visualization of time-oriented data

introduction

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Data types [Shneiderman, 1996]

1-dimensional
2-dimensional
3-dimensional
  Temporal
  = 4D space
    “the world we are living in”
Multi-dimensional
Tree
Network
Spatial + temporal dimensions

Every data element we measure is related and often only meaningful in context of space + time

Example: price of a computer

where? when?
Differences between space and time

Space can be traversed “arbitrarily”
we can move back to where we came from

Time is unidirectional
we can’t go back or forward in time

Humans have senses for perceiving space
visually, touch

Humans don’t have senses for perceiving time
Interactive visualization

Gives us the ability to...

...travel in time virtually.
Time-oriented data?

Event calendar

Snow height & sunshine hours

Organization chart

Visualization of time-oriented data
# Event calendar

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>9.00 bis 10.45</td>
<td>Plenarveranstaltungen 1+2+3</td>
<td>11.00 bis 12.45</td>
<td>Plenarveranstaltungen 4+5+6</td>
<td>13.00 bis 14.00</td>
<td>Mittagsvorlesungen 1+2</td>
<td>14.15 bis 17.00</td>
<td>Sektionen, Arbeitsgruppen, Ad-hoc-Gruppen</td>
<td>17.00 bis 18.00</td>
<td>Authors meet Critics, Foren, Sonderveranstaltungen</td>
</tr>
<tr>
<td>11.00 bis 13.00</td>
<td>Sektions-</td>
<td>11.00 bis 12.45</td>
<td>Plenarveranstaltungen 7+8+9</td>
<td>13.00 bis 14.00</td>
<td>Mittagsvorlesungen 3+4</td>
<td>14.15 bis 17.00</td>
<td>Sektionen, Arbeitsgruppen, Ad-hoc-Gruppen</td>
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<td>Authors meet Critics, Foren, Sonderveranstaltungen</td>
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<tr>
<td>sprechertreffen</td>
<td>Pressekonferenz</td>
<td>11.00 bis 12.45</td>
<td>Plenarveranstaltungen 10+11+12</td>
<td>13.00 bis 14.00</td>
<td>Mittagsvorlesungen 5+6</td>
<td>14.15 bis 17.00</td>
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<td>14.00 bis 17.00</td>
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<td>17.00 bis 18.00</td>
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<td>18.00 bis 20.00</td>
<td>Abendveranstaltungen 1+2</td>
<td>20.00</td>
<td>Kongressparty</td>
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<td>14.00</td>
<td>14.15 bis 17.00</td>
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<td>Podiumsdiskussion</td>
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**Visualization of time-oriented data**
Snow height & sunshine hours
iPod price

Visualization of time-oriented data
What is time?

“If no one asks me, I know. But if I wanted to explain it to one who asks me, I plainly do not know.”
-- Augustinus (AD 354-430, The Confessions)

“Die Empfindung der Zeit hängt davon ab, auf welcher Seite der geschlossenen Klotür man sich befindet.”
-- Albert Einstein
What is time-oriented data?

no formal definition

what is considered as time-oriented data depends on the intended task

*a possible definition:*

Data, where *changes over time* or *temporal aspects* play a central role or are of interest.
Visualization Design

- data
  - time domain
  - time-oriented data

- task
- user

visualization of time-oriented data
## Time domain overview

Adapted from [Frank, 1998]

<table>
<thead>
<tr>
<th>Scale</th>
<th>Scope</th>
<th>Structure</th>
<th>Viewpoints</th>
<th>Granularities</th>
</tr>
</thead>
<tbody>
<tr>
<td>ordinal</td>
<td>point-based</td>
<td>linear</td>
<td>ordered</td>
<td>none</td>
</tr>
<tr>
<td>discrete</td>
<td>interval-based</td>
<td>cyclic</td>
<td>branching</td>
<td>single</td>
</tr>
<tr>
<td>continuous</td>
<td></td>
<td></td>
<td></td>
<td>multiple</td>
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</table>

