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Interactive 3D Visualisation of Exoplanets

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Abstract

We have lots of information about planets outside our solar system. This can be accessed from a database by anyone. However this information is complex and cannot be easily understood by laypeople. This is a problem as it means that the information gained about these planets is not being used effectively to convey knowledge to the masses. To resolve this a visualisation has been created that can convey this information in a way that interested lay people can understand. The result of this project is a visualisation system that can be used as an information source for laypeople wanting to increase their knowledge about planets outside of our solar system. This report outlines the project carried out, the visualisation created, as well as the evaluation to discover its effectiveness at fullfilling the goals driving its creation.

Contents

Figures

Chapter 1

Introduction

This project seeks to design, implement, and evaluate an interactive 3D visualisation software system for displaying the content in the Kepler Exoplanets dataset. The deliverable is intended as a standalone 3D visualisation system with two modes of interaction of keyboard and mouse or Microsoft Xbox Kinect sensor. The resulting visualisation will convey the information in the dataset in a way that the target users, laypeople who have an interest in astronomy, can understand and interact with.

1.1 Problem statement

The complex nature of the data involved in this project causes a range of problems to arrise which this project attempts to address. The following subsections outline these in detail.

1.1.1 Understanding the content in the dataset

We often rely on visualisation when we solve problems. We create an image in our mind of a situation in order to make sense of it. http://nrich.maths.org/6447

Understanding and analysing large datasets whose size defies simplistic or trivial analysis is a known issue that many areas of research are attempting to address, these areas of research range from data mining to visualisations to attempt to discover or highlight important aspects of the data so that people can more efficiently use it

The content in the dataset used for this project is made up of records of each exoplanet discovered, each of which contains 46 fields.

1.1.2 Comprehension of planatery information

Much of the information regarding planets is criptic and uninituitive, this make its understandability difficult. Visualisations in general attempt to address this issue by displaying information in a way that conveys the information in simplisitic ways that allows improved user comprehension.

1.1.3 Exisiting solutions lack functionality

Existing data visualisation techniques using this exoplanet dataset lack the ability to display sufficient detail on each exoplanet and do not provide answers to questions that can be answered by the Exoplanet attributes in the dataset. Existing solutions display only the size, temperature, and orbital information about the exoplanets. While this is useful information that informs users of important facts about the planets, it does leave a lot of potential information unseen and overlooked, for example, information about the type of planet, planets with similar traits, solar system information, similarity to earth and habitability. This project will therefore be focused on researching, implementing, and evaluating a new interactive visualisation system that will display additional information to users not included in previous visualisation systems.

1.1.4 Effective user interaction with visualisation

A visualisation that soley displays information without effective methods of interaction will not have the immersive qualities that keeps users engaged as would be the case with an interactive visualisation

1.2 Key issues project addresses

To summarise the above sections, this project addresses the following key issues:

I1. Content in database form is difficult to view and understand.

I2. Planetary information if complex and difficult to comprehend without a visual reference.

I3. Exsiting visualisations for this dataset lack functionality.

I4. User interaction is needed in a visualisation to make the most of the data displayed.

1.3 Contributions of this project

This project will provide an extension of the Kepler Visualisation Tool [**?**] that conveys more information and is easier for users to interact with than the original. This extension will be evaluated by a user experiment to ensure that it is successful in conveying the information contained in the dataset.

The work and research completed for this project will allow for further improvement by other developers and researchers to extend and improve the visualisation created. This will provide further exposure of the Kepler dataset which will encourage learning about Exoplanets.

Chapter 2

Project Methodologies

2.1 Project management approach

Following a structured project managament approach is important as it avoids the problem caused by following a code-and-fix approach as described as 1) write some code. 2) Fix the problems in the code [?]. By following a process model it encourages thinking about requirements, design, and testing before coding is commenced.

