



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

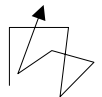
where?

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**

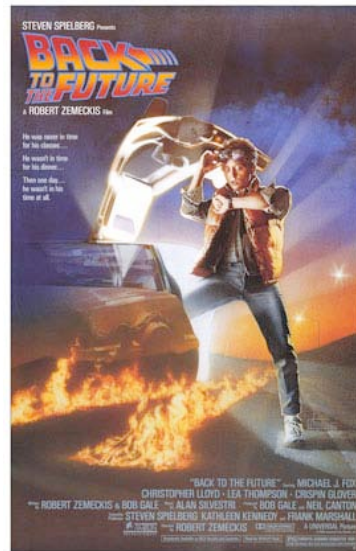
visually, touch

Humans don't have senses for perceiving **time**

Interactive visualization

Gives us the ability to...

...travel in time virtually.



informations-
visualisierung

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visualization of time-oriented data

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Time-oriented data?

informations-
visualisierung

Zeit	Montag 4.10.2004	Zeit	Dienstag 5.10.2004	Zeit	Mittwoch 6.10.2004	Zeit	Donnerstag 7.10.2004	Zeit	Freitag 8.10.2004
	9.00 bis 10.45	Plenar- veranstaltungen 1+2+3	Plenar- veranstaltungen 7+8+9	Plenar- veranstaltungen 13+14	Plenar- veranstaltungen 13+14	Plenar- veranstaltungen 13+14	Plenar- veranstaltungen 13+14	Plenar- veranstaltungen 13+14	Plenar- veranstaltungen 13+14
11.00 bis 13.00	Sektions- sprechertraffen Presse- konferenz	11.00 bis 12.45	Plenar- veranstaltungen 4+5+6	11.00 bis 12.45	Plenar- veranstaltungen 10+11+12	11.00 bis 12.45	Plenar- veranstaltungen 15+16+17	11.00 bis 12.45	Plenar- veranstaltungen 15+16+17
		13.00 bis 14.00	Mittags- vorlesungen 1+2	13.00 bis 14.00	Mittags- vorlesungen 3+4	13.00 bis 14.00	Mittags- vorlesungen 5+6	13.00 bis 14.00	Mittags- vorlesungen 5+6
14.00 bis 17.00	Eröffnungs- veranstaltung	14.15 bis 17.00	Sektionen, Arbeitsgruppen, Ad-hoc- Gruppen	14.15 bis 17.00	Sektionen, Arbeitsgruppen, Ad-hoc- Gruppen	14.15 bis 17.00	Sektionen, Arbeitsgruppen, Ad-hoc- Gruppen	14.15 bis 17.00	Sektionen, Arbeitsgruppen, Ad-hoc- Gruppen
		17.00 bis 18.00	Authors meet Critics, Foren, Sonder- veranstaltungen	17.00 bis 18.00	Authors meet Critics, Foren, Sonder- veranstaltungen	17.00 bis 18.00	Authors meet Critics, Foren, Sonder- veranstaltungen	17.00 bis 18.00	Authors meet Critics, Foren, Sonder- veranstaltungen
		18.00 bis 20.00	Abend- veranstaltungen 1+2	18.00 bis 20.00	Sonder- veranstaltung DGS Mitglieder- versammlung	18.00 bis 20.00	Abend- veranstaltungen 3+4	18.00 bis 20.00	Abend- veranstaltungen 3+4
Ab 20.00	Kongressparty	20.00	Podiums- diskussion	20.00	Sonder- veranstaltung	20.00	Podiums- diskussion	20.00	Podiums- diskussion
Zeit	Montag 4.10.2004	Zeit	Dienstag 5.10.2004	Zeit	Mittwoch 6.10.2004	Zeit	Donnerstag 7.10.2004	Zeit	Freitag 8.10.2004

Event calendar



Snow height &
sunshine hours

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visualization of time-oriented data



iPod price



Organization
chart

[next >](#)

