The Semiology of Graphics

Pat Hanrahan

Stanford/Tableau

Representations

Number Scrabble [Simon]

Given: The numbers 1 through 9

Goal: Pick three numbers that sum to 15

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Example:

A takes 8

Number Scrabble [Simon]

Given: The numbers 1 through 9

Goal: Pick numbers so that 3 numbers sum to 15

Example:

- **A takes 8**
- **B takes 2**

Number Scrabble [Simon]

Given: The numbers 1 through 9

Goal: Pick numbers so that 3 numbers sum to 15

Example:

- **A takes 8**
- **B takes 2**
- **A takes 4**

Number Scrabble [Simon]

Given: The numbers 1 through 9

Goal: Pick numbers so that 3 numbers sum to 15

Example:

- **A takes 8**
- **B takes 2**
- **A takes 4**
- **B takes 3**

Number Scrabble [Simon]

Given: The numbers 1 through 9

Goal: Pick numbers so that 3 numbers sum to 15

Example:

- **A takes 8**
- **B takes 2**
- **A takes 4**
- **B takes 3**
- **A takes 5**

Number Scrabble [Simon]

Given: The numbers 1 through 9

Goal: Pick numbers so that 3 numbers sum to 15

Example:

- **A takes 8**
- **B takes 2**
- **A takes 4**
- **B takes 3**
- **A takes 5**
- **B takes?**

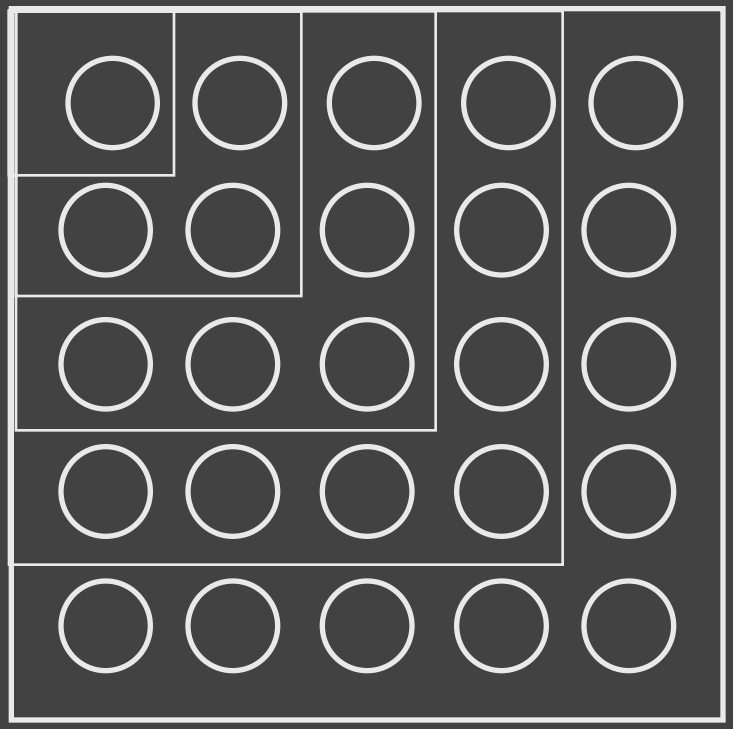
Problem Isomorphs

4	3	8
9	5	1
2	7	6

A takes 8, 4, 5

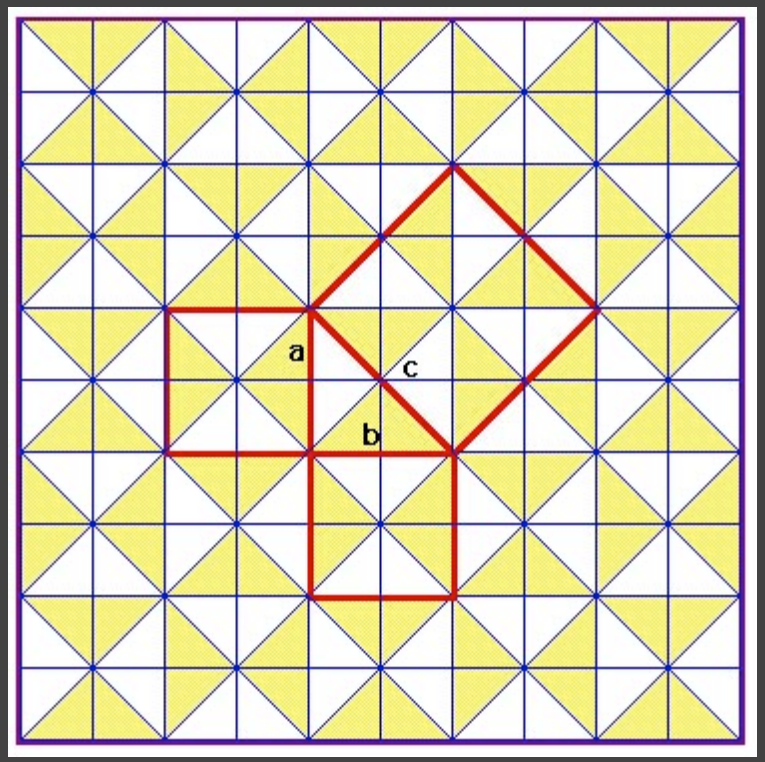
B takes 2, 3, ?

