Dissertation.
Visual Analysis of In-Car Communication Networks.

Michael Sedlmair.
Challenge: Data Flood
Insights into this Data?
Information Visualization (InfoVis)

Definition (Card, 1999):
„Information visualization is the use of computer-supported, interactive, visual representations of abstract data to amplify cognition.“
Various Visualization Techniques and Algorithms

How to use these techniques to support real users in real work environments?
Challenge (Thomas et al., 2005): “Moving research into practice”

Why?

Data Analysis Tasks: Lengthy, Explorative

How to **design** tools for such tasks?

How to **evaluate** data analysis tools?
Challenge (Thomas et al., 2005): “Moving research into practice”

Call echoed by various researchers:


**Carpendale**: Evaluating Information Visualizations. In: Information Visualization: Human-Centered Issues and Perspectives

**Munzner**: A Nested Model for Visualization Design and Validation. InfoVis. 2009.
System Management Professionals.


Economic Analysts.


Biologists.


End-User Collaboration in InfoVis Projects
Moving Research into Practice ...

Automotive Engineering

Within Large Company Setting

Long-term, In-depth Collaboration
Main Contributions.

I) 3.5-year, In-depth Field Analysis.

II) 9 Design Studies / 5 Adopted Systems.

VA of In-Car Communication Networks.

Outline.

- **Motivation**: Domain Problem
- **Overview**: Application Areas
- **Example 1**: AutobahnVis (detailed)
- **Example 2**: MostVis (brief)
- **Lessons Learned**: InfoVis in a Large Company
- **Conclusions**: Summary and Future Work
Motivation: Domain Problem

Overview: Application Areas

Example 1: AutobahnVis (detailed)

Example 2: MostVis (brief)

Lessons Learned: InfoVis in a Large Company

Conclusions: Summary and Future Work
In-car Electronics!

...In-car Communication Networks!
What are In-car Communication Networks?

Function: ACC (Adaptive Cruise Control)
- Funct. Block
  - Method x1
  - Method y1

Function: Airbag
- FB 3
- FB 4
- FB 5

ECU 1
ECU 2
ECU 3
Gateway

Sensors / Actuators

Exchanging Signals packed in Messages
What is the problem?

More and More Functions...

... Increasing Complexity!

Specifications: ~50,000 Data Points / Bus Sy.

Traces: ~50 million Messages / Recorded Hour

Large Data Sets!

~400 Funct.

~70-80 ECUs

~10 Busses

~15,000 Messages/ s
However...

Tools are still text-based!

Time and experience required!

Understand Correlations?

Overview?

Communicate Findings?
Information Visualization?
**VA of In-Car Communication Networks.**

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Who are the target Users?

What is their Task?

What is their Data?

### Development Engineers
- Task: Specifying the Network
- Data: Specification Databases&Docus

### Analysis Engineers
- Task: Debugging the Network
- Data: Message Traces
Application Areas

Development Engineers
- Task: Specifying the Network
- Data: Specification Databases&Docus

Analysis Engineers
- Task: Debugging the Network
- Data: Message Traces

Technique-driven
- 3D Models for Visualizing In-car Communication
Visualization for Development Engineers

Problem / Goal:
Speeding up browsing and searching in large specification catalogs!

Data: Hierarchical

MostVis

Problem / Goal:
Getting Insights into specified dependencies and correlations!

Data: Graph

WiKeVis

RelEx
Problem / Goal: Finding errors in traces!

Data: Time-based

VisTra

AutobahnVis

ProgSpy

Cardiogram
Problem/ Goal: Understanding correlations between mechanical and electronic components!

Data: Physical Location.
Examples today.

AutobahnVis + 3D View
- Analysis Engineers
- Detecting Errors in Traces

MostVis
- Development Engineers
- Browsing Specifications
VA of In-Car Communication Networks.

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Development Process.

- Pre-Design Studies
- Design: AutobahnVis 1.0
- Evaluation
- Redesign: AutobahnVis 2.0
- Evaluation
- Deployment
Pre-Design Studies.

Ethnographic Studies

Lists and Simple Plots

Problem: Traces are very large!

Problem: Finding complex errors!

Novel Perspectives Needed!
Some Challenges.

Overview over Messages?

Message Timing?

Correlation to Vehicle Behavior?
Tool Design and Development.

Paper Prototyping

Final Concept Workshops
AutobahnVis 1.0*

Autobahn View.

Interaction: Zoom and Pan

Message

ECUs / Bus Systems

FA-CAN
ACSM
ICM_QL
Kombi
DSC_Modul
GWS
FRMFA
ZGW
EMF
SZL_LWS
List Views.