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Event calendar

informations-
visualisierung

Zeit	Montag 4.10.2004	Zeit	Dienstag 5.10.2004	Zeit	Mittwoch 6.10.2004	Zeit	Donnerstag 7.10.2004	Zeit	Freitag 8.10.2004
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11.00 bis 13.00	Sektions- sprechertraffen Presse- konferenz	11.00 bis 12.45	Plenar- veranstaltungen 4+5+6	11.00 bis 12.45	Plenar- veranstaltungen 10+11+12	11.00 bis 12.45	Plenar- veranstaltungen 15+16+17	11.00 bis 12.45	Abschluss- veranstaltung
		13.00 bis 14.00	Mittags- vorlesungen 1+2	13.00 bis 14.00	Mittags- vorlesungen 3+4	13.00 bis 14.00	Mittags- vorlesungen 5+6	13.00 bis 14.00	
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		17.00 bis 18.00	Authors meet Critics, Foren, Sonder- veranstaltungen	17.00 bis 18.00	Authors meet Critics, Foren, Sonder- veranstaltungen	17.00 bis 18.00	Authors meet Critics, Foren, Sonder- veranstaltungen	17.00 bis 18.00	
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Zeit	Montag 4.10.2004	Zeit	Dienstag 5.10.2004	Zeit	Mittwoch 6.10.2004	Zeit	Donnerstag 7.10.2004	Zeit	Freitag 8.10.2004

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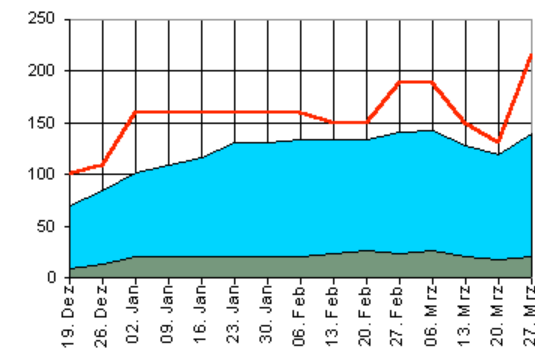
visualization of time-oriented data

[up](#)

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Snow height & sunshine hours

informations-
visualisierung



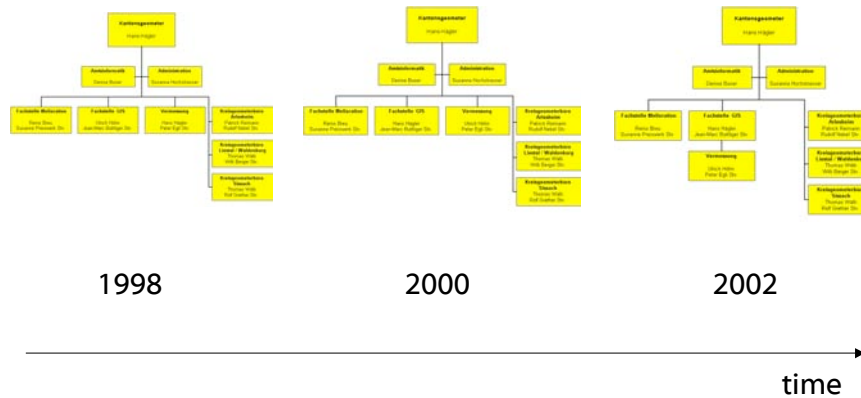
WOLFGANG AIGNER

visualization of time-oriented data

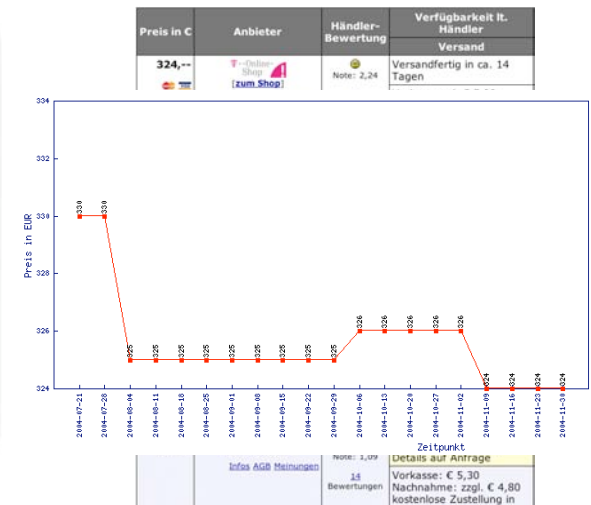
[up](#)

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Organization chart



iPod price



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 of time-oriented data

What?
time & data

1

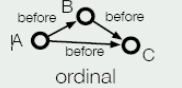
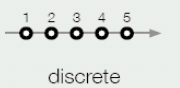
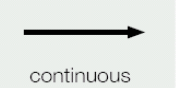


