visualization of time-oriented data

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Version 1.0
3.12.2004

Contents

Introduction
- What makes time a special data dimension?
- What is time-oriented data?

Visualization Techniques
- YOU decide, what we will look at

Roundup & Conclusions

Roundup
- What makes time a special data dimension?
- What is time-oriented data?
- Concepts of time-oriented data
- Visualization techniques

Conclusions
- time-oriented data covers a very broad field
- what is considered as time-oriented data is task dependent
- a lot of different techniques available
- visualizations are task driven
- periodic behaviour is very common but relatively underexplored
- not many dynamic techniques available
  - Only very limited use of animation
- more interactivity is desirable
- Generally: **Visualization sparks interest for further investigation**
visualization of time-oriented data

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6.12.2004

Data types [Shneiderman, 1996]
1-dimensional
2-dimensional
3-dimensional = 4D space
Temporal “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
iPod price
Snow height & sunshine hours
Organization chart

Event calendar

Snow height & sunshine hours
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.

Main tasks

Viewing and creating historical overviews of events or data
discovering intervals; show variability

Detecting regularities and trends
seeing developments; finding patterns; discover underlying processes

Comparing evolution
find correlations; reveal relationships

Viewing and creating future events or planning data
predict future developments
**Basic dimensions**

- Structural Dimension
- Temporal Dimension

**Temporal design space**

<table>
<thead>
<tr>
<th>Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Dimension</td>
</tr>
<tr>
<td>Time-oriented Data</td>
</tr>
<tr>
<td>Temporal Dimension</td>
</tr>
</tbody>
</table>

**Temporal models**

- Present: Currently valid state
- Past: Definite time - data element assignment
- Future: Planning

**Temporal uncertainty**

- Past: Definite time - data element assignment
- Present: Currently valid state
- Future: Planning

**Temporal order**

- Linear: no overlapping
- Sub-linear: overlapping allowed
- Branching: Temporal uncertainty
- Periodic: Temporal uncertainty

**History**

- Valid time, event time
  - time, when an entity is (was) effective
  --> models reality

- Transaction time
  - time, when change was posted into database

- Decision time
  - time, when the decision for a particular action was made
primitives

absolute (anchored) relative (unanchored)

instant - single point in time span - duration of time

interval - duration between 2 instants

domain

discrete continuous
mapping to a set of integers mapping to a set of real numbers

granularity

span between two instants in a discrete domain
problem: different granularities

"Activity A started on Monday, 4th and ended on Saturday, 9th."

possible beginning possible ending

minimum duration maximum duration

representational scheme

for human readability and usability

Calendars

Gregorian

Academic (semester, trimester, ...)

Financial (Quarters, Fiskal, ...)

...
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)
Questions 1/4

1. When are the doors going to be installed and what is done afterwards?
2. Was arthritis diagnosed while a period of tabacco consume? [DEMO]
3. When did "Olson" write the Technical Report for the "DELTA" project?
4. What do I have to do tomorrow?
5. When do I have to leave the office in order to catch my bus? [DEMO]
6. Are 7 days really 7 days?
7. For how long do I need to apply the therapy at minimum?
8. Until when can corticosteroids be given?
9. Can "Controlled Ventilation" and "Crisis Management" overlap temporarily?
10. Who logged into my server at 3pm yesterday?

