

Accessible Diagrams through Natural Language

PhD Defense

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Table of Contents

- 1 Motivation
- 2 State of the Art
- 3 Natural Language Interface to Diagrams
- 4 Formalizing Visualization Semantics
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- 7 Prototype Validation
- 8 Conclusions

Table of Contents

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Diagrams are ubiquitous



Diagrams are ubiquitous

Daily new confirmed COVID-19 cases per million people

7-day rolling average. Due to limited testing, the number of confirmed cases is lower than the true number of infections.

Our World
in Data



Source: Johns Hopkins University CSSE COVID-19 Data

What about blind persons?

- 36 million fully blind persons worldwide^a



^aIAPB 2015 estimate

What about blind persons?

- 36 million fully blind persons worldwide^a
- 217 million persons with moderate to severe visual impairment



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- Numbers set to triple by 2050

^aIAPB 2015 estimate

What about blind persons?



- 36 million fully blind persons worldwide^a
- 217 million persons with moderate to severe visual impairment
- Numbers set to triple by 2050
- Access to visual information imperative
 - Education
 - Job prospects
 - Leisure

^aIAPB 2015 estimate

Problem Investigation

Research Question

RQ1. What are the benefits and drawbacks of current approaches to non-visual access to diagrams?

- Literature Review of Methods

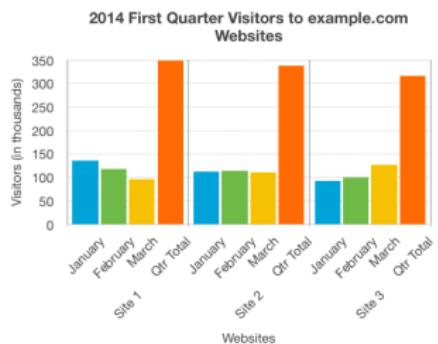
Table of Contents

- 1 Motivation
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Taxonomy of Methods

- According to output modality and main sense

Taxonomy of Methods



Numerical values presented on the image:

2014 First Quarter visitors per site
(in thousands)

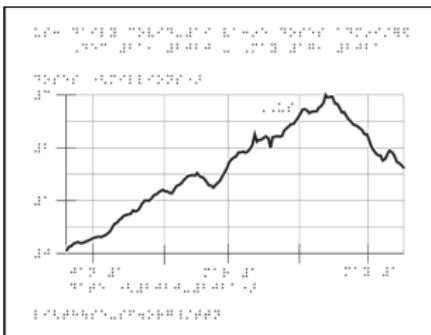
Period	Site 1	Site 2	Site 3
Jan	135	112	92
Feb	117	114	99
March	96	111	126
Qtr total	348	337	308

• Linear Approaches

- incl. interactive software

Figure: Tabular chart alternative

Taxonomy of Methods



- Linear Approaches
 - incl. interactive software
- Haptic Approaches

Figure: Tactile graphic (top), PHANToM Haptic Device (bottom)

Taxonomy of Methods

- Linear Approaches
 - incl. interactive software
- Haptic Approaches
- **Sonification**

Figure: Sonify iPhone app

Taxonomy of Methods

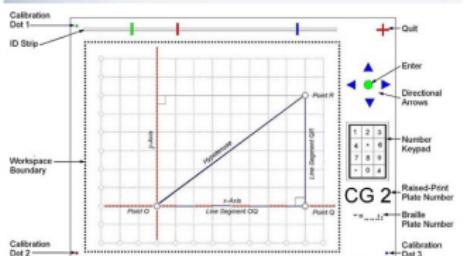


Figure: Talking Tactile Table (TTT)

- Linear Approaches
 - incl. interactive software
- Haptic Approaches
- Sonification
- **Hybrid Approaches**

Usability needs currently not met

	Linear	Interactive Software	Tactile	Haptic	Sonification
Content must be simplified	X		X	X	
Working memory overload	X		X	X	X
Training required		X	X	X	X
Special equipment		X	X	X	X
Expensive			X	X	
Constricted domain		X		X	X
External help required		X	X	X	

Communicative Images (Kopeček et al.)



User: What is in the picture?

System: In the picture, there are Andrew, Table, Philip,

Peter, ... [A long list of all objects depicted follows.

The user would prefer a brief description instead.]

User: What is in the top left corner?

System: In the top left corner there is no object.

User: What is in the middle?

System: In the middle there are James Major, Jesus, Thomas,

Peter, Philip, John and Judas. [User asked for various locations one by one. Then he was wondering about the exact order of figures. Some questions failed at this moment.]

User: Who is on the left side of Jesus?

System: On the left side of the Jesus are Andrew, Peter, Bartholomew, Judas, James Minor and John.

User: Is Peter on the left side of Andrew?

System: From your point of view, Peter is not on the left of Andrew. Peter is on the right of Andrew.

User: Describe the table.

System: The table around which are Jesus and all the Apostles sitting. [This is misunderstanding. In fact, the user was interested in objects on the table, not description of the table.]

Figure: User dialog with a Communicative Image (Phlák, 2014)

Communicative Images (Kopeček et al.)