Brilliant Cognitive Creations



Algebraic relationship:

$1+3+5+7+9=5^2$



Pythagorean theorem:

Chinese proof by dissection

The Representation Effect

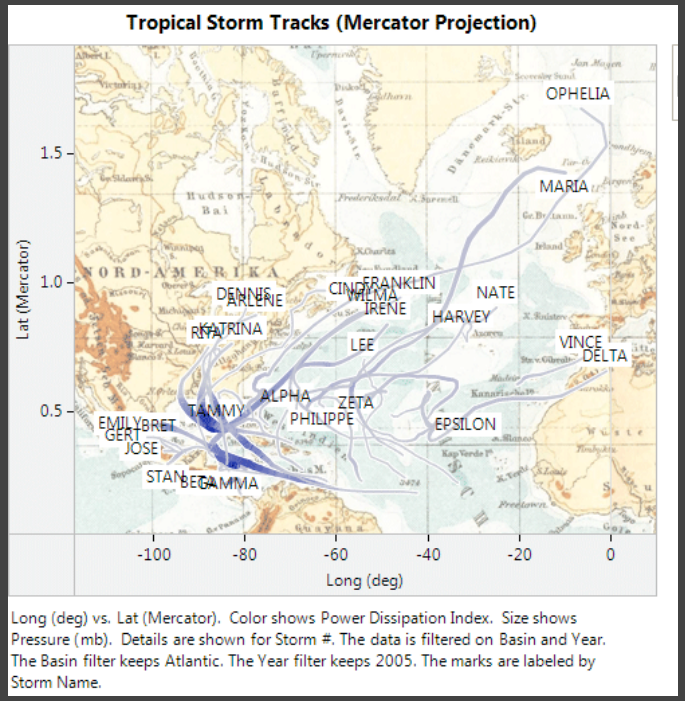
The appropriate representation makes solving problems easier

The best representation depends on the task

Note that this principle is very similar to the use of data structures in computer science

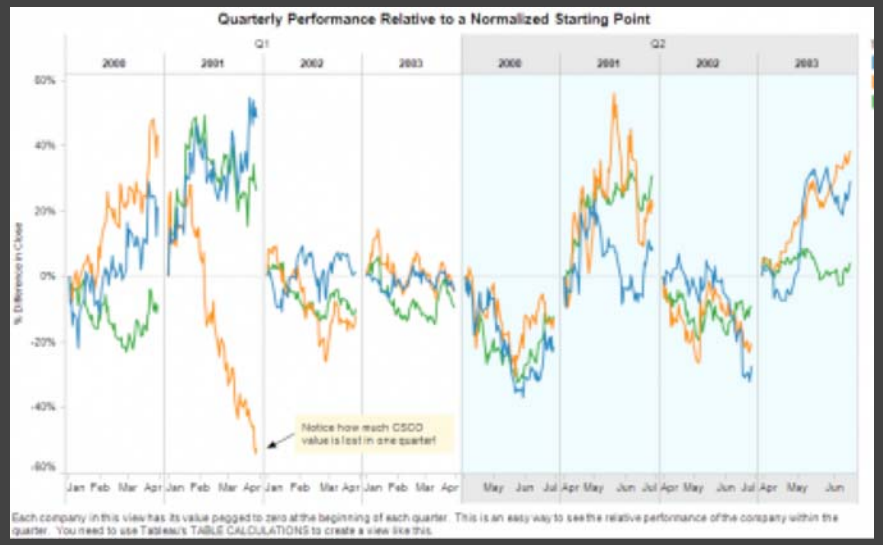
How to Create Good Visual Representations?

