Tutorial 7
Adaptive Graphics Generation in the User Interface

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Introduction

Some arguments for using graphics in the user interface

- most effective medium for many information types (e.g., spatial and visual concepts, quantitative and structural relationships of data etc.)
- takes advantage of the human capabilities for visual perception and thinking
- easy to refer to, e.g. to perform direct manipulations
- more international than language
- decorative and eye catching
- various types of graphics used in the UI

Contents

- Part 1: Introduction - the Role of Graphics in future UI's
- Part 2: Basics - Syntax, Semantics and Pragmatics
- Part 3: Design as Product
- Part 4: Design as Process - Generation Approaches
- Part 5: Showcases, Systems, Applications

Introduction

How do we interact with computers in the future?

Will we still rely on:
- the desktop metaphor
- GUI's with direct manipulation
- screen, keyboard, and mouse

Some of the most popular visions for future UI's

- ubiquitous computing (Ubicomp)
- mobile computing / mobile multimedia
- immersive interaction in virtual worlds and augmented realities
- agent-based and anthropomorphic interfaces
- still multimedia PC's, all alternatives listed above

What role will graphics play in these visions?

Vision 1: Ubiquitous Computing (Ubicomp)

User lives in an environment that is highly instrumented with networked computers. Idea of invisible computers and interfaces (Mark Weiser, Xerox Parc, 1988 ff.)

Ubicomp features an infrastructure for highly decentralised computing services and mobile devices.

But effective information services will still require graphical representations - regardless of the chosen degree of decentralisation.

Example: ParcTab with graphical interface

Source: Xerox Parc
**Vision 2: mobile computing / mobile multimedia**

Information and computing services are available anytime and everywhere for mobile users.

various ongoing R&D activities:
- mobile devices
- telecommunication infrastructure
- protocols & standards
- services „mobile multimedia“

**Implications from vision 1 and 2:**

- strong need for new graphical designs which allow effective information presentations and interactions on very small displays
- strong need for mechanisms which allow to adapt graphical presentations (and other media) so that they accomplish the varying information needs of different users in different situations

**Vision 3: Virtual and augmented realities**

The (virtual) environment will partly become the user interface.

User interacts with virtual world similar to the real one; especially when „full-body“ interaction is supported. Example: Smartroom

Source: MIT Media Lab, project Smartroom

**Vision 3: Virtual realities**

- e.g. CAVE™ (multi-person 3D video/audi-environments)

Source: EVL, Univ. of Illinois at Chicago

**Vision 3: Virtual realities**

- Navigation in 3D space becomes the dominant metaphor for navigation in information spaces
- GUI concepts known from the PC interface are carried over to virtual 3D environments:
  - embedded 2D/3D widgets

Source: Feiner, Blackmore & Seligmann, Columbia Univ. System KARMA

**Vision 3: Augmented realities**

- superimpose text and graphical elements on the visual perception of the real world (annotated worlds)

Source: Feiner, Blackmore & Seligmann, Columbia Univ. System KARMA
Implications from vision 3:

- strong need for spatial navigation support through graphical focusing techniques
- strong need for mechanisms which allow to flexibly configure the environment so that it accomplishes the varying information needs of different users in different situations

Vision 4: Agent-based / anthropomorphic UI’s

User interacts with conversational characters. Agent as a personified entity that becomes an “alter ego” of a computer system

Implications from vision 4:

- strong need for believable agent behaviours. Personal assistants must be able to adapt its behaviour to the personality of the user
- strong need for mechanisms which allow to flexibly configure scripts for information presentations that satisfy particular information needs of the user and which will be performed by the agent

The need for adaptive graphics design in the UI

... implies a need for flexible generation mechanisms

The Idea: Develop components for the automated generation of functional graphics

presentation tasks defined over application data or knowledge sources

generation parameters
- user profiles
- available resources
- display situation

design knowledge

drawings

generation

tasks

automated graphics designer

graphics renderer for target output media

new application types
- mobile services
- live data

refined user models
- information needs
- preferences

new display parameters
- mobile devices
- large screens

diverse display situations
- VR, AR
- @ office/home/on the way

Some previous application fields for automated graphics generators

- abstract information graphics (e.g., charts, scatter plots, function diagrams, ...)
- graph and network layout (e.g., organization charts, circuit drawings, ...)
- icon design / icon-based instructions
- map generation (e.g., topographic maps, weather and other special purpose maps, ...)
- technical drawings (e.g., orthographic and other special purpose projections)
- technical illustrations (e.g., assembly and maintenance of tech. devices)
- virtual media spaces, graphically annotated real world perception
- animation design (e.g., camera paths, show maintenance tasks, animation of algorithms, life-like interface agents, ...)
- "Art"-works (e.g., mimetry of artistic styles, random compositions, etc., ...)
- ...
Different roles for automated graphics design systems in different environments

- standalone system (e.g. as an automated DTP tool)
- assistant in a semi-automated graphics editor (e.g. to make design proposals which can be modified manually, vice versa, improve (beautify) a user's design draft)
- part of an automated multimedia presentation system - e.g. as part of a user interface in a help / tutoring / information system. (graphics design component as one out of further media design components)
- part of an interactive virtual/augmented reality environment (graphics design component in the real-time interaction loop)

Characterisation criteria for graphics generators

- output range: What kinds of graphics are generated (e.g. 2D charts, diagrams, maps, technical drawings, 3D illustrations, ...)
- application domain and purpose (e.g., illustrate maintenance procedures, design patterns for wallpaper, ...)
- input and control (e.g., driven by data, communicative goals, events, ...)
- mode of operation (e.g., fully automated versus interactive; batch versus online, ...)
- underlying generation principle (e.g., composition versus modification)
- implementation of the generation principle (e.g., template selection versus plan-based approaches)
- objective performance measurements (e.g., number of parameters that can be considered, variation in the output compared to variation in the input, speed, ...)
- representation of constituents and structural relationships (e.g., explicit versus implicit, analogue versus symbolic)

