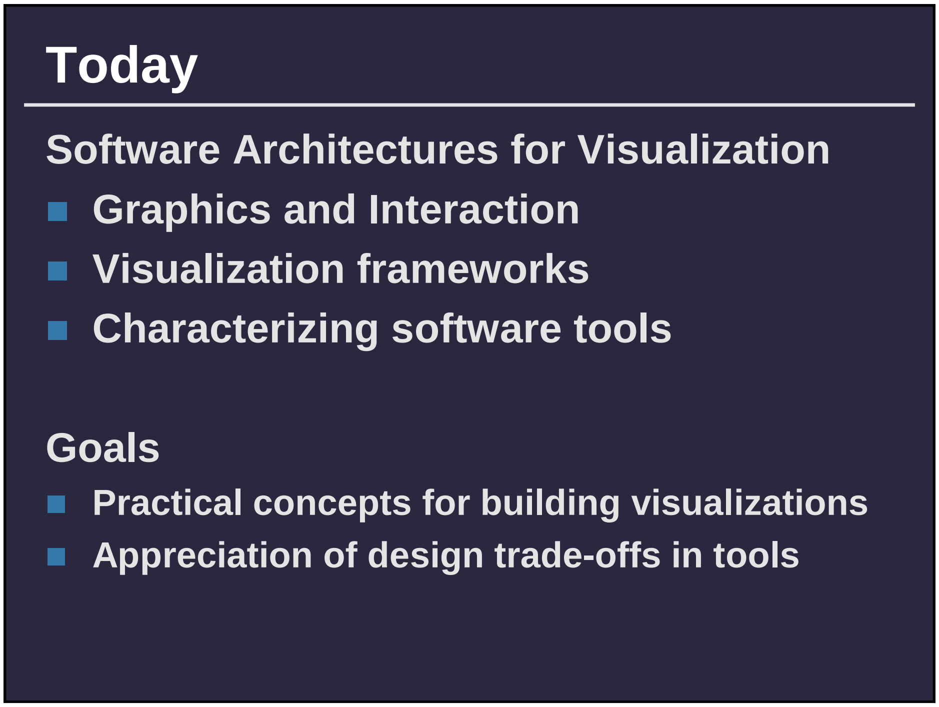
Authoring Visualizations

Jeffrey Heer

CS 294-10: Visualization
Fall 2007



Today

Software Architectures for Visualization

- Graphics and Interaction
- Visualization frameworks
- Characterizing software tools

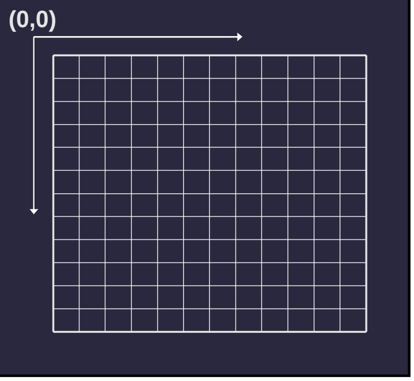
Goals

- Practical concepts for building visualizations
- Appreciation of design trade-offs in tools

The Basics: Interactive Graphics

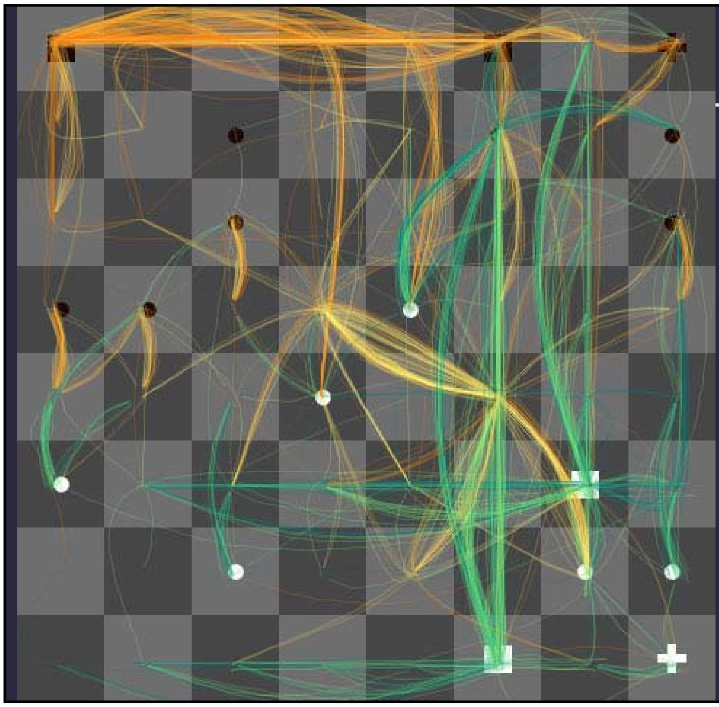
2D Graphics Model

- Drawing Canvas with coordinate system
  - Origin typically at top-left, increasing down and to the right
  - Units depend on the output medium
    - Screen → pixels, printer → cm / inches
- Graphics Context
  - Device-independent drawing abstraction
  - Potentially holds state for
    - Clipping region
    - Color
    - Typeface
    - Stroke model
    - Coordinate transforms
  - Rendering methods
    - Draw, fill shapes
    - Draw text strings
    - Draw images



2D Graphics Implementations

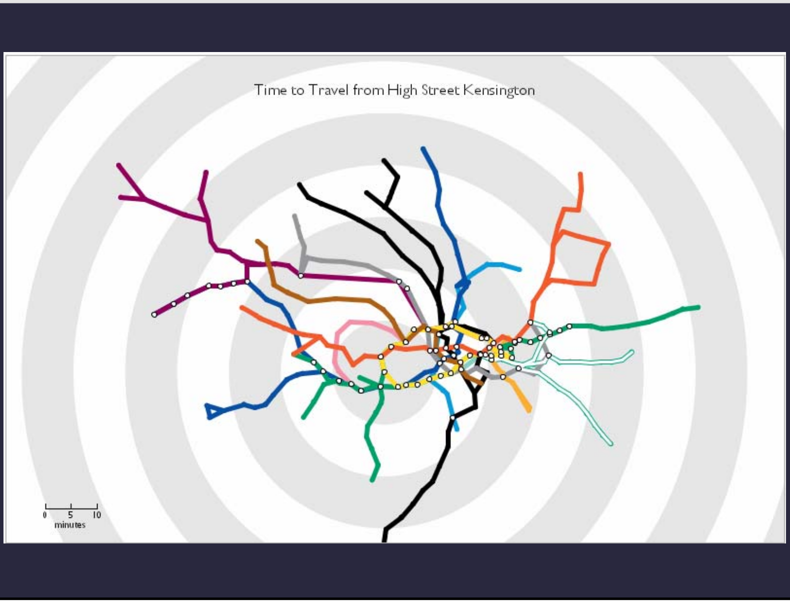
- OpenGL (obviously, also includes 3D)
- Postscript / PDF
  - Very influential, inspired the following:
- Java2D, GDI+ (Win32), Quartz (MacOS X)
  - Platform specific 2D graphics APIs
- Processing
  - Graphics API designed for ease-of-use
  - Based on the metaphor of an artist’s sketchbook
  - Basic interaction: raw mouse and key events