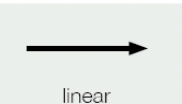



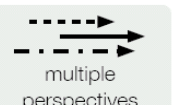
Why?
user tasks

2

How?
visualization & interaction

3

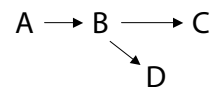
Modeling time

scale	 ordinal	 discrete	 continuous
scope	 point-based	 interval-based	
arrangement	 linear	 cyclic	
viewpoint	 ordered	 branching	 multiple perspectives

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*

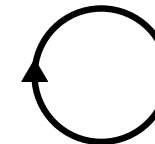
Arrangement

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

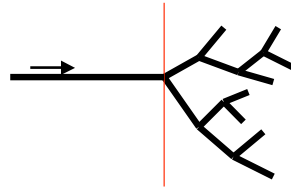
ordered



multiple perspectives



branching



Past
Definite time - data
element
assignment

Present
Currently valid
state

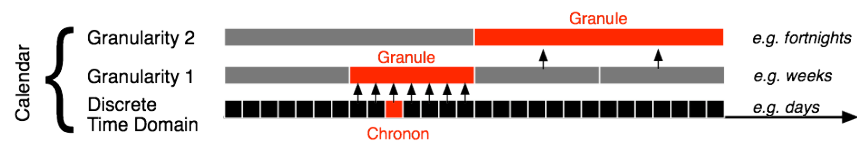
Future
Planning
Temporal uncertainty
Alternative scenarios

Modeling time

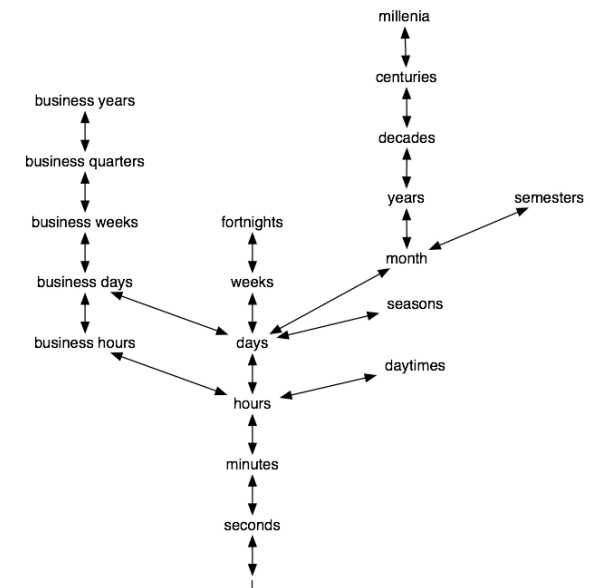
Abstractions

granularity & calendars	none	single	multiple
time primitives	instant	interval	span
determinacy	determinate	indeterminate	

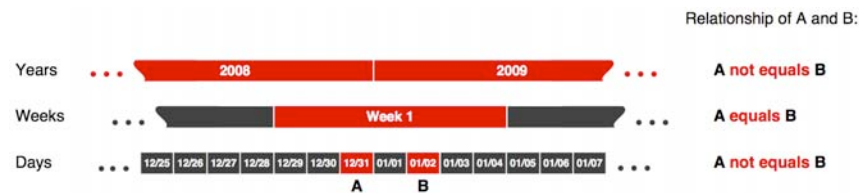
Granularity



Calendar



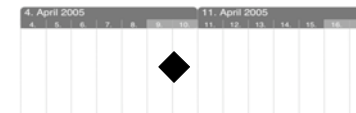
Example: Granularity paradoxon



Time primitives

anchored

instant - single point in time

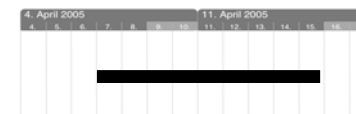


unanchored

span - duration of time



interval - duration between 2 instants



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

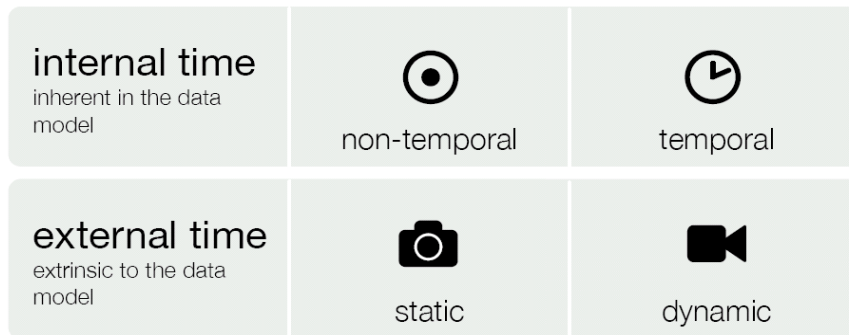
i.e. "one or two days ago"