Some arguments in favour of automated design systems for graphical presentations

- adaptivity: flexible generation mechanisms that allow to customize presentations for special needs and use cases;
- save human resources: take over routine design tasks; release application programmers from worrying about graphics design tasks;
- contribution to quality assurance: can exclude unmotivated changes in style, generation results determined by approved design rules;
- interoperability: graphics design systems can be built in a way so that allows an integration into multimedia presentation systems

Agenda for the development of an automated graphics design system

- define the presentation tasks and the parameters to be considered: what information to be conveyed, what situative context, what user types
- identify the design space: what type of graphics, how much variability required, ...
- choose appropriate conceptualisation (cf. Part 2 and 3): what kind of syntactical and semantic constructs are required
- choose an appropriate approach for an operationalization (cf. Part 4):
  - identify, classify, and formalise required design knowledge
  - specify a generation mechanism
- implementation and coding
- validation: test; make appropriate modifications if not all requirements are met

Object depictions

- charts, networks
- maps, floorplans
- technical diagrams
- many others...
**Basic Assumptions**

(1) **Syntactic dimension:** Graphical presentations can be conceptualized as being compositions of (possibly transformed) graphical objects. The visual appearance of the graphical objects as well as compositions are governed by certain rules.

(2) **Semantic dimension:** The visual attributes of graphical objects as well as the relationships between graphical objects can be used to encode certain properties of an underlying information content.

(3) **Pragmatic dimension:** Graphical presentations are produced and shown to an addressee in order to satisfy a certain communicative goal (intent).

**Capturing the syntactic dimension**

For a certain type of graphics (to be generated):

(1) identify the elementary constituents and their visual properties;

(2) identify the eligible composition and transformation rules which may be applied to compose a graphical presentation.

**Note:** What is considered as being an elementary constituent is always a matter of granularity. Extreme approaches, such as pure Pointillism is in most cases inappropriate.

**Syntactic Dimension of Abstract Presentation Graphics (charts, diagrams, networks etc.)**

**Approach by the graphics designer Bertin** (Bertin 67, 77, 83)

- a graphical presentation is composed of:
  - a finite canvas
  - a set of graphical objects which are implanted into the canvas
- the basic types of graphical objects are: Point, Line, and Area
- graphical presentations and objects have visual variables which can be manipulated to encode information

**Bertin’s 8 Visual Variables**

- 4 variables of the “graphics”
  - x and y position on 2d plane
  - size
  - brightness
- 4 “separating” variables
  - pattern
  - color
  - orientation
  - shape

(Source: Bertin 77)

**Syntactic Definitions of Graphical Languages**

**Approach by Mackinlay** (86) for the automated generation of 2D presentations graphics in the system APT (A Presentation Tool)

- Graphical presentations (i.e., charts, diagrams, networks etc.) are considered sentences of graphical languages that have a precise definition of their syntax (and semantics as well).
- Example languages are: “Horizontal Position”, “Area Position”, “Scatter Plot”, “Nested Rectangles”, etc.

- A graphical sentence \( s \) is defined as a set of tuples:
  \[ s = \{ (o_i, l_i) | o_i \in O \land l_i \in L \} \]

  whereas \( O \) is a set of graphical objects (such as markers, axis’s, and labels) and \( L \) is a set of locations.
**Mackinlay's Definitions of Graphical Languages**

**Example**: Syntax of a sentence $s$ of the graphical language "Horizontal Position" (Mackinlay 86)

\[
\text{HorzPos}(s) \iff \text{h} \cup \text{m} \land (x, y) \in \text{m} \\
\quad \exists \text{const} \land \text{Xmin} < \text{Xpos} < \text{Xmax} \land \text{Ypos} = \text{const}
\]

**Definition**: A graphical sentence $s$ is a well-formed sentence of the language "Horizontal Position", if

- it is composed of a horizontal axis $h$ and a set of positioned markers $m$, and if
- each positioned marker $(x, y)$ of $m$ consists of a $\text{plussobj}$ $o$ that is positioned over the axis $h$ at a constant vertical distance $\text{const}$, and within a eligible horizontal range

**Composition Rules (Mackinlay 86)**

**Idea**: If certain semantic conditions hold, it is possible (and useful) to merge graphical presentations and factor some of commonly used graphical objects.

**Composition Rules**

- **Single-axes-composition**: factor labels of a common axis
- **Double-axes-composition**: superimpose diagrams with common axis's

**Hierarchical representation of charts and diagrams in the Sage system (Roth et al. 94)**

**Grammars for Visual Languages**

**Idea**: Specify the set of eligible graphical compositions through a finite set of term-rewriting rules (similar to the definition of a formal language).

**Example** rule set derivation and resulting composition (with some "magic scaling")

\[
\begin{align*}
R1: S & \rightarrow S \\
R2: S & \rightarrow S \\
R3: S & \rightarrow S \\
R4: S & \rightarrow S \\
R5: S & \rightarrow S \\
\end{align*}
\]

**Application areas**:
- network design
- floor-plan layout
- synthetic plant generation
- molecule visualisation

**Composition of representational graphics from an icon/clipart lexicon**

**Idea**: Start with a set of (more or less) complex icons which are associated with symbolic composition constraints. Define composition rules based on the associated constraints

**Example** (Strothotte 90):

**Picture lexicon**:

**Composition**:

A precise definition of graphical languages is often too complex since one would have to enumerate all eligible spatial arrangements.

**Specification of Syntactic Constraints**

Alternative approach:
- have rules that exclude/avoid bad syntactical arrangements, e.g. positioning of nodes in a network diagram (Marks 93)
Composition of representational graphics through refinement of icons

**Idea:** Start with a set of (more or less) complex icons which are associated with symbolic composition constraints. Define composition and refinement rules based on the associated constraints (e.g. Friedell 84).

