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**Computer Graphics
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Bachelor Thesis

Occlusion Avoidance for Immersive Inspection of 3D Cell Complexes and Cell Surfaces

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22nd November 2022

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Task for the preparation of a Bachelor Thesis

Course: Computer Science
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Title: Occlusion Avoidance for Immersive Inspection of 3D Cell Complexes and Cell Surfaces

Objectives of work

Momentan ist das besagte Thema in aller Munde. Insbesondere wird es gerade in vielen – wenn nicht sogar in allen – Medien diskutiert. Es ist momentan noch nicht abzusehen, ob und wann sich diese Situation ändert. Eine kurzfristige Verlagerung aus dem Fokus der Öffentlichkeit wird nicht erwartet. Als Ziel dieser Arbeit soll identifiziert werden, warum das Thema gerade so omnipräsent ist und wie dieser Effekt abgeschwächt werden könnte. Zusätzlich sind Methoden zu entwickeln, mit denen sich ein ähnlicher Vorgang zukünftig vermeiden lässt.

Focus of work

- Recherche & Analyse
- Entwicklung eines Konzeptes & Anwendung der entwickelten Methodik
- Dokumentation und grafische Aufbereitung der Ergebnisse

First referee: Prof. Dr. Stefan Gumhold
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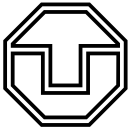
Prof. Dr. Stefan Gumhold
Supervising professor

Statement of authorship

I hereby certify that I have authored this document entitled *Occlusion Avoidance for Immersive Inspection of 3D Cell Complexes and Cell Surfaces* independently and without undue assistance from third parties. No other than the resources and references indicated in this document have been used. I have marked both literal and accordingly adopted quotations as such. There were no additional persons involved in the intellectual preparation of the present document. I am aware that violations of this declaration may lead to subsequent withdrawal of the academic degree.

Dresden, 22nd November 2022

Joris Grau



Abstract

This is an abstract. The abstract is written after finishing the work and should give an overview about the motivation, used methods, as well as the results. It is here to inform the reader about the core topics of the work and if it is relevant to his research. The abstract stands for itself and uses no components of the rest of the work. In consequence, there are no references nor citations used here. It should be around 100 to 250 words. There should always be an english version of your abstract, regardless of the language the work is actually written in.

Zusammenfassung

Das ist eine Zusammenfassung. Die Zusammenfassung wird geschrieben, nachdem die Arbeit fertiggestellt ist und sollte einen Überblick über Motivation, Methoden und die Ergebnisse geben. Die Zusammenfassung informiert den Leser über die Kernthemen der Arbeit und ob die Arbeit für seine Forschung relevant ist. Die Zusammenfassung ist von der Arbeit entkoppelt und verwendet keine anderen Komponenten der Arbeit. In der Folge werden hier keine Referenzen oder Zitierungen genutzt. Sie sollte zwischen 100 und 250 Worten umfassen. Unabhängig von der Sprache, in der die Arbeit verfasst wurde, sollte es immer eine englische Version der Zusammenfassung geben.

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Symbols and Acronyms

VR	Virtual Reality	CAD	computer-aided design
AR	Augmented Reality		
GPU	Graphics Processing Unit		

1 Introduction

The human brain consists of 86 billion neurons. Even if one wanted to pick out, visualize and examine just a tiny fraction of these, it would be very difficult to make any meaningful conclusions, as the sheer volume of data prevents close inspection. Nevertheless, correct and precise analysis of datasets is a cornerstone of any research, but this is often challenging and error-prone, especially when the complexity and size of the dataset increases. A common problem with such large data sets is that the data you are trying to examine is obscured and blocked by other data, this is especially the case with three dimensional data sets and is called occlusion. Therefore, it is important to develop methods and programs that filter or transform data sets and allow a closer look at individual parts of the data set as well as their context. There are many different techniques to avoid and reduce occlusion. These methods can roughly be divided into two types: hiding unimportant data and transforming the data set so that occlusion is avoided. For example, it is possible to use clipping planes to hide foreground data. A common problem with using them is that the context of the data is difficult to recognize, because only a part of the whole is shown. To reduce this, the position of individual data can be changed so that no more occlusion occurs, but all data is still displayed. One way of transforming the data set is through the use of exploded views. Here, individual parts of a model or data set are pulled apart in such a way that each part of interest can be viewed in detail and the original composition of the data set remains recognizable.