thinking machine 4

martin
wattenberg

Travel Time Tube Map

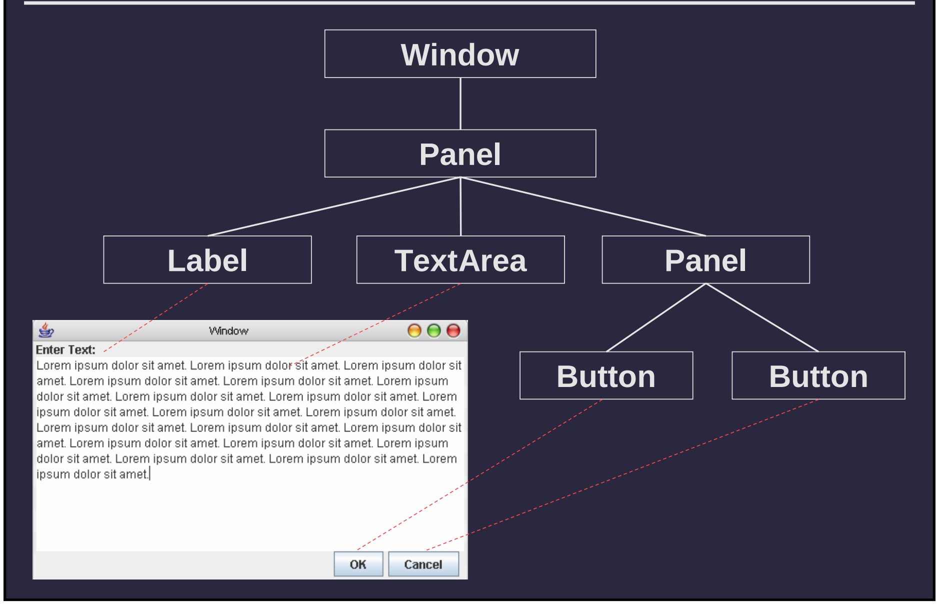


User Interface Toolkits

- Low-level graphics APIs lack structure
  - No built-in notion of visual objects
  - No routing of input events to objects
  - No layout support

- User Interface toolkits
  - Spatially organized set of components
  - Event-driven interaction

Containment Hierarchy



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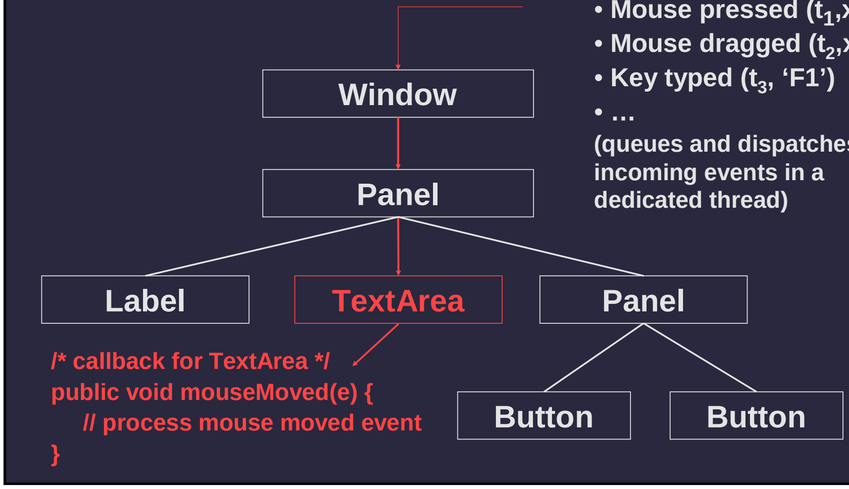
Event Dispatch



```
/* callback for TextArea */
public void mouseMoved(e) {
    // process mouse moved event
}
```

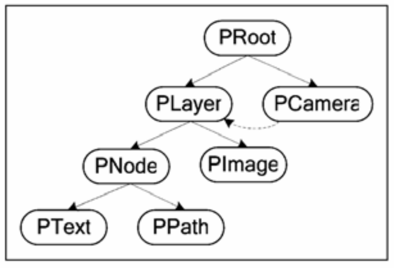
Event Queue

- Mouse moved (t_0,x,y)
- Mouse pressed (t_1,x,y,1)
- Mouse dragged (t_2,x,y,1)
- Key typed (t_3, ‘F1’)
- …

(queues and dispatches incoming events in a dedicated thread)

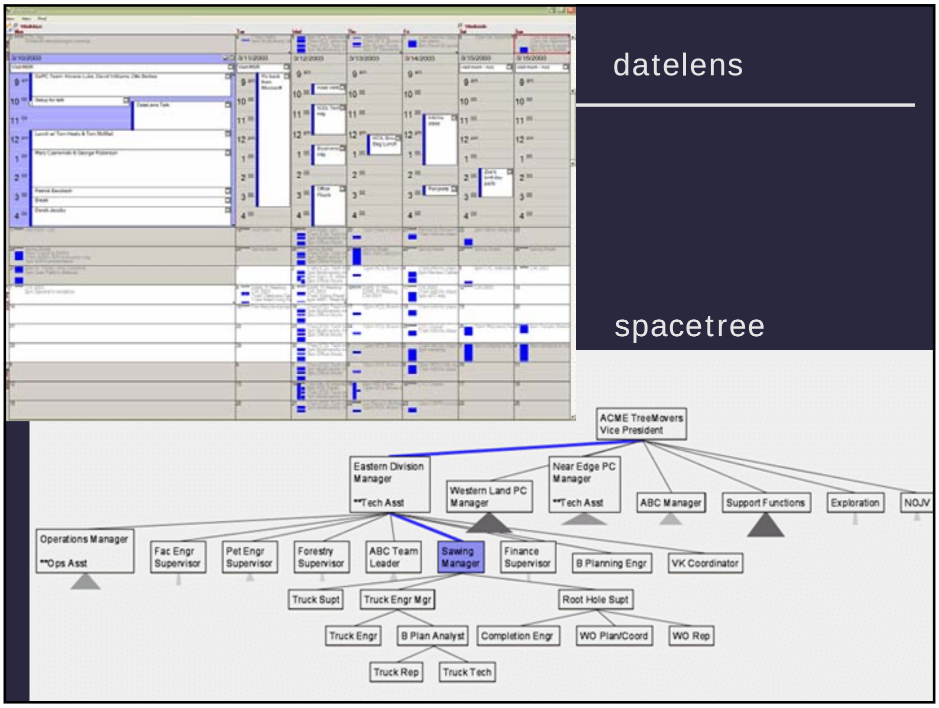
An alternative structure

- Scenegraph
  - Commonly used in 3D toolkits, also applicable in 2D.
  - Models visual elements, properties and groupings in a semantic directed acyclic graph
  - Groups specified relative to their own coordinate systems
  - Can include object groupings, multiple cameras
  - Well suited for panning and zooming



Scenegraph-based tools

- Adobe Flash
  - Hierarchy of “DisplayObject” types
  - Transform of parent affects all children
    - Alpha (transparency)
    - Position
    - Rotation
    - Scale
- Piccolo (Java and C#/.NET)
  - Java Toolkit for Zoomable User Interfaces
  - Functionality consolidated in top-level component
  - Extensibility achievable through compile-time inheritance
  - The successor of Pad, Pad++

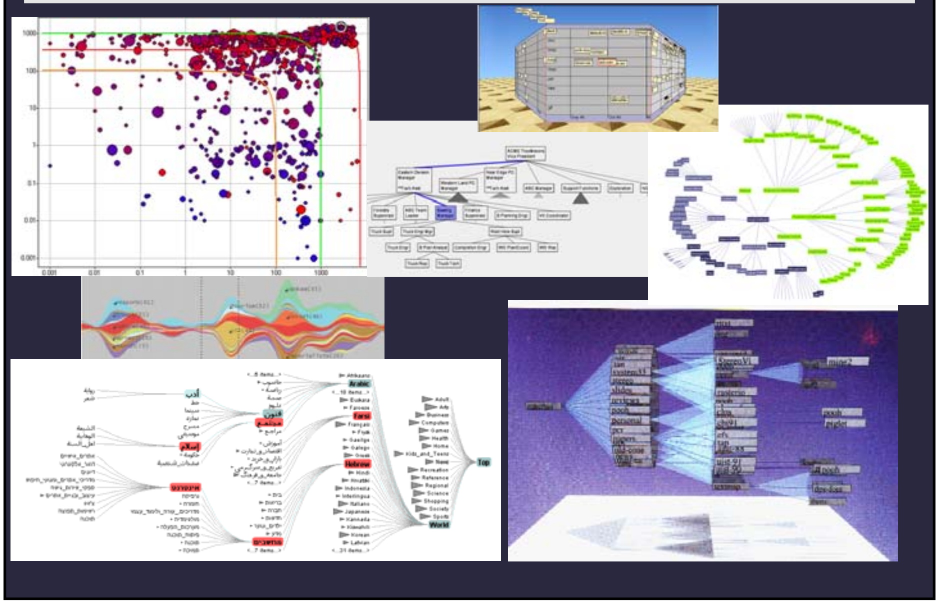


datelens

spacetree

Visualization Toolkits

How to support diverse visualizations?