**Example:**

- Add generic ship icon
- Add crane to ship
- Add/modify colors

Syntactical dimension of representational 3D graphics and illustrations

**Idea:** See a picture as a (possibly complex) arrangement of meaningful graphical objects which occupy certain regions on a canvas. Thereby, a graphical object may itself be a composition of smaller units.

Syntactical dimension of representational 3D graphics and illustrations

**Graphics as collages:** the constituting graphical objects may be of different types (and result from different sources).

<table>
<thead>
<tr>
<th>graphical composition</th>
<th>type of graphical object</th>
<th>origin of graphical object</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D depictions</td>
<td>- wire frame model</td>
<td>e.g., - image database</td>
</tr>
<tr>
<td>2D elements</td>
<td>- drawing primitive</td>
<td>e.g., - text renderer</td>
</tr>
<tr>
<td>typographic elements</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Syntactical dimension of “mixed-media” graphical presentations

**Graphical compositions:** some constituents may be included to achieve certain visual effects, such as hiding less important parts.

<table>
<thead>
<tr>
<th>graphical composition</th>
<th>type of graphical object</th>
<th>origin of graphical object</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D depictions</td>
<td>video frame</td>
<td></td>
</tr>
<tr>
<td>2D element</td>
<td>drawing primitives</td>
<td></td>
</tr>
</tbody>
</table>

Source: Goodman 93

(System: Visual Repair)

Some more problematic cases with syntactical compositions

**Observation:** Important characteristics of components can get lost in a composition, e.g. due to occlusions:

**Example 1:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Example 2:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Occlusion effects are sometimes used in a "constructive manner", e.g., in case a certain form element is not provided by the editing tool.

More complex compositions

**MPEG4 standardisation initiative:** not only graphical compositions but compositions of so-called audio-visuals (2/3D graphics, video, sound)

MPEG4, too, uses hierarchical descriptions for complex arrangements (scenes)
... and what about augmented realities?

Observation: A visual presentation may involve objects of the real world plus superimposed graphical elements.

Possible approach? Describe compositions of visually perceivable objects as it may be captured on a viewer’s retina.

Source: Feiner, MacIntyre & Seligmann 94

Introduction

A compositional description of the syntactic dimension of a graphics seem to work for a broad variety of graphics types.

But is it also possible to adopt the concept of a compositional semantics?

For a certain type of graphics:

(1) identify the semantics of the single constituents, i.e., the graphical objects;

(2) identify the semantics of syntactically well-formed compositions

Bertin’s encoding rules for abstract information graphics

Given:

a set of data items which may be related to each other by some sort of similarity, order or proportionality relationships.

Encoding task:

Choose a graphical design them for the data items that exhibits similarity, order, or proportionality relationships in the data.

Encoding principle:

Information is graphically encoded by implanting into a canvas point/line/area objects and manipulating their visual variables in a certain way.

Basic encoding rules of the type:

If the items of a data set are ordered, then choose an encoding that preserves the ordering in the graphical presentation of the data set. i.e., the graphical representations of the data items should appear ordered as well.

A compositional description of the syntactic dimension of a graphics

A formal semantics of graphical sentences

Approach by Mackinlay 86:

introduce a encoding relation that represents a link between the information (to be presented), and the chosen graphical encoding technique (= graphical sentence) to do so.

Notation:

... reads as:

the graphical sentence that graphically expresses the facts to be presented.

In addition, a third argument refers to the relevant graphical language since one and the same graphical sentence may satisfy the membership criteria of different graphical languages.

Formal semantics of a graphical sentences

Example (Mackinlay 86): compositional semantics of a sentence s from the Horizontal Positioning language.

<table>
<thead>
<tr>
<th>Car Price for 1973</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
</tr>
</tbody>
</table>

- the set of markers encodes the set of cars
- the horizontal axis h encodes the set of car prices
- the position of the markers along the axis h encode the tuples of the has-price relationship

\[ \text{Encodes}(m, \text{Accord, Audi500, ...}, \text{HorPos}) \]

\[ \text{Encodes}(h, [500, 13000], \text{HorPos}) \]

\[ \text{Encodes}((x, y), \text{HorPos}) \equiv (h \cdot \text{scale} \cdot (\text{Position}(x, y) - \text{offset})) \]

\[ \land \text{Encodes}((x, y), \text{has-price}(x, h), \text{HorPos}) \]

Semantic dimension of representational 3D graphics and illustrations

Approach (Rist 90, 95): Use an encoding relationship to capture the meaning of an illustration (inspired by Mackinlay’s encoding relation).

Question: Do we need to formally define graphical languages for illustrations?

Suggestion: Use partial descriptions only, but try to represent all relevant encodings of:

- objects
- object attributes
- relations between objects

Furthermore, specify the context (rather than the graphical language) in which a graphical means is used to encode a certain information unit

\{\text{Encodes} (\text{means}) (\text{info}) (\text{context-space})\}
Encoding of objects/concepts

Rational: If the purpose of a graphical presentation \( g \) is to refer to a domain object/concept \( x \) (e.g., to convey information about \( x \)) then \( g \) shall include at least one picture object \( px \) as an encoding of \( x \).

In this case, the semantic description of \( g \) shall include an entry of the form: (Encodes \( px \) \( x \))

Example:

Abb-4.4a: circuit photo

Excerpt of the semantic picture description corresponding to Abb-4.4a

- (Encodes P1. DIODES Abb-4.4a)
- (Encodes P2. RESISTORS Abb-4.4a)
- (Encodes P3. RESISTORS2 Abb-4.4a)
- (Encodes P4. CIRCUIT BOARD3 Abb-4.4a)

Encoding of object attributes

Rational: If the purpose of a graphical presentation \( g \) is to present an attribute \( A^w \) of a domain object/concept \( x \) then \( g \) shall include at least one picture object \( px \) encoding \( x \) and \( px \) shall have a graphical characteristics or attribute \( A^g \) that is understandable as an encoding of \( A^w \).

