

Evaluating Immersive Approaches to Multidimensional Information Visualization

Jorge Alberto Wagner Filho

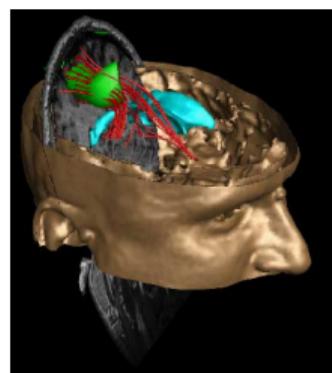
Advisor: Prof. Luciana Nedel
Co-advisor: Prof. Carla Freitas

Graduate Program in Computer Science
Federal University of Rio Grande do Sul

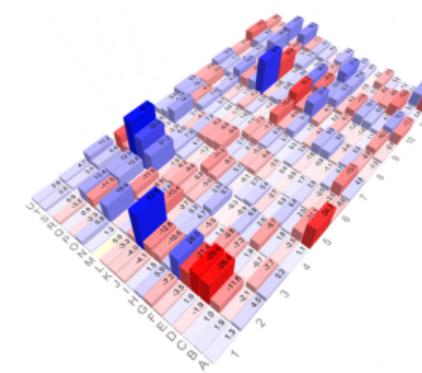
March 7, 2018

Motivation

- **3D representations** are known to offer advantages under many circumstances



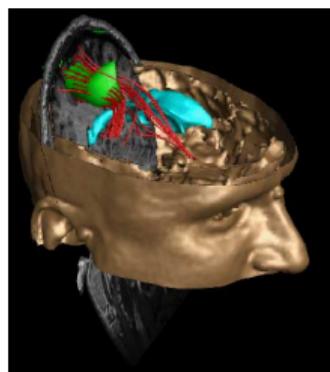
Spatial data (OpenDX.org)



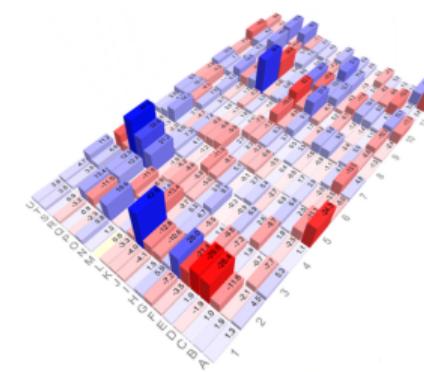
Abstract information (Brath, 2014)

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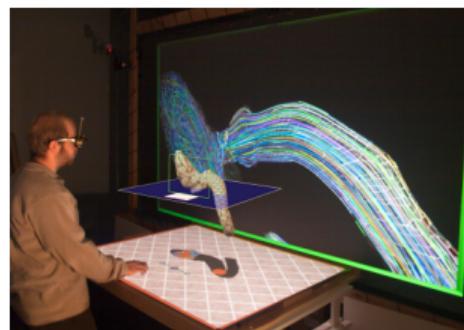
- Nonetheless, their use has also been long **controversial**
 - **Perception** issues
 - **Interaction** issues
 - Data exploration is cumbersome and error-prone

Motivation

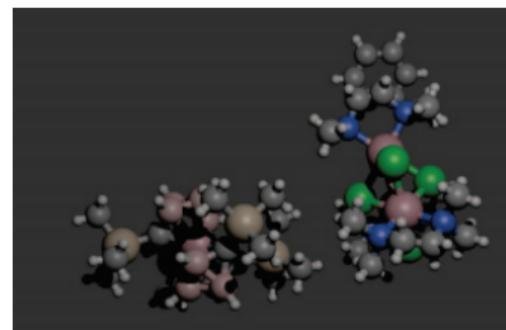
- Progressively explored alternative: **Immersive Analytics**
 - Stereoscopic displays + natural 3D interaction

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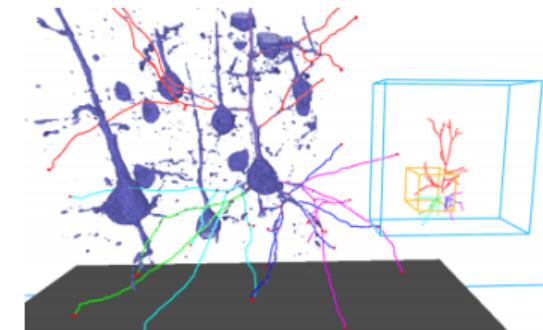
- Progressively explored alternative: **Immersive Analytics**
 - Stereoscopic displays + natural 3D interaction
- Multiple favourable results for **spatial data**



Coffey et al., 2011



Drouhard et al., 2015

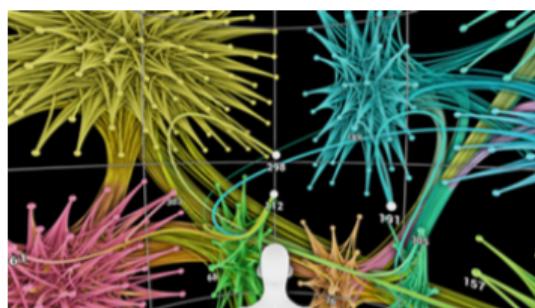


Usher et al., 2017

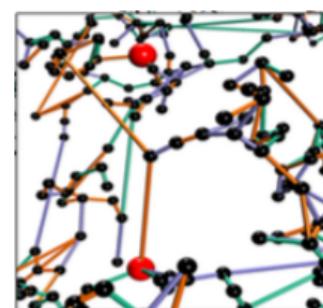
Motivation

- Immersive Analytics of abstract information

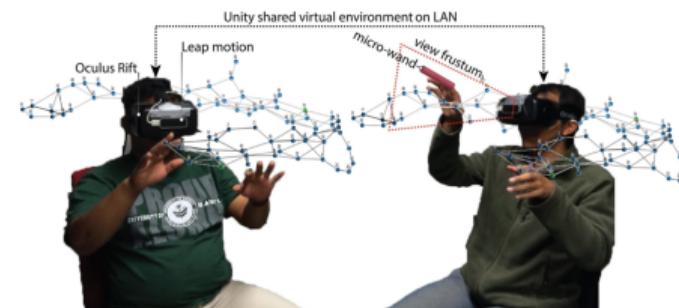
- New evaluations and guidelines are still needed
 - Some promising results have already been demonstrated (e.g. **graph visualization**)



Kwon et al., 2016



Zielasko et al., 2016



Cordeil et al., 2017

Main Goal

- Expand this discussion, taking into consideration a different representation: **3D scatterplots of dimensionally-reduced (DR) data**

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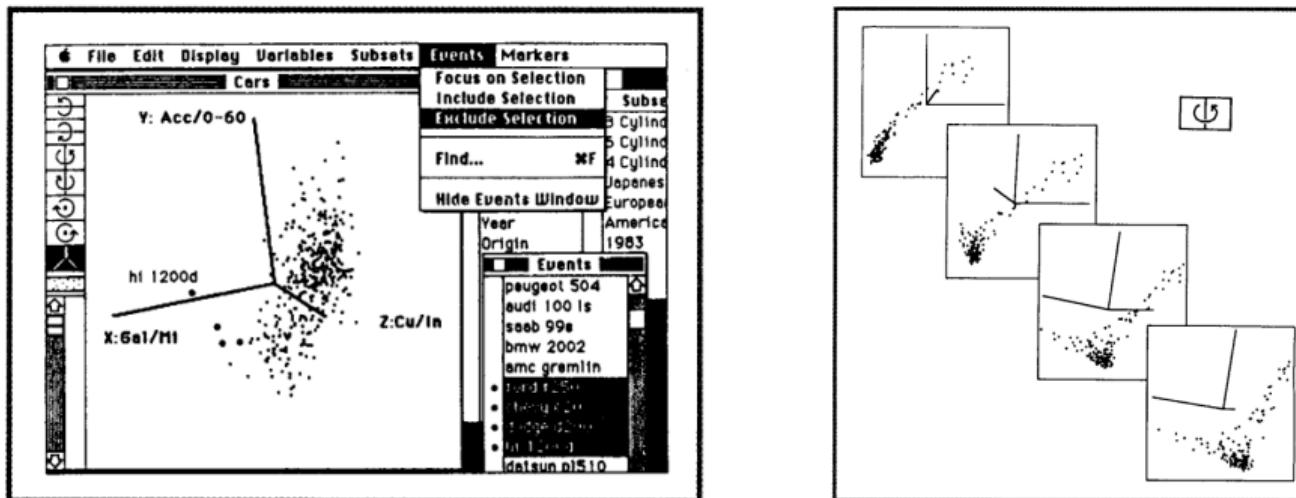
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 - Common approach to multidimensional data visualization
 - Potential advantage in transitioning from 2D to 3D

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- Expand this discussion, taking into consideration a different representation: **3D scatterplots of dimensionally-reduced (DR) data**
 - Common approach to multidimensional data visualization
 - Potential advantage in transitioning from 2D to 3D
 - **Main hypothesis:** since this particular category of scatterplots is always analysed in terms of the distances between points, it could benefit from immersive setups

Context

- The use of **3D scatterplots** has been controversial for a long time



Donoho et al., 1988

Context

- The use of 3D scatterplots for the representation of **DR data** is also often discussed → **contradictory results**
 - Poco et al., 2011
 - Sedlmair et al., 2013
 - Gracia et al., 2016

Context

- Few studies on the impact of **immersion** and stereopsis
 - Most provided only preliminary results
 - Used technologies that have advanced enormously since
 - Used CAVE-style environments



Raja et al., 2004

Research Question

- Could HMD-based immersive environments aid in the exploration of 3D DR data scatterplots?



The Oculus Rift HMD ([ArsTechnica.com](#))

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WIA @ IEEE VIS 2017

Outline

1 Methodology

2 User Study 1: Conventional Flying Approach Evaluation

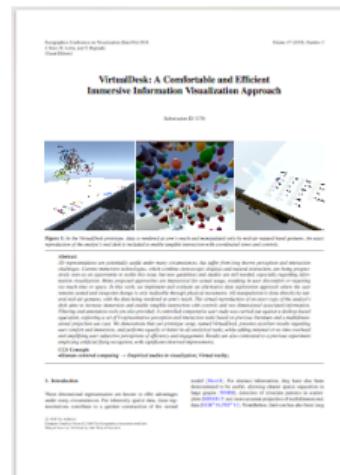
3 VirtualDesk: Novel Proposed Approach

4 User Study 2: VirtualDesk Evaluation

5 Conclusion



IEEE VR 2018 (to appear)



EuroVis 2018 (2nd review round)

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Key Questions

- ➊ How do we assess the contribution of immersive approaches to the analysis of 3D DR data scatterplots?

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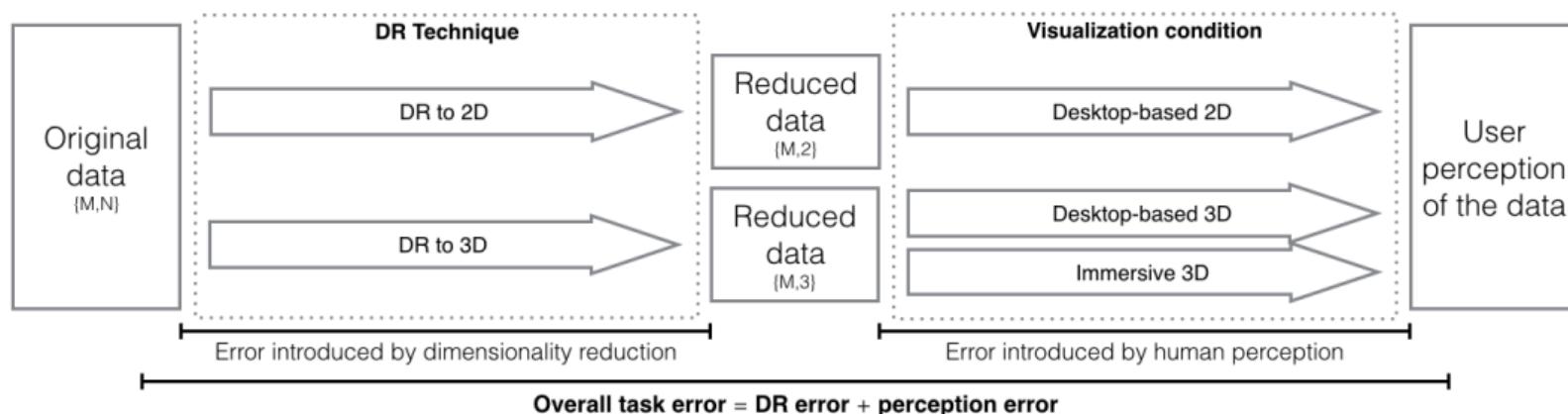
- ① How do we assess the contribution of immersive approaches to the analysis of 3D DR data scatterplots?

- ① What are the specific factors that vary between desktop-based (2D/3D) and HMD-based (3D) approaches?

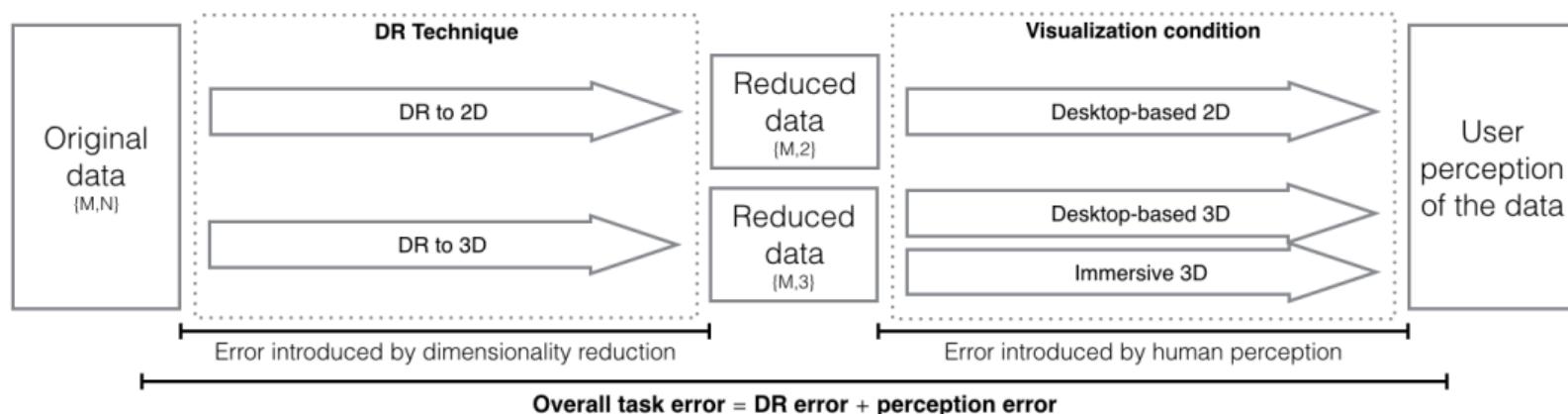
Key Questions

- ① How do we assess the contribution of immersive approaches to the analysis of 3D DR data scatterplots?
 - ① What are the specific factors that vary between desktop-based (2D/3D) and HMD-based (3D) approaches?
 - ② How to quantify each of these factors?