Common Representations

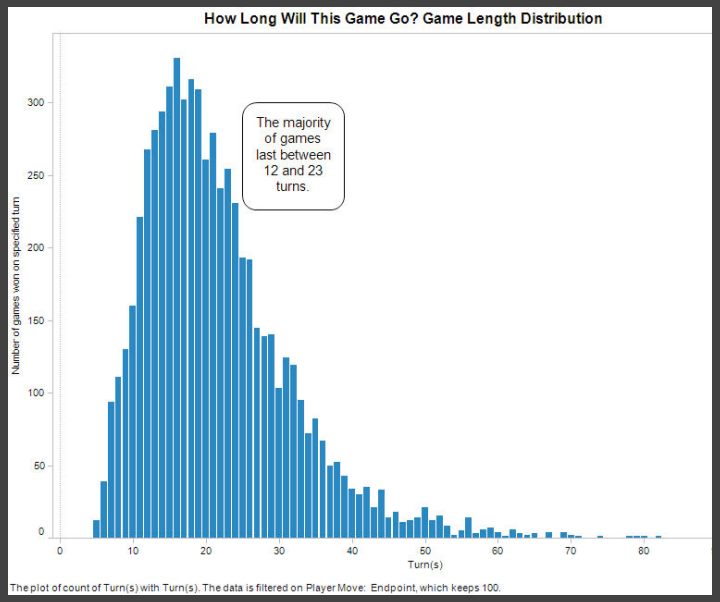


Long (deg) vs. Lat (Mercator). Color shows Power Dissipation Index. Size shows Pressure (mb). Details are shown for Storm #. The data is filtered on Basin and Year. The Basin filter keeps Atlantic. The Year filter keeps 2005. The marks are labeled by Storm Name.

Maps (Space)



Time



Tables and Charts

Currently

Drawing programs (for professional designers)

Illustrator and photoshop, …

Graphics libraries (for professional programmers)

OpenGL, Flash, …

“I was taught assembler, in the second year of school,
It’s like construction work, with a toothpick as a tool”

Song about Lisp by Julia Eckler

The Semiology of Graphics

Jacques Bertin

The properties of the information

The properties of the image

The rules mapping information to images

The analytical tasks

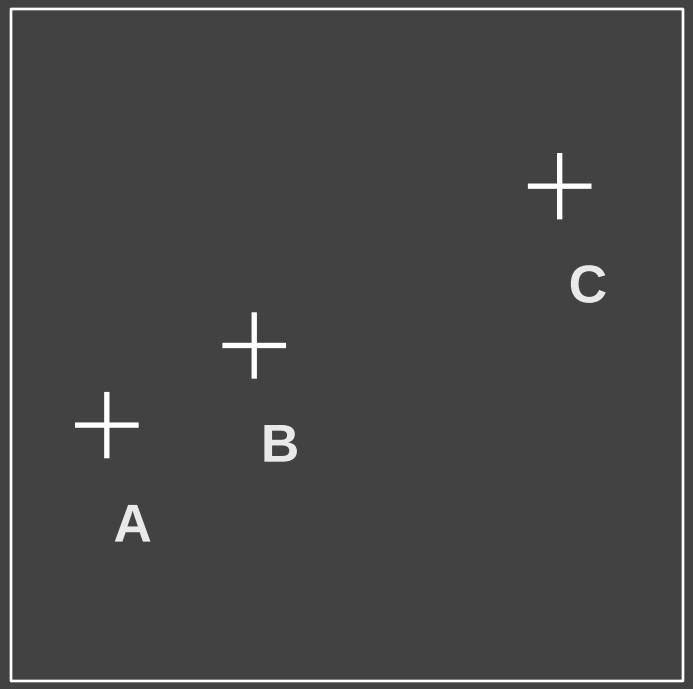
Language Perspective

Sender and receiver use a language with symbols

- Establish code and conventions
- Sender encodes information in these symbols
- Receiver decodes information from these symbols

Semiology – the study of symbol systems

Information in Position



1. A, B, C are distinguishable

   Nominal
2. B is between A and C

   Ordinal
3. BC is twice as long as AB

   Quantitative

"Resemblance, order and proportional are the three signfields in graphics. These signfields are transcribed by visual variables having the same signifying properties" - Bertin