In this case, the semantic description of \( g \) shall include the two entries:

(Encodes \( px \) \( x \)) and (Encodes \( A^g px \) \( A^w x \) \( g \))

Example:

Abb-4.4a: circuit photo

Excerpt of the semantic picture description corresponding to Abb-4.4a

- (Encodes P1. DIODES Abb-4.4a)
- (Encodes P2. RESISTORS Abb-4.4a)
- (Encodes P3. RESISTORS2 Abb-4.4a)
- (Encodes P4. CIRCUIT BOARD3 Abb-4.4a)

Encoding of relations between objects

Rational: If the purpose of a graphical presentation \( g \) is to present an \( \text{relation} R^w \) that holds between the domain objects/concepts \( x_1 \) \( \ldots x_n \) then \( g \) shall include at least \( n \) picture objects \( px_1 \ldots px_n \), with each \( px_i \) is an encoding of \( x_i \), and \( g \) shall expose graphically an relation of the type \( R^g \) that is understandable as an encoding of \( R^w \). (For instance, \( R^g \) may refer to the spatial arrangement of the picture objects, a certain coloring of them. However, there is no common approach to encode relations - but many successful examples).

Example:

Abb-4.4b: circuit diagram

Excerpt of the semantic picture description corresponding to Abb-4.4a

Iconic versus symbolic encoding

What’s mimicry, what’s symbolism?

Difficult to define. However, one can define a set of necessary conditions that must hold for an iconic encoding:

1) visual perceivable attributes of the domain objects should be encoded by visual perceivable attributes of the corresponding picture objects in a more or less canonical way. (e.g., use matching colors, use perceptively correct projections of the object forms, ...)

2) use encodings that preserve structural relationships as much as possible.

(a e.g., preserve ordering relationships (topology, size, etc.)

Example: smooth transition from iconic to a symbolic encodings

Depicting versus illustrating

Illustrations of technical equipment and its maintenance do often go beyond the mere depiction of the involved physical objects. Rather, graphics designers and book illustrators have introduced a broad variety of illustration styles - often neglecting the strive for perfect photo realism. Among other things, illustrations often comprise:

- image constituents which cannot be interpreted as depictions of domain objects;
- image constituents representing domain objects but which expose attributes that are not visually perceivable when looking at the corresponding domain object;
- spatial arrangements of image constituents which do not match the spatial arrangements of the corresponding objects in the world.

Question:

How to capture syntactic and semantic aspects of illustrations?

Using substitutes for domain objects

Rational: Instead of depicting the real object, create a copy of it, modify it for illustration purposes and depict the modified substitute.

Example: cut-away views

Conceptualisation for a syntactic construction

\[
\text{If } px \text{ encodes } x \text{ and } x \text{ is a substitute for domain object } y, \text{ then } px \text{ can be considered as a graphical encoding of object } y \text{ as well.}
\]

Semantic description:

\[
(\text{Encodes } px \ y) \Rightarrow (\text{Encodes } px \ x \ y)
\]
Using substitutes to reduce complexity

- Substitute object \( x \) by a geometrically simplified copy.
- Substitute a group of objects \( x_1, \ldots, x_n \) by a single object to represent the group.

Rational: "Materialise" domain concepts which are not physical objects.
Examples:
- Non-rigid quantities (e.g., liquids, gas, powder, ...)
- Non-material concepts (e.g., trajectories of objects, light and sound waves, smell, taste, burning fire, having an idea, ...)
- Abstract concepts (e.g., negation)

Illustration of the instruction:
"Turn the switch as shown by the arrow" System IBIS (Seligman & Feiner)
Illustration of the warning:
"Do not turn the switch as shown ..." System WIP-GD (Rist)

Illustration of the instruction:
"... and what about the semantics of augmented realities?"

Possible approach: Meaning of a retinal image is derived from the meaning of perceived constituents \( j \), their visual characteristics and the relations between them.

Difficultly: Need to know how the real objects of the environment are projected on the user's retina. This requires either sophisticated computer vision, or eye tracking in combination with a model so that the precepts can be reconstructed.

Some problems with a compositional semantics for graphics

Some grouping phenomena are known as "Gestalt Laws"
E.g., visual grouping by:
- Proximity
- Size
- Shape
- Brightness/colour
- Orientation
- Continuation
- Symmetry
- Spatial closure

Observation: Human visual perception shows some peculiarities that are difficult to deal with when relying on a compositional semantics.

Some problems with a compositional semantics for graphics

Some further Gestalt phenomena: "Interpretations are biased"
Communication with Graphics

Underlying Rationale: Graphical representations are used to convey information from a sender (here: the author/presenter of a graphics) and a receiver (here: the viewer of a graphics).

...the diagram will convince him that sales have dropped

ah, he wants me to believe that sales have dropped ...

Borrowing from Speech Act Theory (Austin 62, Searle 80), the showing of a graphics is a purposeful activity which is carried out to achieve a communicative intent or the discourse purpose of a graphics, e.g.: inform addressee A about a fact
convince A to believe a fact
explain subject matter to A
contrast two facts

An effective graphics is one that:
- brings about the intended effect(s);
- facilitates the addressee’s transition of mental states

Discourse functions of graphics

Caution: Occasionally, one and the same graphics can be used to satisfy different communicative intents.

Example (inspired by Wittgenstein): What does this graphics show?

Note: there are information types and communicative acts which are difficult to perform with graphics alone:
- temporal relations such as duration,
- how to express “A although B”;
- explain how a certain graphics is meant, ....