Problem Modelling

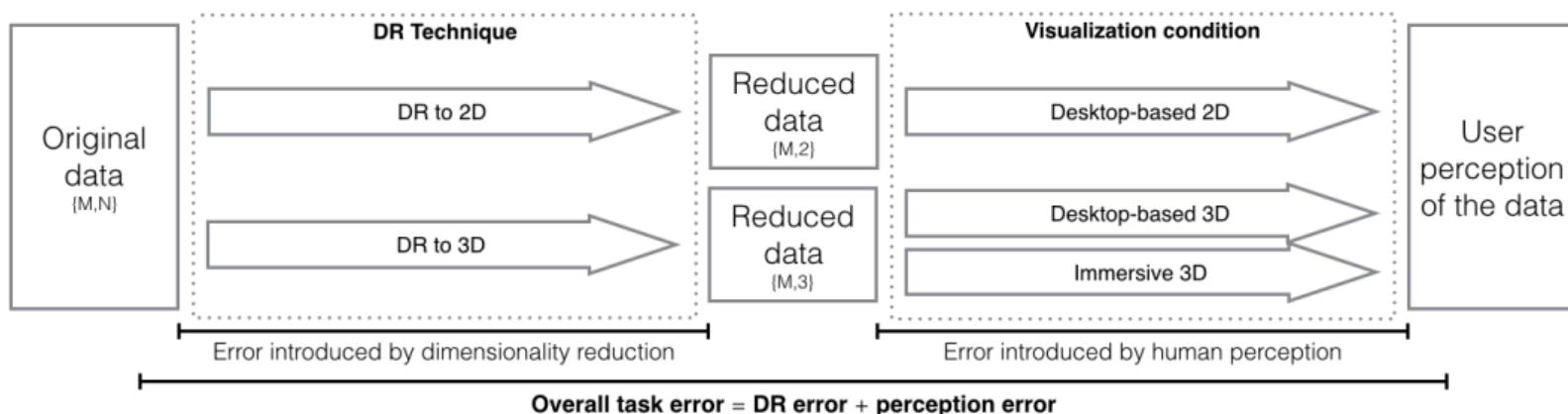


Problem Modelling



- Task-dependent
- Dataset-dependent

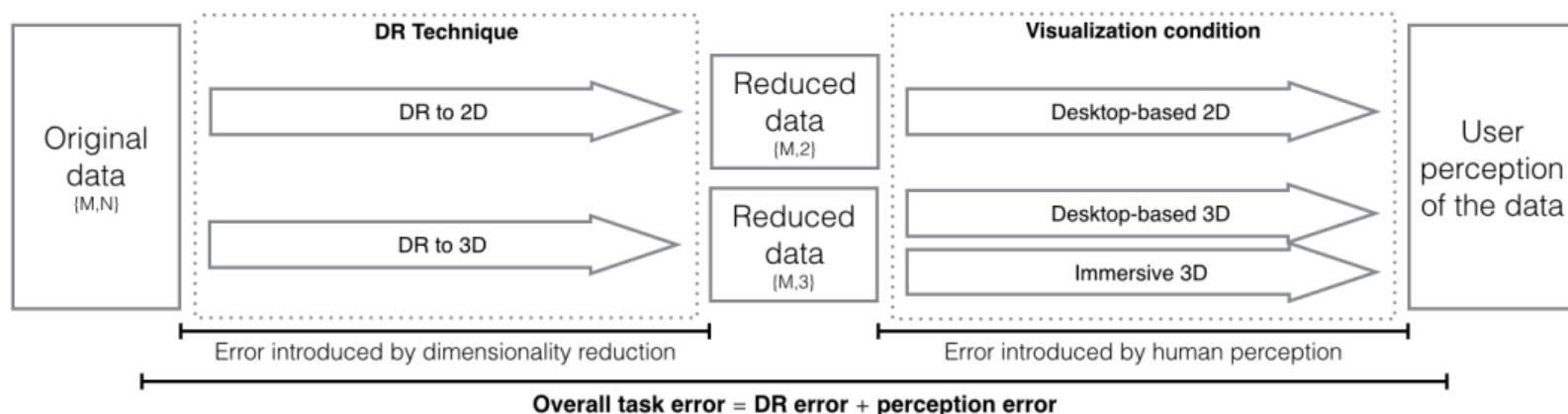
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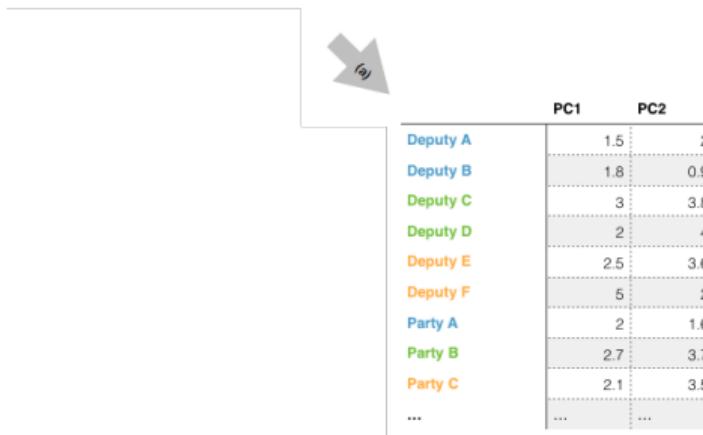
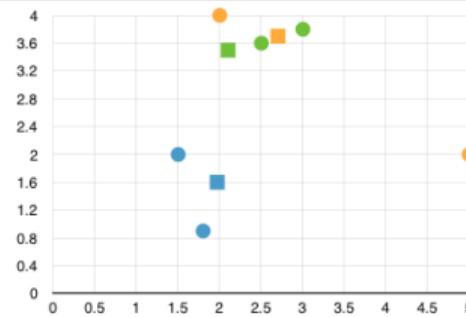
→ Two-step evaluation framework

Targeted Use Case

- Multidimensional **roll call voting** data from the Brazilian Chamber of Deputies
 - Very high dimensionality (430-620)
 - Consistent application of DR techniques
 - Easy definition of semantically meaningful tasks
 - Appeal to the public
- Four legislature datasets: 52nd, 53rd, 54th and 55th

Targeted Use Case

	Roll call 1	Roll call 2	Roll call 3	Roll call 4	Roll call 5	...
Deputy A	Yes (1)	No (-1)	No (-1)	Yes (1)	Yes (1)	...
Deputy B	Absent (0)	Yes (1)	No (-1)	No (-1)	Absent (0)	...
Deputy C	Yes (1)	No (-1)	Yes (1)	No (-1)	Absent (0)	...
Deputy D	No (-1)	...				
Deputy E	No (-1)	Yes (1)	Yes (1)	Yes (1)	No (-1)	...
Deputy F	Yes (1)	No (-1)	Yes (1)	Yes (1)	Yes (1)	...
Party A	Yes (1)	No (-1)	Yes (1)	No (-1)	No (-1)	...
Party B	No (-1)	No (-1)	No (-1)	Yes (1)	Yes (1)	...
Party C	Yes(1)	No (-1)	Yes (1)	No (-1)	No (-1)	...
...



Task Set

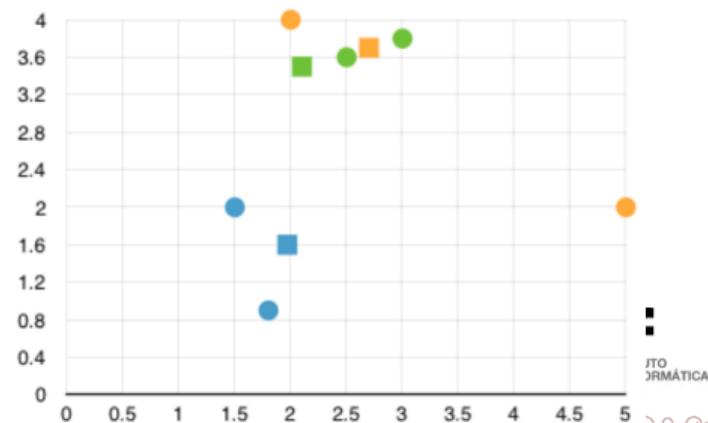
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 - Tasks should assess different competencies in distance judgements
- Designed to be simple and atomic

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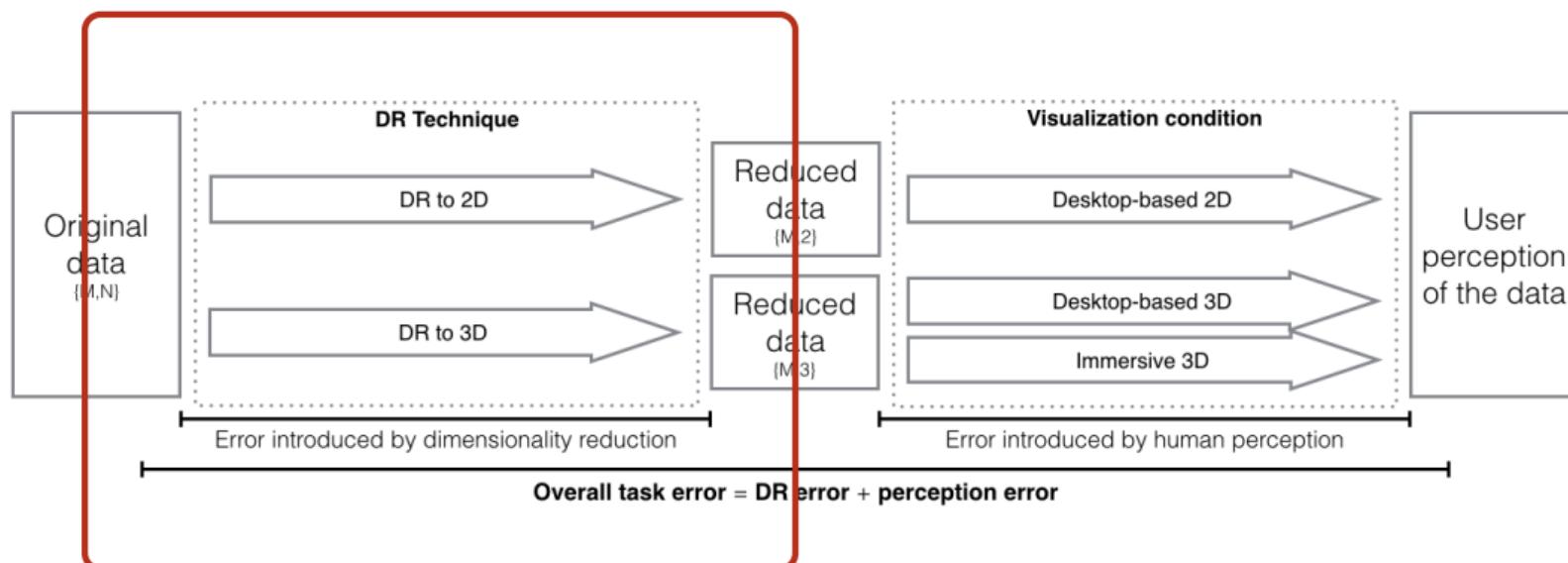
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Point-based distance perception tasks

- T1 *Selection of a deputy's closest deputy*
- T2 *Selection of a deputy's closest party*
- T3 *Selection of a party's furthest member*
- T4 *Selection of a party's closest party*



Step 1: Task-based DR Error Estimation



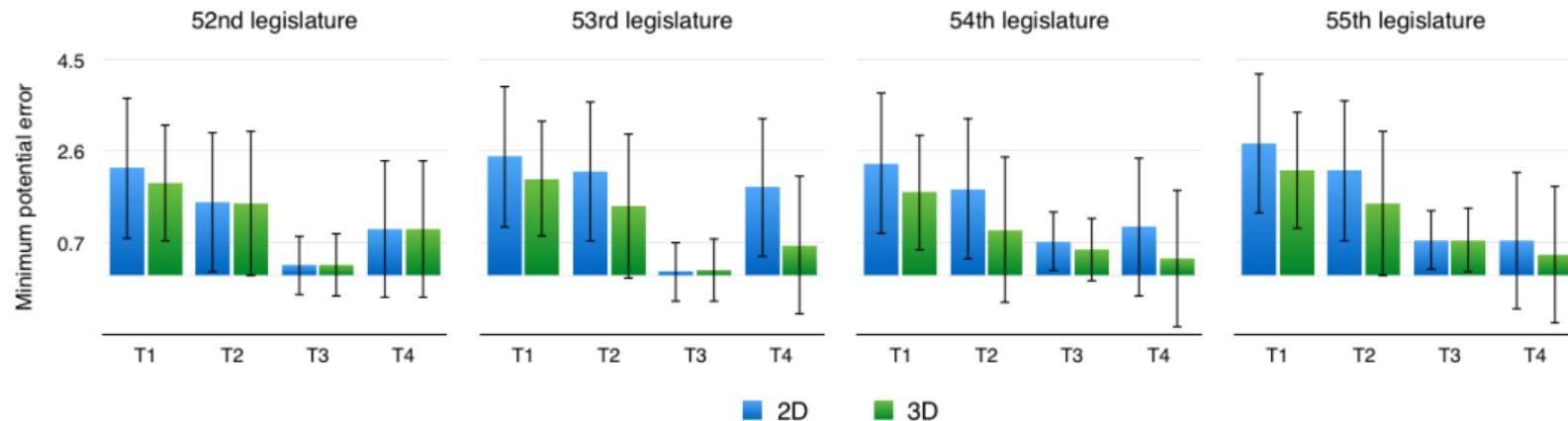
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 - Difficult to estimate real impact on analytical performance
 - Hard to conjecture whether interaction trade-off is worth it