Questions 2/4

11. At what time did Fidel Castro talk most about "oil"? [MOVIE]
12. What kind of food do chimpanzees prefer in winter?
13. Do the stocks of "Microsoft" and "Sun Microsystems" have a similar price history?
14. Is my software project likely to fail?
15. What parts of my software project are stable?
16. How does Beethoven's "Bagatelle" sound and look like? [MOVIE]
17. Which stocks increased in a similar way during the year? [DEMO]
18. Who are the main contributors in an online environment?
19. Which meeting is going to happen on August, 17?
20. How did the prices of various MP3 players change over the last months?
Questions 3/4
21. How is time represented in paintings?
22. How did the ozone concentration in Los Angeles change over the last decade?
23. Can the same pattern of value increase be found in other sessions of dialysis? (MOVIE)
24. How did various authors contribute to the Wikipedia entry on "Islam" over time?
25. How did the blood pressure of Jane Doe evolve over the last hours? (MOVIE)
26. What did Isaac Newton do in 1667 and where did he do it?
27. How do the top 100 news topics during the last day look like?
28. What were the main events in my life so far? (MOVIE)
29. How does an hour worth of "Simpsons" look like in one picture? (MOVIE)
30. Which parts of my website were visited during the last hours? (MOVIE)

Questions 4/4
31. When did Philipp Glass write his fastest songs? (Online DEMO)
32. Who are my main e-mail communication partners?
33. How does the history of photography look like?

Applications 1/3
1. project plans
2. juvenile justice records, patient records (DEMO)
3. document/file collections
4. personal and/or corporate time management (2)
5. time management (DEMO)
6. events on different granularities
7. medical treatment planning (2, 3)
8. network intrusion detection

Applications 2/3
9. document collections (MOVIE)
10. chimpanzees food consumption
11. internet movie database
12. stock prices
13. software evolution (2)
14. music visualization (MOVIE)
15. stock prices (DEMO)
16. microarray data (DEMO)
17. discussion group activity
18. visual arts
Applications 3/3

19. ozone concentration in Los Angeles
20. medical data (MOVIE)
21. Wikipedia document evolution
22. historical events (MOVIE)
23. news
24. personal history (MOVIE)
25. webpage hit evolution (MOVIE)
26. music collection (Online-DEMO)
31. e-mail history

Section B: time & arts

Renaissance

[Masaccio and Masolino, Scenes from the Life of St. Peter, c. 1426-7, Brancacci Chapel, Florence]
Multiple appearences of the same person within a single scene

Cubism

The first documented occurrence of the fourth dimension being used in art appeared in 1910 in Paris.

Origin: mathematics + physics (n-dimensional spaces)

At this point, the fourth dimension was thought as time.

Person walking down stairs -->

Fourth dimension in the painting by picturing different stages of the person's descent

[Marcel Duchamp, Nude Descending a Staircase, 1912]
Cubism
New ideas about the fourth dimension into the static domain of pictures.
Overlays many different observations.
Emphasizes process of looking and recording over time.

Comics
Visual story telling over time.
Many interesting techniques / paradigms.
If you want to know more, start here:
[Scott McCloud, Understanding Comics, 1994]

Section C: visualization techniques

TimeSearcher
visualization tool for time-series data
timebox query model
- rectangular regions that specify constraints over time series data sets
- x-axis extent: time period of interest
- y-axis extent: constraint on the range of values
- combinations of multiple timeboxes
data + query envelope
http://www.cs.umd.edu/hcil/timesearcher/
**Interactive Parallel Bar Charts (IPBC)**  
Basic vis technique: bar charts  
Bar charts only suitable for 1 time series; more -> 3D  
Analysis of medical data  
Occlusions can be removed by flattening occluding elements  
-> matrix visualization  
Tide mode (highlighting areas)  
Smooth transitions  

**Midgaard 1/2**  
Visualization of medical intensive care data  
Qualitative scales  
Quantitative scales  
Qualitative / Quantitative hybrids  
Semantic zoom  
Smoothly integrated  

**Midgaard 2/2**  
Different granularities  
Vis of measurement deviation, trustability of data points, and missing data  

**TimeWheel / Zeitrad 1/2**  
Time axis in the center  
Variable axis arranged circularly  
Lines connecting time and feature values  
Similar to parallel coordinates  
Variables parallel to time axis (upper and lower) can be explored most effectively  
Focus + Context by shortening of rotated axis and color fading
User interaction:
Rotation of variable axes
(moving axes of interest into a position parallel to the time axis)

