MAV-Vis: A Notation for Model Uncertainty

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Models in Software Engineering Workshop at ICSE
“The reality of today’s software systems requires us to consider uncertainty as a first-class concern in the design, implementation, and deployment of those systems.” [Garlan, 2010]

Our focus:

Uncertainty about *design decisions* – the contents of a model.

Our agenda:

Enable MBSE with design uncertainty using *Partial models*. 

![Diagram showing partial models and their related research papers.](image-url)
Design Uncertainty

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Enable MBSE with design uncertainty using *Partial models*.

What does a usable notation for Design Uncertainty look like?

this paper
Usable Notation for Uncertainty

Partial models: effective for *automated* reasoning. However:

Existing notation ("MAV-Text") developed ad-hoc. Is it effective for *human* communication?

Need to maximize *cognitive effectiveness*. “Physics of Notations” [Moody, 2009]
Principles for designing graphical languages.

What we did:

- Developed a new notation: MAV-Vis
- Evaluated our implementation with a user study: “*Does MAV-Vis improve cognitive effectiveness?*” Speed, ease, accuracy for reading and writing.
1 Introduction

2 Design Uncertainty

3 Designing MAV-Vis

4 User Study

5 Conclusion
What is Design Uncertainty

Example: a simple class diagram.

What does the modeler know?

![Class Diagram]

- Vehicle
- LandVehicle
  - numDoors
What is Design Uncertainty

Example: a simple class diagram.

What does the modeler **not know**?
What is Design Uncertainty

Example: a simple class diagram.

What does the modeler \textbf{not know}?
What is Design Uncertainty

Example: a simple class diagram.

What does the modeler **not know**?
What is Design Uncertainty

Example: a simple class diagram.

What does the modeler **not know**?
Uncertainty: a Set of Possible Refinements

If we remove all uncertainty, we have a concrete refinement.
Modeling Uncertainty with Partial Models

Explicating uncertainty in a partial model.

unknown when the model should contain more elements

Unknown if or how many LandVehicles will be subclass of Vehicle

Unknown how many LandVehicles there will be

Vehicle

LandVehicle

numDoors

unknown which class will contain this attribute
Modeling Uncertainty with Partial Models

Explicating uncertainty in a partial model.

- **May**: Element is optional.
Modeling Uncertainty with Partial Models

Explicating uncertainty in a partial model.

- **May**: Element is optional.
- **Abs**: Element can be multiplied to many copies.
Modeling Uncertainty with Partial Models

Explicating uncertainty in a partial model.

- **May**: Element is optional.
- **Abs**: Element can be multiplied to many copies.
- **Var**: Element can be merged with others.
Modeling Uncertainty with Partial Models

Explicating uncertainty in a partial model.

- **May**: Element is optional.
- **Abs**: Element can be multiplied to many copies.
- **Var**: Element can be merged with others.
- **OW**: Model is incomplete.

![Diagram](image)
Modeling Uncertainty with Partial Models

Explicating uncertainty in a partial model.

- **May**: Element is optional.
- **Abs**: Element can be multiplied to many copies.
- **Var**: Element can be merged with others.
- **OW**: Model is incomplete.
“Extended” Partial Models

Expressing dependencies between points of uncertainty.

e.g. May Model: variant presented in [ICSE'12]
alternative refinements and relations between them.

- Explicate uncertainty
- May elements
- Syntactic annotations [FASE'12]

- May formula
- Correlate points of uncertainty
Existing Notation: MAV-Text

\[ (((\bigwedge_i a_i \land \neg \bigwedge_i b_i) \lor (\neg \bigwedge_i a_i \land \bigwedge_i b_i)) \land ((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land (\neg b_4 \Rightarrow \neg d_1) \]
Assessing MAV-Text

MAV-Text: Textual annotations + Propositional formula

Assessment (based on [Moody, 2009]):

Pros:
- Graphically economical
- 1:1 symbol-concept correspondence

Cons:
- Hard to visually distinguish symbols
- Does not intuitively suggest meaning
- Must annotate each element individually
- Does not take advantage of graphics
- Dependencies “hidden” in formula
- Must know how to read propositional formulas
1 Introduction

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Introducing MAV-Vis

((\bigwedge_i a_i \land \neg \bigwedge_i b_i) \lor (\neg \bigwedge_i a_i \land \bigwedge_i b_i)) \land
((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land
(\neg b_4 \Rightarrow \neg d_1)
Introducing MAV-Vis

Representing Var

\[
((\wedge_i a_i \land \neg \wedge_i b_i) \lor (\neg \wedge_i a_i \land \wedge_i b_i)) \land \\
((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land \\
(\neg b_4 \Rightarrow \neg d_1)
\]
Introducing MAV-Vis

