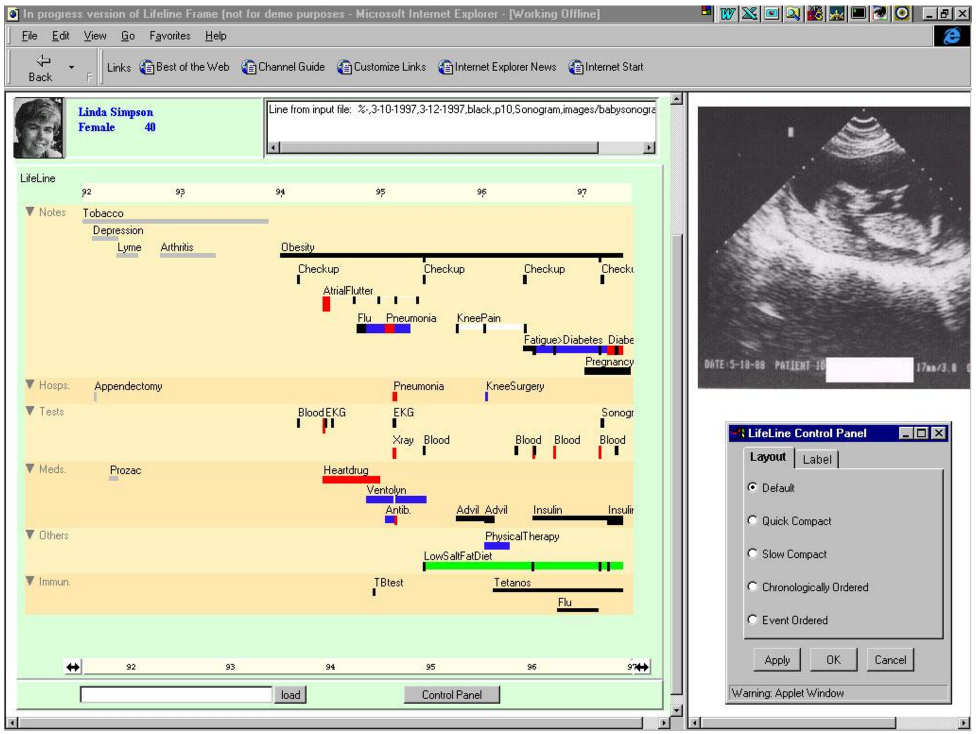
Visualization of Temporal Event Sequences



Introduction

Temporal event sequences

- represent behavior of customers, visitors of websites, diagnosis and treatment of patients, behavior of users based on log-files, project management, criminal activities, news

They are analyzed to

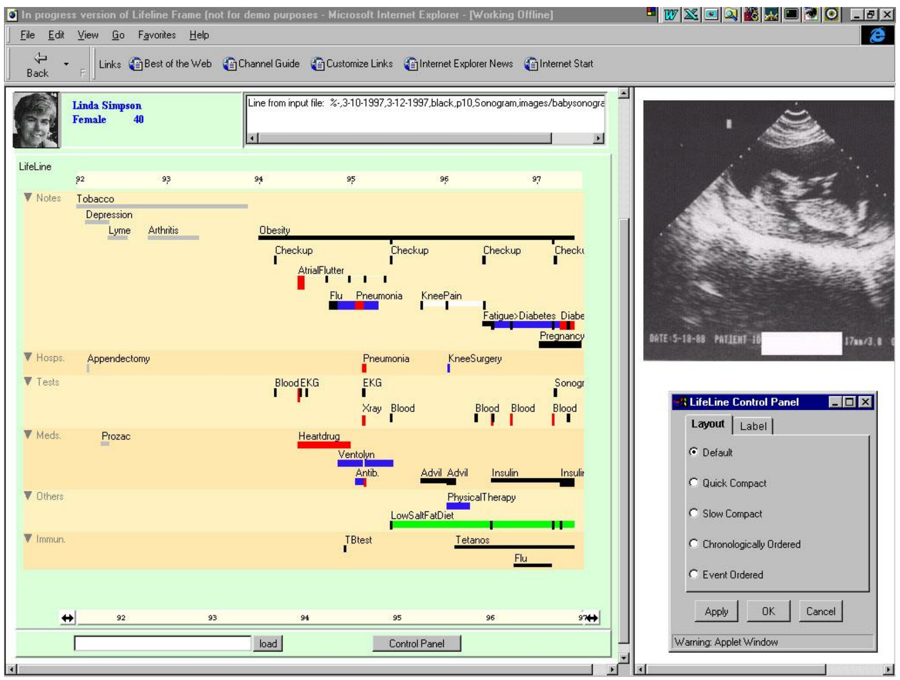
- understand which events and temporal patterns occur often and which patterns deviate from „normal“
- compare sequences leading to a different outcome (visitor of the website buyed something or not, patient in the emergency room of a hospital died or survived).
  - Which earlier events are correlated with a positive or negative outcome?