Intentional structure of an illustration with an inset

Source: Rist 95

Approach (André&Rist 93): Generalise Rhetorical Structures for the description of texts so that they can be used to describe pictures, and text-picture combinations as well.

Classification of graphical communication acts

Maybury 93

André & Rist 90, 93

Depict Acts
highlight, blink, circle, etc.
indicate direction
Display Control Acts
display-region
zoom (in, out)
pan (left, right, up, down)
Depict Acts
depict image
draw (line, arc, circle)
animate-action
Visualisation Acts
visualise (non-visual object property, object trajectory, assembly structure, handling, etc.)
Labelling Acts
label object with (name, explanation)
Emphasising Acts
focus on object(s)
contrast attribute

Context:
information system AIMI
presentation system WIP
How well an illustration can achieve the associated intentional goals is also a matter of its focus structure. Focus structure need to be compatible with the intentional structure. A nested focus structure can be derived from the nesting of visual groupings:

**Observation:** Illustrations - or parts of them - often have more than one communicative goal associated. I.e., they are to achieve several goals at once.

**Example:** Sharing of graphical background objects.

**Implication:** Sharing should be reflected in the structural description.

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**Part 3**

**What are appropriate encodings?**

- Design as a product
- Expressive and effective designs
- Approaches to evaluate the effectiveness of designs

---

**Graphical designs**

**Design as product:** In this view design is regarded as the outcome or resulting product of a construction process. Designs can be characterised by the chosen syntactic and semantic properties. They may be evaluated among expressiveness and effectiveness criteria.

- **Expressiveness** (recall from Part 2) ideally means that:
  - all the relevant information gets encoded
  - no other information gets encoded

- **In practice:**
  - try to encode all relevant aspects
  - try to restrict the viewer’s interpretation of the graphics as much as possible; avoid ambiguities
  - try to avoid encoding of irrelevant information; prevent the viewer from drawing unwanted inferences, e.g., make sure that additional aspects can be recognised as being subordinate

---

**Evaluating the expressiveness of graphical presentations**

**Purpose:** Check whether a certain graphical design encodes all the information that should be conveyed with regard to a given presentation task.

- **For the case of abstract 2D graphics:**
  - relatively easy comparison of content descriptions provided that the design has been constructed on a well-defined syntax and semantics. That is:
    - all constituents and their properties have well-defined meanings
    - all syntactically well-formed graphical constructions that are present in a graphics have a well-defined meaning
### Expressiveness of graphical sentences

**Approach by Mackinlay**

Formulate constraints that make explicit what kind of information can be expressed with a certain encoding technique. A sentence $s$ can express a set $f$ of facts, iff:

- $s$ encodes all facts of $f$
- $s$ encodes no facts which are not in $f$

<table>
<thead>
<tr>
<th>Encoding Techniques</th>
<th>Expressiveness Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Position</td>
<td>$X \rightarrow Y$ (X is nominal)</td>
</tr>
<tr>
<td>Apposed Position</td>
<td>$X \times Y$ (X is nominal)</td>
</tr>
<tr>
<td>Retinal List</td>
<td>$X \rightarrow Y$ (X is quantitative)</td>
</tr>
<tr>
<td>Connection</td>
<td>$L \rightarrow X_{ij}$ (L is a location)</td>
</tr>
<tr>
<td>Misc. ($\text{Angle, Conta}$)</td>
<td>Generally, $X \times Y$</td>
</tr>
</tbody>
</table>

### Expressiveness of some map types for roads

Display types with different degrees of expressiveness:
- single roads
- road net topology
- road contours
- road section areas
- hierarchically structured information about a road net

### Expressiveness of graphical designs

**For the case of representational graphics and illustrations**

More difficult since it is often too unpractical to enumerate all encoding relationships that are present in a graphics. However, comparison may be done on partial content descriptions.

**Example:** Check whether all subparts of a domain object have graphical counterparts in the corresponding object depiction.

### Effectiveness of graphical designs

**Effectiveness** (recall from Part 2) is a quality measure to judge:

- how well an encoding achieves its associated discourse purpose as compared to other (known) encoding techniques.

Effectiveness refers to the way how humans process graphical presentations. Thus it's a complex subject matter including, among other aspects, the peculiarities and limitations of the human visual sense, a viewer's prior knowledge and experience about encoding conventions, as well as his/her cultural background with regard to aesthetics.

**Effectiveness of graphical designs**

- can be easy understood by the viewer;
- exploit the capabilities of the human visual perception (idea: reduce cognitive effort for explicit reasoning by exploiting the human's visual "hardware");
- attract the viewer's attention, e.g., by satisfying aesthetic criteria

**Guidelines for the design of effective graphics**

Rules and guidelines for the design of effective graphics can be acquired from the literature, especially on graphics design, technical drawing, fine arts, psychophysics, cognitive psychology, pedagogy, ...
Effectiveness of graphical designs

**General Approach:** Choose a set of effectiveness criteria and define an ordering function that ranks graphical designs by the criteria.

**The empirical approach:** Conduct empirical studies to rank how well human subjects perform certain perceptual tasks. (cf. Cleveland & McGill 84, 85).

Apply findings to graphics design: rank how accurate human subjects are able to recognize quantitative relationships between data elements when presented by a certain graphical encoding (cf. Mackinlay 86). E.g., position and length are well suited for the encoding of quantitative relationships - volume, color, and density are not.

Effectiveness of graphical presentations

**Empirical findings** do not explain why a certain perceptual task is easier to solve than others.

**The task analytic approach**, in contrast, tries to define a ranking as an estimate of required cognitive processing for solving a perceptual task (cf. Casner 91).

**Basic idea:** For a given “application task” try to construct an equivalent “perceptual task” and estimate its relative difficulty.