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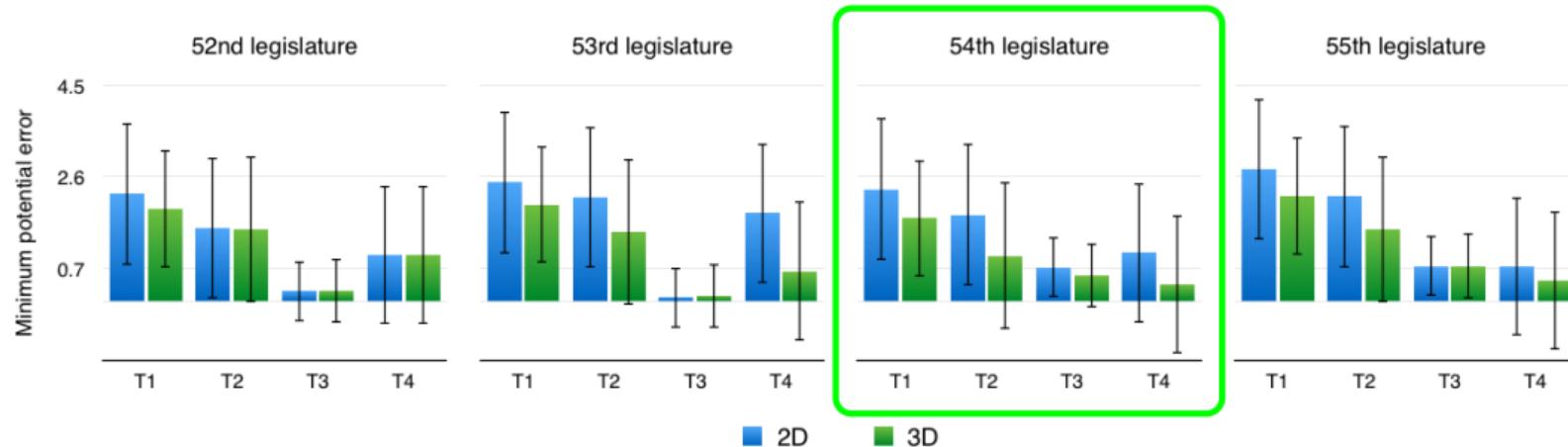
- Current approaches to DR information loss estimation
 - Difficult to estimate real impact on analytical performance
 - Hard to conjecture whether interaction trade-off is worth it
- Our approach
 - Empirical, task-based
 - **Maximum potential performance** concept
 - **Simulation** of the *minimum error* a user could achieve in each scenario (2D/3D)
 - Assuming absolute accuracy in perceiving the presented information
 - Averaged over all possible instances of a task

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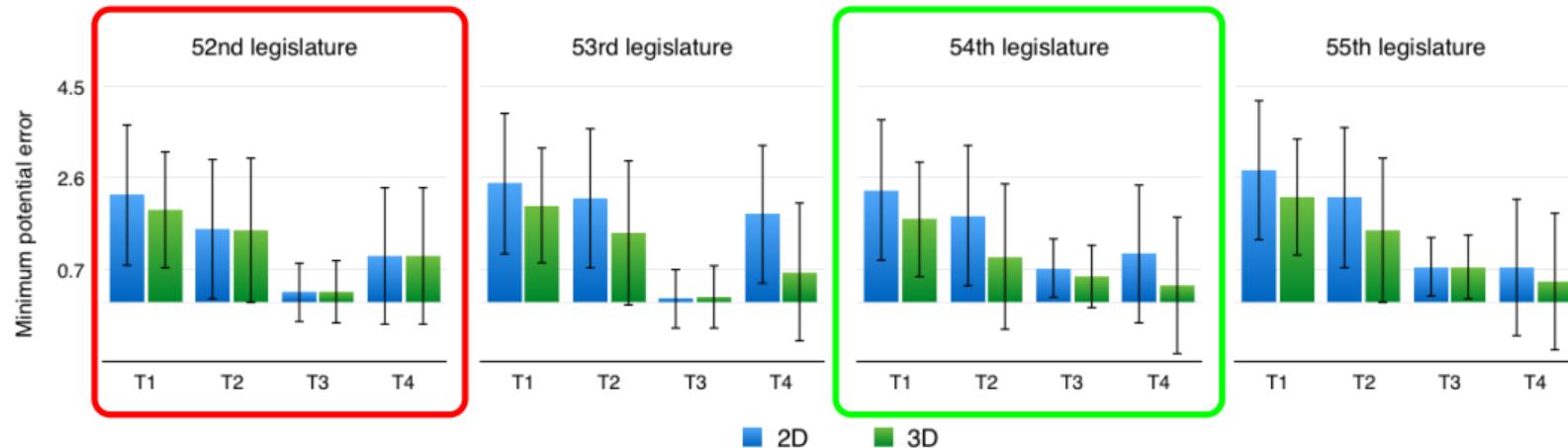
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 - 54th legislature: all tasks appear to benefit from 3D → D1
 - 52nd legislature: no task appears to benefit from 3D → D2

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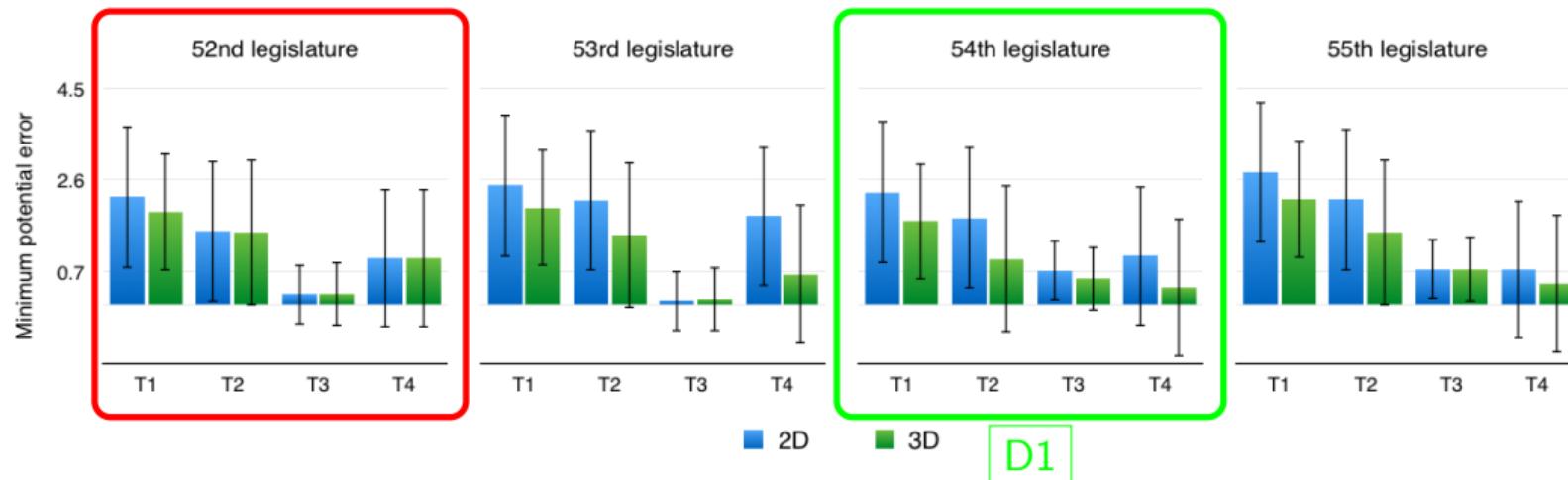
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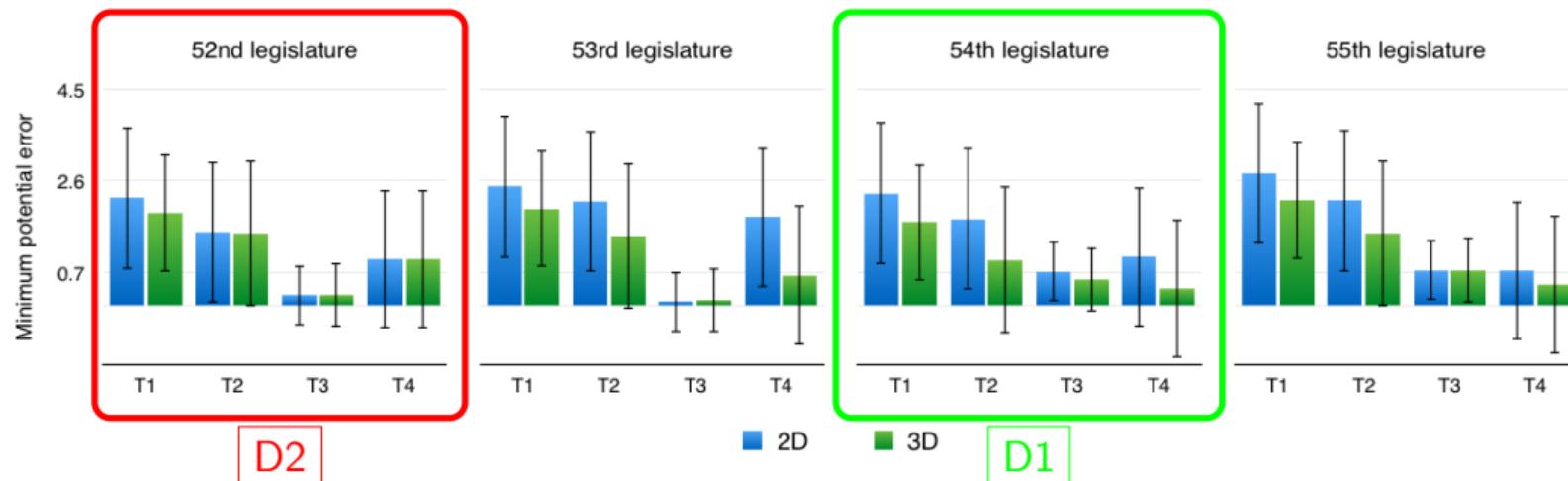
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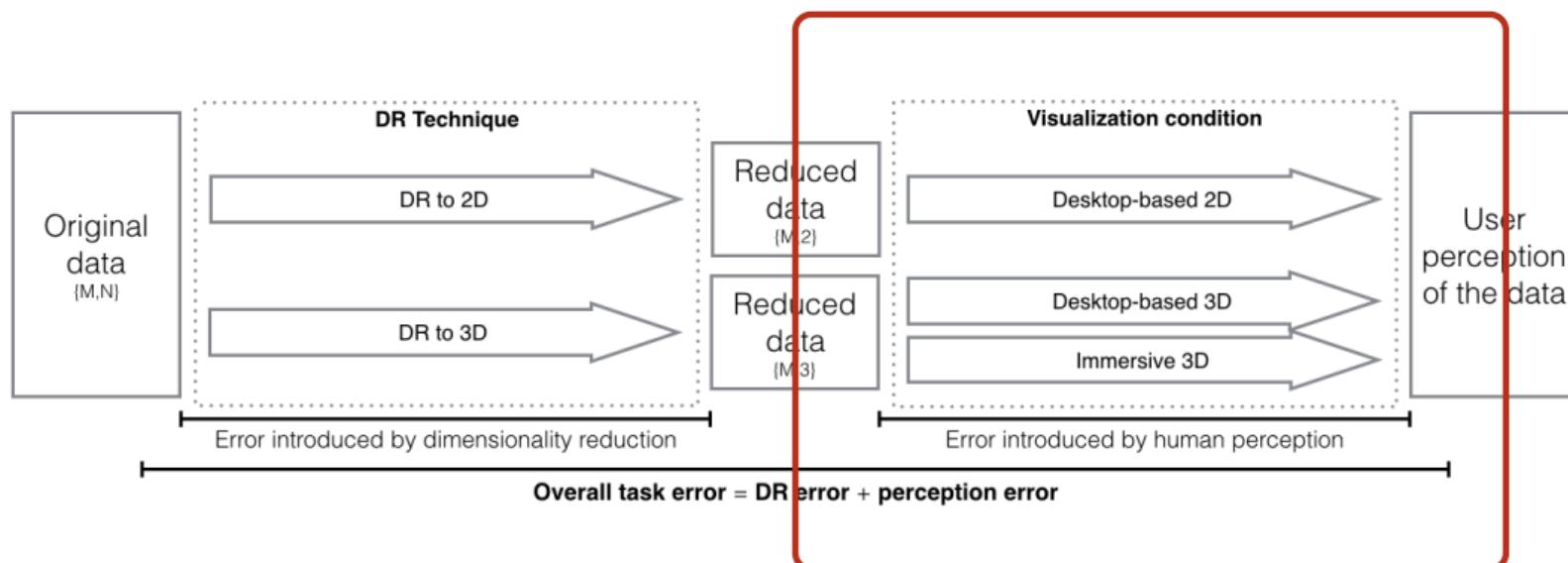
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Step 2: Perception and Overall Error Assessment



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- Evaluation approach: **controlled comparative user studies**
 - Within-subjects protocols
 - Standardized questionnaires (SUS, Nasa TLX, SSQ, IPQ)

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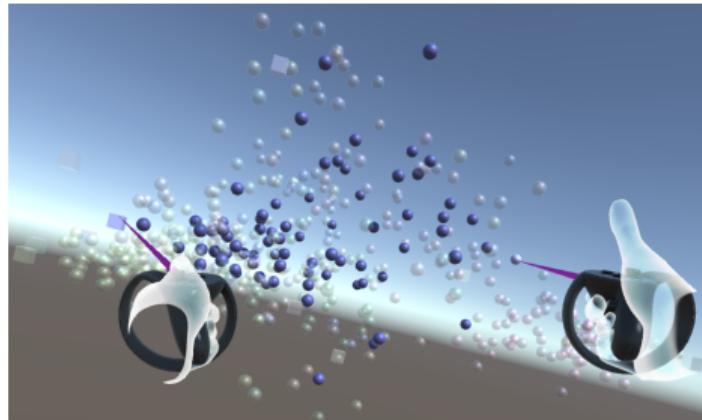
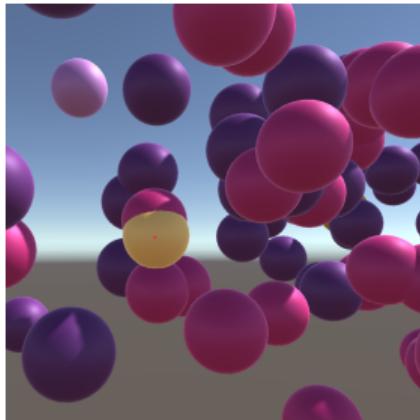
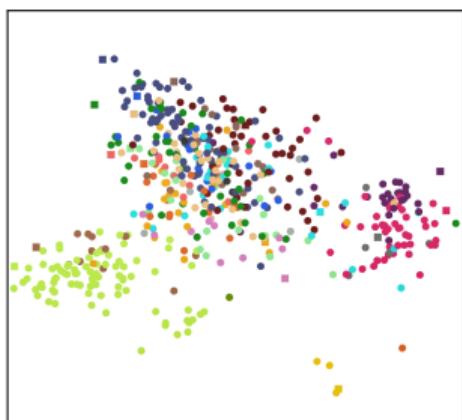
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First User Study