Useful higher-level tools?

[In-Class Brainstorm]

- Data
  - Data Transforms (Aggregation)
  - Filters
- Visual Encoding
  - Layout Algorithms
- Animation
- Interaction
  - Brushing and Linking (Coordination)
  - Dynamic Queries
  - Selection
- Diagnostics and Meta-Data
- Automated Evaluation

Needs of an InfoVis Framework?

Most UI Toolkits provide unified structures for Graphics and Interaction

InfoVis frameworks must also consider:

- Data modeling and manipulation
- Mappings from data to visuals

Higher-level constructs also possible

- Layout techniques
- Visual transformations
- Interaction techniques (dyn. queries…)

Information Visualizer

Perhaps the first integrated framework for visualization.

Built on early Silicon Graphics machines ($$$), using a LISP graphics language.

Provided a centralized ‘governor’ that oversaw animation, ensuring 100ms or better frame rates, decreasing rendering quality as necessary.

Video: Cone Trees, Perspective Wall

InfoVis Toolkit [Fekete 2004]

Extensible collection of infovis ‘widgets’

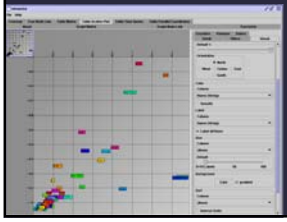
- scatterplot, treemaps, graph visualizations, etc

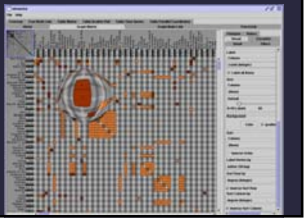
Table-based data model, similar to database

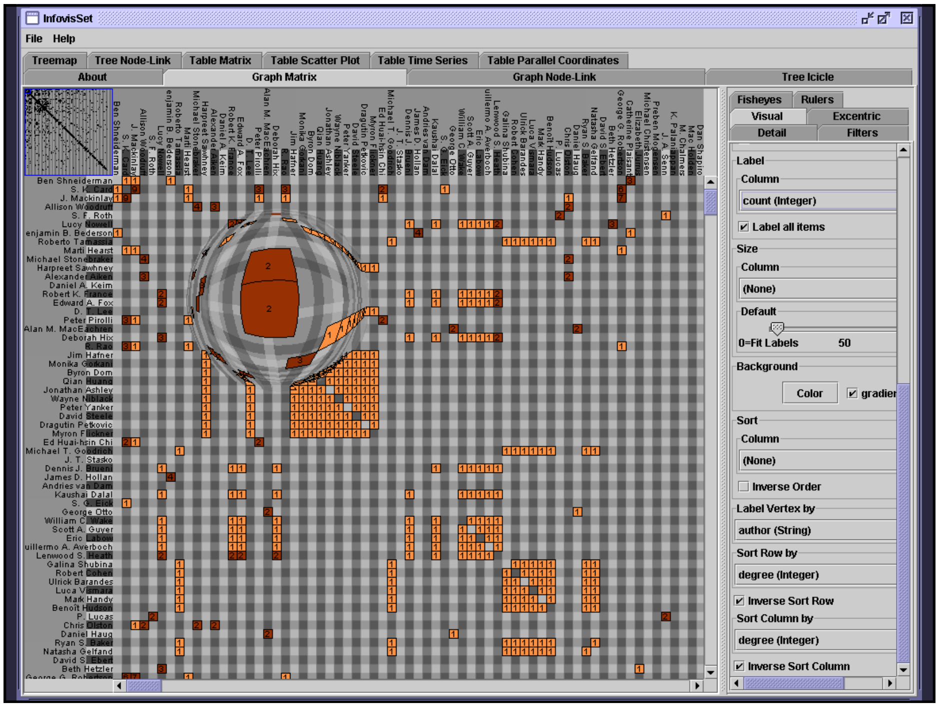
General interactive components

- dyn queries, distortion lenses, excentric labels

http://infovis.sourceforge.net







Label

Column

count (Integer)

☑ Label all items

Size

Column

(None)

Default

0=Fit Labels 50

Background

Color ☑ gradient

Sort

Column

(None)

□ Inverse Order

Label Vertex by

author (String)

Sort Row by

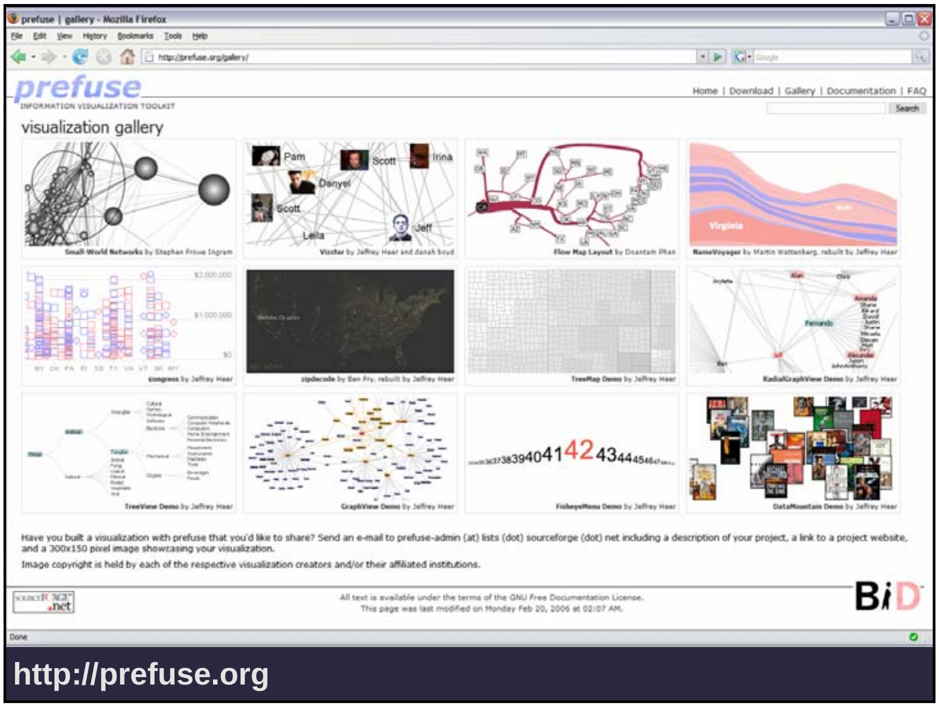
degree (Integer)

☑ Inverse Sort Row

Sort Column by

degree (Integer)

☑ Inverse Sort Column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visualization gallery

Small-World Networks by Stephan Frowe Ingram

Vizster by Jeffrey Heer and danah boyd

Flow Map Layout by Doantam Phan

NameVoyager by Martin Wattenberg, rebuilt by Jeffrey Heer

congress by Jeffrey Heer

zipdecode by Ben Fry, rebuilt by Jeffrey Heer

TreeMap Demo by Jeffrey Heer

RadialGraphView Demo by Jeffrey Heer

TreeView Demo by Jeffrey Heer

GraphView Demo by Jeffrey Heer

FisheyeMenu Demo by Jeffrey Heer

DataMountain Demo by Jeffrey Heer

Have you built a visualization with prefuse that you'd like to share? Send an e-mail to prefuse-admin (at) lists (dot) sourceforge (dot) net including a description of your project, a link to a project website, and a 300x150 pixel image showcasing your visualization.

