TU WIEN Informatics

# Titel der Arbeit

## Optionaler Untertitel der Arbeit

BACHELORARBEIT

zur Erlangung des akademischen Grades

**Bachelor of Science**

im Rahmen des Studiums

**Medieninformatik und Visual Computing**

eingereicht von

**Pretitle Manuel Eiweck, Posttitle**
Matrikelnummer 0123456

an der Fakultät für Informatik

der Technischen Universität Wien

Betreuung: Pretitle Forename Surname, Posttitle
Mitwirkung: Pretitle Forename Surname, Posttitle
Pretitle Forename Surname, Posttitle
Pretitle Forename Surname, Posttitle

Wien, 1. Jänner 2001

| Manuel Eiweck | Forename Surname |
|---|---|

TU WIEN Informatics

# Title of the Thesis

## Optional Subtitle of the Thesis

BACHELOR'S THESIS

submitted in partial fulfillment of the requirements for the degree of

**Bachelor of Science**

in

**Media Informatics and Visual Computing**

by

**Pretitle Manuel Eiweck, Posttitle**
Registration Number 0123456

to the Faculty of Informatics

at the TU Wien

Advisor: Pretitle Forename Surname, Posttitle
Assistance: Pretitle Forename Surname, Posttitle
Pretitle Forename Surname, Posttitle
Pretitle Forename Surname, Posttitle

Vienna, 1st January, 2001

Manuel Eiweck | Forename Surname

# Erklärung zur Verfassung der Arbeit

Pretitle Manuel Eiweck, Posttitle

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

Wien, 1. Jänner 2001

Manuel Eiweck

# Danksagung

Danksagung

# Acknowledgements

Acknowledgments

# Kurzfassung

Kurzfassung

# Abstract

Abstract

# Contents

**Kurzfassung** **xi**

**Abstract** **xiii**

**Contents** **xv**

**1 Introduction** **1**
1.1 Motivation . . . . . 1
1.2 Aim of the Work . . . . . 2
1.3 Approach . . . . . 2

**2 Background** **3**
2.1 Visualization Techniques . . . . . 3
2.2 Network Visualization . . . . . 4
2.3 VR Technology . . . . . 4

**3 Related Work** **7**
3.1 Graph Visualizations . . . . . 7
3.2 VR Visualizations . . . . . 9
3.3 Application and Libraries . . . . . 11

**4 Proposed Solution** **13**
4.1 Concepts . . . . . 13
4.2 Position of Nodes . . . . . 14
4.3 Usage of different Visual Features . . . . . 15
4.4 Graph Exploration . . . . . 15
4.5 Interaction . . . . . 16

**5 Implementation** **17**
5.1 Preprocessing Scripts . . . . . 17
5.2 Position . . . . . 17
5.3 Rendering . . . . . 17
5.4 VR Interactions . . . . . 18
5.5 Scale . . . . . 18

**6 Results** **19**
6.1 Our Impression . . . . . 19
6.2 Performance . . . . . 19
6.3 Discussion . . . . . 19

**7 Conclusion and Future Work** **21**
7.1 Future Work . . . . . 21

**List of Figures** **23**

**List of Tables** **25**

**List of Algorithms** **27**

**Bibliography** **29**

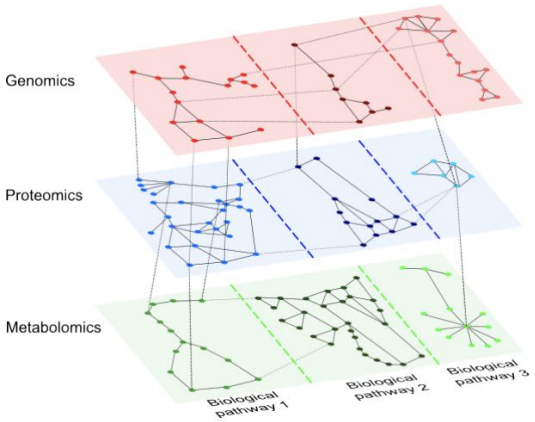
CHAPTER 1

# Introduction

## 1.1 Motivation

From proposal:
The goal is to visualize a hierarchical network with n Layers. Each Node in a graph can represent a graph itself. There are multiple examples where this has been visualised in 2D, however we believe that with an additional dimension and when 3D graphs are analysed in VR we can get even more insight and a better overview of the data.

