognizable. A colour is used to indicate to which team they belong.

To make a selection the criteria are used to rate the variants using a Harris profile. In figure 4.3 can be seen that variant 3 comes out as best according to the Harris profile. The problem with the lines of variant 1 and 2 is that is can easily get messy, and for variant 1 there is also a good system needed that can adjust the height of the names so that they never overlap. Therefore variant 3 has the best legibility.

Function 2: displaying the speed with the name

For the previous function (function 1) the variant that is presented next to the map is chosen. The speed will be placed with the name, so will also be placed next to the map. Figure 4.2 shows that the speed is only showed when the map

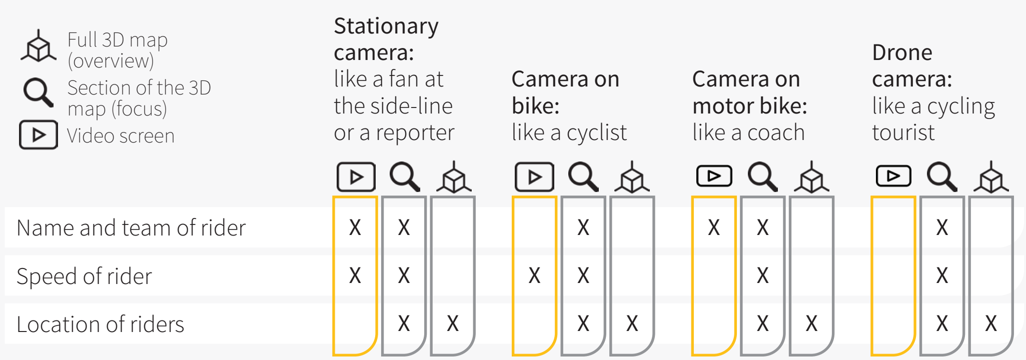


Figure 4.2: section of figure 3.10 with specification of information per informing element

is in the focus mode, which means that only the cyclists that are visible on the camera are presented on the map. The three variants for this function are shown in the second row of figure 4.4.

Variant 1 is a speed-time graph with a colour coding for high or lower speed. Next to the graph a speed-meter-icon is shown, which makes the graph easier to find in case there are multiple graphs shown on the screen. Also the specific number of the current speed of that cyclist is shown in the graph. Variant 2 is a minimalistic numerical representation of the current speed. Also the average speed of that cyclist is shown. When the speed gets in the top 10 of highest speeds, the colour of the number will change. Variant 3 represents the speed using a speed-meter. Here also the exact value of the speed is shown next to the visual.

When comparing these variants, the following can be noted: variant 3 is the most quickly findable because the shape is literally a speed-meter. But on the other requirements variants 1 and 2 score better. Variant 1 and 2 have a very similar result, only variant 2 is more easy to understand, but there is also less information to understand. Variant 1 gives more information on the data and can therefore be interesting for the viewers who want more detail. So variant 1 will be shown when a cyclist is selected, variant 2 will be used for all the other cyclists that are not selected.

Function 3: displaying the camera locations and camera identifications

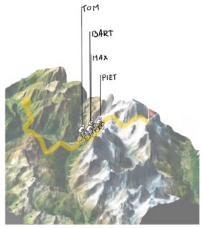
The variants of function 3 are focussed on displaying the camera locations on the 3D map. The indication at the screen of which camera is selected and thus of which camera the footage is shown, will be presented in a similar way, but then next to the screen. All the variants will appear larger on the map than they really are, so they are better visible, the same counts for the bikes that show the location of the cyclists. Variant 1 uses 3D models that are similar to the real cameras. Variant 2 and 3 use a cube for a traditional camera and a sphere for a 360 camera. The difference between variant 2 and 3 is in the identifications of the cameras. Variant 1 and 2 use only numbers, this is simple but the number could become high when there are many cameras. Variant 3 has a letter as index that indicates what type of camera it is (motor, bike, drone or stationary). The viewer has to learn what these indexes mean, but because they are quite simple and intuitive it is expected that the information value is higher that the effort it takes to learn. Based on this, variant 3 is chosen to implement in the concept.

Conclusions

- The names of the cyclists will be shown next to the map
- The names are presented in the order of the ranking of the race
- The speed is shown next to the name by a number
- The speed of the selected cyclist will be presented in a speed-time graph
- The camera locations will be depicted using cubes and spheres and the identification is shown on the 3D shape
- The cameras (and bikes) are shown larger than how they in reality are

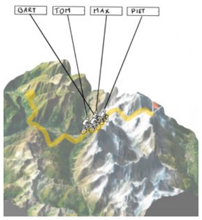
Function 1: display the name

variant 1/ function 1



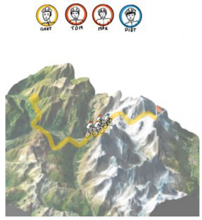
	--	-	+	++
3a intuitive mapping			■	■
3b legibility		■		
3c quickly findable	■	■		
3d easy to understand			■	

variant 2/ function 1



	--	-	+	++
req. 3a			■	■
req. 3b			■	
req. 3c		■		
req. 3d			■	

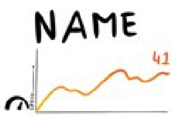
variant 3/ function 1



	--	-	+	++
req. 3a			■	
req. 3b			■	■
req. 3c			■	
req. 3d			■	■

Function 2: display the name and speed

variant 1/ function 2

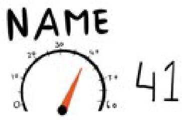


	--	-	+	++
3a intuitive mapping			■	
3b legibility			■	■
3c quickly findable		■		
3d easy to understand			■	

variant 2/ function 2

	--	-	+	++
req. 3a			■	
req. 3b			■	■
req. 3c		■		
req. 3d			■	■

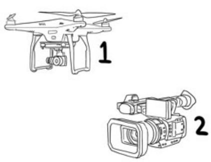
variant 3/ function 2



	--	-	+	++
req. 3a		■		
req. 3b			■	
req. 3c			■	
req. 3d			■	

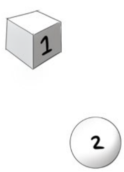
Function 3: display camera locations

variant 1/ function 3



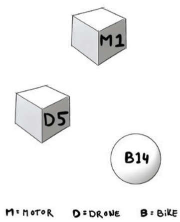
	--	-	+	++
3a intuitive mapping			■	■
3b legibility	■	■		
3c quickly findable		■		
3d easy to understand			■	■

variant 2/ function 3



	--	-	+	++
req. 3a			■	■
req. 3b			■	■
req. 3c			■	
req. 3d			■	■

variant 3/ function 3



	--	-	+	++
req. 3a			■	■
req. 3b			■	■
req. 3c			■	
req. 3d			■	■

Figure 4.3: sketches of the different ideas for function 1, 2 and 3, and their selection

4.2.2 Design of the 3D map

The detailing of the map addresses two points, namely the representational fidelity of the map and the orientation of the map. In section 2.4.5.1 it was mentioned that the decision on which degree of fidelity to use depends on the vision and goal of the project. Figure 4.4 shows examples of maps with different levels of fidelity. The goal of the map is that it has to inform the viewers about the shape of the terrain, that it offers a base on which other information can be presented and it should fit the style of a 'Tour de France' experience. In current 'Tour de France' visuals the imagery has a very high fidelity and the information are simple graphics. The two most right examples would fit best to the style of a 'Tour de France' experience. The informative function of the map however requests it to be easy to read and it should not include many distracting elements. Also a high fidelity map could be unpleasant for people with fear of heights, since the viewer is floating high above the 3D map Therefore a 3D map with a mid to high fidelity will be used, similar to the fourth example in figure 4.4, including a simplified 3D model, with simplified textures and a minimal selection of map-elements like trees or buildings.

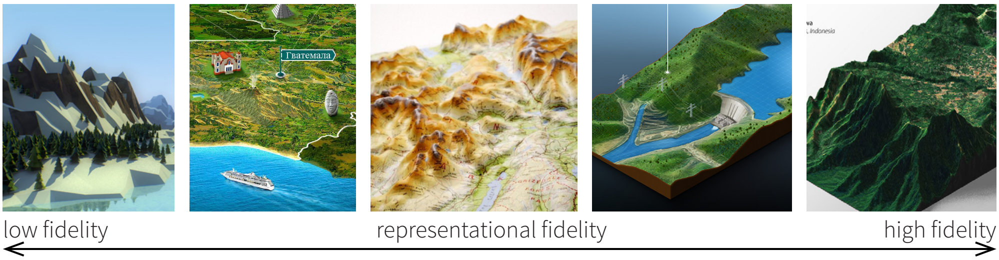


Figure 4.4: examples of maps with different levels of representational fidelity. Image sources: (Sharp, 2018), (Zagranica.by, 2010), (Map Logic, n.d.), (Tzscheppan, 2017), and (The-Orange-Box.com, 2018).

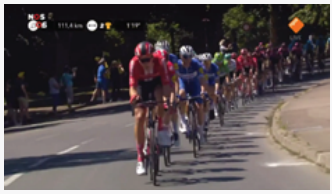
For the orientation of the 3D map it is important that it is easy to read and that the information is clearly visible. To find the most challenging moments for presenting the positions of the cyclists and cameras on the map, different moments of a cycling race broadcast are analysed. Figure 4.5 shows different situations from a television broadcast, which can be categorised using the following three parameters:

1) Type of view: front/ side/ back/ top/ 360
2) Visibility: all riders clearly visible/ riders are overlapping/ riders are very small
3) Amount of riders: one/ a few/ many/ none

The most challenging moments for displaying information are when there are many cyclists on the screen that are overlapping, or cyclists that are very small (far away). These situations shown in the images are likely appear on the 3D map as well. The visualisation method should work best in most of these situations.
The cyclists are most likely to overlap when they are shown from the front- or back view. A solution for the 3D map is to have it always oriented with the road perpendicular towards the user. The system knows what section of the road is shown on the screen (how will be explained in section 4.3.2.1), and uses that section of the road to rotate the map.
When there are many cyclists on the map section, like on image 3, 7 and 8 in figure 4.5, it is almost impossible to present the data of all cyclists, or the information would be too much to digest by the viewer. Therefore a smart way of mapping, or a way of data selection is needed. System will select the highest ranked or most promising cyclists of the race when there are more than 10 cyclists shown, and shows only the information about them.

1: back-view

2: a few riders from the back (overlapping)



3: front-view (many, not all completely visible)

4: top-view (tiny riders)

5: side-view

6: no riders in the video (fans in this case)

7: cyclists in a hairpin curve

8: screen filled with cyclists (many, overlapping)

Figure 4.5: examples of different situations in the video of the broadcast

The cyclists will be small when the 3D map is in overview mode (even with an adjusted scale), but the focus mode can be used to zoom in on the map. If the viewer wants to see or follow one specific cyclist, it is possible to use the search bar to find the cyclist and select it.

Conclusions

- The map will rotate to orientate the road perpendicular to the user.
- When there are more than 10 cyclists shown, the system selects the three most promising cyclists of the race and shows only the information about them.
- The 3D map will have a mid to high representational fidelity

4.2.3 Concept combination with interactions

The two previous sections described the visualisation of the information and the design of the map. This section will present these elements combined and the interaction with the elements. Beside the information and the map there are a few more elements (three buttons under the screen and the selected camera indication at the right side under the screen) in the virtual environment (VE) to support the interactions with them. First the complete VE is presented and then a few specific interactions are described.

Figure 4.6 shows the VE of the concept in three visualisations of different states. The top part (visualisation 1) includes an image of the headset at the location where the virtual camera in the VE would be. This is left out of the other visualisations but would be present at the same location. The bottom part of figure 4.6 shows two states where the map is in the focus zoom-level. It can also be seen that the map is rotated in a way that the road is perpendicular to the viewer.

The first visualisation in figure 4.6 shows the map in the overview zoom-level and the screen that corresponds to the selected camera, which is a motor camera at the front of the race. This is the setup in which every race will start. On the map the locations of the cameras and cyclists depicted. The cyclists are depicted using 'rolling' disks, because a realistic bike would be too small to recognize. When multiple cyclists of the same team are cycling closely together, they are represented with one disk. The colours of the disks indicate to which team the cyclists belong.

Under the screen there are three buttons: a 'search' button, an 'information' button and a 'select zoom area' button. In the first visualisation the 'select zoom area' button is selected, indicated by the yellow outline. When selecting the 'select zoom area' button is selected using the laser-pointer and pressing the track-pad (most right button of the three buttons under the screen), a transparent orange cube appears at the end of the laser-pointer when it touches the map. This cube can be used to select the area for the focus zoom-level. When the cube is at the location where the user wants to focus on, the touch-pad can be pressed to set the selection area. When the laser-pointer in the orange cube hits a cyclist

Figure 4.6: concept presentation

or camera (on the map of at the side of the screen), the cube will follow the object. When the laser-pointer does not hit a camera or cyclist during the selection, the selected area will not move but stay at the selected location.
Visualisation 2 and 3 show the map in 'focus' zoom-level. The user can exit the 'select zoom area state by pulling the trigger or selecting the 'select zoom area' button again. When the user is in the focus zoom level, the 'select zoom area' button changes into the 'return to overview map' button.
At the right side of the screen information about the cyclists is presented, which includes their name, speed and a picture. When the map is in overview zoom-level, information about the three cyclist on top of the ranking are shown. If the map is in focus zoom-level, and when 5 or less cyclists are on the map, the information about all cyclists is shown. If the map is in focus zoom-level, and when 5 or more cyclists are on the map, the information about only the three most promising cyclists of the cyclists that are shown on the map are shown. The names are always presented on the order of the ranking of the race.
The second visualisation in figure 4.6 shows the interaction of selecting a camera and the third visualisation shows the result where the selected camera, which is the drone camera, is shown on the screen. The third visualisation shows the selection of a cyclist. When a cyclist is selected, more information of that cyclist is shown in the information at the right of the screen, and both the cyclist on the map and the picture at the information at the right of the screen are highlighted. Also when a name at the right side of the map is selected, the cyclist on the map will be highlighted. When pressing the 'information' button under the screen while a cyclist is selected, a panel at the left side of the screen appears with more information about that cyclist and his performance in the race are shown.

An overview of the buttons in the VE is shown in figure 4.7. Additional interactions that are not described above are shortly mentioned here:

- Selecting the 'information' button: the viewer can use this button when wanting to know more about (a specific element of) the race. For example, when a cyclist is selected the information panel at the left of the screen can show more information about him. Another example is that when around the moment that the viewer pressed the button the cyclists used a specific technique or cycling tactic, an explanation of this can be

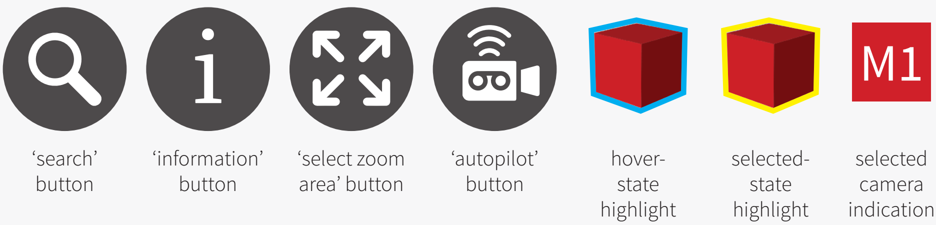


Figure 4.7: overview of the buttons and selection indicators in the VE

shown on the information panel. So the content of the information panel is selected by the system based on what the viewer requested, based on recent event that happened during the race, or based on a prediction of what the viewer would like to know. For the latter, user feedback like ‘like’, ‘save’ or ‘don’t show again’ are used. The viewer can also to back and forth to the previous or next shown information elements.