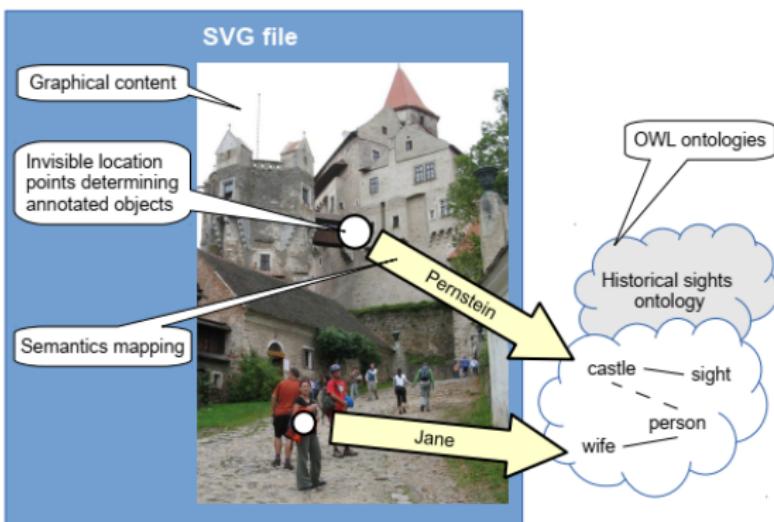


Figure: Structure of a Communicative Image (Phlák, 2014)

Table of Contents

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Natural Language Interface to Diagrams

Can the approach of Communicative Images be adapted to statistical charts?

Natural Language Interface to Diagrams

Can the approach of Communicative Images be adapted to statistical charts?

	Linear	Interactive Software	Tactile	Haptic	Sonification	NLI?
Content must be simplified	X		X	X		
Working memory overload	X		X	X	X	
Training required		X	X	X	X	
Special equipment		X	X	X	X	
Expensive			X	X		
Constricted domain		X		X	X	
External help required		X	X	X		

Natural Language Interface to Diagrams

Can the approach of Communicative Images be adapted to statistical charts?

Particularities

Natural Language Interface to Diagrams

Can the approach of Communicative Images be adapted to statistical charts?

Particularities

- ① Underlying data

Natural Language Interface to Diagrams

Can the approach of Communicative Images be adapted to statistical charts?

Particularities

- ① Underlying data
- ② Design language

Natural Language Interface to Diagrams

Can the approach of Communicative Images be adapted to statistical charts?

Particularities

- ① Underlying data
- ② Design language
- ③ Inference

Natural Language Interface to Diagrams

Design Problem

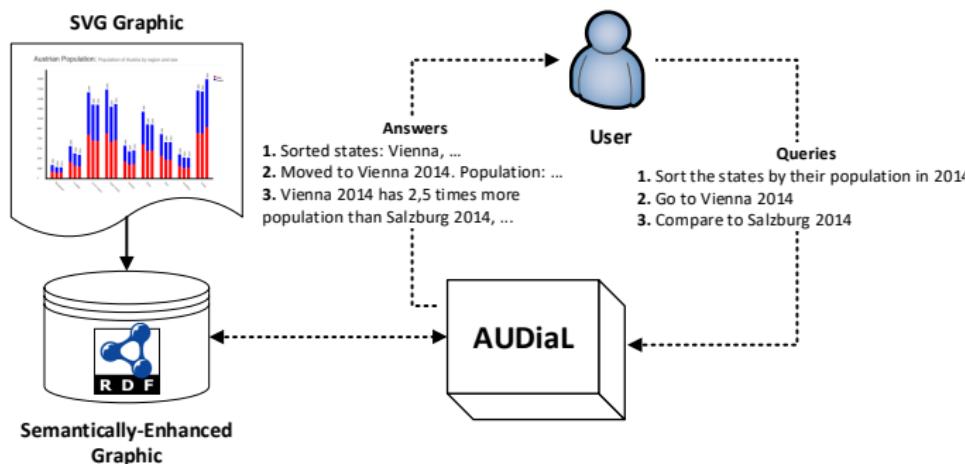
NLI to Diagrams (statistical charts)

Natural Language Interface to Diagrams

Design Problem

NLI to Diagrams (statistical charts)

- Accessible Universal Diagrams through Natural Language (**AUDiaL**)



Formalizing Visualization

Research Question

RQ2. How can the semantics of diagrams be formalized for their efficient natural language-based retrieval?

Design Problem

Formalizing Visualization for effective non-visual NLI access

Table of Contents

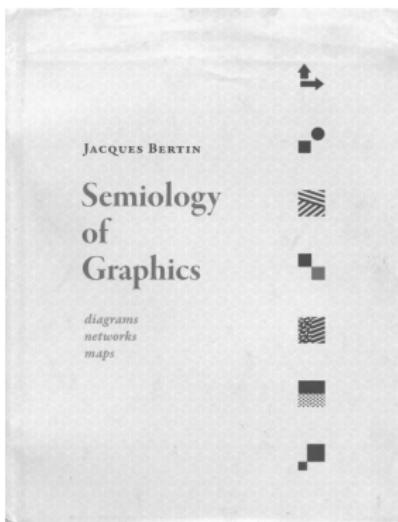
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Visualization Metalanguages

Categorical adoption and aggregation of literature (diagram metalanguages)