The project methodology chosen for this project was a customised Spiral Model made up of requirements analysis, design, implementation, and evaluation phases as shown in the below figure. The reason for limiting the model to these 4 phases was because.... Using a

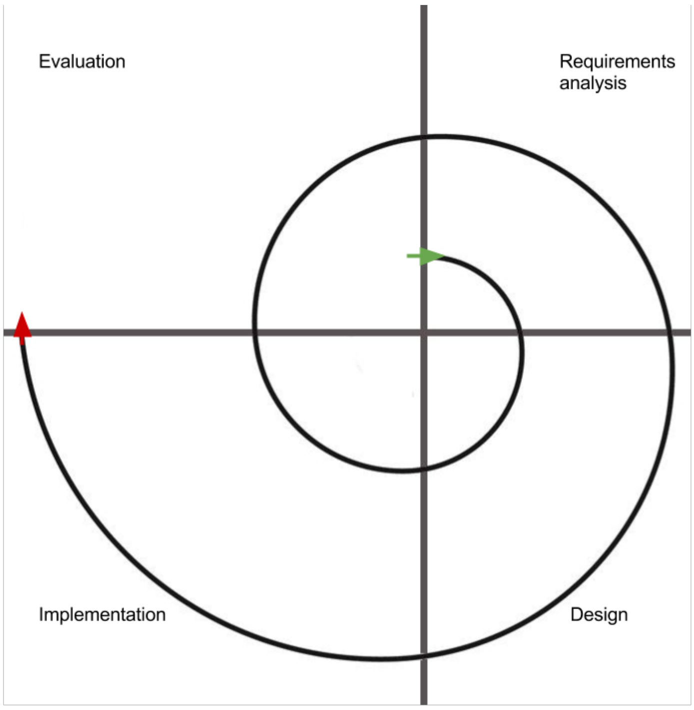

Figure 2.1: Spiral process model followed

spiral model allowed me to produce a deliverable feature at the end of each iteration of the model, this ensured that I did not become delayed or stuck in my development. By using this methodology it also allowed me to prioritise the features that were the most important to the visualisation which reduced the risk that there would be missing or incomplete components at the end of the project.

The advantages of this methodolgy over other choices such as the waterfall model or an agile aproach such as Scrum was that it provided me with the benifits of a structured workflow that is a feature of the waterfall model as well as a flexible iterative process that is a feature of Agile methodologies. Following a pure waterfall methodology would not have allowed me to iteratively design, develop, and evaluate each feature which would have forced more upfront design which .... Following a pure agile approach would not have been optimal as most Agile methodologies are more benificial to projects that have a team working on them.

This project management technique supported the creation of a visualisation as

The choice of this project management apprach meant ....

Weekly meetings with the supervisor of the project, Dr Stuart Marshall, were used to provide guidance and

Using using other supporting project management techniques such as Gantt charts [APPENDIX] and work breakdown structures(WBS) [APPENDIX] allowed efficient documentation of planning and work completed in the project as well as displaying the following stages requried to complete the project.

2.2 System design approach

To guide the creation of the visualisation a user oriented design approach was used, in particular making use of user models (personas) were created to create a sense of empathy and understanding for the forseen users of the visualisation in order to better understand the requrirements and design decistions to be made.

2.3 Key difficulties in project

As this project builds upon a previous system much of the exisiting code and execution flow needs to be modified. This requires understanding of how the system was originally built and designed. Because this system does not have any unit or integration tests, going ahead without a comprehenive knowledge of the core functionality would be foolish.

Encountered errors in Processing framework due to number of elements needing to be displayed on screen.

Having a time constraint of 300 hours for this project over the course of a year meant that ....

Chapter 3

Requirements Analysis

The design of the visualisation was based heavily on User Centered Design as it provided a method of user interface design as well as visualisation design. User Centered Design is a process in which the needs, wants, and limitatons of the end users of a system are given extensive attention. To achieve this, personas were created (also known as archetypal users), which are a personification the needs of a larger group of related users. These personas act as stand-ins for real users, describing them in terms of their goals and personal characteristics, and although they are fictitious, they are based on knowledge of real users. This design methodology supported my understanding of how users were likely to use the visualisation.

