Sub-volume Selection Methods with No Priors in Virtual Reality

Thomas van Coller
Department of Computer Science
University of Cape Town

Willem Van Ryswyck
Department of Computer Science
University of Cape Town

Jesse Plant
Department of Computer Science
University of Cape Town

Supervisor: James Gain
Department of Computer Science
University of Cape Town

Co-supervisor: Lucia Marchetti
Department of Astronomy
University of Cape Town

Co-supervisor: Alex Sivitilli
Department of Astronomy
University of Cape Town

1 INTRODUCTION

The scientific community continually advances through new technologies and ideas; these advances result in improved methodologies for retrieving and analyzing data. According to R. Norris [11], the yearly increase in data leads to a bottleneck in many scientific contexts with data analysis. Hence, there is always a need for improved sub-selection and analysis techniques for data. One such scientific field facing this bottleneck is astronomy in which telescopes are under constant improvement and continuously document large volumes of data.

Astronomy often uses data cubes, which are three-dimensional datasets that can store astrophysical data. Astronomers have made use of recently emerging technologies such as Virtual Reality (VR) headsets when visualizing data cubes due to its innate advantage of having three dimensions. One such example of these technologies is iDaVIE-v. It is software developed in South Africa at the University of Cape Town by L. Marchetti, T Jarrett et al. [6] for the purpose of studying these astronomical data cubes through the visualization and interaction of this data. It was primarily developed in the context of astronomy. However, it has shown to have potential across other scientific fields. This project aims to extend this software and use it as a basis for our experiments.

To provide adequate analysis of these data cubes, scientists often require the ability to hone in on sub-volumes of these cubes. The project will provide methods of sub-volume selection for these data cubes within iDaVIE-v. When iDaVIE was developed, only the initial methods of selection thought of were implemented and have been shown to have limitations. Moreover, no experiment into whether these methods provide any value compared to analyzing data cubes in a desktop environment has been conducted. This project's purpose is to develop multiple sub-volume selection techniques in VR, which will be evaluated in comparison to a desktop technique.

2 PROBLEM STATEMENT, RESEARCH QUESTION/AIMS

Our aim is to develop four selection techniques for 3D astronomical data. This will be done in the iDaVIE-v software [6]. We are working with the iDaVIE-v team, as well as our supervisor James Gain, to implement these selection methods. Improving this software would benefit all scientists that use it, and providing more selection techniques may allow for iDaVIE-v to be extended to different fields of study.

Although part of this project may improve the selection methods for iDaVIE-v, our research will focus on experimenting whether selection in VR provides an advantage in comparison to a desktop environment when interacting with data cubes. Currently most work with data is done on a desktop computer, but with multidimensional data becoming more common, being able to interact with data in an environment with more than two dimensions could provide great benefit. P Millais et al. [10] have found that using VR to interact with data can provide greater accuracy and usability. Hence our research question is as follows: *Does volumetric selection in virtual reality provide an improvement (increased efficiency, accuracy, and usability) in both selecting and analyzing data compared to a desktop environment?*

3 PROCEDURES AND METHODS

3.1 Overview

As mentioned previously, we aim to develop and test three methods to allow for more efficient and intuitive selection with no priors (selecting volumes from scratch without any automatic selection) in VR. In addition to this, we aim to develop a method for the desktop interface to use as a benchmark for our evaluating our methods. Our three methods will consist of: selection using different 3D shapes paired with Boolean operations, a lasso technique, and a sub-volume deformation. The desktop method will also make use of a lasso technique. These methods will be explored further in the coming subsections.

3.2 Selection Methods

3.2.1 3D Shapes + Boolean Operations. The 3D shape selection will use a series of slightly transparent shapes and Boolean operations. The user will have a palette of available shapes to choose from and place into the data cube. These shapes will be of varying types to allow for a range of different angles and curves to be utilized when making the selection. The shapes can be manipulated, and the Boolean operations will decide whether a shape is removing or adding voxels to the selection, and what the intersection of two shapes results in. For each shape, a large cube outline will be placed around it when selected, so that the Hand-In-The-Middle (HIM) two-handed selection technique [4] can be used to scale the shape. All voxels within the selection shapes will be included in the final mask and touch-ups can be done using a circular brush.