**Example:**

a) verbal description of application task: “Find flight connection from A to B”

b) construct a formalized procedural description of the application task:

Example (cont.):

c) try to substitute the logical operators in the description of the application task by equivalent perceptual operators; i.e., construct an equivalent perceptual task:

Example (cont.):

d) construct a graphical design that is consistent with the procedural description of the perceptual task. E.g.:

Example (cont.):

e) render graphical presentation according to the design specification

(reproduced after Casner 91)

Effectiveness of representational graphics

**Basic idea:** Define evaluation functions for the encoding techniques to be used. Evaluation can be based on a comparison of an “ideal case” with the actual design.

**Example task:** evaluate how well a certain view direction conveys the spatial extension of a 3D object

**Observation:**
- front views are the worst
- extension along the three spatial dimensions is often expressed best, if none of them gets preferred
Effectiveness of representational graphics

Possible evaluation approach: An isometric projection of a cube or a block-like object preserves the object’s spatial extension on the x-y-z dimension equally well; i.e. 1:1:1. Thus, one may take the isometric projection of an object’s bounding box as the constructible ideal case and compute for a given object and viewing specification:
- a projection of the object’s bounding box
- in the projection the length of the edges adjacent to a corner with a maximal number of shown edges;
- the quotients of the edge lengths. The more the quotients differ from the ideal 1:1:1 relation, the worse gets the spatial extension conveyed.

Example task:
evaluate how well an association between two domain objects gets encoded by a certain spatial layout of the corresponding graphical objects

Observation:
tendency for seeing two objects grouped depends on their distance:
- relative to the picture size
- relative two their distances to other picture objects
- other aspects such as common attributes, knowledge about domain and conventions, ...

Example evaluation for seeing A and B as a group based on comparing distances:
g(A,B) = 0.5
\begin{align*}
g(A,B) &= 0.25 \\
g(A,C) &= 0.6 \\
g(B,C) &= 0.6 \\
g(A,B) &= 0.04 \\
g(A,C) &= 0.54 \\
g(A,D) &= 0.07 \\
g(B,C) &= 0.46 \\
g(B,D) &= 0.94 \\
g(C,D) &= 0.46
\end{align*}

Evaluating designs with regard to aesthetics

Problem:
Given two designs: how to evaluate which one “looks better” than the other?

General approach:
define a ranking function based on certain countable / measurable qualities of a graphics. However, there is no common solution to capture aesthetics.

Application field:
- computer-generated
- art works
- wall paper patterns

Example:
Improve the design of network layouts according to aesthetic criteria
(Source: Marks 93)

early approach by Birkhoff 1932 to define an aesthetic measure by:
# ordering relationships apparent in G
# graphical constituents in G

Designing Graphics

Design as process:
This view focuses on the steps involved in the construction of effective and expressive designs. However, there are many different ways to construct graphical designs.

- compositional design approaches
  - start from a set of primitives (graphical elements or likewise operators for the creation of graphical elements from a source, such as a geometry model)
  - apply operators to modify attributes of the graphical elements and to create compositions and arrangements of them until the presentation goal is accommodated

- evolutionary design approaches
  - start from an available design (graphical)
  - apply modification operators until new presentation goal is accommodated

Part 4

How to choose appropriate encodings?

Design Approaches

- Design as process
- Representing design knowledge
- Templates
- Rules
- Plan-based design
- Case-based design
- Other approaches
Designing graphics

**Rational:** Decompose the design task into smaller subtasks so that they become maintainable.

**Example:** Decomposition of the manual design task (after Horton 91):

1. Pick a graphical symbol for the concept. E.g. to compare the speed of processors, encode a processor by a bar.
2. Pick a graphical characteristic for the concept. E.g., to encode the speed of the corresponding processor.
3. Choose a scaling function. Define an algorithm, procedure, or heuristics to assign graphical values for data values. The scaling function can be linear, logarithmic or geometric.
4. **Note:** different graphical genres and design contexts will suggest different task decompositions.

### Automating the design of graphics

**Rational:** Identify design-relevant knowledge and formalise it so that it can be used by a program running on a computer.

<table>
<thead>
<tr>
<th>knowledge type</th>
<th>possible representation</th>
</tr>
</thead>
</table>
| **knowledge for decision making** | - selection rules  
- if <candidate> satisfies <Predicate>  
then <candidate>  
- constraints  
- implicit in a design template |
| **construction knowledge** | - operators of an algebra  
- procedural in a program |
| **evaluation knowledge** | - evaluation rules  
- evaluation functions |

**Example:**

- chart templates in a statistics package
- select chart template
- instantiate template
- often, only automated template instantiation
- template selection may be done with a decision tree

### Rule-based selection of encoding techniques

**Principle:** Specify conditions under which a certain encoding technique may be used.

**Example:**

- "Bar Chart Rule" in the APT system (Mackinlay 86)
  
  if  
  - there is a functional dependency between the values of a set X and a set Y, and  
  - the values of Y or ordered, and  
  - there are less than 25 different values that an X element can take on  
  then try to present the relation R(X, Y) as a bar chart in which:  
  - the vertical axis is a scale encoding the range of X,  
  - the bars (lines) encode the elements of Y

### Rule-based composition of encodings

**Principle:** Specify semantic conditions under which two graphical presentations can be combined.

**Example:**

- "Mark-Composition-Rule" in the APT system (Mackinley 86)

- The two graphical presentations can be combined to a scatter diagram since the mark objects encode the same information in both diagrams (here cars).

### The "illustration pipeline"

For the computer-aided/automated creation of 3D illustrations one can rely on:

- manipulations at the model level; i.e., one constructs an "illustrational scene"
- modifications on the way how a model gets projected onto a 2D picture plane
- manipulations at the picture level

The "illustration pipeline" starts with the world model, continues via the illustrational scene, and ends with a 2D collage-style graphics.