**Starting idea: 2D Multilayer see figure, why not make use of all 3 axes in VR, instead of flat layers use 3D objects like cubes/spheres to bundle one layer**




(Email 14.08.2020 https://arxiv.org/pdf/1902.06815.pdf)

Ideas:

- Example applications with hierarchical network data
- current 2D visualizations of hierarchical networks
- power of VR visualizations and board availability

## 1.2 Aim of the Work

Ideas:

- provide a prototype application
- benefits of webbased implementation
- experiment with different concepts/approaches
- experiment with different interactions
- ...

> However, there is considerable value in research that solves a well-motivated problem using a combination of preexisting solutions

Sadana
Redefining a Contribution for Immersive Visualization Research

## 1.3 Approach

I want to give a short summary of chapter 4 proposed solution here.

Ideas:

- short description of planned final solution (web based, htc vive compatible, rendering multi hierarchical dataset, screenshot of solution)
- short overview of used technologies and frameworks why? what it simplifies, ...
- Customized Forces
- rendering, nodes inside parent, comparison to a default 2D Circle Packing plot https://observablehq.com/@d3/zoomable-circle-packing
- available interactions

CHAPTER 2

# Background

Hint:
1.line: One Author
2.line: Title
3.line: Desc

## 2.1 Visualization Techniques

Papers:

Shneiderman
The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations
Visual Information Seeking Mantra

Kobourov
Gestalt Principles in Graph Drawing

Brath
3D InfoVis is Here to Stay: Deal with It
Warum allgemein 3D Infos Vis Vorteile hat

Lee
Task Taxonomy for Graph Visualization
a list of tasks for graph visualization that has enough detail and specificity to be useful to: 1) designers who want to improve their system and 2) to evaluators who want to compare graph visualization systems.

## 2.2 Network Visualization

### 2.2.1 Network Visualization Basics

Kerren
**Introduction to Multivariate Network Visualization vorallem Chapter9: Heterogeneous Networks on Multiple Levels**
gute Zusammenfassung von Multilayer Network Visualization

West
Introduction to graph theory

### 2.2.2 Force-directed graph drawing

alt:
Fruchterman
Graph drawing by force-directed placement

Kamada Kawai
AN ALGORITHM FOR DRAWING GENERAL UNDIRECTED GRAPHS

aktueller:
Yifan Hu
Efficient, High-Quality Force-Directed Graph Drawing
Algorithmus für force Graph, Erklärkung barnes hut etc Sehr detailliert, viel info

Kobourov
Spring Embedders and Force Directed Graph Drawing Algorithms
Mehrere Algorithmen für Force Graph, Sehr detailliert

## 2.3 VR Technology

Content:

- Describe the technologie stack (OpenVR, WEBXR/WEBVR, A-Frame, ThreeJS)

- Devices, HTC-VIVE, Oculus-Rift, Vendors
- Room scale vs Table vs Standing, possibilities of tracking
- 6 DOF vs 3 DOF (degrees of freedom)
- Vergleich HMD zu früheren Möglichkeiten mit "Cave" Virtual Reality

official Specs / Docs:
Desktop API:
https://www.khronos.org/openxr/
https://github.com/ValveSoftware/openvr

Web API:
WebXR
https://immersiveweb.dev/
https://github.com/immersive-web/webxr/blob/master/explainer.md
https://immersive-web.github.io/webxr/
https://blog.mozvr.com/webxr-emulator-extension/

WebVR:(deprecated wird aber von unserer AFrame Version verwendet daher trotzdem relevant)
https://webvr.info/

Papers:
Cruz-Neira
The CAVE: audio visual experience automatic virtual environment

M Cordeil
Immersive Collaborative Analysis of Network Connectivity: CAVE-style or Head-Mounted Display?