- Selecting the ‘search’ button: the user can use this button to find a specific element in the race, like a cyclist, camera, point on the route, etc. When the element that the viewer was searching for appears, there are three options: select, focus the zoom-area, and show more information.
- ‘auto pilot’: this function can be used when the viewer wants to sit back and relax while watching the race. When the ‘auto pilot’ is selected, the system selects cameras that in a way that they exactly follow the cameras of the regular broadcast and the map will stay in the overview zoom-level.

4.3 Implementation of the concept

The implementation of the concept is described using three topics, namely i) functional implementation, ii) technical implementation, and iii) feasibility. The latter addresses the technological feasibility, economic feasibility, and the desirability for the stakeholders.

4.3.1 Functional requirements

The elements that are needed to fulfil the functions of the concept are shown in the system architecture diagram (see figure 4.8). The direct connections are indicated using continuous arrows. Implicit connections are indicated using dashed arrows. Implicit connections are for example the data that it collected by the transmitters attached to the bikes and is saved in a database, but to get there it travels via the data truck before it is saved in the database.

The data that is collected at the race about the cyclists and the cameras is send to data trucks and via those stored in cloud databases. The location data is used to update the locations of the cyclists and cameras at real time in the VE. At the home of the user is a PC with a VR system connected and the 'TdF' application installed. The application is launched via the 'steamVR' platform, which regulates the connection and communication with the VR system. This platform regulates that the virtual camera moves similar to the VR HMD in reality. This counts for the controllers as well, of which also the input and interaction is registered and communicated with the application. The user is wearing the VR headset and the usage (interactions) is stored, via the application, on a database that is located in the computer.

The concept includes functions that are designed to help the viewers in their learning, and to make the use of the product more comfortable or easy. It is known that people learn better when they are exposed to information repetitively over a longer period of time. That is for example why people can easily remember commercials without putting effort in the learning. The CPS principles are used to create a system that helps the user in the learning by selecting information in a personalised way.

The sense-reason-learn-adapt cycles are used to select the content of what and how it is shown to the viewer. By sensing what the viewer views, likes and dislikes, the system can reason about what type of information the user is interested. Based on this the system can adapt what information is shown to the viewer. By collecting feedback on the adaptions the system can learn about the user's informational needs and adapt the information according to that better. This works similar to the methods that are used in for example 'Spotify' or 'Pinterest' where content is shown based on what the user likes and views.

The system also keeps track of which information elements the user has seen and how often. These information elements are for example background information about cyclists or teams, or explanations about cycling tactics and strategies. Based on this, the system can select what information to show about a specific topic. This works similar to how language learning apps, like 'Memrise' knows how well the user knows a word, the worse the user knows a word the more often that word is asked. The difference is that in language learning applications the words

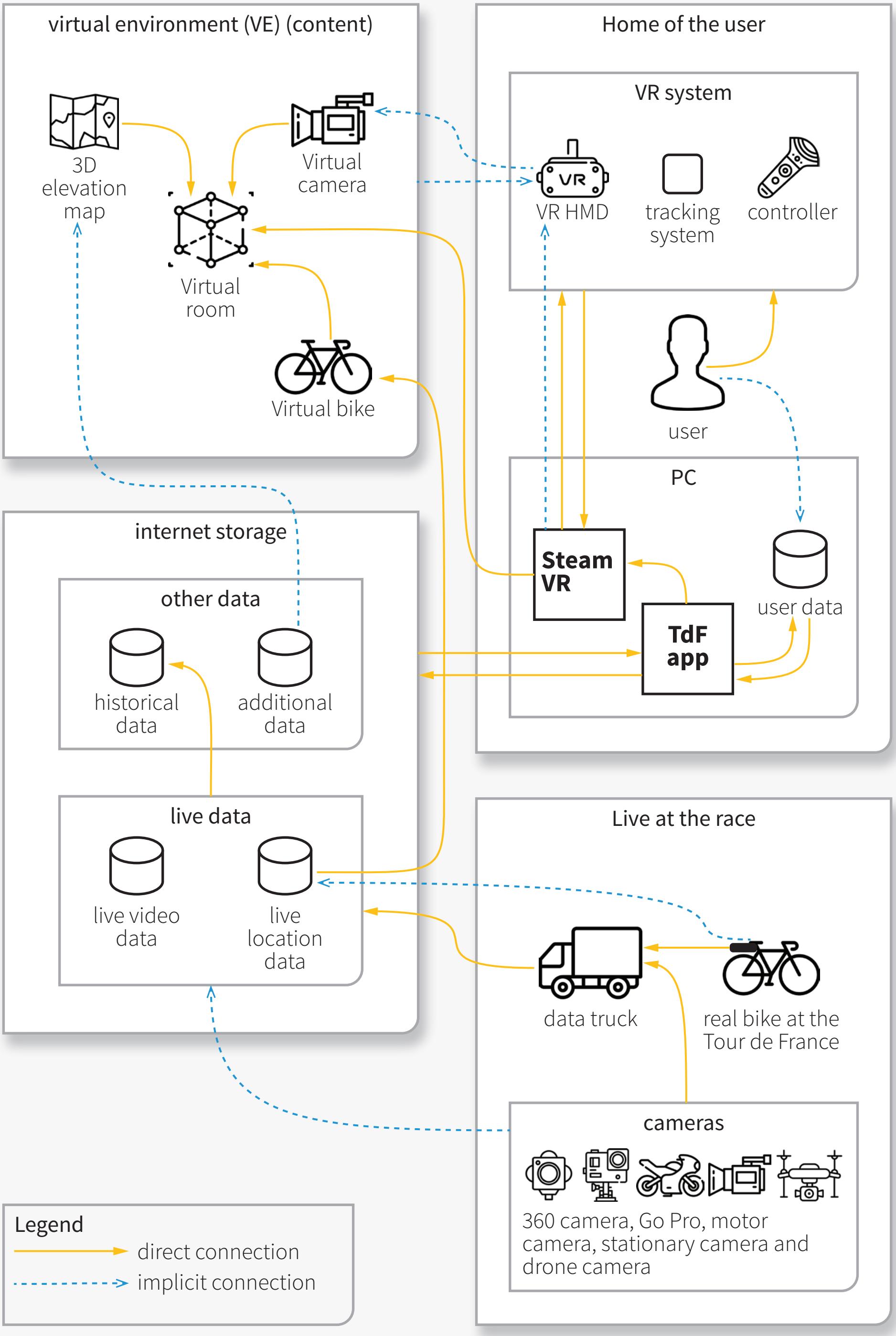


Figure 4.8: system architecture diagram

are asked, so the system knows very well what the user knows. This concept does not include a quiz function, so the system only knows how well a user knows about something by tracking how long a viewer looks at a information element (assuming that when the information is not known, the viewer spends more time reading or looking at it. For this eye-tracking is needed to know what the user looks at. This function is currently implemented in the 'HTC Vive PRO eye' headset which is currently targeted for businesses and not for consumer usage (HTC corporation, 2019).
The predictions that are currently made about the race outcomes are used for selecting from which cyclist the information is shown on the right panel (names and speed information) when there are many cyclists on the screen and map.
Lastly reasoning about the amount of changes in the order of the rankings is used to adjust the interval in which the order of the displayed information is being changed. This is needed because when the order changes often the information will not be readable and informative anymore. So when the order changes often, like how it mostly happens mainly at the beginning and end of the race, the system will use a longer time to wait before refreshing with new data.

4.3.2 Technical implementation

The two topics addressed for the technical implementation are the processing of the computer and the databases. In the detailed concept descriptions (section 4.2.3) several functions were described where the system has to make selections or decisions. How this works is firstly described, and then the databases and interactions with them are described.

4.3.2.1 Processing of the computer

The functions described in 4.3.3 need computing to execute them. This section explains the basic principles of how this can be done. Figure 4.9 shows the use case diagram of the service. Each oval represents a use case, which is a specific function of the product. The use case 'view the presented information' has three child use cases that each include the most important computing tasks where the system has to make a selection or decision. These are summarised in table 4.1.

Table 4.1: overview of the most important computing tasks

Use case	Most important computing task
Information on left panel (information screen)	Predicting users informational needs (and keep track of learnings)
Information on left panel (information screen)	Select information to show
Information on right panel (names and speed)	Selection of cyclists about who information is shown at the right panel
Information on the 3D map	'autopilot' function (the system highlights the cameras on the map based on the broadcast)

The use case diagram in figure 4.9 shows two actors: the user and the database. Inside the rectangle that represents the TdF VR application, the use cases are shown. The use cases that have a blue outline are the ones that are described in more detail using activity diagrams after this description of the use case diagram.

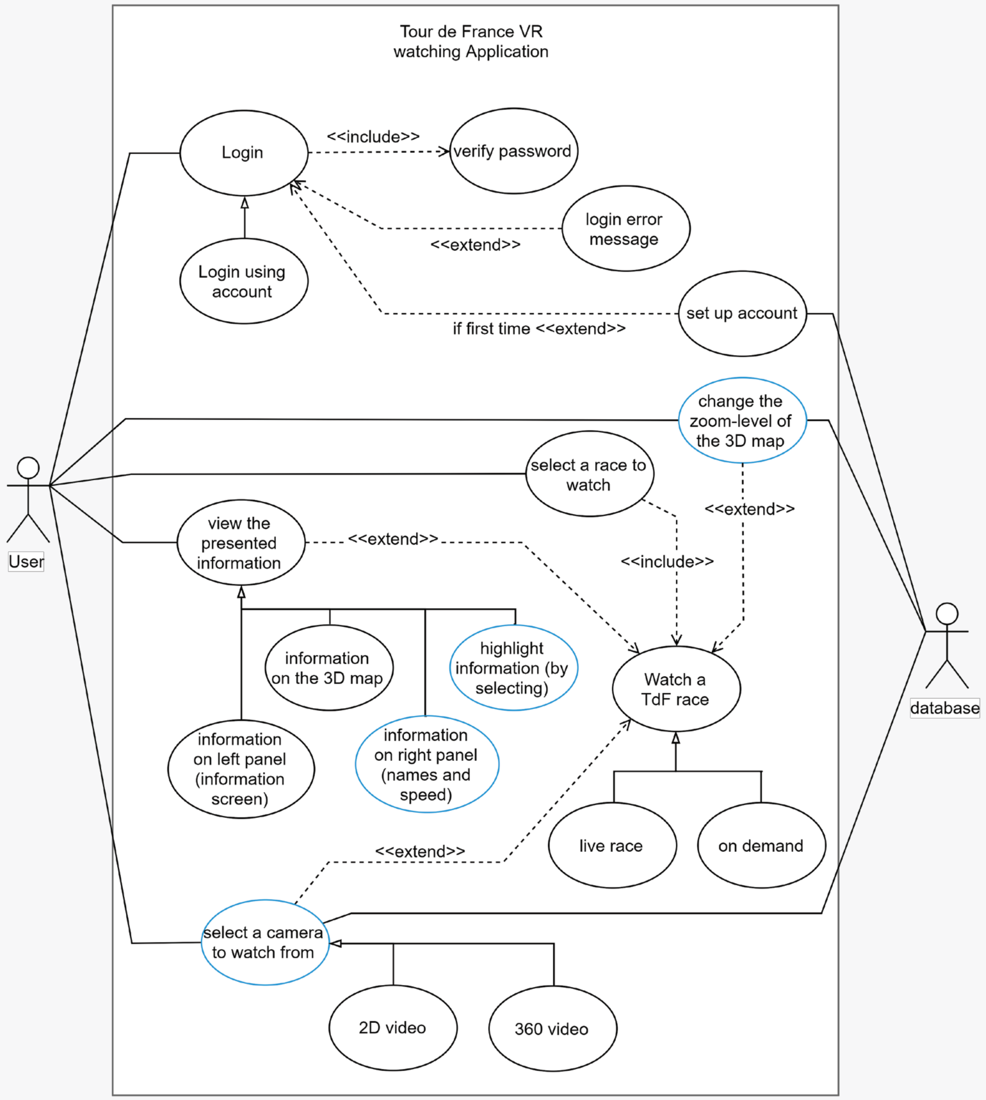


Figure 4.9: use case diagram

The following preconditions have to be met before using the service:

- The user should use a VR HMD in combination with a computer on which a VR launcher is installed and the application is downloaded.
- The user needs an account for the TdF VR application.
- User must agree to data usage consent.

The VE of the concept consists of the following main elements:

- 3D map of the race's route
- 3D models of bikes that move on this map according to the race data (location and speed)
- Locations for all camera's marked in the 3D space (also moving according to the race data)
- A screen to show the video footage of the selected camera
- A panel at the right side of the screen showing names (in order of the ranking) and speed of the cyclists
- A panel at the left side of the screen where extra information can be shown.

The interactions possible are:

- Selecting from which camera to watch the race.
- Selecting a cyclist to highlight the related information (name and speed)
- Changing the zoom-level of the 3D map and selecting the zoom area
- Requesting extra information or explanation using the 'information' button
- Searching for an element (to highlight, follow or find information about) using the 'search' button

The basic order of steps is:

1. Login
2. On-boarding
3. The App opens on the home page
4. The user selects a race to watch
5. Different interactions possible while watching the race

Postconditions:

- The user should have learned about the story of the race.
- The user has enjoyed watching the race.

Alternative flows and exceptions:

- At step 1 the user could use wrong credentials, an error message will be displayed.
- When the user is not connected to the internet, an error message will be displayed.

Additional comments:

- The default camera when starting to watch a race is the camera in front of the riders attached to the back of a motorbike.
- The default state of the map is the overview zoom-level.

The following pages show the activity diagrams for the following use cases: change the zoom-level of the 3D map, highlight information (by selecting), view information on the right panel (names and speed), and select a camera to view from.

Change the zoom-level of the 3D map

Description:
- there are two zoom-levels for the map: verview (zoomed out) and focus (zoomed in)
- when the map is in the overview state the 'select zoom area' button is shown.
- when the map is in the focus state the 'go back to overview' button is shown.