multiple granularities

Characterizing data

scale	3.14 3.27 4.88 quantitative	coconut banana apple qualitative
frame of reference	▼ abstract	🌐 spatial
kind of data	⌈ ⌋ events	— — states
number of variables	~ univariate	~ multivariate

Relating data & time



Visualization of time-oriented data

What?
time & data

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visualization & interaction

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Low-level Task List 1/2

[McEachren, 1995]

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 List 2/2

[McEachren, 1995]

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?

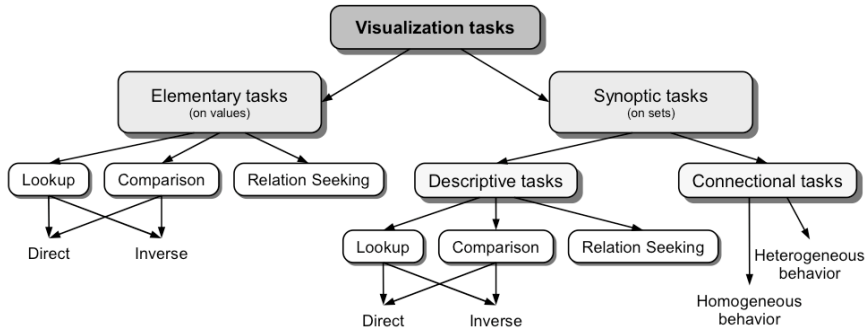
Example: Did the explosion happen before or after the car accident?

Synchronization

Do data elements exist together?

Example: Is Jill's birthday on Easter Monday this year?

Task Taxonomy 1/2



Task Taxonomy 2/2

Task Type	Example
<i>Elementary</i>	
Direct lookup	What was the price of Google stocks on January 14?
Inverse lookup	On which day(s) was the lowest stock price for Amazon in 2010?
Direct comparison	Compare the stock prices of Yahoo and Microsoft on January 14.
Inverse comparison	Did the price of an Apple stock reach \$200 before or after January 14?
Relation seeking	On which days was the price of Adobe stocks higher than the price of AOL stocks?
<i>Synoptic</i>	
Direct lookup (pattern definition)	What was the trend of Oracle stocks during January?
Inverse lookup (pattern search)	Find months in which the price of Novell stocks decreased.
Direct (pattern) comparison	Compare the behavior of the stock price of Hewlett-Packard in January and June.
Inverse (pattern) comparison	How is a decreasing trend of Dell stocks related to the period of summer vacation?
Relation seeking	Find two contiguous months with opposite trends in the stock price of Lenovo.
Homogeneous behavior	Is the behavior of Nokia stocks influencing the behavior of Motorola stocks?
Heterogeneous behavior	Do the phases of the moon influence the behavior of Intel stocks?

Visualization of time-oriented data

What?
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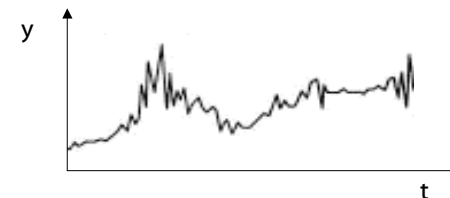
Visualization roots

Statistics

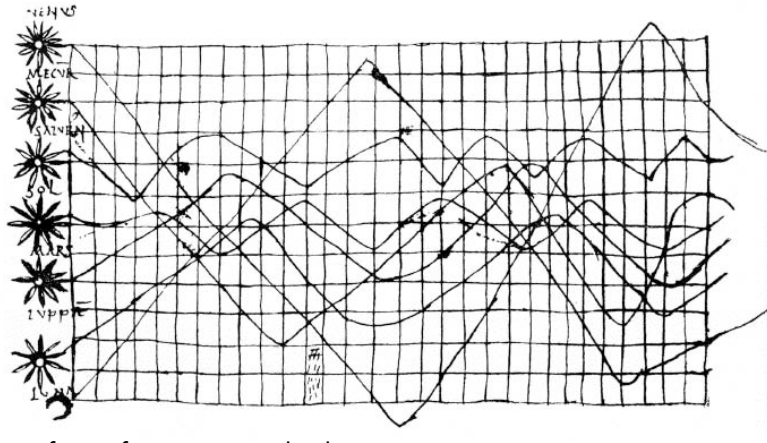
Visualization of time-series.