An additional tool used during requirements analysis was User Scenarios which describe the foreseeable interactions of the user personas with the visualisation. A scenario is made up of a functional goal for the visualisation and describes how it is carried out by a persona. Both of these tools force you to think about the tasks needed for the visualisation and their context in the system as a whole. Once the personas and scenarios have been completed you can then start to design specific elements of the user interface and visualisation based on the requirements and interactions described in the scenarios.

3.1 User models

Below are the two personas that were used in the design of the visualisation for this project. They depict users that would use the visualisation in the context of a terminal or display in an observatory environment.

and also provided clear defined personas that could be validated during evaluation of the visualistaion with real users that match the core values of the personas.

3.1.1 John Truman (Primary Persona - The interested layperson)

24 year old John is interested in planets and space and has a basic knowledge about both. John has used is used to playing computer games and using visualisations and is not overwhelmed understanding and using new systems. He finds that he learns better when provided with visual examples than when reading or listening to information. John is comfortable using keyboard and mouse when interacting with a computer but is also happy to use other gesture based methods.

3.1.2 Cara Thompson (Secondary Persona -)

3.2 Scenarios

A good use scenario does a number of things:

- Describes the user's goals and motivations.
- Describes a specific task or tasks that need to be accomplished.
- Describes some of the interaction, with enough detail to make it compelling, but not so much detail as to be overwhelming.
- Provides a shared understanding for everyone on your team about what a user might want to do and how they might do it.
- Helps you construct the sequence of events that are necessary to address in your user interface.
- Can be sketchy, as long as it provokes ideas and discussion.

3.2.1 Scenario 1: View planets ordered by their similarity to earth and Kepler Object of Interest number

3.2.2 Scenario 2: Select ranges for attributes of each planet displayed

3.2.3 Scenario 3: Select planets to display more information

3.2.4 Scenario 4: View planets in the same solar system

3.2.5 Scenario 5: View the goldilocks zones of each planet

3.3 Requirements summary

3.4 Existing systems

3.4.1 Worlds: The Kepler Planet Candidates - Non Interactive

This animation [?] shows planet candidates found by NASA's Kepler mission. These candidates are animated in orbit around a single star. They are drawn to scale with accurate radii, orbital periods, and orbital distances. They range in size from 1/3 to 84 times the radius of Earth. Colors represent an estimate of temperature with red indicating warmest, and blue indicating coldest candidates. This animation is layed out very similarly to the Kepler Visualisation Tool that I am extending. This means that it provides insights into how my visualisation can be improved as Worlds is a much more visually appealing system. By researching how it displays its Exoplanets I can further improve my own visualisation.

3.4.2 The Kepler Orrery and The Kepler Orrery 2 - Non interactive

The Kepler Orrery [?] illustrates the exoplanet candidates in their own solar systems. The orbit radii are to scale with respect to each other and planet sizes are to scale with respect to each other, but orbits and planet sizes are different scales. The colors are in order of semi-major axis: two-planet systems (242 in all) have a yellow outer planet; 3-planet (85) green, 4-planet (25) light blue, 5-planet (8) dark blue, 6-planet (1, Kepler-11) purple. This system

