Laura Bassi Centre of Expertise
Centre for Visual Analytics Science & Technology

Maybe… Maybe not: Uncertainty in Time-Oriented Data Visualization

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TDE XIMES®

Overview

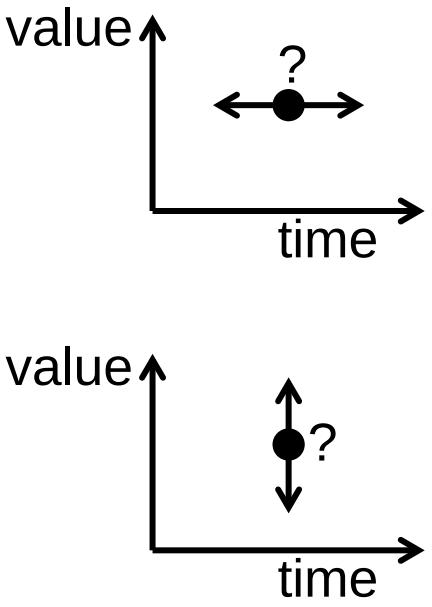
Characteristics of time

Modeling time

Visualizing time

Visualizing temporal uncertainty

Visualizing uncertainty of time-oriented data



CHARACTERISTICS OF TIME

Data Types

[Shneiderman, 1996]

1-dimensional

2-dimensional

3-dimensional

Temporal

Multi-dimensional

Tree

Network

= 4D space
“the world we are living in”

Spatial + Temporal Dimensions

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

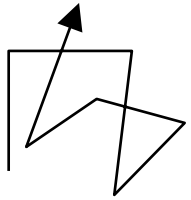
Example: price of a computer

where?

when?

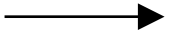
Differences between Space and Time

Space can be traversed “arbitrarily”



We can move back to where we came from

Time is unidirectional



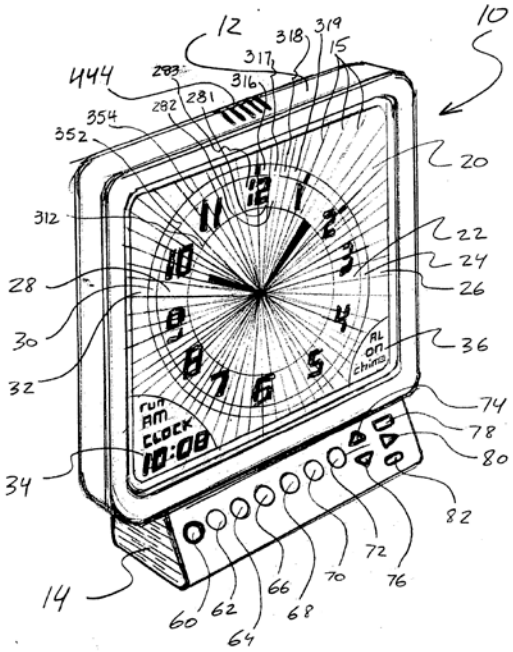
We can’t go back or forward in time

Humans have senses for perceiving **space**

Visually, touch

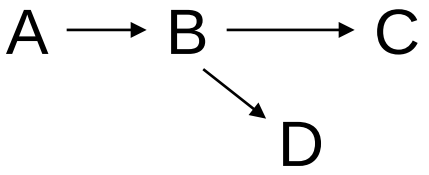
Humans don’t have senses for perceiving **time**

Time has a Complex Structure



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

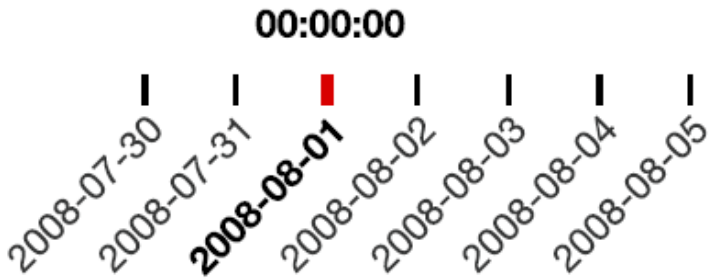
dense time

comparable to Float

Scope

point-based

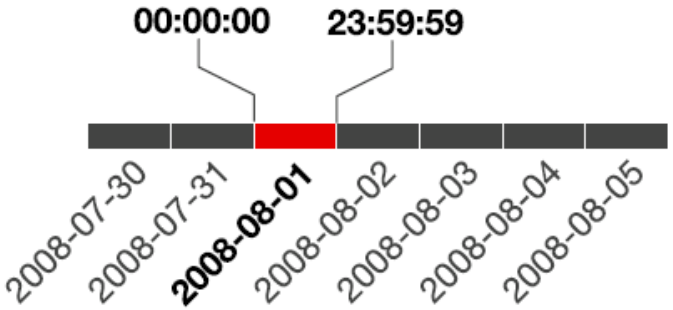
example: August 1, 2008



no information is given in between two time points

interval-based

example: August 1, 2008



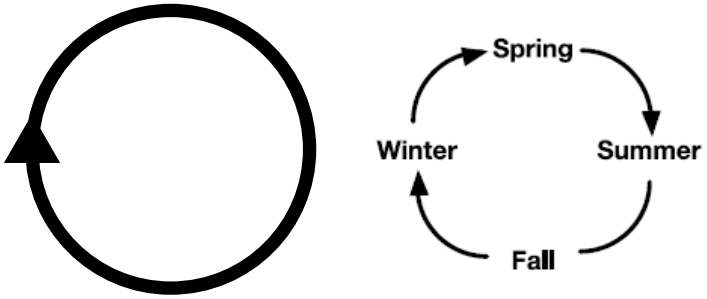
each element covers a subsection of the time domain greater than zero

Arrangement

linear

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

cyclic

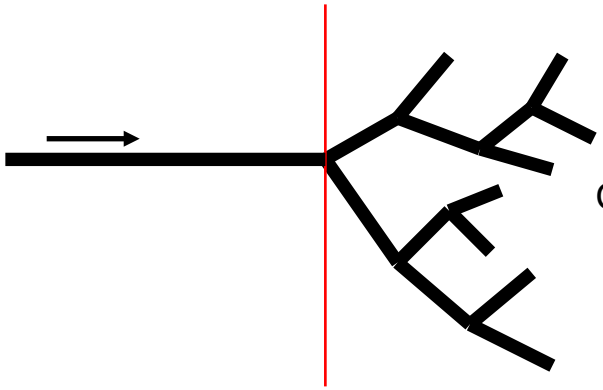


summer is before winter, but winter is also before summer

Viewpoints

ordered

branching



Past

Definite time - data element assignment

Present

Currently valid state

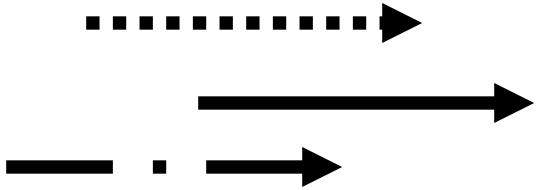
Future

Planning

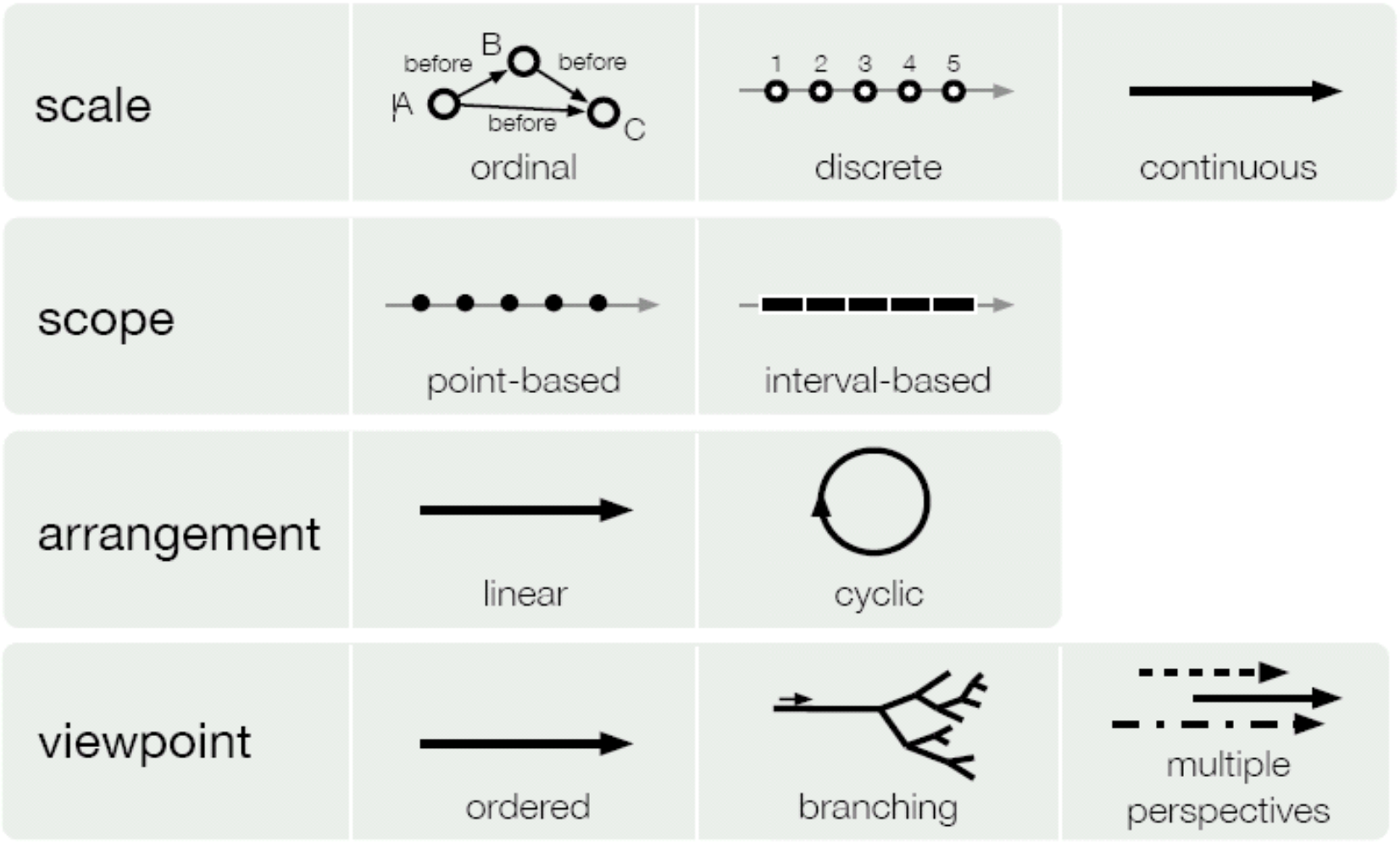
Temporal uncertainty

Alternative scenarios

multiple perspectives

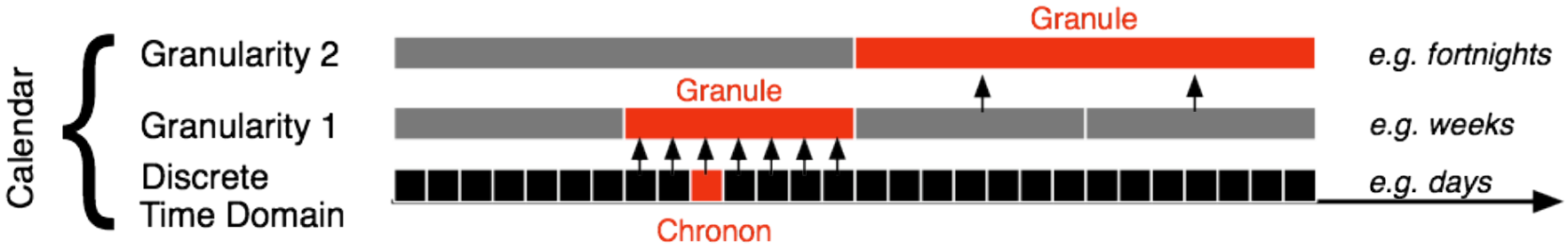


Time Structure

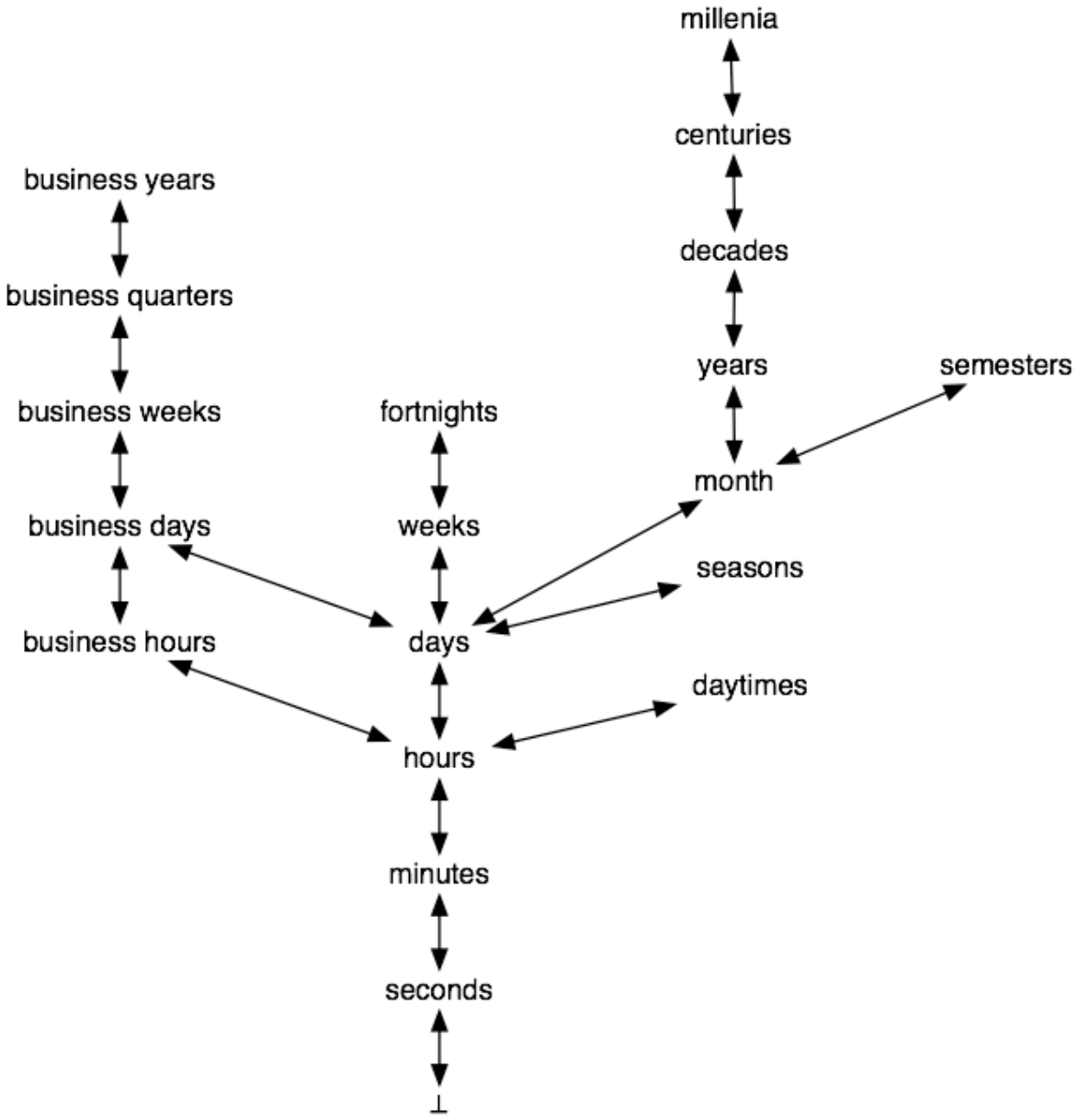


MODELING TIME

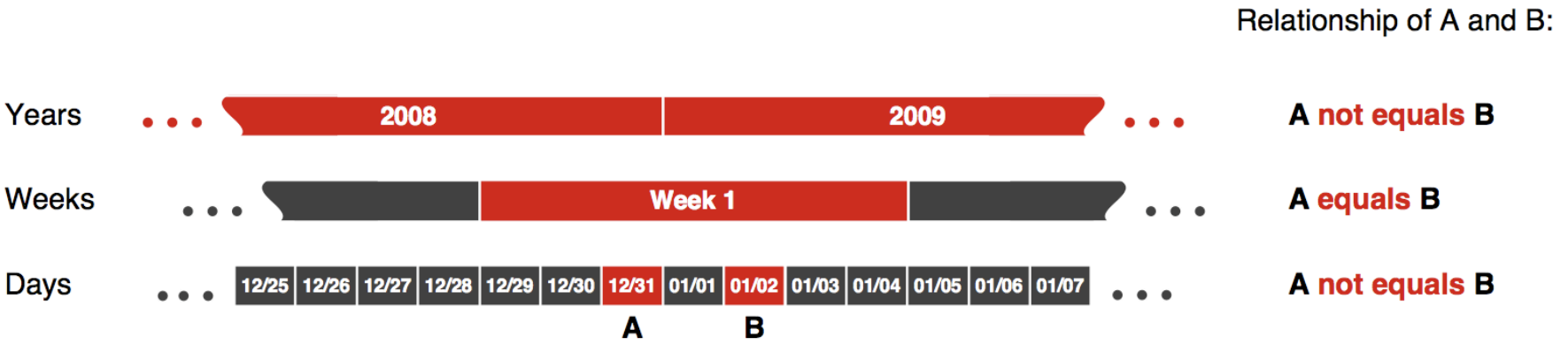
Granularity



Calendar


millenia
centuries
decades
years
semesters
business years
business quarters
business weeks
fortnights
month
business days
weeks
seasons
business hours
days
daytimes
hours
minutes
seconds
⊥