The goal of this work is to examine and compare different methods for generating such exploded views for cell complexes. Furthermore, it will be tested which of these methods are suitable for inspection in virtual reality (VR) and what new possibilities and difficulties this innovative environment brings. Since the immersive visualization of such models in virtual reality and its intuitive interaction creates completely new possibilities for exploded views, it is important to find out which techniques are effective and which established methods are not suitable. To do this, an analysis of the state of research and a classification of the different methods will be developed, followed by a prototypical implementation of some selected techniques for exploded views and a comparison of their effectiveness in the VR. For this purpose, a data set of a cell complex is available which is visualized and transformed. This dataset was simulated and it describes the change of the cell complex over a defined period of time. Therefore it is necessary that the visualization and the explosion view can also

show the temporal change of the individual cells of the cell complex. Furthermore, different interaction types are to be tested.

In order to achieve this, the work is divided into **the following structure**. First, general terminologies and problems of exploded views are explained, then a thorough literature analysis takes place on related works and their solution approaches on the subject of occlusion avoidance of dynamic and static data sets. It continues with a more precise classification of the topic and the solution approaches that are pursued in this work. Then the results are shown and explained in a subsequent discussion. At the end there is a summary of the work as well as further approaches that could be explored in a future work.

If you look at traditional hand-drawn explosion views, you can see that both the explosion direction in which the parts are moved and the spacing of the parts must be well chosen. A number of other properties are also helpful for exploded views that are as meaningful as possible.

2 Background

When examining complex data sets or models, it is often important to understand the composition of the individual components and their order of assembly. This is especially the case for technical and biological models, where the order of composition defines the function. A problem that often arises is how to inspect the inner parts of such a model without breaking the compositional order. One possibility is to use filters and to cut away the frontal parts, but this is done at the expense of the overview and can make it difficult for the viewer to correctly identify the position of the part in the object. To avoid this, this work focuses on exploded views, as they offer the possibility to reveal internal parts of complex models while preserving their position in relation to other parts. Furthermore, they offer good interactive possibilities, which can also be transferred to the interaction in virtual reality.

Exploded views are drawings or information graphics that pull apart a complicated object as if it were blown up in a controlled manner. The individual parts are then spatially separated so that their position inside the object or model becomes visible. Often the projection of the object takes place in a planar view from the side or from slightly above. This type of representation has a long history and can be found in many technical drawings, as the individual parts can be named and the order of assembly becomes clearly recognizable.

Looking at traditional hand-drawn explosion views, it becomes apparent that both the explosion direction in which the parts are moved and the spacing between the parts must be well chosen. In order to create the most informative explosion views, Li et al. describe five additional desirable conventions in their paper.

- **Blocking constraints:** Parts should be translated so that they do not pass other parts, this is to show the viewer how the components fit together and indicate their relative position.
- **Visibility:** The spacing of all parts should be chosen so that each part of interest is visible.
- **Compactness:** Parts should be moved as little as possible from their original position to facilitate the viewer's mental reconstruction.
- **Canonical explosion directions:** Most objects have a canonical direction, i.e. an axis in which the object can best be aligned after the explosion. This is determined by various

object-specific properties. In order to reduce the visual clutter, only a few of these axes should be chosen, otherwise the viewer will have difficulty recognizing the original composition.

- **Part hierarchy:** Complex models are sometimes divided into different exploded views and axes, this can illustrate the composition of smaller parts of the object.

If internal parts of an object are completely enclosed, it is necessary to either remove or cut open the outer part. According to Li et al., it should be ensured that when the outer object is cut, the distance with which the outer parts are pulled apart is kept as minimal as possible, whilst still leaving the inner parts visible. In such cases it is also common to hide the outer parts to reveal the inner composition.

A distinctive feature which is relevant for this work are the utilized data sets. They have been generated using the program *Morpheus* which is being developed at the TU Dresden. *Morpheus* can be used to simulate and visualize the temporal changes of cell complexes and their evolution. The datasets thus represent a biological model in which there is no fixed order of composition and the individual parts may change their position and size over time.

3 Related Work

Occlusion avoidance is a well-studied area of computer visualization that is constantly evolving as technology advances. Innovative ways to expand and enhance existing concepts and techniques are made possible by new devices and technologies. This is especially true for visualization methods like cutting planes and exploded views, which greatly profit from these novel interaction possibilities.