Axis based technique
Multiple parameters on multiple time axis, circularly arranged
Outward from the center of star-shaped
Aggregated view of “past” values in the center

radial bar graph --> 3D over time
visualizing an object at different epochs
central axis represents time
transparent veil to enhance evolution
not suited for nominal data

Visualize both, serial + periodic properties to reveal certain patterns
Time continues serially, but weeks, month, and years are periods that reoccur
Map time onto a spiral + spokes for orientation
Data values are mapped to blots on spiral
Area of blot proportional to value
**Serial Periodic Data 2/6**

**Pure serial periodic data**

Periods with constant durations

**Event-anchored serial periodic data**

Periods with different durations

Start of a new period is indicated by an event

*Examples:*
- Multi day racing data
- Project based time tracking

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**Extension to 3D:**

- Z-axis for different sets of data
- No quantitative meaning of z-axis
- Color coding of data sets
- Lidless, hollow “cans”
- Instead of blots
- Prevent occlusion
- Volume of can is proportional to data value

*Pro:* good overview

*Cons:*
- Occlusion
- Clutter
- Z-position meaningless
- Double mapping (z-pos + color)

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**Serial Periodic Data 4/6**

User control:
- Rotation, zoom, pan, tilt

Annotation features:
- Align different spirals vertically
- Definition of data derived border lines

Display of several data sets simultaneously
- Using bar charts
- Color coded
- Multiple, linked spirals

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**Serial Periodic Data 5/6**

Interval data
- Only duration of element

Periodicity unknown
- Animation

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**Serial Periodic Data 3/6**

Figure 1: A visual display of activity consumption percentage for all users during the period 9000 - 10000.
Serial Periodic Data 6/6

User experience findings:
+ Users quickly accept the notion of serial periodic data on a spiral
+ Users react to the spiral displays
  - When they saw patterns, they tried to explain them by telling stories
+ Users want more
  - Visualization sparked interest for further investigation
- Tool not self explanatory
  - Trained operator needed

Spiral Graph 1/3

Main intention: detection of periodic behavior
Mapping data onto a spiral
- Mapping of data values to
  - color and
  - thickness of line
Nominal + ordinal + quantitative data
1 cycle = period length
[Weber et al., 2001]

Spiral Graph 2/3

Two possibilities to detect periodic behavior:
1. **Computational:**
   - Compute frequencies with higher amplitudes via Fourier Transformation
2. **Visually:**
   - Utilize the visual system of a human observer to discover structures
     - Spiral is animated by continuously changing the cycle length
     - Periodic behavior becomes immediately apparent (changing from unstructured to structured)
   - User can stop animation when period is spotted

Spiral Graph 3/3

Extensions:

**Multi Spirals**
- Compare a data set with cyclic patterns in other data.
- Rendering intertwined Spiral Graphs.

**3D extension**
- Problem: space
  - mapping onto a helix.
  - Brushing integrated.
- Selected region is displayed in 2D spiral.
- 3D helix best used for navigation only.
**GANTT charts 1/2**

Project management, project planning
Tasks and their temporal attributes (location, duration)
Milestones
Past + present + future
Hierarchical decomposition

**GANTT charts 2/2**

**Pros:**
Well known representation
Collapsible hierarchical decomposition
Easy to comprehend
Hundreds of tools available (i.e. MS Project)

**Cons:**
No uncertainty
Space consumption (diagonal layout)

**LifeLines 1/2**

Based on Time Lines
Facets
Visualizing personal histories and patient information
Horizontal bars showing temporal location and duration of data elements
Past + Present

**LifeLines 2/2**

**Pros:**
Simple and easy to comprehend
Better layout than GANTT
Use of vertical dimension
Interactive time scale (zoom, pan)

**Cons:**
No hierarchical decomposition (only Facets)
(Just past and present)

[Plaisant et al., 1996, Plaisant et al., 1998]

[Plaisant et al., 1998]
**Perspective Wall**

[Mackinlay et al., 1991]