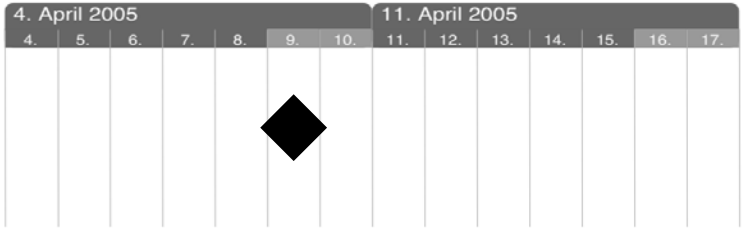
Example: **Granularity Paradoxon**



Time Primitives

anchored

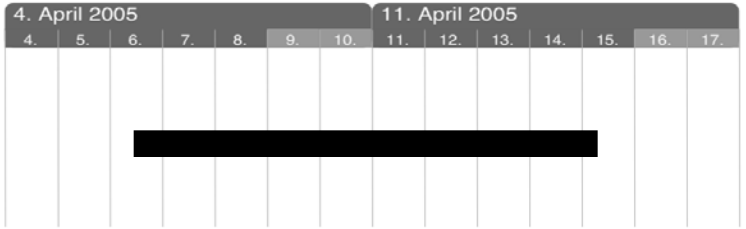
instant - single point in time



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

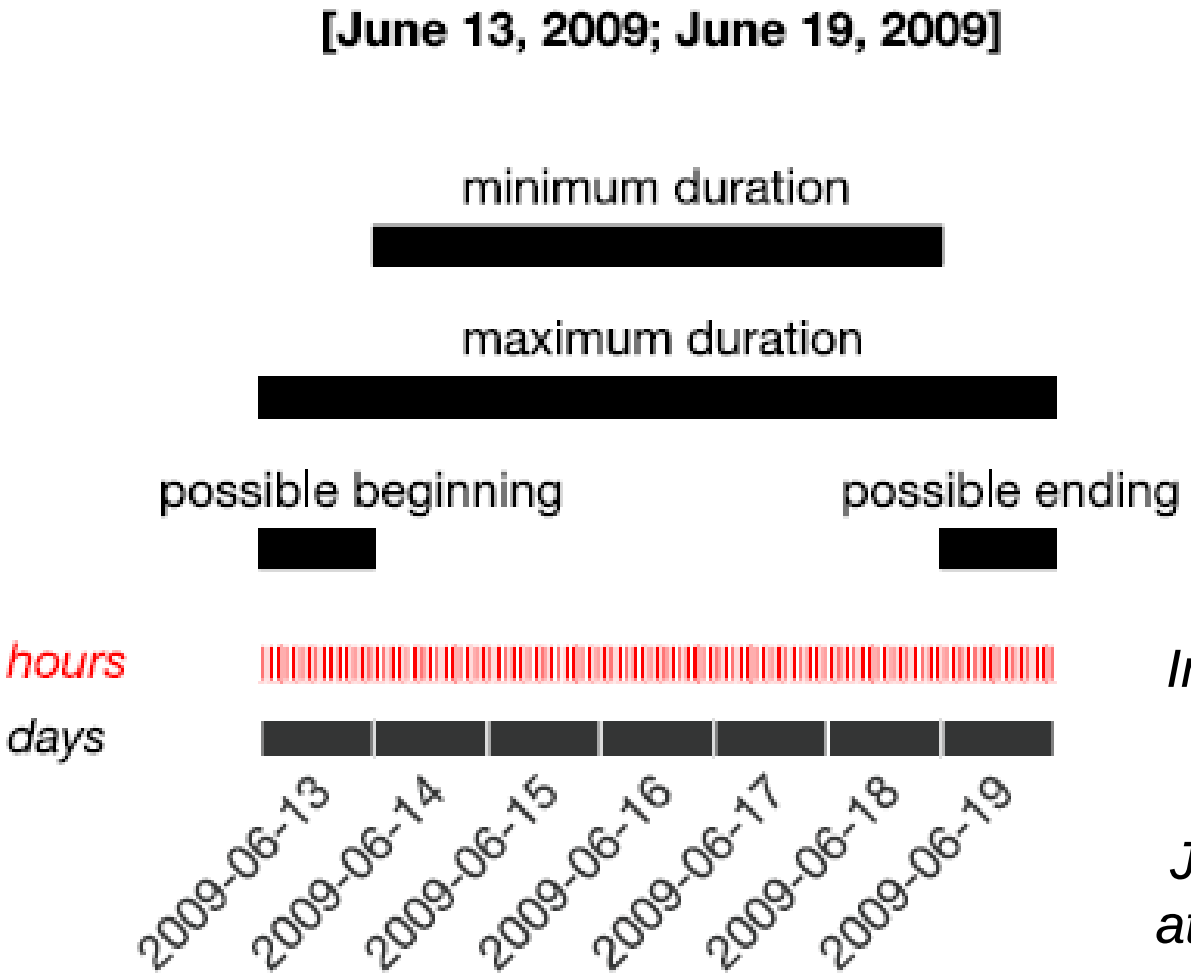
i.e. “it will take 2-3 weeks”

imprecise event times

i.e. “one or two days ago”

multiple granularities

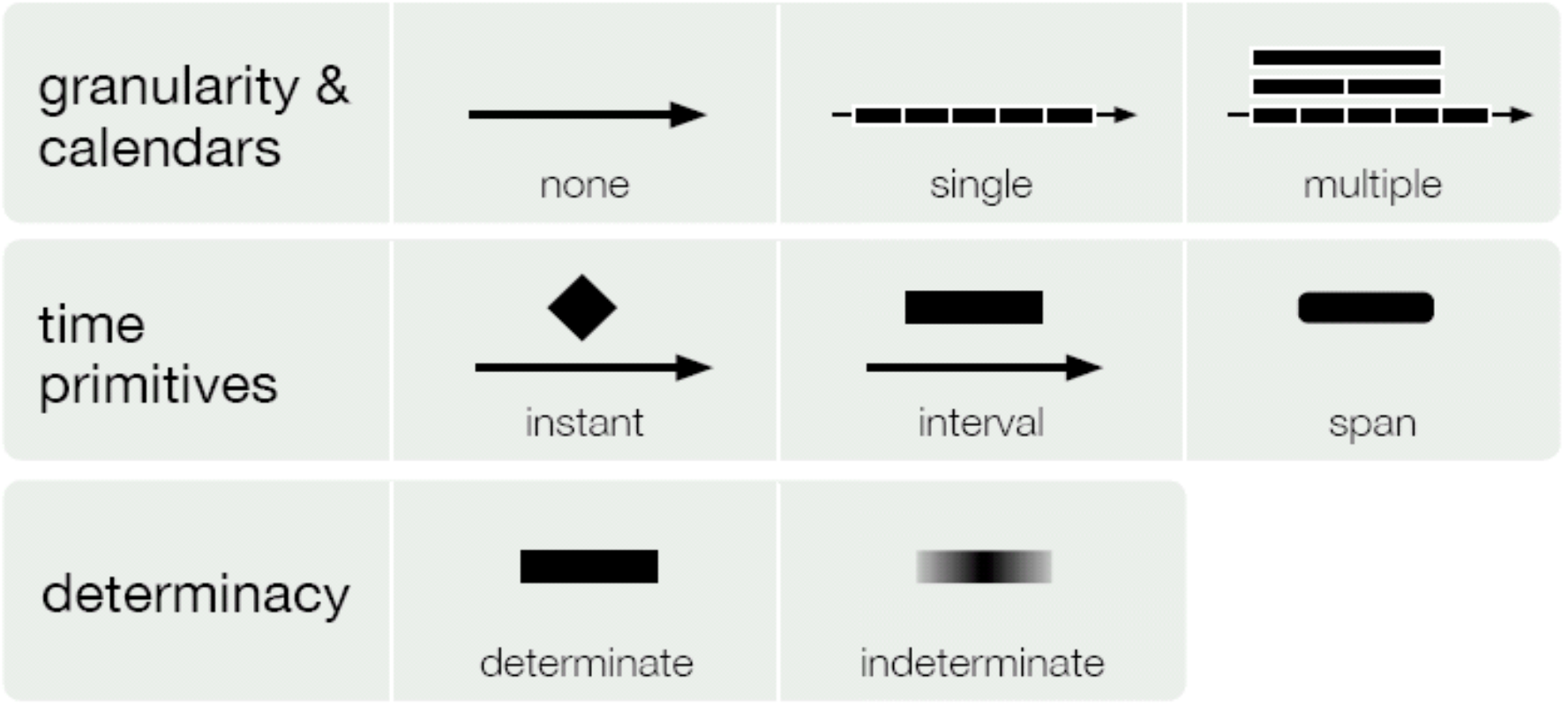
Temporal Uncertainty



*Implicit indeterminacy when representing the interval [June 14, 2009; June 17, 2009] that is given at a granularity of **days** on a finer granularity of **hours***

Modeling Time

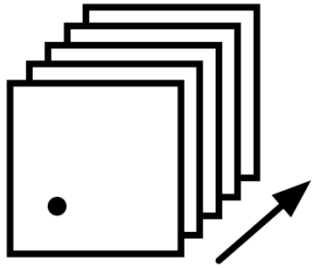
Abstractions



VISUALIZING TIME

Visual Mapping of Time

Dynamic: *Time → Time (Animation)*



probably the most natural form of mapping

no “conversion” of concepts needed in between

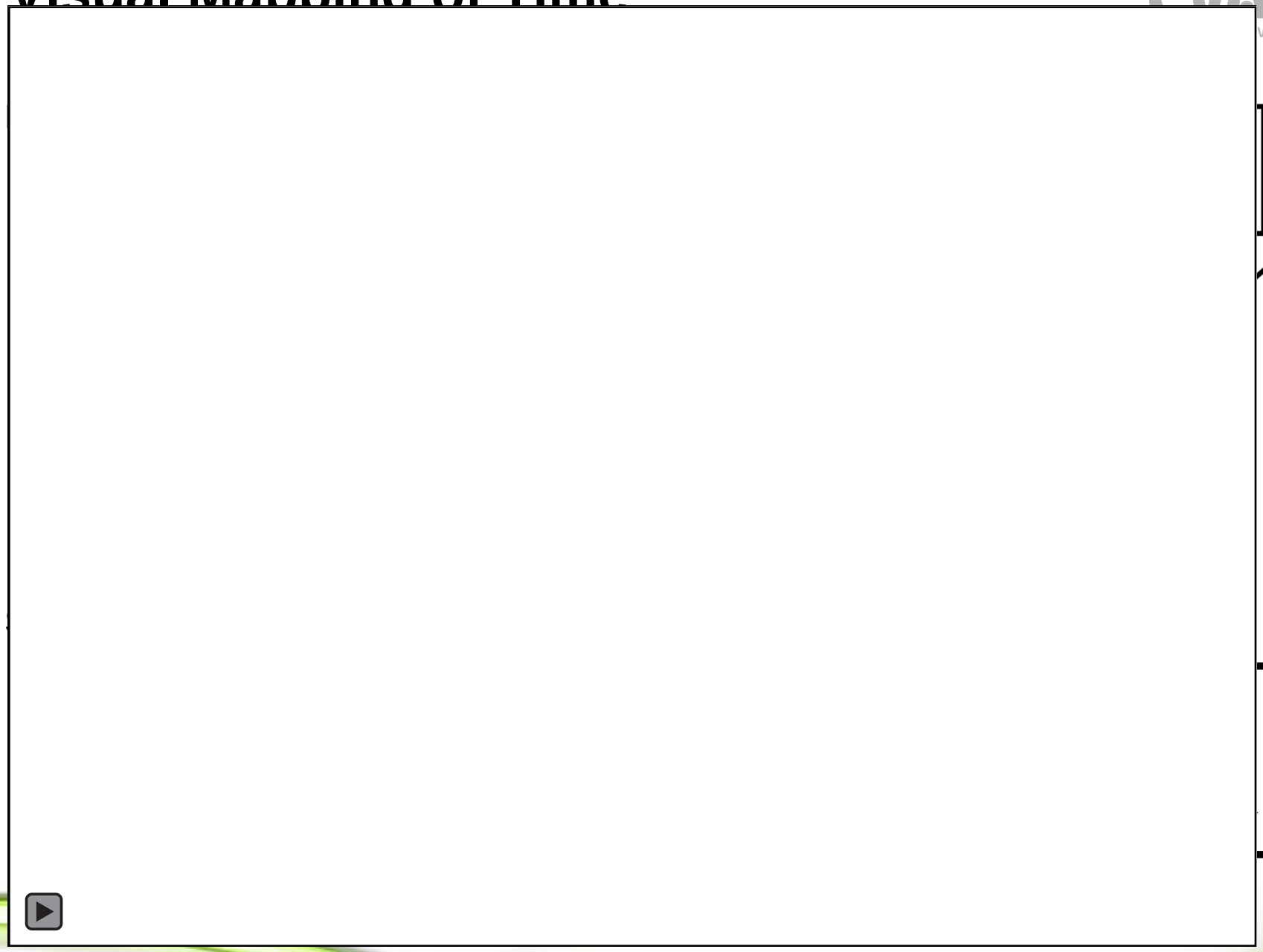
well suited for

- 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

Visual Mapping of Time



Visual Mapping of Time

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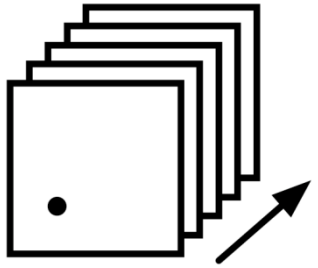

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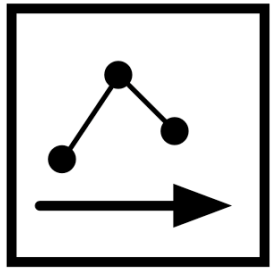
Static: *Time → Space*

mapping of time to visual features

direct comparison of parameters between different points in time is possible



Visual Mapping of Time

Dynamic: *Time*

probably the

no “conversi

well suited fo

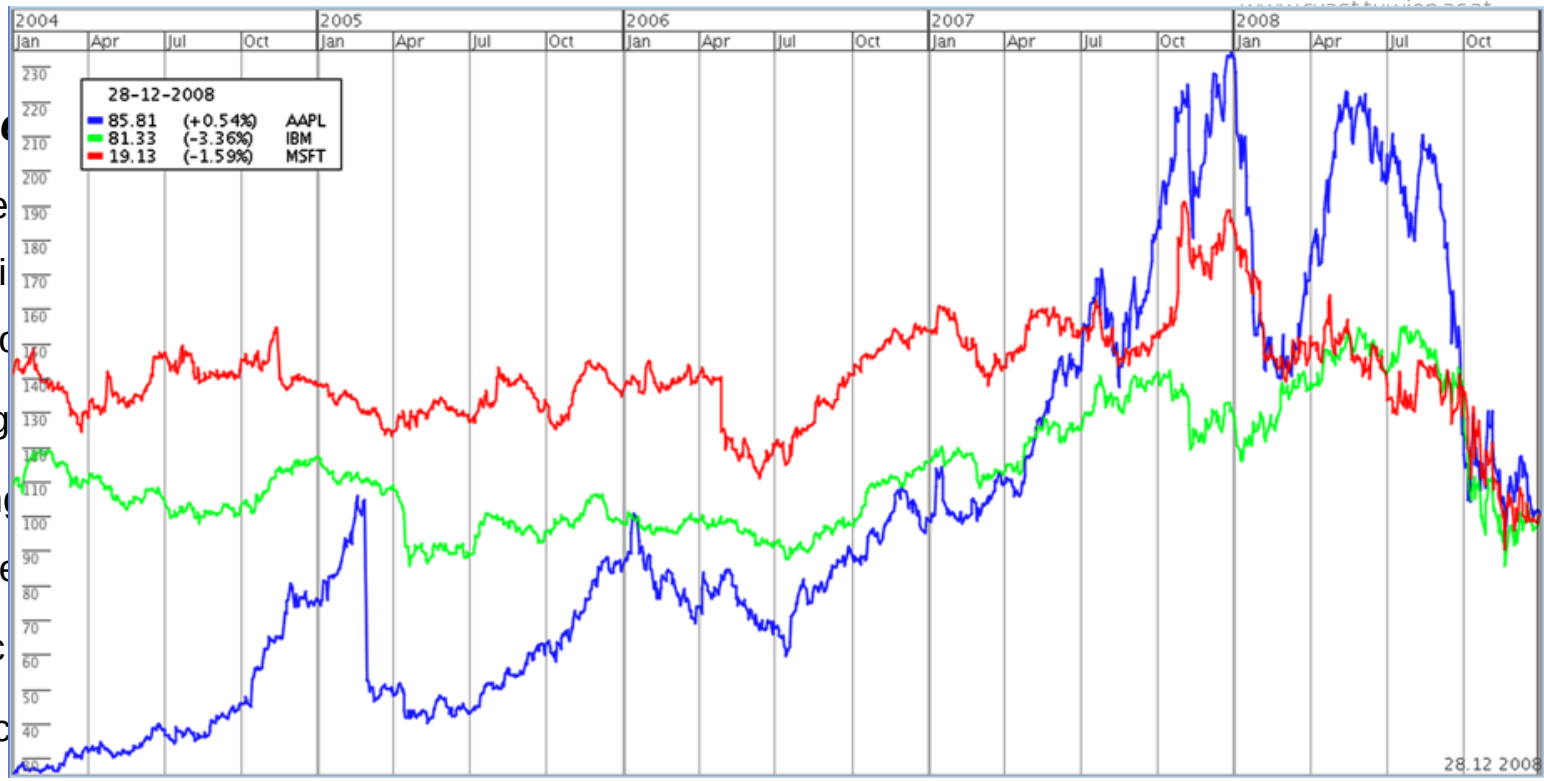
keeping

followin

not well suite

analytic

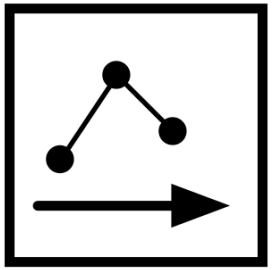
no direc



Static: *Time* → *Space*

mapping of time to visual features

direct comparison of parameters between different points in time is possible



InfoVis Basics – Marks

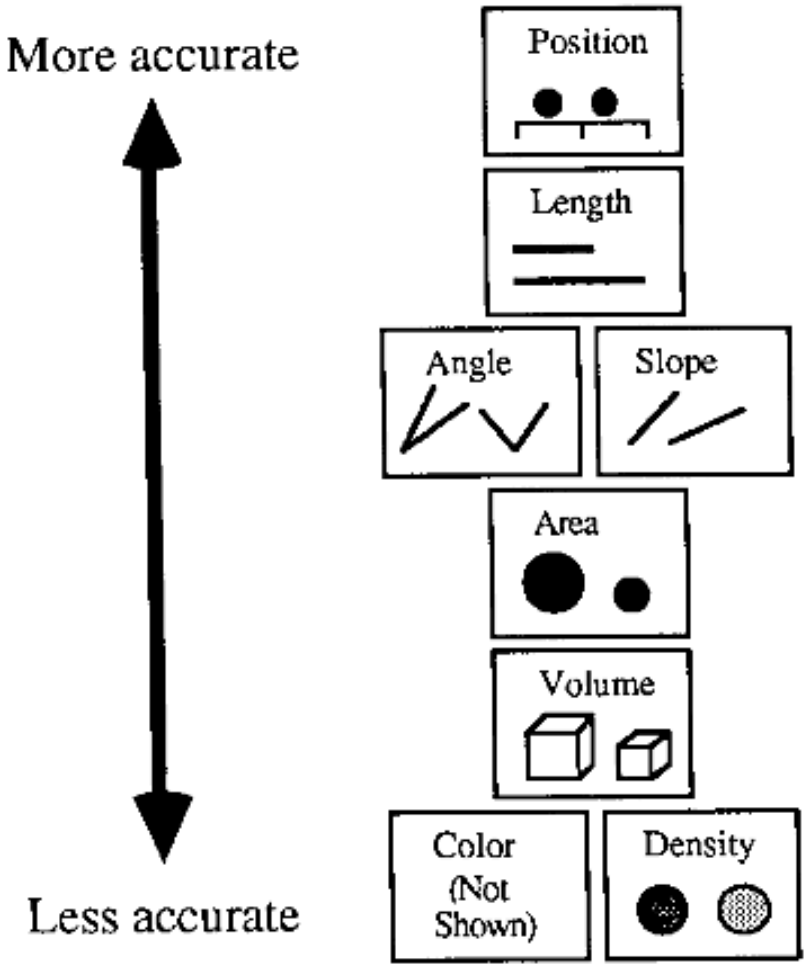
Points (0D)

Lines (1D)

Areas (2D)

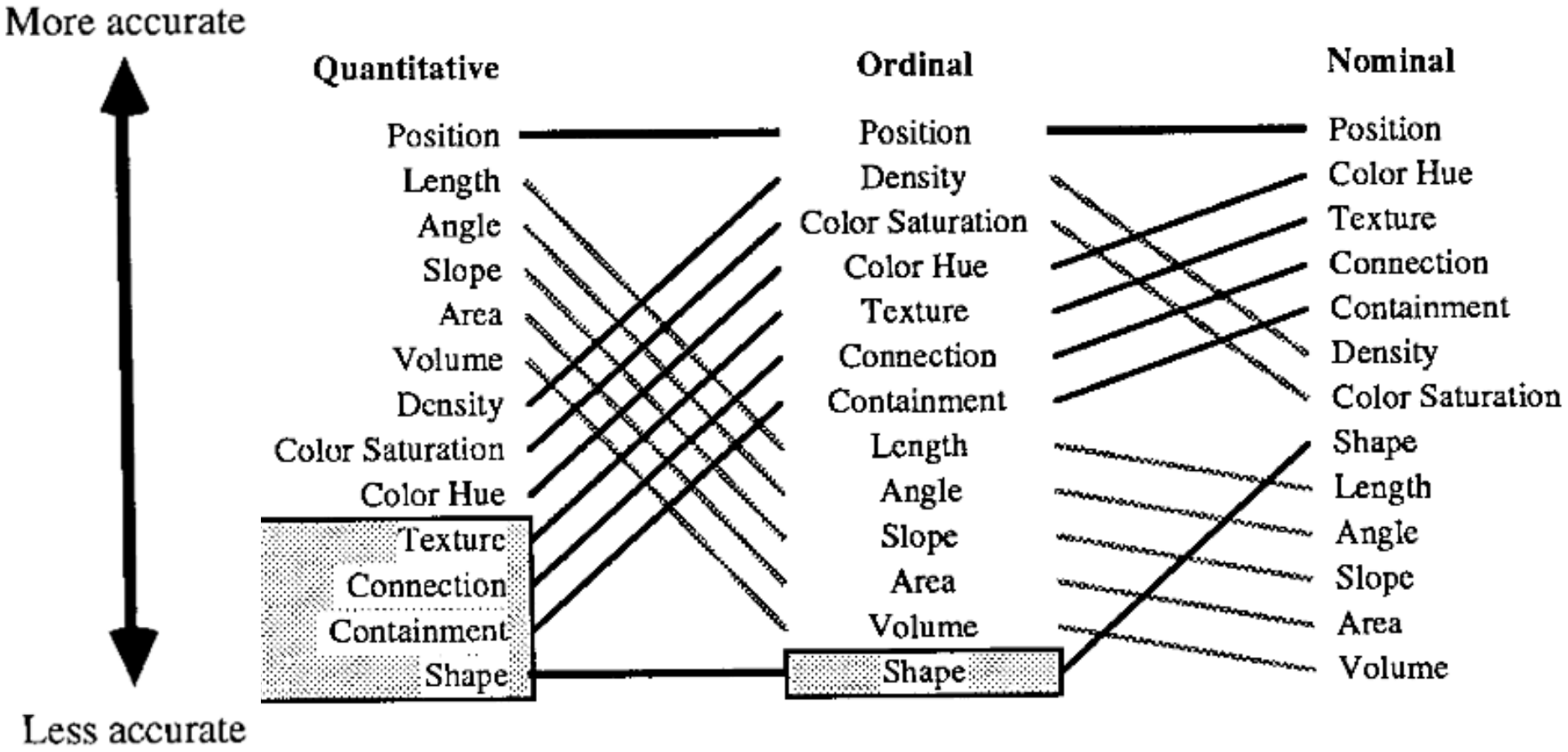
Volumes (3D)