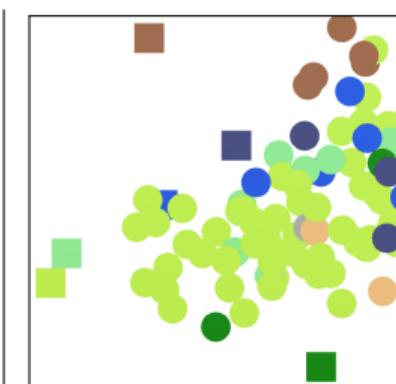
- 30 subjects (20 male/10 female)
- Comparison between **three conditions**
 - Desktop-based 2D (2D)
 - Desktop-based 3D (3D)
 - HMD-based 3D (*IM*)
- Immersive approach: **Gaze-directed Flying**
 - Conventional metaphor
 - Simple to learn
 - Places the user inside the representation

Visualization Conditions – Interaction

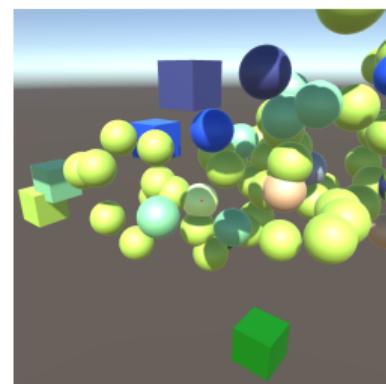


- Possible actions:
 - **Select** point
 - **Highlight** whole party

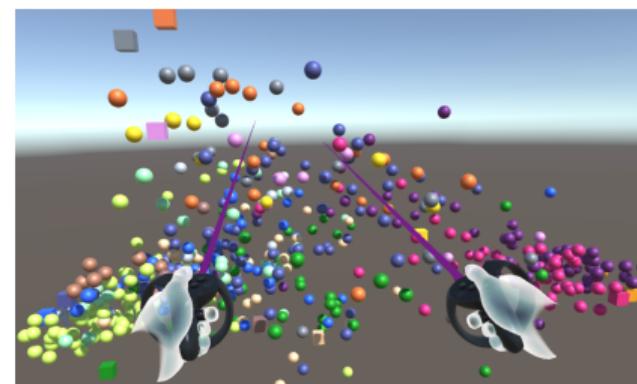
Visualization Conditions – Selection & Navigation



2D



3D



IM

Selection

Mouse cursor

Reticle cursor

Pointer rays

Navigation

Zooming + Panning

Flying + Strafing

Hypotheses

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- H4** *2D* will be the quickest, given its smaller navigation and interaction costs.

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- H5** The benefits provided by immersion will be reflected on the subjective evaluations.

Experiment Design

- For each of the *3 visualization conditions*
 - Familiarization phase on a separate dataset
 - For each of the *4 tasks*
 - 3 executions in one dataset
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- Question sets repeated only once per condition
 - Maximized sampling and *cross-validation*
- Total time: ~45 min (incl. questionnaires)

Results: Perception Errors

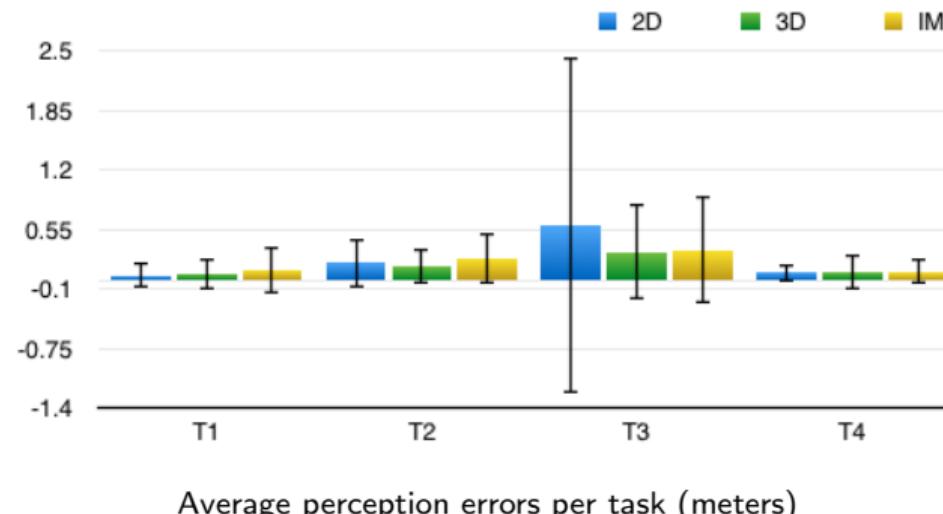
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- Difference in Euclidean distances, **in two or three dimensions**, to the given answer and to the correct one **in the representation**
- In this analysis, we do not differentiate between datasets
- Surprisingly, no significant differences were observed (**H1**)



Results: Overall Task Errors

- Differences in Euclidean distances, **in the original vote matrix**, to the given answer and to the correct one **in the real multidimensional data set**

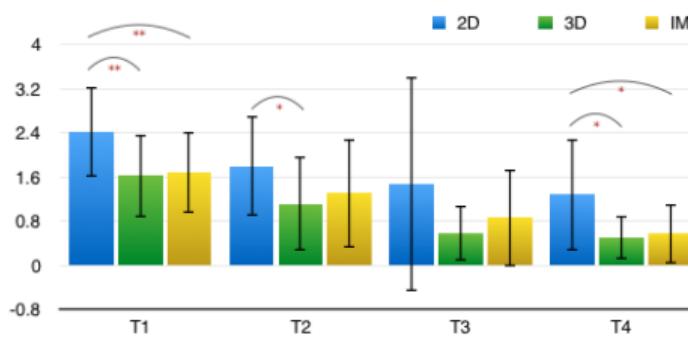
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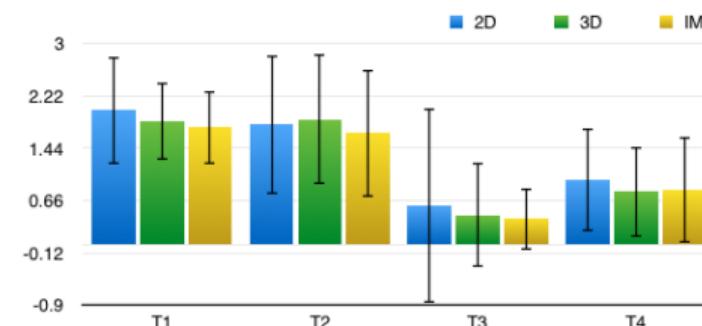
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(a) D1



(b) D2

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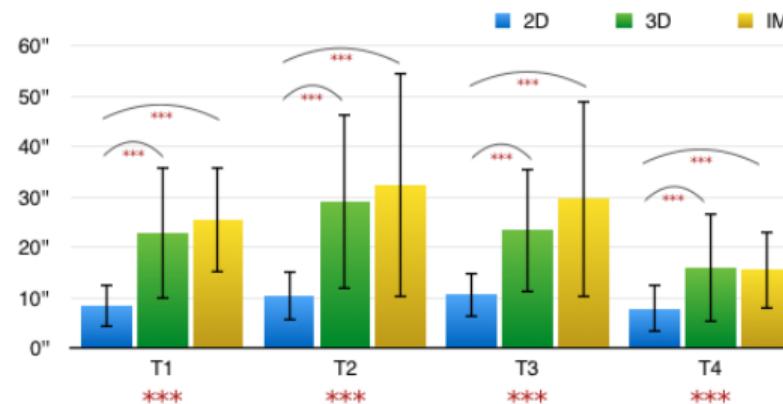
Results: Task Completion Time

- 2D allowed consistently faster task completion (**H4**)

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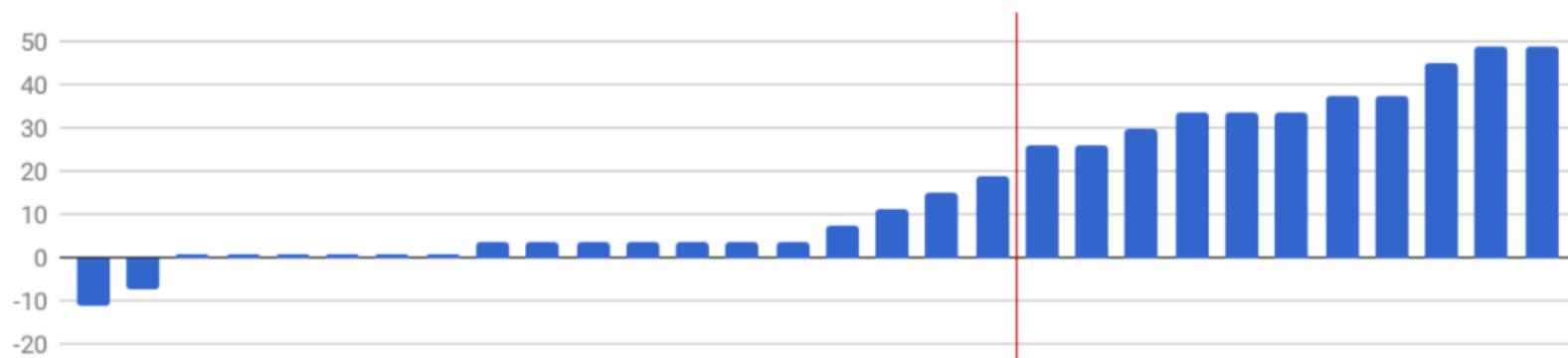
- 2D allowed consistently faster task completion (**H4**)
- 3D and IM did not show significant differences in any case
 - **Despite** slower navigation in IM
 - Explanation: **navigation** was larger in Desktop 3D (up to 38%)



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Results: Simulator Sickness

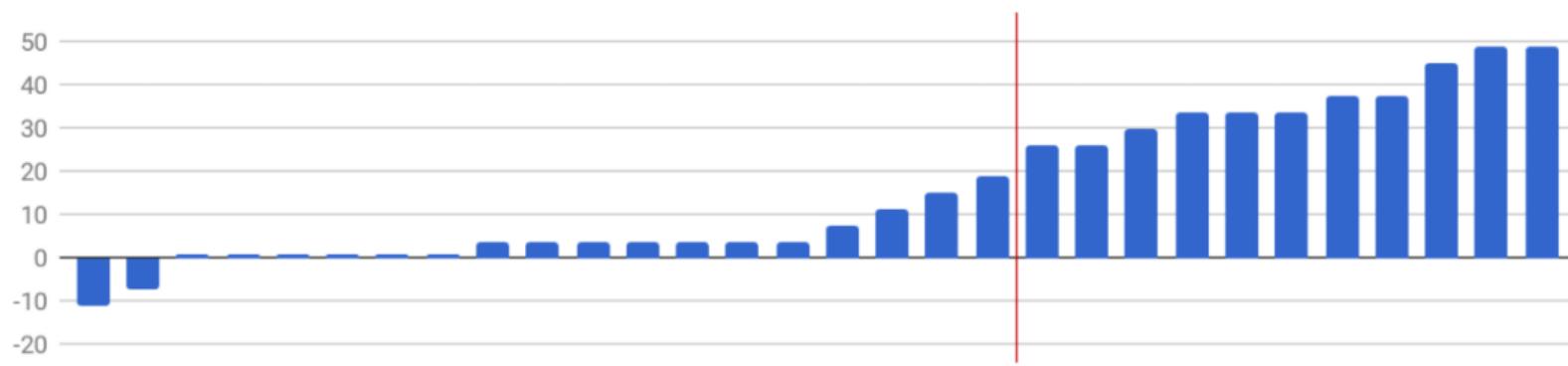
- Around 60% of the participants reported only minor symptoms



Participants' SSQ scores in increasing order

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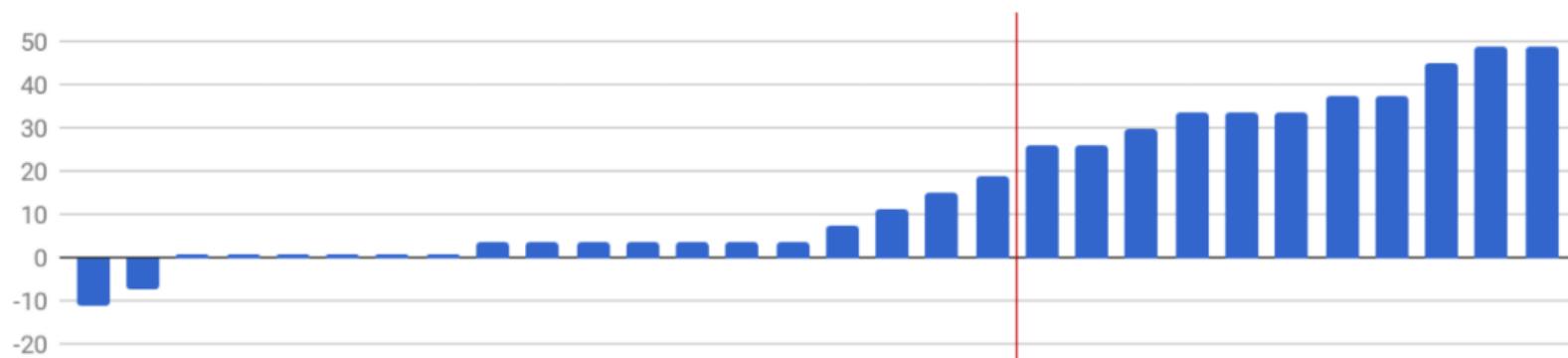
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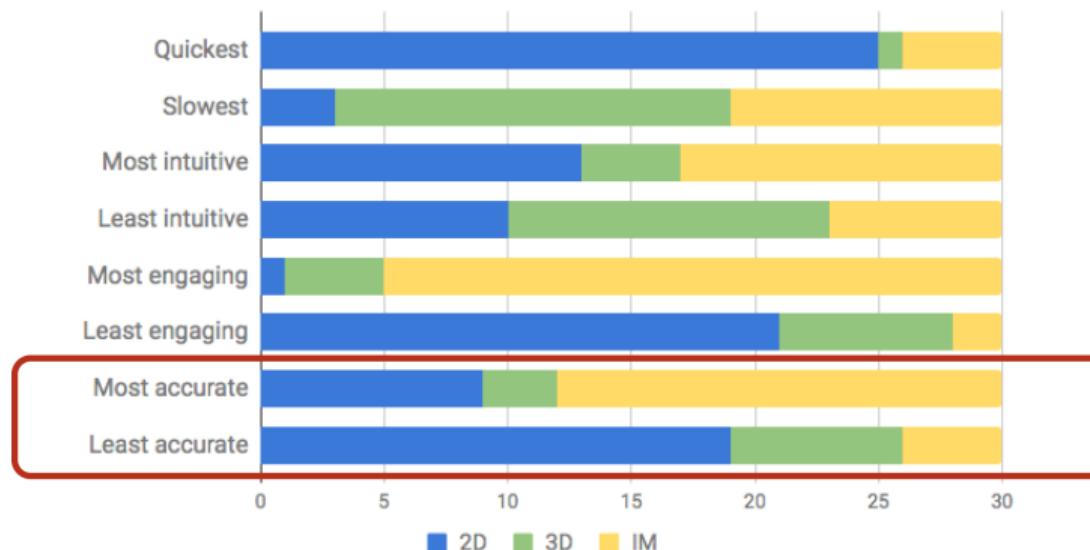
- Around 60% of the participants reported only minor symptoms
- Others, however, presented quite significant discomfort levels
- Perception results did **not** appear to be impacted (-0.1 correlation)