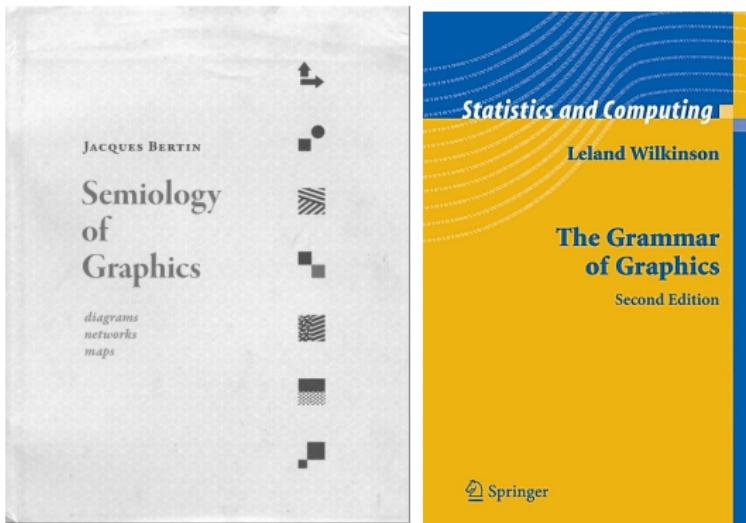
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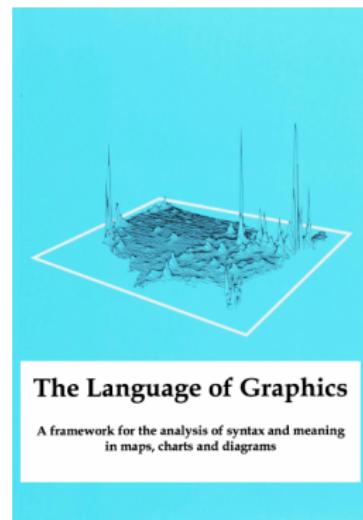
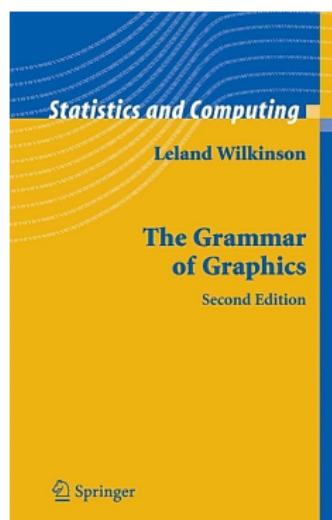
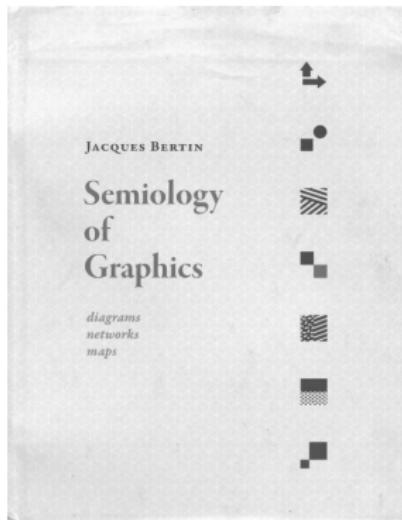
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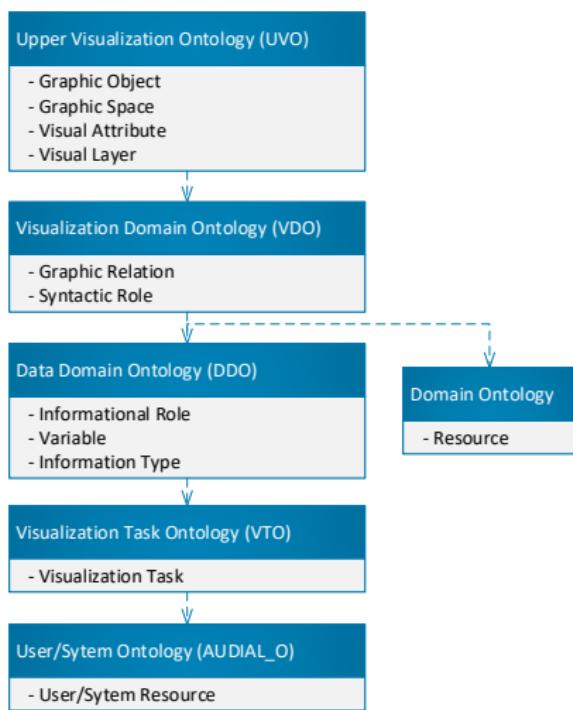


Visualization Metalanguages

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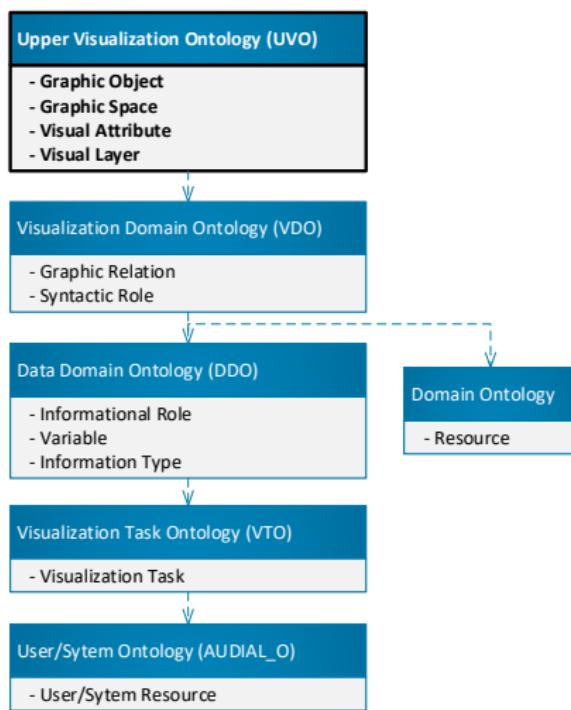
Desired result: **Unifying, formal, descriptive framework**

Ontologies for Visualization



Hierarchical arrangement of
ontologies underpinning:

Ontologies for Visualization

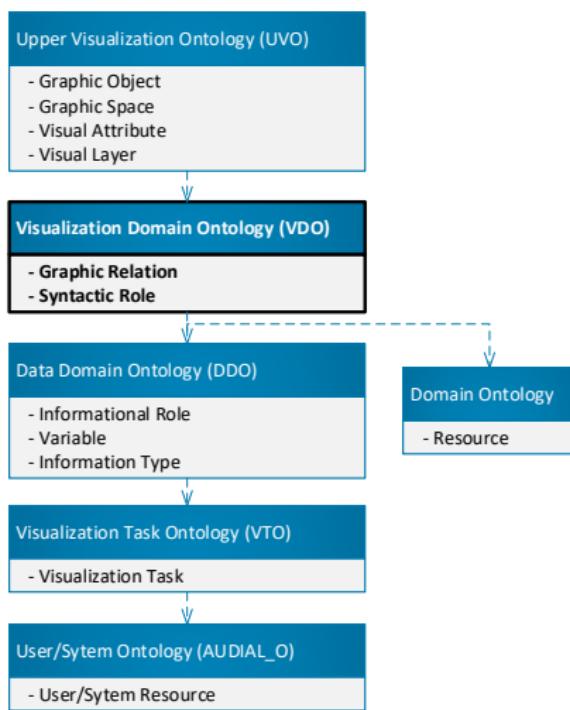


Hierarchical arrangement of ontologies underpinning:

- **Lexicon**

- Graphic objects
- Graphic spaces
- Visual Attributes
- ...