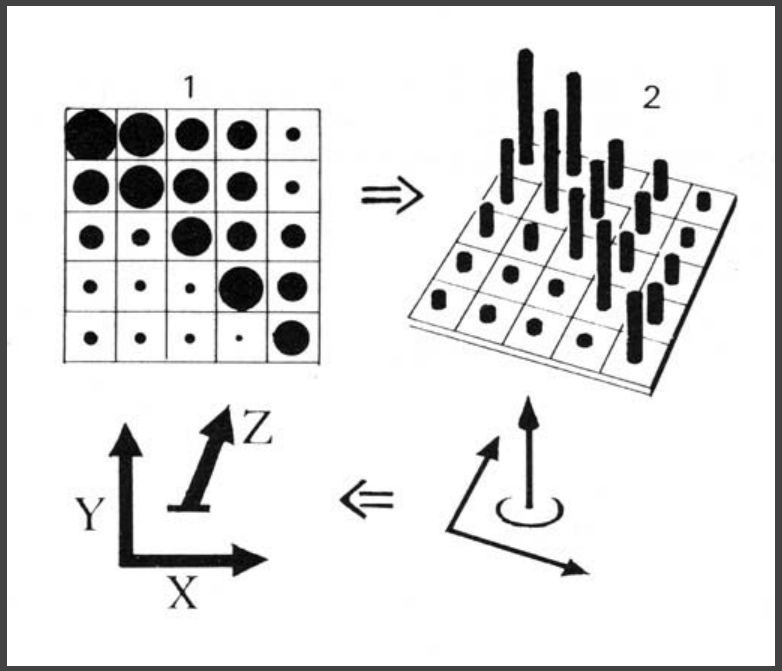
8 Visual Variables

[x,y]

- Position

[z]

- Size
- Value
- Color
- Texture (frequency)
- Orientation
- Shape (pattern)



Bertins' "Levels of Organization"

Position	N	O	Q
Size	N	O	Q
Value	N	O	Q
Texture	N	O	
Color	N	O	
Orientation	N		
Shape	N		