Representing Abs

((\land i a_i \land \neg \land i b_i) \lor (\neg \land i a_i \land \land i b_i)) \land
((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land
(\neg b_4 \Rightarrow \neg d_1)
Introducing MAV-Vis

Representing May: a color for each PoU

\[
\left( \left( \bigwedge_i a_i \land \neg \bigwedge_i b_i \right) \lor \left( \neg \bigwedge_i a_i \land \bigwedge_i b_i \right) \right) \land \\
\left( (c_1 \land \neg d_1) \lor (\neg c_1 \land d_1) \right) \land \\
(\neg b_4 \Rightarrow \neg d_1)
\]
Introducing MAV-Vis

Representing May: identify alternative

\[ ((\land_i a_i \land \neg \land_i b_i) \lor (\neg \land_i a_i \land \land_i b_i)) \land ((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land (\neg b_4 \Rightarrow \neg d_1) \]
Introducing MAV-Vis

Representing May: grouping elements in alternatives

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Introducing MAV-Vis

Representing May: the other alternative

\[ ((\bigwedge_{i}a_i \land \neg \bigwedge_{i}b_i) \lor (\neg \bigwedge_{i}a_i \land \bigwedge_{i}b_i) ) \land \\
((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land \\
(\neg b_4 \Rightarrow \neg d_1) \]
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Representing May: numbers for different alternatives
Introducing MAV-Vis

Representing May: alternative with many parts
Introducing MAV-Vis

Representing May: a different PoU

\[
((\bigwedge_i a_i \land \neg \bigwedge_i b_i) \lor (\neg \bigwedge_i a_i \land \bigwedge_i b_i)) \land \\
((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land \\
(\neg b_4 \Rightarrow \neg d_1)
\]
Introducing MAV-Vis

Representing May: expressing PoU dependencies

\[
((\bigwedge_i a_i \land \neg \bigwedge_i b_i) \lor (\neg \bigwedge_i a_i \land \bigwedge_i b_i)) \land
((c_1 \land \neg d_1) \lor (\neg c_1 \land d_1)) \land
(\neg b_4 \Rightarrow \neg d_1)
\]
Introducing MAV-Vis
Introducing MAV-Vis

\[(\bigwedge_i a_i \land \neg \bigwedge_i b_i) \lor \neg \bigwedge_i a_i \land \bigwedge_i b_i) \land \neg (c_1 \land \neg d_1) \lor \neg (c_1 \land d_1)] \land \neg b_4 \Rightarrow \neg d_1\]
Introducing MAV-Vis

MAV-Vis: A Notation for Model Uncertainty

M. Famelis, S. Santosa

I

II

- date
- status
- requires
- internet access
- Accessor
- id
- number
- type
- beds
- localize
- Access
- securityAttributes
- date
- securityAttributes
- gain
- require
- reservation
- Reservation

- creditcard
- phone
- name
- surname
- Customer
- isA
- Person
- wage
- SIN
- name
- surname
- Employee

- m1
- g1
- m2
- g2
Improvements in MAV-Vis

Based on the principles in [Moody, 2009]:

- 1:1 symbol-concept correspondence
- Different retinal vars for each symbol (shape, texture)
- Notation (more) suggestive of concepts
- Relationships are visualized
- Grouping of annotations (not per-element)
- Visually expressive (using shape, color, texture, size)
- Dual coding with text and color
- No need to know propositional logic (per se)
- Relatively economical, cognitively manageable
MAV-Vis Limitations

**Portability**  Annotation language → cannot guarantee symbols won’t conflict!

 Implemented for Class Diagrams, E-R Diagrams.
 Porting to other notations not automatable.
 BUT: can use with any abstract syntax (MOF)

**Less powerful**  than propositional logic (of course)
 But dependency sub-language can be extended.

**No OW**  OW annotates entire model.
 (Megamodeling?)

**No tooling**  Out of scope here: focus on ideal notation.
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**Overview**

**Motivation**  Evaluate MAV-Vis as an implementation of the theory in [Moody, 2009].

**Goal**  User study to confirm or refute the hypothesis:

> “MAV-Vis improves cognitive effectiveness for reading and writing compared to MAV-Text”

Cognitive Effectiveness:

*Ease, Speed, Accuracy*

**Participants**  12 unpaid particip., with Bach. in CS or higher

Average experience in MAVO: 2.2/5

(3 participants were experts in MAVO, already familiar with MAV-Text)
Setup

Procedure:
- Tutorial
- Freeform exercise
- [Reading, Writing ]x2
- Questionnaire

Design:
- Within subjects to allow comparison and minimize selection bias
- 2x2 Latin square to control for:
  - Order of syntaxes (MAV-Vis, MAV-Text)
  - Modeling scenario

Measurements:
- **Ease** Questionnaire responses
- **Speed** Task completion time
- **Accuracy** Error counts and comprehension scores
Results

Ease:
- MAV-Vis considered more intuitive, easier to remember, efficient to read
- MAV-Text and MAV-Vis almost tied for writing efficiency
- MAV-Vis gathered more preferences

Speed:
- MAV-Text took 2:08min longer for reading.
- MAV-Vis was 13sec slower for writing.