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Rule-based construction

Principle: Obtain construction steps for a graphics as a side effect of a chain of applied rules. There are two basic strategies:

- **Forward Chaining:**
  - Given fact A, apply construction rules until no more rule is applicable
  - Possible derivations: R1, R2, R3 with graphical construction steps G1, G2, G3
  - R1, R2, R4 with graphical construction steps G1, G2, G4

- **Backward Chaining:**
  - Given fact E, try to reach (or prove) A by “reading” the rules backwards
  - Possible derivation: R4, R2, R1 with graphical construction steps G1, G2, G3

Example rule base:
- R1: if A then B and G1
- R2: if B then C and G2
- R3: if C then D and G3
- R4: if C then E and G4

Rule-based selection of view points

Principle: Rules vote for or against a certain choice (here, the view point from which a 3D object shall be depicted)

- Apply rules and choose best ranked view direction

Example rule base:
- VD1: if object x has a functional front, then prefer showing the functional front
- VD2: if object x has a functional side, then avoid views that don’t show the side
- VD3: if the spatial extension of x is of interest, then prefer 3-sided views

26 basic views
- V := front
- U := bottom
- O := top
- R := right
- L := left

Plan-based design

Principle: Define construction steps for a graphics as operators of a planning system

Approach:
1) Define construction states of a graphics
   - start state Z0: empty canvas
   - goal state Zn: finalised graphics G that fulfills the presentation goal
   - intermediate states Zi with Z0 < Zi < Zn
2) Define planning operators Oi whose execution would cause a transition from the current construction state to the next. There may be several operators for the next transition Zi - Oi -> Zi+1
3) Planning task:
   - define a goal state Zn so that the presentation goal is fulfilled
   - determine an operator sequence (O1, ..., On) whose execution would lead from Z0 to Zn
   - i.e., Z0 - O1 -> Z1 - O2 -> Z2 - ... - On -> Zn

Example: plan-based beautifier
- Bolz 93, Hertzberg et al. 93
- User: drafts a 2D graphics
- System: tries to improve user’s draft
- Design knowledge: encoded in state descriptions and...

Operator example (from Bolz 93, Hertzberg et al. 93)

- transforms rectangles to lines
- introduces graphical situations as construction states:
  - draw a circle with no other circle
  - suppose (2 circles) intersect 1 circle
  - description (2 circles) intersect 1 circle
  - merge these two circle

... and its application to improve a design.
Design as hierarchical decomposition and refinement of goals/constraints

**Principle:** Given an illustration goal, treat it as a constraint that a presentation must fulfill in order to be used as an illustration to achieve this goal. Decompose and refine the goal into a set of visual constraints that can be achieved by applying appropriate construction/modification operators.

**Example:**
- Illustration goal: "Show trajectory of object x".
- Design task: Derive visual constraints that a graphics $G$ must fulfill.

- $G$ shows trajectory of $x$.
- $G$ shows trajectory as a 3D arrow.
- $G$ shows trajectory using ghost images.
- $G$ shows trajectory using a sequence.
- $G$ shows trajectory as a 3D arrow with an emphasis on the start position.

**Representing design strategies for illustrations**

[51] Heads:
- (DETECT OBJECT $x$apos; $y$apos; $z$apos;)
  - [DETECTABLE $x$apos; $y$apos; $z$apos;]
  - [VISIBLE $x$apos; $y$apos; $z$apos;]
  - [Distinguishable $x$apos; $y$apos; $z$apos;]

**Description-Update:**
- $(x$apos; $y$apos; $z$apos;)

[54] Heads:
- (DETECTABLE $px$)
  - [OBJECT $px$]
  - [SCALE COPY $px$]
  - [PART OF $px$]
  - [ANNOTATE $px$]

**Description-Update:**
- $(px)$

**Designing Illustrations**

Illustration after applying design strategy S4 and the execution of the construction operators derived from S4.

**Interleaving design and realization by evaluation**

**Observation:** It is often quite difficult to anticipate the exact outcomes of construction operators. E.g., adding a further object to an illustrational scene may produce unwanted side effects such as occlusions, shadows or visual groupings. Since such effects are highly context-dependent, they can only be determined when the execution of the operator gets simulated in the particular context. Thus, determining effects of an operator execution is often expensive.
Introduction

Case-based design approaches

**Principle:** Store previous design solutions in a "case-base". Solve a new design task by:
- retrieving a similar case from the store
- adapting the previous solution so that it solves the new case
- add the new solution to the store as it may be reused to solve future tasks

Applying case-based reasoning to graphics design:
- **cases:** construction steps of a design (e.g., a sequence of operators)
- **rational:** similar presentation task require similar construction steps
- **adaptation:** skipping / adding / replacing certain steps of the "old" case
- **tuning:** try to generalise design solutions by abstracting from details

Example: System TYRO McNeil90.
Application domain: subway network diagrams

Representation of cases in TYRO

**Design task 1:** Encode segments of a subway path
**New design task 2:** Show subway station on path

Solution: insert new step in design procedure for task 1

Example: System Mondrian (Lieberman 95).
Application: trainable graphics editor

System observes the user while constructing a graphics and compiles from the observations some design macros which can be used for further constructions

Some other approaches

**Genetic programming** (Marks 95):
- start from an initial design
- mutate design
- rank mutation according to an evaluation function
- if mutation is ranked higher than previous designs, continue with mutation

**Constraint-based design**
- translate presentation task into a set of constraints over graphical elements
- rely on a constraint solving technique to find bindings for all variables so that all constraints are satisfied

E.g.: consider the three graphical objects Circle, Rectangle, Triangle with the following constraint set: Color.x ∈ {blue, red, green}, Color.Triangle = red, Color.Circle ≠ Color.Rectangle, and Color.Circle ≠ Color.Triangle,

Possible assignments:

- blue
- green
- blue
- red
- green
- red

Conclusions on design approaches

- There is a variety of different approaches that may be used for designing graphics, each of them having particular strengths and weaknesses.
- Rule-based composition seems a good choice for the design of abstract presentation graphics. A hierarchical planning approach seems to be adequate in case a complex presentation goal needs to be subsequently decomposed and refined.
- Design knowledge comprises knowledge for making choices and selections, procedural knowledge, and knowledge on how to evaluate designs.