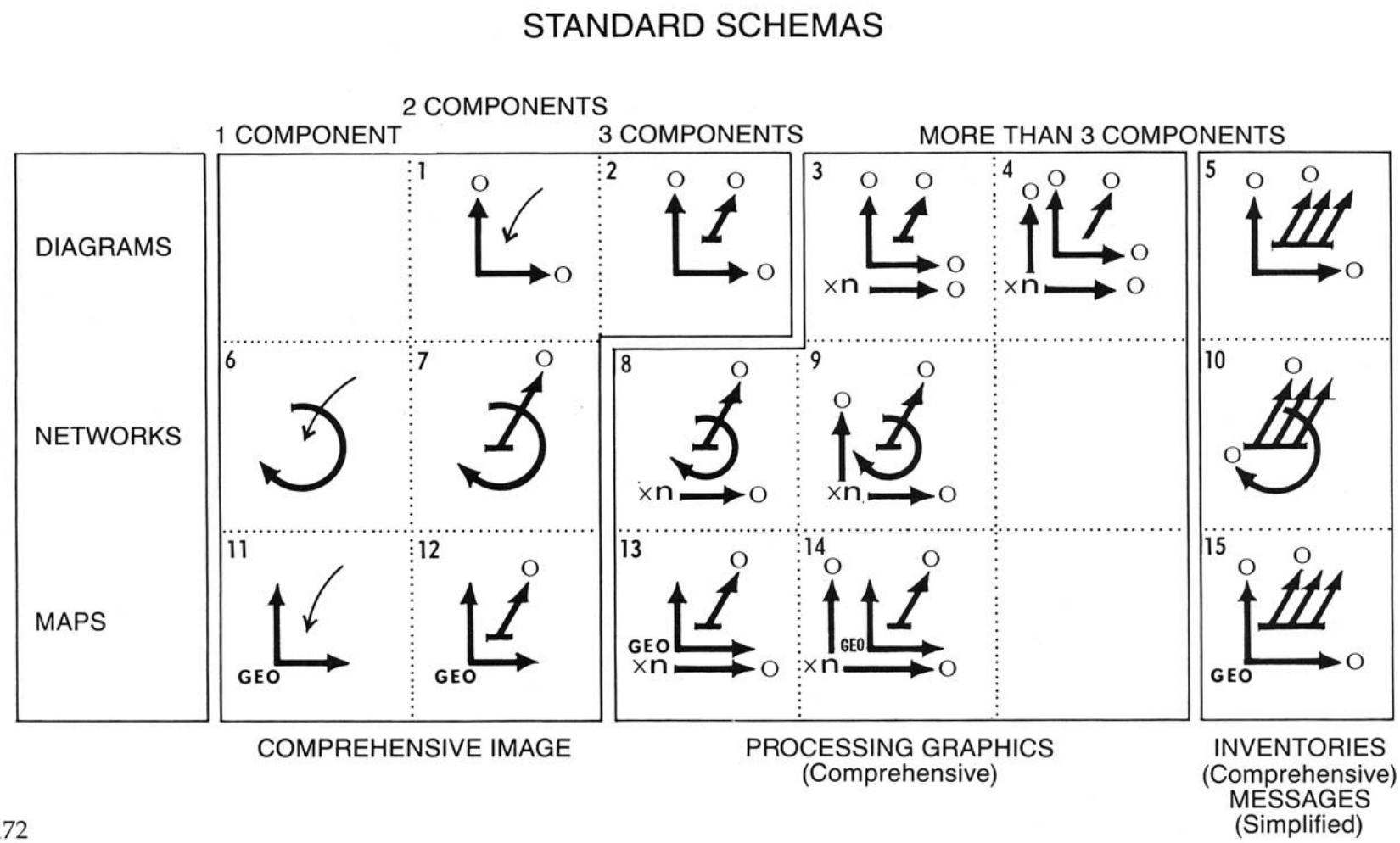
N Nominal

O Ordered

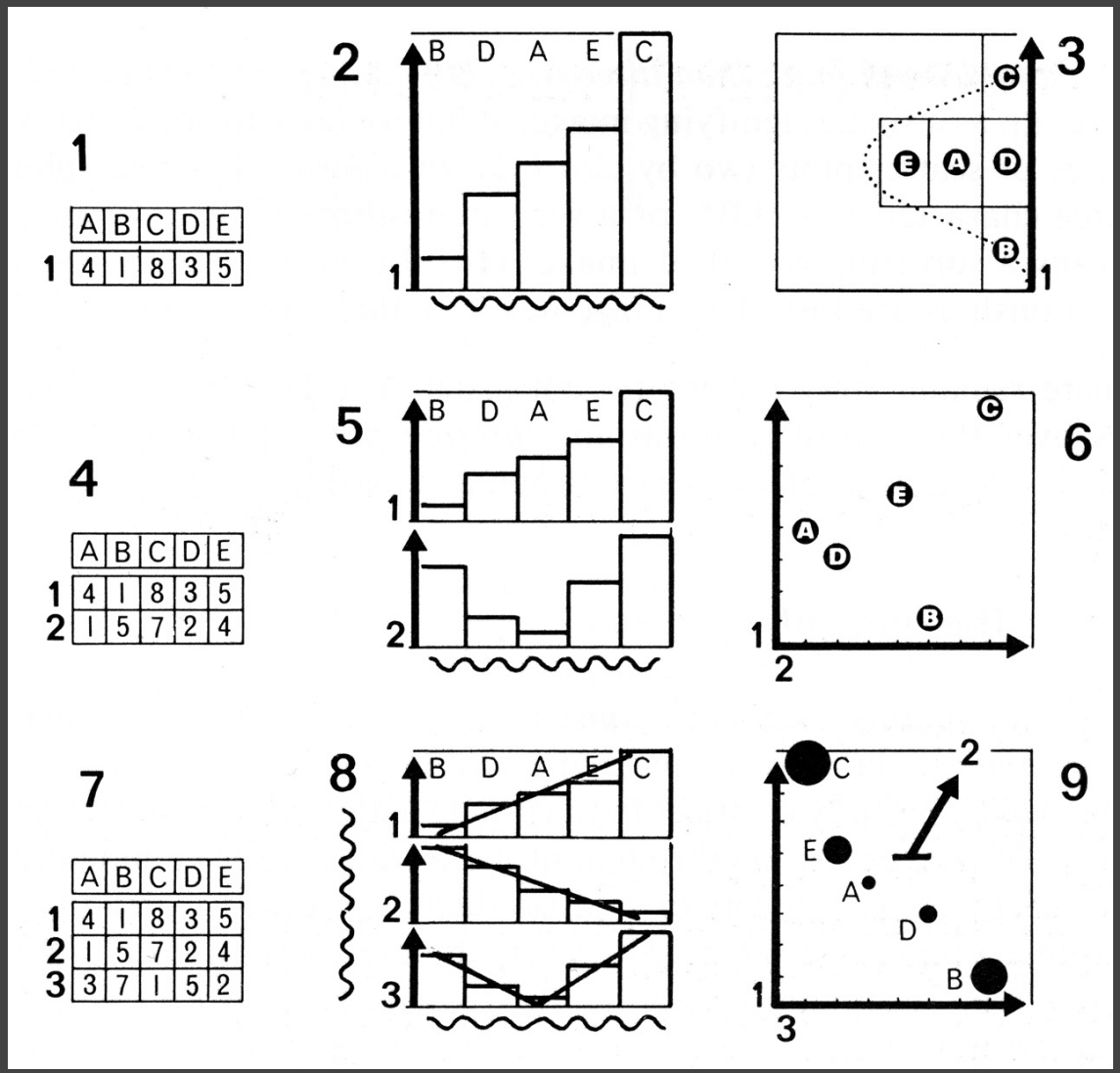
Q Quantitative

Note: Q ⊂ O ⊂ N

Graphical Schemas or Languages



Design Space



Jock Mackinlay's Thesis

Automatic Presentation Tool

- Rigorous formulation of Bertin's approach
- Designed a simple set of visual languages
  - Not meant to be complete
- Implemented languages in logic programming language
  - Not necessarily the most practical approach
- Given a relation, enumerated the sentences in the language that encode that relation
- Choose the best one using expressibiity and effectiveness criterion (Cleveland)