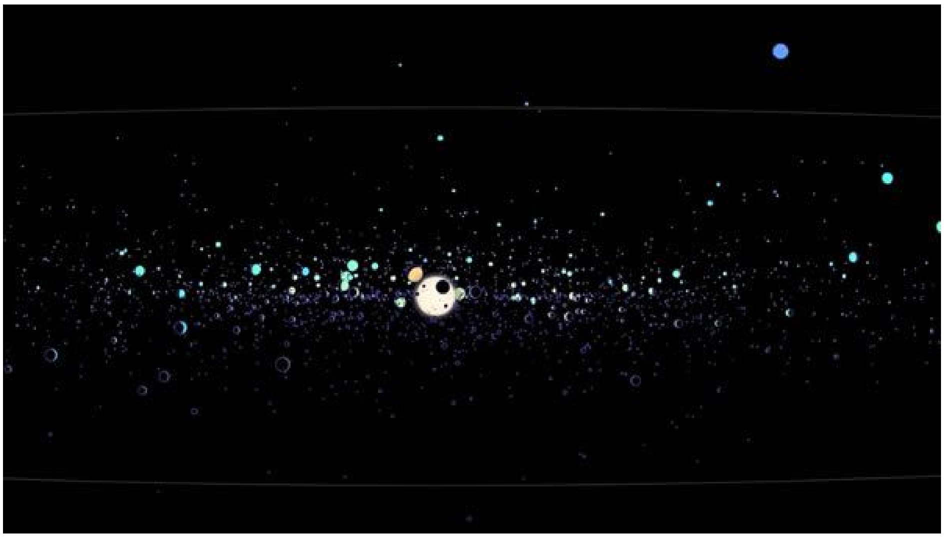

Figure 3.1: Image of Worlds Visualisation

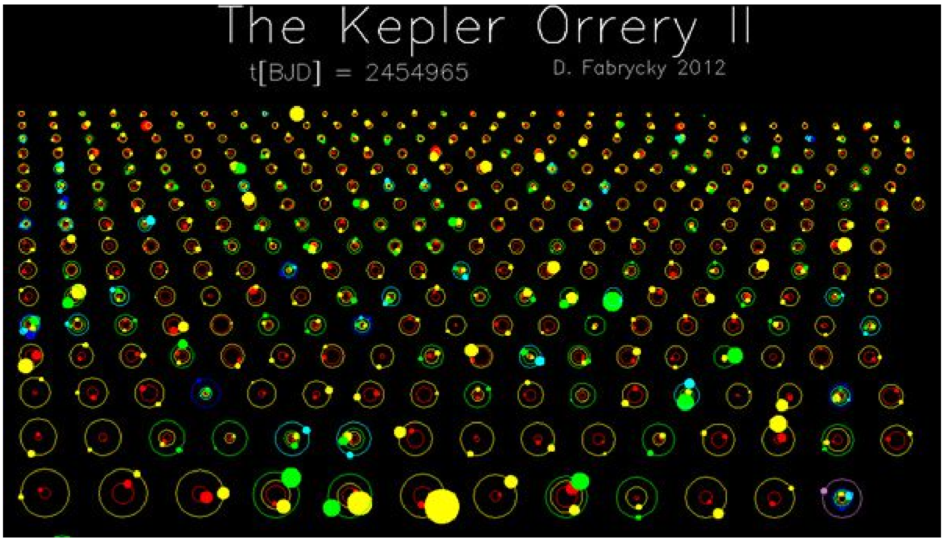

Figure 3.2: Image of The Kepler Orrery Visualisation

exhibits small multiples, a grid of small similar graphics or charts, allowing them to be easily compared. This provides insights into how I can use small multiples to display information about groups of planets. This will be important for displaying which planets share a solar system.

3.4.3 Celestia - Interactive

Celestia [?] is a free real-time space simulation that lets you visually experience the universe in three dimensions. It is an open source system written in C++. This visualisation is much larger and more encompassing system than is needed for this project, as it is a full 3D space simulation. However is does offer insights into how to effectively portray planets and their orbits (See Figure 2.3). It also provides textures that can be used in my visualisation to depict what planets actually look like to increase user immersion.