Introduction

- Time should not be considered as just another dimension!
- Time has unique characteristics,
  - Temporal changes include periodicity and other patterns that should be conveyed.
- A large set of information visualization techniques exploits and emphasizes the temporal character.
- Event sequences are a special, discrete variant of time-oriented data.

Introduction

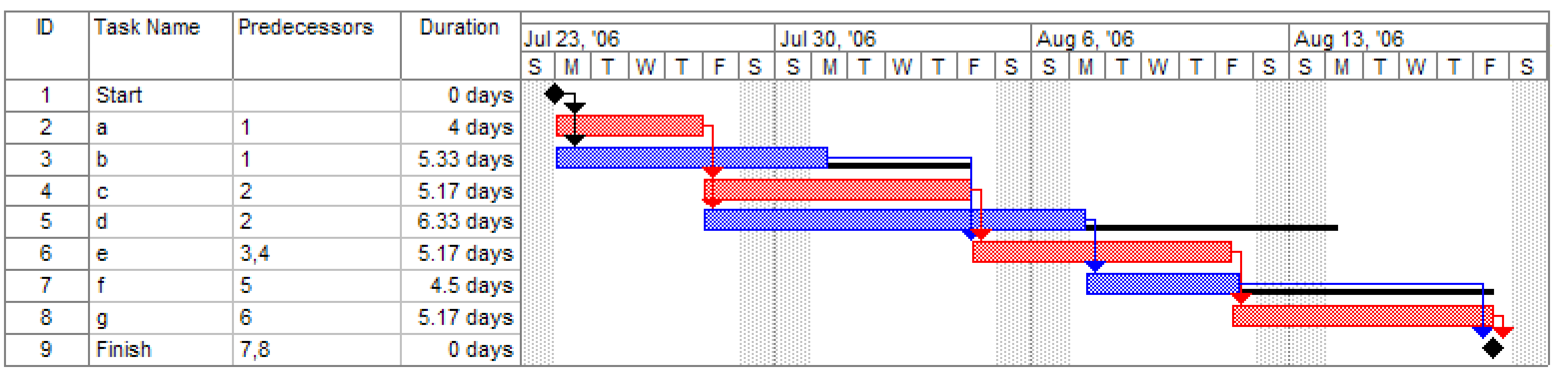
- Early systems: restricted to single event sequences, provide filtering, e.g. adjustment of time ranges and attribute-based filters and give an overview (LifeLines, …)
- Recent systems: support comparison of sequences and incorporate analytics, e.g. temporal association rule mining and provide analysis at different LODs



Events categorized: event-type color-coded. Duration conveyed along a time scale. Labels are essential (From: Plaisant, 1996).

Gantt charts for project planning and control.

- Concurreny and sequence of activities
- Events: start and end of working packages and milestones. Colors denote different stakeholders.
- Duration of activities and dependencies are essential.
- Advanced: Support „what if“ scenarios, incorporate planning uncertainties (risks), percent-complete shading



(From: Wikipedia)

Introduction

Types of events:

- *Sentinel event*: Distinct and essential event, often the cause for following events, e.g. an accident, arrival of a patient in a hospital
  - Following events are displayed in relative time to the sentinel event
- Marker or milestone events: Essential events, often used for alignment of records, e.g. 1000th tweet, outbreak of a severe disease
- Event categories: To cope with many unique event types, *categories* are introduced, e.g. in medicine medication, diagnosis, treatment, change of a room in a hospital.
- Subcategories may comprise a group of drugs, diagnosis.