3.2.2 Lasso Method. The lasso technique that will be developed draws inspiration from the Cloud Lasso technique developed by L. Yu and K. Efstathious [13]. Cloud Lasso will be extended to VR headsets and sub-volumes will not be selected based on density calculations. Instead, it will select sub-volumes based on multiple lasso selections from various angles, refer to Figure 1. To use the

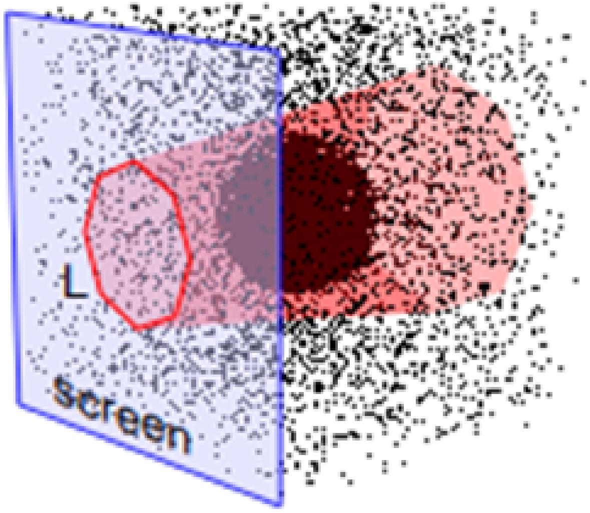

Figure 1: Lasso Method making a selection, taken from [13].

technique, the user will be required to outline a closed loop that encompasses the desired sub-volume with the VR controllers. If the lasso does not close, the lasso will be corrected to contain a sub-volume similarly to the work by [13]. The user will then repeat the process at least once more from another perspective to identify the desired sub-volume more accurately. Once the user is satisfied, all voxels within the desired sub-volume will be selected.

3.2.3 Sub-volume deformation. This method will be implemented in a similar manner to how A. Scalas et al. [12] implemented interactive deformation of volumes in VR. This method will adopt and extend their method of deformation to allow for selection of sub-volumes within data cubes. The deformation technique will work as follows: the user will choose the selection by deformation option. This will place a sphere in the user's frame of view which they can place where they desire. The user will be able to adjust the size and the shape of the sphere (i.e. make it more of an ellipsoid) to fit the general shape of the sub-volume they wish to select. The user can now begin to deform the shape by selecting and "tugging" on different points on the sphere/ellipsoid to morph it into the desired shape. The deformation will be implemented using a cage as is done in [12]. This consists of creating a coarse mesh of triangles and vertices over the selection volume, with these vertices being the points used for deformation. Figure 2 gives a general idea for how this would look.

Once the desired shape is created, the user can confirm the selection and all voxels within the sub-volume will be selected.

3.2.4 Desktop Method. The desktop method will be similar to the SlicerAstro tool which goes through the data cube slice by slice [5]. For each slice, a lasso will be drawn around the desired part of that 2D image to be selected and the final product will put these slices together. The final mask is created using the CloudLasso technique with a specific threshold to make sure all emissions are included in the created mask [13].

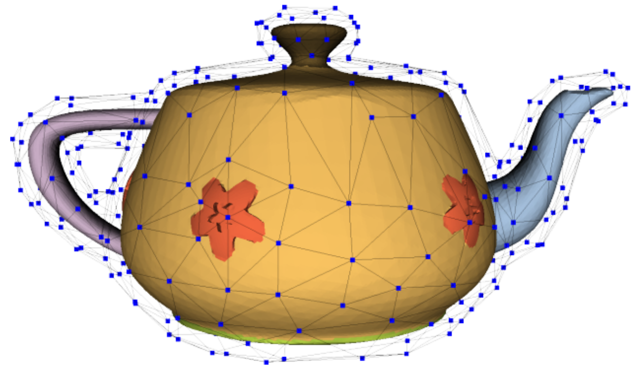

Figure 2: Mesh for deformation around a tea cup, taken from [12].

3.3 Implementation

Our implementation will be on the same development platform used by the iDaVIE-v team, in this case Unity with C as the programming language [6]. Our implementation will extend the user interface to allow for our selection methods to be used, as well as implementing the actual selection methods themselves. Our implementation strategy will begin by taking time to understand the system and how it has currently been implemented, this will be done with the assistance of our supervisors who are familiar with the system. Following this, we will begin development; we intend to take an agile-like iterative approach in which we present our progress to our supervisors at regular intervals and receive feedback to ensure we maximize user satisfaction.