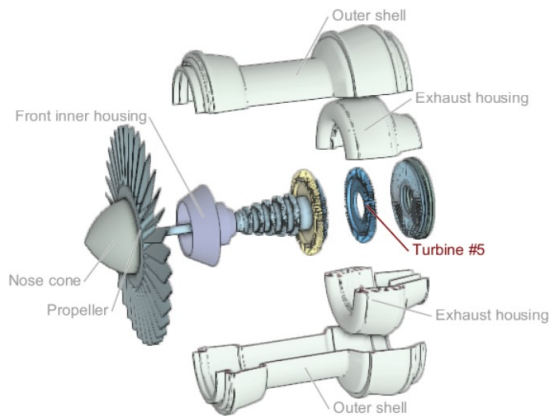
Li et al. provide an example of this.[LAS04] In their work, they demonstrate an algorithm that automatically separates traditional drawn explosion views to make them interactive. Their algorithm takes 2D images of explosion view diagrams and automatically cuts them apart, both reducing visual clutter and clarifying the spatial separation of the individual components. Furthermore, the separated parts can be labeled more precisely and retracted and extended as needed.

Since the interaction capabilities of two-dimensional images are limited and data sets and models have become increasingly complex, the question arises as to how the same principles of exploded views can be applied to three-dimensional objects. For this purpose, Mohammad et al. developed a tool that creates exploded views for three-dimensional CAD models. It shows both precise spatial relationships and the order in which the object was assembled.[MK93] This is especially useful when visualizing machines and technical objects, as it gives the viewer a clear idea of how the parts are arranged. One disadvantage of their implementation is that the individual relations must be clearly defined by a designer beforehand in order to generate the explosion view and calculate the position of the exploded parts. As a result, the order of composition and the blocking elements must be known and manually defined.

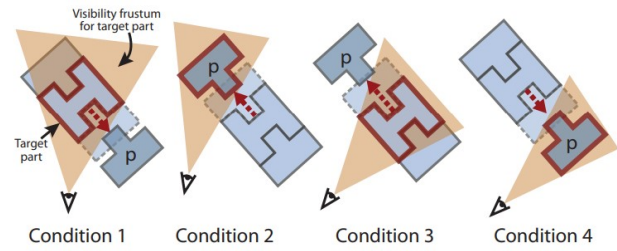
Li et al. therefore presented a system that automatically extracts non-blocking exploded views from a 3D model, focusing on rearranging parts instead of hiding obscuring geometry.[Li+08] They also provide a list of tools to interact with the exploded views and dynamically select



Figure 3.1: Interactive car diagram in its fully expanded (left) and fully collapsed configurations (right). [LAS04] [Figure 16]



(a) System presented by [Li+08] [Figure 1]

(b) Conditions for moving part p . For each condition, the target part is outlined in red. The orange visibility frustums show how unwanted occlusions have been eliminated in each case. [Li+08] [Figure 8]

and show parts of interest. Their implementation works for both hierarchical and non-hierarchical models, which also allows it to process biological datasets where there is no fixed assembly order. The algorithm works by calculating an explosion graph when loading the model, which describes the blocking elements of each part from different angles. This allows to retrieve at runtime the sequence of elements needed to disassemble the object without parts passing through others. Thus a dynamic explosion graph can be generated which shows an animated composition from all viewing directions. An important part of this is the generation of a correct explosion graph. To accomplish this, two problems have to be solved: first, how to move the parts to uncover the target parts without occluding them, and second, how to deal with enclosed parts. Li et al. solve this problem by iteratively going through all the parts and testing for two conditions: each part must be moved so that none of the target parts are obscured; if the part is a target part, it must not be obscured by any part that has already been visited. In order to isolate target parts from other touching parts, it is also made sure that they are completely visible and close parts are moved further away. If one part is completely enclosed by another, the outer one is separated in the bounding box center and pulled apart so that the inner parts are completely visible, then the algorithm continues. The resulting application generates animated exploded views for models with up to fifty parts. However, a disadvantage of this implementation is that it only works for static data sets and does not provide any solution for time-varying data sets.