CHAPTER 3

# Related Work

## 3.1 Graph Visualizations

### 3.1.1 Layout

#### Tree Visualization

Shneiderman
Tree visualization with tree-maps: 2-d space-filling approach

Schulz
Treevis.net: A Tree Visualization Reference

Wang
Visualization of large hierarchical data by circle packing
In this paper a novel approach is described for tree visualization using nested circles. (2D+3D)

Görtler
Bubble Treemaps for Uncertainty Visualization

#### Force based

Papers:

Kobourov
Spring Embedders and Force Directed Graph Drawing Algorithms

In this survey we consider several classical algorithms ... for large and dynamic graphs

Jacom
ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software
Forcetlas2 is a force-directed layout close to other algorithms used for network spatialization. Integrate different techniques.

**VR Specialized Layouts**

Kwon
A Study of Layout, Rendering, and Interaction Methods for Immersive Graph Visualization

### 3.1.2 Multilayer Visualization

Ghonie McGee
The State of the Art in Multilayer Network Visualization

De Domenico
MuxViz: a tool for multilayer analysis and visualization of networks
We demonstrate the ability of muxViz to analyse and interactively visualize multilayer data using empirical genetic, neuronal and transportation networks https://github.com/manlius/muxViz

### 3.1.3 Hierarchical Visualization

Nobre
The State of the Art in Visualizing Multivariate Networks

Shi
Hierarchical Focus+Context Heterogeneous Network Visualization
OnionGraph, aggregated based on node attributes or network topology, best of both worlds.

Jonker
Graph mapping: Multi-scale community visualization of massive graph data

Balzer
Hierarchy Based 3D Visualization of Large Software Structures

Holten
Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data

Itoh
Hierarchical data visualization using a fast rectangle-packing algorithm

Munzner
H3: laying out large directed graphs in 3D hyperbolic space

Mansmann
Exploring OLAP aggregates with hierarchical visualization techniques

## 3.2 VR Visualizations

Sorger
Immersive Analytics of Large Dynamic Networks via Overview and Detail Navigation
Orig Paper https://vis.csh.ac.at/vrnetexplorer/

Kwon
A Study of Layout, Rendering, and Interaction Methods for Immersive Graph Visualization
considerations of layout, rendering, and interaction methods for visualizing graphs in an immersive environment user study to evaluate our techniques
Strat: The viewer is placed at the center of the sphere, on which the graph is laid out.

Büschel
Augmented Reality Graph Visualizations
We present an exploration of the design space for edge styles and discuss the results of a user study comparing six different edge variants.

Yang
Embodied Navigation in Immersive Abstract Data Visualization: Is Overview+Detail or Zooming Better for 3D Scatterplot

Halpin
Exploring Semantic Social Networks Using Virtual Reality

### 3.2.1 Advantages of Visualization in VR

Kraus
The Impact of Immersion on Cluster Identification Tasks
quantitative user study to investigate the impact of immersion on cluster identification tasks in scatterplot visualizations

Doug A. Bowman
Virtual Reality: How Much Immersion Is Enough?

M Cordeil
Immersive Collaborative Analysis of Network Connectivity: CAVE-style or Head-Mounted Display?

### 3.2.2 Navigation

Content:

- "Minimap"/Worlds-in-Miniature (WIM) in VR
- Scaling
- Room scale vs Table vs Seating
- Overview + Detail

Papers:

M Usoh
Walking > walking-in-place > flying, in virtual environments

Zielasko
Remain seated: towards fully-immersive desktop VR

Drogemuller
Examining virtual reality navigation techniques for 3D network visualisations

Wolfgang Stuerzlinger
Simulated Reference Frame: A Cost-Effective Solution to Improve Spatial Orientation in VR
aka. Nintendo Wii Board Navigation

**Wolfgang Stuerzlinger**
**Evaluating Automatic Parameter Control Methods for Locomotion in Multi-scale Virtual Environments**

### 3.2.3 Interaction

Content:

- Edge Filtering
- Raycast/Laserpointer Selection

Yi-Jheng Huang
A gesture system for graph visualization in virtual reality environments