Fast Access to Raw Data
Adding an Additional 3D View.

Coordinating the 3D View with AutobahnVis (1).

Linking and Brushing
Coordinating the 3D View with AutobahnVis (2).

Semantic Linking

Panning over Time

Translating Messages into Mechanical Behavior
Video
Evaluation: Pair Analysis.

9 Domain Experts (4 with add. 3D View)
Results Autobahn View: Overview and Insights.

<table>
<thead>
<tr>
<th>Message Burst (1)</th>
<th>Cyclic Messaging (2)</th>
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<tbody>
<tr>
<td>Overview and Navigation</td>
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<table>
<thead>
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<th>Message</th>
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<tr>
<td>V_VEH_COG</td>
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<tr>
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<td>Signal ungültig</td>
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<tr>
<td>QU_V_VEH_COG</td>
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<td>Fahrzeug steht</td>
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<td>CRC_V_VEH</td>
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<tr>
<td>ALIV_V_VEH</td>
<td>7</td>
</tr>
</tbody>
</table>

VS.
Results 3D: Communication.

Com. between different levels of expertise
But not usable in daily practices...

Scalability!

Missing Features!

Integration with data and other tools?

Results of our studies:

Estimations, not Real Usage Examples!
AutobahnVis 2.0

Redesign

Integration
Semi-transparent Diamonds

New: Signal and Filter View

Integration with an In-house tool

Restrictions: 3D, “ECU-Lanes”
Evaluation: MILC*.

- 8 Weeks
- 5 Test Users
- Anecdotic Evidence

Measuring Hardware Breakdown
Message Bursts
Cyclic Messaging
Simplification and Speedup
Correlating Messages to Signals
Request/Response Messaging

... more and detailed examples in the thesis.
Deployment of AutobahnVis 2.0

Participants still use the Tool

End-Users convinced Stakeholders

Integration into ‘Core Components’

Moving Research into Practice!
VA of In-Car Communication Networks.

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Development Engineers

Task: Specifying the Network

Data: Specification Databases&Docus

Analysis Engineers
“We have a problem!”
Employee-Pull

**Users:** MOST Engineers

**Task:** Specifying MOST

**Data:** MOST Function Catalogs, ~40,000 Elements
Problem

Problem: Increased data has made searching and browsing time-intensive with current tools.

Text-based Tools: BNE, Specs (Pdf, Paper)
Design: MostVis.

Tree Vis. of MOST hierarchy.

Variety of Views and Functions.

* M. Sedlmair, C. Bernhold, D. Herrscher, S. Boring, and A. Butz:
MostVis: An Interactive Visualization Supporting Automotive Engineers in MOST Catalog Exploration. IV. 2009.
Evaluation: Lab Study.

14 Domain Experts
9 Domain-specific Tasks
Significantly Faster!

Insights into data analysis processes?
No, but... Deployment

Results convinced Stakeholders

Funding and Integration!

Moving research into practice!
VA of In-Car Communication Networks.

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After all this experience...

Pre-Design
- Observational Studies
- Focus Groups

Explorative/ Predictive Studies
- Interviews

Design
- Heuristics
- Test Users
- Thinking Aloud
- Design Workshops

Formative Studies

Post-Design
- Pair Evaluation
- Formal Experiments

Summative Studies
- Questionnaires
- Longterm Studies (MILCs)

...Practical Guidance for other Researchers?
InfoVis-Research in Large Companies.

- Interesting Problems
- Real Data and Users
- Funding and Integration

Moving Research into Practice!

Specific Challenges for Designing, Deploying and Evaluating InfoVis tools
Practical Guidance for other Researchers!

9 Challenges*

16 Recommendations*

* 1. **M. Sedlmair**, P. Isenberg, D. Baur, and A. Butz:
   Evaluating Information Visualization in Large Company Settings. BELIV. 2010. (Best Paper Award)
Challenges - Recommendations.

Studying Tools “In-depth”?

Overcome Technical Problems of Tool Integration!
## Challenges - Recommendations.

### Getting Time from Domain Experts

<table>
<thead>
<tr>
<th>Short Name</th>
<th>Description</th>
<th>pre</th>
<th>during</th>
<th>post</th>
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<tbody>
<tr>
<td>C1-INTEGRATE</td>
<td>Integrating Tools in Daily Work Processes</td>
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<td>x</td>
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<tr>
<td>C2-DATA</td>
<td>Getting the Data</td>
<td>x</td>
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### The Magic One Hour Rule!