Participants' SSQ scores in increasing order

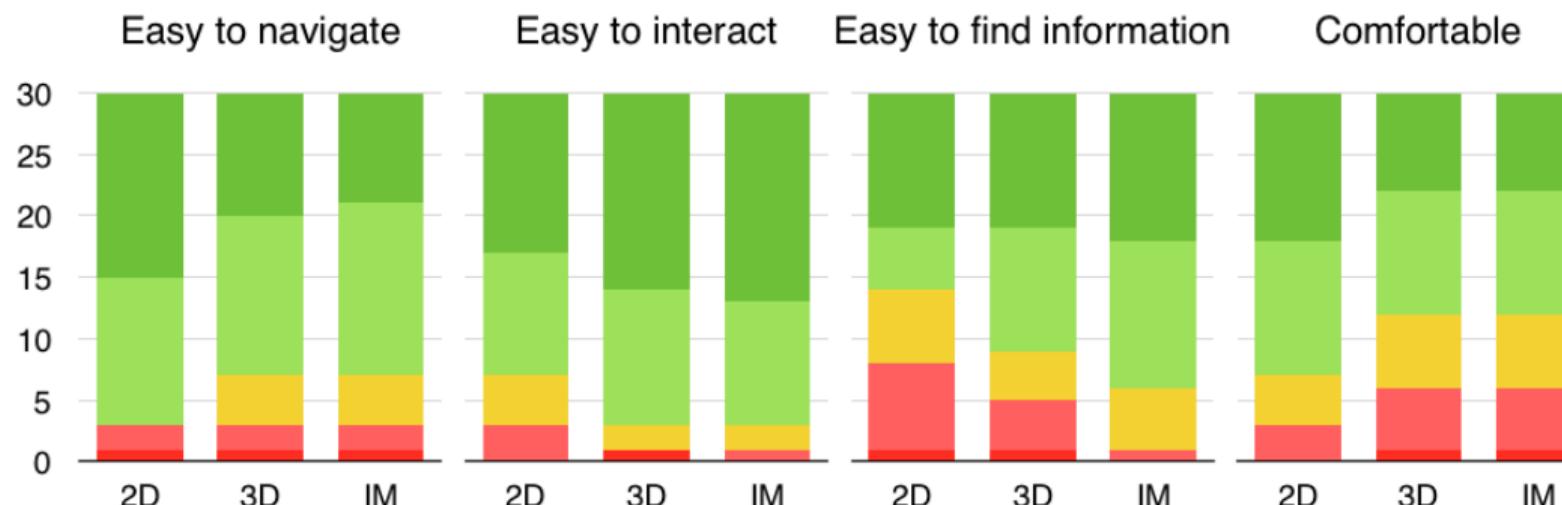
Results: User Feedback – Ranking Question

- Subjective **perception of accuracy** in *IM* was much larger than in *3D* (**H5**)



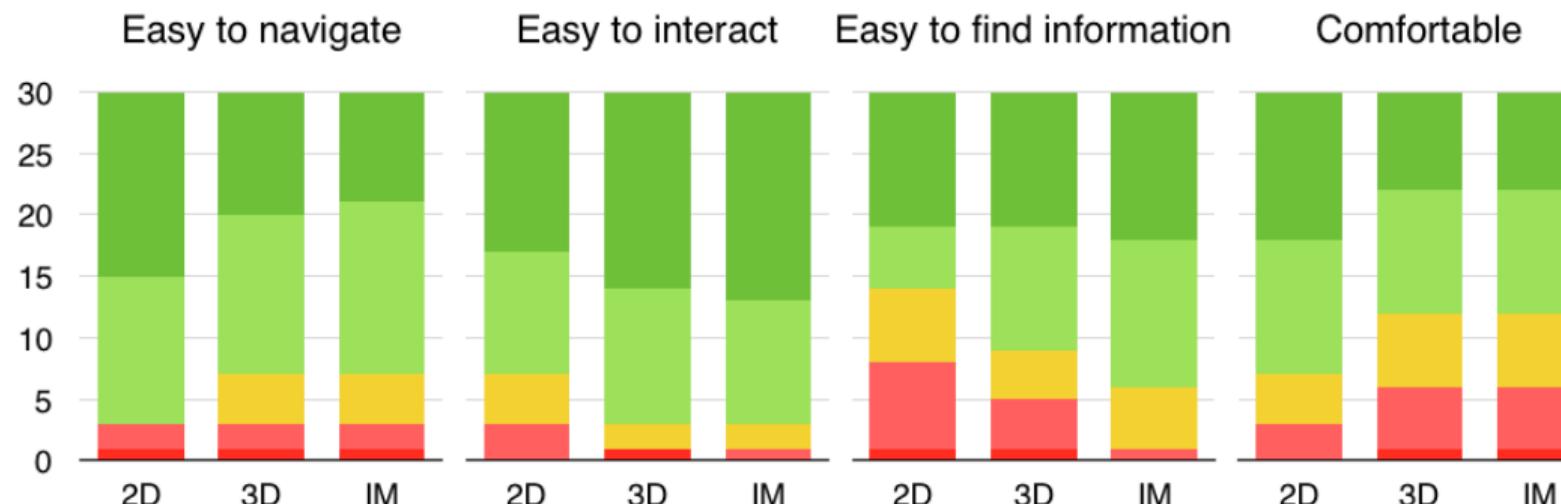
Results: User Feedback – Likert-scale Agreements

- All techniques were well rated in terms of ease of navigation and interaction



Results: User Feedback – Likert-scale Agreements

- All techniques were well rated in terms of ease of navigation and interaction
- *IM* was better rated in terms of **ease to find information**, and performed as well as *3D* for comfort



Hypotheses Recap

- H1 The perception error will be smaller in *IM* than in *3D*.
- H2 For **D1**, the overall task error in *IM* will be smaller than in *3D* or *2D*.
- H3 For **D2**, the overall task error in *IM* will be at least as good as in *3D* or *2D*.
- H4 *2D* will be the quickest, given its smaller navigation and interaction costs.
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Discussion

- Game-like *desktop 3D* with multiple depth cues may explain absence of perception differences to *IM* (**H1** and **H2**)

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 - An equivalent performance appears to have taken considerable less effort and navigation in the immersive scenario
 - Subjectively perceived accuracy was also much larger for *IM*

Discussion

- Game-like *desktop 3D* with multiple depth cues may explain absence of perception differences to *IM* (**H1** and **H2**)
- +
 - An equivalent performance appears to have taken considerable less effort and navigation in the immersive scenario
 - Subjectively perceived accuracy was also much larger for *IM*
- -
 - Times were around 3x slower in *IM* than in *2D*
 - Simulator sickness was still a major issue

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- Many proposed approaches are **impractical** for actual usage
 - Flying → time-consuming and high simulator sickness
 - Real walking → time-consuming and requires space

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 - Flying → time-consuming and high simulator sickness
 - Real walking → time-consuming and requires space
- Goal: **propose**, **implement** and **evaluate** an alternative data exploration approach to circumvent the observed limitations

The *VirtualDesk* Exploration Metaphor

- Viewpoint change only realisable through head movements
 - Expected to minimize simulator sickness

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- Data rendered in smaller scale at arm's reach
 - Higher precision and stronger stereopsis and parallax cues (Mine et al., 1997)

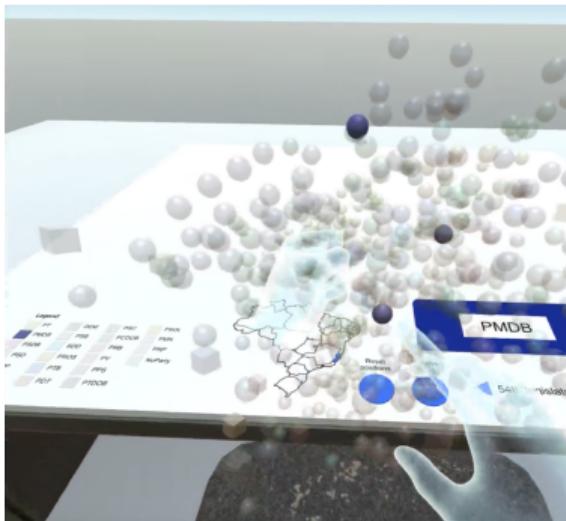
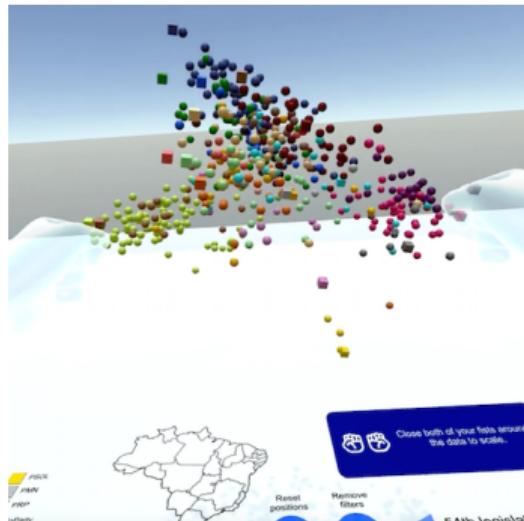
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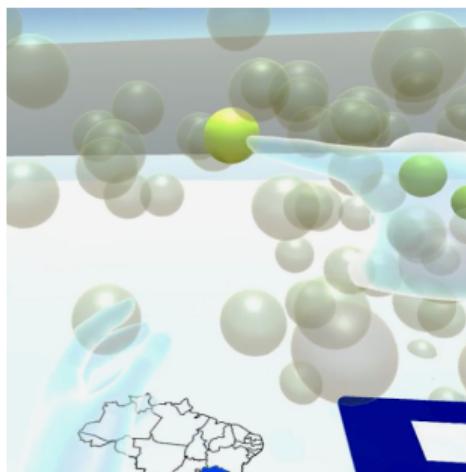
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 - Higher precision and stronger stereopsis and parallax cues (Mine et al., 1997)
- Direct data manipulation through natural mid-air gestures
 - Spatio-data coordination (Cordeil et al., 2017)
- Reproduces an exact copy of the analyst's desk (Zielasko et al., 2017)
 - Enable display of two-dimensional associated views
 - Enable interaction with tangible controls

The *VirtualDesk* Prototype



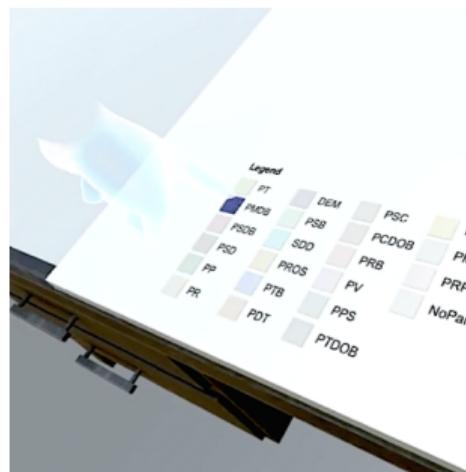
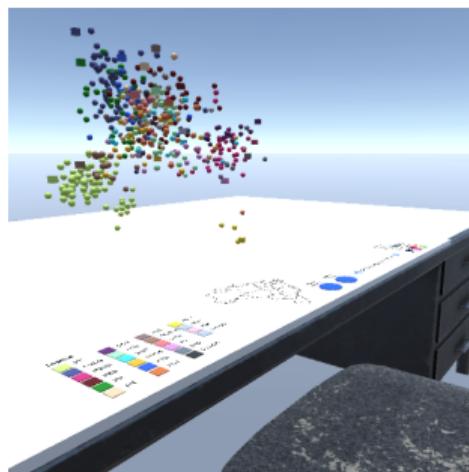
- **Grabbing** action
 - Translation
 - Rotation
 - Scaling

The *VirtualDesk* Prototype



- **Double tapping** action
 - Left hand: highlight
 - Right hand: select
 - Haptic feedback

The *VirtualDesk* Prototype



- **Tabletop interaction**

- Combinable filters
 - Legend (categorical)
 - Map (spatial)

- Annotations

- Control buttons

1 Methodology

2 User Study 1: Conventional Flying Approach Evaluation

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4 User Study 2: VirtualDesk Evaluation

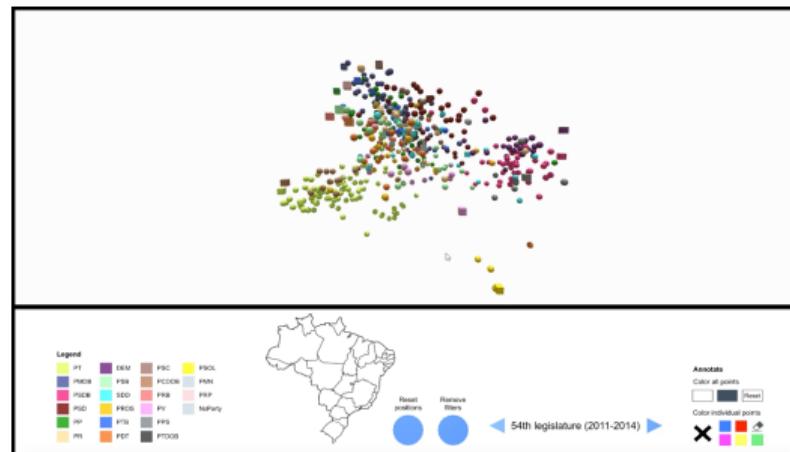
5 Conclusion

Second User Study

- 24 subjects (20 male/4 female)
- Comparison between **two 3D conditions**
 - New desktop-based 3D
 - Immersive VirtualDesk
- Evaluated in terms of **perception** only