3.4 Evaluation

We intend on doing user experiments to test our methods. Ideally these users will be knowledgeable in astronomy, as the user experiments will be conducted with astronomical data sets. However, this is not vital as a demonstration and some time to practice and get accustomed to the system will be conducted. After the demonstration and practice session, the users will undertake a selection task in the VR and desktop environments. The users will be presented with a data cube whereby they need to select a sub-volume (galaxy) of interest. The users will make the selection multiple times using each of the techniques. Various metrics will be measured throughout this process, these being discussed shortly. Using these metrics, we can assess whether our VR selection methods provide a benefit over using a desktop environment. We aim to have around forty users for testing. Our primary recruitment will be from the astronomy department at the University of Cape Town. We expect that attaining forty participants from this department alone will be unlikely, in this event we will extend our recruitment to the entire science faculty at the university. The following metrics will be used to assess our selection methods:

3.4.1 Completion Time. For us to gauge how efficient our selection methods are we will measure the time taken to complete the selection with each respective method.

3.4.2 Selection Accuracy. Selection accuracy involves observing the degree to which the intended selections are made against the actual selection performed. There are two common metrics used to measure the accuracy of a selection method: F_1 Score and the Matthews Correlation Coefficient (MCC). The following table outlines the terms used in these metrics:

Table 1: Variables for Selection Accuracy

Variable	Abbreviation	Description
True Positives	*TP*	Correctly selected points
False Positives	*FP*	Incorrectly selected points
False Negatives	*FN*	Missing points that had to be selected
True Negatives	*TN*	Correctly non-selected points

F_1 Score: Lingyun Yu et al. [13] states that *the F_1 score calculates the harmonic mean of precision and recall and is often used in information retrieval to measure query classification performance.* It is defined as $F_1 = P \cdot R/(P + R)$ where P is precision and is calculated by $P = TP/(TP + FP)$ and R is recall (the fraction of particles that were selected) and is calculated by $R = TP/(TP + FN)$.

The F_1 score does not take TN into consideration, MCC provides a metric in which it is. MCC is defined as follows:

$$MCC = \frac{TP \cdot TN - FP \cdot FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}}$$

Both of these metrics are commonly used in conjunction with one another when evaluating the selection accuracy of a selection technique.

3.4.3 Task Load Index (TLX). A task load index (TLX) is a tool for measuring and assessing the mental workload a task has on the user performing that task. TLX was developed by NASA and is sometimes referred to as NASA-TLX [8]. TLX is evaluated on a few sub-metrics that are then weighted and combined to form the overall TLX value. These sub-metrics are mental demand, physical demand, temporal demand, effort, performance and frustration. For each task we will observe the user while they perform the task and assign a rating to each field. Each field is then weighted, the weighting of each of these in the final calculation is decided by the observers.

3.4.4 Fatigue. Fatigue measures the physical strain a task creates for a user. Measuring fatigue involves a qualitative questionnaire that the users will fill out, in which they indicate which body parts experienced the most fatigue during the selection [2, 4]. In a VR environment, users will use a lot more body movement to perform tasks compared to a desktop environment. Hence, attaining feedback on the physical strain our selection methods apply to the users is vital.

3.4.5 System Usability Scale (SUS). To gauge how usable the selection methods are we intend to use the system usability scale [1]. This scale requires users to answer various questions regarding usability of some entity, these questions are answered via a rating from 0-5. These values are then used in a calculation to provide the overall usability on a scale from 0-100. We will require our users in the user study to answer these questions for each selection method.

4 RELATED WORK

4.1 3D Shapes + Boolean Operations

The work by Ulinski et., al [4] proposed the use of a six-sided rectangle to encompass a sub-volume for selection. This is the basis of the shape selection technique as the data needing to be selected does not necessarily have a precise shape. It will be extended to allow for the use of multiple shapes and Boolean operations for shape intersection. The HIM (Hand In Middle) selection method has been shown to result in the lowest fatigue when multiple selections are made [4], which will be incorporated for the new selection.

4.2 Lasso Method

There exist many implementations of selecting sub-volumes using a lasso, yet none have been implemented into a VR environment. Traditionally lasso methods make use of a digital tablet and pen to read user input as done by Bowman et al [9]. The user input of some arbitrary shape is then projected into the environment to select a 3D volume. The work of Bowman et al. [9] was later improved by L. Yu et al [13] in two variations, TeddySelection and CloudLasso. Both CloudLasso and TeddySelection use a density threshold to select points of interest within the lasso automatically. These density calculations are computationally expensive and hence we intend to omit these density calculations to mitigate simulation sickness. Rather, we intend to implement a lasso technique dependent on cross reference selection through multiple lasso selections.

