Meaningful Modeling: What’s the Semantics of “Semantics”?

Harel, D. & Rumpe, B. IEEE Computer, 2004

CSC2125 September 9, 2012
Presented by Stephanie Santosa
Problem: Defining a modeling language

• To standardize UML, need to represent semantics
• Difficult to account for all subsets, kinds of systems, relationships, ...

• Clarify notions about defining modeling languages:

Syntax (notation) vs Semantics (meaning)
Information Representation

- Syntactic representation as data requires interpretation (mapping to assign meaning)
- Mixing can lead to confusion

June 20, 2000

“The last day of the first spring in the second millennium”

“John’s Birthday”
Defining a Language

- Syntax
- Semantic Mapping
- Semantic Domain
Syntax (L)

- **Textual**: linear character sequences
- **Iconic**: pictorial signs
- **Diagrammatic**: lines, arrows, closed curves, boxes, connections, ...

- Formal, rigid set of syntactic rules is essential for communication
- “Properly defining diagrams seems much harder”

- Worthless without semantics
  
  e.g. $X = X + Y$
Semantic Domain (S)

- Semantics provide meaning – an element in a well defined domain => Universe of discourse

- How to describe semantic domain? English or formal math

- UML’s semantic domain is difficult to define

  Why?

  Many diagrammatic sublanguages, combinations of messages, states, events, data values
Semantic Mapping (M)

• Relates syntactic expressions to semantic domain elements

M: L$\rightarrow$S

• Does not exist for full UML
Representation of Elements

- **Layered definition**

<table>
<thead>
<tr>
<th>TEXTUAL</th>
<th>VISUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characters (alphabet)</td>
<td>Topological elements: open and closed line segments</td>
</tr>
<tr>
<td>Words (keywords, numbers, delimiters)</td>
<td>Types of lines and shapes (arrows, boxes, circles)</td>
</tr>
<tr>
<td>Sentences/Expressions (context-free grammar)</td>
<td>Diagram meaningful combinations</td>
</tr>
<tr>
<td>Context conditions (variable types)</td>
<td>Context conditions (for set of legal diagrams)</td>
</tr>
</tbody>
</table>

- **Notations:** $N_L$ (abstract syntax) $N_S$ (semantic domain) $N_M$ (mapping)
  - Should also accommodate audience (e.g. natural lang for broad range of users)

*Context conditions provide syntax with algorithm for parsing concrete into abstract – Examples?*
Notations for Visual Formalisms

• Two approaches for modeling abstract syntax for diagrammatic languages
  • Graph grammars
  • Entity-relationship diagrams (UML class diagrams)
    • More intuitive, less expressive

• Metamodeling: Official UML definitions use class diagram approach, also with context conditions written in Object Constraint Language

Examples?

• Problem of defining semantics for full UML remains
Formality

• “Visual” ≠ “Informal”

• Doodling phenomenon: mind-set that diagrams are scribble work; real work done with textual languages

![Diagram showing the relationship between language precision and statement precision. The diagram is divided into four quadrants. The top left quadrant, labeled “30 < X < 70,” indicates that imprecise statements with rigorously defined language are possible. The bottom right quadrant, labeled “Not possible,” indicates that precise statements with imprecise language are not possible. The other two quadrants are labeled “Number of about 100” and “99 < X < 101.”]
Insights from Defining Semantics

- Process seeks answers to questions; can improve the language itself
- Inconsistencies in UML can be examined while defining semantics

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
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<tbody>
<tr>
<td>Does the given formalization capture the intended users’ intuition?</td>
<td></td>
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<tr>
<td>Are the context conditions sufficient to ensure that language expressions are consistent and meaningful?</td>
<td></td>
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<tr>
<td>Does the notation permit the specification of important semantic domain properties?</td>
<td></td>
</tr>
<tr>
<td>If analysis techniques or transformations for the language exists, are they sound with respect to semantics?</td>
<td></td>
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</tbody>
</table>
Example 1:

Arithmetic Expressions

- Syntax (L) given by BNF-like grammar

- Semantic domain (S) is all natural numbers

- Semantic mapping (M) associates expression to natural number

- Expressions are combined with operators

\[
\begin{align*}
\langle \text{Exp} \rangle & ::= \langle \text{Number} \rangle \mid \langle \text{Variable} \rangle \\
& \quad \mid ( \langle \text{Exp} \rangle ) \mid - \langle \text{Exp} \rangle \\
& \quad \mid \langle \text{Exp} \rangle + \langle \text{Exp} \rangle \mid \langle \text{Exp} \rangle \ast \langle \text{Exp} \rangle \\
& \quad \mid \text{foo} ( \langle \text{Exp} \rangle )
\end{align*}
\]

\[S<\text{Exp}>=\text{Nat}\]

\[M<\text{Exp}>: \langle \text{Exp} \rangle \rightarrow \text{Nat}\]

\[M(a \text{ “+” } b) = M(a) + M(b)\]

\[M( \text{ “foo(” a “)” } ) = M(a) \ast M(a)\]
Example 2: Dataflow diagrams

- Syntax (L)
- Semantics (S)
- To describe structure?
- To describe behaviour? (deterministic, no memory)

\[IO_{\text{func}}: \text{Nat} \rightarrow \text{Nat}\]
\[IO_{\text{func}}(n): n(n+1)/2\]

- Semantic domain: set of traces

\[IO_{\text{trace}} = \{x \mid x \in (I \cup O)^*\}\]
Wrong Ways to View Semantics

- Semantics is the metamodel
- Semantics is the semantic domain
- Semantics is the context conditions
- Semantics is dealing with behaviour
- Semantics is being executable
- Semantics is the behaviour of a system
- Semantics is the meaning of individual constructs
- Semantics means looking mathematical
Current State of UML Semantics?

Figure 6.1 - A schematic of the UML semantic areas and their dependencies

From Object Management Group UML Superstructure document