Image copyright is held by each of the respective visualization creators and/or their affiliated institutions.

http://prefuse.org

Structuring InfoVis Applications

Structuring InfoVis Applications

InfoVis apps often require flexibility

Small Multiples and multiple views

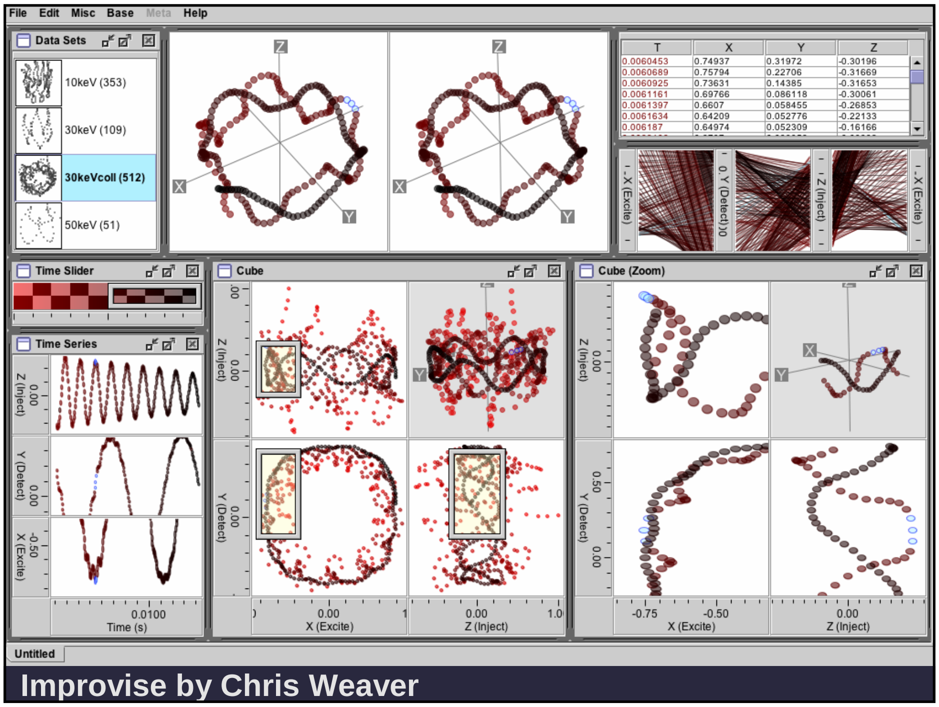
- Different visual encodings of the same data

Overview + Detail displays

- Different views of the same visualization

Flexible and varied user input sources

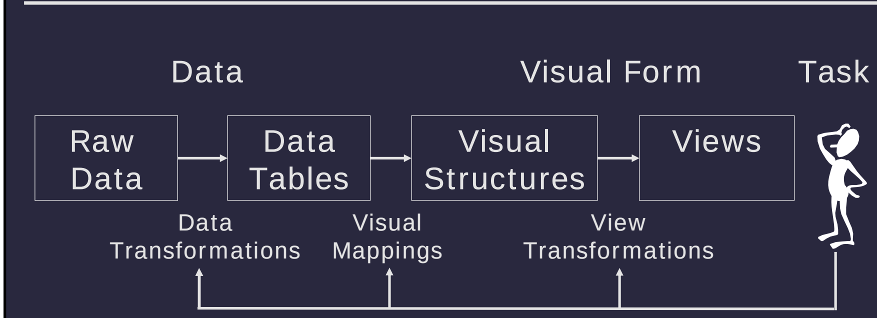
- Interaction techniques, dynamic queries



T	X	Y	Z
0.0060453	0.74937	0.31972	-0.30196
0.0060689	0.75794	0.22706	-0.31669
0.0060925	0.73631	0.14385	-0.31653
0.0061161	0.69766	0.086118	-0.30061
0.0061397	0.6607	0.058455	-0.26853
0.0061634	0.64209	0.052776	-0.22133
0.006187	0.64974	0.052309	-0.16166

Improvise by Chris Weaver

InfoVis Reference Model [Card et al]



Data Transformations
- Mapping raw data into an organization fit for visualization

Visual Mappings
- Encoding abstract data into a visual representation

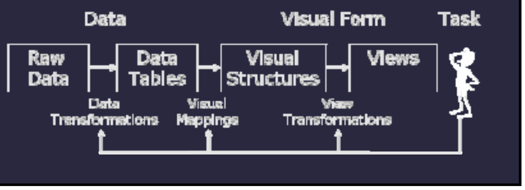
View Transformations
- Changing the view or perspective onto the visual representation

User interaction can feed back into any level

Reference Model Examples

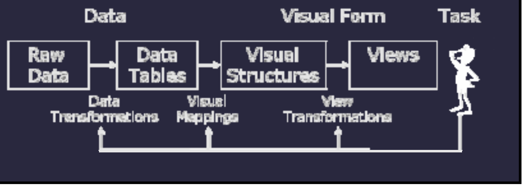
Visual mappings
- Layout (assigning x,y position)
- Size, Shape, Color, Font, etc…

View Transformations
- Navigation: Panning and Zooming
- View Distortion (e.g., fisheye lens)



InfoVis Reference Model

- Extension of MVC pattern
- Tiered level of models
  - Data model and visualization model
  - Visualization model can have any number of view/controllers
  - Controllers can feedback to the view or either model



Apply the model: cone trees

Raw Data: File system directories

- Data Transformations: Traverse file system subtree

Data Tables: Parsed/extracted directory tree

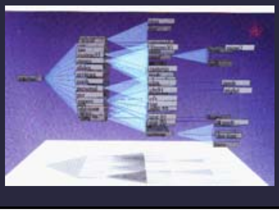
- Visual Mappings: Assign 3D coordinates to tree elements (layout), assign colors, fonts. Set lighting.

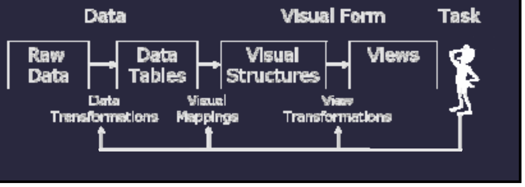
Visual Structures: 3D model of tree

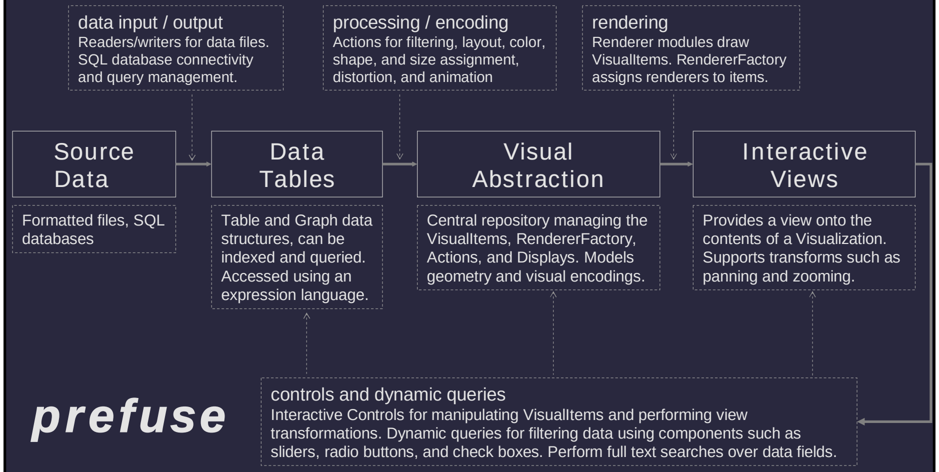
- View Transformations: Camera placement

View: Rendered, interactive visualization

Interaction: Selection of new focus node: changes visual mappings by forcing new layout calculation







data input / output
Readers/writers for data files. SQL database connectivity and query management.

processing / encoding
Actions for filtering, layout, color, shape, and size assignment, distortion, and animation

rendering
Renderer modules draw VisualItems. RendererFactory assigns renderers to items.