InfoVis Basics – Visual Variables / Properties of Marks



[Cleveland & McGill, 1984]

InfoVis Basics – Visual Variables / Properties of Marks



[Mackinlay, 1987]

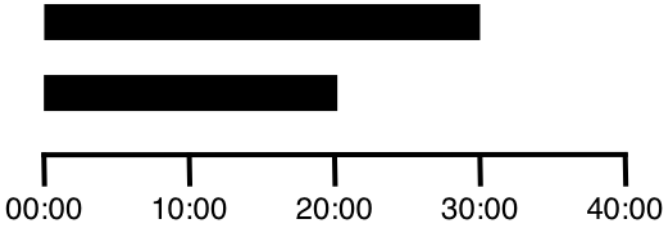
Visual Variables

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

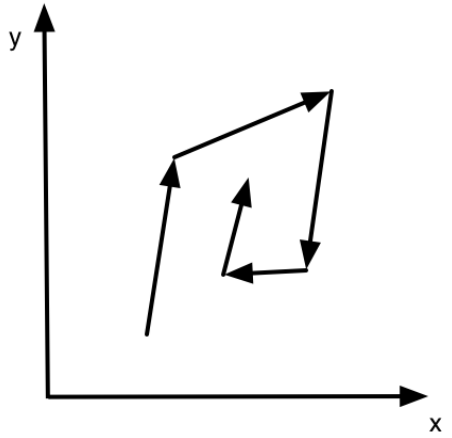
angle, slope

analog-clock-based visualizations

connection

connecting arrows or lines

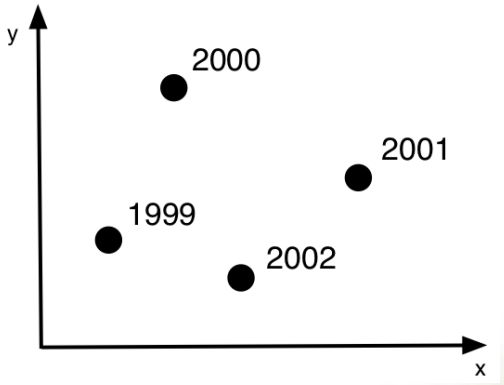
“before element” --> “after element”



text, label

simple text labelling

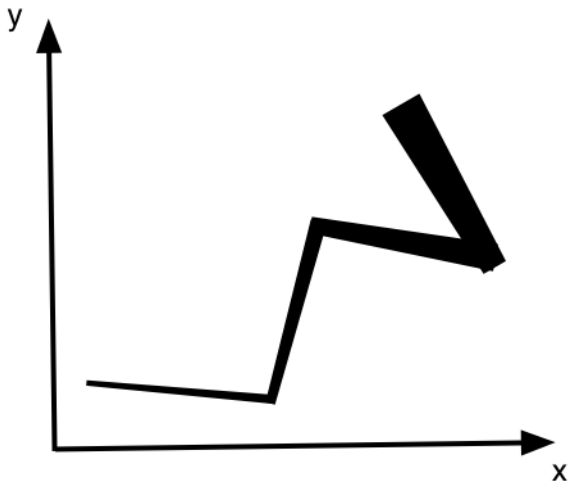
often combined with “connection”



Visual Variables

line (thickness)

increasing or decreasing with time

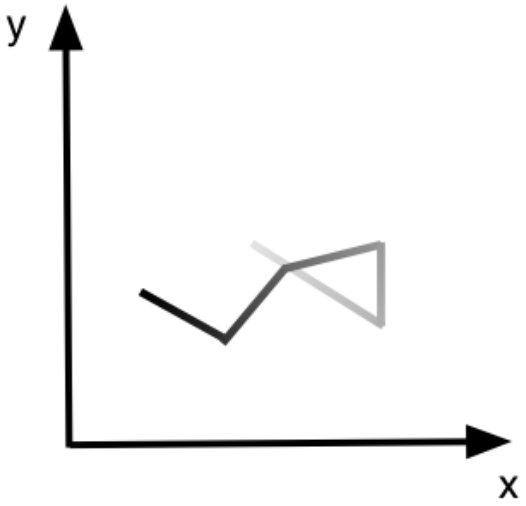


color (brightness, saturation, hue)

brightness most appropriate

“fading away” against the background

transparency



Visual Variables

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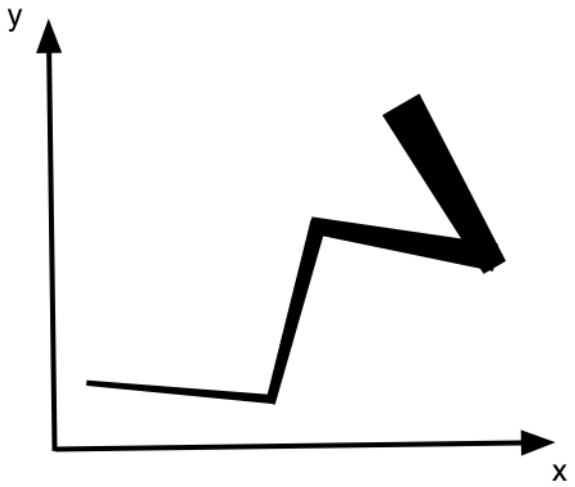

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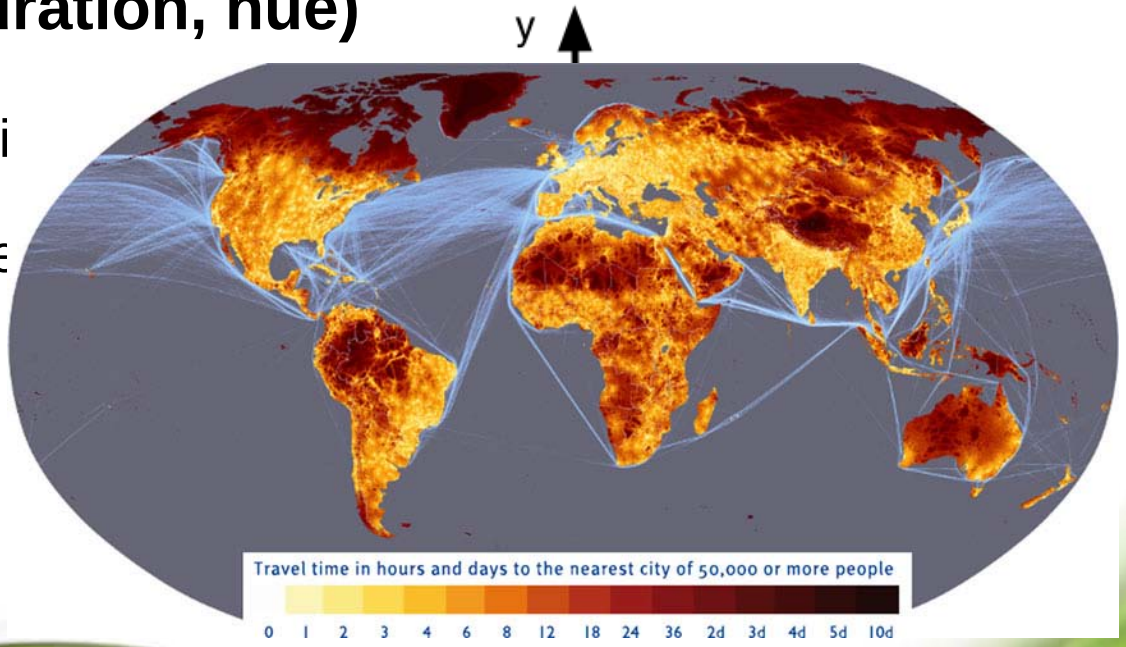


Visual Variables

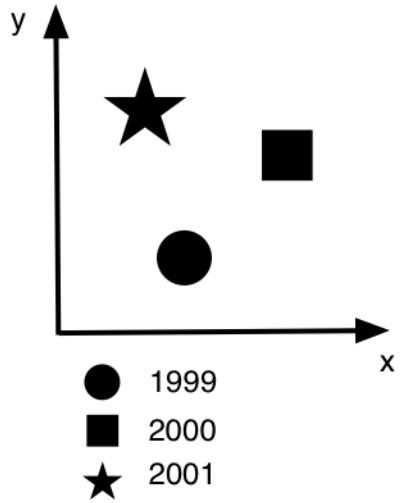
area

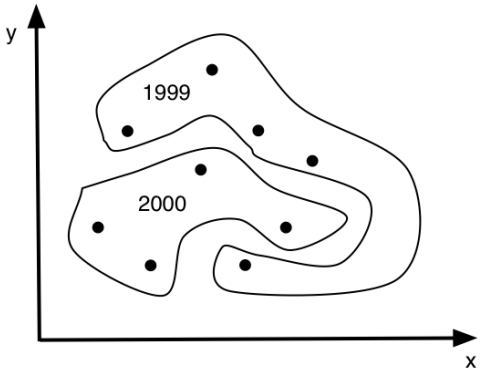
enclosure

size

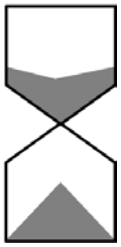
texture

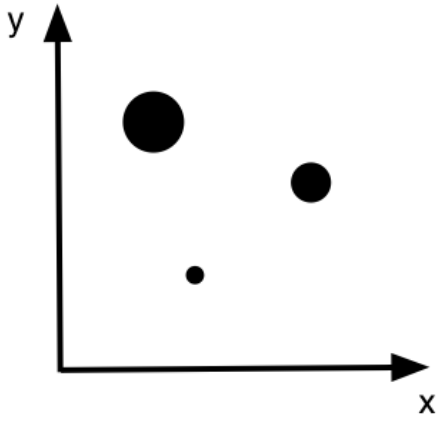
shape

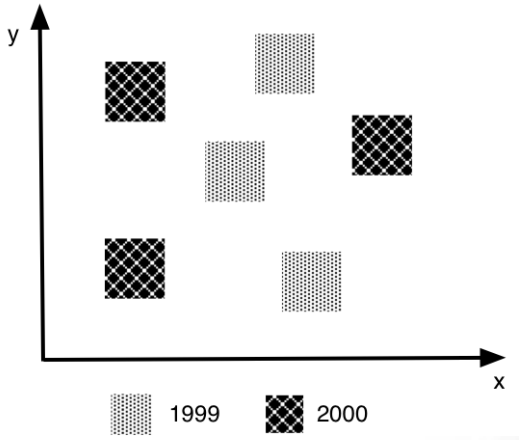


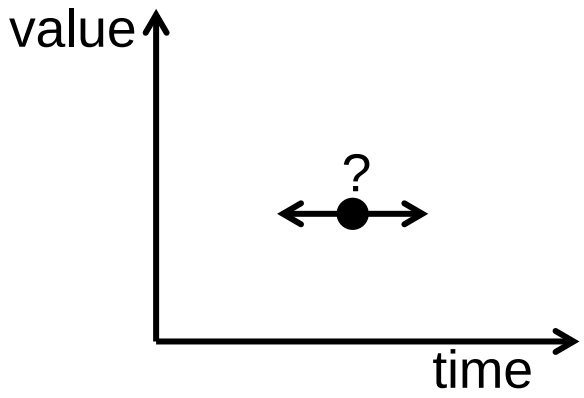


less suited









VISUALIZING TEMPORAL UNCERTAINTY

Methods to Visually Encode Uncertainty

Glyphs/Icons:

- Error bars, error ellipses, box-plots, confidence intervals,…
- Ambiguation,
- Orientation of additional lines,
- Streamlines, contourlines, isolines,…

Properties of marks:

- Focus (blur),
- Opacity (transparency),
- Size (length, height, line width,…),
- Color (saturation, brightness,…),
- Texture,
- Animation (blinking, toggle between two views, sequence of possible values…),
- Sound,…

Juxtaposition:

- Side-by-side displays of competing results,
- Side-by-side displays of data values and uncertainty values,…

Additional transparent layers,

Additional symbols,…

[Pang et al., 1997]
[Olston and Mackinlay, 2002]
[Correa et al., 2009]
[Senaratne and Gerharz, 2011]
[Kandel et al., 2011]
[Brodlie et al., 2012]

Paint Strips

[Chittaro and Combi, 2003]
[TimeViz, Aigner, et al., 2011]

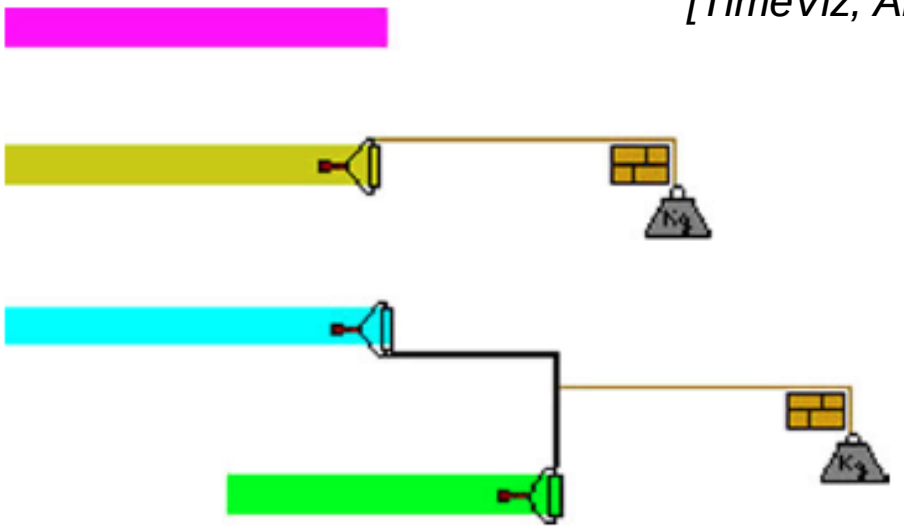
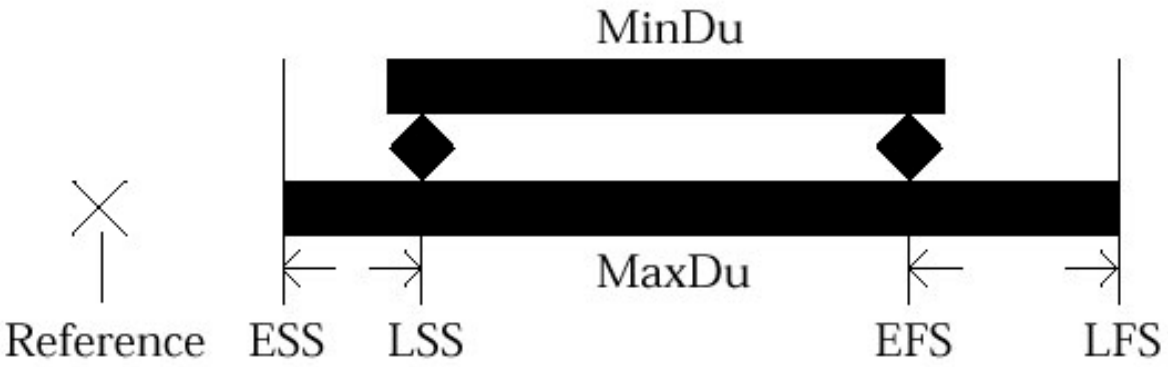


Fig. 7.20: Paint strips indicate the location and duration of time intervals, effectively allowing users to assess relationships of intervals. Temporal indeterminacy of intervals is indicated by paint rollers that can move flexibly within certain constraints, which are represented by wall elements. *Source: Image courtesy of Luca Chittaro.*

Time Annotation Glyph

[Kosara and Miksch, 1999]

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



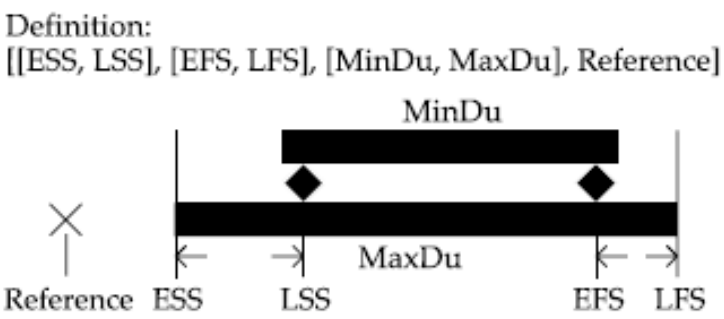
For representation of future planning data (uncertainty / indeterminacy)

Characteristics:

- Time points are relative (Reference point)
- ESS/EFS: earliest starting/finishing shift
- LSS/LFS: latest starting/finishing shift
- MinDu/MaxDu: Minimum/Maximum duration

Time Annotation Glyph

[Kosara and Miksch, 2001]
[TimeViz, Aigner, et al., 2011]



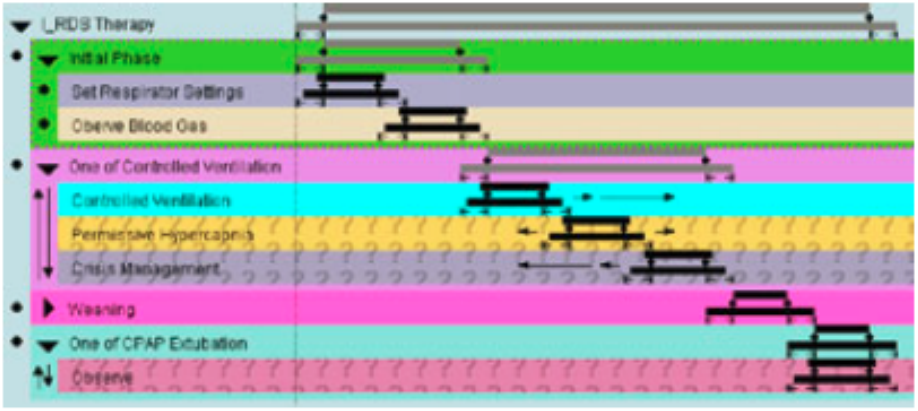
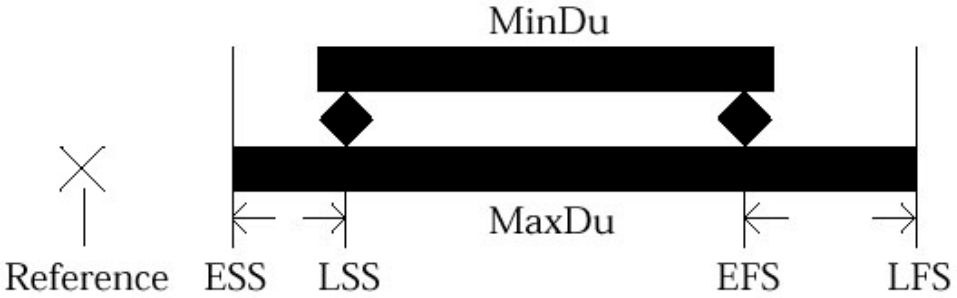


Fig. 7.22: The time annotation glyph was designed to represent the temporal constraints of medical treatment plans. It uses the metaphor of bars that lie on pillars. Left: Single glyph and associated parameters. Right: Usage in a tool for representing the temporal and hierarchical aspects of a medical treatment plan as well as the execution order of individual parts.
Source: Images courtesy of Robert Kosara.