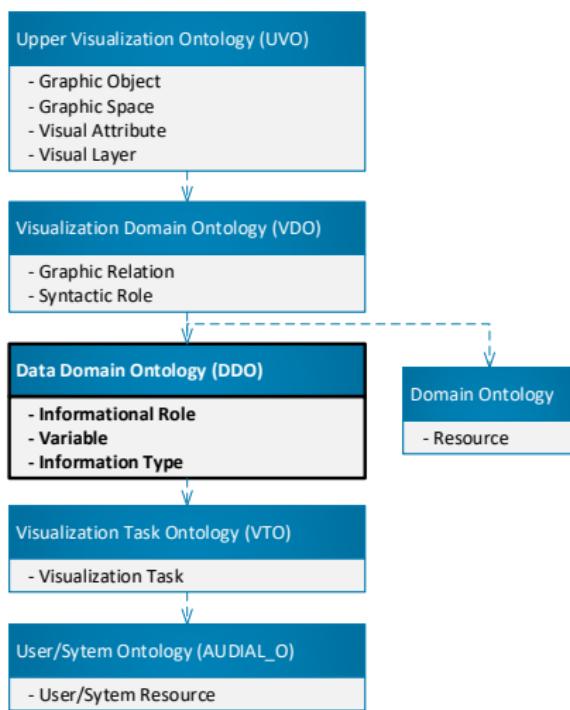
Ontologies for Visualization



Hierarchical arrangement of ontologies underpinning:

- **Syntax**
 - Graphic relations
 - Syntactic roles

Ontologies for Visualization

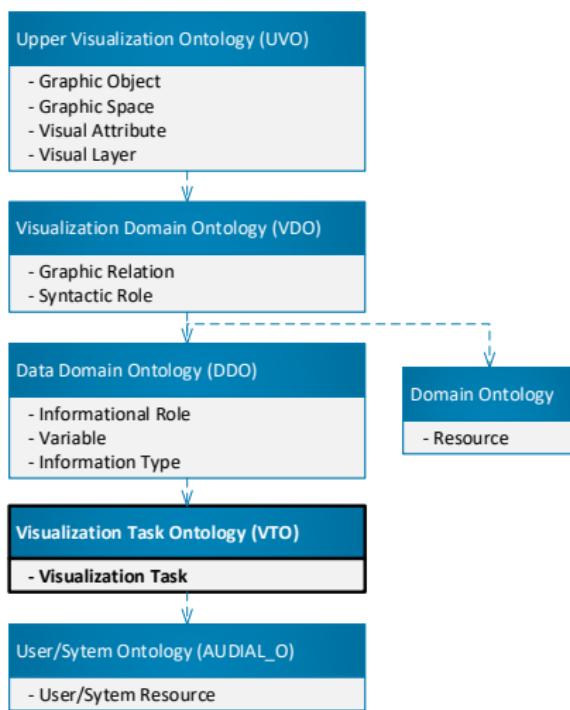


Hierarchical arrangement of ontologies underpinning:

• Data Semantics

- Informational Roles
- Informational Types
- Variables
- (external world)

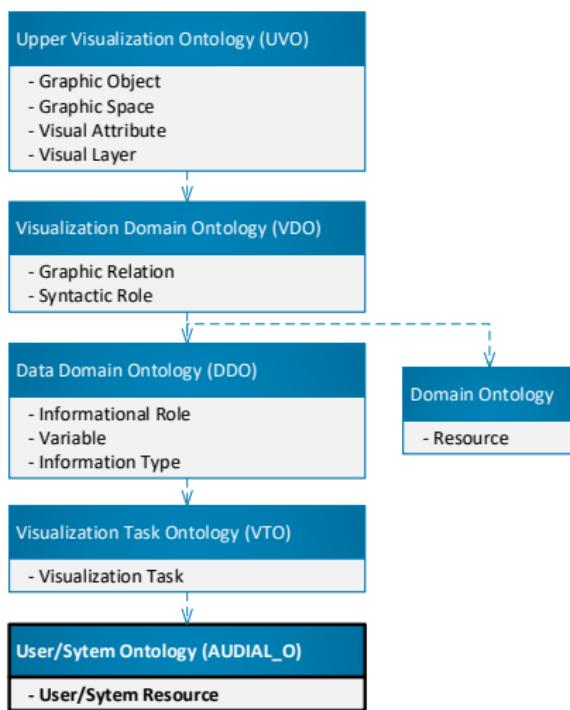
Ontologies for Visualization



Hierarchical arrangement of ontologies underpinning:

- Tasks
 - Analytical Tasks
 - Navigational Tasks

Ontologies for Visualization



Hierarchical arrangement of ontologies underpinning:

- **Custom**
 - User resources
 - System resources

Why Ontologies?

- Coherent (“formal, explicit specification of a shared conceptualization”)

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- Addition of world knowledge (Semantic Web)
- Effective natural language querying
- XML serialization formats
- Output accuracy
- *A priori* knowledge for statistical image processing

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Semantically-Enhanced Diagram



Authoring Semantically-Enhanced Diagrams

Research Question

RQ3. How can semantically-enhanced graphics be authored effectively?