Large collections of documents
Focus + Context of elements over time
Intuitive 3D metaphor for distorting 2D layout
Color coding
Smooth transitions, 3D interactive animation

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**Dynamic Timelines**

[Kullberg, 1995; Kullberg, 1996]

3D presentation of historical information
history of photography
seamless micro and macro readings
semantic zoom
translucency
animated visual transition
F+C by selective transparency (queries)

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**Timeline Cinematic Temporal Ride**

[Elise Co, 1997]

3D representation
timelines are created from date, image and text data
subjective reshaping and repositioning
animation / ride along an individual timeline

http://acg.media.mit.edu/projects/timelines/

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**The Historical Event Markup and Linking Project (HEML)**

http://www.heml.org/

marking up web documents
different representations
table timeline
map animated map
XML-Schema for historical events
participants, dates, location, keywords, evidence (ref)
web service
use of open technologies
XSLT, SVG, Servlets, ...

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Temporal Objects 1/2

Depict data with different granularities
- Starting instant (earliest start, latest start)
- Ending instant (earliest end, latest end)
- Maximum duration
- Minimum duration

Based on LifeLines
- Two encapsulated bars with caps at each end

Temporal Objects 2/2

Pros:
- Simple representation for complex time attributes
- Different granularities
- Easy to comprehend

Cons:
- Only presentation, no interaction
- No direct manipulation

Time Annotation Glyph 1/2

Characteristics:
- Time points are relative (Reference point)
- Notion for temporal granularity
- Notion for missing values / incomplete specifications
- Metaphor of bar lying on diamonds (preventing invalid constellations)
- User interaction / can be manipulated

Time Annotation Glyph 2/2

Definition:
[ESS, LSS, EFS, LFS, [MinDu, MaxDu], Reference]

Example: [[3 d, 11 d], [6 d, 11 d], [Diagnosis]]
Paint Strips

Metaphor of paint rollers
Paint roller at the end of a line = line can expand
Wall = expansion limit
Smaller set of temporal attributes as “Temporal Objects” and “Time Glyph”
Combination of strips (rope)
Starting and finishing interval can’t be defined independently from duration

SOPOs 1/2

Rit’s Set of Possible Occurrences

2D technique
Area depicts set of valid (start, end) tuples
Designed for easy graphical propagation of temporal constraints
Cons:
- Representation more complicated than LifeLine based ones
- Space consumption

SOPOs 2/2

Start interval: x-axis
End interval: y-axis
Minimum duration, maximum duration: constraining borders parallel to 45° time flow axis

Intrusion Detection

Visualization of user access to machines over time.
Mapping:
- Time: circumference
- User: cylinder slice
- Machines: cubes on top
- Access: connection lines
Annotations via tool tips (mouse hovering)
Visualize thematic variations over time.
Across a large collection of documents.
River Metaphor: the "river" flows through time.
Changing width to depict changes.
Themes or topics are colored "currents".

Discrete values
Exact values
Hard to follow a single current
Easy to follow a single current (curving continuous lines)

Pencil-like geometric objects
Mapping time-dependent variables onto faces of the pencil
Heterogenous data
**Software Evolution Analysis**

- Analyzing evolution of SW-systems / product families
- 3D visualization
- Colors encode versions
- Changes of parts over time
- Hierarchical decomposition
- Pattern analysis
- Not as information rich as Time-wheel

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**PeopleGarden 1/2**

- On-line environment user visualization
- Flower metaphor for individuals
- Garden metaphor for environment
- Visualization of social network / behavior

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**PeopleGarden 2/2**

- Time of posting --> ordering, saturation
- Amount of response --> circles on top of petals
- Whether a post starts a new conversation --> color
- How long a user is on the board --> flower height

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**History Flow 1/2**

- Wiki web visualization (Wikipedia)
- Evolution of entries
- Finding collaboration patterns
  - Revealed complex patterns of cooperation and conflict
  - I.e. “Self healing” - malicious edits were typically repaired within 2 minutes
- Show relationships between multiple document versions
**PostHistory 1/2**