Outline

- Introduction
- Event Sequences as Special Time-Oriented Data
- Requirements
- Event-based visualization
  - Overview
  - Simplification and Aggregation
- Interactive exploration of event-based visualization
- Incorporation of analytical results
- Examples

Event Sequences as Special Time-Oriented Data

Event sequences: important example of time-oriented data (Aigner, 2011).

Time-oriented data also includes *continuous* information, such as stock prices or energy consumption over time, where *trends* and *periodic behavior* are investigated.

Temporal events, in contrast, is *discrete data*. An event is time-stamped and may have a duration.
→ *point events* and *interval events*.

Visual analysis is challenging when

- a large number of events or
- a large number of unique event patterns exist

→ simplification and aggretation of event-typed data

Event Sequences as Special Time-Oriented Data

Time-oriented data visualization use (Aigner, 2011)

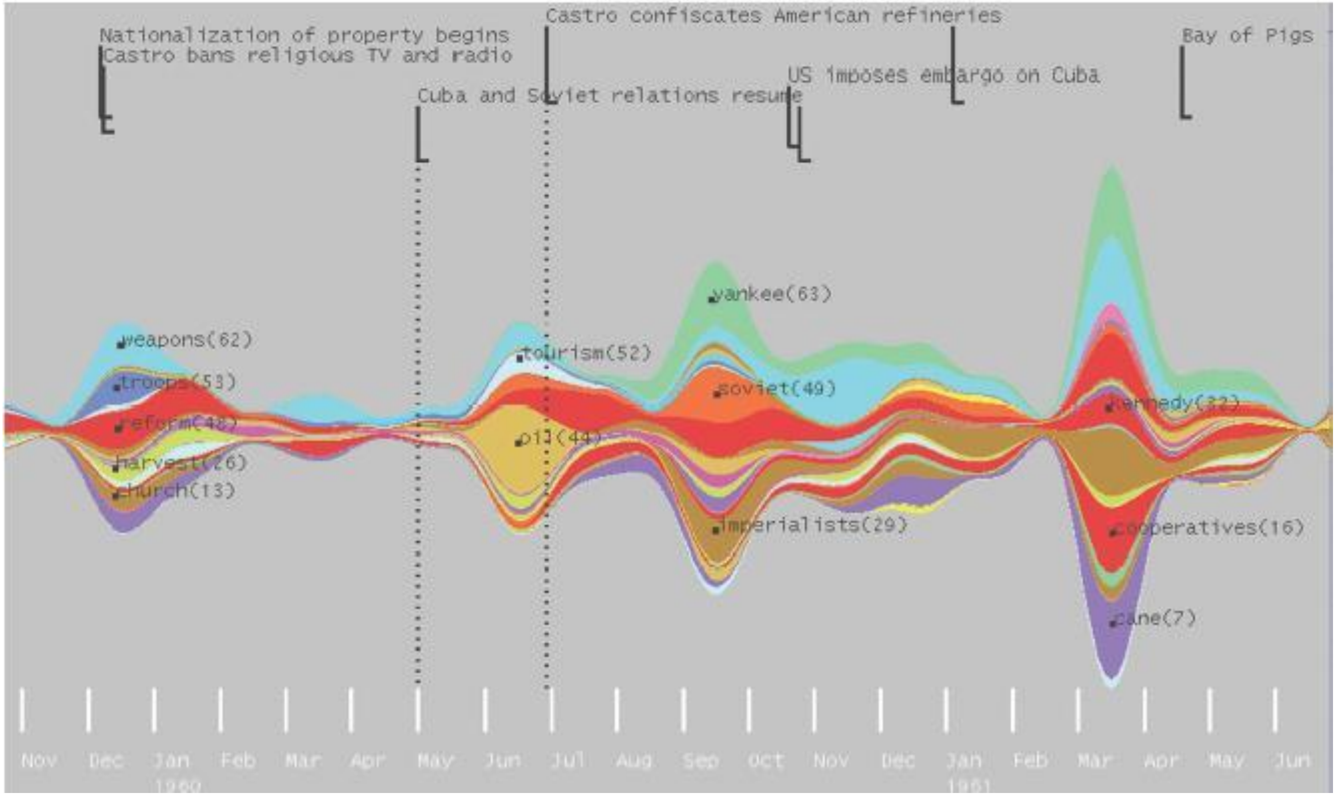
- The x-axis for displaying time when time is linear,
- A spiral for displaying time, when time is cyclic and periodic patterns are analyzed, e.g. days of the week, hours of a day, seasons of the year (Weber, 2001)

Event-based visualizations: typically linear (time line browsers)

Continuous temporal data involves temporal smoothing, outlier removal.