Source Data

Formatted files, SQL databases

Data Tables

Table and Graph data structures, can be indexed and queried. Accessed using an expression language.

Visual Abstraction

Central repository managing the VisualItems, RendererFactory, Actions, and Displays. Models geometry and visual encodings.

Interactive Views

Provides a view onto the contents of a Visualization. Supports transforms such as panning and zooming.

prefuse

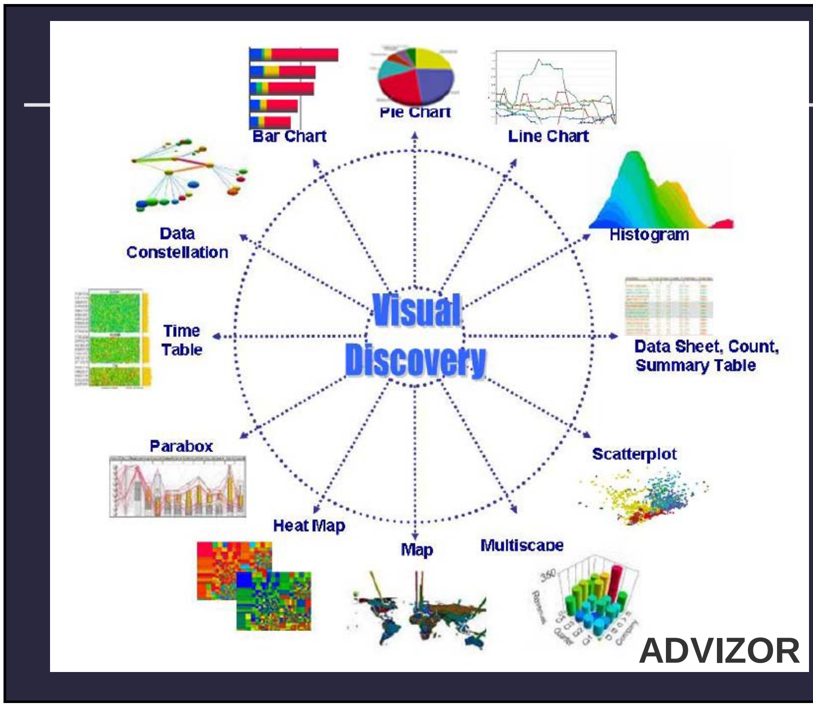
controls and dynamic queries
Interactive Controls for manipulating VisualItems and performing view transformations. Dynamic queries for filtering data using components such as sliders, radio buttons, and check boxes. Perform full text searches over data fields.

Visualization Component Models

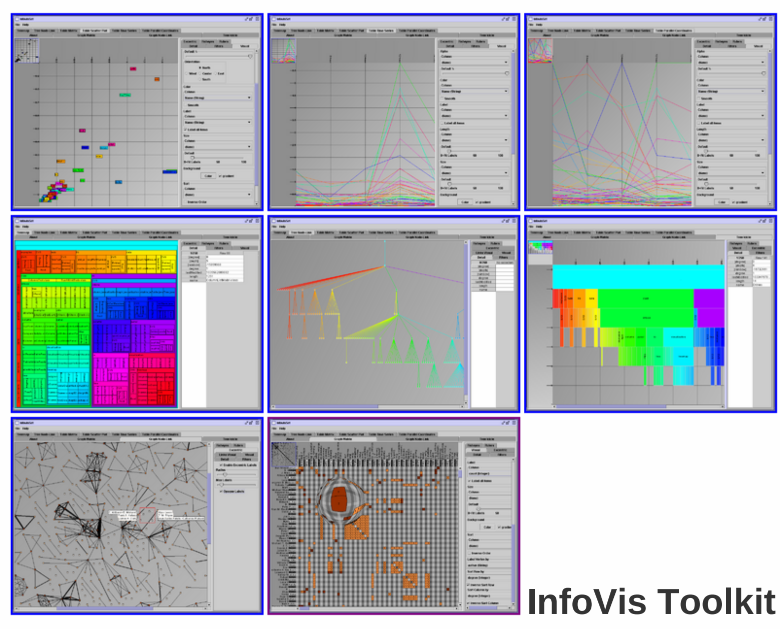
Monolithic vs. Polylithic Design

- monolithic: primarily use compile-time inheritance to extend functionality
  - Component or “widget” model for different visualization types (Advizor, InfoVis Toolkit)
- polylithic: primarily use run-time composition to extend functionality
  - Fine-grained operators are composed to create desired behaviors (prefuse, VTK)
- Systems are rarely purely one or the other

c.f. Bederson et al, “Toolkit Design for Interactive Structured Graphics”, TSE 30(8),

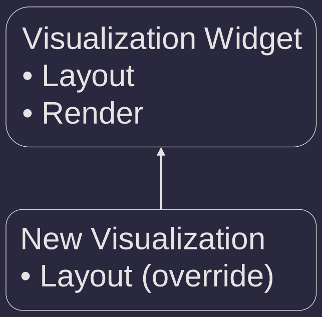


ADVIZOR



InfoVis Toolkit

The Hierarchical Approach



Visualization Widget
- Layout
- Render

New Visualization
- Layout (override)

widget hierarchies

extension by subclassing

typing is static

often can't decompose visualizations into compositions of basic techniques

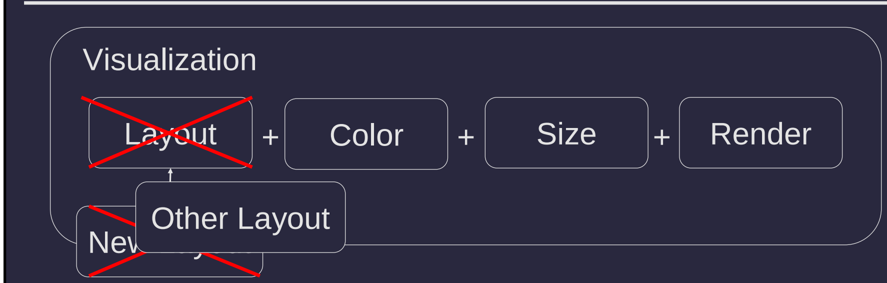
monolithic toolkits

- those that primarily use compile-time *inheritance* to extend functionality
- [Bederson et al]

A Compositional Approach

[DEMO]

A Compositional Approach



Visualization

~~Layout~~ + Color + Size + Render

~~Nev~~

Other Layout

Chain together desired components

Extend/replace techniques directly

Directly add new components (or lists of components) to customize visualizations

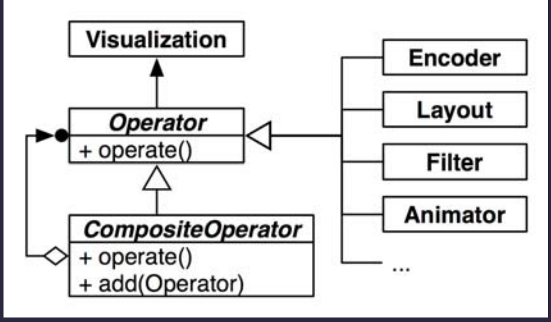
Enables dynamic changes in composition

polylithic toolkits

- those that primarily use run-time *composition* to extend functionality [Bederson et al]

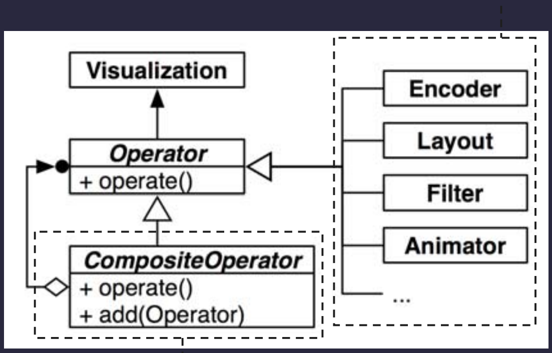
Operator Pattern

Decompose visual data processing into a series of composable operators, enabling flexible and reconfigurable visual mappings.