Preconditions:
1. The user is logged in and started watching a race

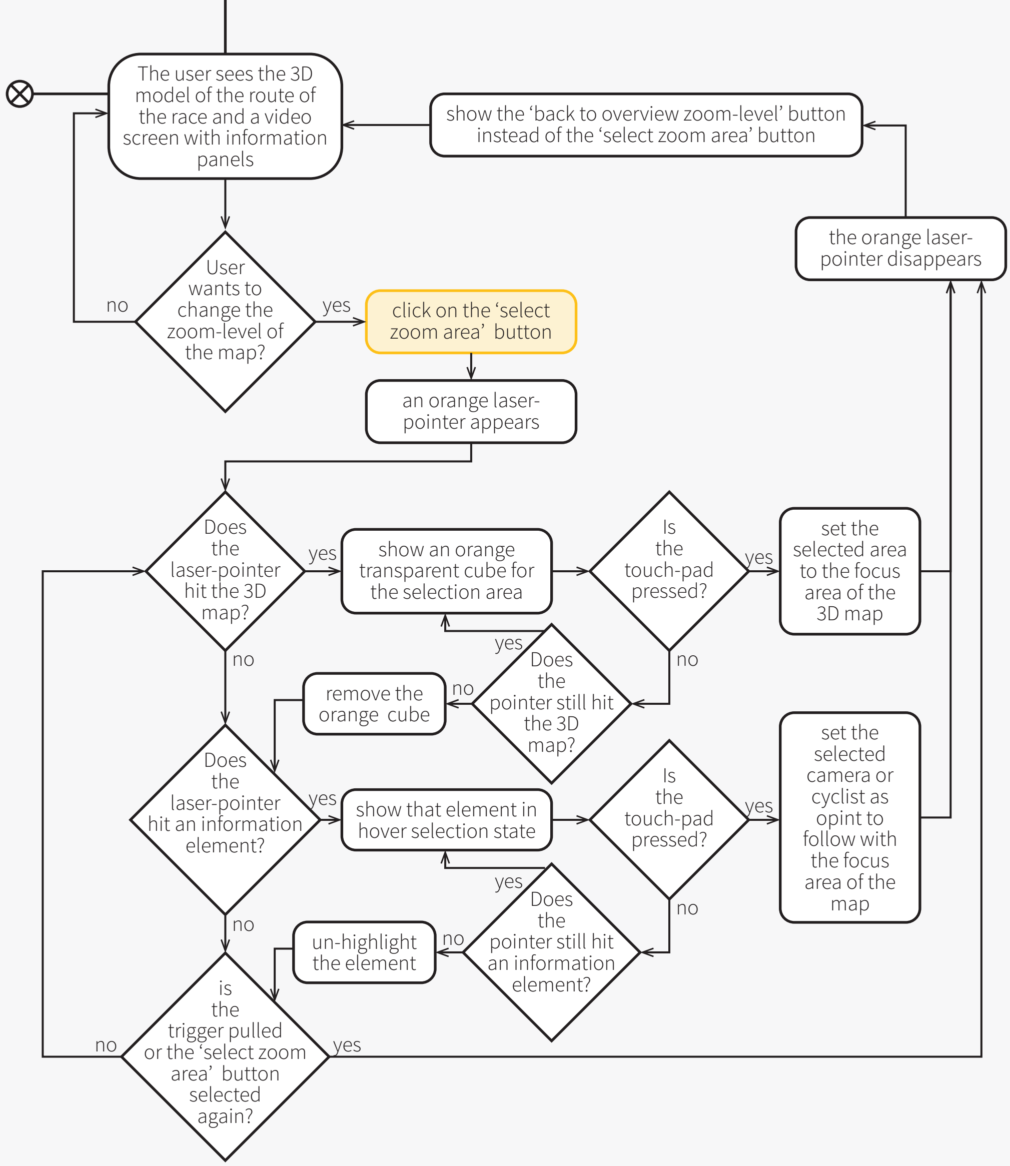


Figure 4.10: activity dragram for the use case 'change zoom level of the 3D map'

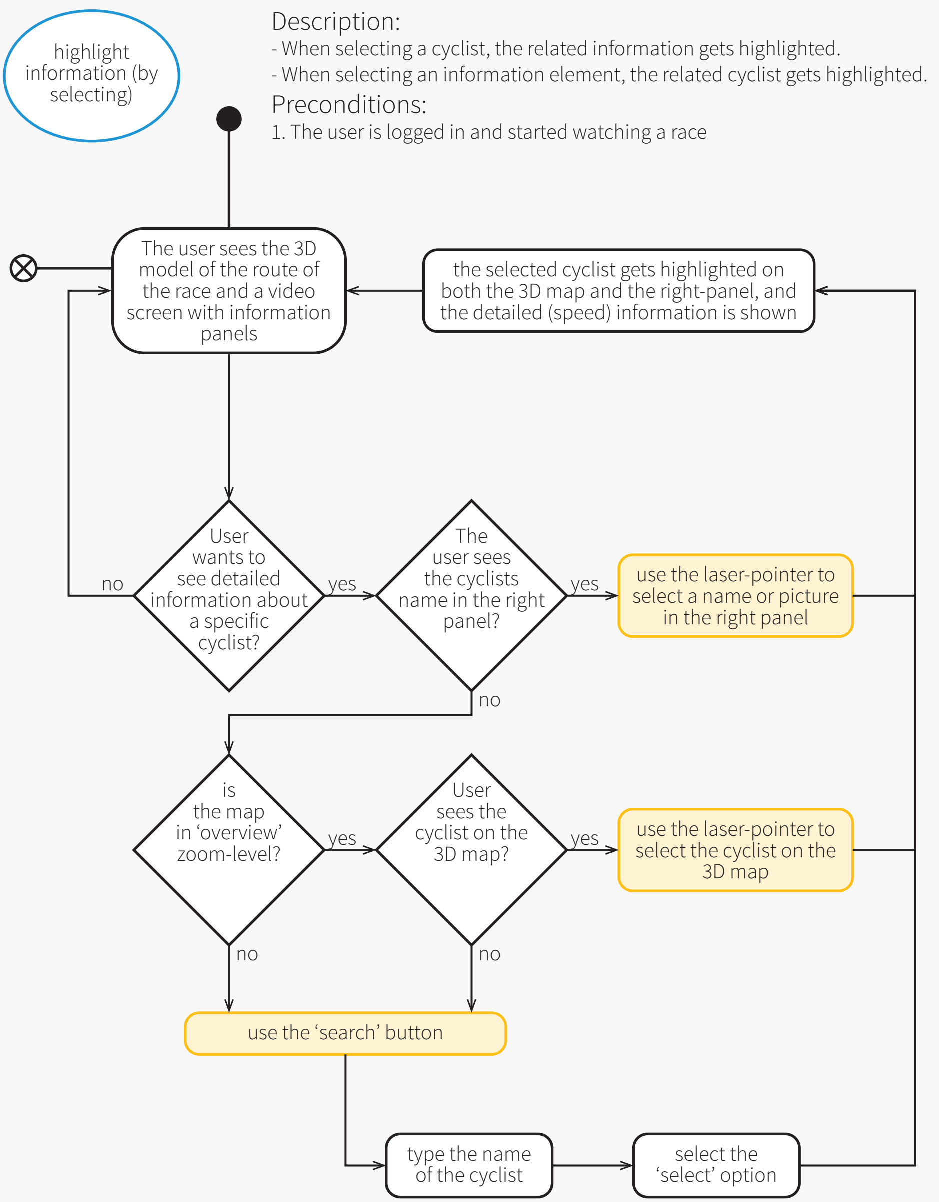


Figure 4.11: activity dragram for the use case 'highlight information (by selecting)'

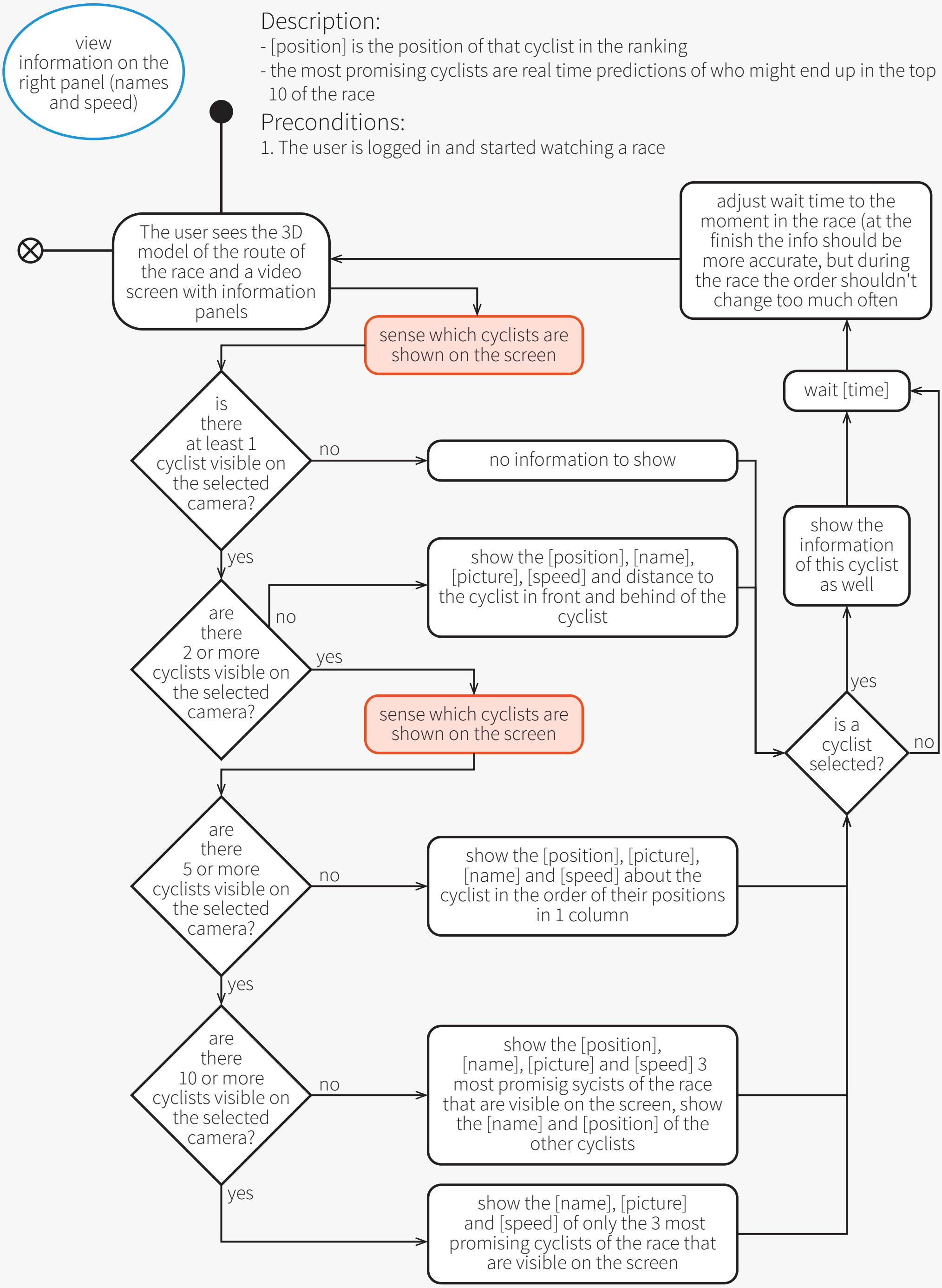


Figure 4.12: activity dragram for the use case 'view information on the right panel'

select a camera to watch from

Description:

-When selecting a 360 camera to view from a preview of that camera will be shown on the 2D screen. A button to change to 360 viewmode wil appear.
- The '360 viewmode' button is only shown when watching a video that is available in 360 viewmode.
- When watching in the 360 viewmode the 3D model is not visible anymore.
- When watching in the 360 viewmode a 'return to 2D viewmode' button is shown.

Preconditions:

1. The user is logged in and started watching a race

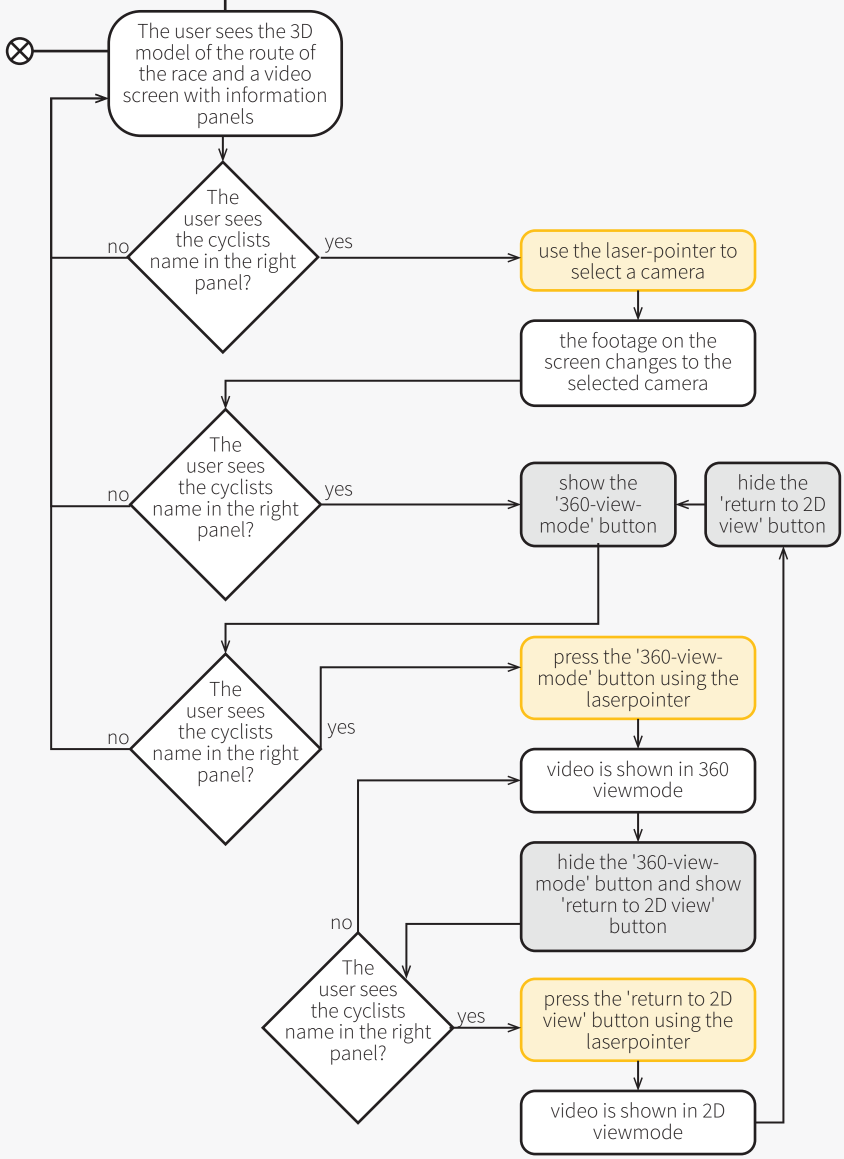


Figure 4.13: activity dragram for the use case 'select a camera to watch from'

4.3.2.2 Databases: acquisition, storage, processing and retrieval

The system architecture diagram (Figure 4.8) previously showed an overview of the elements of the system, including the databases and where the data comes from and where it is used. In this section the databases are elaborated on the four aspects (data storage, data acquisition, data communication & data processing). These four aspects are shown in figure 4.14, which is a section of figure 2.9.

Data acquisition

The currently used tracking devices of the cyclists are still used, but for the additional needed data new tracking devices or systems are needed. These new data are the camera location, direction and view angle, a 3D elevation map of the route, 180/ 360 video recordings, and route markers for challenges that are shown on the 3D map. Table 4.2 shows how the new data for the mentioned data variables is collected.

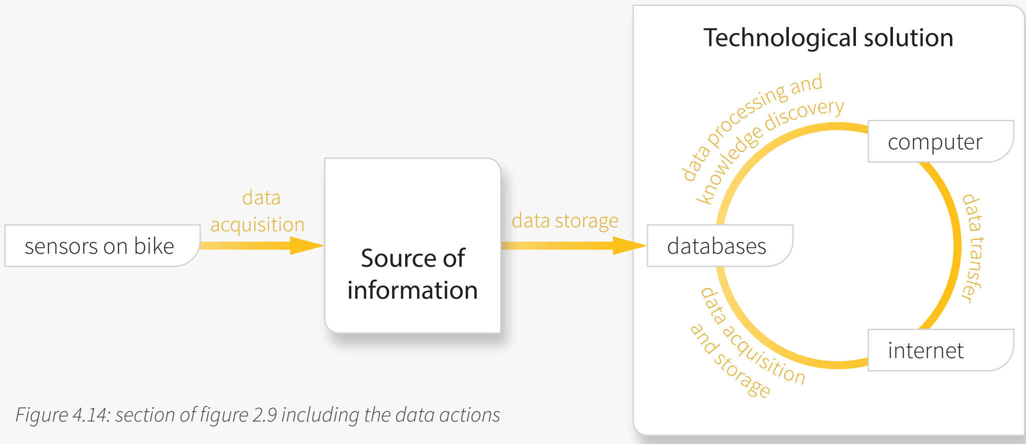


Figure 4.14: section of figure 2.9 including the data actions

Table 4.2: data sources for the newly needed data

Data	Sensor/ data source/ data generation
Camera location	Same tracking devices as the cyclists currently have attached to their bikes. JSON file including time-stamp, latitude, longitude, and speed.
Camera direction	Motion sensor: gyroscope of the camera. I assume that this is already included in the meta data of the camera.
Camera viewing angle	Metadata of the camera, this includes information about the lens type and zoom settings. Using this information the viewing angle can be calculated (see figure 4.15). Metadata of broadcasting cameras is often communicated using MXF files, so I assume that this will be the case here as well. A MXF fil is a video file format that supports full timecode and metadata which allows professional use of the video contents, especially in TV broadcasting. (Corel Corporation, 2019)
Camera recording area in coordinates	Reasoning: By projecting the camera location, direction and viewing angle onto the 3D map, the area that is visible on that camera can be found. (see figur 4.15)
3D elevation map of the route	On the website https://maps3d.io/ a 3D map of an area selected on google maps, or defined using a GPS track can be generated. This application uses elevation data from Amazon's 'Terrain Tiles', which is open source data so can be used for this concept to create 3 dimensional maps of the stages of the Tour the France.
180/ 360 video recordings	180/ 360 cameras can be placed at the side-line or on (motor)bikes. There are cameras developed for sporting events like the 'PanaCast Live', which is described as "the first fully integrated, portable, professional video broadcasting system, delivering uncompressed 180 degree 4K 3D video at 60 frames per second" (Altia Systems, 2018). Intel Sports is currently using this camera for broadcasting sporting events. To decide which cameras are exactly needed, and how they are integrated in the race, more research on this specific topic has to be done.