Part 5

Showcases, Applications, Systems

- Interactive Graphics
- Collaborations with graphical representations
- Automated graphics design in a multimedia context
- Animated interface agents
Interactive Graphics: The case of Hypergraphics

G is a hypergraphics shown by S, if the user can refer to parts of G (e.g. through pointing) in order to formulate new input to S.

Hypergraphics

Example: “Adapt level of detail on request”

a) depiction simplified by abstraction techniques

b) selection of a sensitive picture part interpreted as a request for showing more details

c) showing the details

Source: Krüger & Rist 95

Interactive Graphics: Dynamic Maps

“Show selected roads in relation to the parameter: maximum speed”
The map design is adapted continuously with regard to a user controlled input variable (here: velocity).

Source: Müller & Rist, 1995

Interactive Graphics: The 3D Zoomillustrator

Both the 3D display and the annotation labels get continuously updated while a user manipulates the viewing specification (i.e. zoom, pan, rotate, ...)

Source: Preim 1997, University Magdeburg

Collaboration with Graphics

Application task

- Provide the user with cartographic information in a way that suits the available communication channels of the access device
- Enable joint interactions between users on displayed material

User of a phone with a small LCD display:

- Bahnhofstrasse ends at the market

Subgoal 1: Generate different views on the underlying information, e.g.

PC user:
- high-resolution, colored map

PDA user:
- less detailed network display

User of a phone with a small LCD display:
- Manhatten-style graphics
- telegram-style text

Source: Rist & Huether 1999, EU project i3-Magic Lounge
Introduction

**Approach for generating different views**
- Represent data hierarchically organized layer model
- Define presentation types for the layers

- Named objects
- Road net topology
- Road contours
- Road section areas
- Pixmap

- Speech/text only
- Sparse graphics
- Small graphics PDA
- Fully-fledged multimedia

**Subgoal 2:** Enable collaboration via heterogeneous views on the same underlying information

**Collaboration: Export a marking from the „PDA-view“ into the „PC-view“**

- PDA user refers to a certain street segment by marking it.
- Server sends the mark to the ML server.
- Updated PC display.

**Collaboration: Export a marking from the „PC-view“ to the mobile phone**

- Mark PC (street #1)
- Mark PDA (street #1)

**Approach for synchronizing different views**
- Actions like markings, selection, scrolling, zooming etc. are applied to view-specific object presentations.
- Action broadcasting means to apply corresponding actions to the presentations of the same object in all other views.

**Collaboration: Export a complex marking from the „PC-view“ to the mobile phone**

- Sequentialize complex markings. User of mobile phone can follow a marked route by browsing through the single segments.

- Approach:
Automated graphics generation in a multimedia context

Observation: Graphics is often used best in combination with other media (cf. Part 2).

Given a presentation task and a set of parameters, such as target group, and output capabilities of display devices, decide:

- Which material to present?
- How to present it?
  - Which media to choose
  - How to encode information in a medium?
  - Which presentation acts to perform?
  - In which temporal order?

Automated generation of illustrated instructions for technical devices in the COMET system

Source: Seligmann & Feiner 1994 Columbia Univ.

Automated generation of illustrated instructions for technical devices in the WIP system

Source: Wahlster et al. 93, DFKI

Generated text/picture combination

Automated generation of illustrated instructions for technical devices in the WIP system

Source: Wahlster et al. 93, DFKI

Automated multimedia design for decision support in traffic management applications

Source: EU project FLUIDS
Combination of presentation elements

<table>
<thead>
<tr>
<th>Presentation Task</th>
<th>Potential Presentation Elements</th>
</tr>
</thead>
</table>
| "Inform about current situation" | • Text  
  - sentence by sentence enumeration of events  
  • Speech  
  - spoken telegraph-style descriptions  
  • Static Graphics  
  - annotated maps |
| "Inform about problem solution" | ...... |

Presentation of a problem solution

- **Text**
- **Diagram**
- **Speech**

"Non-uniform delay situation for line 63"

Monotonous animation of a graphical display

For each time point \( t \) during display time, it must be ensured that:

\[
\text{#elements}(G_{t_i}) \leq \text{#elements}(G_{t_{i+1}})
\]

Overview on the generation process

**Input:** Data to be presented

**Planning:** Composition of the rhetorical document structure & design of presentation elements

**Scheduling:** Determination of the temporal structure (= script)

**Output:** Display of the presentation script

Script and resulting presentation

Projects on animated interface agents

- **Cosmo**, the Pedagogical Agent of the Internet Advisor System (Lester, 98)
- **Persona**, the Animated Presentation Agent of the PPP System (DFKI)
- **API for Interactive Agents on Windows platforms, Microsoft Agent**
- **Training in Virtual Environments** (system Steve, Rickel 98)
- **Persona, the Animated Presentation Agent of the PPP System (DFKI)**

23
What do we get by interface agents?

Enable realization of additional media combinations as known from human-human communication
- text
- graphics
- pointing
- speech

Source: Andre et al., 98

What do we get by interface agents?

can help the user recognize cross-media and cross-window references

What do we get by interface agents?

commented “menus” for restricted user interaction (follow-up questions, setting of generation parameters)

Overview on the presentation planning process

presentation task
- e.g., describe modem

determine presentation acts

determine presentation schedule

executed presentation

Combining presentation planning with reactive and self-behaviors

Generation example of the PPP system

The system generates the graphical illustrations, the verbal comments and explanations, as well as the script for the agent

Source: PPP-Projekt, DFKI, 1996