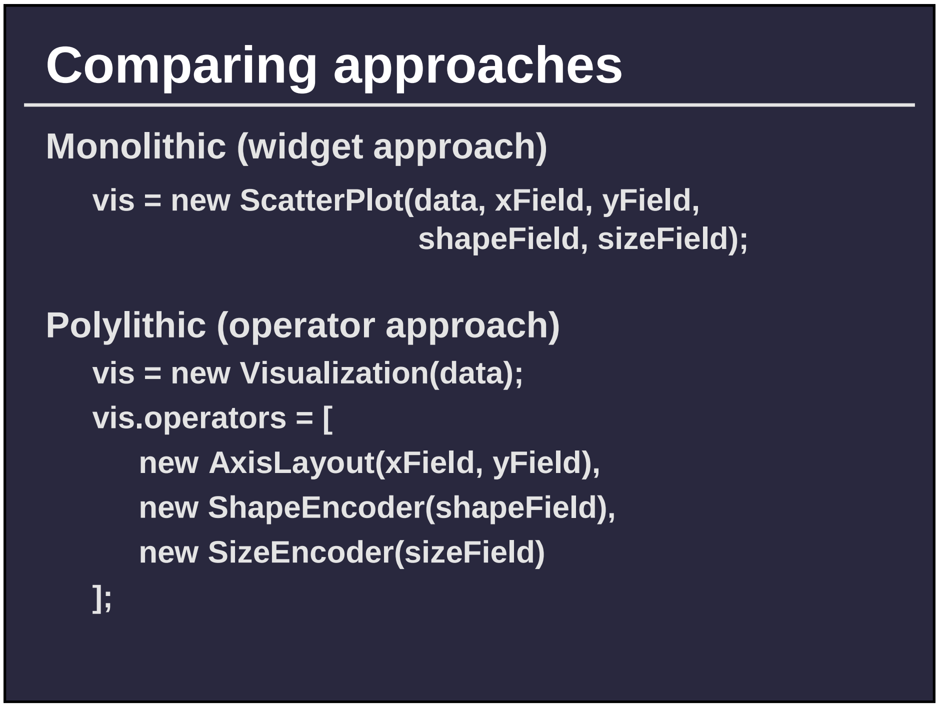


Operator Pattern

Class Hierarchy of Visualization Operators



Create Compound (Batch) Operators or Operator Conditionals



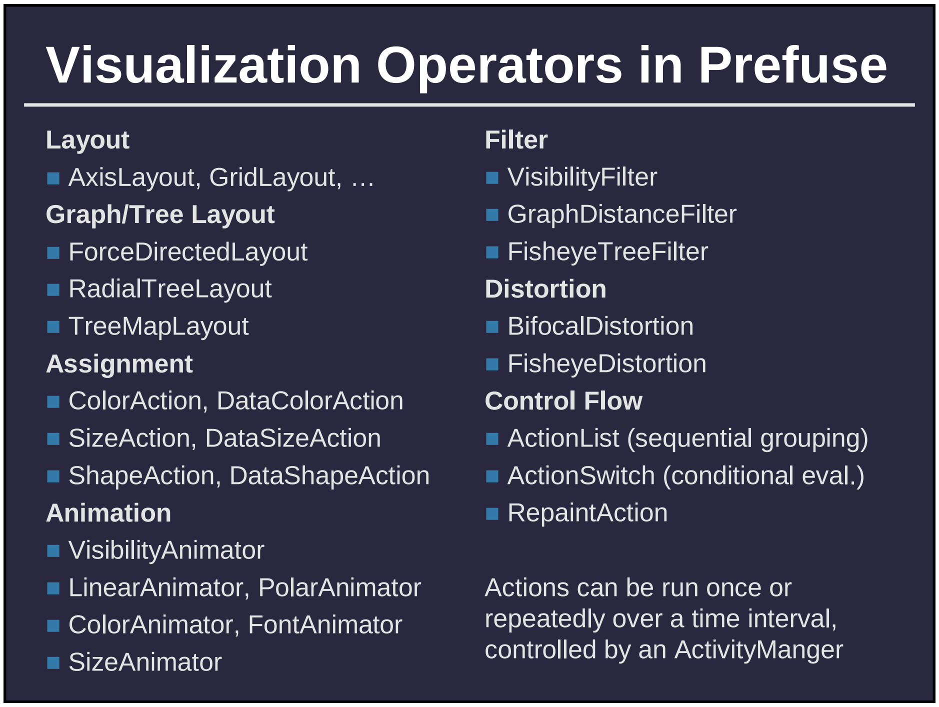
Comparing approaches

Monolithic (widget approach)

```
vis = new ScatterPlot(data, xField, yField,
                              shapeField, sizeField);
```

Polylithic (operator approach)

```
vis = new Visualization(data);
vis.operators = [
    new AxisLayout(xField, yField),
    new ShapeEncoder(shapeField),
    new SizeEncoder(sizeField)
];
```



Visualization Operators in Prefuse

Layout

- AxisLayout, GridLayout, …

Graph/Tree Layout

- ForceDirectedLayout
- RadialTreeLayout
- TreeMapLayout

Assignment

- ColorAction, DataColorAction
- SizeAction, DataSizeAction
- ShapeAction, DataShapeAction

Animation

- VisibilityAnimator
- LinearAnimator, PolarAnimator
- ColorAnimator, FontAnimator
- SizeAnimator

Filter

- VisibilityFilter
- GraphDistanceFilter
- FisheyeTreeFilter

Distortion

- BifocalDistortion
- FisheyeDistortion

Control Flow

- ActionList (sequential grouping)
- ActionSwitch (conditional eval.)
- RepaintAction

Actions can be run once or repeatedly over a time interval, controlled by an ActivityManger

Trade-Offs

- Monolithic model cited as easier for programmers
  - Fits existing programming models well
  - Less code for common cases
  - Works well when not much extensibility is needed

- Polylithic model provides more flexibility and dynamic behavior
  - Easier to add, extend, and modify application behavior
  - Supports creation of end-user (non-programmer) tools

Animation

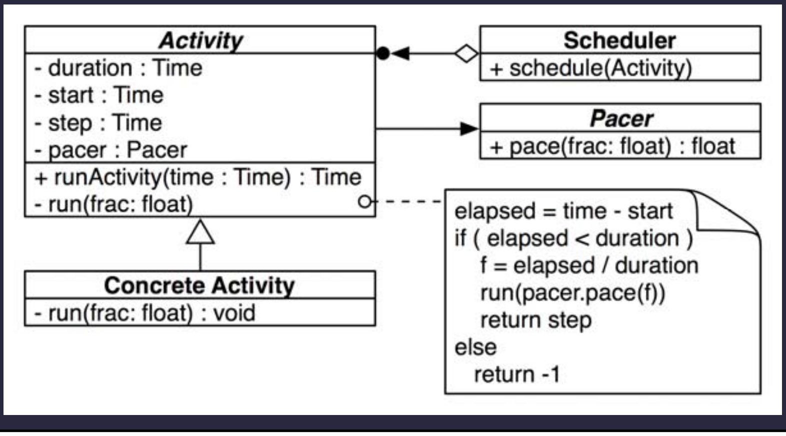
- Operator pattern provides mechanism for fine-grained composition of techniques