Drogemuller
VRige: Exploring Social Network Interactions in Immersive Virtual Environments
Raycast+Filter Cube

Wolfgang Stürzlinger
Analyzing the Trade-off between Selection and Navigation in VR

## 3.3 Application and Libraries

References: https://neo4j.com/developer/tools-graph-visualization/

### 3.3.1 Applications

Software
Gephi

Software
Neo4j Bloom

### 3.3.2 Libraries

Bostock
D3: Data-Driven Documents
Examples

Software

http://www.popotojs.com/

Software
https://visjs.org/

CHAPTER 4

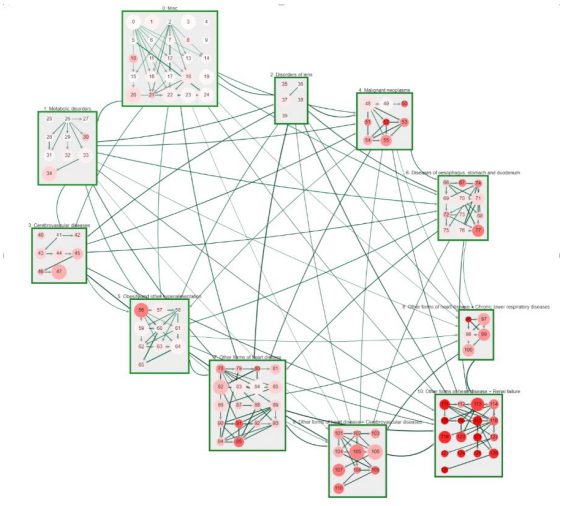
# Proposed Solution

Ideas:

- Progress
  - begin flat multilayer rendering

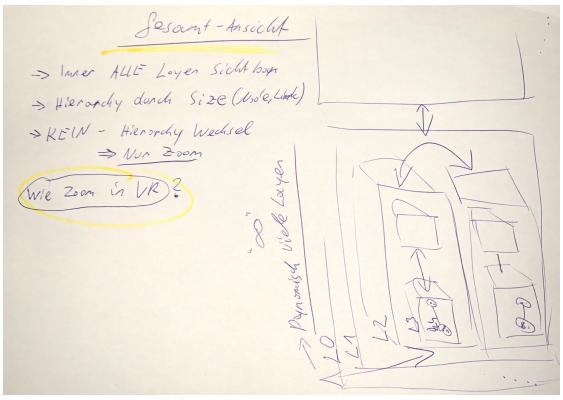
## 4.1 Concepts

### 4.1.1 Original 2D Visualization



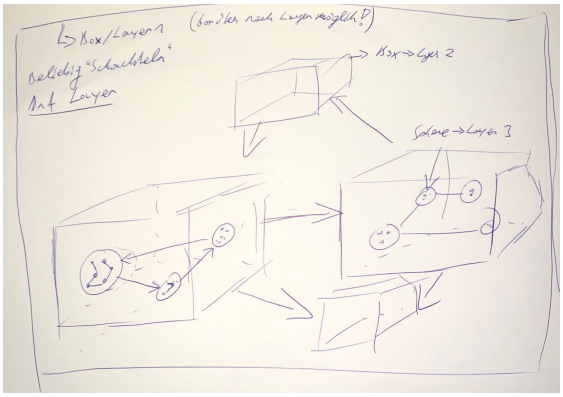
Problem only two layers supported

### 4.1.2 2-Layer Concept




Cube/ (half) sphere position of sub-graphs
Starting idea, why it was discarded

### 4.1.3 n-Layer Concept




Improved concept
no fixed cube/(half) sphere position instead each layer calculate its own position
circle over boxes
Begin: flyspeed only, later on problem on VR