Discrete event-based data involves plausibility controls (e.g. patient died before getting a drug prescription → probably wrong data entry)

Event Sequences as Special Time-Oriented Data



Visualization of continuous temporal data where some (point) events are added. Frequency of word/categories in document collections over time visualized with ThemeRiver (From: InfoVis-wiki.net, Havre, 2002)

Event Sequences as Special Time-Oriented Data

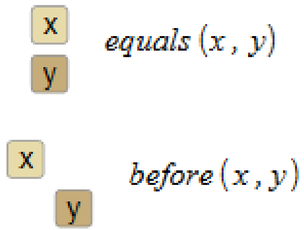
Linear and Non-linear presentation

- Presentation of events along a linear time scale is ideal for comparison of event sequences and to convey intervals between events.
- For single event sequences representing long periods with a strongly different event density, a linear scale is not ideal.
- To better convey sequences
  - Eventful periods are stretched.
  - Long periods without events are compressed (1D fisheye).

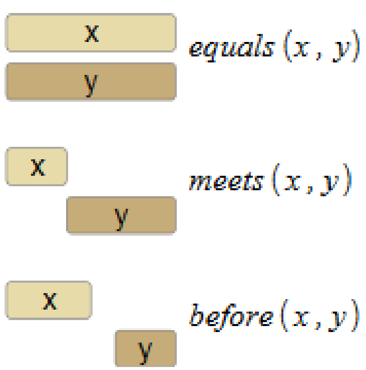
Event Sequences as Special Time-Oriented Data

- Event-based visualizations are based on temporal logic, temporal reasoning in AI and temporal queries for databases.
- For *interval events*, the temporal algebra from James Allen lists 13 possible relations between two interval events (Allen, 1983, see Link).
- Often, a subset is supported in visual query specifications.

Relations between point events



Relations between interval events (by exchanging x and y, we receive the remaining 6 events)



Requirements

- Provide an overview (many records and events per record)
- Provide filtering for
  - records,
  - event types,
  - temporal intervals of specific sequences, e.g. those that should not happen (quality control)
- Provide details (event attributes) for selected events
- Include analytic results (e.g. frequent sequence mining)
- Consider uncertainty, e.g. in project management w.r.t. start and duration of activities

Requirements (cont.d)

- Support
  - inter-record understanding (repeating patterns in a single long sequence) and
  - intra-record understanding (comparison of records and groups of records)
- Intra-record understanding requires proper alignment
- Comparison needs metrics defining how similar to records are