Comparable condition



- More representative of a typical 3D visualization tool
- *Rotate-Pan-Dolly* paradigm
- **Two panels interface**

Extended Task Set

Point-based distance perception tasks

- T1** *Selection of a deputy's closest deputy*
- T2** *Selection of a deputy's closest party*
- T3** *Selection of a party's furthest member*
- T4** *Selection of a party's closest party*

Extended Task Set

Class-based density perception tasks

T5 *Density comparison between two parties*

T6 *Density comparison over time*

Extended Task Set

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Clustering task

T7 *Estimation of the number of clusters in a given point cloud*

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Class-based density perception tasks

T5 *Density comparison between two parties*

T6 *Density comparison over time*

Clustering task

T7 *Estimation of the number of clusters in a given point cloud*

Interaction tasks

T8a *Filtering of a party-state combination*

T8b *Selection of all remaining deputies*

Hypotheses

H1 Enhanced **perception** of distances and densities in VR

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- H4** The VirtualDesk metaphor will be more **comfortable** and **efficient** (time and task correctness) than *Flying*

Experiment Design

- For each of the 2 *visualization conditions*
 - Tutorial phase
 - For each of the 9 *tasks*
 - 3 executions in dataset **D1** only

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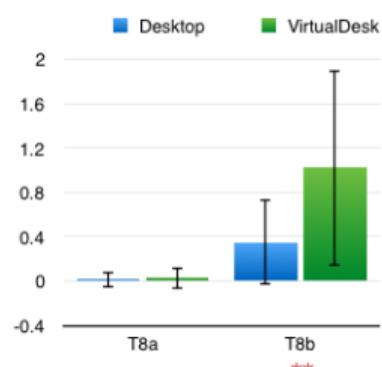
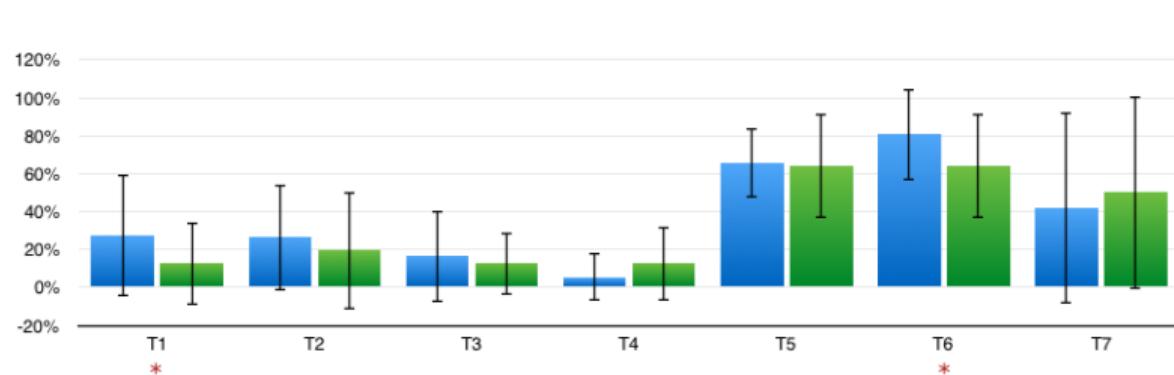
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 - 3 executions in dataset **D1** only
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 - Accurate in T1-T7
 - Fast in T8
- For T1-T4, same question points from the previous study
- Total time: ~40 min (incl. questionnaires)

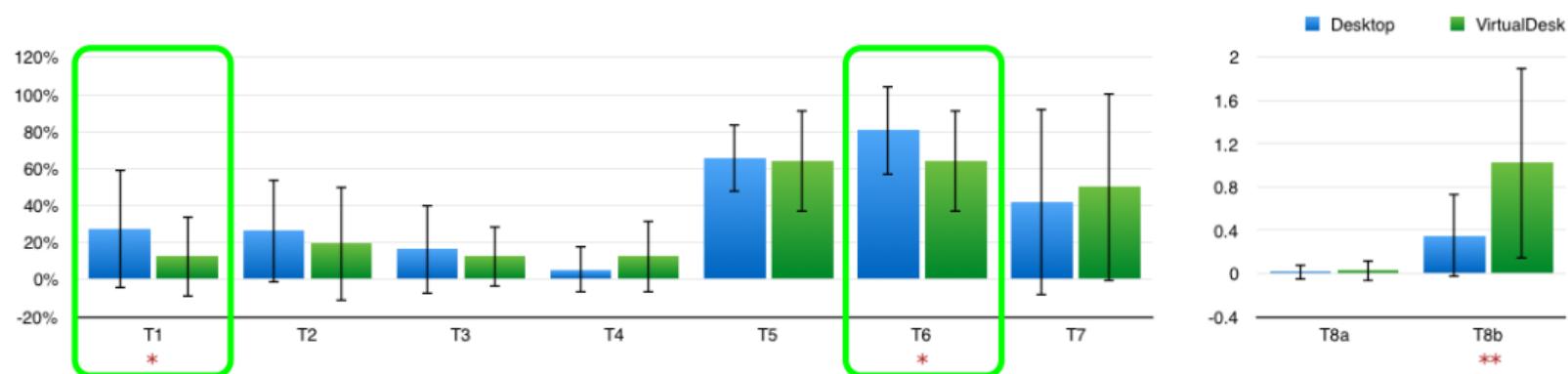
Results: Error Rates

- **Perception** tasks always performed equally or better in VirtualDesk (**H1**)



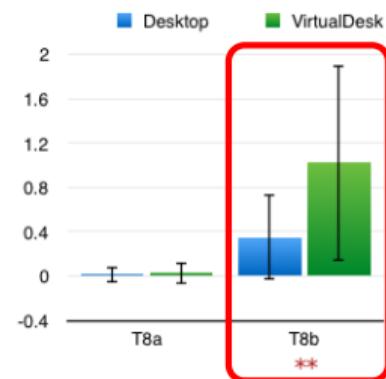
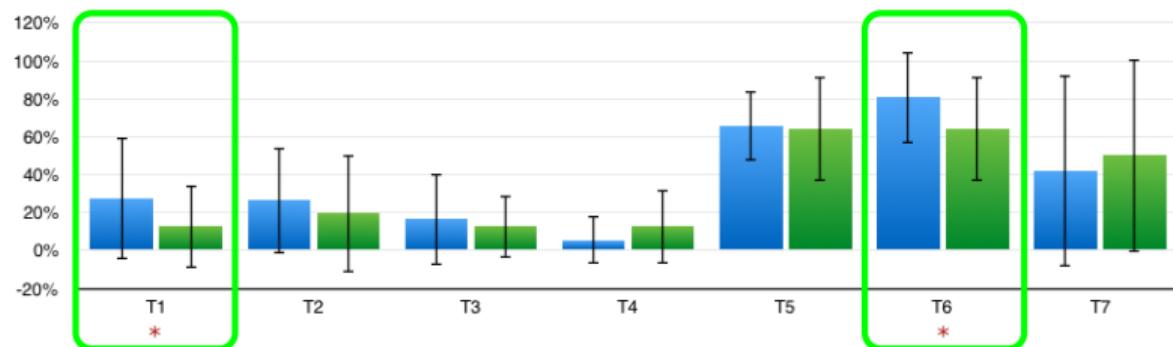
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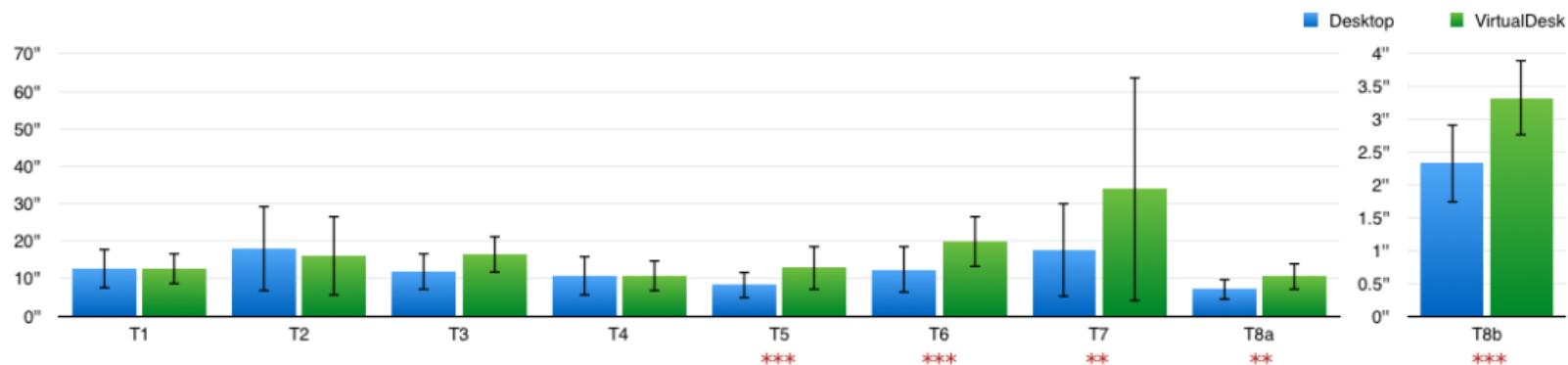
- **Perception** tasks always performed equally or better in VirtualDesk (**H1**)
- Desktop more accurate for point **selection** (**H2**)



(*) for $p < .05$, (**) for $p < .01$ and (***) for $p < .001$

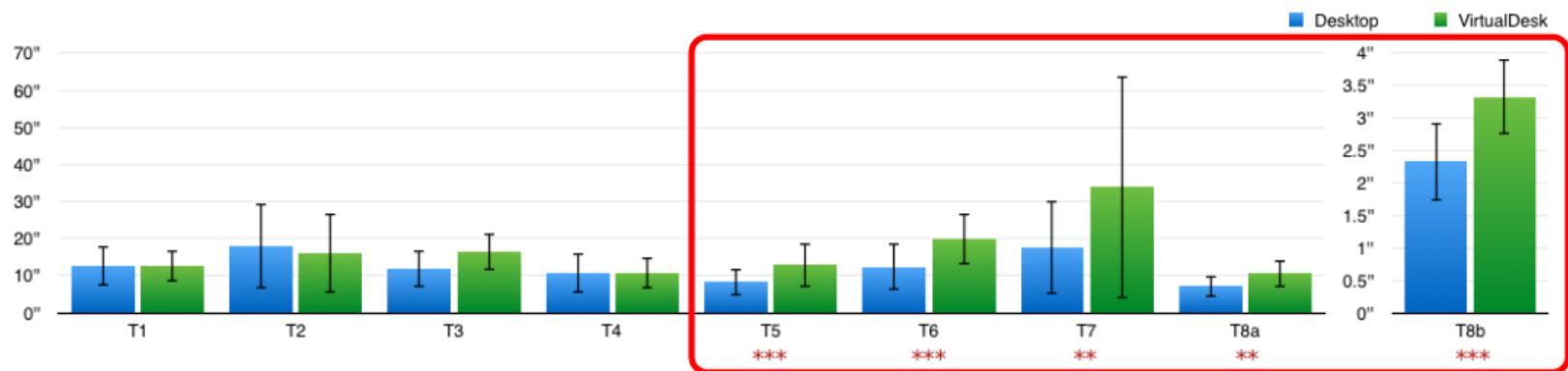
Results: Task Completion Time

- VirtualDesk slower for T5-T8
 - Required interaction w/ tabletop controls



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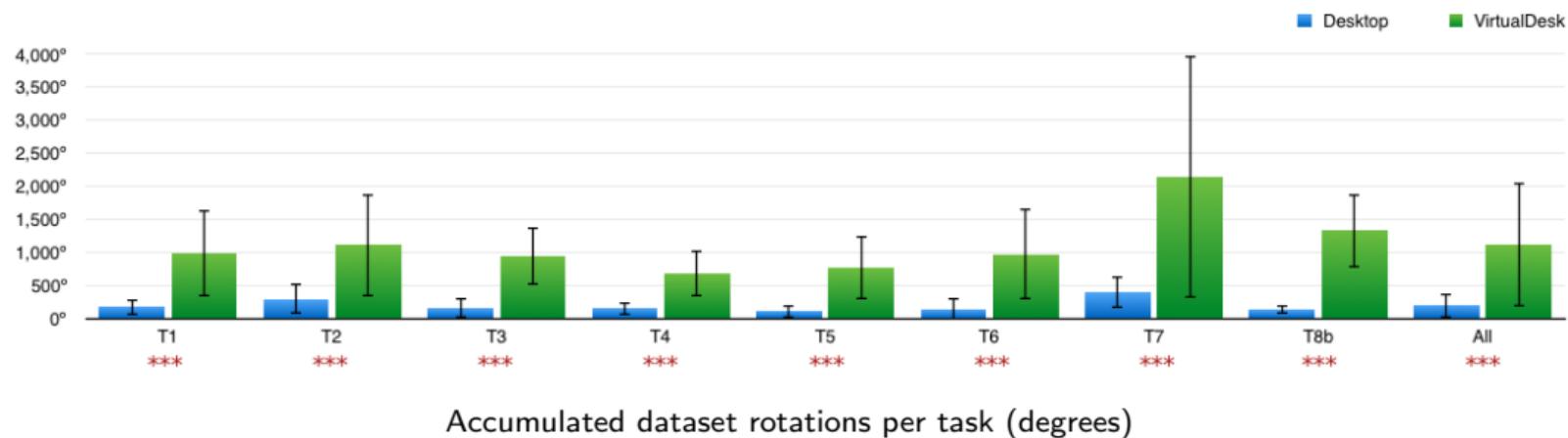


(*) for $p < .05$, (**) for $p < .01$ and (***) for $p < .001$

T8b times normalized per selected point

Results: Data Exploration

- Interesting difference observed in terms of **dataset rotations**
 - Performed **5.8x more** in the immersive condition



(*) for $p < .05$, (**) for $p < .01$ and (***) for $p < .001$

Results: Workload

- Higher task load score (NASA) in VirtualDesk (*)
 - 30.9 (SD 14.7) vs 23.2 (SD 15.4)
- Especially influenced by two components
 - **Physical Workload** (37.4 vs 9.7) (***)
 - **Effort** (36.1 vs 23.6) (*)