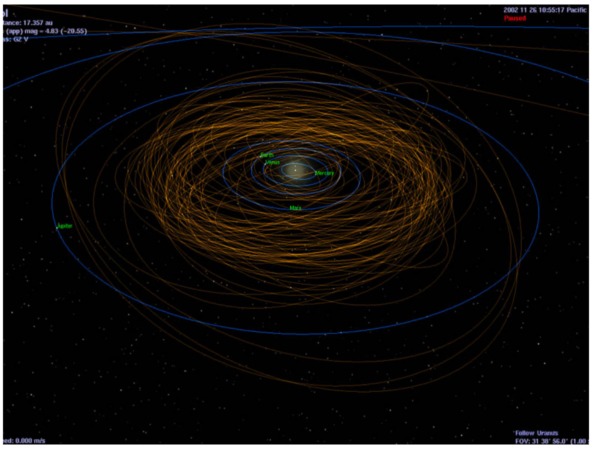

Figure 3.3: Image of Celestia Visualisation

3.4.4 Kepler Visualisation Tool

An existing system built with Processing is the Kepler Visualisation Tool[**?**, **?**]. It is a simple visualisation focusing on displaying the candidate Exoplanets temperatures and their locations in relation to their distance from their nearest star, so that a sense of scale can be perceived. Each candidates estimated size, orbital speed, and orbital separation is accurately depicted, and each planet is color-coded according to its estimated effective temperature.

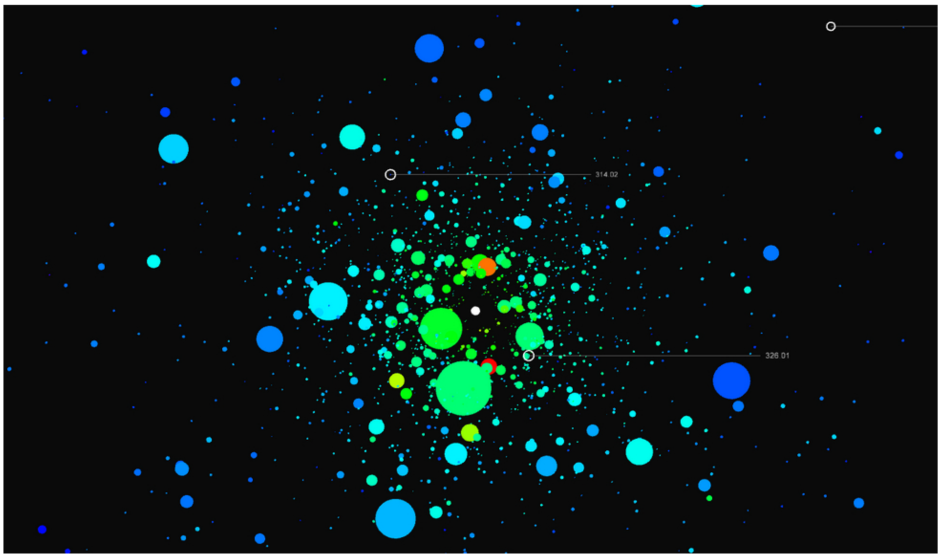

Figure 3.4: Kepler Visualisation Tool Orbital View

The existing work in this system would serve as foundation for this project. Because much of the visual aspects, and initial data manipulation of the existing system are already complete. It means that implementing the features needed for this projects completion could be focused on more heavily and larger improvements to the existing system can be undertaken, such as better labeling and information displays and user interaction methods.