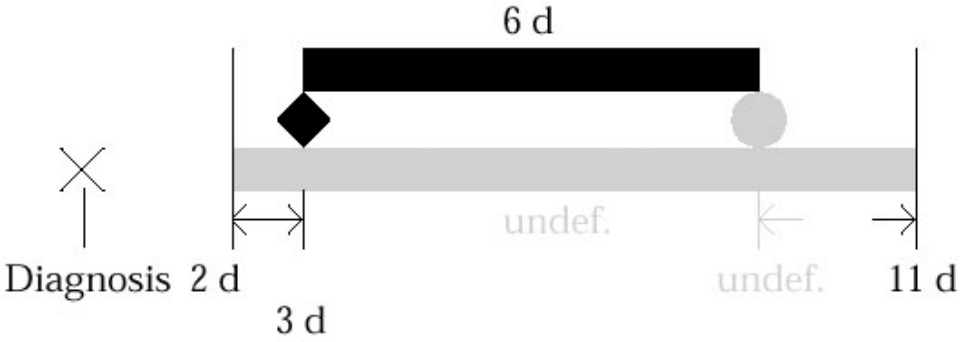
Time Annotation Glyph *2/2*

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



MinDu and LFS defined to higher precision than time axis

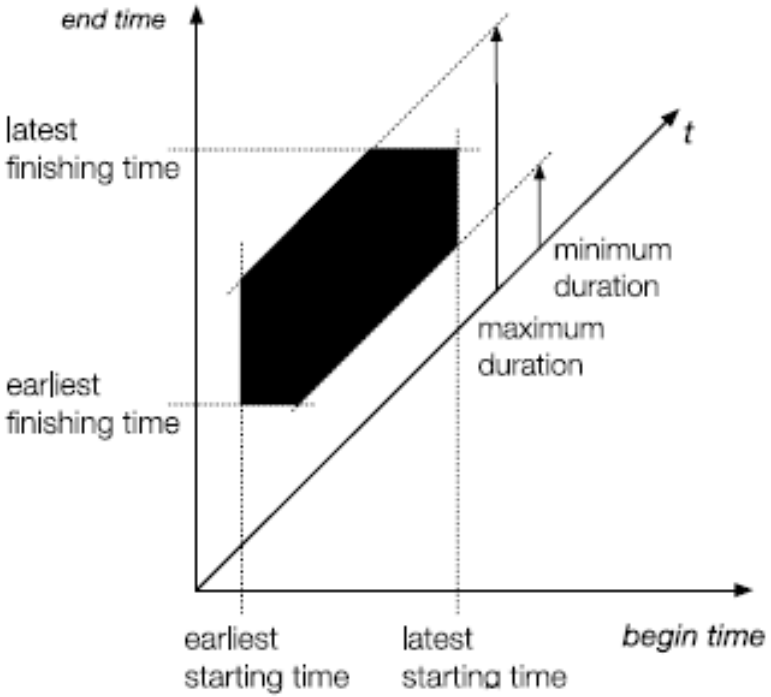
Example: [[2 d, 3 d], [_, 11 d], [6 d, _], Diagnosis]



MinDu and LFS defined to lower precision than time axis

SOPO Diagram

[Kosara and Miksch, 2002]
[TimeViz, Aigner, et al., 2011]



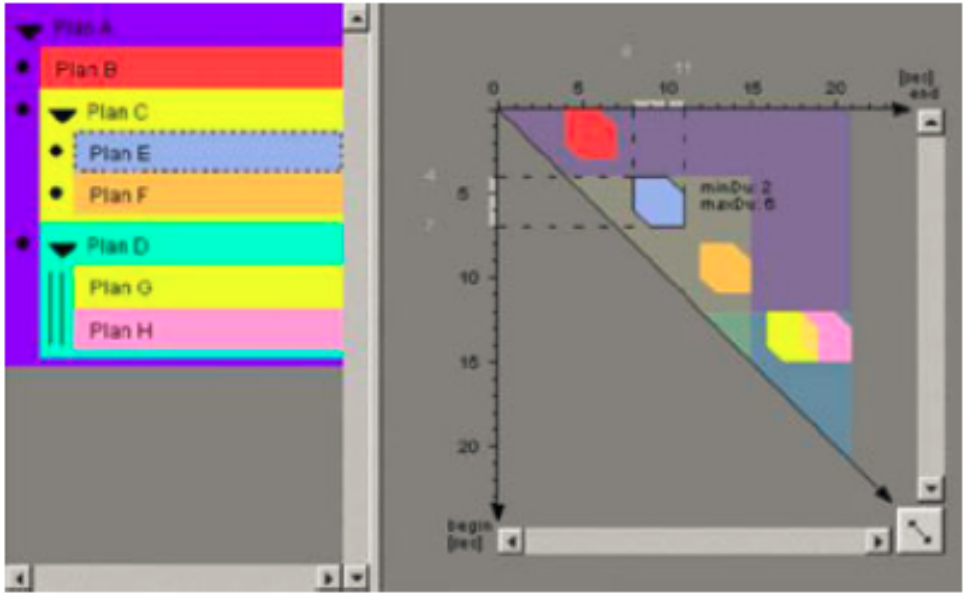
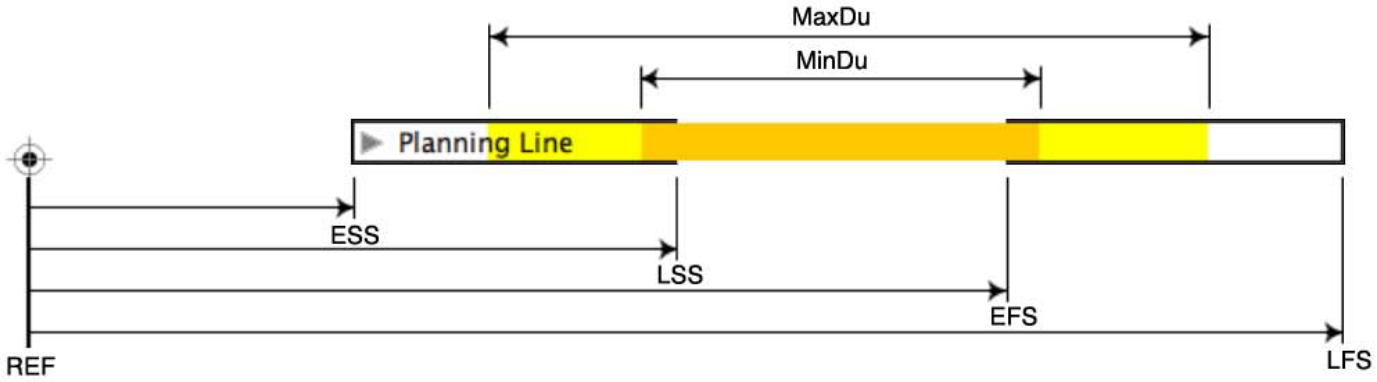


Fig. 7.23: A SOPO diagram shows the possible configurations of the begin and end times of an event via a constrained polygonal shape. Right: SOPOView – an interactive visualization tool for working with SOPOs applied for medical treatment plans.
Source: Images courtesy of Robert Kosara.

PlanningLines

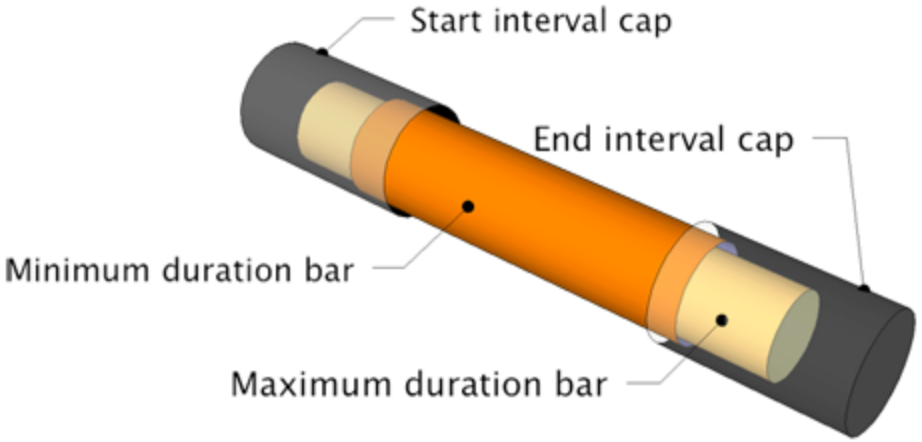
[Aigner et al., 2005]



REF...Reference Point

MinDu...Minimum Duration
MaxDu..Maximum Duration

ESS...Earliest Starting Shift
LSS...Latest Starting Shift
EFS...Earliest Finishing Shift
LFS...Latest Finishing Shift



PlanningLines

[Aigner et al., 2005]
[TimeViz, Aigner, et al., 2011]

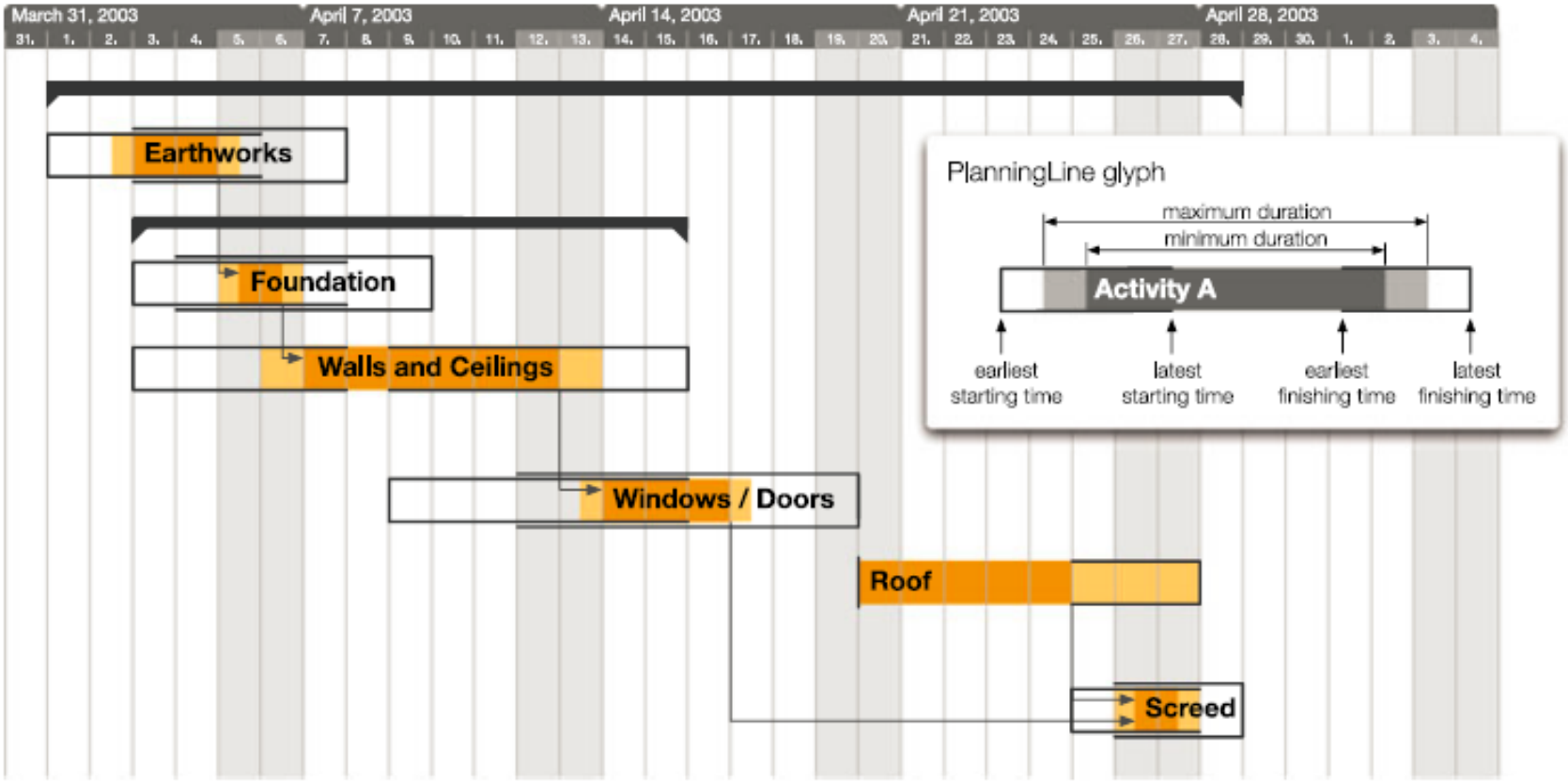
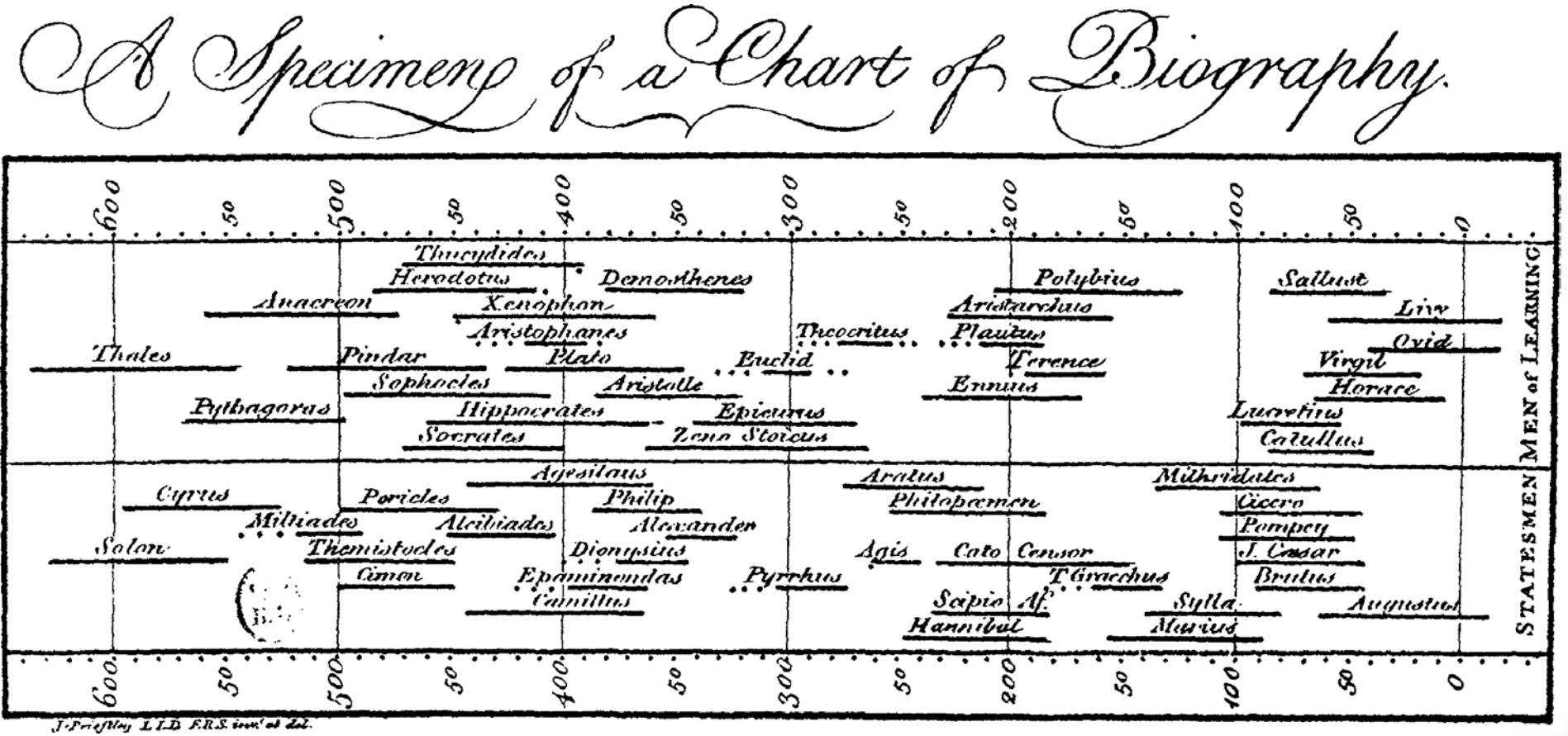


Fig. 7.21: Project plan of construction works that represents temporal uncertainties via PlanningLines. A PlanningLine glyph consists of two encapsulated bars, which represent minimum and maximum duration. The bars are bounded by two caps encoding the start and end intervals. *Source: Adapted from Aigner et al. (2005).*

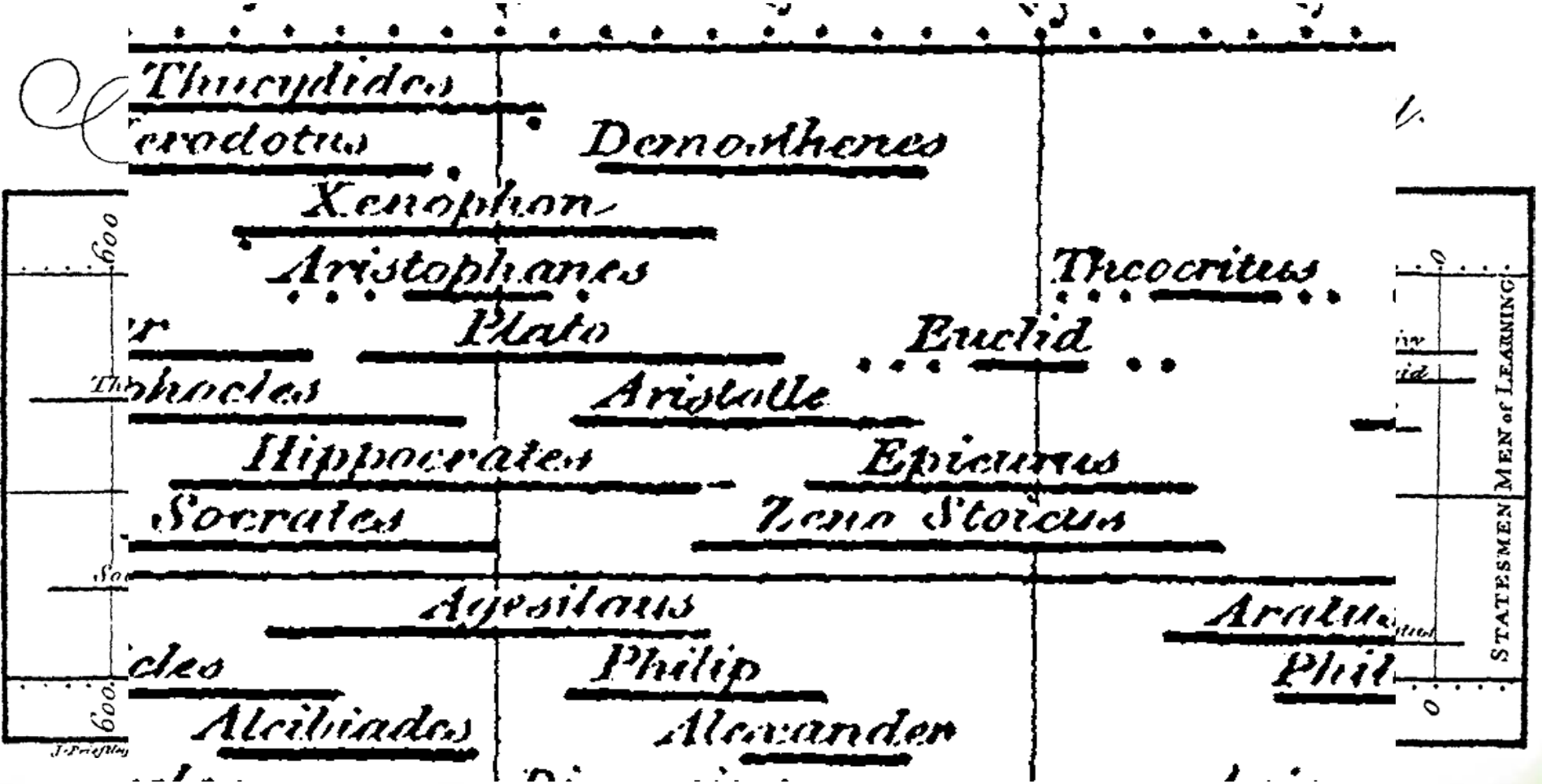
Joseph Priestley's chart of biography

[Priestley, 1765]
[TimeViz, Aigner, et al., 2011]



Joseph Priestley's chart of biography

[Priestley, 1765]
[TimeViz, Aigner, et al., 2011]



Methods to Visually Encode Uncertainty

Glyphs:

- Error bars, error ellipses, box-plots, confidence intervals,…
- Ambiguation,
- Orientation of additional lines,
- Streamlines, contourlines, isolines,…

… often used to encode temporal uncertainty

Properties of marks:

- Focus (blur),
- Opacity (transparency),
- Size (length, height, line width,…),
- Color (saturation, brightness,…),
- Texture,
- Animation (blinking, toggle between two views, sequence of possible values…),
- Sound,…

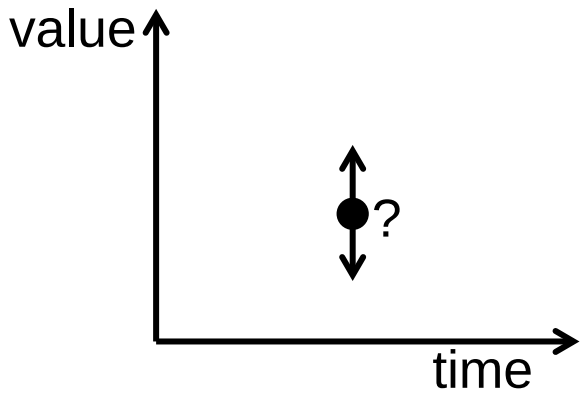
Juxtaposition:

- Side-by-side displays of competing results,
- Side-by-side displays of data values and uncertainty values,…

Additional transparent layers,

Additional symbols,…

[Pang et al., 1997]
[Olston and Mackinlay, 2002]
[Correa et al., 2009]
[Senaratne and Gerharz, 2011]
[Kandel et al., 2011]
[Brodlie et al., 2012]



VISUALIZING UNCERTAINTY OF TIME-ORIENTED DATA

What is Time-Oriented Data?