Design Problem

Semantic Annotator for Inkscape

Semantic Annotator for Inkscape

Inkscape plug-in:

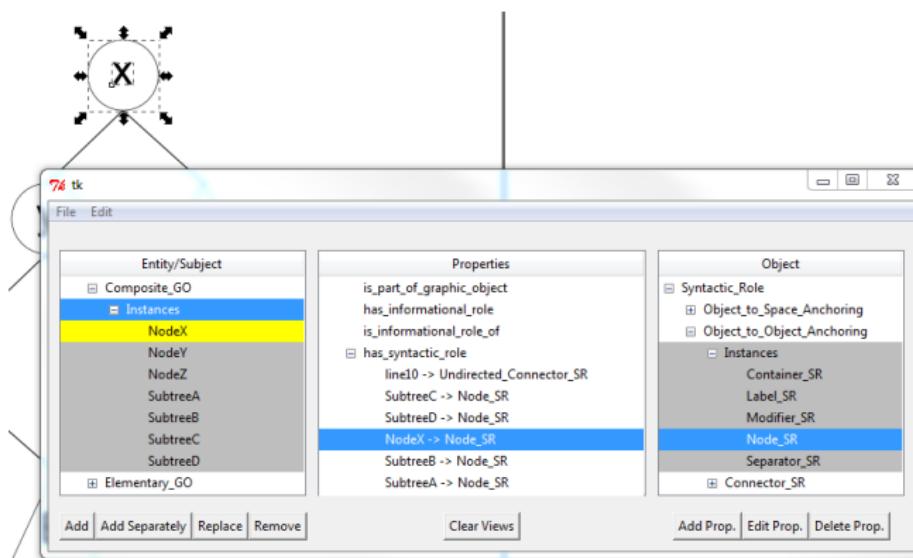


Figure: Graphical User Interface of SAI

Features of SAI

- Single workspace

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- Native support of SVG images

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- Automatic naming mechanism (parallel instantiation)
- Automatic addition of structural properties
- Ontology serialization
- **Effective authoring** of semantically-enhanced diagrams

Table of Contents

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- 2 State of the Art
- 3 Natural Language Interface to Diagrams
- 4 Formalizing Visualization Semantics
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Natural Language Interface (NLI) to Diagrams

Main Design Problem (rephrased)

Accessible NLI to semantically-enhanced statistical charts

Natural Language Interface (NLI) to Diagrams

Main Design Problem (rephrased)

Accessible NLI to semantically-enhanced statistical charts

Functional Requirements:

- ① Execute typical tasks supported by charts in natural language (close domain)

Close-Domain Natural Language Processing Pipeline

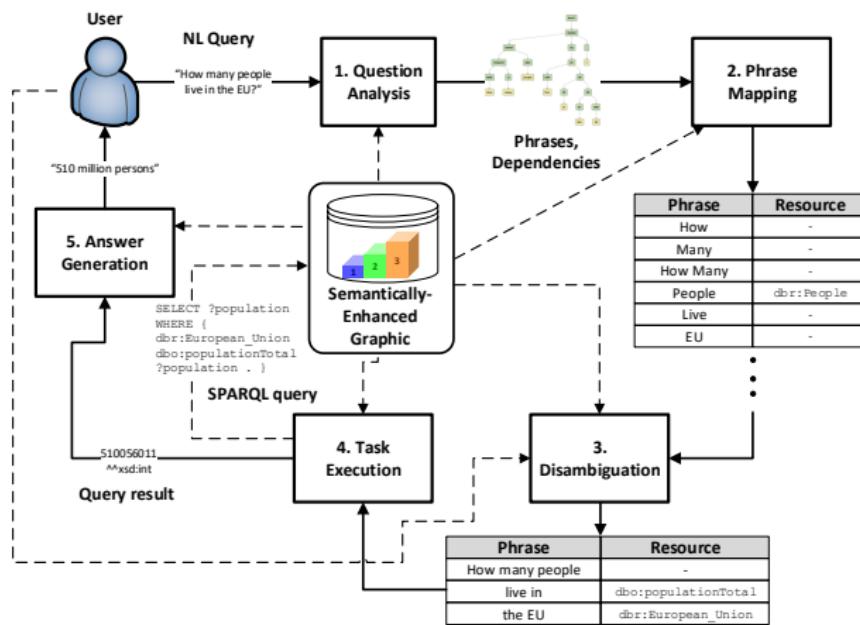


Figure: Natural Language to Ontology Pipeline

Natural Language Interface (NLI) to Diagrams

Main Design Problem (rephrased)

Accessible NLI to semantically-enhanced statistical charts

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Natural Language Interface (NLI) to Diagrams

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Functional Requirements:

- ① ✓ Execute typical tasks supported by charts in natural language (close domain)
- ② ✓ Answer queries in open-domain ontologies
- ③ Habitable NLI (learn from users)