### Delight with Usability and Aesthetics, not Eye-candy!

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<td>C6-CONFIDENTIALITY</td>
<td>Confidentiality of Information</td>
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<tr>
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<td>C8-STAKEHOLDERS</td>
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<td>x</td>
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<tr>
<td>C9-PUBLISHING</td>
<td>Publishing</td>
<td>x</td>
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Challenges - Recommendations.

Complex Work Processes

Be in Constant Close Cooperation!
Challenges - Recommendations.

Convincing Stakeholders?

The Magic Metric Money!

Consider Employee-pull and Researcher-Push!
VA of In-Car Communication Networks.

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Summary.

Moving Research into Practice in a Large Company
Use Case: InfoVis for In-car Communication Networks
Summary.

2 Example Projects (from 9 Design Studies)
InfoVis in a Large Company Setting

### Summary.

#### Study/Application Design

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#### Participants

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<td>C4-TIME</td>
<td>Getting Time From Domain Experts</td>
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<tr>
<td>C5-CONVENTIONS</td>
<td>Attachment to Conventional Techniques</td>
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<tr>
<td>The Technical Obstacles of Tool Integration</td>
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<tr>
<td>Additional Steps to Work with Domain-specific Data</td>
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<tr>
<td>Improving Your Study Environment with Care</td>
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<td>Effective Employee-pull and Researcher-push Solutions</td>
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<td>Combining Usability and Aesthetics, Avoid Window-dressing</td>
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<tr>
<td>Installing and Tech Support</td>
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<tr>
<td>Effective One Hour Limit</td>
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<td>Targeting the Target Audience</td>
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<td>x</td>
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<tr>
<td>Encouraging the Experts</td>
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<td>User Usability Studies with Outside Testers</td>
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<td></td>
<td></td>
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<tr>
<td>Reminders</td>
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<tr>
<td>R12-LEGAL</td>
<td>Try to get a License, Do Studies in any Case</td>
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<tr>
<td>R13-CCC</td>
<td>Be in Constant, Close Cooperation</td>
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<td>x</td>
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<td>R14-MONEY</td>
<td>The Magic Metric: Money</td>
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<tr>
<td>R15-SKILL</td>
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<td></td>
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<tr>
<td>R16-PUBLISH</td>
<td>Clarify Publishing Conditions Upfront</td>
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</tr>
</tbody>
</table>
Future Work.
Future Work.

BMW: More In-depth Studies
Future Work.

InfoVis: Other Large Companies

InfoVis: Other Areas in General
Future Work.

Me: Users of DimRed
Thank you.
Questions?

Michael Sedlmair
Backup Slides
<table>
<thead>
<tr>
<th>Publication</th>
<th>Prototype</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M. Sedlmair, P. Isenberg, D. Baur, W. Jacobi, M. Mauerer, C. Pigorsch, and A. Butz.</strong> Visual Analysis of In-Car Communication Traces. <em>In submission.</em></td>
<td>AutobahnVis &amp; Cardiogram</td>
</tr>
</tbody>
</table>
This function reports the current state of theSacRadio subscription status, whether the subscription status is stable, or whether the subscription status (and hence the list of subscribed stations) is undergoing update.
Example: Cardiogram.
Many more Problems Beyond AutobahnVis...

Very large Traces?
Tons of Traces?
Visualization...
+ Data Abstraction!
+ Automation!
Cardiogram: Basic Idea ...

... Using State Machines.

Core Components

Editor → State machine database → State Machine Engine → Cardiogram Visualization

Trace
Editor.
Database.

State Machines + Description.

Enables Collaboration
Engine.

Data Preparation
Carmen Integration
Out: Verification Tag
Out: Transition List
Visualization.

In: Transition List
Evaluation: MILC.

Core Components
1 year / 15 users

Visualization
8 weeks / 2 users
+ Pair Analysis / 6 Users
Results.

- Externalization of Expert Knowledge
- Mass Analysis instead of Sample Testing
- Insights into State Correlations
- Overview
- State Machine Verification
AutobahnVis
<table>
<thead>
<tr>
<th>Time</th>
<th>Nachricht</th>
<th>N-Wert</th>
<th>Sender</th>
<th>Klemme</th>
<th>Bus</th>
<th>B-Num</th>
<th>Rahmentyp</th>
<th>DLC</th>
<th>Flags</th>
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<tbody>
<tr>
<td>00:00:05,692 490</td>
<td>Daten Roll-Over Sensor</td>
<td>0x0F5</td>
<td>ACSM</td>
<td>Klemme 15</td>
<td>FA-CAN</td>
<td>356</td>
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<tr>
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<td>1C 7B FF FF FF FF 77 FF FF</td>
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<tr>
<td>00:00:05,721 318</td>
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### List Messages

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**Length?**

**Staples?**
Message Timing
Cyclic Messaging