CVAST
www.cvast.tuwien.ac.at

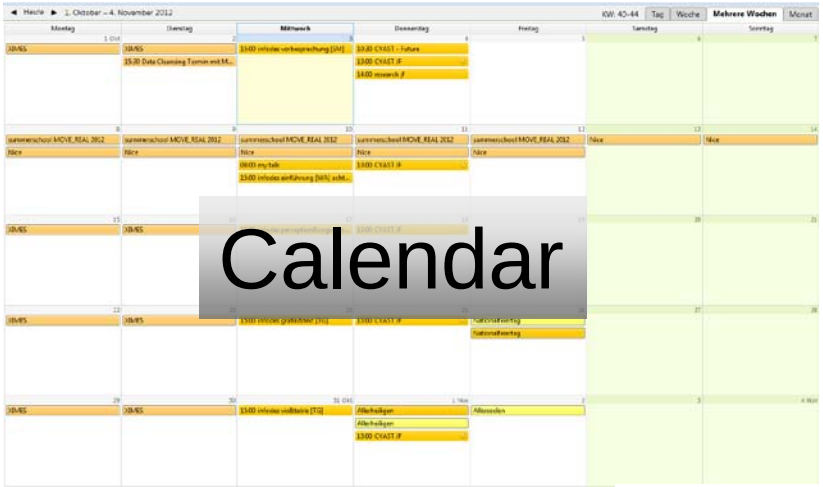
No formal definition

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.

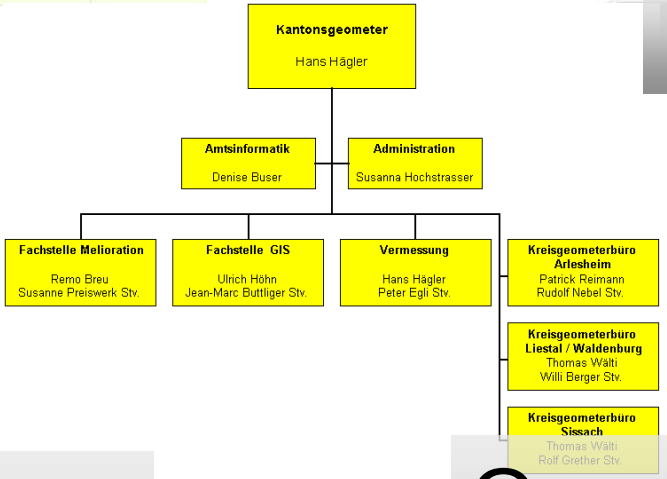
Time-Oriented Data?



Calendar

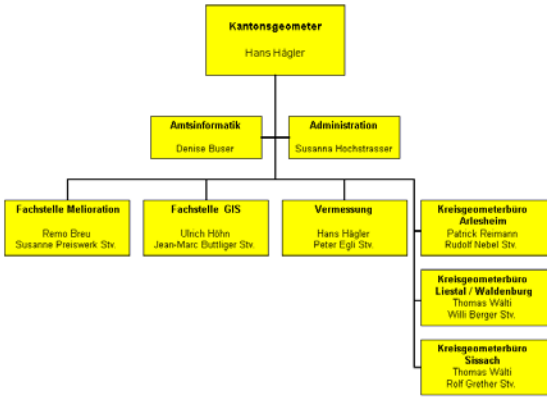
iPad price

Snow height & sunshine hours

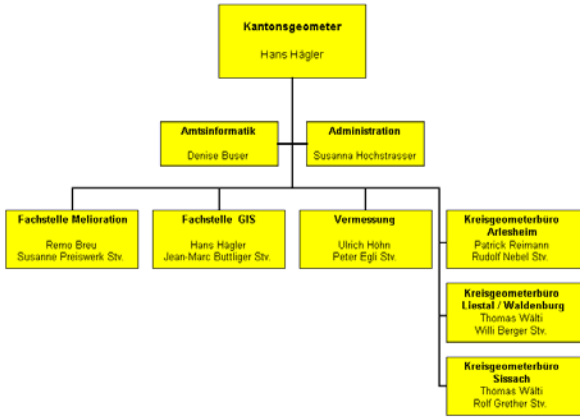


Organization chart

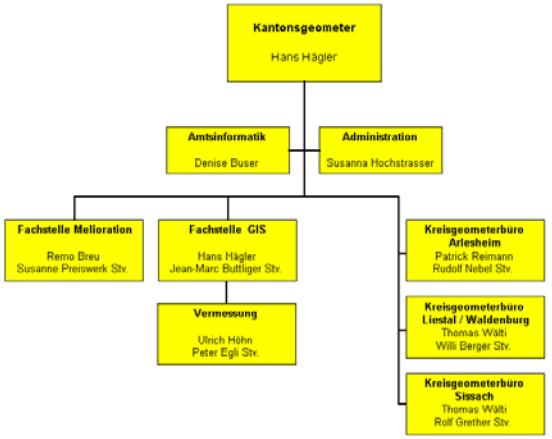
Organization Chart



1998



2000

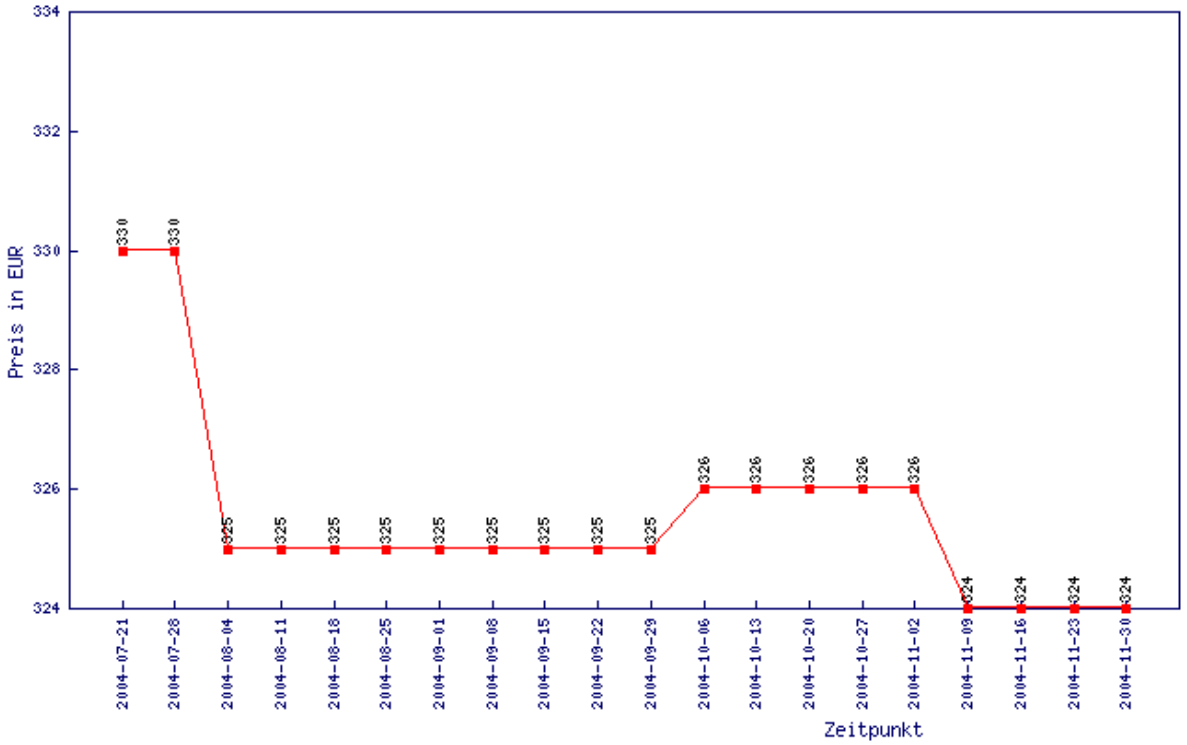


2002

time

iPod Price

Preis in €	Anbieter	Händler-Bewertung	Verfügbarkeit lt. Händler / Versand
324,--	T-Online-Shop [zum Shop]	Note: 2,24	Versandfertig in ca. 14 Tagen
	Infos AGB Meinungen	14 Bewertungen	Details auf Anfrage Vorkasse: € 5,30 Nachnahme: zzgl. € 4,80 kostenlose Zustellung in

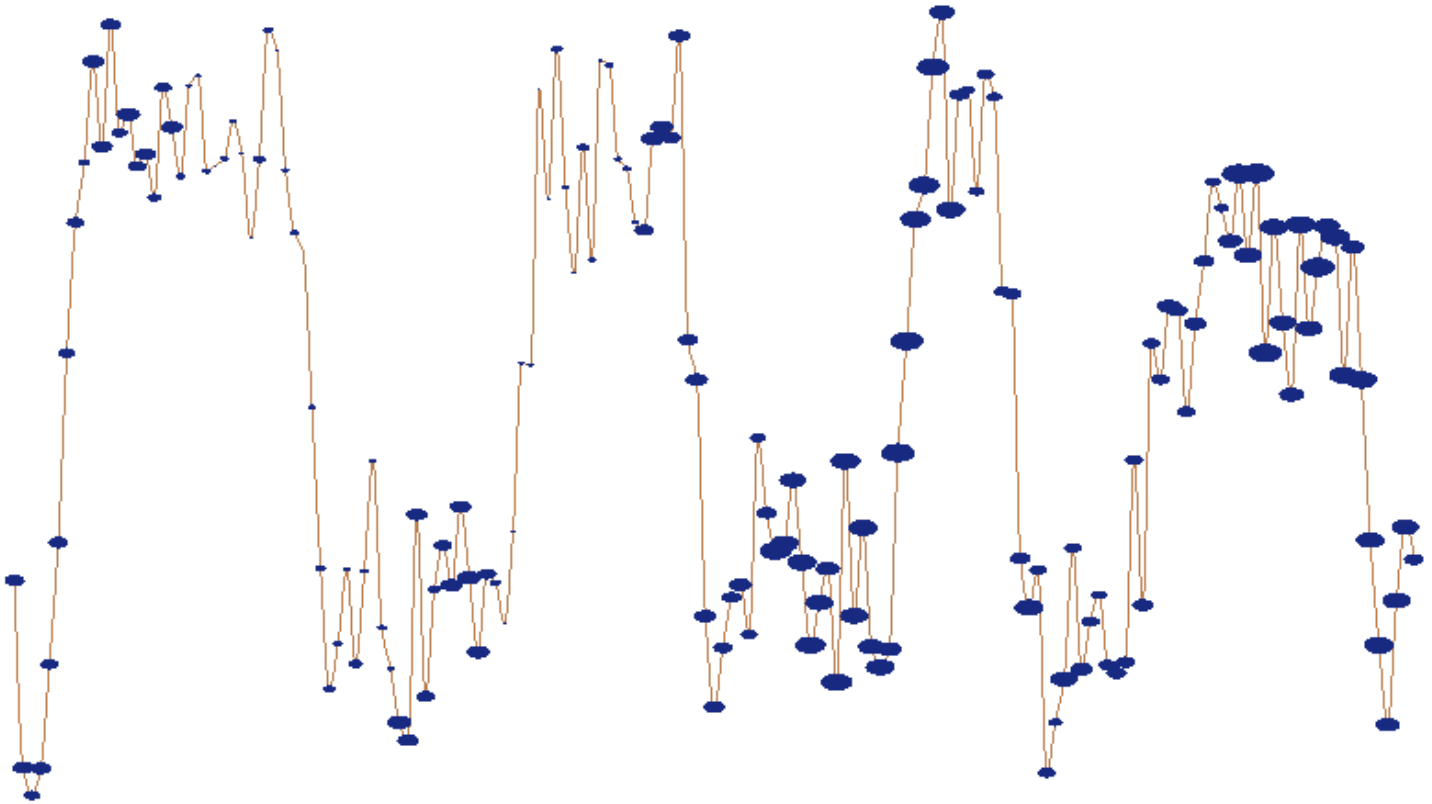


Characterizing Data

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

Quantitative Time-Oriented Data

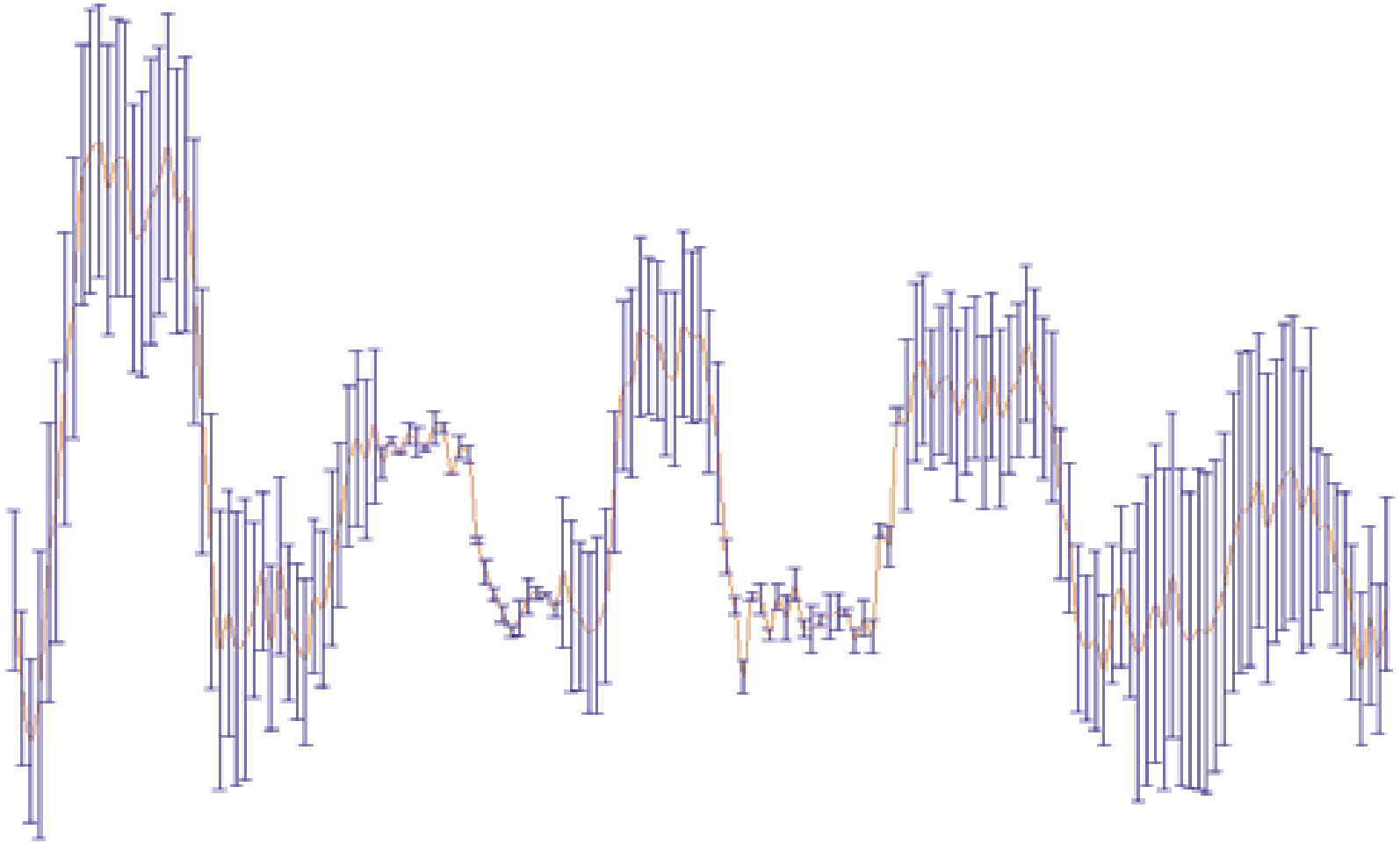
size of marks



[Sanyal et al., 2009]

Quantitative Time-Oriented Data

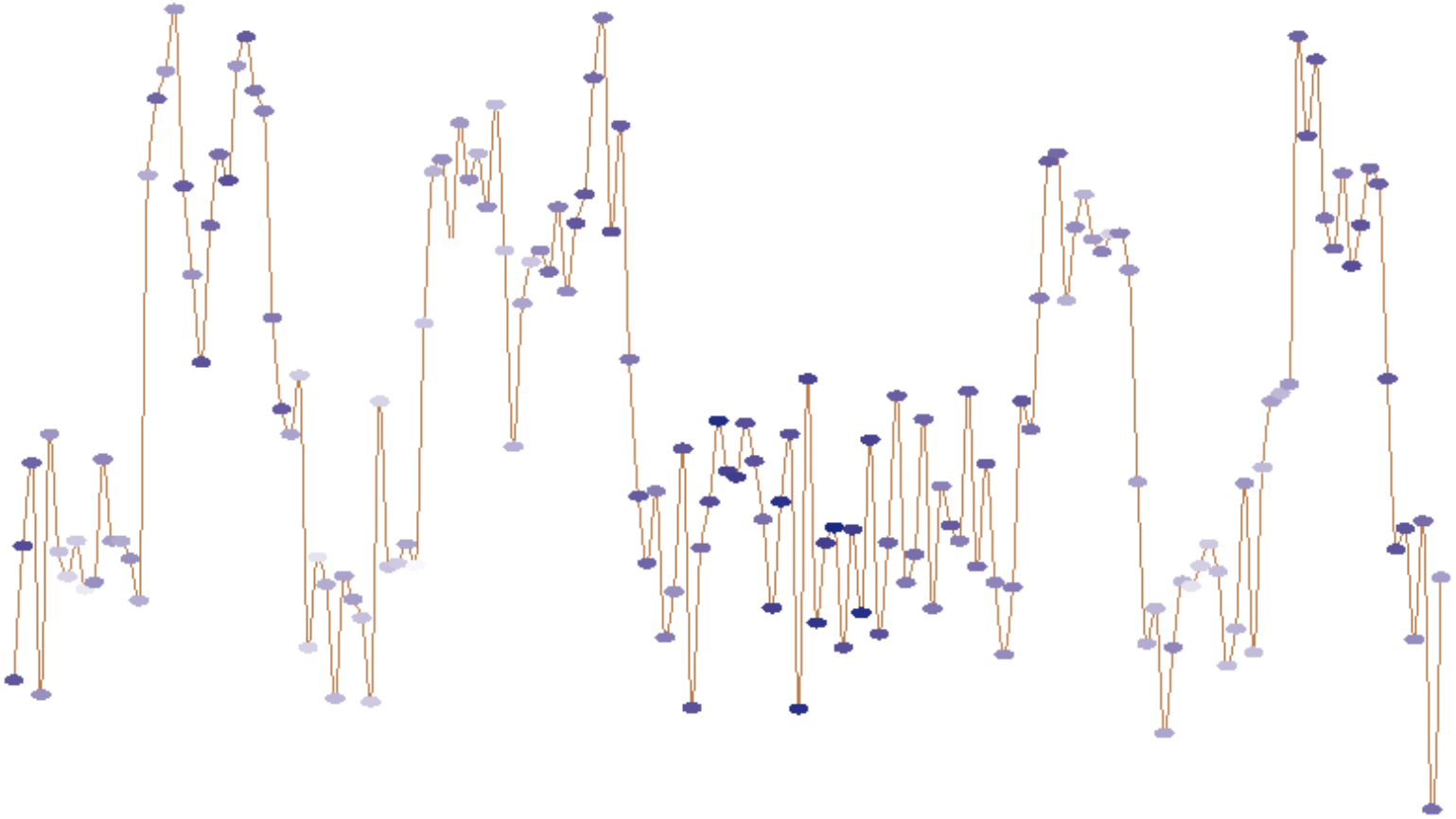
error bars



[Sanyal et al., 2009]