Table 4.2: data sources for the newly needed data (continued)

Data	Sensor/ data source/ data generation
Route markers for challenges	Reasoning: The route can be analysed on challenges in several ways: o Image analysis: satellite views can be used to detect changes in the conditions of the road e.g. narrower, cobblestone, etc. o Coordinates (GPS) and elevation analysis: sharp corners or steep inclinations o Weather predictions: wind in combination with the shape of the route o Manually added information o This information will be connected to the locations.

Data storage

The collected data will be stored in online databases. This is also how 'Dimension Data' currently saves the data for the 'Tour de France'. The figure below shows which data is stored in the different databases, every column shows the data that is dependent on a specific variable. The live recorded data will directly be saved into a history database.

Data processing and retrieval

The databases shown in the table 4.3 are sorted per variable that can be used to locate and retrieve the data from it. Data variables from different columns can be matched when there is a common variable in the dataset. For example when the user wants to know if the cyclists on the currently shown video will face a challenging part of the race soon the location and direction of the camera is used to see which cyclists are shown on the video, and then their location can be compared to the locations of the challenging moments.

Table 4.3: elaboration of the internet-storage part of the 'system architecture diagram' (figure 4.8)

timed data	location based data	race data	analysis data
live video (time)	route shape (coordinates)	rankings	race outcome predictions
cyclist location and speed (time and coordinates)	challenging points (coordinates)	route markings	connections to external data sources (like 'Twitter' or other databases
camera location and direction (time and coordinates)	local weather data (coordinates and time)	used tactics that are matched to the race	

In section 2.4.1.2 it was mentioned that the retrieval of video data can be difficult. Additional data in this concept helps to make it possible to retrieve video data that shows a specific area or cyclists. For this the location of the cameras, in relation to the cyclists (similar to how the cyclists locations are tracked currently, but camera locations also include the altitude and direction), is used. Figure 4.15 shows how the camera information is used to find out what or who is showed on the footage. The area that is visible per camera (explained in table 4.3) can be used to find the video that matches a specific moment of the race at a specific location. When using the locations of the cyclists and the area that is covered by a camera, videos that show specific cyclists can be found. This can also be used to know which cyclists are currently shown on the video, so the shown information can be adjusted to match these cyclists.

4.3.3 Feasibility

This section will describe the feasibility of the concept on technical and economical level and the desirability for the stakeholders.

4.3.3.1 Technology: when can it be ready?

As described in the functional and technical requirements, a few changes during the 'Tour de France' races are needed to make this concept work. The biggest changes are the location and orientation information of the cameras, and the usage of additional cameras. All the other changes are on the software and cyber-ware domains. Besides the changes at the race, improvements in VR headsets will

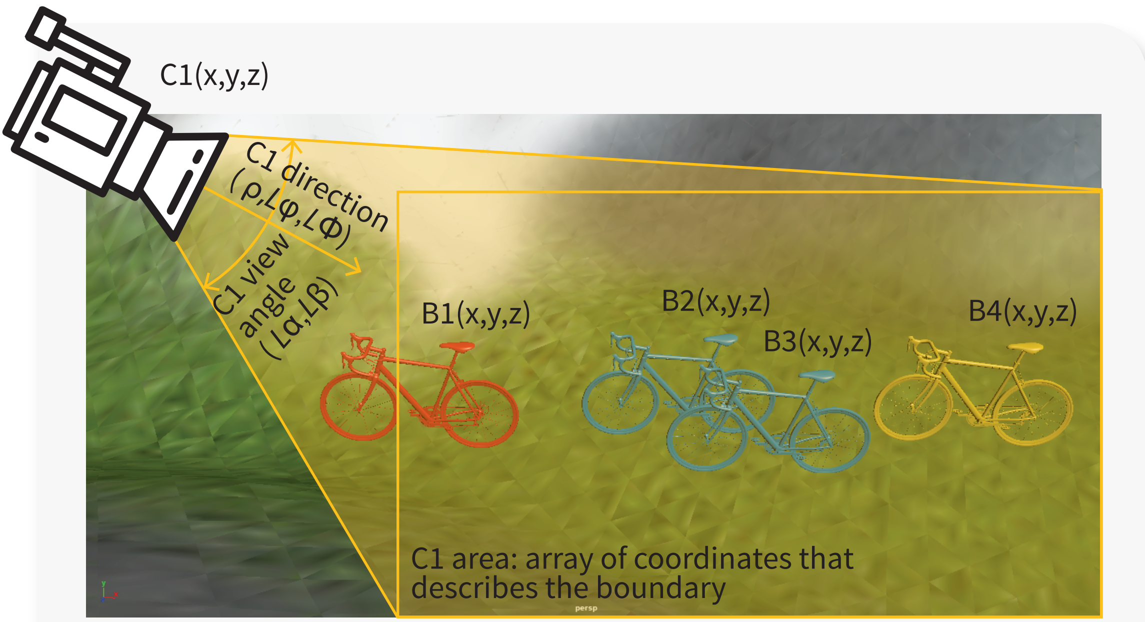


Figure 4.15: the area that a camera covers (yellow area) and the locations of the cyclists and camera on the route

help to create a better experience.
The timeline in figure 4.16 shows an estimation of the development of these technologies over time. At the left side it shows a selection of important technological developments for this concept and a prediction of future developments. These predictions are based on the detailed technology roadmap that can be found in appendix H. The right side of the figure shows the technological developments of the last five years, and the future steps that are needed for the implementation of the 'TdF VR application'.

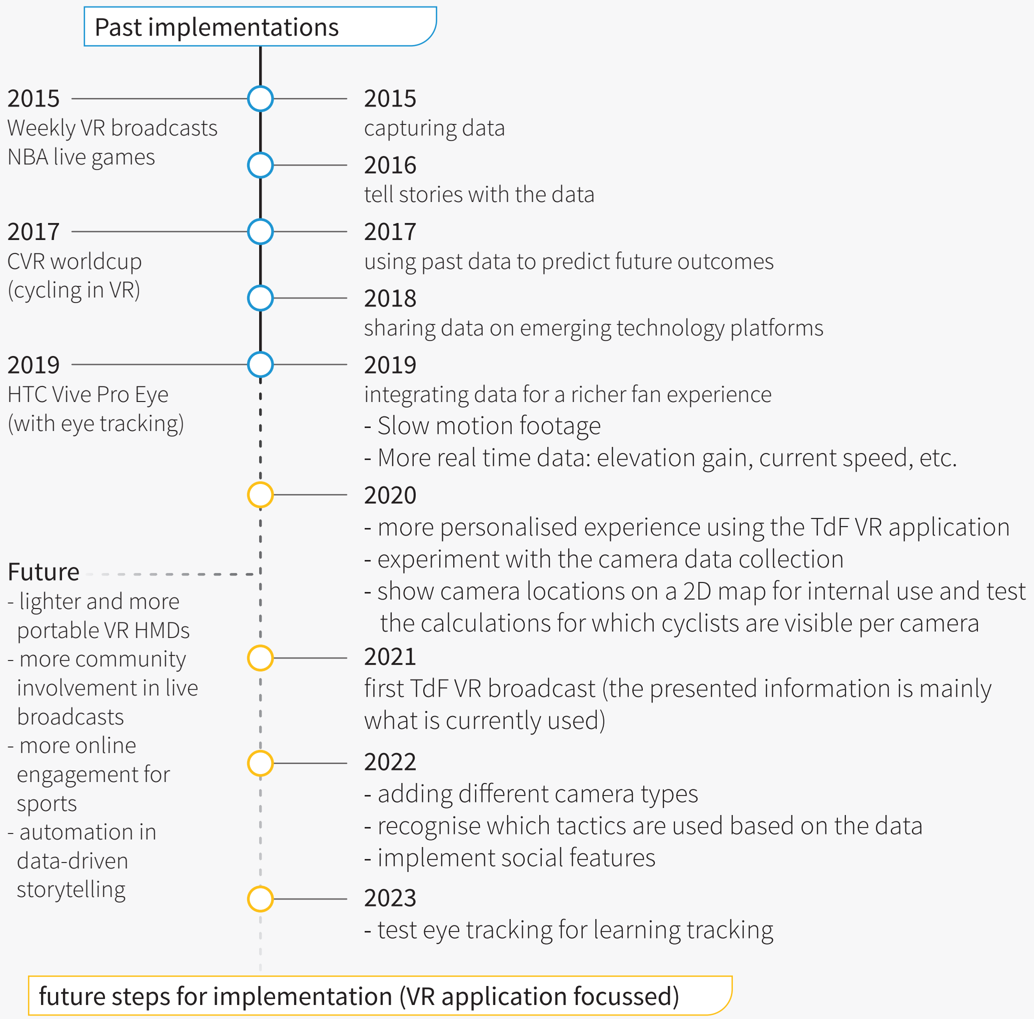


Figure 4.16: timeline for future development for the TdF VR application

4.3.3.2 Economy: is it financial feasible?

For the software developments it is not expected to bring high costs for the 'Tour de France'. 'Dimension Data' is currently working on many different ways to innovate with the data they collect at the 'Tour de France'. This concept uses elements that they already developed. For example the predictions that 'Dimension Data' already developed are dynamically be matched with the live rankings of the race to select the cyclists to present the information about. In case new tracking devices have to be developed for the camera location and direction data, there will be more costs. But since every bike currently has a tracking device attached, it is not expected that e few extra devices for the cameras will be a problem. Especially when the service helps the 'Tour de France' organisation to reach their ambitions.

For the viewers it is not expected that they will buy a VR set solely to use this experience. This means that the first users will be only early adopters who already own a VR HMD, friends of people who own a VR device, or people who visit events where the experience can be tried out. The VR market is currently growing, and it is expected that the size of the worldwide VR hardware market will grow almost double the market size by 2021 (Statista, 2019). When more people own a VR HMD, it provides the opportunity for interesting selling plans of this service, for example (this is not further detailed as it is not part of the scope of the project):

- Provide a freemium version that can be upgraded with extra features
- Get it as a gift when purchasing a more expensive television subscription
- Be able to pay for the footage and information you are interested in e.g. pay for extra video material of their favourite cyclist
- Tour de France promotion or remote experience events for fans or advertisement
- Users pay for downloading the application

4.3.3.3 Stakeholders

In the introduction of the project two stakeholders were defined, the Sports Engineering Institute and the users which are cycling fans. The focus of this thesis is to explore the opportunities of the third dimension in VR and the role that ICPS principles can play in a service for providing more information to cycle fans who want to learn more while watching the Tour the France. By providing information that is tailored to individual informational need, this service can help the users to learn more about the sport in an interactive and entertaining manner. The continuation of the developments of analytic and predictive algorithms will make it possible to provide the viewers with deeper insights about the sport. The usage of VR will help the users to get a better overview of the race and a better perception of depth about the routes. The immersion and personalised content can increase the quality of the relationship with the fans.

For the Sports Engineering Institute this service, but mainly the analysis of the possibilities, lays a foundation for the use of VR in cycling in a much broader range of applications. For example the use of VR by cycling team coaches or professional cycling athletes themselves for pre-race debriefing or post-race analysis. This concept can be analysed and used as an inspiration for these types of applications.

5 Prototyping

5.1 Introduction and process of the prototyping phase

The objective of the prototyping phase is to develop a demonstration of the concept, using the HTC Vive and 'Unity'. The prototype is a demonstrative prototype, which means that it is not a prototype of how the final service would look like, but it demonstrates a selection of features to show how the service would be like.

The goal is to use the prototype during user tests to get feedback on the concept, and to find points for improvement. It includes the three basic features that were describes in phase 3.

In this section the prototype implementation plan is explained and then the process of building the prototype is described. Figure 5.1 shows the process of this phase.

Process of the prototyping phase

Implementation plan for a testable prototype that uses one, or a combination of the enhanced concepts.

make a demonstrative prototype of the enhanced concept

feature 1 | feature 2 | feature 3

collect video footage of cyclists (drone, gopro, 360 and camera) and the following dta for one of the cyclists: GPS, heartrate, power)

Figure 5.1: process of the prototyping phase

5.2 Prototype implementation plan

The goal of the demonstrative prototype is to show that a service where VR is combined with CPS principles, has the capability to achieve the project's goal. It will be used to verify the concept with users during a user test in the evaluation phase. In this chapter the features and differences between the prototype and concept are explained. The chapter ends with a section about the data collection of the data to use in the prototype.

5.2.1 Implemented features in the prototype

Since it is not possible to make a prototype of the complete concept, the prototype is a simplification of the concept that can demonstrate the main features of the concept. The points where the prototype deviates from the concept are indicated in table 5.1. The first steps of using the service, being creating a user profile, logging in and selecting a race to watch are left out of the prototype. The prototype starts directly with the displaying of a cycling race. In the prototype a short cycling race that is acted out by 6 cyclists is recreated with recorded data using a bike with sensors attached and video-recordings of 5 different cameras (of which two were 360 cameras). This means that no live data is implemented but a race on-demand is mimicked. The only interaction that is possible in the prototype is the selection of the different cameras. For the 360 cameras, the 360 videos are only available as 2D previews, the user won't be able to go into the 360-viewmode in the prototype. Because the route of the recorded race is very short the zoom-levels of the map will not be able to provide the same experience as it would for a real race, so the zoom-levels of the map are left out of the prototype. Because the recording of the race does not include the real cyclists of the 'Tour de France', they cannot be recognised by the cycling fans by seeing the picture. So instead of pictures of the cyclists, the prototype shows the colour of the bike to the name of the cyclist, which is the same as the bike on the 3D map. The information that is shown on the screen is fixed per camera as following:

- Bike camera: speed of the cyclist that has the camera, position on- and shape of the route
- Finish camera: speed, name and ranking of cyclists
- Drone camera: no extra information, the footage itself already shows the shape of the route and positions of the cyclists
- Scooter camera: name of cyclists

Table 5.1: elaboration on the points where the prototype deviates from the concept

	Concept	Prototype
Broadcast type	Live & on-demand	On-demand
Real data	Yes, recorded at the 'Tour de France'	Self-recorded and fictional data
Data shown	Name & team of the cyclist, speed, ranking, the cyclist & camera locations, indications of the selected camera and/ or cyclist, challenging moments on the route, and additional information.	Name & speed of the cyclist, cyclist & camera locations, indication of the selected camera
Databases	Accessed via internet	Saved in the 'Unity' project
Experience	Full 'Tour de France' experience, including selection of cameras, selecting elements or information to highlight, personalised data selection, 'search' button, 'information' button, and 'autopilot' button.	Stripped down experience to test specific functionalities, the only interaction possible is the camera selection
Amount of cyclists	176	6
Information panels	Left: additional information	
Right: name and speed information	Left: name and speed information	
Zoom-levels of the map	Overview and focus	Because the recorded race is a short route, no zoom levels are implemented. The map was always shows in the focus level.
Rotation of the map	Perpendicular to the route	Because the route of the recorded race was mostly straight, no rotation was implemented. The map only moved slowly from right to left.