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

Mostly one parameter over time.

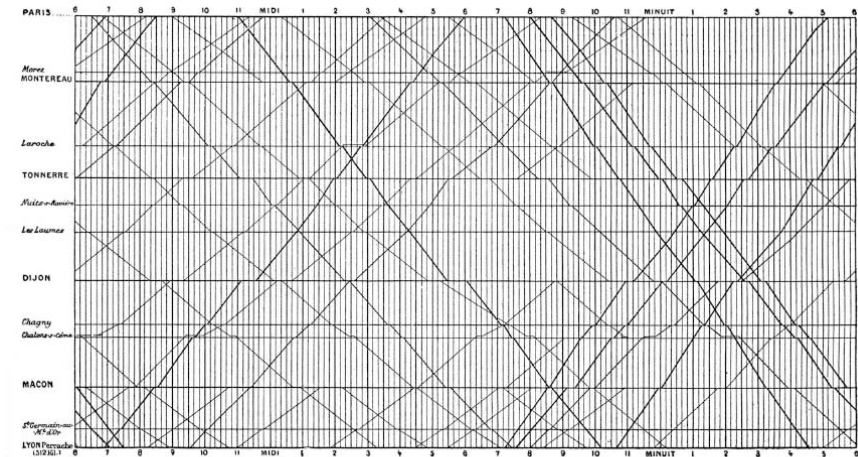


Early time-series plot



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

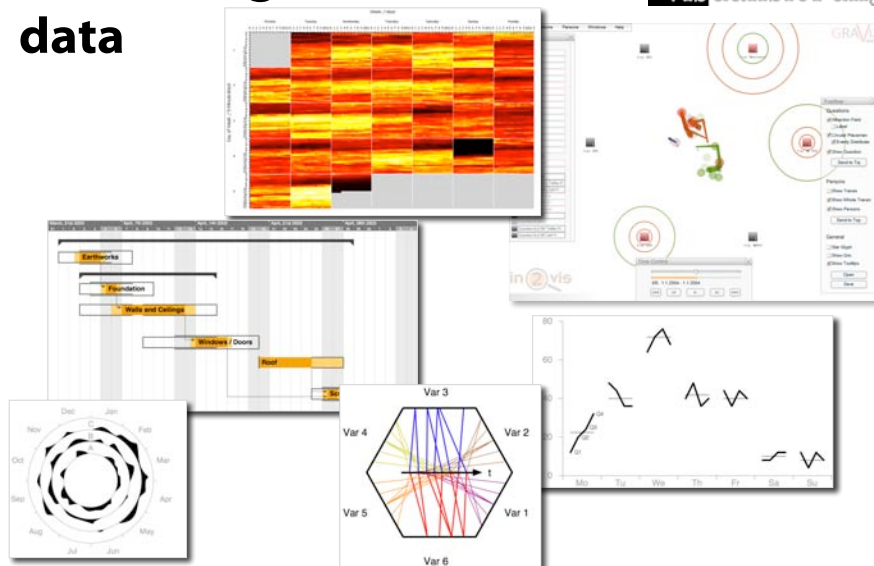
Train schedule



Paris to Lyon (1880s)

E. J. Marey, *La Méthode Graphique* (Paris, 1885), p. 20. The method is attributed to the French engineer, Ibry.

Visualizing time-oriented data



Visual mapping of time

Dynamic: 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

Static: Time → Space

mapping of time to visual features

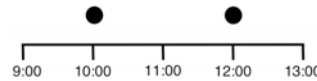
direct comparison of parameters between different points in time is possible



Visual variables

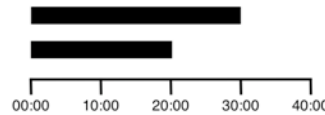
position

most common mapping
the most accurately perceived visual feature



length

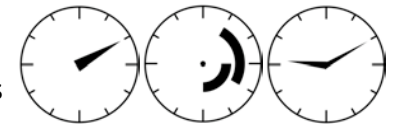
second most accurate attribute
typically, the length of an object denotes the duration, as for example in timelines