- However, what about time-based processing?
  - Animation (e.g., interpolation, iterated layout)
  - Hysteresis (e.g., delayed reaction to input)

- Two Approaches
  - Frame-based (redraw scene for each frame)
  - Time-based (update items over a duration)

Scheduler Pattern

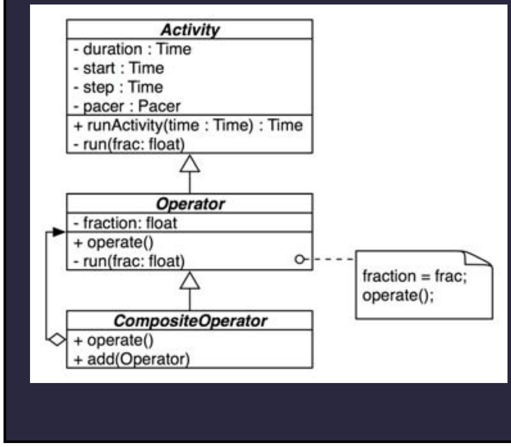
Provide schedulable activities for implementing time-sensitive, potentially recurring operations.



```
elapsed = time - start
if ( elapsed < duration )
   f = elapsed / duration
   run(pacer.pace(f))
   return step
else
  return -1
```

Operator + Scheduler

Implement Operators within the Scheduler pattern: each Operator is also an Activity



```
fraction = frac;
operate();
```

Enables animated and timing-sensitive visualization operators.

Animation in prefuse

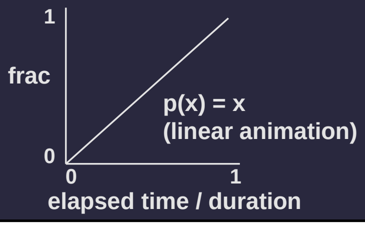
Animation API: `public void run(double frac)`

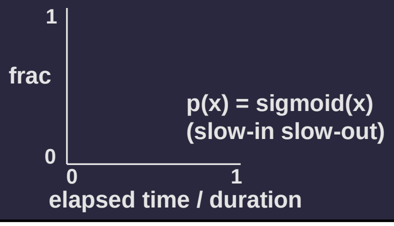
Single method allows easy extensibility

All Actions can be scheduled to run repeatedly over a time interval, enabling animation.

`frac` is a value between 0 and 1 indicating the progress through the time interval.

A pacing (or *easing*) function p(x) can be used to modify the rate of change of the `frac` parameter.



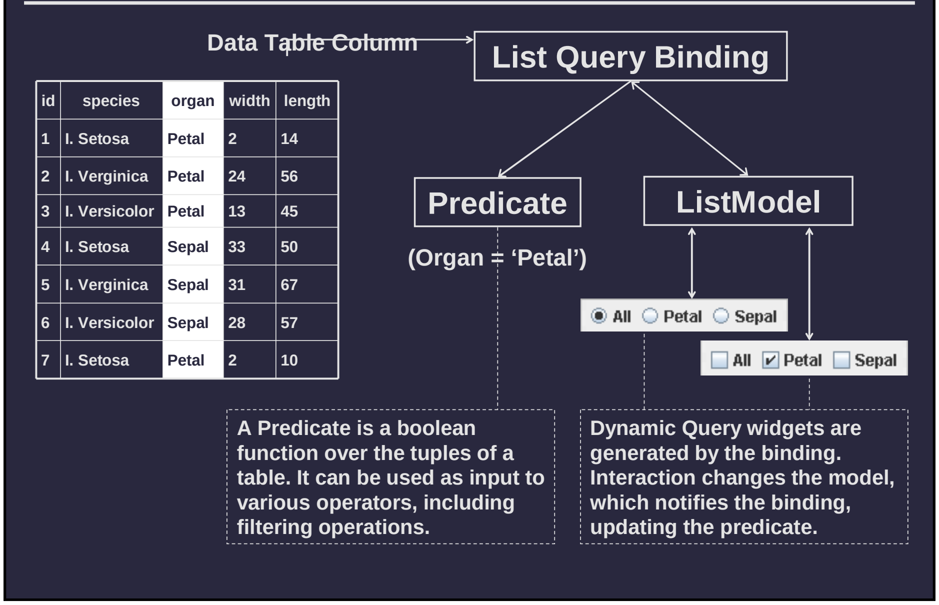


Dynamic Queries

Dynamic Query Bindings

- Range Queries
  - Filter a range of values
  - Ordinal and quantitative data
  - Widgets: range slider, slider
- List Queries
  - Filter individual data values
  - Any data type, though small lists are better
  - Widgets: combo box, list box, radio buttons, checkboxes
- Search Queries
  - Filter items in response to a text search
  - Search engine types: prefix matching, regular expressions, full keyword search (inverted index)
  - Textual data
  - Widgets: text box

Dynamic Query Bindings

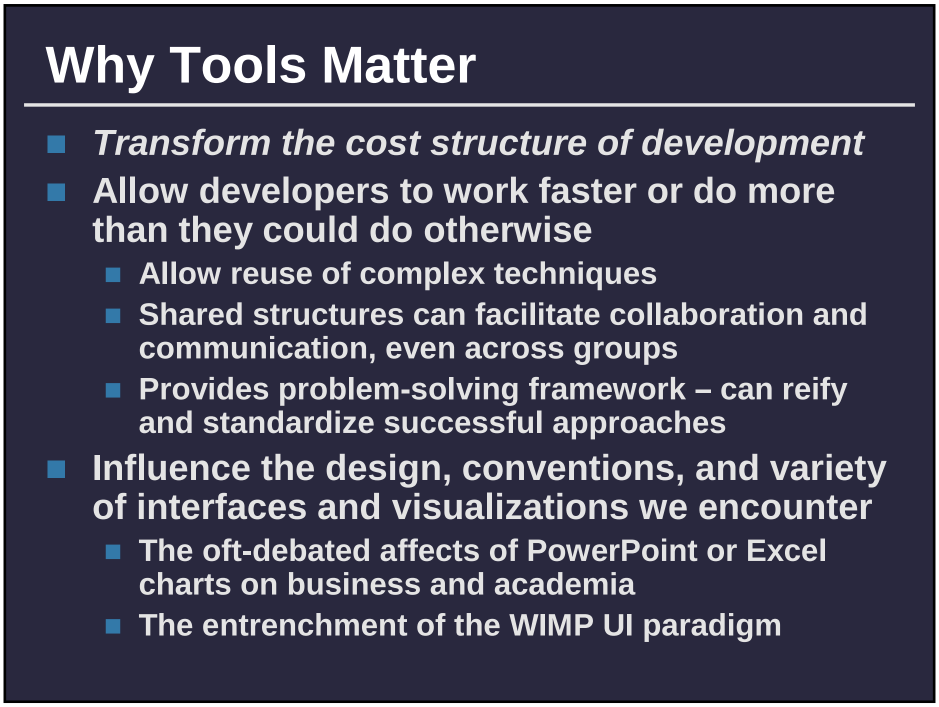


id	species	organ	width	length
1	I. Setosa	Petal	2	14
2	I. Verginica	Petal	24	56
3	I. Versicolor	Petal	13	45
4	I. Setosa	Sepal	33	50
5	I. Verginica	Sepal	31	67
6	I. Versicolor	Sepal	28	57
7	I. Setosa	Petal	2	10

A Predicate is a boolean function over the tuples of a table. It can be used as input to various operators, including filtering operations.