5.2.2 Collecting the data for the prototype

To be able to present the information of the functionalities in the prototype, data had to be recorded. This data includes the locations of cyclists, their speed, and several video recordings from different types of cameras that follow the race in a different manner. For the recording of the data, a group of six cyclists performed a fictional short race of three minutes in a flat meadow area in the Netherlands (on a street named 'Spookverlaat') (see appendix I1 for more details). This race is recorded with the five different cameras (of which two are 360-degree cameras) that are shown in figure 5.2. Due to limitations, the speed and location (and additional data like power, heart-rate, etc.) were only recorded of one of the cyclists using a bike with sensors attached.

5.3 Building the prototype

This section explains the building process of the digital prototype. First will be explained how the self-recorded data is prepared to use. Then the basic setup of the different elements in 'Unity' will be showed, followed by an explanation how the scene in 'Unity' is set up to use with data and the HTC Vive. It ends with an explanation of the code that defines the animations, data presentation and interactions in the prototype.

5.3.1 Preparing the data

The videos were all cut at the same length and matched in the timing before placing in 'Unity'. When there was no footage of a video the whole race, like for the finish camera, a black screen was shown for that time to make the video the

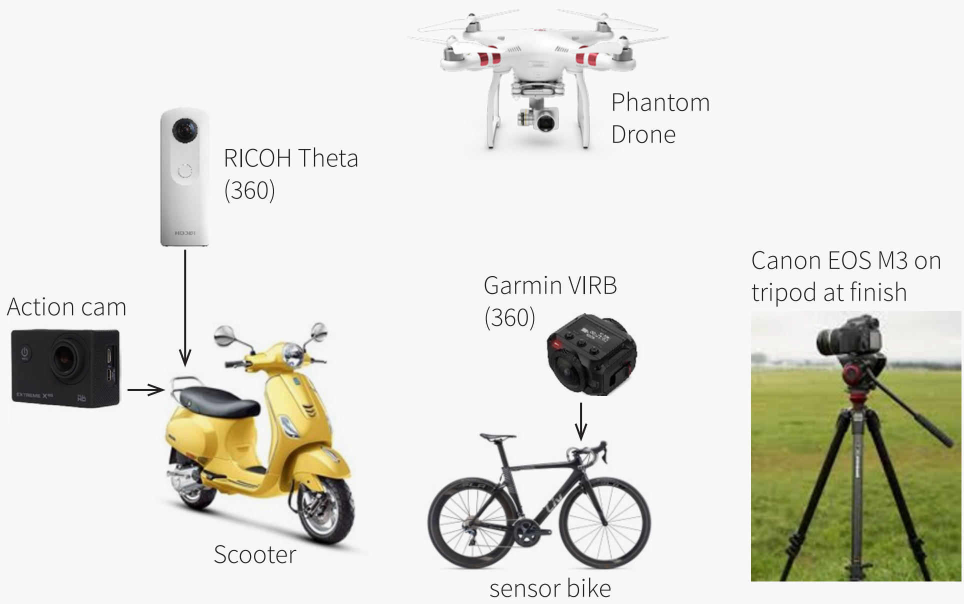


Figure 5.2: the five different cameras that are used to record

same length. Figure 5.3 shows the time-line for the five cameras, the grey bars represent a black screen that is shown when there is no video-footage available. This figure also shows yellow markers which indicate that a cyclist is at a specific point on the route, used to match the timing of the different videos.
I only managed to place the speed data in the video editing program that came with that camera, the raw file itself was not directly usable. Because of that the 'real' speed values were entered manually in a csv file format to use it for the data presentation in 'Unity'.
For the speed that the virtual bikes were moving at a file with 'artificial speed data was used to match the movements of 3D model to the videos. This was needed because the bikes were not on scale on the map to make them better visible. To show that there was a distance between the groups, the distance on the 3D map was made slightly larger to be better visible.

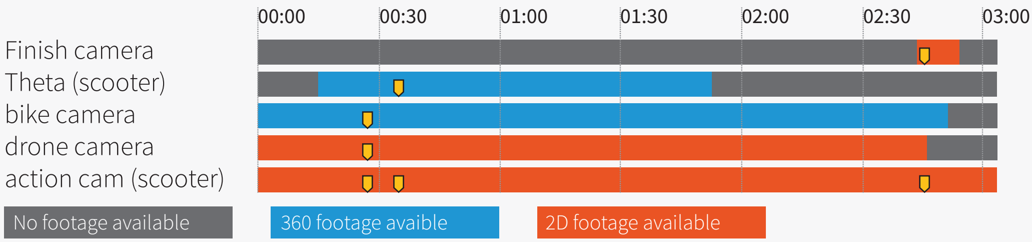
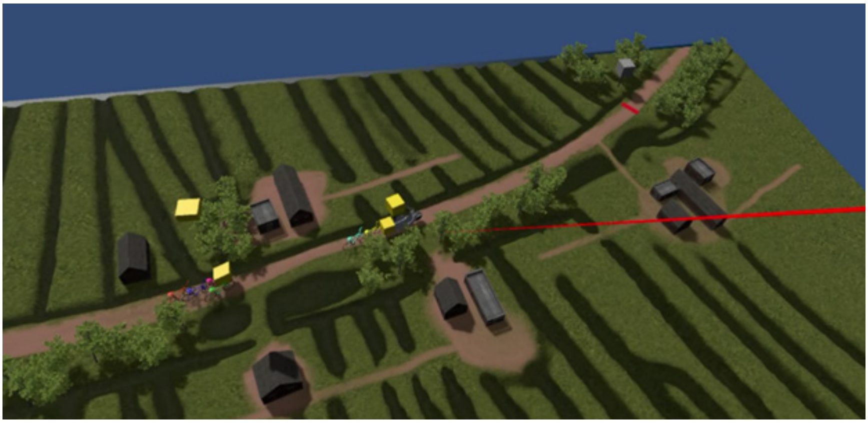


Figure 5.3: the video time-line that shows when there was footage available for each camera

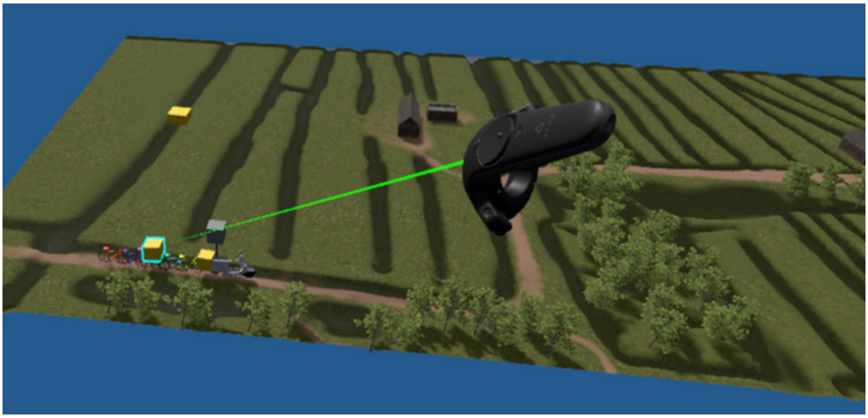
5.3.2 'Unity' basic scene setup

The elements that are needed are a 3D map, bikes, a scooter, cameras, a video screen and a canvas to draw the information on. The 3D models for the bike and scooter and the elements on the map (trees and sheds) were downloaded. The cameras and video screen are the standard cube of 'Unity'. The 3D map itself is made using reference images from google-earth (see appendix I1) and using 'Substance Painter' which is like a digital claying and 3D-painting program. The following two pages show screen-shots of the prototype, presenting the lay-out ant highlighting specific details.

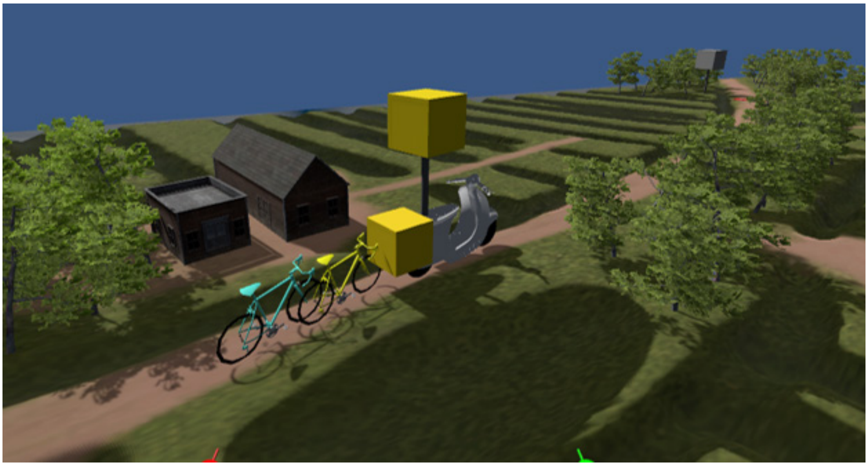
a: The information is shown next to the screen



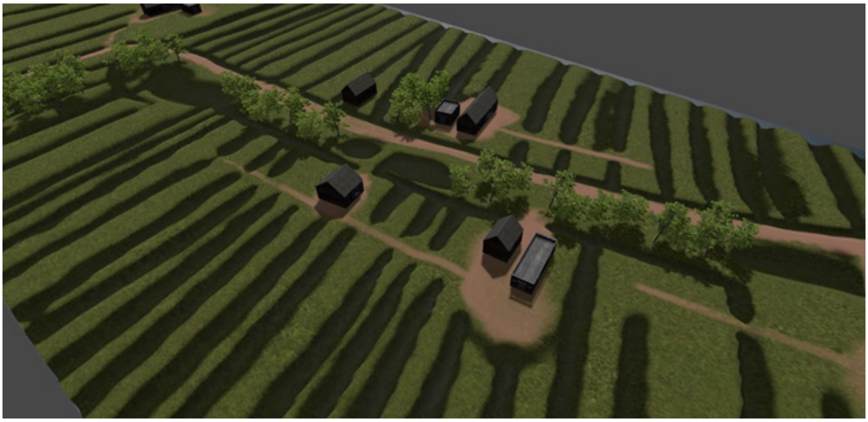
b: The laser pointer gets activated when touching the circular touch-pad on the controller: a red 'laser' appears.



c: When the laser hits a target is turns green, the currently selected camera has a red outline (see a) and the camera where the laser pointer 'hovers' over has a blue outline.



d: The vehicles and 3D vehicles on the map



e: The 3D elements on the map (trees and sheds)

f: The finish-line is indicated using a bright red line.

5.3.3 Preparing 'Unity' project for VR and data usage

The following assets were downloaded and had to be set up in the project:

- CSV2Table: this asset makes it possible to read the CSV file in 'Unity'. This is used to read the files that contain the data for the speed of the bikes.
- SteamVR: is needed to communicate with the HTC Vive. It contains 3D models of the controllers so they are visible in the virtual scene as well.
- VRTK: this asset includes basic scripts for VR interactions. The basis of the laser pointer from this asset is used to create the interactions in the prototype. This asset could only be used with 'Unity' version 2017.3 and an older version of SteamVR. The steps and URL for the Downloads can be found in appendix I2.

5.3.4 Implementation in coding

For explaining how the prototype is implemented in code in 'Unity', this section will first explain some basic elements of 'Unity', then provide a short summary of all classes and their functions and end with an explanation of the scripts of the most important classes.

5.3.4.1 Introduction to 'Unity'

The following elements in 'Unity' will be introduced now: 'Game Object', 'Inspector panel' and how scripts are used in the program. A 'Game Object' is an object in 'Unity' that can represent for example elements of the scenery like the bikes, camera's and map in this project. When attaching components to a 'Game Object' it is able to implement functionalities. The 'Inspector' panel displays detailed information about the currently selected 'Game Object', including all attached components and their properties, and allows you to modify the functionality of 'Game Objects' in your Scene. In 'Unity' a script is a type of component that can be attached to 'Game Objects', and thus also functions or variables can be edited via the inspector. Because of this, the explanation of the scripts using pseudo-code include screen-shots of 'Unity' to show the input of variables in 'Unity'. (Unity Technologies, 2019)

5.3.4.2 Overview of classes

The two columns at the left in figure 5.4 show an overview of the classes in the scripts. These five scripts are used to make the bikes move at the right speed. The 'MovementPath'-script creates a path between an array of points that are placed in the environment. The 'FollowPath'-script makes that a bike follows this path, and the 'LookAt'-script makes the bike face the next point in the path so it always faces forward. To read the CSV-file with the speed the 'LoadData'-script is used.
The two columns at the right in figure 5.4 show the class diagrams of the scripts that are used for the interface elements other than the moving bikes. The 'PrintSpeed'-class reads the 'real' speed data from a CSV file (a new value every second) and then prints it on the correct canvas for each bike. The 'MoveMap'-script is a simple script that makes the map (and all the elements attached to it) slowly move from one point to another point. This is used to let the map move from right to left while the race is going on, so the cyclists stay centred. This makes

the selection more easy and the movement is almost not noticeable for the viewer because it is very slow. The 'VRTKExample_PointerObjectHighlighterA'-script includes the methods to set the highlight colour of the cameras to the right colour, and to print the name of the object that is selected by the laser pointer on the canvas under the video screen.

Since it was complicated to start the videos at a specific time when a camera gets selected, a different method is used in this prototype. All videos are started to play on their own screen when the scene starts. In the scene there are actually five screens (one for every camera) that are all placed on the exact same place, but the visibility of only one screen is turned on.

In 'Unity' these screens have a 'VideoMaterial' that has the 'VideoMaterialTexture_[CameraName]' attached to the albedo and emission colour. There is also an 'empty GameObject' (this is a GameObject that does not have any visibility in the scene) called VideoPlayer_[CameraName] which has the VideoPlayer-component attached to it. This is a component that plays video content onto a target. For each camera the video file (.mp4) is played on the corresponding VideoMaterialTexture_[CameraName] as target. The VideoPlayer-component is set to 'Play On Awake' which means that it directly starts when the scene is started.

When a camera gets selected by the user using the laser pointer, the currently shown screen is hidden and the screen that matches the selected camera is set to visible. Because the videos were prepared to be all the same length and matching in the timing, the video that is shown is always shown at the correct time.