Visual variables

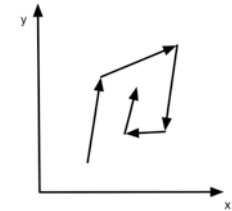
angle, slope

analog-clock-based visualizations



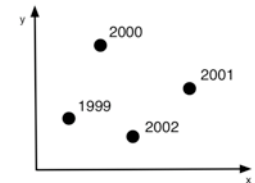
connection

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



text, label

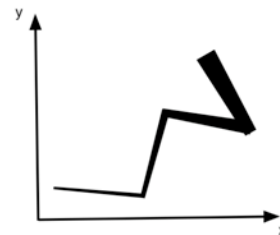
simple text labelling
often combined with "connection"



Visual variables

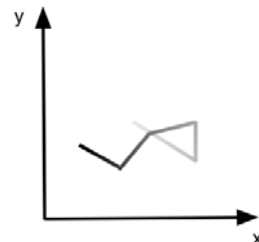
line (thickness)

Increasing or decreasing with time



color (brightness, saturation, hue)

brightness most appropriate
"fading away" against the background
transparency



Visual variables

area

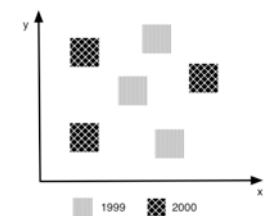
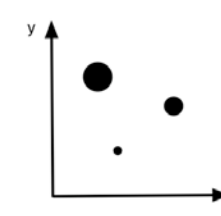
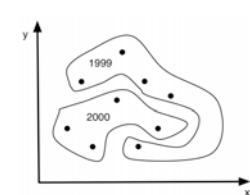
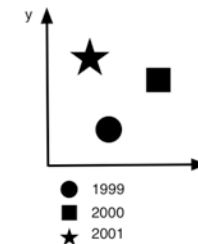
enclosure

size

texture

shape

less suited



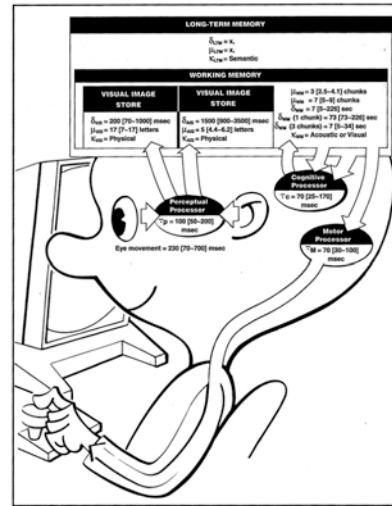
Interaction facilitates active discourse with the data and visualization

see



modify

think



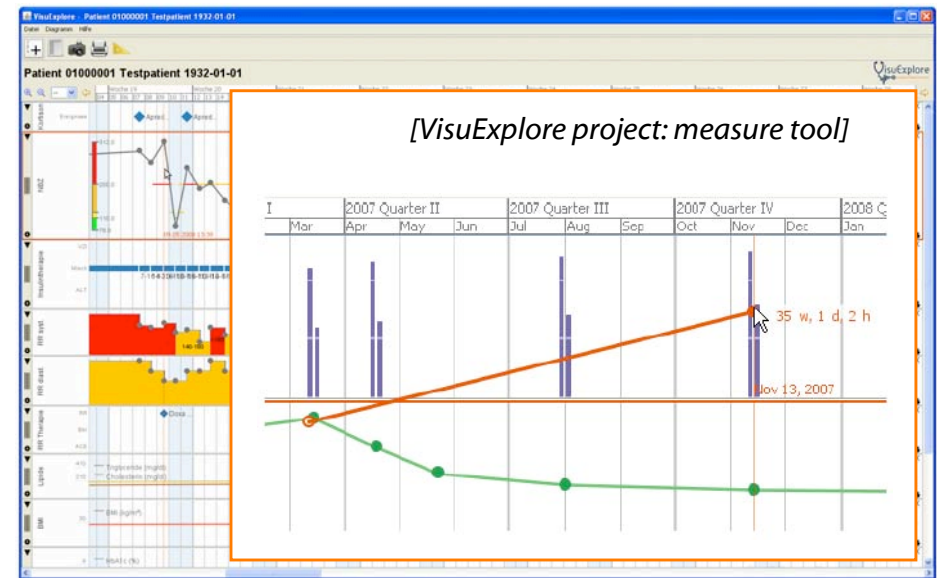
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visualization of time-oriented data