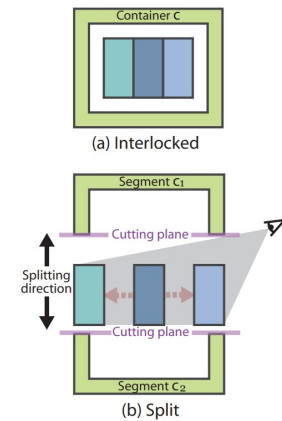


Figure 3.3: Splitting container to reveal enclosed parts [Li+08] [Figure 7]

Tatzgern et al. improve on the work of Li et al. by finding frequently recurring subsets in a mesh and grouping them, then selecting the best representative of that group and exploding it based on a quality score.[TKS10] The frequently recurring subsets are found automatically based on a frequent sub-graph search. The resulting explosion diagrams are especially useful for technological models where there are many identical subsets, and the explosion displays only one of them instead of doing this for each of these subsets and taking up a lot of screen space. For biological datasets, however, this extension is less useful, since it brings

little advantage due to the distinct structure of biological objects. More relevant, however, is its quality score which is used to select the representative. This is also applicable to general explosion views and can be used to quantitatively describe the quality of an explosion view. It is defined by the following evaluation criteria:

- **Size of the footprint of the exploded view:** Describes the entire screen space that the exploded view occupies.
- **Visibility of parts of the exploded group:** Describes the relative measure for the general visibility of the parts.
- **Part directions relative to current camera viewpoint:** Assumes that explosions similar to viewing direction are more difficult to read, they compute the average dot product between the viewing angle and the explosion direction.
- **Size of footprint of all other similar groups without any displacements:** Describes how well other similar groups are visible when selected representative is exploded.

These criteria are then weighted by Tatzgern et al., which influences the selection of the representative. Even if not all of these points are suitable for use in virtual reality, some ideas can still be applied. In particular, using the dot product between the camera position and the direction of the exploding parts is a helpful approach.

While Li et al. and Tatzgern et al. relied on calculating the position of the exploded parts, Bruckner et al. used various **force-based techniques** to transform parts to generate explosion diagrams.[BG06] Their presented method works with volumetric data sets and splits them into pieces before exploding them. For this purpose, they present three tools that interactively split the dataset at runtime using split axes and cutting planes. The first tool splits the first object hit by a ray based on the camera's viewing direction, the second splits all objects not just the first, while the third allows the user to draw a line onto which all parts are projected, if the projection lies on the line the part is split. These tools are designed to work with volumetric data sets and can also be applied to voxel data sets and are therefore suitable for biological objects. Another interesting approach they use is the definition of forces acting on all parts to explode the object. These forces are defined by Bruckner et al. as follows:

- **Return force:** The part should move as little as possible from its original position. Therefore, there is a force pushing the part back to its original position. Bruckner et al use the following formula, where r is the vector from the current vertex position to that of its original and c_r is a constant factor.

$$F_r = c_r * \ln(\|r\|) * \frac{r}{\|r\|} \quad (3.1)$$

- **Explosion force:** The user can select individual parts and the force will push all other parts away from the selected parts. Bruckner et al. use the following formula to describe the force F_e that emanates from each selected part and acts on every part P_i .

$$F_e = \frac{c_e}{e^{\|r\|}} * \frac{r}{\|r\|} \quad (3.2)$$

Here c_e is a constant factor and r is a vector from the explosion point to the closest point of the geometry of part P_i .

- **Viewing force:** To make the exploded view interactive, Bruckner et al. introduce another force that takes the camera position into account, obscuring parts are thus pushed away from the viewing direction. The procedure is described by Bruckner et al. as follows: "For a part P_i we determine the point along the viewing ray corresponding to the explosion point's projection which is closest to the center of P_i . The force F_v is then:"

$$F_v = \frac{c_v}{\|r\|} * \frac{r}{\|r\|} \quad (3.3)$$

Here c_v is again a constant factor and r a vector which points from the shortest point on the viewing axis to the center of the part P_i .

- **Spacing force:** The last force F_s pushes all parts away from each other to avoid overlapping and is described by the following formula:

$$F_v = \frac{c_s}{\|r\|^2} * \frac{r}{\|r\|} \quad (3.4)$$

Again, c_s is a constant factor and r is a vector pointing from the center of part P_i to the center P_j of every other part.