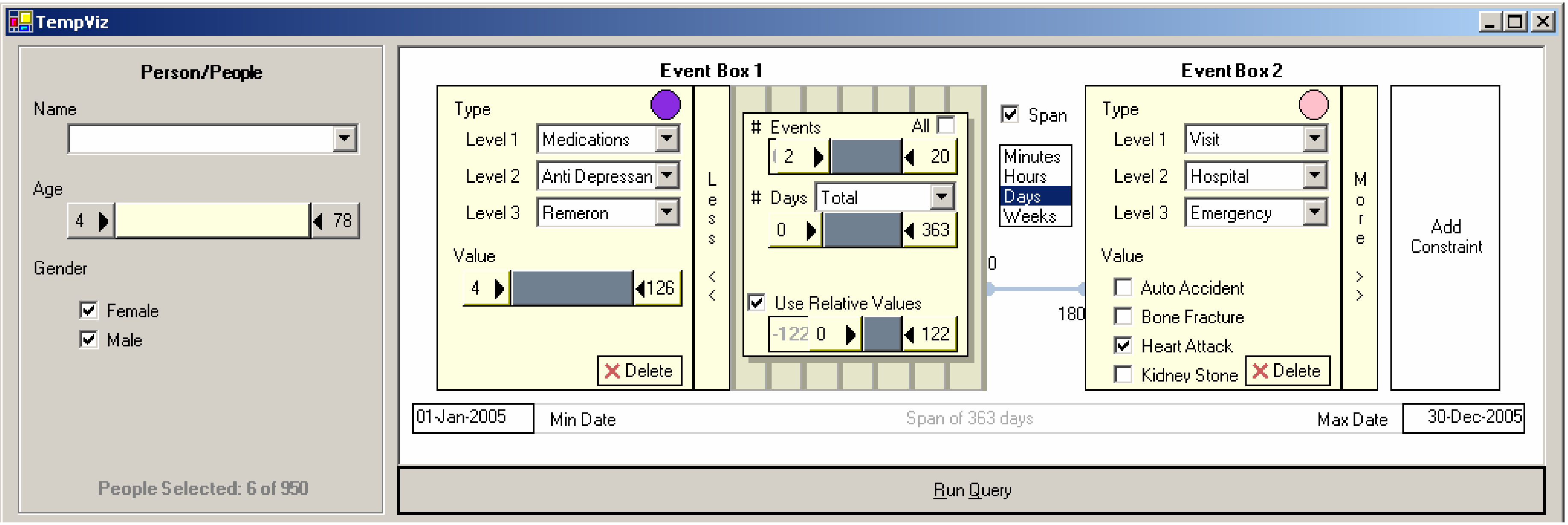
Event Specification

- Detection of temporal patterns and understanding of large event databases require filtering (queries)
- SQL queries for temporal aspects get complex and are hard to master
- Visual queries including event categories, subcategories and specific names as well as intervals and thresholds for event attributes.
- Example: PatternFinder (Fails, 2006) supports pattern finding across multiple records.

  EventSeq = **Event** {[**TimeSpan**] **EventSeq**}

→ Event sequences consist of at least two events with an optional time span between

Event Specification



PatternFinder: Event specification using a three leveel event hierarchy, sliders for event frequencies and duration and an optional second event connected to the first with a time span and a certain interval (From: Fails: 2006).

Any change in the interface adapts the event visualization.

Event Specification

Pattern Finder (see Link):

Users may also search for trends, e.g.

- increasing blood pressure,
- monotically increasing blood pressure,
- 50% drop white blood cells