Learning Subsystem

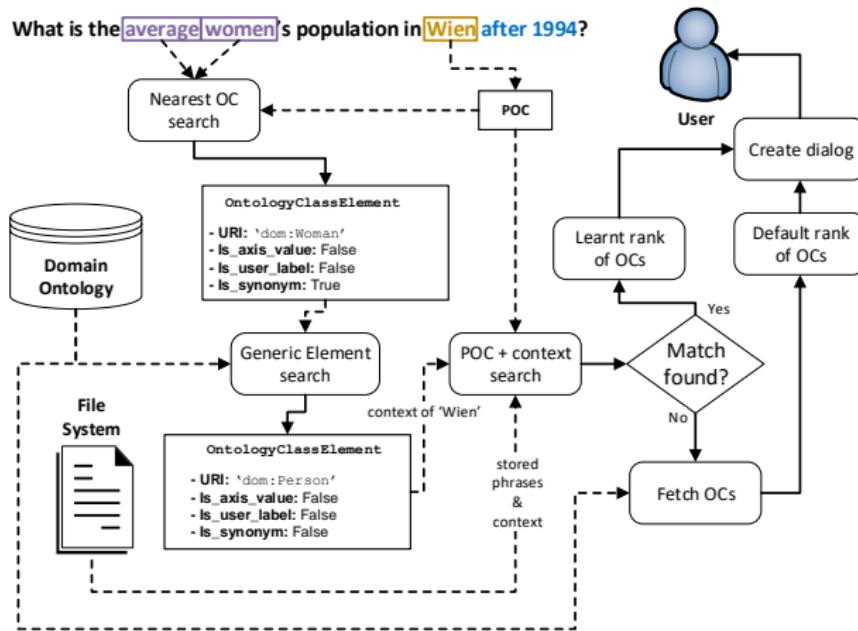


Figure: AUDiaL Learning Subsystem Workflow

Natural Language Interface (NLI) to Diagrams

Main Design Problem (rephrased)

Accessible NLI to semantically-enhanced statistical charts

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Main Design Problem (rephrased)

Accessible NLI to semantically-enhanced statistical charts

Functional Requirements:

- ① ✓ Execute typical tasks supported by charts in natural language (close domain)
- ② ✓ Answer queries in open-domain ontologies
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- ④ Log and timestamp user queries and system answers

Natural Language Interface (NLI) to Diagrams

Main Design Problem (rephrased)

Accessible NLI to semantically-enhanced statistical charts

Functional Requirements:

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HCI Techniques

Research Question

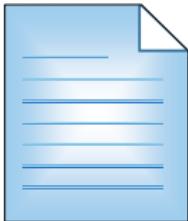
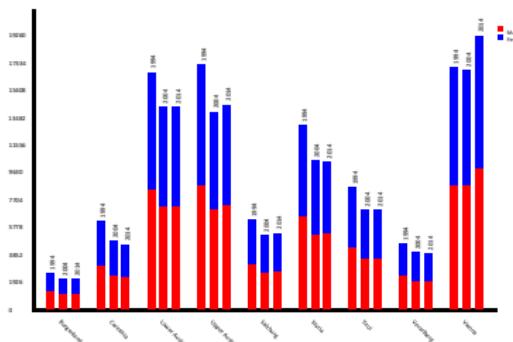
RQ4. How should a Natural Language Interfaces (NLI) be adapted to the specific needs of blind persons accessing diagrams?

Design Problem

Addition of **HCI techniques** to AUDiaL

- Aim: compensate for lack of cognitive benefits

Main HCI Techniques



- High-level summary

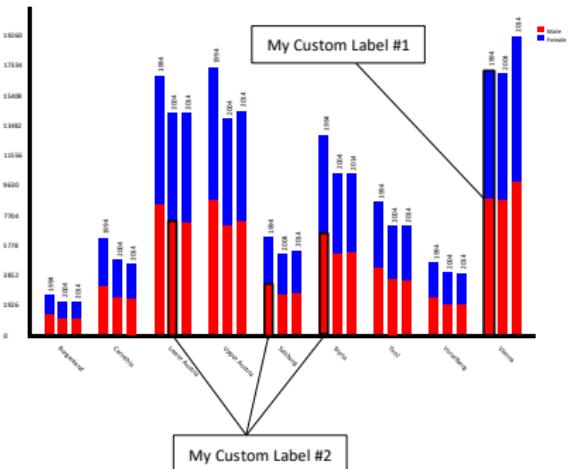
Main HCI Techniques

- High-level summary
- **Hierarchical and sequential navigation**

Main HCI Techniques

- High-level summary
- Hierarchical and sequential navigation
- **Quick jumps in navigation**

Main HCI Techniques



- High-level summary
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Main HCI Techniques

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- **Home node**

Main HCI Techniques

- High-level summary
- Hierarchical and sequential navigation
- Quick jumps in navigation
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- Home node
- **Trend descriptions**

Table of Contents

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- 2 State of the Art
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AUDiaL validation

Research Question

RQ5. Are Natural Language Interfaces (NLI) a suitable means for accessing statistical charts non-visually?

- Validation of AUDiaL with end users

AUDiaL validation

Laboratory sessions with 9 blind participants

- AUDiaL vs. traditional alternative

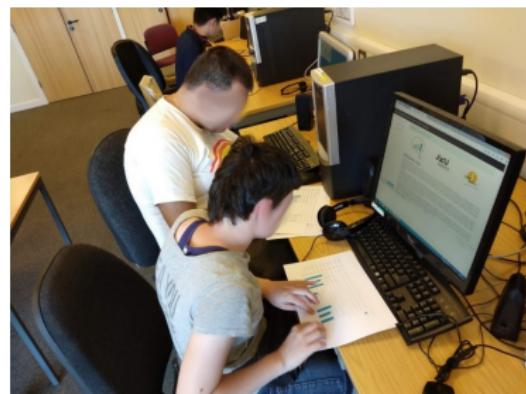


Figure: Participants during a validation session

AUDiaL validation

Laboratory sessions with 9 blind participants

- AUDiaL vs. traditional alternative
 - 8 cognitive tasks of varying difficulty

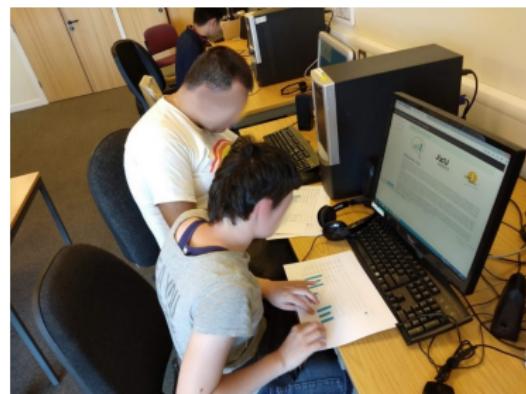


Figure: Participants during a validation session

AUDiaL validation

Laboratory sessions with 9 blind participants

- AUDiaL vs. traditional alternative
 - 8 cognitive tasks of varying difficulty
 - Three variables:
 - Effectiveness
 - Efficiency
 - User Satisfaction

