The “Physics” of Notations: Towards a Scientific Basis for Constructing Visual Notations in Software engineering

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Introduction

- Visual Languages

Cave art – Lascaux cave, France ~17,300 years old
Introduction

- Anatomy of visual language
  - Graphical symbols
  - Compositional rules
  - Definitions of symbols
    - 1D (lines), 2D (areas), 3D (volumes), text (labels), spatial relationships

Visual syntax
Introduction

- What makes a good visual notation?
What makes a good visual notation?

Cognitive effectiveness

*speed, ease and accuracy* with which the human mind processes

A visual notation must

a. Effectively communicate with business stakeholders
b. Support design and problem solving by sw engineers
Introduction

- It’s location location location baby.

VS

The same? Different? What is intuitive?
Introduction

- Visual dialects

Figure 2. Visual Dialects: De Marco DFDs vs Gane & Sarson DFDs. Same semantics, different visual syntax: which is best?
Introduction

- Visual dialects

Figure 3. Semantically equivalent forms of the ER Model. All these visual forms express the same underlying relationship semantics.
Figure 6. Theory of Diagrammatic Communication: communication consists of two complementary processes: encoding and decoding.
Design space

Figure 7. Visual Variables [8]: these define a set of elementary graphical techniques for constructing visual notations.
Design Space

- **Primary Notation**
  - Formal definition. Set of symbols with prescribed meanings

- **Secondary Notation**
  - Visual variables *(reinforcing or claritive nature)*

- **Visual Noise**
  - Accidental secondary notation *(result in distortion of intended message)*
Descriptive Theory

- Solution Space
- Human graphical information processing

**Seeing**
(automatic and executed in parallel)

**Understanding**

Figure 8. The Solution Space: maximising cognitive effectiveness means optimising notations for processing by the human mind
Prescriptive Theory

Each principle has:

- Name
- Semantic definition
- Operational definition
- Design strategies
- Exemplars and counter exemplars

Figure 9. Principles for designing cognitively effective visual notations: the modular (“honeycomb”) structure supports modifications and extensions to the principles.
1. Semiotic Clarity

Figure 10. Semiotic Clarity: there should be a 1:1 correspondence between semantic constructs and graphical symbols.
Symbol Redundancy: multiple graphical symbols represent same semantic construct

Figure 11. Symbol redundancy (synographs) in UML: there are alternative graphical symbols for interfaces on Class Diagrams (left) and package relationships on Package Diagrams (right).
Symbol Overload: different constructs are represented by the same symbol (ambiguity)

Figure 12. Symbol Overload (homographs) in ArchiMate: the same graphical convention can be used to represent different types of relationships: generalisation (left) and composition (right)
**Symbol Excess:** symbols don’t correspond to semantic constructs

**Figure 13.** Symbol Excess in UML: the comment is a useful notational feature but should not be shown using a graphical symbol.
Symbol Deficit: semantic constructs are not represented by symbols
2. Perceptual Discriminability

Figure 14. Experimental studies show that rectangles and diamonds in ER diagrams are frequently confused by novices.
Prescriptive Theory

2. Perceptual Discriminability

Figure 14. Experimental studies show that rectangles and diamonds in ER

Figure 15. Entities and relationships could be made more discriminable by using shapes from different families
2. Perceptual Discriminability

Figure 14. E in ER diagram

Figure 15. E discriminable

Figure 17. Redundant Coding: using multiple visual variables (shape + colour) to distinguish between symbols
Prescriptive Theory
# Prescriptive Theory

## Table 1. Relationship Types on UML Class Diagrams

<table>
<thead>
<tr>
<th></th>
<th>Aggregation</th>
<th>Association (navigable)</th>
<th>Association (non-navigable)</th>
<th>Association class relationship</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraint</td>
<td>Dependency</td>
<td>Generalisation</td>
<td>Generalisation set</td>
<td>Interface (provided)</td>
<td></td>
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<tr>
<td>Interface</td>
<td>N-ary association</td>
<td>Note reference</td>
<td>Package containment</td>
<td>Package import (public)</td>
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</tr>
<tr>
<td>(required)</td>
<td></td>
<td></td>
<td></td>
<td>«import»</td>
<td></td>
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<tr>
<td>Package import (private)</td>
<td>«access»</td>
<td>«merge»</td>
<td>Realisation</td>
<td>Substitution</td>
<td>Usage</td>
</tr>
</tbody>
</table>
Prescriptive Theory