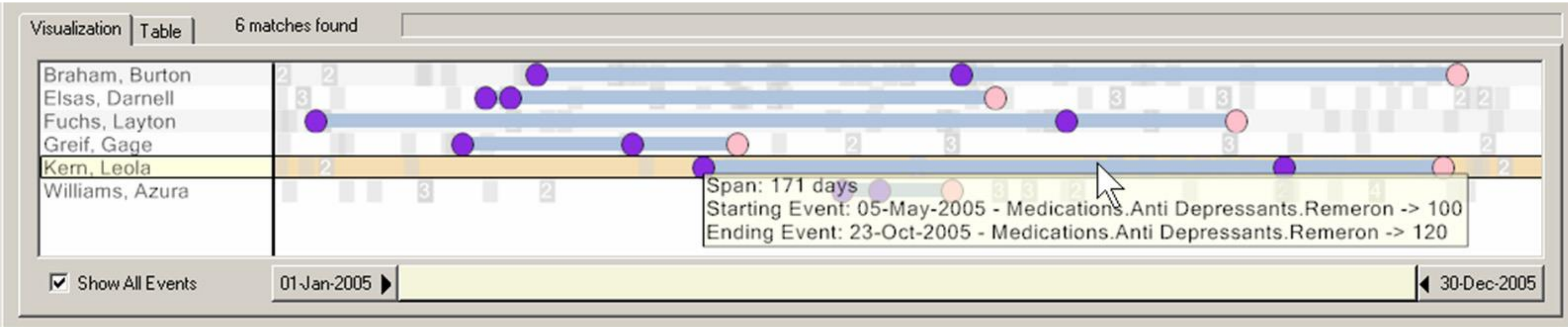
within a certain period

Event Specification

```
SELECT  P.*
FROM    Person P, Event E1, Event E2,
        Event E3, Event E4
WHERE   P.PID = E1.PID
        AND P.PID = E2.PID
        AND P.PID = E3.PID
        AND P.PID = E4.PID
        AND E1.type = "Medication"
        AND E1.class = "Anti Depressant"
        AND E1.name = "Remeron"
        AND E2.type = "Medication"
        AND E2.class = "Anti Depressant"
        AND E2.name = "Remeron"
        AND E3.type = "Medication"
        AND E3.class = "Anti Depressant"
        AND E3.name = "Remeron"
        AND E2.value > E1.value
        AND E3.value >= E2.value
        AND E2.date > E1.date
        AND E3.date >= E2.date
        AND E4.type = "Visit"
        AND E4.class = "Hospital"
        AND E4.name = "Emergency"
        AND E4.value = "Heart Attack"
        AND E4.date >= E3.date
        AND 180 <= (E4.date - E3.date)
```

The corresponding SQL statement (search for persons with a heart attack within 6 months after receiving a certain drug against depression) (From: Fails, 2006).

Event Specification



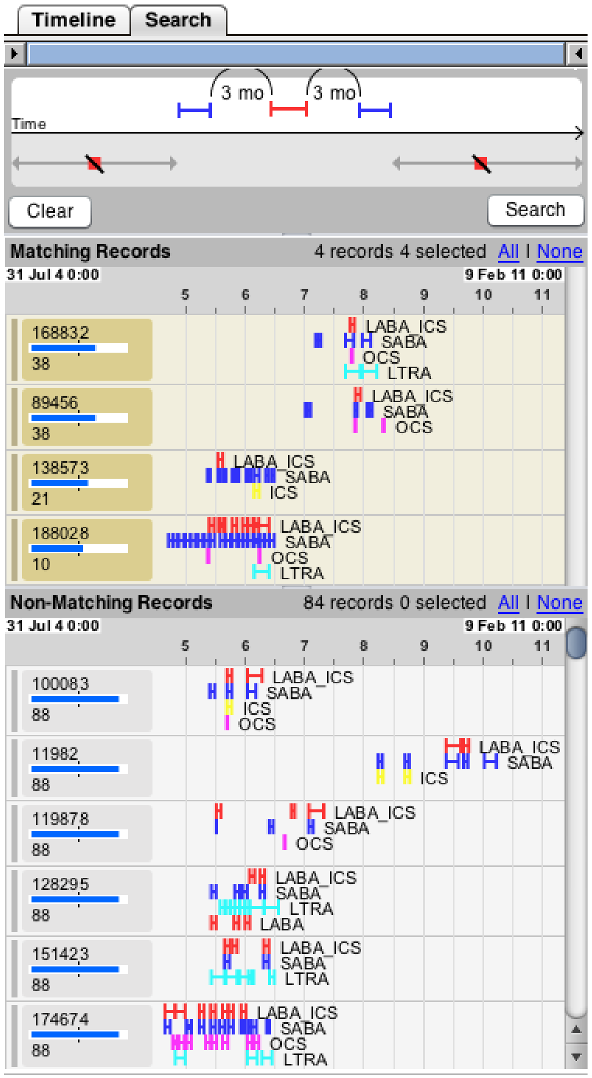
Visualization of the query result with ball-and-chain display of interval events. Tooltips show details, e.g. the span and the exact dates. In addition, a table view is generated. Both are synchronized (From: Fails, 2006).

Visualization | Table | 6 matches found

FullName	LastName	FirstName	Age	Gender	TotalNumEve	TotalNumMat
Braham, Burt	Braham	Burton	23	Male	41	1
Elsas, Darnell	Elsas	Darnell	17	Male	44	1
Fuchs, Layto	Fuchs	Layton	27	Male	29	1
Greif, Gage	Greif	Gage	43	Female	24	1
Kern, Leola	Kern	Leola	52	Female	31	1
Williams, Azu	Williams	Azura	78	Female	34	1

Event Specification: Interval Events

- Queries get more complex but significantly more powerful if intervals are considered.
- **EventFlow**: The top panel enables to select events and draw arcs representing duration between.
- Matching and unmatching records are displayed.
- Drug prescriptions for asthma treatment (sequences of heavy and mild drugs within a certain time span) (From: Monroe, 2013, CHI).