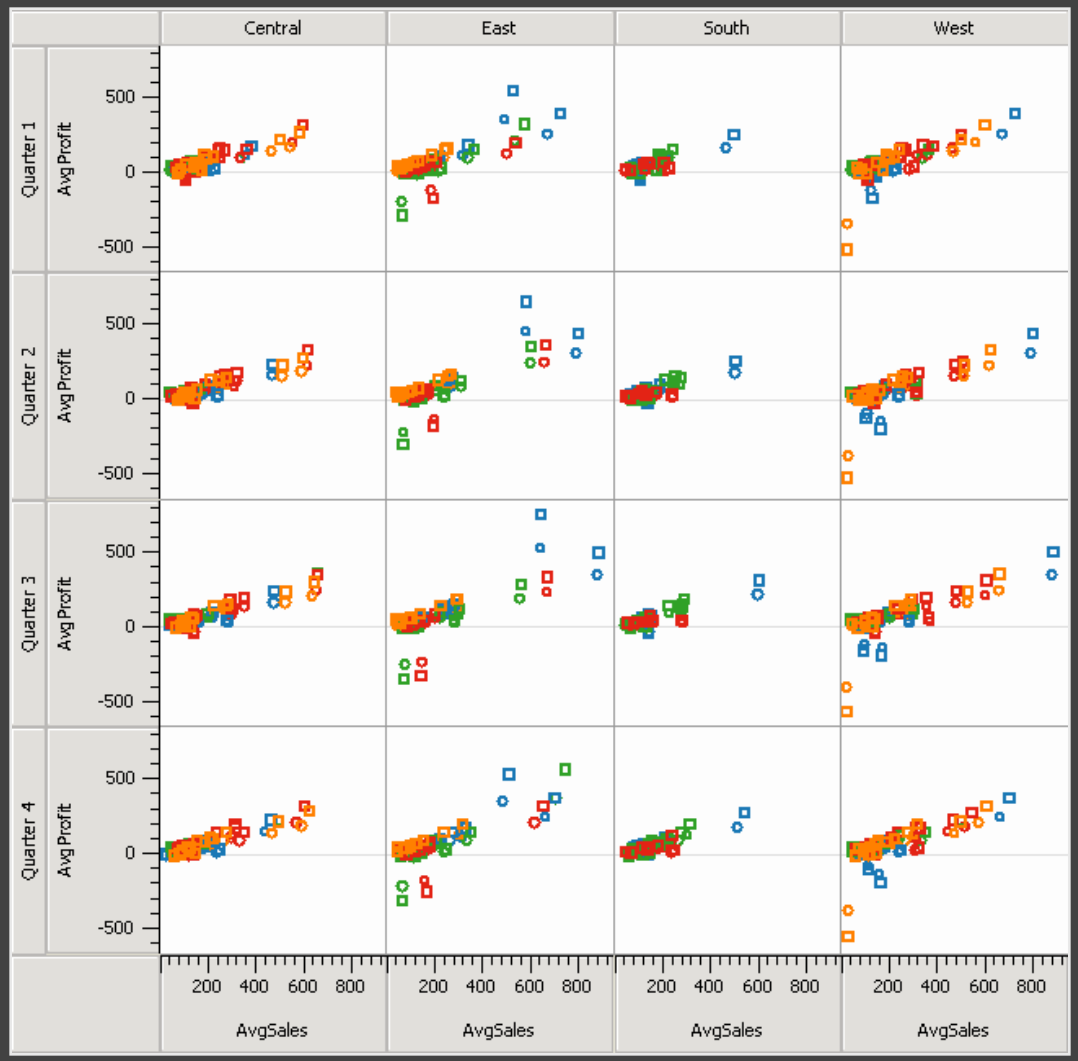
Chris Stolte's Thesis [S, Tang, H]