[Card et al., 1983]

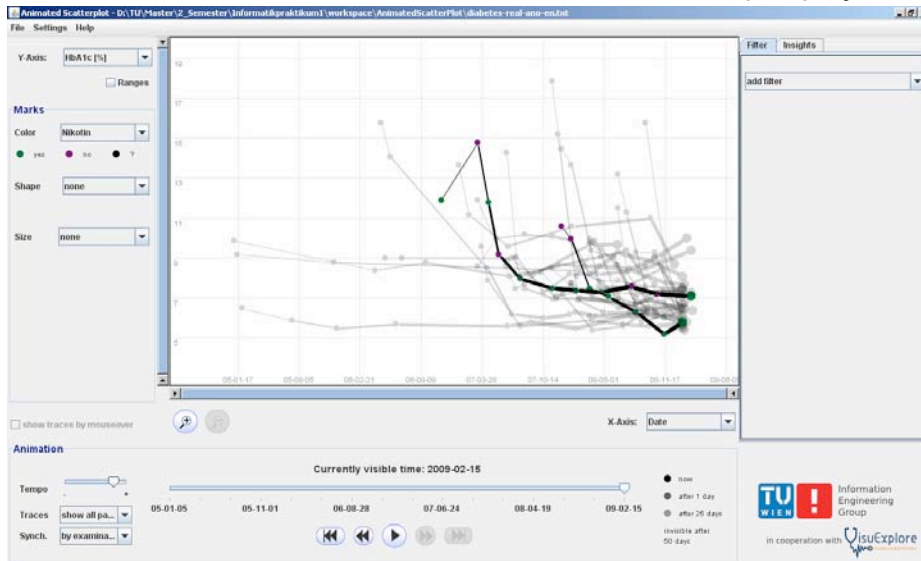
Interacting with time

informations-visualisierung
[VisuExplore project]



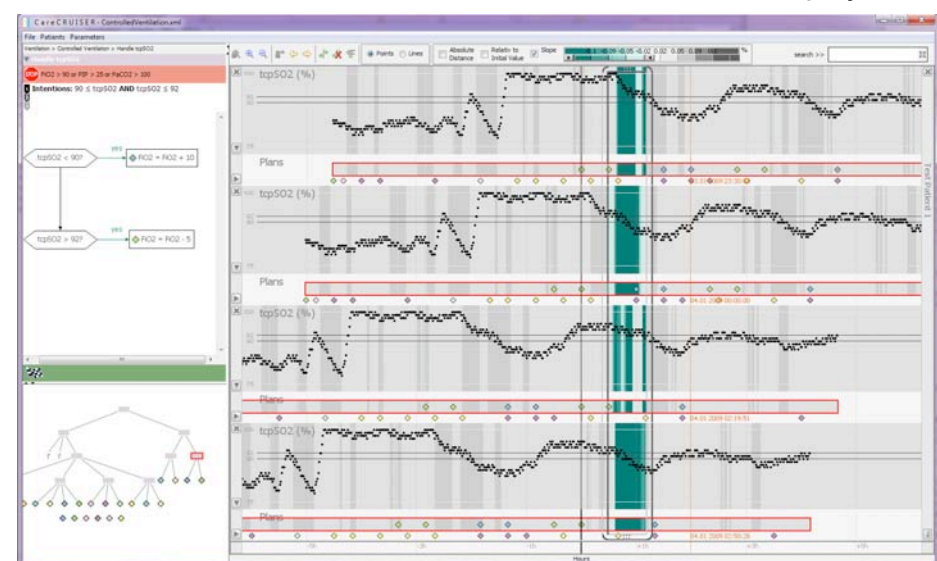
Interacting with time

informations-visualisierung
[Animated Scatterplot project]



Interacting with time

informations-visualisierung
[CareCruiser project]