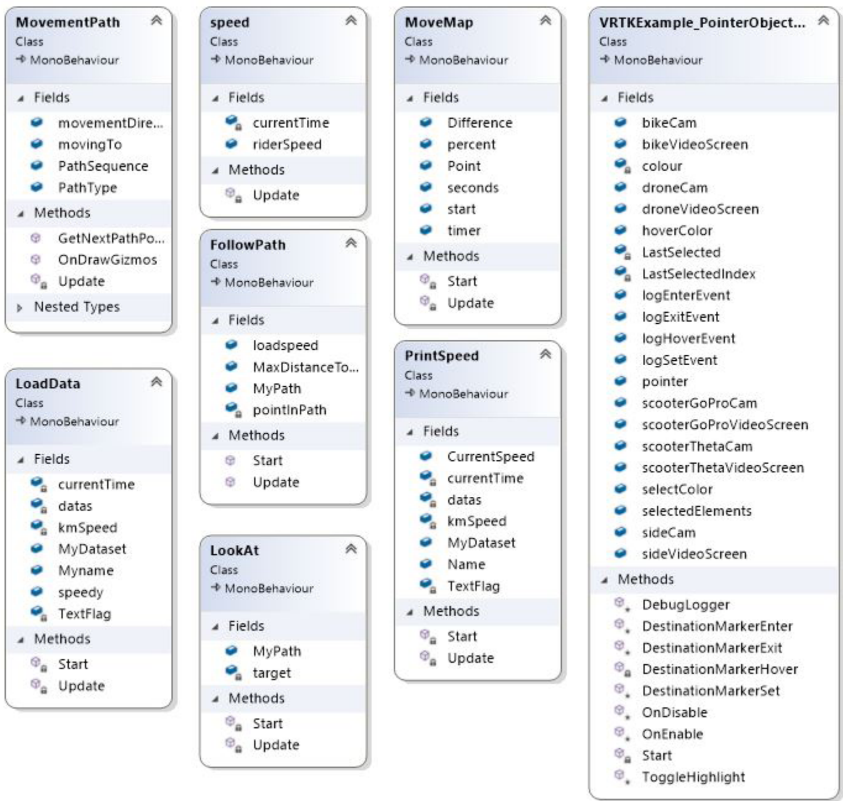


Figure 5.4: Left two columns: class diagrams for bike movement; right two columns: Class diagrams for interface elements

5.3.4.3 Details of the three most important classes

The most important scripts are the 'FollowPath'-script, the 'VRTKExample_PointerObjectHighlighterActivator'-script, and the 'PrintSpeed'-script and their code will be explained in more detail now using pseudo-code and 'Unity' screen-shots.

The 'FollowPath'-script

The code in this class lets the bike to which this code is attached move over the path made in the 'MovementPath' class at a speed that is defined in the 'LoadData' class. Every bike has its own path and speed dataset attached. Figure 5.5 shows the FollowPath script (in the 'inspector' panel) that is attached to Bike-01 (see in the 'hierarchy' panel) and that the corresponding path and dataset are declared (drag and dropped into the variable boxes).

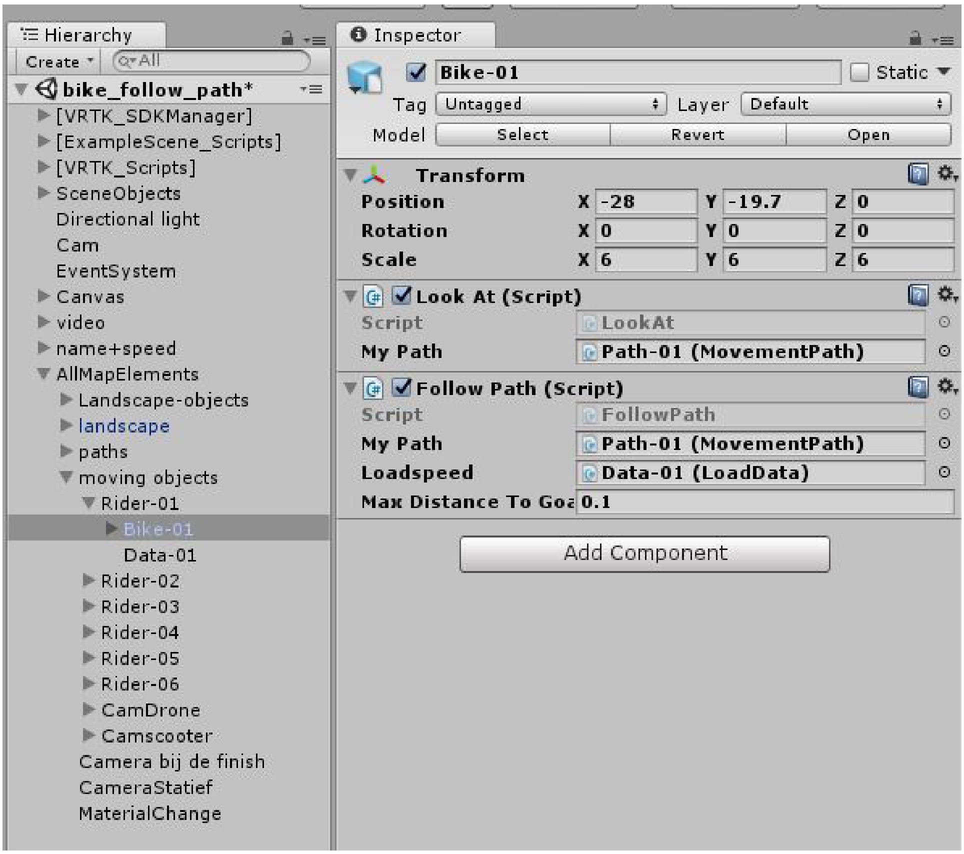


Figure 5.5: a screen-shot of 'Unity': Bike-01 'Game Object' selected, the 'Inspector' panel shows the attached scripts.

```
CLASS FollowPath
{
// the following two references will be attached to the code in the
'Inspector' panel in unity (see figure 5.5):
Get a reference to the path that is used for this bike
Get a reference to the speed dataset that is used for this bike
        START
                Set the starting value for the speed at 0
                Check if a Path is declared:
                IF there is no path declared
                        LOG "Movement Path cannot be null, I must have a
                        path to follow." With the name of the GameObject
                        END the START method
                END IF
                Check if a the Path has points:
                IF there are no points in the path
                        LOG "A path must have points in it to follow"
                        With the name of the GameObject
                        END the START method
                END IF
                SET the position of the GameObject to which this code is
                attached to the first point in the path
        END START

        UPDATE
                UPDATE the speed value //the LoadData-script moves every
                second to the next value in the array that has the speed
                values of the speed dataset that is connected to this
                bike
                MOVE the GameObject to the next point in the path
                Check if the GameObject is close enough to the next point
                to start moving to the following one:
                IF the distance of the GameObject to the next point is
                smaller than the reference value
                        Get the next point of the MovementPath
                END IF
        END UPDATE
}
```

The 'VRTKExample_PointerObjectHighlighterActivator'-script

This script has the code from the VRTK straight laser pointer-asset as base for the pointer. The interaction that shows the matching video screen when a camera is selected is added to this script. Figure 5.6 (see page 118) shows a screen-shot of ' Unity' where the script is shown in the 'Inspector' panel.

```
CLASS VRTKExample_PointerObjectHighlighterActivator
{
// the 'Destination' in this script is a GameObject that can be selected
by the laser-pointer
// this script includes several methods that can be activated by the
VRTK_pointer-script. So in example when the touchpad on the controller
is pressed when the laser is hitting a 'Destination', the VRTK_pointer-
script uses the DestinationSet-method from this script.
// the following two references will be attached to the code in the
'Inspector' panel in unity (see figure 5.6):
SET the colours for the 'hover' and 'select' mode of the laser-pointer
Get a reference to each camera and screen
        START
                SET the video screen of the Scooter GoPro to ACTIVATED
        END START

        ON ENABLE
                Check if there is a controller connected:
                IF there is a controller connected
                        ENABLE the following actions to USE:
                        DestinationEnter, Destination Hover,
                        DestinationExit and DestinationSet
                ELSE
                        LOG "REQUIRED COMPONENT MISSING FROM GAMEOBJECT",
                        "VRTK_DestinationMarker" and the name of the
                        Controller alias
                END IF
        END ON ENABLE

        ON DISABLE
                Check if there is a controller connected:
                IF there is a controller connected
                        DISABLE the following actions from USE:
                        DestinationEnter, Destination Hover,
                        DestinationExit and DestinationSet
                END IF
        END ON DISABLE

        DESTINATION_ENTER
                SET the highlight colour of the Destination-highlight to
                the 'hover'-colour
                LOG "POINTER ENTER" and the name of the Destination
        END DESTINATION_ENTER
```

```
DESTINATION_HOVER
        LOG "POINTER HOVER" and the name of the Destination
END DESTINATION_HOVER

DESTINATION_EXIT
        IF the colour is 'hover'-colour
                CLEAR colour
        END IF
        LOG "POINTER EXIT" and the name of the Destination
END DESTINATION_EXIT

DESTINATION_SET
        CLEAR the colour of the selected Destination
        SET the colour of the selected Destination to
        'select'-colour
        CLEAR the colour of the previous selected Destination
        LOG "POINTER SET" and the name of the Destination
        IF the selected GameObject is the Drone camera
                SET the video screen of the Drone Camera to
                ACTIVE
                SET all the other video screens to NOT ACTIVE
        ELSE IF the selected GameObject is the Side camera
                SET the video screen of the Side Camera to
                ACTIVE
                SET all the other video screens to NOT ACTIVE
        ELSE IF the selected GameObject is the Bike camera
                SET the video screen of the Bike Camera to
                ACTIVE
                SET all the other video screens to NOT ACTIVE
        ELSE IF the selected GameObject is the Scooter GoPro
                camera
                SET the video screen of the Scooter GoPro Camera
                to ACTIVE
                SET all the other video screens to NOT ACTIVE
        ELSE IF the selected GameObject is the Scooter High
        camera
                SET the video screen of the Scooter High Camera
                to ACTIVE
                SET all the other video screens to NOT ACTIVE
        END IF
        SET the text under the screen to "Selected: " and the
        name of the selected GameObject
END DESTINATION_SET
```

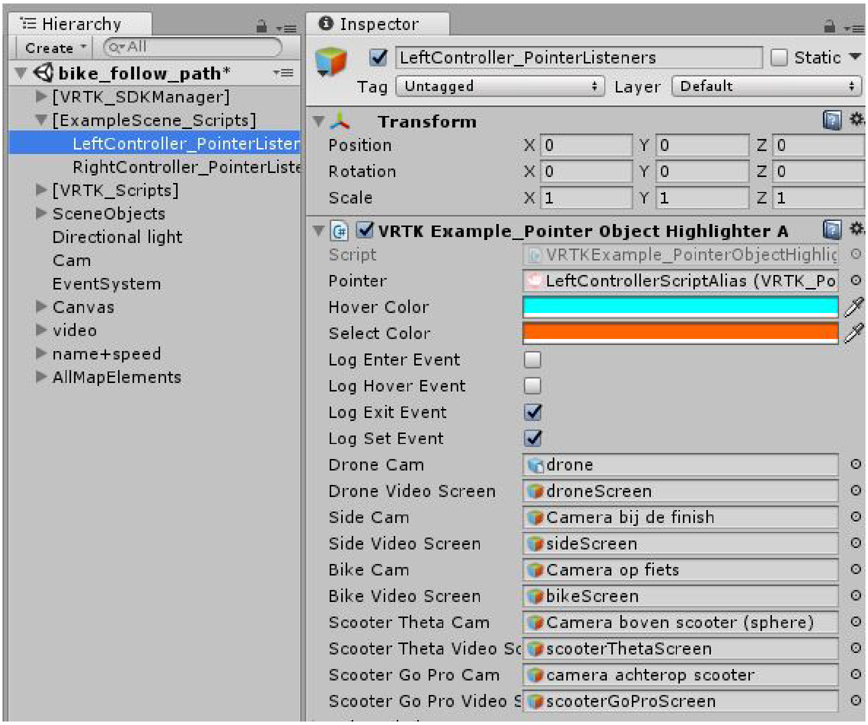


Figure 5.6: a screen-shot of 'Unity': LeftController_PointerListener 'Game Object' selected, the 'Inspector' panel shows the attached scripts.

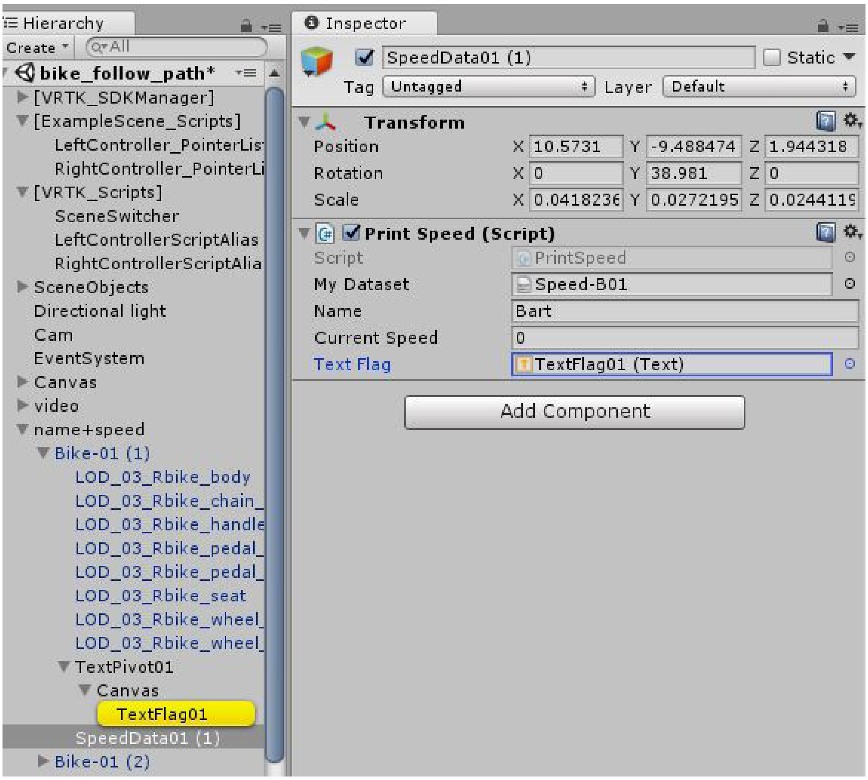


Figure 5.7: a screen-shot of 'Unity': 'SpeedData01' selected, 'TextFlag01' highlighted, and the 'Inspector' panel shows the attached scripts.

The ‘PrintSpeed’-script

Next to the screen are the speed values of each cyclist shown. This script connects the correct dataset to the text-box and updates the shown text to the current speed values.

```
CLASS PRINTSPEED
{
// the following two references will be attached to the code in the
‘Inspector’ panel in unity (see figure 5.7):
Get a reference to the DataSet to use
Get a reference to the TextFlag that this dataset belongs to
Make a field in the inspector to type the name of the cyclist
        START
                SAVE the content of the dataset (csv file) in a temporary
                array, start a new row after every ‘enter’ in the file
                FOR all the rows in the array that is just created
                        Start a new row after every comma in the dataset
                        and save this in a temporary array
                        IF the second column is NOT empty
                                Add a new row to the Data-list
                                SAVE each value in that new row in the
                                Data-list
                        END IF
                END FOR
        END START

        UPDATE
                ADD 1 to the CurrentTime value EVERY second
                IF CurrentTime does NOT exceed the total time of the race
                        SET the value for CurrentSpeed to the value that
                        is in the next row in the Data-list that has the
                        same number for the id as CurrentTime
                ELSE
                        SET the speed value to 0
                END IF
                LOG “speed: ” with the value of CurrentSpeed
                SET the text on the TextFlag to “Name: ” + Name on the
                first line, and  “Speed: ”, with the speed value and “
                km/h” on the second line.
        END UPDATE
```

6

Evaluation & Conclusion

6.1 Introduction and process

The objective of the evaluation phase is to i) obtain objective feedback from the user on the concept, ii) to check how well the it fulfils the goal of the project and iii) to find points for further development and improvement. This section describes the performed user test, the test results, conclusions from the testing and recommendations for further research. Figure 6.1 shows the process of this phase.

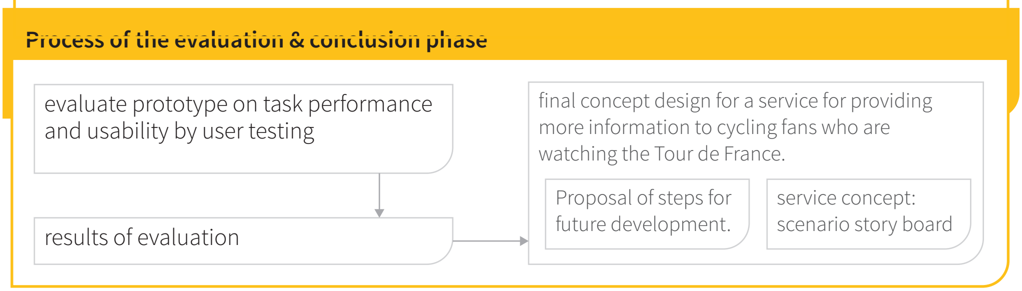


Figure 6.1: Process of the evaluation and recommendations phase

6.2 Plan for user testing

The objective of this project is to educate the viewers about the story of the race to prepare them for a quiz. The goal of this evaluation is to find out how well the users can learn using the proposed solution. The research is designed to evaluate the proposed system on the level of learning performance and experience.