Accuracy:
- No difference in reading Abs, Var.
- Noticeable difference for reading May (on average 1.4 fewer errors)
- On average 0.7 more errors writing with MAV-Vis. (most errors were about coloring PoUs)
### Result Tables

#### TABLE III
**Ease results.**

<table>
<thead>
<tr>
<th></th>
<th>Intuitive</th>
<th>Easy to Remember</th>
<th>Efficient to Read</th>
<th>Efficient to Write</th>
<th>Number Preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abs</td>
<td>MAV-Text</td>
<td>3.2</td>
<td>3.3</td>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>MAV-Vis</td>
<td><strong>4.2</strong></td>
<td><strong>4.2</strong></td>
<td><strong>4.3</strong></td>
<td><strong>3.6</strong></td>
</tr>
<tr>
<td>Var</td>
<td>MAV-Text</td>
<td>2.5</td>
<td>2.8</td>
<td>3.3</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>MAV-Vis</td>
<td><strong>3.3</strong></td>
<td><strong>3.7</strong></td>
<td><strong>3.8</strong></td>
<td><strong>3.2</strong></td>
</tr>
<tr>
<td>May</td>
<td>MAV-Text</td>
<td>2.9</td>
<td>3.6</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>MAV-Vis</td>
<td><strong>3.8</strong></td>
<td><strong>4.1</strong></td>
<td><strong>3.9</strong></td>
<td><strong>3.8</strong></td>
</tr>
<tr>
<td>May Groupings</td>
<td>MAV-Text</td>
<td>2.8</td>
<td>3.2</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>MAV-Vis</td>
<td><strong>3.7</strong></td>
<td><strong>3.8</strong></td>
<td><strong>3.5</strong></td>
<td><strong>3.3</strong></td>
</tr>
</tbody>
</table>

#### TABLE IV
**Speed results.**

<table>
<thead>
<tr>
<th></th>
<th>Reading (mm:ss)</th>
<th>Writing (mm:ss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAV-Text</td>
<td>14:06</td>
<td>9.29</td>
</tr>
<tr>
<td>MAV-Vis</td>
<td><strong>11:58</strong></td>
<td>9.42</td>
</tr>
</tbody>
</table>

#### TABLE V
**Accuracy results.**

<table>
<thead>
<tr>
<th>(a) Read</th>
<th>Abs (score/6)</th>
<th>Var (score/6)</th>
<th>May (score/6)</th>
<th>Total (score/6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAV-Text</td>
<td>3.9</td>
<td>5.1</td>
<td>2.8</td>
<td>11.8</td>
</tr>
<tr>
<td>MAV-Vis</td>
<td>3.9</td>
<td>5.2</td>
<td><strong>4.2</strong></td>
<td><strong>13.3</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(b) Write</th>
<th>Syntax (error count)</th>
<th>Comprehension (error count)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAV-Text</td>
<td><strong>2.3</strong></td>
<td>1.7</td>
</tr>
<tr>
<td>MAV-Vis</td>
<td>3.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Threats to Validity

• Small sample size: no statistics
  Results to be understood as preliminary evidence

• Prior exposure to MAVO

• Familiarity with propositional logic

• Confusion regarding uncertainty concepts (MAVO)
  (But both syntaxes affected equally)

• Selection bias from imbalanced knowledge of UML/E-R
  (Reported by 1 subject)
Overall: MAV-Vis more efficient but more writing errors.

Most writing errors: PoU colors.
(PoU not a formal concept)

However:
Not necessarily universal solution!

Cognitive Fit
Learning Style and Expertise

Discussion

Freeform: *dashes, piles question marks, ellipses*
**Summary**

Partial models:
 Formalism for management of design uncertainty.

Existing work:
 Automated reasoning vs human communication
 Ad-hoc notation (MAV-Text)

What we did:
 Developed MAV-Vis, using [Moody, 2009]
 Performed user study to evaluate our implementation
 Cognitive Effectiveness for reading and writing:
   Ease, Speed, Accuracy

Results:
 MAV-Vis more efficient but more writing errors.
Next Steps

Larger picture:
Notation only one aspect.
Effective methodological support for Design Uncertainty.
Patterns of uncertainty? Sources?
How do users already cope with Design Uncertainty?

Focused on notation design, not tooling.
Future:
Tooling integration and impact on cognitive effectiveness
“MAVO-isation” of arbitrary languages

Dependency sublanguage:
What are reasonable extensions?
Relation to patterns.
Impact on tooling.
Questions?
Bibliography I