Quantitative Time-Oriented Data

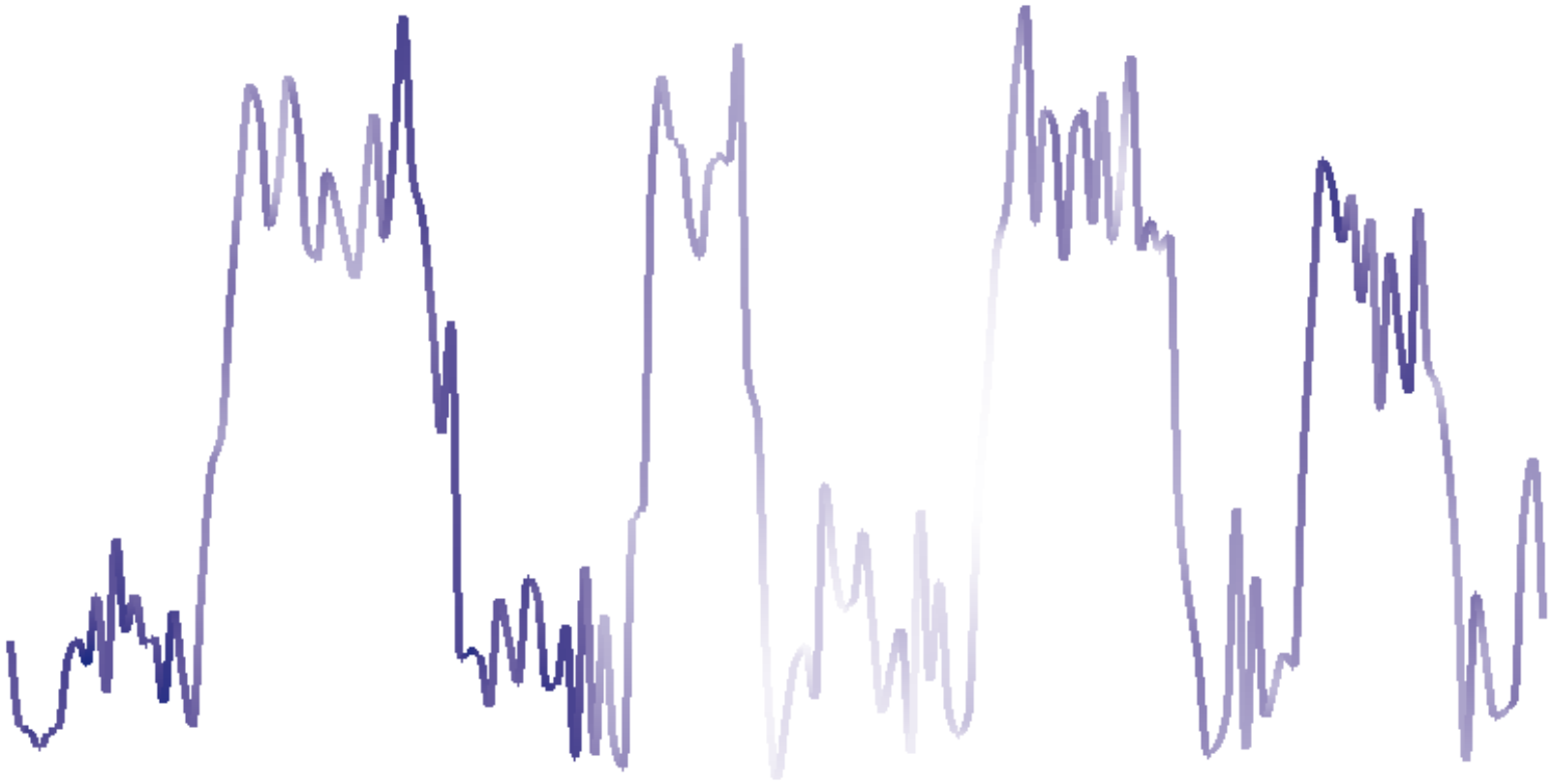
color of marks



[Sanyal et al., 2009]

Quantitative Time-Oriented Data

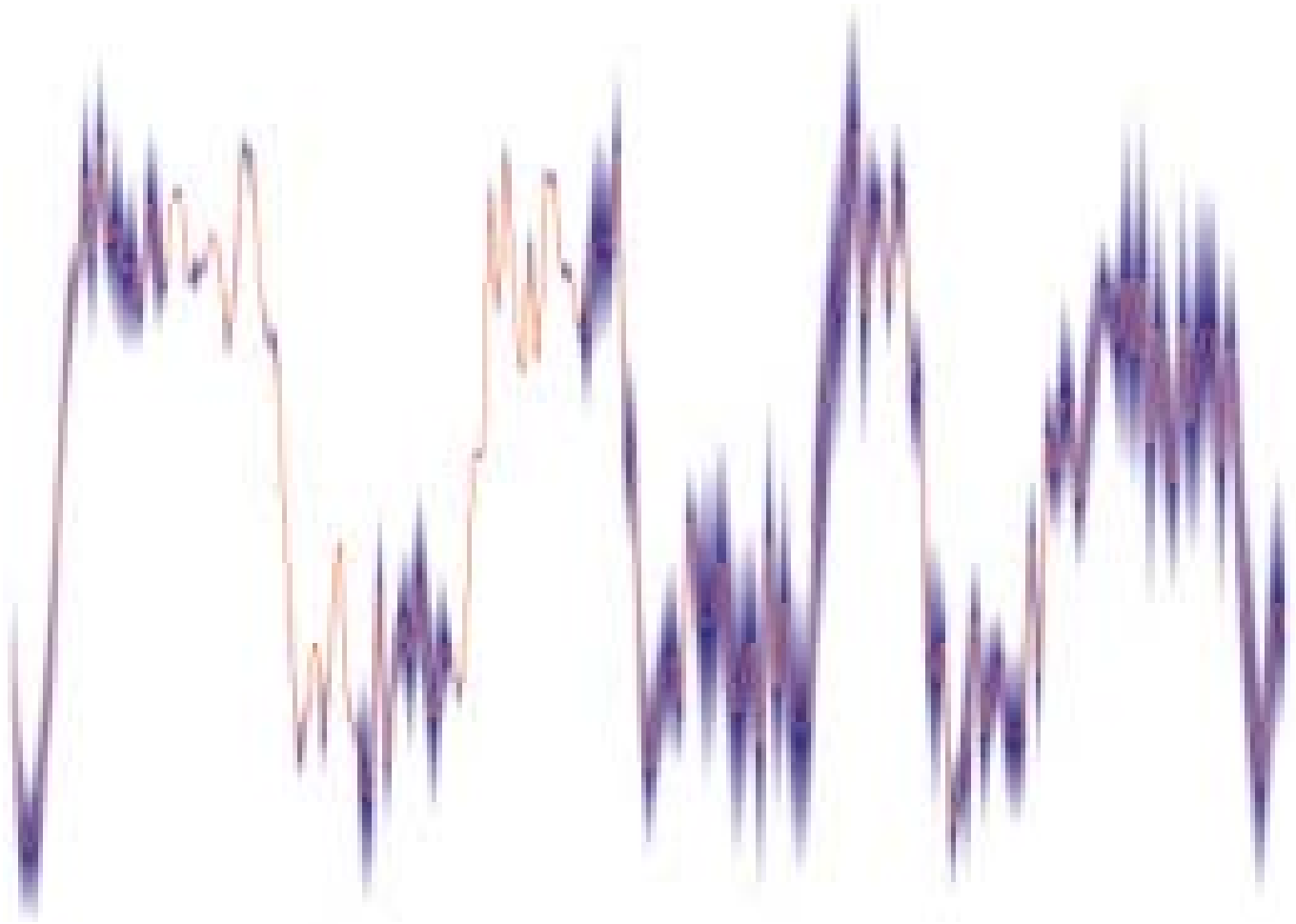
color of line



[Sanyal et al., 2009]

Quantitative Time-Oriented Data

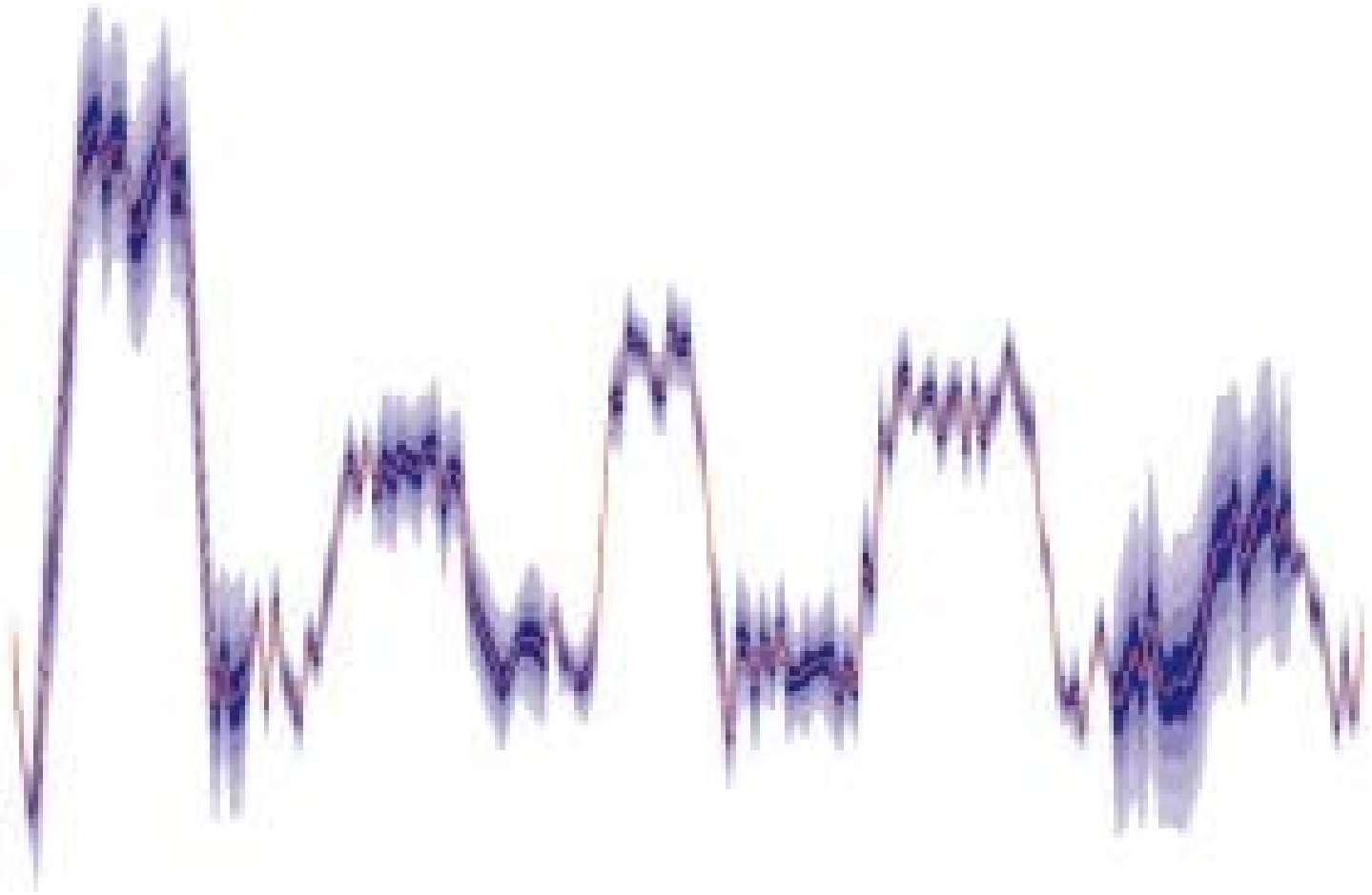
width of gradient



[Sanyal et al., 2009]

Quantitative Time-Oriented Data

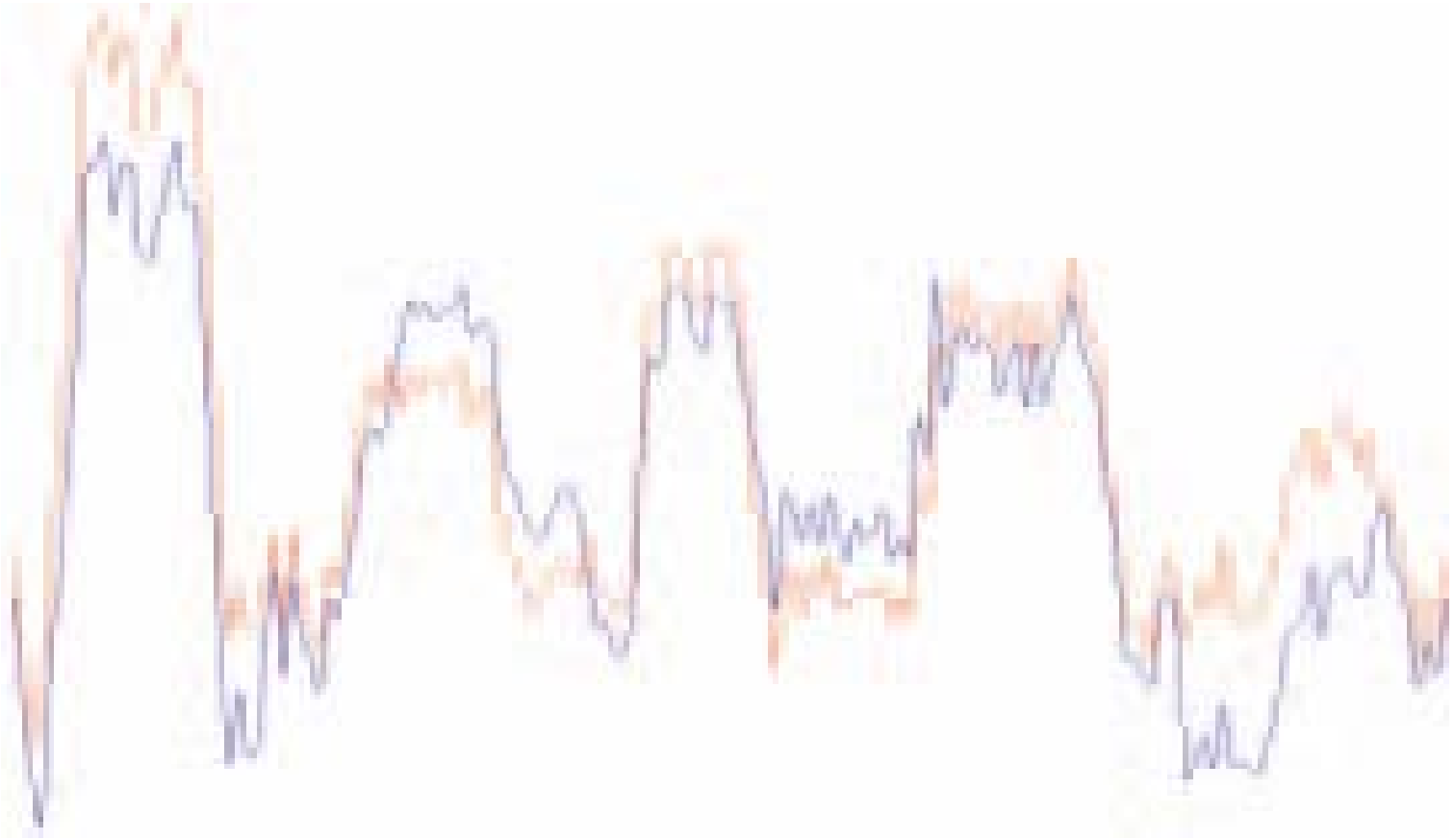
width of striped gradient



[Sanyal et al., 2009]

Quantitative Time-Oriented Data

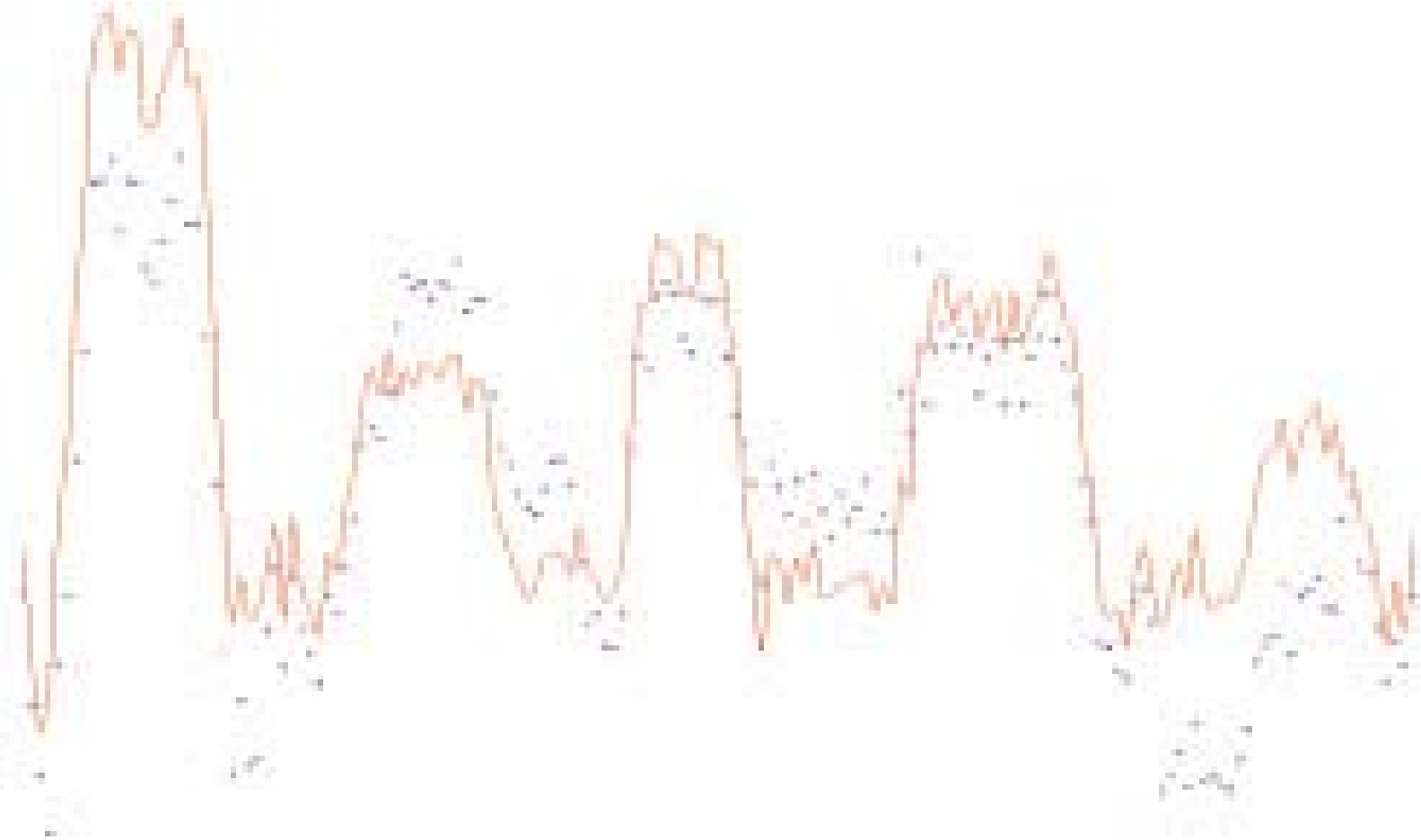
animation of additional line



[Sanyal et al., 2009]