These forces are then weighted by Bruckner et al. and applied to each part. The result is a view-dependent explosion diagram which can be edited and expanded at runtime. Thus, it is also possible to uncover enclosed parts by separating the outer part through user input.

Sonnet et al. also use a similar force-based approach.[SCS04] However, their application differs in that a probe is used for explosion which the user can move through the dataset and whose effect radius determines the translation of the parts. An interesting addition presented for dealing with enclosed objects is that when loading the data set, the size of the bounding box determines the weight of the object. Smaller objects that are inside a larger one will hence be pushed away stronger from the effect radius of the probe. This method is a simple way to avoid occlusion in the case of an enclosed object, but it causes problems when the point used to explode the inner and outer object are the same, since the weighting then has no influence.

Virtual reality opens up new possibilities to interact with and study exploded views. In their paper, He et al. describe several types of interaction methods to explore a CAD model of a brain using VR devices.[HGM17] To compute an explosion graph that defines the transformation of the parts, they use the bounding box of each mesh, then build a complete bounding volume hierarchy from the bottom-up. This is necessary because medical data does not have a specific assembly order that can be revealed. In their work, they use parent-child relationships to constrain the transformation and guide it in a constructive manner. To allow for easy manipulation of the exploded view's axis, they use Hermit splines, which can be drawn with VR controllers. They also describe several ways of interacting with the mesh to trigger different exploded views:

- **linear explosion:** The user defines an axis by moving the controllers apart in parallel, the mesh is then pulled apart along this axis.
- **leafing interaction:** He et al. describe this interaction as slicing the object and then leafing through the pieces as if one were leafing through a book.

- **fanning interaction:** This interaction also first cuts the object into slices, then the individual slices are fanned out as if you were holding playing cards with their backs facing upwards in front of you.

Not only the interaction with VR plays an important role in this work, but also the special feature of a **time-varying data set**. Special measures are necessary to display these in an exploded view, but after extensive research no related work could be found. Therefore, in this work, a focus must be placed on solving this problem.

While exploded views are a large part of this work, they are not the only way to avoid occlusion. Another approach that can be combined well with interaction in VR is the use of **magic lenses**. This is like a kind of magnifying glass that allows the user to look inside an object and hide the obscuring geometry of the surface. One advantage of this over cutting planes is that the context is preserved because only a selective subarea is hidden. One possible implementation of this has been described by Viega et al. among others.[Vie+96] They hide the surface of a hand to reveal the underlying skeleton. The same concept was extended by Hua et al. to work in augmented reality with a physical prototype.[HB06] This also works like a magnifying glass which can be moved over a desktop and thus enables a look into the interior of various objects. For example, you can look inside the buildings of a model of a city or explore the inside of a human body. Their user study showed that "magic lenses are efficient cognitive filters that dynamically organize and display data when and where it is needed." [HB06] They proved to be more efficient and intuitive than a traditional interface, although their prototype lacked stability. Another alternative approach, which is combinable, is proposed by Preim et al. In their paper, they use different scaling techniques to enlarge and dynamically label objects of interest, making it easier to identify details.[PRS97]

Another unique method was presented by McGuffin et al.[McGuffin] They show various tools they have developed to inspect volumetric data by peeling and cutting parts away. They introduce a Leafer tool to slice and open the dataset, and a Peeler tool to show different layers of the dataset. They also introduce a Boxspreader tool that pushes voxels away, a Hinge Spreader tool, and a Sphere Extender tool to cut and extend different layers of the dataset. With these, complex transformations of the data are possible, which can provide insights into the interior of various volumetric data sets. One observation made by McGuffin et al. is that animations have greatly improved the usability of these tools, because without them, users had difficulty understanding how the tools operated.

Another related work was presented by Tania Krisanty at the Chair of Computer Graphics at the TU Dresden. She uses a similar slightly simplified version of the same data set used in this work and shows the use of cutting planes in virtual reality.[Kri22] She presents several interactions in virtual reality, like grabbing a new cutting plane from an imaginary backpack. One problem that arises is the loss of context when viewing the inner cells, a possibility that has been developed for this is the selective deactivation of cells, which eases the examination of individual cells in the interior, but does not solve the problem completely.

4 Methods and Implementation

5 Results

6 Conclusion and Further Work

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List of Figures

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A Appendix I

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

B Appendix II

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like "Huardest gefburn"? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.