## 4.2 Position of Nodes

Independent per layer / sub-graph inside parent node
use of existing implemented and already good tested(prevents overlapping, good distribution, ...) forces (collision, link, manyBody, ...)
use of own forces to place sub-graphs inside parent graphs
adjustable force strengths
Node size grow with number of child nodes

two possible solutions: web-worker vs live

## 4.3 Usage of different Visual Features

Position
linkWidth
linkColor
linkDirection
currentLayer on Controller Overlay

## 4.4 Graph Exploration

### 4.4.1 Overview Layout

Orbital Camera

### 4.4.2 Detail Layout

Free Fly Camera
change FlySpeed based on current node the camera is located. As deeper the layer as slower the flyspeed
Problem experiments showed this does not work well in VR –> manual / automated scaling.

flyToNode
flyToParentLayer

### 4.4.3 Visibility of the Visualization

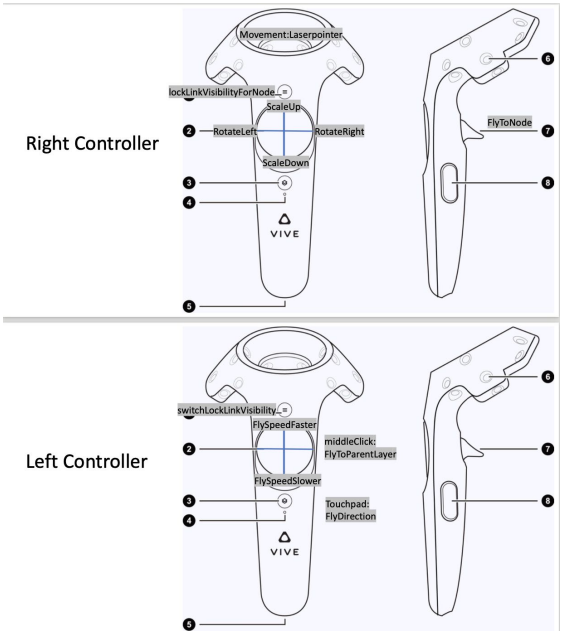
#### Nodes / Layers

wireframe

#### Links

lockLinks

## 4.5 Interaction



CHAPTER 5

# Implementation

## 5.1 Preprocessing Scripts

Flexible transforming any CSV Data to our own data format
generation of test data
coloring, filtering, ... parameter
File Format of final processed .JSON for the actual web-based visualization

## 5.2 Position

### 5.2.1 D3-Forces

List of used forces and its strength/importance, why is each force included

### 5.2.2 Optimization

Separate Forces per layer and calculating them successively.

## 5.3 Rendering

### 5.3.1 Instanced nodes

### 5.3.2 Transparency

### 5.3.3 Visability

Nodes (wireframe), Links ausblenden.

## 5.4 VR Interactions

### 5.4.1 Camera Rig vs Camera

camera rotation, correct position

### 5.4.2 Flyspeed

### 5.4.3 Button Mapping

### 5.4.4 Raycast(nur bei Bedarf da keine eigene Implementerung)

## 5.5 Scale

### 5.5.1 Scale of layer components

Scale of nodes, link, label, ...

### 5.5.2 Scaling interactions

Relevant Paper:
Axelsson
Dynamic Scene Graph: Enabling Scaling, Positioning, and Navigation in the Universe

**Manual scaling**

**Automated scaling**

CHAPTER 6

# Results

## 6.1 Our Impression

### 6.1.1 Clarity of the Visualization

Information Density ...

## 6.2 Performance

### 6.2.1 Measurements

### 6.2.2 Possible optimization

## 6.3 Discussion

### 6.3.1 Flyspeed vs Scaling

Scaling only necessary in VR due to missing spatial impression in Browser Only Mode as there is no walkable area / moveable area with the head.

### 6.3.2 Automated interactions vs manual interactions

CHAPTER 7

# Conclusion and Future Work

## 7.1 Future Work

Ideas:

- refactor application with the knowledge of the learned mistakes, remove "Aframe-forcegraph-component" as we are not really using any feature now, use a clean dependency management
- port to newer version of A-Frame and Three-Js
- after upgrading A-Frame version optimize for other VR Headsets, Oculus Quest, ...
- add hand gesture support
- optimize data structure (tree data structure with optimized searched methods)
- experiment with different visibility of links/nodes/layers
- ...

# List of Figures

# List of Tables

# List of Algorithms

# Bibliography