- Can I get you one of these?
2. Perceptual Discriminability

Figure 18. Textual Differentiation: UML uses labels and typographical characteristics to distinguish between symbols.
3. Semantic Transparency

Figure 19. Semantic Transparency defines the degree of association between a symbol’s form and its content.
3. Semantic Transparency

Figure 20. Rich pictures: a rare but highly effective example of iconic representation in SE [17]
3. Semantic Transparency

Figure 21. Semantically transparent relationships: these spatial relationships are interpreted in a spontaneous or natural way [147]
3. Semantic Transparency

Figure 22. Spatial enclosure and overlap (right) convey the concept of overlapping subtypes in a more semantically transparent way than arrows (left).
Figure 23. In the absence of complexity management mechanisms, ER models must be shown as single monolithic diagrams.
Prescriptive Theory

4. Complexity Management
4. Complexity Management

Figure 24. Hierarchical organisation allows a system to be represented at multiple levels of abstraction, with complexity manageable at each level.
5. Cognitive Integration
Conceptual integration

Figure 26. Contextualisation: each diagram should include its surrounding context to show how it fits into the system as a whole
5. Cognitive Integration
   Perceptual integration

- Orientation
- Route choice
- Route monitoring
- Destination recognition
6. Visual Expressiveness

Figure 27. Visual Expressiveness
6. Visual Expressiveness

Figure 28. Visual Monosyllabism: ER diagrams and DFDs use only a single visual variable to encode information (shape).
Prescriptive Theory

6. Visual Expressiveness
### 6. Visual Expressiveness

Table 2. Different visual variables have different capabilities for encoding information: Power = highest level of measurement that can be encoded; Capacity = number of perceptible steps

<table>
<thead>
<tr>
<th>Variable</th>
<th>Power</th>
<th>Capacity</th>
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<tbody>
<tr>
<td>Horizontal position (x)</td>
<td>Interval</td>
<td>10-15</td>
</tr>
<tr>
<td>Vertical position (y)</td>
<td>Interval</td>
<td>10-15</td>
</tr>
<tr>
<td>Size</td>
<td>Interval</td>
<td>20</td>
</tr>
<tr>
<td>Brightness</td>
<td>Ordinal</td>
<td>6-7</td>
</tr>
<tr>
<td>Colour</td>
<td>Nominal</td>
<td>7-10</td>
</tr>
<tr>
<td>Texture</td>
<td>Nominal</td>
<td>2-5</td>
</tr>
<tr>
<td>Shape</td>
<td>Nominal</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Orientation</td>
<td>Nominal</td>
<td>4</td>
</tr>
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</table>
7. Dual Coding

Perceptual Discriminability and Visual Expressiveness say no to text

However when we use both, information is encoded in separate systems in working memory and referential connections are strengthened
7. Dual Coding

Figure 32. Dual Coding: the Best of Both Worlds?
8. Graphic Economy

Everything does not have to be in a diagram!

More is not necessarily better.
9. Cognitive fit

- Know thy audience
  - Novices have trouble recalling multiple symbols
  - Novices have trouble discriminating between symbols
  - Novices are affected by complexity

- Know thy medium
  - Whiteboard? Paper? Computer program?
10. Combining principles

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<thead>
<tr>
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<th>Perceptual Discriminability</th>
<th>Semantic Transparency</th>
<th>Complexity Management</th>
<th>Cognitive Integration</th>
<th>Visual Expressiveness</th>
<th>Dual Coding</th>
<th>Graphic Economy</th>
<th>Cognitive Fit</th>
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<td><strong>Dual Coding</strong></td>
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**Figure 36. Interactions between principles:** + indicates a positive effect, – indicates a negative effect, ± indicates a positive or negative effect depending on the situation.
Conclusions and significance

Visual syntax has been undervalued or ignored

Key points:
- Design goal
- Descriptive theory
- Prescriptive theory