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 - **Physical Workload** (37.4 vs 9.7) (***)
 - **Effort** (36.1 vs 23.6) (*)
- **Mental Workload** was also higher but without significance (**H3**)
 - 26.3 (SD 16.2) vs 22.2 (SD 20)

(*) for $p < .05$, (**) for $p < .01$ and (***) for $p < .001$

Results: User Feedback – Likert-scale agreements

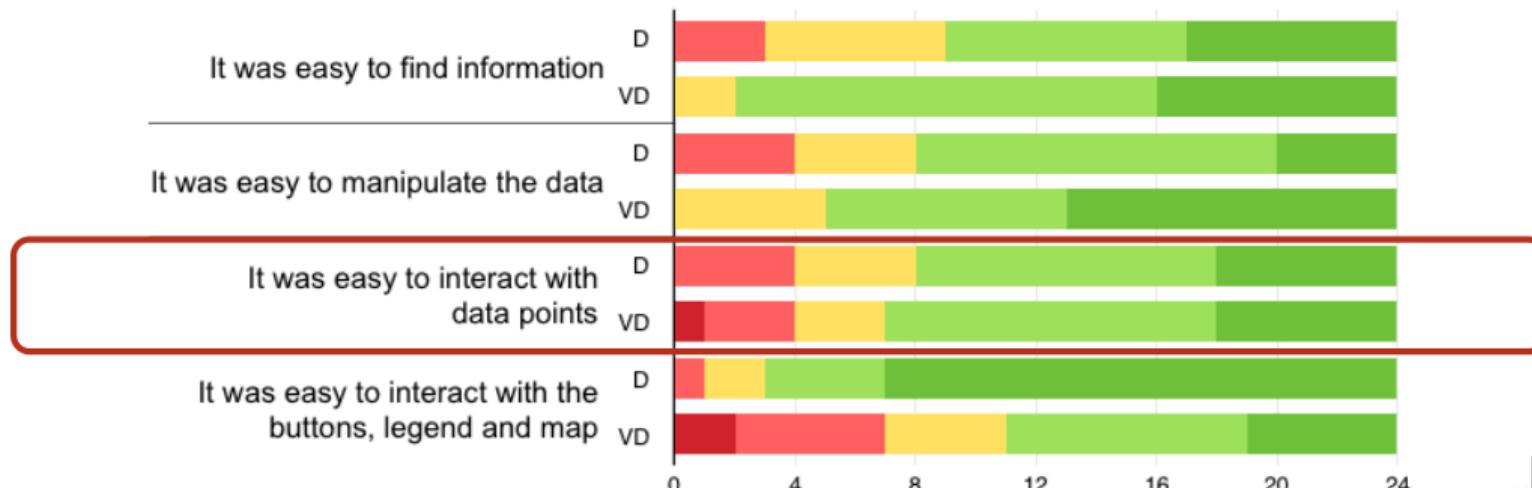
- 46% more participants agreed that it was easy to **find information** in VirtualDesk



D: Desktop / VD: VirtualDesk

Results: User Feedback – Likert-scale agreements

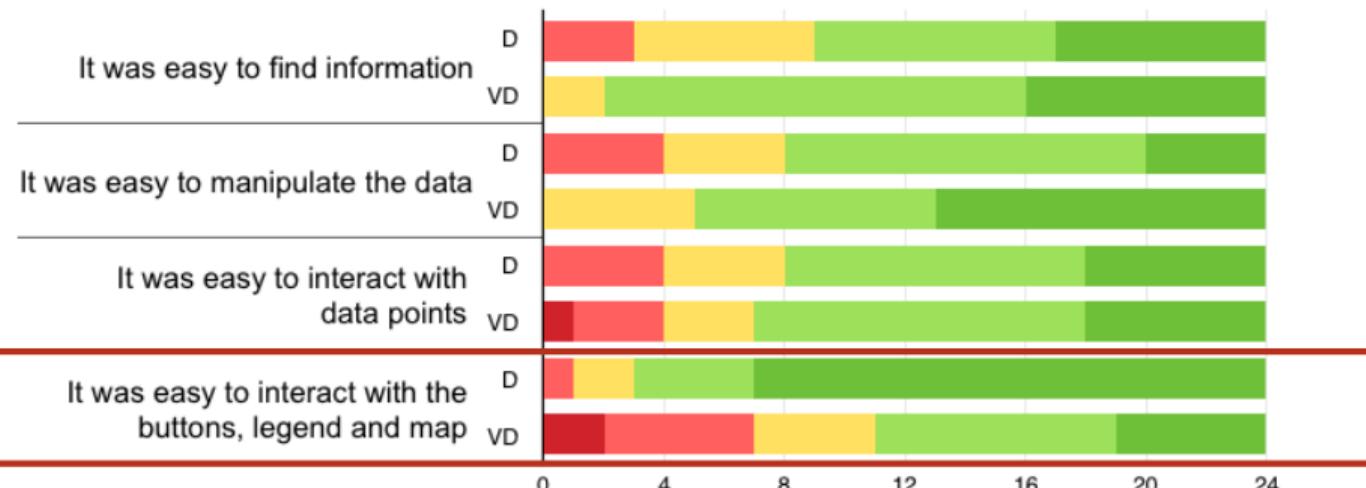
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- Interaction with **data points** was rated similarly in both versions



D: Desktop / VD: VirtualDesk

Results: User Feedback – Likert-scale agreements

- 46% more participants agreed that it was easy to **find information** in VirtualDesk
- Interaction with **data points** was rated similarly in both versions
- Difficulties with the **tabletop interaction** were the main prototype weakness



D: Desktop / VD: VirtualDesk

Results: User Feedback – Ranking Question

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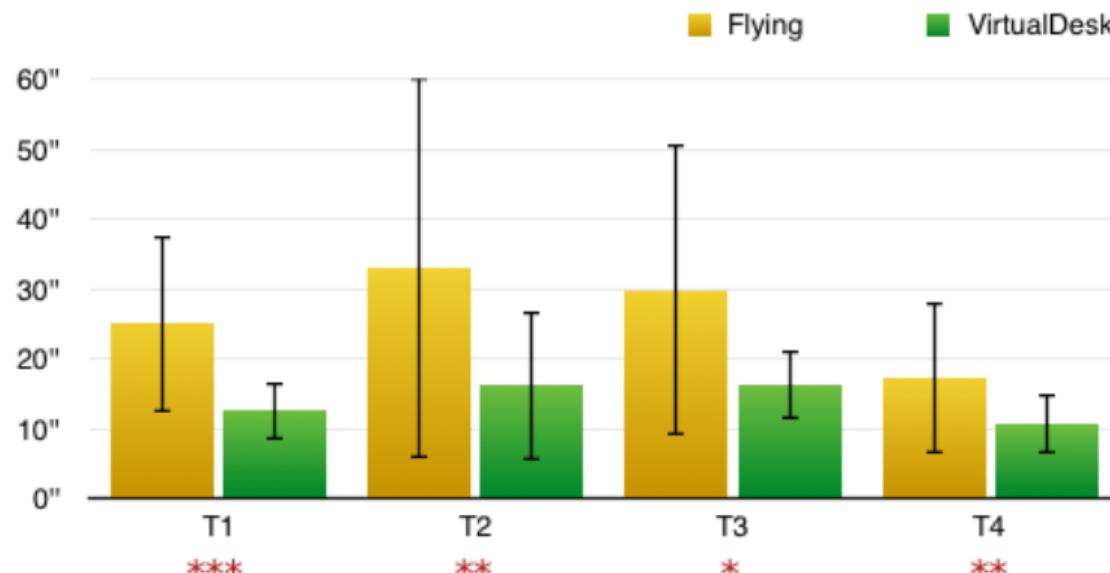
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- All participants selected VirtualDesk as **most engaging (H3)**
 - Partially related to the novelty of VR
- 21/24 selected VirtualDesk as **most intuitive**
- 15/24 selected VirtualDesk as **fastest**
- 12 selected each condition as most accurate
 - Many reported that Desktop was most accurate for selection, but VirtualDesk for manipulation

Comparison with Flying: Time

- As expected, VirtualDesk was more **time-efficient**
 - All tasks were executed significantly faster (up to 51%)

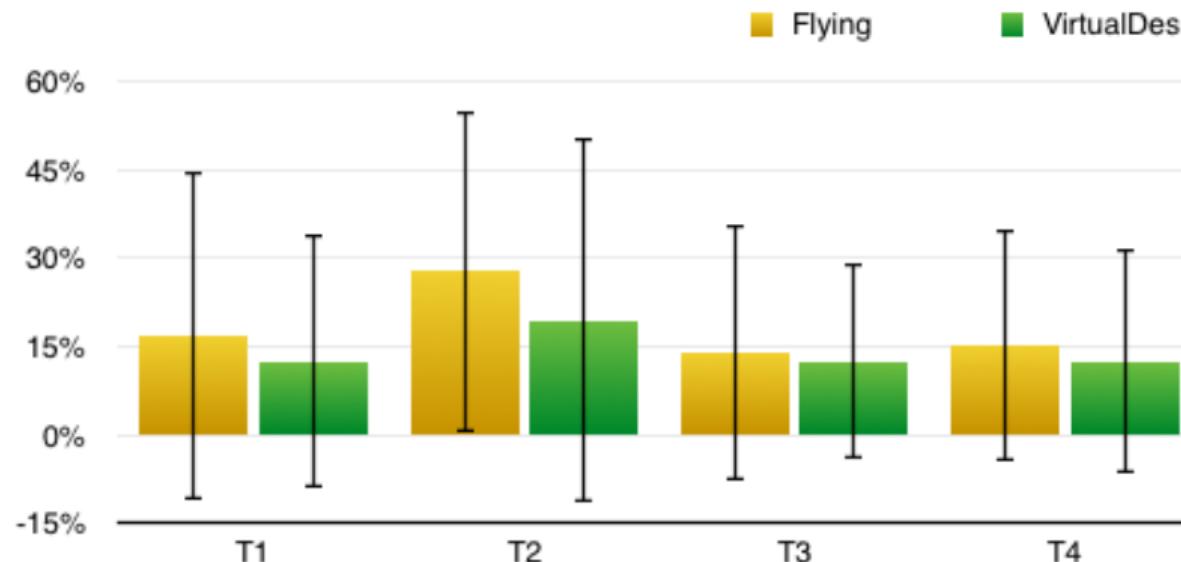


(*) for $p < .05$, (**) for $p < .01$ and (***) for $p < .001$

Considers only the first 24 participants from US1

Comparison with Flying: Error Rates

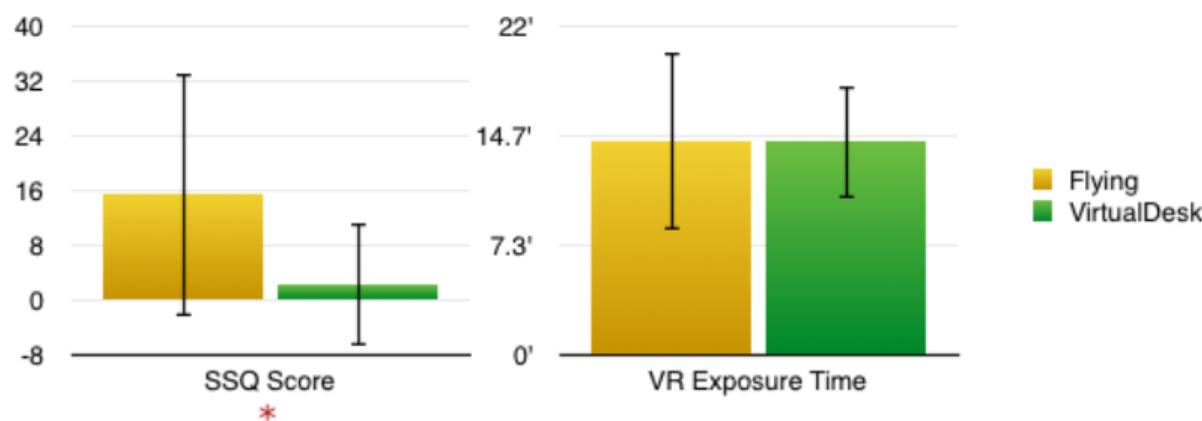
- VirtualDesk also achieved lower error rates, but without statistical significance



Considers only the first 24 participants from US1

Comparison with Flying: Simulator Sickness

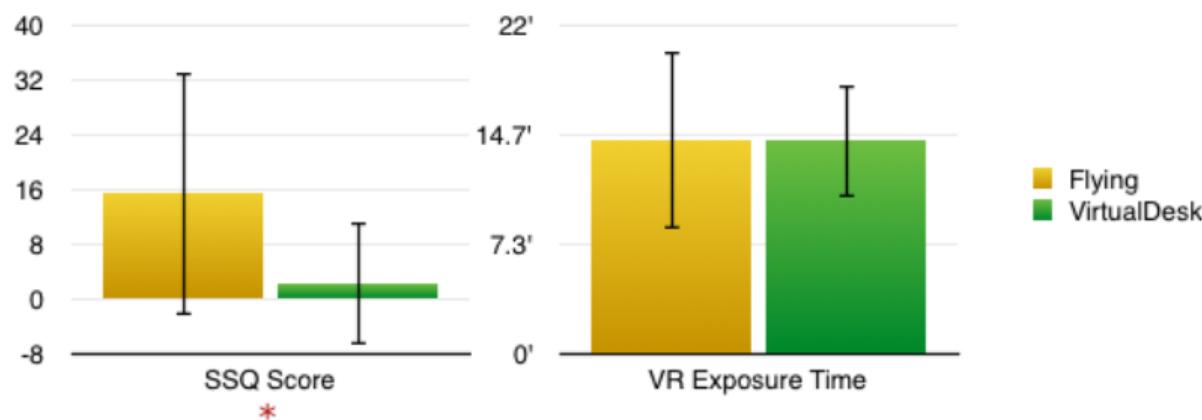
- **7x smaller SSQ score than the previous Flying approach (H4)**
 - Despite very similar VR exposure times



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Comparison with Flying: Simulator Sickness

- **7x smaller SSQ score than the previous Flying approach (H4)**
 - Despite very similar VR exposure times
- **No user reported discomfort during or after the tasks**