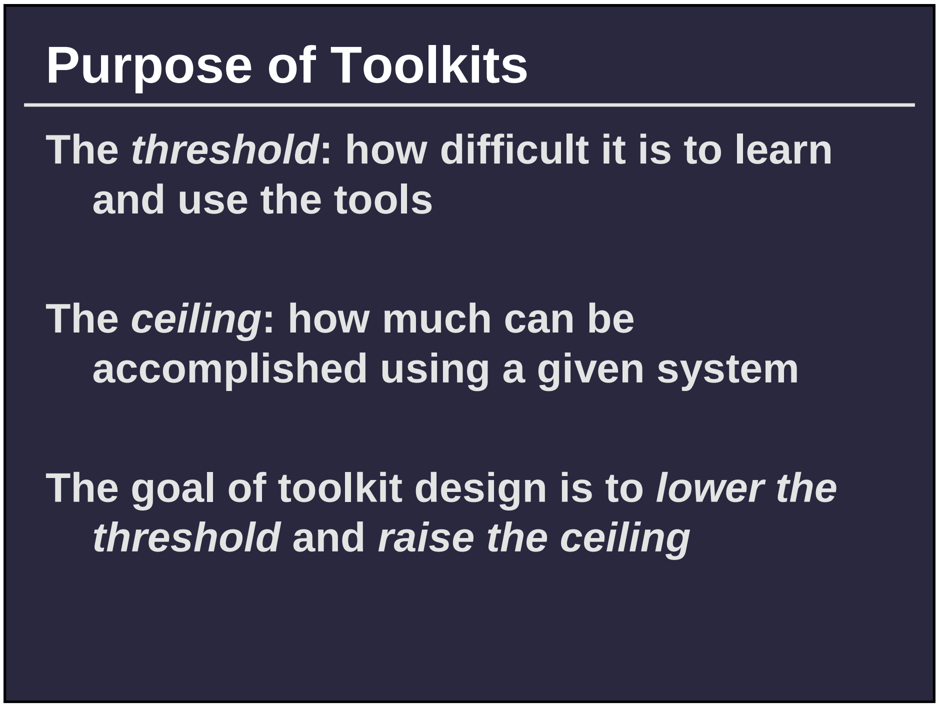
Dynamic Query widgets are generated by the binding. Interaction changes the model, which notifies the binding, updating the predicate.

Summary



Why Tools Matter

- *Transform the cost structure of development*
- Allow developers to work faster or do more than they could do otherwise
  - Allow reuse of complex techniques
  - Shared structures can facilitate collaboration and communication, even across groups
  - Provides problem-solving framework – can reify and standardize successful approaches
- Influence the design, conventions, and variety of interfaces and visualizations we encounter
  - The oft-debated affects of PowerPoint or Excel charts on business and academia
  - The entrenchment of the WIMP UI paradigm

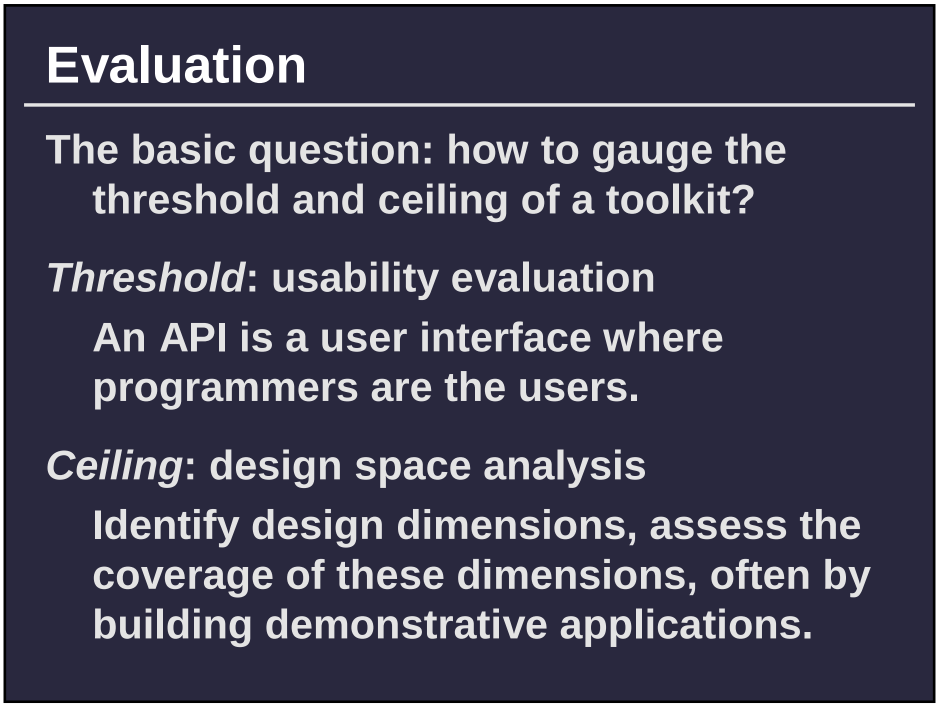


Purpose of Toolkits

The *threshold*: how difficult it is to learn and use the tools

The *ceiling*: how much can be accomplished using a given system

The goal of toolkit design is to *lower the threshold* and *raise the ceiling*



Evaluation

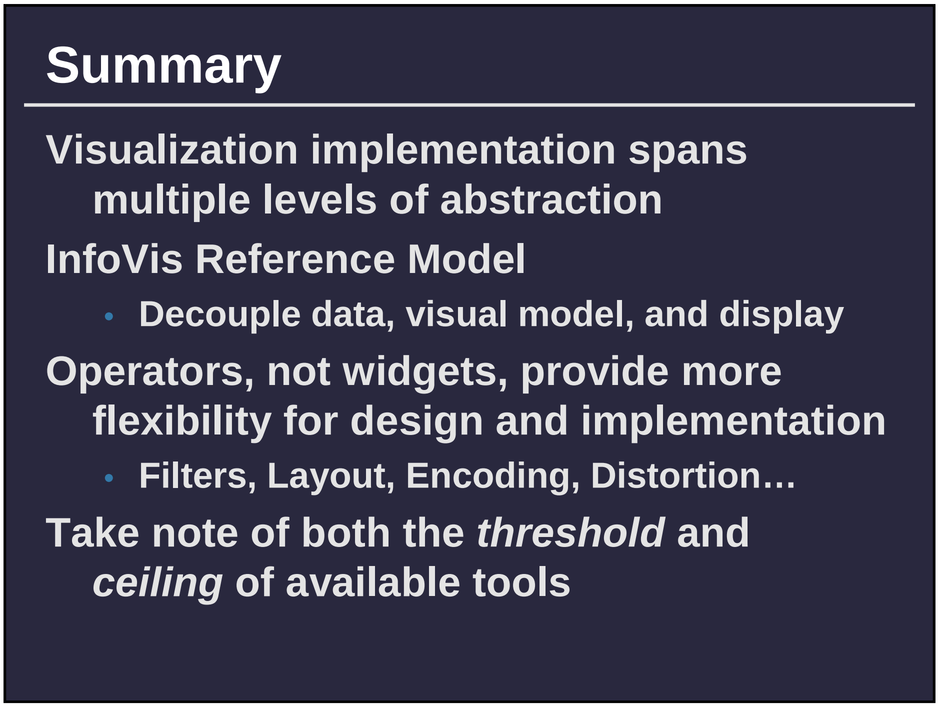
The basic question: how to gauge the threshold and ceiling of a toolkit?

Threshold: usability evaluation

An API is a user interface where programmers are the users.

Ceiling: design space analysis

Identify design dimensions, assess the coverage of these dimensions, often by building demonstrative applications.



Summary

Visualization implementation spans multiple levels of abstraction

InfoVis Reference Model

- Decouple data, visual model, and display

Operators, not widgets, provide more flexibility for design and implementation

- Filters, Layout, Encoding, Distortion…

Take note of both the *threshold* and *ceiling* of available tools