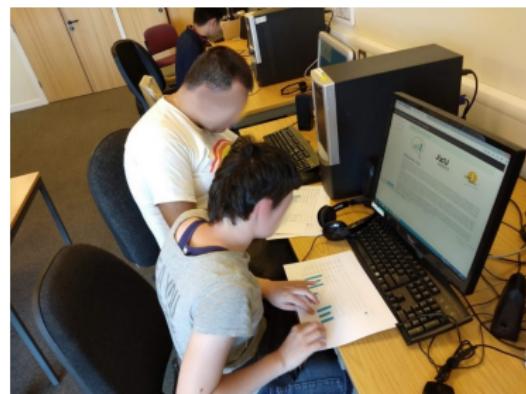


Figure: Participants during a validation session

Results: Effectiveness

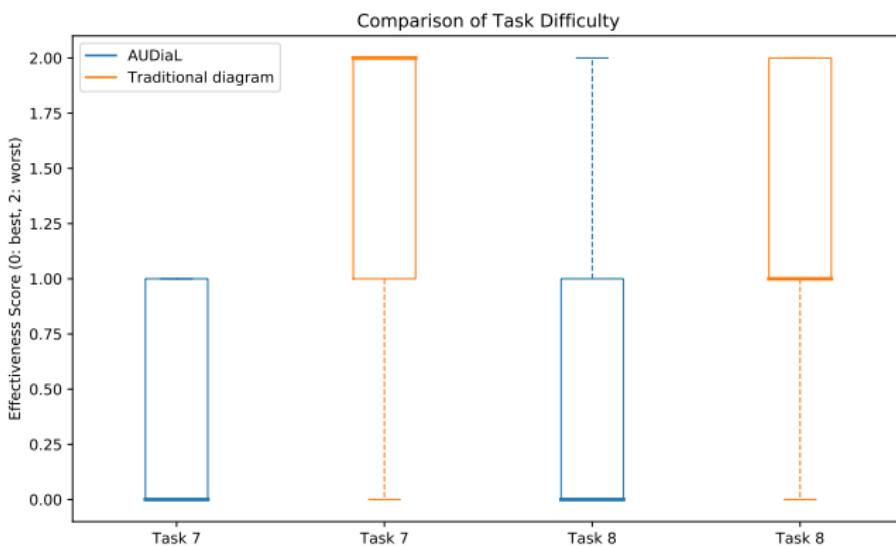


Figure: Comparison of Effectiveness scores

Results: Efficiency

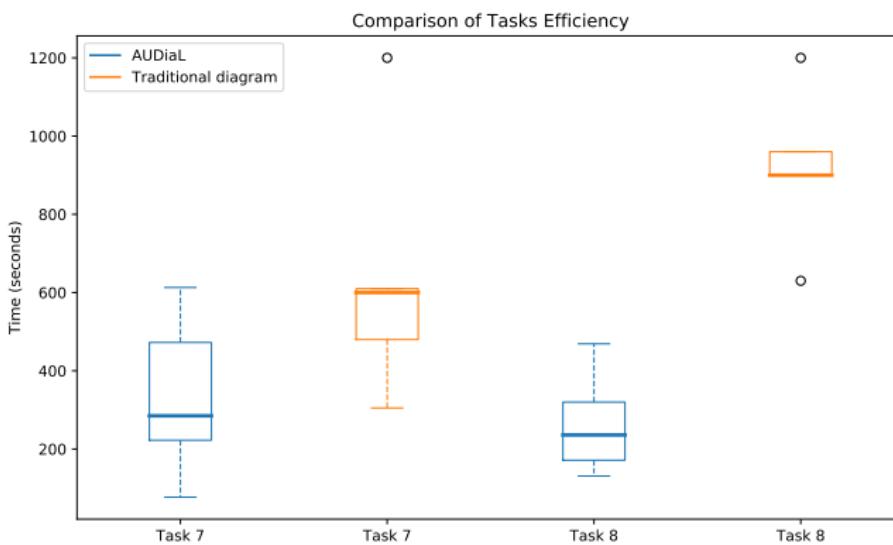


Figure: Comparison of Efficiency scores

Results: User Satisfaction (NASA-TLX)