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Hypotheses Recap

- H1 Enhanced **perception** of distances and densities in VR
- H2 The mouse will still be **quicker** and **more accurate** for the selection tasks
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- We believe the choice for the **Oculus Touch controllers** instead of other hand tracking solutions was appropriate
 - Highly realistic and precise modelling of the hands and gestures
 - **But:** hand models must be adjusted according to real size
- **Long term evaluations** are still needed
 - Interaction times and errors should decrease w/ more training
 - Comfort could vary for longer exposures

1 Methodology

2 User Study 1: Conventional Flying Approach Evaluation

3 VirtualDesk: Novel Proposed Approach

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- Our main objective was to demonstrate that current off-the-shelf VR technologies may effectively aid in analytical tasks for **abstract information visualization**

Conclusion

- In an effort to **extend discussions** about *Immersive Analytics* to new contexts, we presented, in this work, evaluations on a particular representation for **multidimensional data**
- Our main objective was to demonstrate that current off-the-shelf VR technologies may effectively aid in analytical tasks for **abstract information visualization**
- We believe VirtualDesk is one of the first implementations for immersive exploration of abstract information actually convenient for **real world usage**, requiring only minor improvements

Summary of Contributions

- ① An improved **modelling** of the problem in hand
- ② A task-based evaluation **framework**
- ③ The identification of a complete set of relevant **tasks**
- ④ Results from two comparative **user studies**
- ⑤ The recommendation of a so-far atypical data **exploration metaphor**
- ⑥ **Baseline results** to be used in future work and paths pointed for improvement

Future Work

- Improvement of the VirtualDesk prototype based on participants' feedback
- Further testing under different conditions, including different **datasets** and **representations**
 - Strong candidates: *node-link diagrams* and *space-time cubes*
- Combination with the non-immersive counterpart could be an interesting approach

Evaluating Immersive Approaches to Multidimensional Information Visualization

Jorge Alberto Wagner Filho

Advisor: Prof. Luciana Nedel

Co-advisor: Prof. Carla Freitas

Graduate Program in Computer Science
Federal University of Rio Grande do Sul

March 7, 2018

Publications

Immersive Analytics of Dimensionally-Reduced Data Scatterplots
Jorge A. Wagner Filho^{1*} · Marília F. Rey² · Carla M.D.S. Freitas¹ · Luciana Nezzi²
¹Instituto Interdisciplinar
PUCRS University of Porto Alegre do Sul

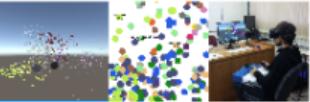


Figure 1 shows two screenshots of immersive environments. The left screenshot shows a 3D scatterplot of colored points against a blue sky background. The right screenshot shows a person wearing a VR headset and holding a controller, interacting with a similar 3D scatterplot on a computer screen.

Figure 1. Immersive environments for the visualization of dimensionally-reduced data scatterplots. 3D soft and 3D hard environments. Through the use of hand controllers, users can interact with the data. The 3D soft environment is HMD based, while the 3D hard environment is a desktop-based hand controllers setup. A comprehensive user interface was designed to be efficient on each environment.

Abstract: In this work, we evaluate the use of an HMD-based immersive environment for the visualization of dimensionally-reduced data scatterplots. We hypothesize that the benefits observed, such as a more natural state of mind, can be leveraged to facilitate the analysis of data and to help to comprehend the spatial dynamics of these dimensional reductions. We conducted a user study with 10 participants from the Brazilian Chamber of Deputies. A user study was conducted to allow a comparison between a desktop-based hand controllers setup and an HMD-based VR system. Positive subjective evaluations in terms of immersion, interaction, and user satisfaction were observed in both environments. Data, as well as its distance perception and user satisfaction, did not show significant differences between the two environments. The proposed immersive framework has also ruled out a sense of presence in the virtual environment.

Keywords: Immersive analytics, dimensionality reduction, 3D scatterplots

Index Terms: H.5.1 [Information Interfaces and Presentation]: Information Systems — Artificial, augmented, and virtual reality; I.4.1 [Information Systems]; I.4.2 [Information Systems]

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1. Introduction
Over the past decades, the visualization community has proposed many approaches to support decision-making displays and user interactions.

2. Related Work
In the past, several studies have been conducted on the use of dimensionality reduction techniques, such as PCA, t-SNE, and MDS, to support decision-making displays and user interactions [12, 20]. To the best of our knowledge, however, no work has been conducted on the use of VR environments to support decision-making displays on these topics. Most of these have only provided preliminary evaluations, such as the use of VR environments for the visualization of the last few years [5, 7, 22]. Therefore, we believe that our work is the first to evaluate the use of VR environments for the visualization of dimensionality-reduced data scatterplots.

In this paper, we present initial findings of our research, resulting from a user study conducted at the Brazilian Chamber of Deputies. Using the data from the Brazilian Chamber of Deputies, we evaluated the user satisfaction, immersion, and user interaction when the proposed framework was applied to the visualization of dimensionality-reduced data scatterplots.

We hypothesize that the benefits provided by immersion, such as

Immersive Visualization of Abstract Information: An Evaluation on Dimensionally-Reduced Data Scatterplots
Jorge A. Wagner Filho^{1*} · Marília F. Rey² · Carla M.D.S. Freitas¹ · Luciana Nezzi²
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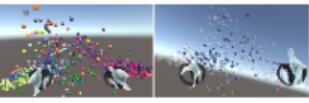


Figure 2 shows two screenshots of immersive environments. The left screenshot shows a 3D scatterplot of colored points against a blue sky background. The right screenshot shows a person wearing a VR headset and holding a controller, interacting with a similar 3D scatterplot on a computer screen.

Figure 2. Immersive HMD-based immersive environments for the evaluation of dimensionally-reduced data scatterplots. 3D soft and 3D hard environments. Through the use of hand controllers, users can interact with the data. The 3D soft environment is HMD based.

Abstract: This work presents a user study comparing two immersive environments for the evaluation of dimensionally-reduced data scatterplots. The main goal is to evaluate the user satisfaction, immersion, and user interaction when using two different environments: a desktop-based hand controllers setup and an HMD-based VR system. We hypothesize that the overall user performance, the immersion, and user satisfaction will be higher when using the HMD-based VR system. In this paper, we present a user study comparing two different environments for the evaluation of dimensionally-reduced data scatterplots. The main goal is to evaluate the user satisfaction, immersion, and user interaction when using two different environments: a desktop-based hand controllers setup and an HMD-based VR system. We hypothesize that the overall user performance, the immersion, and user satisfaction will be higher when using the HMD-based VR system. The user study involved 10 participants from the Brazilian Chamber of Deputies. The results showed that the user satisfaction, immersion, and user interaction were higher when using the HMD-based VR system compared to the desktop-based hand controllers setup.

Keywords: Immersive analytics, dimensionality reduction, 3D scatterplots

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1. Introduction
The visualization community has progressively explored the use of VR environments for the visualization of abstract information [2]. Nevertheless, even though immersive 3D environments have been used for the visualization of abstract information [2], there is still a lack of research on the use of dimensionality reduction (DR). We propose a new methodology for the visualization of abstract information using dimensionality reduction. We hypothesize that the overall user performance, the immersion, and user satisfaction will be higher when using the HMD-based VR system compared to the desktop-based hand controllers setup.

The use of DR scatterplots has been controversial among long time researchers [1, 11, 12]. Dimensionality reduction techniques allows users to quickly explore and understand complex data sets while using two or three dimensions at a time. DR scatterplots are often used in scientific research to support decision-making processes. In this work, we focused on the use of dimensionality reduction techniques to support decision-making processes. We hypothesized that the overall user performance, the immersion, and user satisfaction will be higher when using the HMD-based VR system compared to the desktop-based hand controllers setup.

In this paper, we present initial findings of our research, resulting from a user study conducted at the Brazilian Chamber of Deputies. Using the data from the Brazilian Chamber of Deputies, we evaluated the user satisfaction, immersion, and user interaction when the proposed framework was applied to the visualization of dimensionality-reduced data scatterplots.

We hypothesize that the benefits provided by immersion, such as

EuroVis Conference on Visualization EuroVis 2018
EuroVis 2018, Porto, Portugal, May 2018
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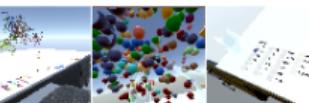


Figure 3 shows the EuroVis 2018 conference logo, which consists of a stylized globe with various colored dots and lines representing data points and connections.

VirtualDesk: A Comfortable and Efficient Immersive Information Visualization Approach
Submission ID 1776

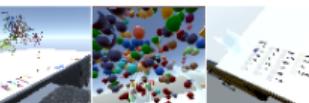


Figure 4 shows two screenshots of immersive environments. The left screenshot shows a 3D scatterplot of colored points against a blue sky background. The right screenshot shows a person wearing a VR headset and holding a controller, interacting with a similar 3D scatterplot on a computer screen.

Figure 4. Immersive environments for the visualization of abstract information. A user study of 2 users was conducted to evaluate the user satisfaction, immersion, and user interaction when using the 3D soft environment.

Abstract: 3D representations are preferred over 2D when visualizations are used for decision-making. The right environment has been proposed to support decision-making tasks, such as strategic planning, decision-making, and reporting. These proposed methods are used for better user readability in decision-making or reporting tasks. In this work, we propose a method to evaluate the user satisfaction, immersion, and user interaction when using the 3D soft environment. The user study involved 2 users. The user satisfaction, immersion, and user interaction were higher when using the 3D soft environment compared to the desktop-based hand controllers setup.

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These dimensionality-reduced data are becoming more widespread in decision-making tasks, such as strategic planning, decision-making, and reporting. These proposed methods are used for better user readability in decision-making or reporting tasks. In this work, we propose a method to evaluate the user satisfaction, immersion, and user interaction when using the 3D soft environment. The user study involved 2 users. The user satisfaction, immersion, and user interaction were higher when using the 3D soft environment compared to the desktop-based hand controllers setup.

2. Related Work
Most [1, 2] of the proposed information visualization approaches have been developed to support decision-making tasks, such as strategic planning, decision-making, and reporting. These proposed methods are used for better user readability in decision-making or reporting tasks. In this work, we propose a method to evaluate the user satisfaction, immersion, and user interaction when using the 3D soft environment. The user study involved 2 users. The user satisfaction, immersion, and user interaction were higher when using the 3D soft environment compared to the desktop-based hand controllers setup.

3. Methodology
The proposed approach is composed of three main steps: visualization, immersion, and interaction. The visualization step is responsible for generating the 3D representation of the data. The immersion step is responsible for providing the user with a comfortable environment for the visualization. The interaction step is responsible for allowing the user to interact with the visualization in a natural way.

4. Results
The results of the user study show that the user satisfaction, immersion, and user interaction were higher when using the 3D soft environment compared to the desktop-based hand controllers setup.

5. Conclusion
The proposed approach is composed of three main steps: visualization, immersion, and interaction. The visualization step is responsible for generating the 3D representation of the data. The immersion step is responsible for providing the user with a comfortable environment for the visualization. The interaction step is responsible for allowing the user to interact with the visualization in a natural way.

6. Future Work
The proposed approach can be extended to support other types of data, such as 3D point clouds, 3D meshes, and 3D volumes. The proposed approach can also be extended to support other types of visualization, such as 3D scatterplots, 3D bar charts, and 3D pie charts.

7. Acknowledgments
We would like to thank the anonymous reviewers for their valuable feedback and suggestions, which greatly improved the quality of this paper.

8. References
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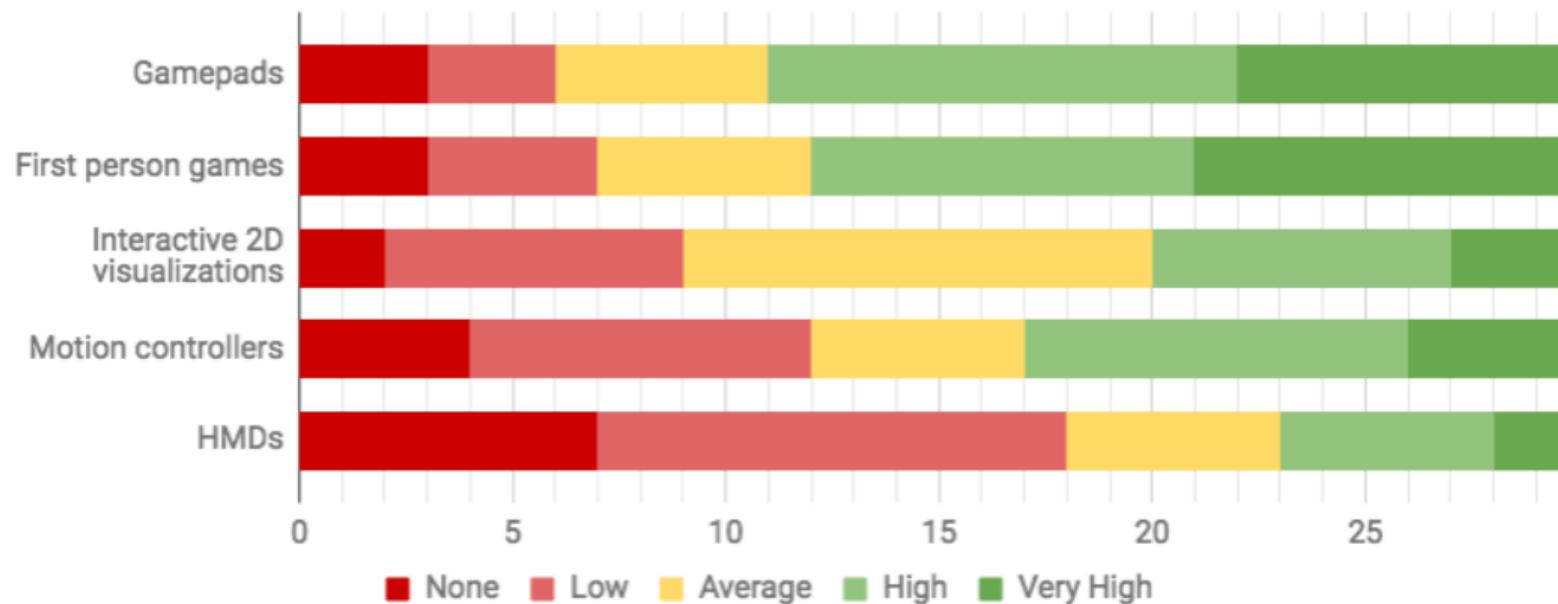
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User Study 1 - Participants

- 30 subjects (20 male/10 female)
- Mean age 25.2, ranging from 17 to 50



User Study 2 - Participants

- 24 subjects (20 male/4 female)
- Mean age 23.7, SD 2.7