4.3 Sub-volume deformation

There have been various attempts to create ways for sub-volumes to be deformed in VR. M. Mcguffin et al. [7] created a method to deform volumetric data with slicing. They implement many different methods for deforming the data cubes, all of which are aimed to separate layers in the data, e.g. a human head could be separated by skin, bone etc. Even though deformation through slicing is a great method for analyzing data cubes, separating the data into layers is not of use to this selection method. The deformation we aim to achieve is that of clay, think of a clay ball that you can deform by pulling, tugging, pushing etc. A. Scalas et al. [12] have developed a method for deforming volumes in virtual reality that aligns with this “clay-like” deformation we aim to implement. They achieve this by surrounding objects in the environment with a course mesh of triangles, whereby the user can interact with the vertices in the mesh to deform the objects. Figure 2 shows how this mesh could look. This is the approach we intend to take to implement the deformation in iDaVIE-v. This method will be extended to allow for the deformed object to be used for selection.

4.4 Desktop Method

The desktop method implemented will be similar to the SlicerAstro tool, which is used for selecting volumes within a 2-D visualization [5]. It allows a selection to be made around every slice of a smoothed 3D shape, to create a final mask using all the slices put together. SlicerAstro uses their own lasso algorithm called AstroCloudLasso which makes use of the CloudLasso technique mentioned above [13]. A similar lasso technique will be used for the desktop method.

5 ETHICAL, PROFESSIONAL AND LEGAL DETAILS

There are a variety of ethical and legal issues that need to be addressed and considered for our project to be a success. This section outlines what they are and how we are keeping consideration for them.

5.1 User Studies

Since we intend to conduct user experiments, ethical clearance will be required for our project. With any user study it is vital to thoroughly consider how the experiment will impact your users. Our experiment only involves users selecting sub-volumes from astronomical data cubes, and hence does not have any emotional weight attached to it. The major concerns we need to account for are simulation sickness and fatigue. N. Dużmańska et al. [3] defines simulation sickness as a syndrome similar to motion sickness and can be experienced as a side effect during and after exposure to different virtual reality environments. Symptoms include discomfort, drowsiness, nausea, disorientation, fatigue, nausea, and in some cases vomiting. To combat this as well as fatigue, we will ensure the users are clear that they can step out of the experiment at any time with no consequence, and ensure they are aware to make it known to us if they are experiencing any of the above symptoms. Moreover, the iDaVIE-v system already has some measures in place to reduce the likelihood of simulation sickness. Our methods will also be developed to minimize latency to further reduce this risk. The training session before the tests will also allow users to get accustomed to the virtual environment, reducing the risk of simulation sickness.

5.2 Data Collection and Usage

The data we intend to collect is only pertaining to the metrics described above. We expect very little personal information will be collected from our users, and any needed information will ensure that users consent to us collecting it. The astronomical data we will be using for our user experiment is under no copyright, and we will not be altering this data in any way.

5.3 Code

We will be developing original code, using open-source libraries and ensuring to cite any resources used to build our selection methods. We intend to primarily extend the iDaVIE-v code, which we have permission to use and extend.

5.4 Referencing and Figures

Information used from other work will be accurately and correctly cited. Any figures used will also be referenced correctly.

5.5 Intellectual Property

All intellectual property developed throughout this project is owned by the University of Cape Town. The iDaVIE-v source code is currently not open-source; hence we will not use or copy any information we have learnt from developing this project for our own personal gain. If it is decided that our code be integrated into the iDaVIE-v system, it will not be open-source until the iDaVIE-v team decides to release the source code. Otherwise, our code will be made available to anyone working on the project in the future.

6 ANTICIPATED OUTCOMES

6.1 Expected Features

By the project's end, three selection techniques will have been developed and implemented for sub-volume selection on data cubes without priors. Moreover, a method for selecting the data in a desktop environment will also be implemented. We expect to conduct user experiments to evaluate these methods. The metrics used in our user tests will indicate whether selecting methods in VR as opposed to a desktop environment provides any benefit.