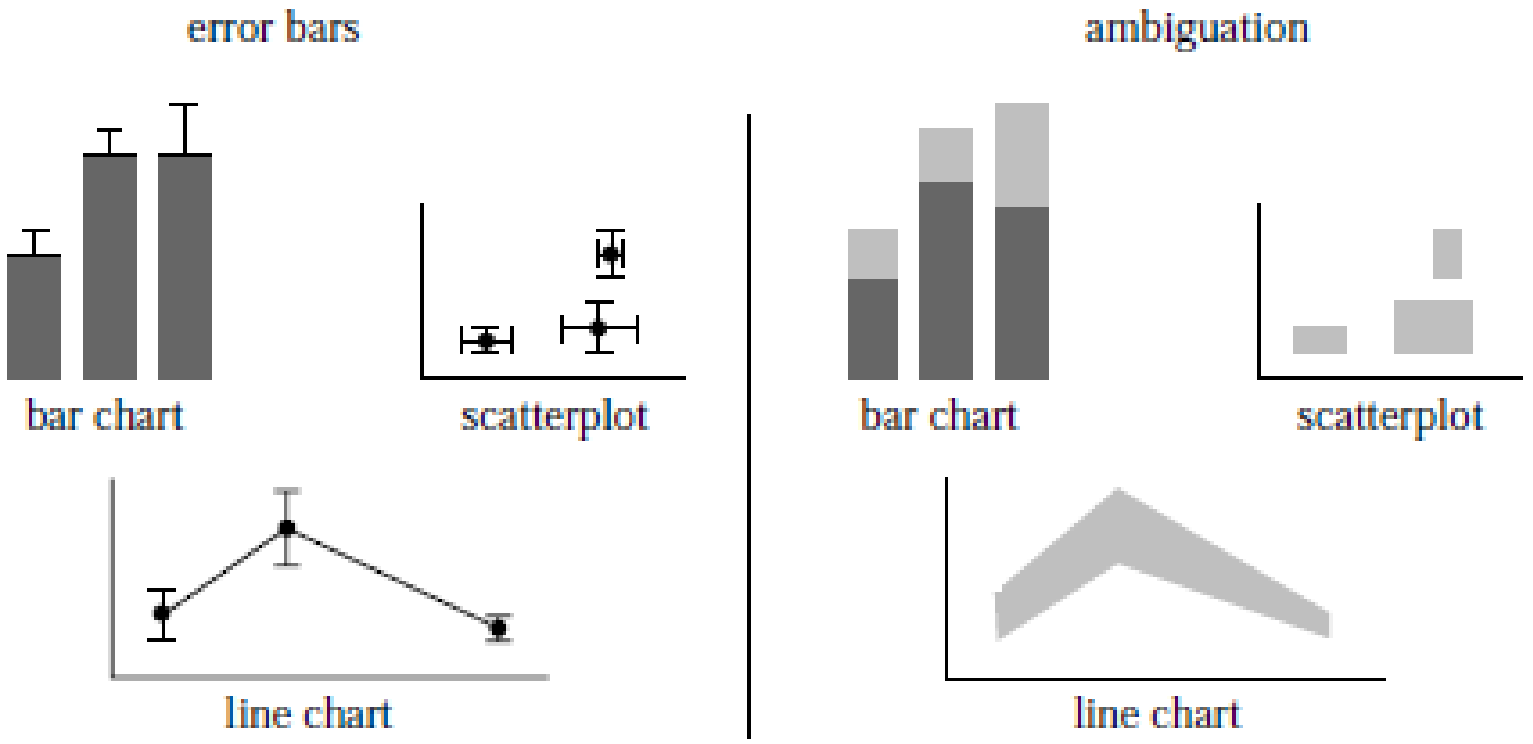
Quantitative Time-Oriented Data

animation of additonal marks



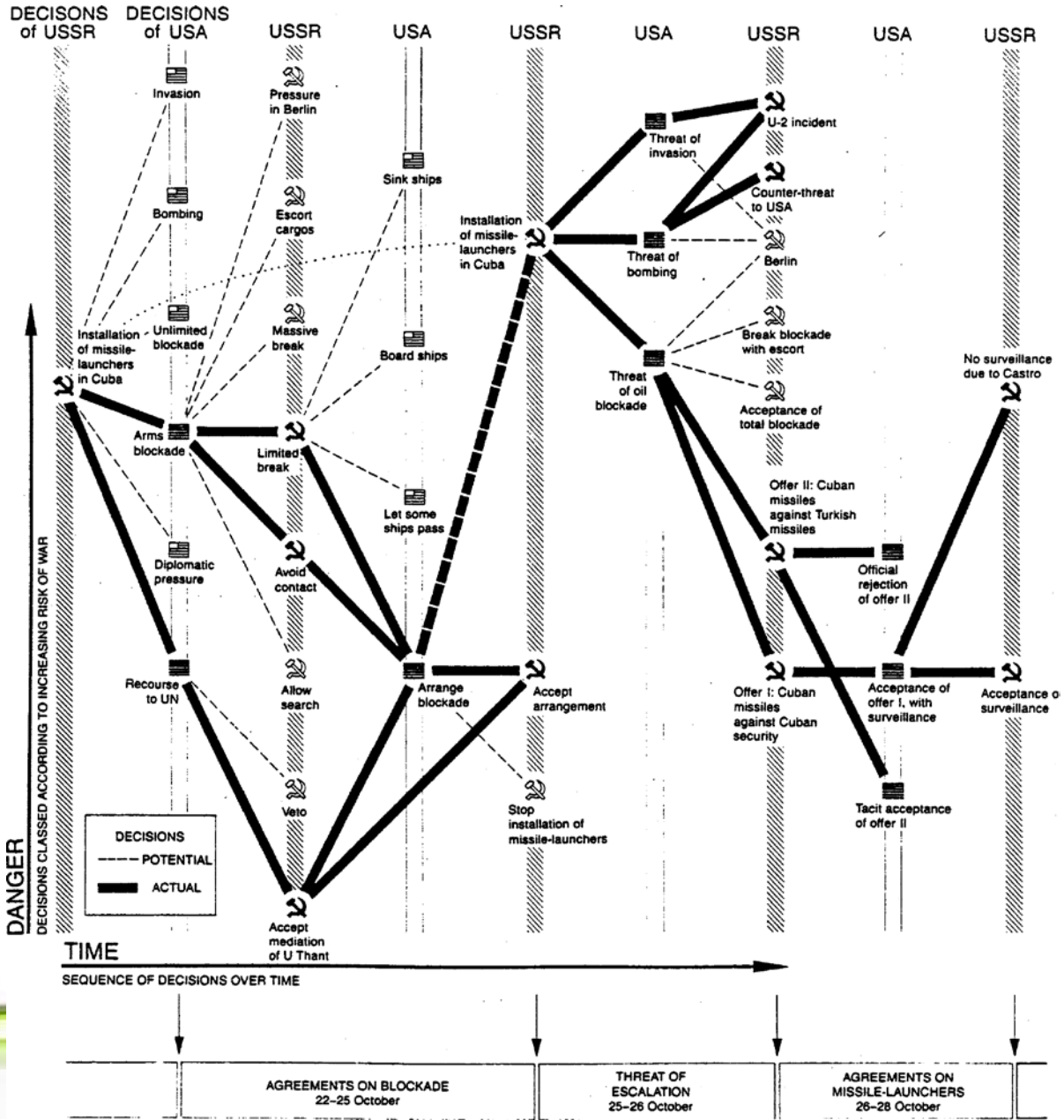
[Sanyal et al., 2009]

Statistical vs. Bounded Uncertainty



[Olston and Mackinlay, 2002]

Qualitative T-O Data : Cuban Missile Crisis

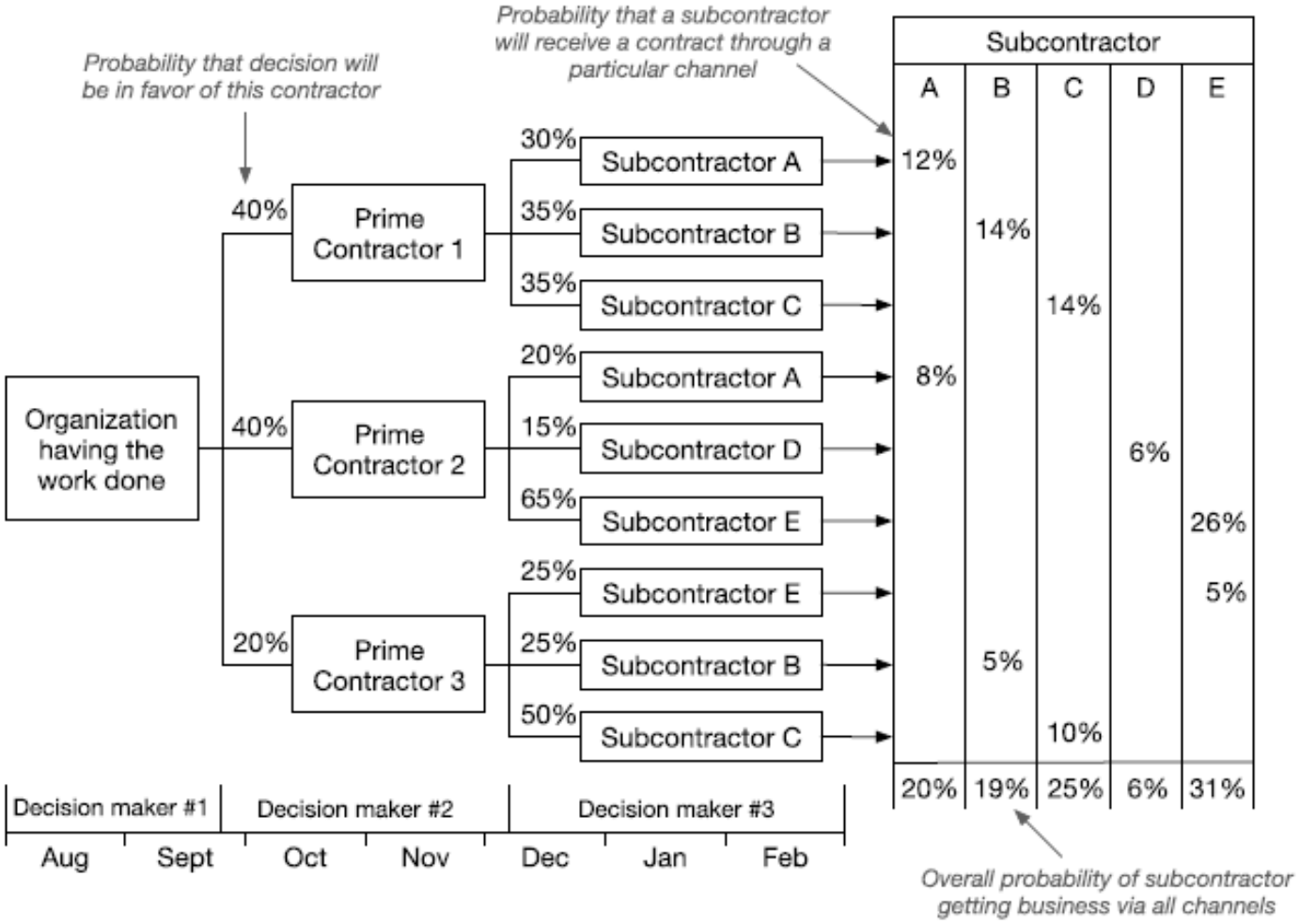


[Bertin, 1983]

side-by-side displays of (competing) results

Qualitative Time-Oriented Data: Decision Chart

[Harris, 1999], [TimeViz, Aigner, et al., 2011]



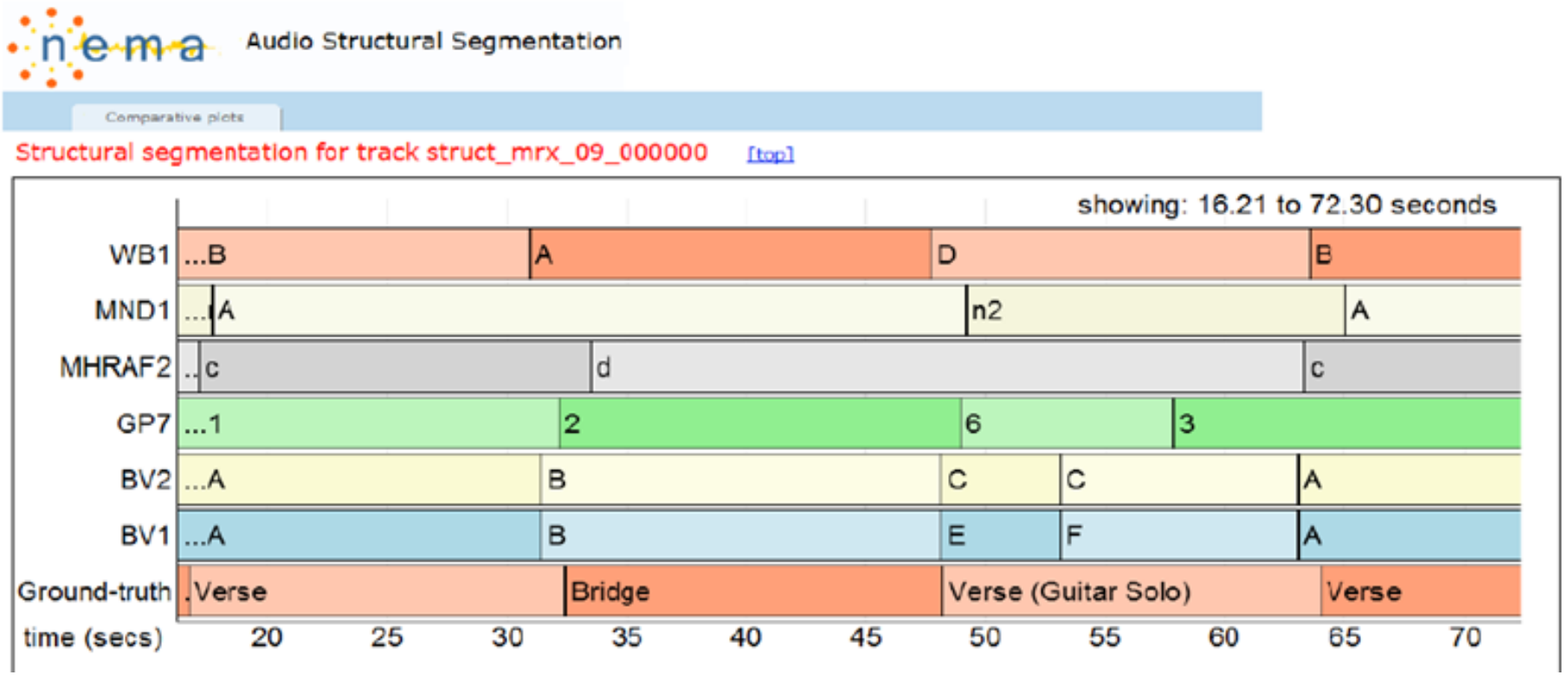
side-by-side of competing results

Fig. 7.8: Future decisions and corresponding alternative outcomes are depicted over time along with their probabilities.
Source: Adapted from Harris (1999).

Qualitative Time-Oriented Data: Segmentation of Songs

side-by-side of
competing results

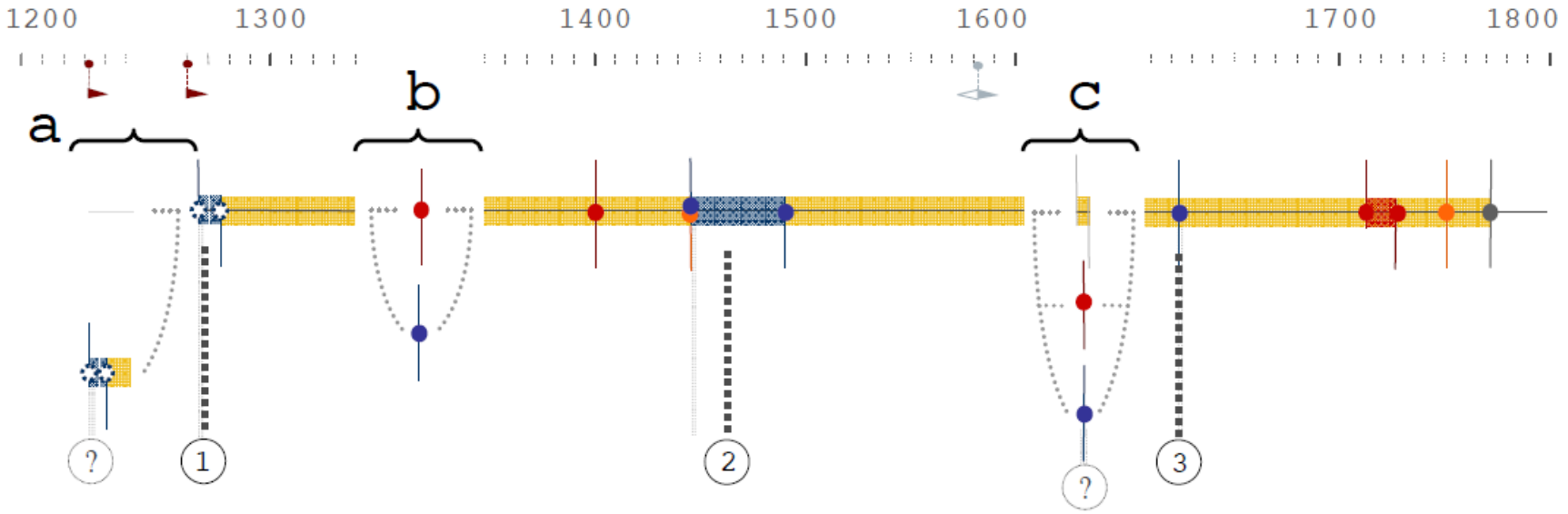
[http://www.clir.org/pubs/reports/pub151/case-studies/salami]



Qualitative Time-Oriented Data: Multi-Hypothesis Chronology Diagram

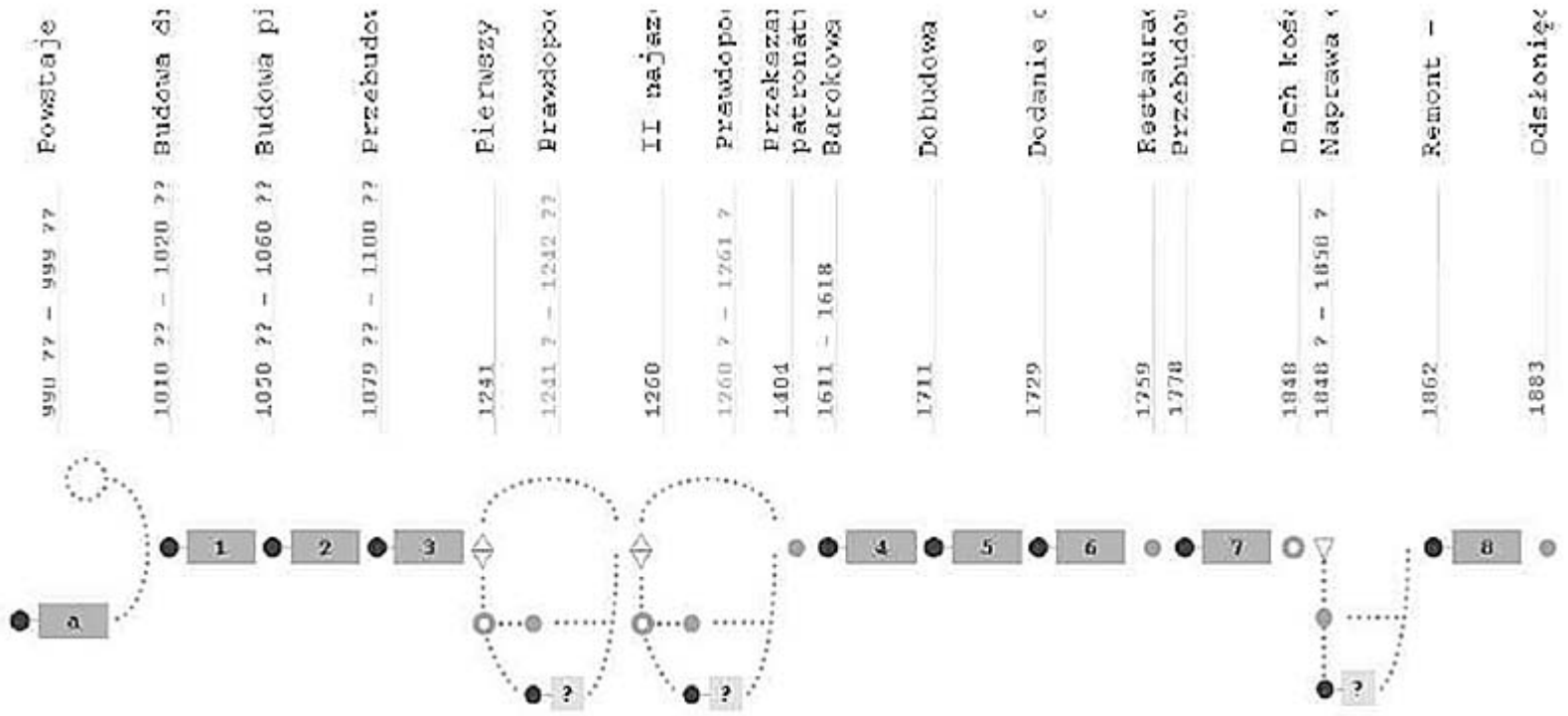
side-by-side of
competing results

[Dudek and Blaise, 2011]