System for Visual Analysis

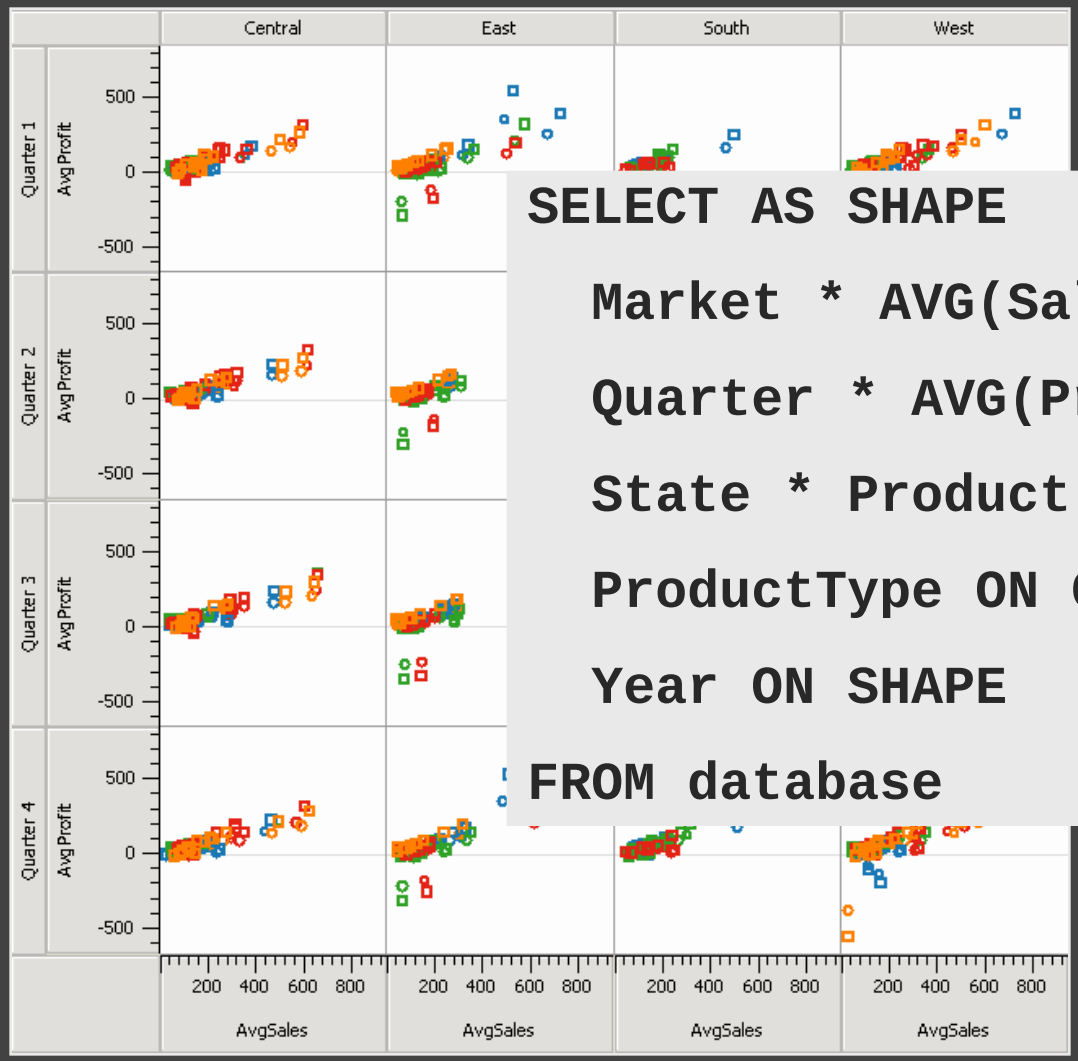
- Designed a visual language that allowed for many common visual representations
  - Tables, chart, timelines, maps, …
- Designed and implemented the language using relational algebra
- Built an easy-to-use interactive system to query, analyze and visualize a relational database

Demonstration

Visual Query Language (VizQL)



Visual Query Language (VizQL)




```
SELECT AS SHAPE
   Market * AVG(Sales) ON COLS
   Quarter * AVG(Profit) ON ROWS
   State * Product IN PANES
   ProductType ON COLOR
   Year ON SHAPE
FROM database
```

Bread-and-Butter of Analysis

Selection

Filtering

Sorting

Calculation

Grouping and Aggregation

Basically what SQL and Excel do …

Litmus test for an analysis system

Visual Queries

Two insights

- Query-By-Example (QBE)
  - Adopted by Microsoft Access, Paradox
- Dimension/Measure model from BI
  - Dimensions are independent, x
  - Measures are dependent, y = f(x)
  - Adds grouping and aggregation to QBE

Query-By-Example [Zloof, 1975]

Department Relation

SALES	DEPARTMENT	ITEM
	STATIONARY	DISH
	HOUSEHOLD	PEN
	STATIONARY	PENCIL
	COSMETICS	LIPSTICK
	TOY	PEN
	TOY	PENCIL
	TOY	INK
	COSMETICS	PERFUME
	STATIONARY	INK
	HOUSHOLD	DISH
	STATIONARY	PEN
	HARDWARD	INK

Supplier Relation

SUPPLY	ITEM	SUPPLIER
	PEN	PARKER
	PENCIL	BIC
	INK	PARKER
	PERFUME	REVLON
	INK	BIC
	DISH	DUPONT
	LIPSTICK	REVLON
	DISH	BIC
	PEN	REVLON
	PENCIL	PARKER

Query-By-Example [Zloof, 1975]

Q2. Find the department(s) that sells an item(s) supplied by the supplier Parker.