6.2 Expected Results

It is expected that each selection method will be more useful in some areas than others. Some may have greater efficiency, ease of use, and accuracy than others. We anticipate that all our VR selection methods will improve on a desktop environment in all these areas. It is expected that the deformation selection will achieve the best accuracy and have worse completion times, catering to use cases with atypically shaped sub-volumes. Furthermore, the deformation selection is expected to be the most computationally demanding technique which could cause difficulties in user experience, increasing risk for simulation sickness. It is expected that the use of Boolean operations involving 3D shapes will struggle to achieve accuracy readings akin to the deformation technique. However, for simple selections this method is expected to exhibit improved completion times. Moreover, it is expected that this method will struggle with atypically shaped volumes. We anticipate the lasso method to provide quick selections in many instances, but we expect a lower accuracy than the other methods, but the best usability of all the methods.

6.3 Expected Effects

We expect that on successful implementation of our selection methods, the iDaVIE-v system will allow for more efficient, simple, and accurate selection methods. This will improve the experience of scientists using the software. We also anticipate that having more selection methods within the software will make it easier to extend to other use cases.

6.4 Key Success Factors

Completing the development of all our methods in time to conduct the user experiment is key to the success of our project. Without time for user experiments we cannot evaluate our research question. The user tests will provide us with metrics to evaluate our selection methods and how they compare to selection in a desktop environment. Our project will be deemed a success if the user tests allow us to answer whether our selection methods in VR provide a benefit or not over that of a desktop environment.

7 PROJECT PLAN

7.1 Risk Factors

The risk factors are outlined in the appendix under A1.

7.2 Timeline

Our timeline is displayed in the Gantt Chart under A2. This also highlights our milestones.

7.3 Project Deliverables

Our project deliverables are displayed in the table below:

Table 2: Project Deliverables

Deliverables	Date(s)
Literature Review	Mon 18-March
Project Proposal Demonstrations	Mon 22-April to Thu 25-April
Project Proposal	Tue 30-April
Ethics Application	Mon 6-May
Project Progress Demonstration	Mon 22-July to Fri 26-July
Draft of Final Paper	Fri 23-Aug
Project Paper Final Submission	Fri 30-Aug
Project Code Final Submission	Mon 9-Sep
Final Project Demonstration	Mon 9-Sep
Poster	Fri 27-Sept
Website	Fri 4-Oct

7.4 Resources

As this project is making use of virtual reality and an already existing software, the project resources are quite specific. In terms of software, Unity will be used to code the application and will need to be integrated with the iDaVIE-v software application. GitHub will be used as a project management tool. A VR headset (HTC Vive Pro) will be needed for testing the development and a computer powerful enough to run the VR application. 40 people are needed for the user experiment, and they are to preferably be from an astronomical background. An astronomy data set with a simple galaxy will be needed to test the selection methods and allow for a standardized user experiment. This data set will come from the astronomy department.

7.5 Work Allocation

7.5.1 Thomas. Develop a selection method in VR that makes use of spatial deformation and manipulation.

7.5.2 Jesse. Develop a selection method in VR that uses a simplified version of Cloud Lasso.

7.5.3 Willem. Develop a selection method in VR that makes use of 3D shapes and Boolean operations. As well as develop a desktop selection method using SlicerAstro.

7.5.4 Combined Work. We all contributed equally to this document. We will all assist in the planning and execution of the user experiments, as well as in analysing the data.

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APPENDIX

A1 – Risk Factors

Risk	Description	Likelihood	Impact	Mitigation Strategy
Scope Creep	Group takes on too much and starts doing parts not asked of them.	Low	Medium	Ensure that all members stick towards what is outlined in their section for what to do.
Member Leaves	A member leaves the group and the project.	Low	Medium	Ensure each member has an independently working section of the project so that they are not affected.
Time Constraint	Time estimations are incorrect meaning that Gantt chart is not followed, and time runs out.	Medium	High	Be strict about following deadlines and ensure careful time management. Overestimating time needed to ensure room for error.
Limited VR Access	Time using VR labs is limited due to demand within groups and other groups, especially around testing time.	High	Medium	Ensure there is a strict and fair allocation system in place and people adhere to it to give all an equal opportunity.
Ethics Approval	If ethics approval is not received soon enough, experimentation will be delayed.	Medium	High	Ensure ethics approval is submitted early and done with top priority.
Number of Participants	The desired number of participants for the experiments is not reached.	High	Medium	Ensure that the minimum number of participants (20) is found by starting recruitment early.

A2 – Gantt Chart