Visualization of time-oriented data
Scale

**ordinal**

*only order is known*

**discrete**

*every element of time has a unique predecessor and successor*

*comparable to Integer*

**continuous**

*between any two elements in time there might be another one in between*

*dense time*

*comparable to Float*
Structure

linear

each element of time has a unique predecessor and a unique successor

cyclic

summer is before winter, but winter is also before summer
Viewpoints

ordered

multiple perspectives

branching

Past
Definite time - data element assignment

Present
Currently valid state

Future
Planning Temporal uncertainty Alternative scenarios
Granularity

Calendar

- Granularity 2
- Granularity 1
- Discrete Time Domain

Granule

Chronon

e.g. fortnights

e.g. weeks

e.g. days
Calendar

- Business years
- Business quarters
- Business weeks
- Business days
- Business hours
- Days
- Weeks
- Fortnights
- Months
- Seasons
- Year
- Decades
- Centuries
- Millenia
- Semesters
Determinacy

determinate
  complete knowledge of temporal attributes

indeterminate
  incomplete knowledge of temporal attributes
  no exact knowledge
    *i.e.* “time when the earth was formed”
  future planning
    *i.e.* “it will take 2-3 weeks”
  imprecise event times
    *i.e.* “one or two days ago”
  multiple granularities
Time primitives

**anchored**

**instant** - single point in time

**interval** - duration between 2 instants

**unanchored**

**span** - duration of time
### Time-oriented data

<table>
<thead>
<tr>
<th>Number of variables</th>
<th>univariate</th>
<th>multivariate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame of reference</td>
<td>spatial</td>
<td>abstract</td>
</tr>
<tr>
<td>Relation to time</td>
<td>direct</td>
<td>indirect</td>
</tr>
<tr>
<td>Kind of data</td>
<td>events</td>
<td>states</td>
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Visualization Design

Visualization of time-oriented data
Low-level Task Taxonomy 1/2

**Existence of a data element**
Does a data element exist at a specific time?
*Example: Was a measurement made in July, 1960?*

**Temporal location**
When does a data element exist in time?
*Example: Is there a lecture taking place on November 24, 2005?*

**Time interval**
How long is the time span from beginning to end of the data element?
*Example: How long was the processing time for data set A?*

**Temporal texture**
How often does a data element occur?
*Example: How often was Jane sick last year?*
Low-level Task Taxonomy 2/2

Rate of change
How fast is a data element changing or how much difference is there from data element to data element over time?

Example: How much did the price of gasoline change since last September?

Sequence
In what order do data elements appear?

Example: Did the explosion happen before or after the car accident?

Synchronization
Do data elements exist together?

Example: Is Jill’s birthday on Easter Monday this year?
High-level Task Taxonomy

**Navigational Tasks**
- navigation in time or temporal data
- search (implies a specific user-defined target); browse

**Observational Tasks**
- different characteristics of a single temporal history
- searching for patterns; detecting disruptions and discontinuities; studying the distribution of the data to identify concentrations of data (or classes of values)

**Comparison Tasks**
- relating multiple temporal histories
- comparing of two elements; rearranging; overlaying; studying correlation;
- searching for effects of causality; comparing evolution relative to a reference value

**Manipulation Tasks**
- manipulation of data values
- value aggregation and segmentation

[Daassi], 2003
Visualization Design

data

visualization

task

user

visualization of time-oriented data
Visual mapping of time

Time → Time (Animation)
probably the most natural form of mapping
no “conversion” of concepts needed in between
well suited for
  keeping track of changes
  following trends and movements
not well suited for
  analytic and explorative tasks
  no direct comparison of parameters between different points in
time is possible

Time → Space
mapping of time to visual features
direct comparison of parameters between different points in time is possible
Visual variables

**position**

most common mapping

the most accurately perceived visual feature

**length**

second most accurate attribute

typically, the length of an object denotes the duration, as for example in timelines
Visual variables

angle, slope
analog-clock-based visualizations

connection
connecting arrows or lines
"before element" --> "after element"

text, label
simple text labelling
often combined with "connection"
Visual variables

**line (thickness)**
Increasing or decreasing with time

**color (brightness, saturation, hue)**
brightness most appropriate
“fading away” against the background
transparency
Visual variables

area
enclosure
size
texture
shape

less suited
Visualization roots

Statistics

Visualization of time-series.

*The time-series plot is the most frequently used form of graphic design.* [Tufte, 1983]

Mostly one parameter over time.
Early time-series plot

Part of a text for monastery schools
10th or 11th century (!)
Inclinations of the planetary orbits over time
800 years before other time-series plots appeared
Train schedule

Paris to Lyon (1880s)