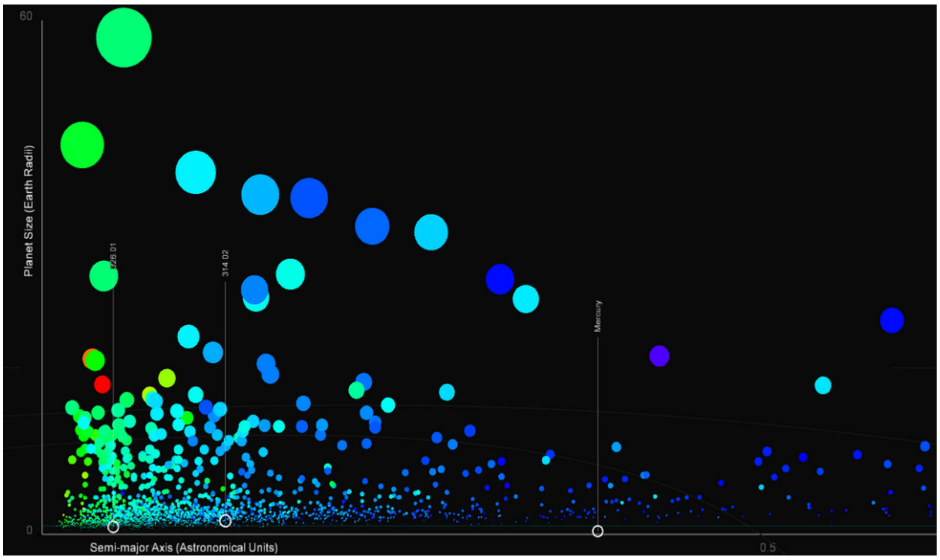

Figure 3.5: Kepler Visualisation Tool Graph View

Chapter 4

Solution Design: Improved Kepler Visualisation Tool

This section discusses the deliverable visualisation that will be created as part of this project. The visualisation for this project will be created using Processing, a Java framework for visualisations. As the time is short for this project, extending a previous visualisation that uses the same dataset, the Kepler Visualisation Tool [**?**, **?**], will increase the amount of progress that can be made in the time afforded.

The visualisation was designed to emphasis small multiples and filtering of the Exoplanets to display the information more clearly to users.

Instead of the visualisation only answering the 5 key questions as proposed in the proposal, the aim will now be displaying as much of the information in the dataset as possible without detracting from the effectiveness of the visualisation whilst still answering the questions.

This is because the 5 questions did not fully utilize the information in the dataset.

However I will need to ensure the effectiveness of the visualisation does not become diminished by trying to convey to much information which would lead to cluttering and overlapping in the visualisation, as well as information overload for users. There will also be larger emphasis placed on making the existing system more usable by improving the interaction methods for users. The following list outlines the new requirements for the visualisation being developed. This will be done by providing GUI elements for each form of interaction with the system, as well as ensuring all interaction methods are intuitive for users.

4.0.5 Visualisation Layout

Component Layout

As the majority of the interaction and movement of visualisation elements occurs in the center of the window it caused a aspect ratio that SOMETHING SOMETHING. It was BETTER to use 2 vertical columns to view and control the visualisation as it had a higher aspect ratio which allowed more of the content to be seen on the screen at once thanks to the fact that the majority of computer screens have a wide ratio.