To reach this goal, the following research questions have to be answered:
RQ1: Does the proposed system provide a better learning effect compared to the traditional broadcast?
RQ2: How do the users experience the proposed system?

Respectively to these research questions, the following hypothesis are stated:
H1: The proposed system provides a better learning experience compared to a traditional broadcast.
H2: The proposed system is expected to score high on attractiveness, stimulation and novelty.

Experiment design

The user test has a between group study design with two groups of participants (G1 and G2). G1 is the control group that performs the test with an experience similar to a traditional broadcast, and G2 is the research group who tests the proposed system in VR. To keep the content for both groups similar two prototypes are needed: one for a traditional television broadcast, and one of the proposed system.
The learning performance is measured using a quiz about events that happened during the race shown in the prototype. The information needed to give answers to these quiz questions is provided in both prototypes in a similar way. The user experience is evaluated using the User Experience Questionnaire (UEQ). (Laugwitz, Held, & Schrepp, 2008) The Dutch version of this questionnaire is acquired from the UEQ webpage. (HInderks, Schrepp, & Thomaschewski, 2018)
The UEQ includes 26 items in total that measure on the following 6 scales:

- Attractiveness: Overall impression of the product. Do users like or dislike the product?
- Perspicuity: Is it easy to get familiar with the product? Is it easy to learn how to use the product?
- Efficiency: Can users solve their tasks without unnecessary effort?
- Dependability: Does the user feel in control of the interaction?
- Stimulation: Is it exciting and motivating to use the product?
- Novelty: Is the product innovative and creative? Does the product catch the interest of users?

The complete test plan, including a more detailed description about the methods used, the test procedure and the materials used, can be found in Appendix J1.

Test setup

The setup for both groups (S1 for G1 and S2 for G2) are kept as similar as possible. Figure 6.2 shows the setup of the room with a chair, table and screen. This is the same for S1 and S2. For S2 the VR headset and controller will be placed on the table, and a stool is placed at the spot where the user can view the VR prototype.

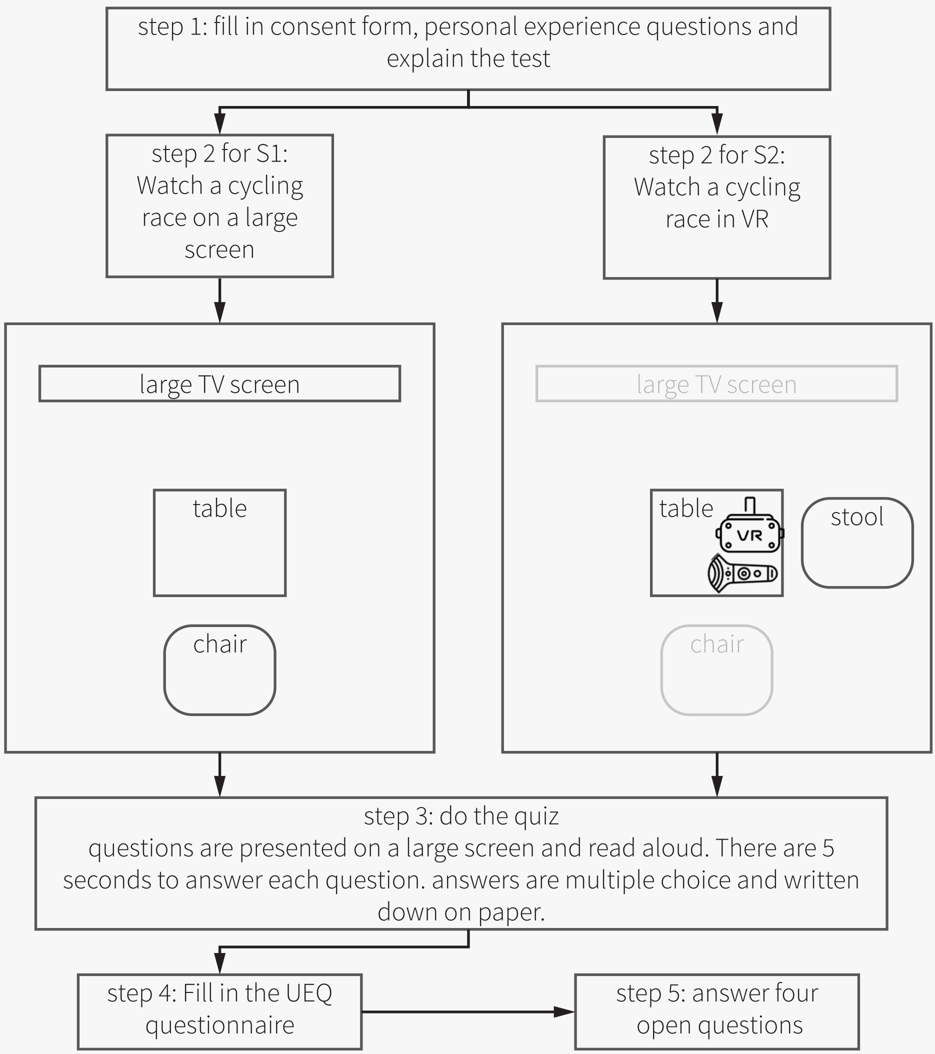


Figure 6.2: schematic overview of the test setup

Participants

The selection criteria for participants are the same for both groups:

- The age of the participants should be between 18 and 55 years old.
- Both groups should have a similar division of people who know about cycling and who are not familiar with the cycling sport.
- Both groups should have a similar division in men and women.

Minimum sample size

The calculation of the minimum sample size is based on comparing the means of the amount of correct answers on the quiz. The formula to use for estimating the minimum sample size when comparing two independent means is
$N = x / (\delta/\sigma)^2$ (p.10 of Imre's document on sample size calculation).
In this formula the following variables are used:
x: multiplier
δ: the difference in means to detect
σ: the estimated standard deviation

Table 6.1: Multipliers for the minimum sample size estimation formula

	Multiplier	
Power ($1 - \beta$)	One sample	Two sample
0.50	4	8
0.80	8	16
0.90	11	21
0.95	13	26
0.975	16	31

Because of the limitations of the amount of participants that can be used for testing in this project, a low value for the power is accepted (P = 0.5). This means that a higher change on the occurrence of a type II error is accepted. A type II error is the change that a "false negative" occurs. Because the data of two groups is compared, the value from the 'two sample' column is taken. For P=0.5 and two sample, the multiplier is 8.

The difference in the amount of correct answers to detected for showing a better learning result is set to 1,5 correct answers. To estimate the standard deviation is estimated using the properties of a normal distribution. Figure 6.3 shows that 99.7% of the data falls in a range of six standard deviations. So when dividing the (highest possible amount of correct answers - lowest possible amount of correct answers) by six, a close estimation of the standard deviation can be made.

σestimated = (highest possible answer - lowest possible answer)/6
= (9-0)/6
= 1,5

When placing the following values in the formula, the minimum sample size is estimated.

x =8

δ = 1,5

σ = 1,5

$N=8 / (1{,}5/1{,}5)^2 = 8$ participants per group (minimum) For calculating the minimum sample size the following possible errors are taken into account as well:

α = error of understanding the quiz questions

> This error is not expected to be high because the questions are relatively simple, read aloud during the test and tested in a pilot.

β = reliability of properly formulating the answers

> In VR the data is shown in the 3D space, the participants have to be able to map this information to the 2D space, for the screen setting the data representation was already 2D. Because of that the error rate for S2 is estimated a bit higher that for S1.

γ = response percentage

> Each quiz question has to be answered within 5 seconds. This error takes into account that the participants are not able to give the answer within this time. In the pilot is tested that 5 seconds should be enough time to note the answer when the participant knows the answer. So this error is also expected to be low.

For S1 (the control group) the error values are set to:

$\alpha_1 = 0{,}95$; $\beta_1 = 0{,}95$; $\gamma_1 = 0{,}95$

For S2 (the research group) the error values are set to:

$\alpha_2 = 0{,}95$; $\beta_2 = 0{,}85$; $\gamma_2 = 0{,}95$

The following formula uses the previously calculated minimum sample size and divides it by the error estimations mentioned above: minimum estimated sample size= $N/(\alpha*\beta*\gamma)$. This results in a minimum sample size of 10 for S1 and 11 for S2.

This results in a minimum sample size of 10 for S1 and 11 for S2

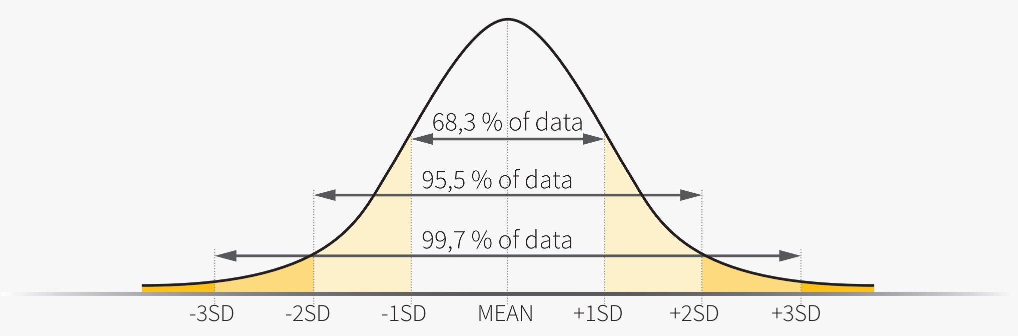


Figure 6.3: the areas under the curve lie between 1, 2 and 3 standard deviations on each side of the mean

6.3 Test results

This section will present the results from the user test. The table below (table 6.2) shows a summary of the participants. The group for S2 has one more participant and the average age is higher by approximately 8 years.

Table 6.2: overview of the test participants

	amount of participants	amount of cyclists	male/ female	never used any VR	average age
s1	10	3	7 / 3	2	24,80
s2	11	5	7 / 4	3	32,45

6.3.1 Results quiz

Figure 6.4 shows the percentage of participants that gave a correct answer, presented per question. Question 5 is not taken into account for both situations since there are no results for S1. The largest difference in the amount of correct answers is noticed at question 7, which asked the name of the cyclist who was in front of the peloton for most of the time?

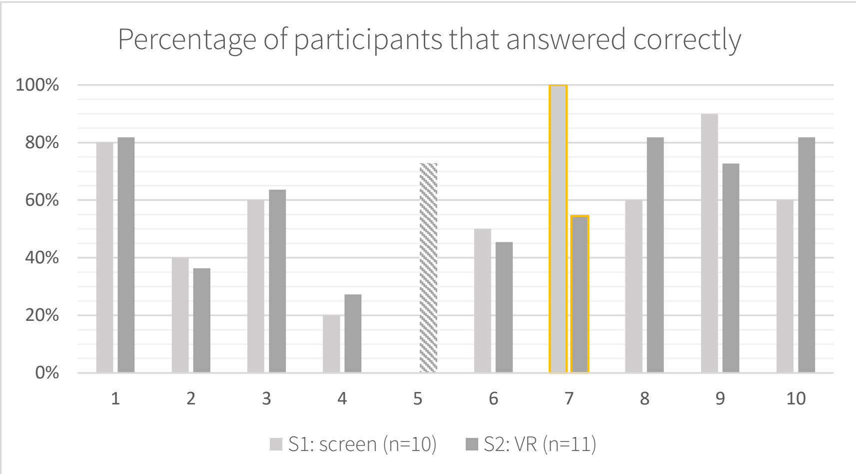


Figure 6.4: the percentage of participants that answered the quiz questions correctly, presented per question.

The amount of correct answers per participant is shown in table 6.3, the total amount of questions taken into account is 9. To see if the data for 'the amount of correct answered questions' is normally distributed a Kolmogorov-Smirnov test is used. The outcome is that for both situations (S1 and S2) the data is normally distributed (see figure 6.5).

Table 6.3: quiz results per participant

participant	test version	Amount of correct answers	participant	test version	Amount of correct answers
1	S1	6	11	S2	5
2	S1	8	12	S2	6
3	S1	3	13	S2	7
4	S1	5	14	S2	5
5	S1	4	15	S2	7
6	S1	7	16	S2	5
7	S1	6	17	S2	6
8	S1	8	18	S2	5
9	S1	4	19	S2	2
10	S1	5	20	S2	7
			21	S2	5
	average	5,6		average	5,45

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of Amount of correct answers out of 9 questions occur with equal probabilities.	One-Sample Chi-Square Test	,977	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of Amount of correct answers out of 9 questions occur with equal probabilities.	One-Sample Chi-Square Test	,364	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is ,05.

Figure 6.5: Nonparametric tests for top: S1-screen and bottom: S2-VR

The first research question of this user test is as following: Does the proposed system provide a better learning effect compared to the traditional broadcast? The hypothesis of this research question is: The proposed system provides a better learning experience compared to a traditional broadcast. As can be seen in the summary table (table 6.4), the mean of S2 is 0,15 lower than the mean of S1, so it cannot be proven that S2 provides a better learning compared to S1. The only thing that can be checked is if this difference is significant. To find out, the following hypothesis will be tested:

H(0): there is no difference in the amount of correct answers given by group S1 and S2.

H(a): there is a difference in the amount of correct answers given by group S1 and S2.

In table 6.5 can be seen that based on the Levene's test (sig = 0.376 > 0.05) can be assumed that the variances are equal. The T-test shows that t(19)= 0.211, p= 0.835, so H(0) cannot be rejected. This means that there is no difference in the amount of correctly given answers between group S1 and S2.

Table 6.4: summary table

Group Statistics	Scenario	N	Mean	Std. Deviation	Std. Error Mean
Amount of correct answers out of 9 questions	S1 screen	10	5,60	1,713	,542
	S2 VR	11	5,45	1,440	,434

Table 6.5: Independent Samples Test

				t-test for Equality of Means					95% Confidence interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	lower	upper
Amount of correct answers out of 9 questions	Equal variances assumed	,821	,376	,211	19	,835	,145	,688	-1,295	1,586
	Equal variances not assumed			,210	17,702	,836	,145	,694	-1,315	1,605

6.3.2 Results UEQ

Before analysing the results on the UEQ, the data will be checked on inconsistencies. Due to misunderstanding of the scale items, or due to not seriously answering, a participant could give inconsistent answers on the scale. In the document that explains the UEQ, the detection of inconsistent answers is explained as following "The idea to detect random or not serious answers is to check how much the best and worst evaluation of an item in a scale differs. If there is a big difference (>3) this is seen as an indicator for a problematic data pattern. … if this is true for 2 or 3 scales this is of course a clear hint that the response is somehow suspicious. … We suggest to remove answers from the data set that shows a value of 3 or higher in the ' Critical?' column." (Schrepp, 2018) Table 6.6 shows the amount of scales that were answered inconsistent per participant. Participant 18 answered inconsistent on 3 scales, and is therefore removed from the dataset.