Visualization of time-oriented data

What?
time & data

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visualization & interaction

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Forthcoming book 2011



Visualization of Time-Oriented Data

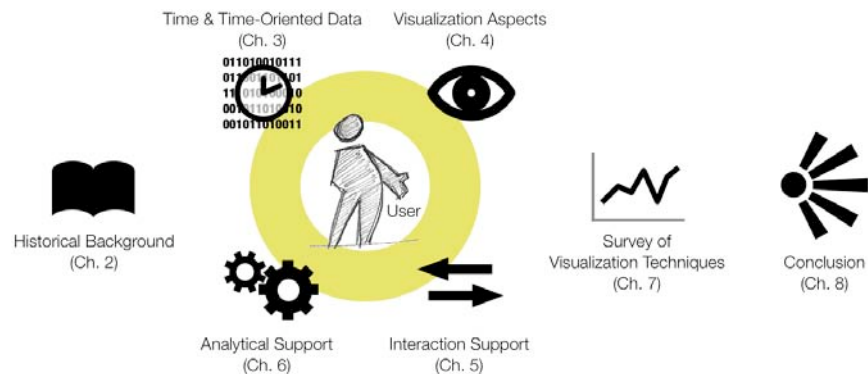
Series: » Human-Computer Interaction Series

Aigner, W., Miksch, S., Schumann, H., Tominski, C.

1st Edition., 2011, XVI, 184 p. 150 illus. in color., Hardcover
ISBN: 978-0-85729-078-6

Due: May 20, 2011

Aigner, Miksch, Schumann, Tominski: Visualization of Time-Oriented Time (2011)

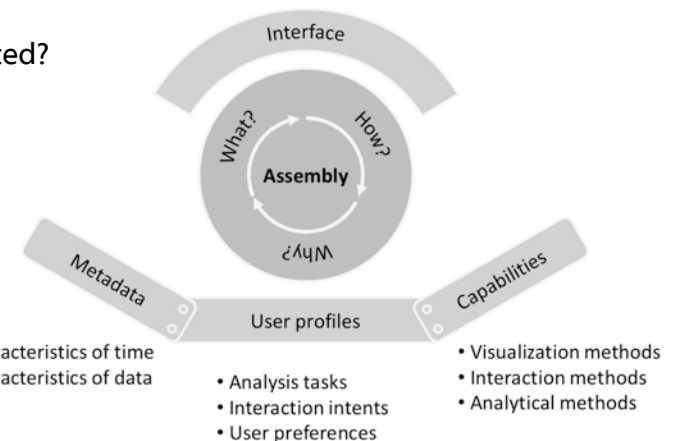


Visualization design

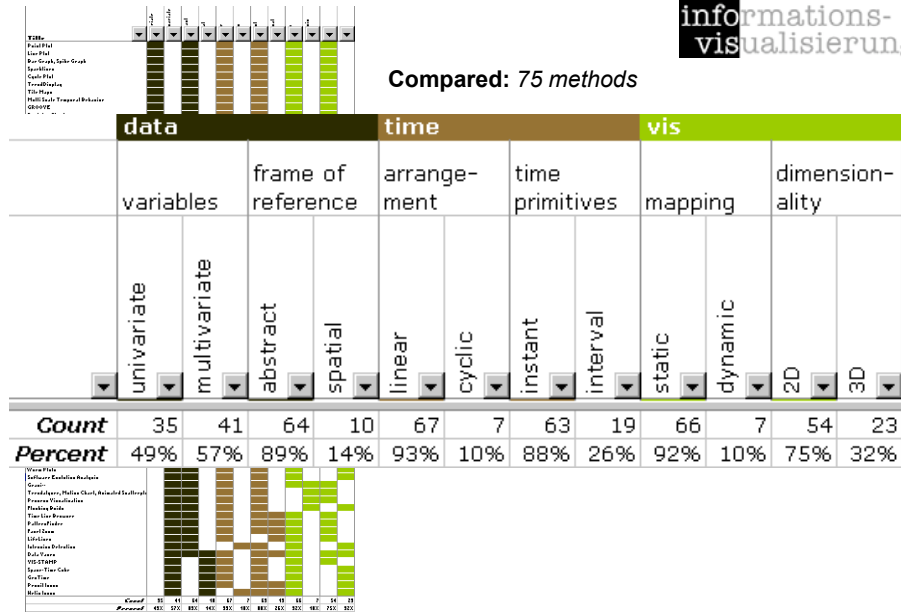
What is presented?
time and data

Why is it
presented?
user tasks

How is it
presented?
**visual
representation**



Compared: 75 methods



[Aigner, Miksch, Schumann, Tominski, 2011]