Selection of planets

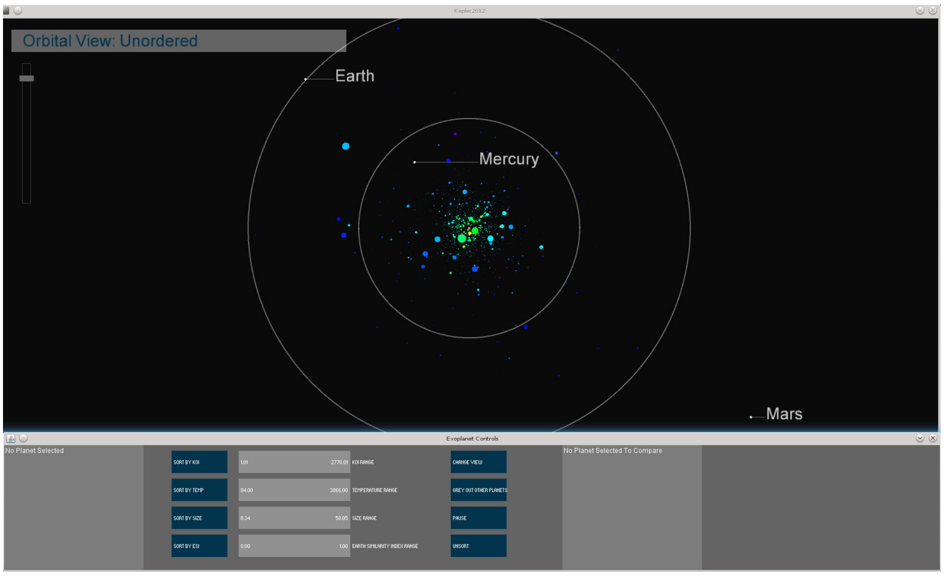

Figure 4.1: Original Horizontal Layout

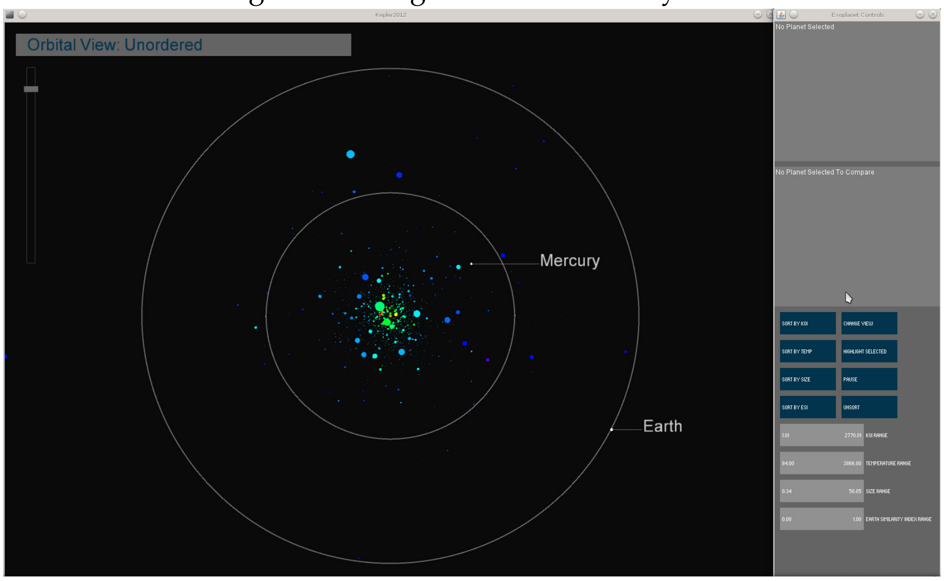

Figure 4.2: Improved Vertical Layout

4.1 Extensions from project initiation document

Kinect for improved user interaction and immersion

Chapter 5

Visualisation implementation

This section details the implementation of the Improved Kepler Visualisation Tool. It details decisions that were made during the project such as choosing a viable framework, the choice of extending a previous system, and platform choice.

5.1 Technology choice

Many technologies were looked into,experimented with, and the positives and negatives of each weighed up before a decision was made about which would be the choice for the visualisation.

D3

Processing

Prefuse

	D3 (Appendix A.1.2)	Processing (Appendix A.1.1)	Prefuse (Appendix A.1.3)
Potential for 3D	***No***	***Yes***	***No***
Has low learning curve	***Yes***	***Yes***	***No***
Prior evidence of successful visualisations	***Yes***	***Yes***	***Yes***
Interactive	***Yes***	***Yes***	***Yes***
Dynamic transitions	***Yes***	***Yes***	***Yes***
Has existing solution related to planets	***No***	***Yes***	***No***

Figure 5.1: Table of technology choices

5.1.1 System design and structure

5.1.2 Tools and artifacts used

5.2 Extension to initial design

Chapter 6

Visualisation Evaluation

Following the completion of the implementation stage of this project a final user evaluation was carried out on the visualisation to discover whether the visualisation designed and implemented

Chapter 7

Conclusions

7.1 Future Work

The work from this project can be taken further in many different ways depending on how it is intended to be used. There is the option of using the system as a terminal that users would use at an observatory or attraction where prior knowledge of the system is limmited and amount of time users would spend on the system would be small. In this case further expanding the user experience and improved Kinect interaction would be benificial as immersion would be the decider on its success. Another option for the system would be for a standalone desktop system that users would use multiple times and so prior knowledge of how to use the system could be expected. This would mean that more complex functionality could be introduced witht he expectation that it could be used by users. The systems current state could me modified to fit into either of these two options.

Bibliography