Table 6.6: consistency of answers on the UEQ per participant (participant 8 is removed)

	participant	1	2	3	4	5	6	7	8	9	10	
S1	Critical?	1	2	0	0	1	0	0	2	0	1	
	participant	11	12	13	14	15	16	17	18	19	20	21
S2	Critical?	0	1	0	0	0	1	2	3	2	1	2

The second research question of this user test is as following: How do the users experience the proposed system? The hypothesis of this research question is: The proposed system is expected to score high on attractiveness, stimulation and novelty. Figure 6.6 shows the means per UEQ-scale and the error bars of the 95% confidence level of the data. Values higher than 0,8 represent a positive evaluation (Schrepp, 2018). Based on this the means for S2 represent a positive evaluation for all scales except on the dependability scale. S1 is only evaluated positively on the perspicuity scale, and neutral on the remaining scales. Due to the small sample size this data has a low precision. Because most of the error bars exceed the 0,8 boundary, the results of the means can only be considered as rough estimations without any significance. Figure 6.6 shows that only for the result on the novelty scale the error bars of S2 and S2 do not overlap. To find out if this difference is significant the following hypothesis will be tested:

H(0): The measured experience on the UEQ scales of S1 and S2 is equal.

H(a): there is a difference in the measured experience UEQ scales of S1 and S2.

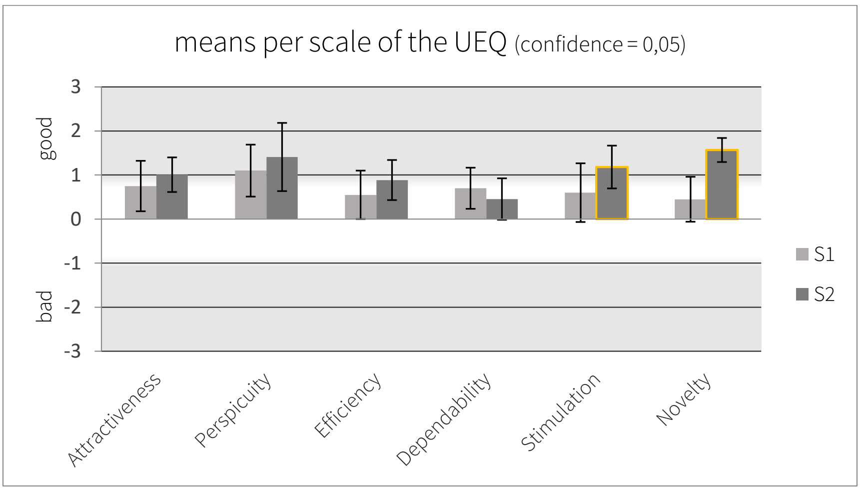


Figure 6.6: Means per scale of the UEQ (User Experience Questionnaire)

The comparison between the means of S1 and S2 shows a significant difference only for the novelty scale t(14,6)=-3.720, p=0,002 (see table 6.7 for the results of the T-test)). So S2 scores significantly better on novelty compared to S1, on the other scales no significant difference is detected.

Table 6.6: a summary of the T-test table with only the rows of the relevant variance assumption (see appendix J for the complete table.

	equal variances assumed?		t	Df	sig. (2-tailed)
Attractiveness	yes	Sig. 0,357	-0,659	18	0,518
Perspicuity	yes	Sig. 0,297	-0,888	18	0,386
Efficiency	yes	Sig. 0,771	-0,855	18	0,404
Dependability	yes	Sig. 0,570	0,701	18	0,492
Stimulation	Yes	Sig. 0,747	-1,261	18	0,222
Novelty	no	Sig. 0,033	-3.720	14,605	0,002

6.3.3 Results open questions

This section provides a summary of the given answers, translated from Dutch into English, the full answers per participant are shown in appendix J2.4.

Positive points:

S1: overview and clarity. The names help to recognize the cyclists (especially for people who are not known with watching cycling). The footage from the bike was mentioned as a positive point, since there is a better sense of how fast the cyclists are going.

S2: Overview and structure. Pleasurable designed without clutter. You can pick yourself what information is important to you. There was a suggestion that this concept could be interesting as well for the broadcasting editors, who have to have a good sense of where the cameras are located and what is happening where.

Comparison: both situations are mentioned to give more overview. In S1 the outstanding point was the footage from the bike, in S2 this was the interaction of selecting what is shown.

Negative points:

S1: Movement and position of information was annoying or disturbing. Low quality of the footage.

S2: Too much information, which can distract and lead to missing information or moments of the race. Difficult to select cameras that are close to each other. The headset was heavy or uncomfortable for some participants.

Comparison: The information shown in both cases was not optimal, in S1 the content was perceived positive, but the representation not. And for S2 the shown information was perceived as too much.

Missing information:

S1: Qualification, route, time, height, distance between groups, information about cyclists, weather information, performance (are they doing well?), map of the route permanently shown.

S2: Qualification, time, height, speed plotted over time, distance to go, signal for important moments, autopilot camera, voice comments.

Conspicuous about the product:

S1: quite similar to the current broadcasting, different information per shot.

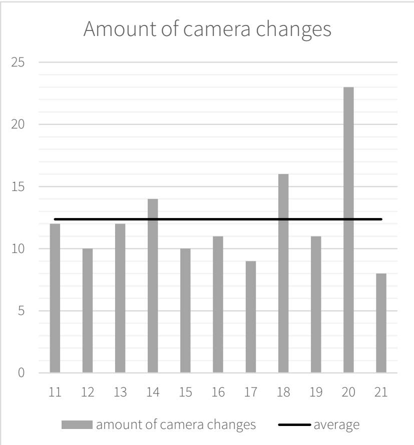
S2: A better overview of the situation, it was easy to learn, having the control in your hands, innovative, more involved in the race, the environment was neat. One participant mentioned that it felt more like a computer game than a visual reportage of a race.

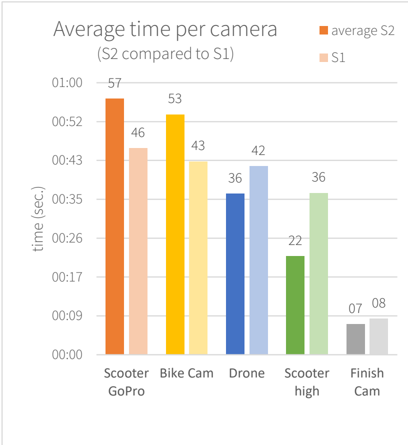
6.3.4 Observations

1. The focus of the viewer is often on 1 element at a time (screen/ info/ map)
2. It can take time to select a camera, while selecting viewers focus on this task and notice less about what is happening in the race.
3. The connection between the order of the cyclists in the info and the real race (screen and map) is not recognised by all participants, a given reason was that the order did not change in the first part of the race, only at the end.
4. Users tend to try out different camera's first before picking the view they like.
5. Even though the viewers knew that a grey camera did not have any video (this was shown during the practise VR scene before the real race was shown), the participants still tried to select is sometimes.
6. Pointing down to select the cameras results in a weird and uncomfortable position for the hand/ wrist (see figure 6.7 right side).
7. The moving objects can be hidden behind the trees, which makes it hard to see and select them.
8. The participants often held the controller in a position that is covered the map.
9. None of the participants, of both settings, recognised that the shown information was connected to the type of view on the race. Some participants noted that the shown information changed.

Figure 6.7: pictures of the test. Left: watching the video in S1; middle: viewing the scene in VR (S2); right: doing the quiz (S1 and S2)

The figure 6.8 shows three graphs with information about the camera changes in S2 (and for some compared to the edited video of S1).
In the edited video for S1 there were 10 camera changes. The average of camera changes by the participants in S2 is 12.4 (see figure 6.8 top left). When leaving out participant 20 who changed much more often compared to the other participants the average is 11.3 changes of camera. This is not a big difference when comparing S1 and S2.
The table on the top left shows the amount of time that a camera is viewed per participant of S2 compared to the edited video of S1. For S1 the amount of time for the first four cameras does not differ much, but for S2 the first two are viewed more than the others.
The amount of time viewed per camera is more detailed shown per participant in the bottom graph. In this graph can be seen that the distribution is very different for each participant, and no pattern can be detected. It also shows that not every participant selected the finish camera at the end, and some of the participants who selected the finish camera were too late and couldn't see everyone finishing.





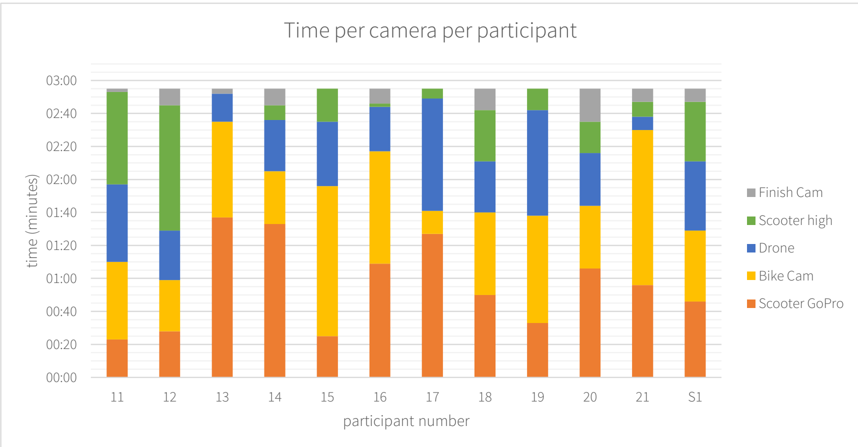


Figure 6.8: left top: amount of camera changes; right top: average time per camera for S2 compared to S2; bottom: the amount of time per camera per participant of S2 compared to S1.

6.4 Evaluation/ conclusions

In this section the conclusions on the two measures of this user test (learning and experience) are presented. These are based on the results of the quiz, UEQ and observations that are described previously.

6.4.1 Learning

The T-test, on the amount of correct given answers, showed that there was no difference between S1 and S2. This means that there is no better or worse learning effect achieved in the VR environment compared to the screen broadcast. There are a few possible causes for this result:

Not enough data: Since a high value for a Type II error was accepted during the estimation of the minimum sample size, it is possible that with more participants a difference can be detected.

Missing out on moments: In S1 the users were guided in the information they saw, in S2 the users were free to choose where to look at (information, map or screen) and they could choose what was shown on the screen by selecting cameras. For example when focussing on the speed values while a cyclist was catching up on the peloton, the viewers could miss that moment. Or when viewing from the camera on the scooter and not to the map or the bike camera, it is also possible to miss the moment of the escape of a cyclist. These moments are difficult to predict by the viewers, and need some sort of indication. This is normally given by the sports commentator and broadcast editor during a TV broadcast. By adding an indication to the VR environment, the users will know when to expect the important moments. Also the autopilot-function and the indication of challenging moments on the 3D map (these functions were presented in the concept presentation but are not included in the prototype) can be used to indicate the important moments in the race.

Focus on the interaction of selecting cameras: The amount of camera changes of the participants in S2 and the edited video in S1 did not differ much. When looking at the order and duration of the viewed camera's per participant (see appendix J2.3), no difference is detected. This suggests that there is no general preference for a specific camera at a specific time, or that they do not know well how to select the best viewpoint. It is possible that the viewers were focussed on or distracted by selecting the cameras. But this is not expected to have a big influence, because when looking at the map to find a camera, the viewers also see the bike and spatial information that the TV broadcast viewers would not see.

Lay-out of the elements: In S1 there was only one screen for the participants to look at, in S2 there were three elements (screen, map and information). For S2 it was difficult to see all the elements at the same time. On one side this provides a better focus on the shown elements, on the other side this could also make it more difficult to see the connections between the elements. A function that was not implemented in the prototype, but that was presented at the concept presentation is that the user can select an element, for example a bike, and the related information gets highlighted. This related information can be the name and speed that are shown next to the screen.

6.4.2 Experience

Only for the UEQ scale 'novelty' S2 scores significantly better than S1. This was as expected, since S1 was very similar to the traditional broadcasts and S2 used VR which is not used yet for cycling broadcasts. Even though S2 had a higher evaluation on novelty, this didn't negatively influence the learning of the participants. In the open questions there were many comments about that the usage of VR helped them to get a better overview, and that it was easy to learn how to use the system. What was also mentioned multiple times is that in S2 when using VR they get more involved in the race.

The scales other than 'novelty' are not significant to prove a difference, but with a larger amount participants these are expected to show differences on the other scales as well.

One point that could have had a negative influence on the experience in both situations is the low resolution of the videos. Using a large screen or a VR HMD this got even more noticeable. But from the overall results the experience was rated to the positive side, so with a better video resolution it is expected that the scores for experience can only be higher.

6.5 Recommendations for future project(s)

In this final section of the report I present my ideas on interesting points for a follow-up research, and for further development of this project.

Broader context

Even though the target group of this thesis are cycling fans, the knowledge that is obtained lays the foundation for the use of VR in cycling in a much broader range of applications. For example the use of VR by cycling team coaches or professional cycling athletes themselves for pre-race debriefing or post-race analysis. Or think about using such a service for people who do not know much about cycling. The explanations can be adjusted to their knowledge levels and in that way they will understand what is happening and get more interested in the sport. The technology and the principles should be similar in the different situations.

Development of computing elements

Synchronisation was left out of the scope of this project, but it is an important challenge to ensure a good quality for the service. The needed precision of the synchronisation has to be determined and a solution has to be developed for achieving this precision in the context of the service.

Another computing element that is important for the learning effectiveness is the algorithm that selects when to present what information. This is briefly addressed in the concept, but is not developed. The information could be additional background information or explanations about the cycling sport, including tactics and strategies. The system should learn about the users informational needs and adjust the content towards that. This means that the needs have to be detected. The proposed method in this thesis is to use eye tracking to sense where the user looks at and how much time the user spends looking at informational elements.

This system should be tested to know how well it works. More detailed examples of how the CPS principles could be implemented in the concept for supporting learning by the viewers are shown in Appendix K.

Usage of data

During this project a selection of functions and data is used to design a concept. But there is much more data available, so the possibilities that this data offers can be researched in more detail.
The main new data source in the designed concept is data about the existing and new cameras. To decide which camera views could improve the learning capabilities of the users, more research on this specific topic has to be done. The usage of different camera types, like panorama, 360 cameras or drone cameras can be explored when used on different locations.

Refine the design and lay-out of the VE

During the user test one of the observations was that the user has to move their wrist in a unnatural position to select the elements on the map. To improve the ergonomics, different orientations of the map in the space can be explored (e.g. place the map under an angle). This could improve the angle that the wrist makes to select a camera, and also it could improve the visibility of the bikes on the map. The elements that were not tested in the prototype should be tested and refined. For example the zoom levels of the 3D elevation map should be tested.

Duration of the experience

Currently VR HMDs are quite heavy, several participants mentioned this during the user test. This can make it uncomfortable to watch a complete Tour de France race, which easily takes a couple of hours. It is expected that in the future VR HMDs will get lighter and have a better quality, but that can take a while and is not something to wait for. A solution could be to research and design a shorter experience that for example gives live summaries of the race. I believe that this could be an interesting feature for the VR experience, since it provides a short and information-rich experience. And using live data, the viewer can watch summary at any time about the events that happened until that moment.

Use even more immersion

The concept proposed the integration of 360 cameras to immerse the viewers in the race and to present information in relation to the space. This feature is also not tested yet, but could be promising. In an interview with the cyclist Mark Cavendish about the role of data at the Tour de France he stated: “I think it would be interesting to show fans just what it takes for a rider to do what they do in terms of how far they are from the finish line, the difference in speeds, and so on. Something like on-board cameras could give a sense of what I would feel like to be in our position, creating an immersive experience for fans.” (NTT, 2019) If this on-board camera is the 360 camera that is used in this project for creating the prototype, the viewer can be ever more immersed, which can help in a better understanding of the hectic moments in the race from the viewpoint of a cyclist.

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An explorative project to the opportunities of the third dimension in Virtual Reality (VR) and the role that Informing Cyber Physical System (ICPS) principles can play in a service for providing more information to cycle fans who want to learn more while watching the Tour the France.

Master Thesis
Integrated Product Design
November 2019
TU Delft