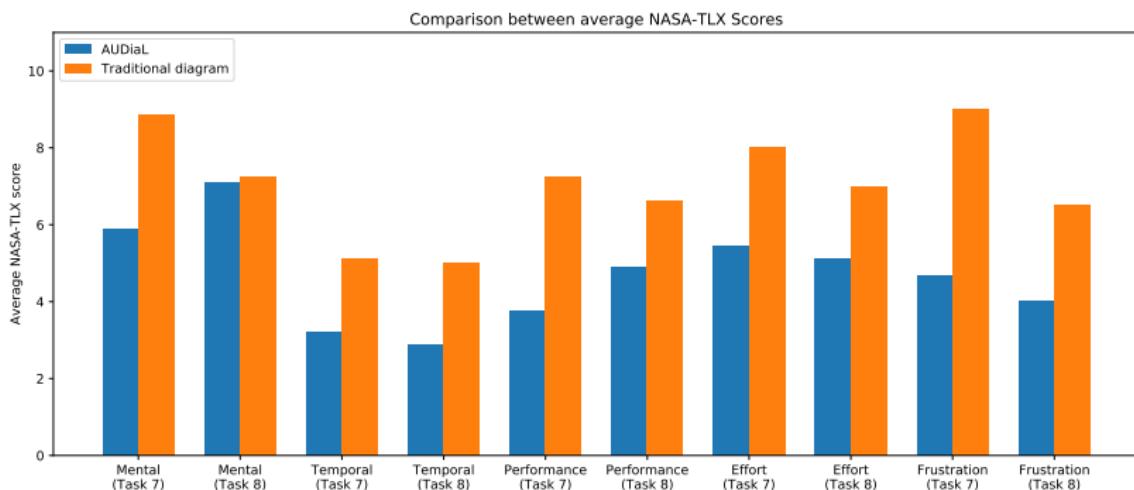


Figure: Comparison of NASA-TLX scores

Results: User Satisfaction (SUS)

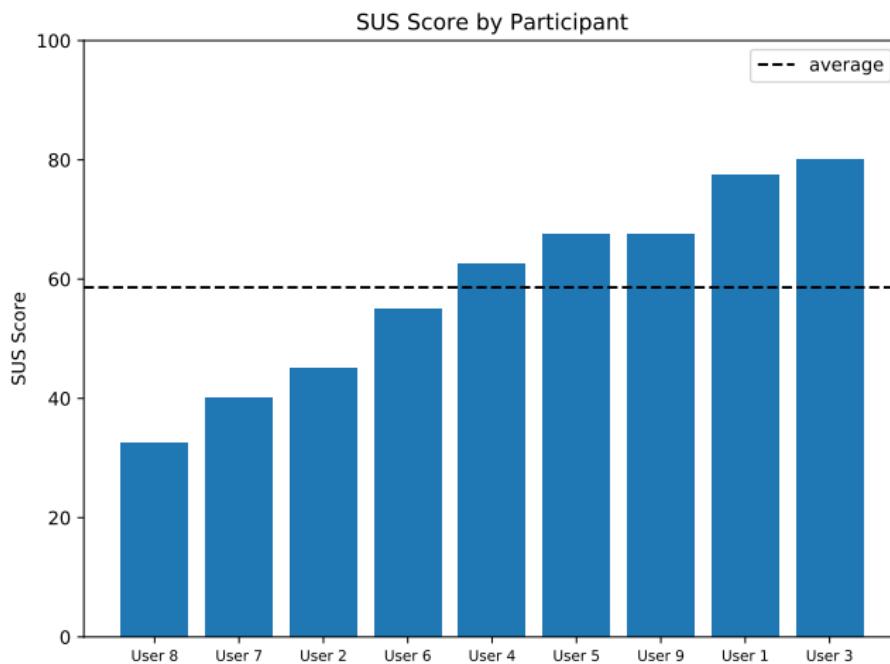


Figure: Collected SUS scores

Results: User Satisfaction (SUS)

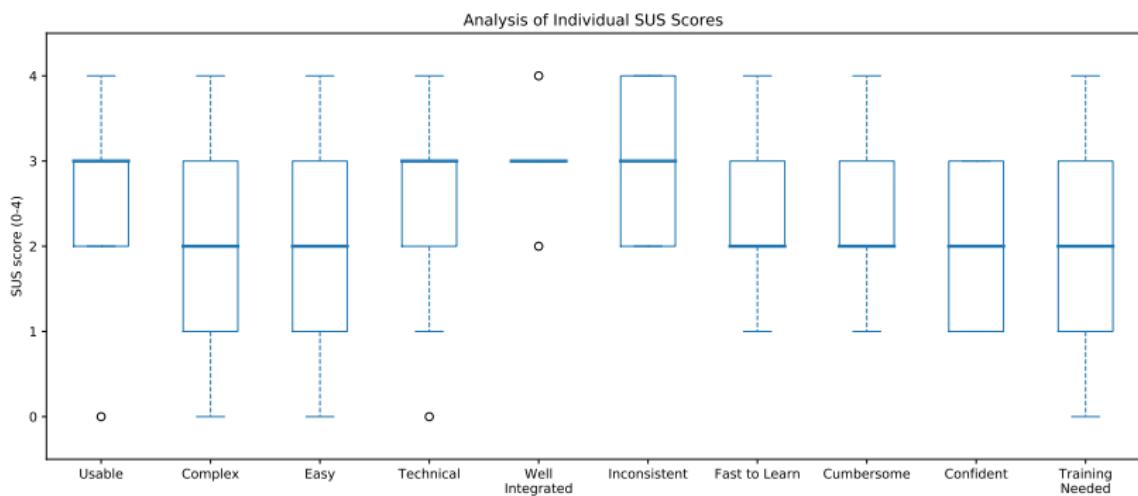


Figure: Distribution of collected individual SUS scores

Table of Contents

- 1 Motivation
- 2 State of the Art
- 3 Natural Language Interface to Diagrams
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- ⑤ Strong correlation between STEM interest and user satisfaction

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- ② Diagram semantics can be transparently embedded and queried via natural language
- ③ NLI to diagrams *effective* and *efficient* for accessibility
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- ⑤ Strong correlation between STEM interest and user satisfaction
- ⑥ NLI must be enhanced with specific accessibility techniques
 - Some techniques more useful than others, further research needed

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- ② Diagram semantics can be transparently embedded and queried via natural language
- ③ NLI to diagrams *effective* and *efficient* for accessibility
- ④ Prototype usability (user satisfaction) needs improvement
- ⑤ Strong correlation between STEM interest and user satisfaction
- ⑥ NLI must be enhanced with specific accessibility techniques
 - Some techniques more useful than others, further research needed
- ⑦ Blind users do not enquire about visualization terms
 - Focus on the data?

Thank you for your attention!