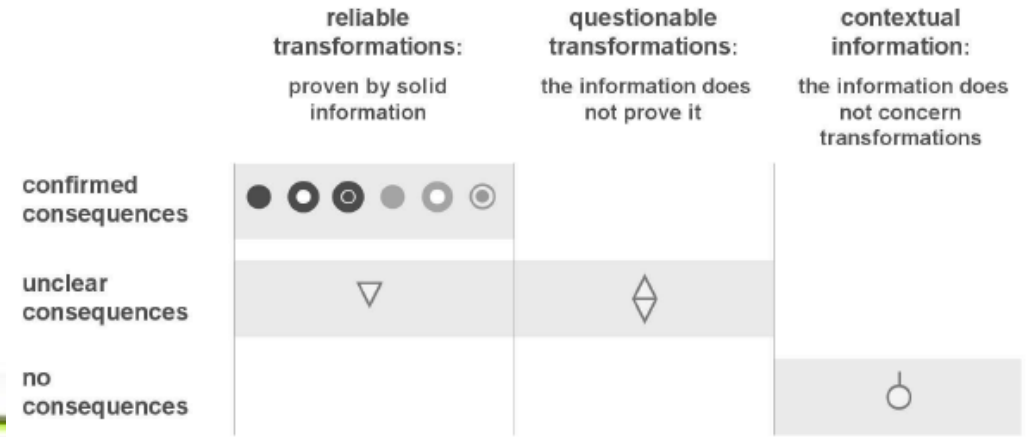


Qualitative Time-Oriented Data: Graph of Potential Interactions

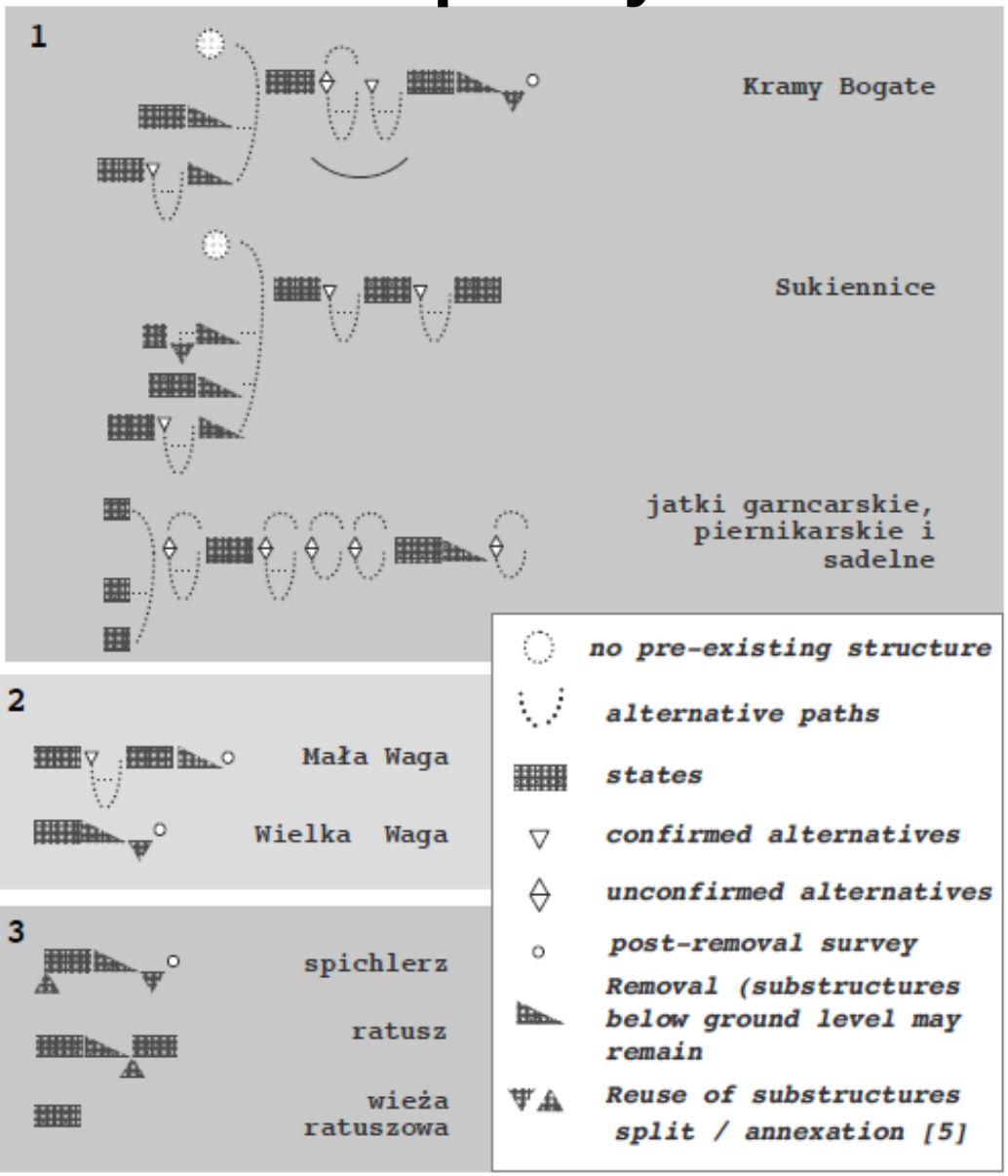
[Dudek and Blaise, 2011]



side-by-side of competing results



Qualitative Time-Oriented Data: Visual Measure of Complexity

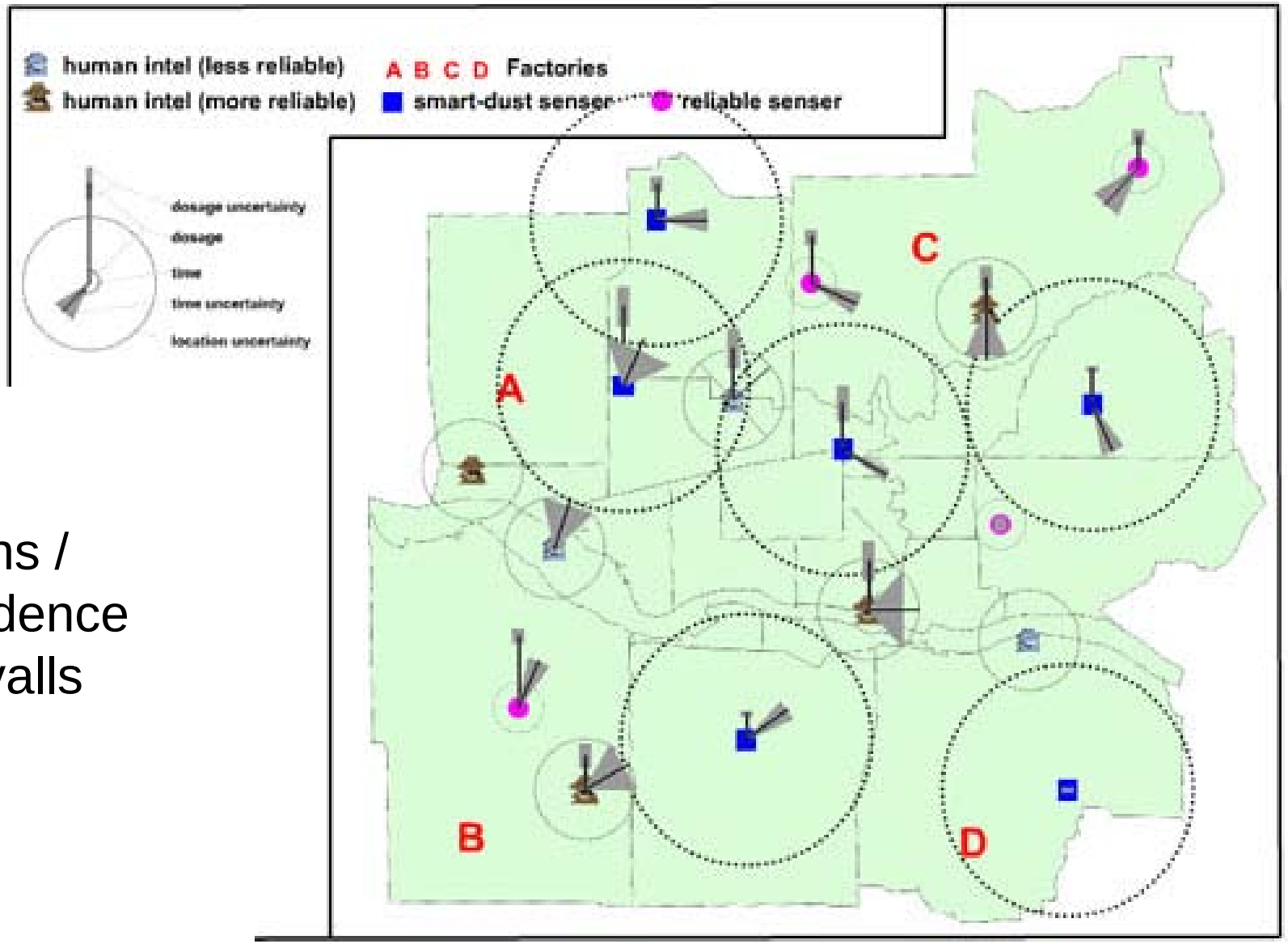


side-by-side of competing results

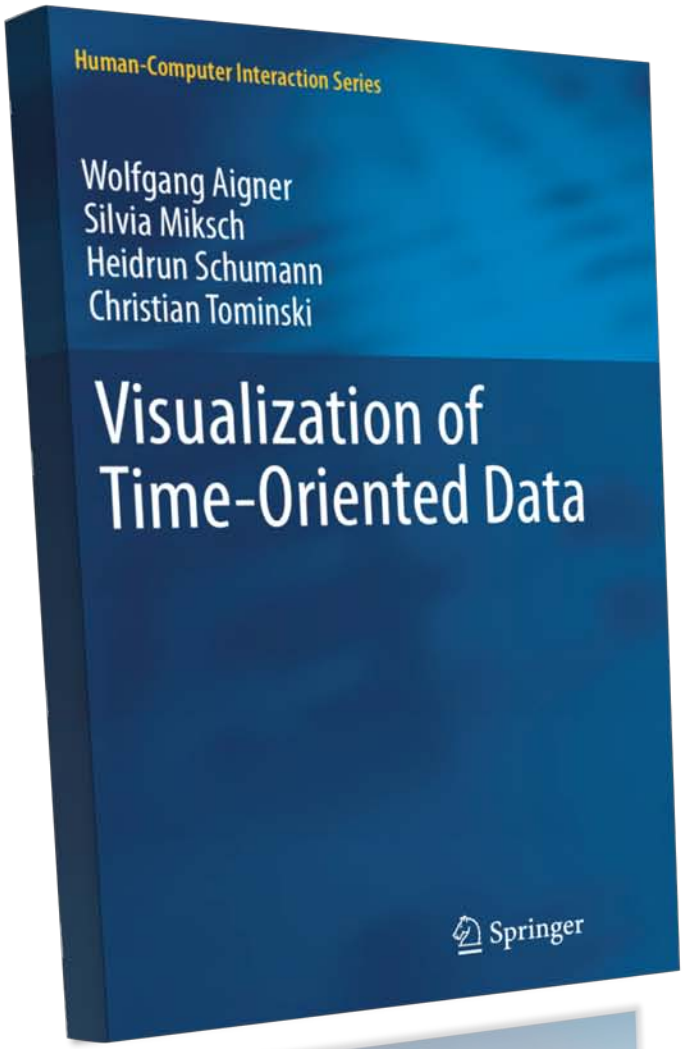
[Dudek and Blaise, 2011]

Spatial, Temporal & Quantitative Uncertainty

[MacEachren et al., 2004]



Glyphs / confidence intervalls



Wolfgang Aigner • Silvia Miksch
Heidrun Schumann • Christian Tominski

Visualization of Time-Oriented Data

with a foreword by Ben Shneiderman

Springer

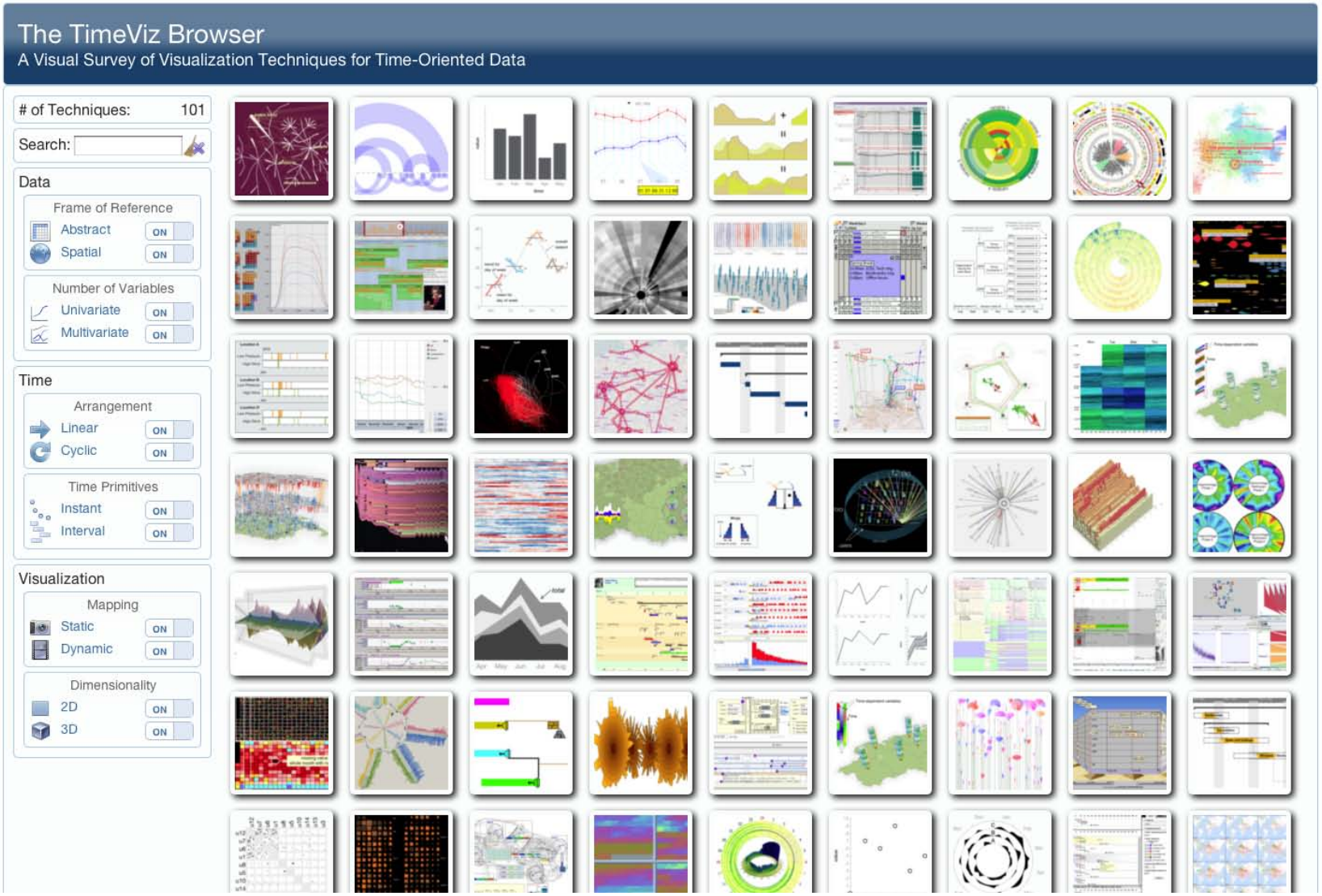
1st Edition, 2011, XVIII, 286 p. 221 illus., 198 in color.
Hardcover, ISBN 978-0-85729-078-6.

Table of Contents

www.timeviz.net

TimeViz Browser

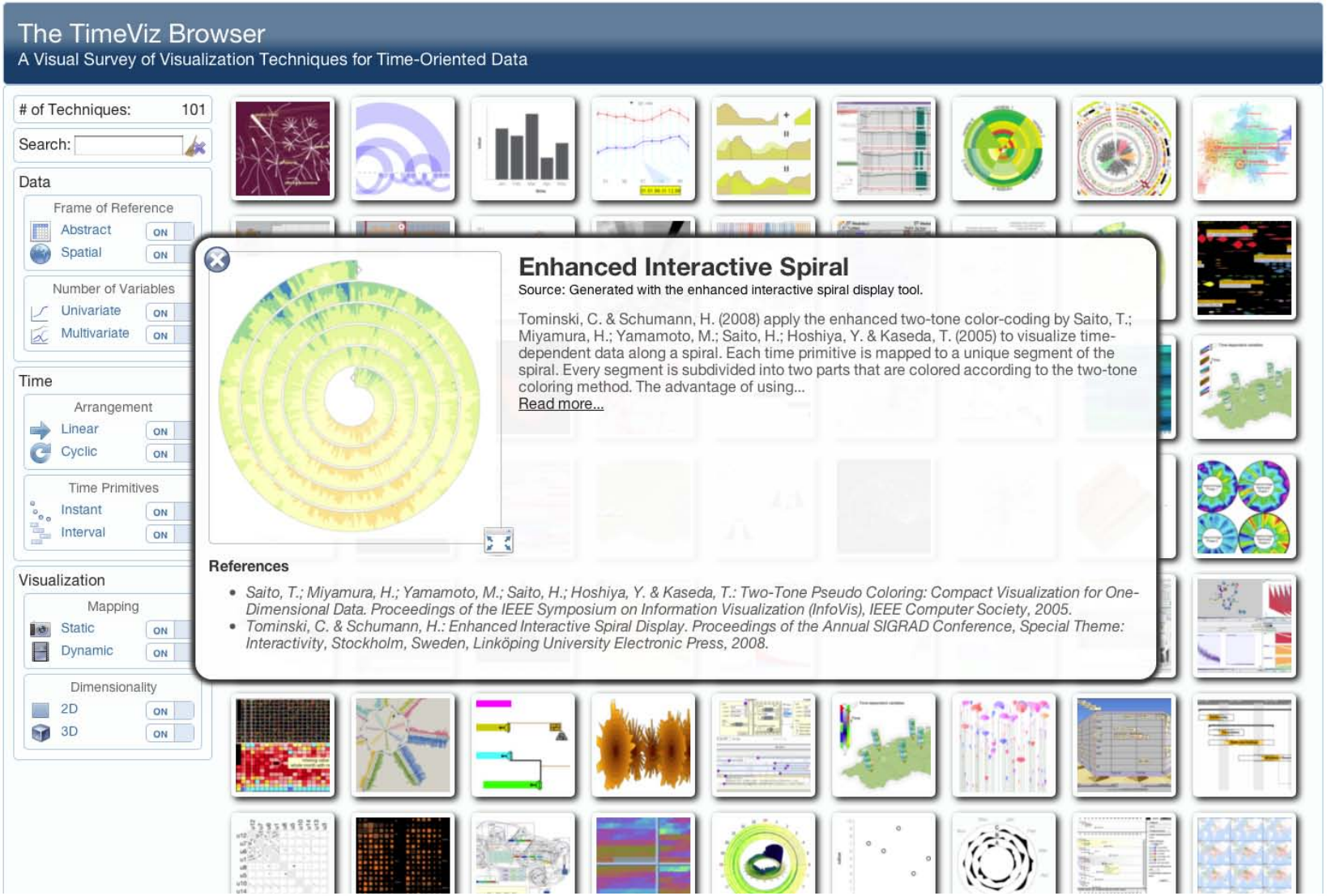
CVAST
www.cvast.tuwien.ac.at



survey.timeviz.net

TimeViz Browser

CVAST
www.cvast.tuwien.ac.at



survey.timeviz.net

Summary

Time has special characteristics

Temporal uncertainty mostly visualized by glyphs

Time-oriented data:

- Quantitative -- qualitative
- Abstract – spatial

Statistical uncertainty – bounded uncertainty

Need to further evaluate different methods to visually encode uncertainty

Contact

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