Here the user fills in both the SALES and the SUPPLY Tables as follows.

SALES	DEPT	ITEM
	P.TOY	PEN

SUPPLY	ITEM	SUPPLIER
	PEN	PARKER

ANS:

DEPT
HOUSEHOLD
TOY
STATIONARY
HARDWARE

Equivalent to the Domain Relational Calculus [Zloof, Ullman]

N.B. the question and answer style of query languages

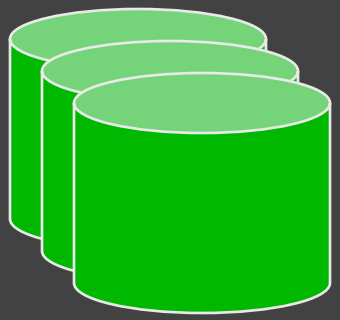
Generality!

By following the lead of QBE, I can PROVE it is possible for VizQL to generate ANY SQL query

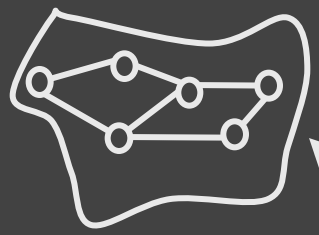
Thus, analyze and query by creating a picture that you want to see

Now make it fluid …

Sensemaking Loop [Card, …]



Task/Question



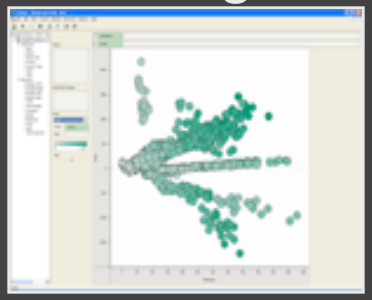
Forage
for data

Decide and act

Search for
best visual representation

Find answer or
discover insight

Visual representation
shows relationships and patterns



Visual Statistics?

A simple idea

- Model formula are widely used to specify linear and non linear models (R/S, SAS, …)
- Two examples are linear regression and factor analysis
- Visual specification related to “model formula” in statistics
- Creating a picture can also specify a formula …

Demonstration

Automatic Graphic Design?

1. Automatic marks
   - Choose a visual mark based on the type of the fields on axes
   - Choose other default visual attributes based on the properties of the field
2. Incrementally adding a field to a shelf
   - Encode using Bertin-like rules
3. Creating a visualization from scratch
   - Read our InfoVis2007 paper

Demonstration

Formalism Enables …

Formally construct queries using a visual interface

- Map shelves into queries ala QBE
- Enables drag-and-drop visual analysis

Formally construct linear models using visualization

- Model languages are like visual languages
- But not all models have a visualization

Automatic design of visualizations

- Captures low-level graphic design “rules”
- Picks reasonable defaults

Software Engineering

Declarative (what), not imperative (not how)

- Like database query languages

More efficient software

- Generative versus monolithic components
- Optimized interpreter / scalable

Simplifies useful features

- Undo/redo/bookmarks: save specifications
- Collaborative visualization: share specifications
- History of analysis: log specifications

Future Work

Visualization transformation

- Program transformations create new visualizations from existing visualizations
- Rules for rearranging fields

Learn good visualizations

- Use machine learning to find design rules using examples of good design

Limitations

- Currently, rather simple representations
  - Bertin did consider networks (node-link)
  - Bertin did not consider 3D, animation, …
  - Semantically richer designs such as diagrams
    - Take 3??
- Data model is weak
  - Unstructured data??

Limitations

- Perceptual foundations are shaky
  - What are the right visual attributes?
  - How can they be combined?
- Cognitive models are too simple
  - Important additional factors include context, engagement, style, aesthetics, …
  - No easy way to get at task …

Summary

A journey …

- Some insights from cognitive science

  How to choose and create the right representation for a task?

- Combine Bertin's ideas about the semiology of graphics with relational algebra and databases
- Platform to explore query and analysis, hypothesis testing, and design

The power of inventing new ways to create visualizations

Thank you