**visualizing email activities**
- dyadic email relationships (people)
- time

**uncover email patterns**
- social networks
- email exchange rhythms
- the role of time in these patterns

**mail traffic vs. content**
- aggregates
  - Daily email averages (send / receive)
  - Daily "quality" of emails (directly / copy / mailing list)
  - Frequency of email exchanges with contacts
  - Comparative frequency of email exchanges with contacts

**PostHistory 2/2**

**calendar panel**
- intensity of email exchanges over time
- each square represents a single day
- row --> week; one year at a time
- amount of received emails --> size of square
- personal or directed (mailing-list) --> color
  (average is calculated)

**contacts panel**
- names of the people who have sent messages to the user
- different layouts
- interaction by highlighting and animation through time

**Anemone**

**organic information design**

**evolution of webpage usage (visited pages)**

**branches are created when visited for the first time**

**branches that are visited often, grow**

**pages that aren’t visited slowly fade away**

**user interaction**

http://acg.media.mit.edu/people/fry/anemone/
**Music Animation Machine (M.A.M.) 1/2**

Visualization of music
- Dynamic representation
- Relate audio to visual structure
- Simple representation for music
  - extremely complex system
- Complex patterns

Online: http://www.well.com/user/smalin/mam.html

**Music Animation Machine (M.A.M.) 2/2**

Each note is represented by a colored bar
- Each bar lights up as its note sounds
- The length of each bar corresponds exactly to the duration of its note as performed
- The vertical position of the bar corresponds to the pitch
- The horizontal position indicates the note’s timing

**Calendar Tools**

Past + present + future
- Calendar scale
- Events over time, repeating events
- Icons, Reminder
- Very well known (MS Outlook, iCal, …)

Interactive Techniques:
- Overview + Detail
- Zoom
- Filter
- Details on Demand
- Multiple Views
- Focus + Context

**SpiraClock 1/2**

Visualization technique for nearby events.
- Intention: fill gap between static calendar and pop-up reminders.
- Continuous and non-intrusive feedback.
- Analog clock with white spiral inside representing near future.
**SpiraClock 2/2**

Interaction:
- Change time by moving hands.
- Adjust number of spiral revolutions (visibility of future events)

Range: 1 hour - several days

Not suited for all kinds of events
- i.e. conference, 20. – 25. October

Java applets and applications:
- http://www.emn.fr/spiraclock
- Bus schedule, MS Outlook and vCal import

**Spiral Calendar**

[Mackinlay et al., 1994]

- Individual schedule
- 3D spiral layout
- Behaviour: clicking, animation
- Animated transitions

**TileMap / Matrix Vis.**

Visualization of quantitative histories
- Histories whose values are numbers
- Each square represents one day
- Good for displaying data with a seasonal pattern

**Time-wheel 1/3**

[Chuah and Eick, 1997]

Visualization of software projects over time
- Multiple time-series placed in a circle
- Data attributes are color coded
- Global trends
- Helps to examine different trends within one object
- Easy recognition of two trends:
  - Increasing trend
  - Tapering trend
**Time-wheel 2/3**

Increasing trend

"Prickly fruit"

Tapering trend

"Hairy fruit"

**Time-wheel 3/3**

*Extension to 3D:*
- Encodes the same attributes as the Time-wheel
- Uses height dimension to encode time
- Variables are encoded as slices of a base circle

**Pro:** Easier to identify overall trends

**Cons:**
- Occlusion
- Perspective

**10x10**

10 x 10

100 words and pictures that define the time

RSS news feeds are scanned + linguistic analysis → top 100 words

fisheye menu for selecting words

**Glass Engine**

http://www.philipglass.com/glassengine/

music of Philipp Glass

navigation along various attributes
“Last is a clock that is a record of its own history”

video input data
different zoom levels / display of
  last minute
  last hour
  last 12 hours

http://www.edleader.co.uk/last/