Event-based Visualization: Overview

Design decisions:

- Events are typically color-coded. An alternative would be encoding events via glyph attributes, Combinations are possible (event category mapped to color, specific event to glyph).
- Coding needs to be conveyed (color or glyph legend)
- Linear time axis or calendar-based views may be used.
- Calender-based views are preferred when the sequence of days, weekends, months is essential.
  - Example: Consumption of energy to control regenerative energy use
- Granularity: For most applications, „days“ is the finest granularity.

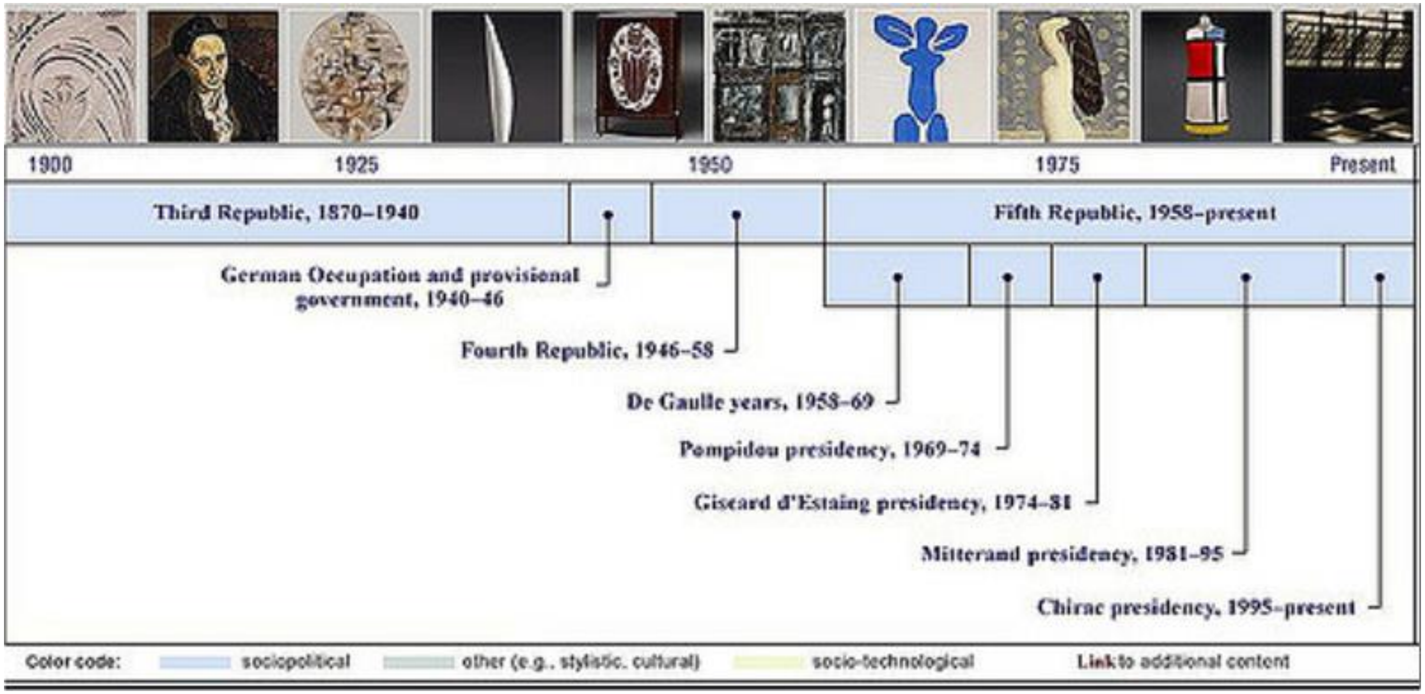
Event-based Visualization: Overview

More details on glyph design:

- An event such as an accident or the outbreak of a disease may have many attributes: type, subtype, urgency, associated cost.
- A glyph may convey a number of attributes, using its overall shape (triangle, ellipsoid, rectangle, …), boundary thickness, boundary color, foreground color or texture
- Glyph attributes should be predefined, but it should be possible (within limits) to adapt this mapping.

Event-based Visualization: Overview

Basic metaphor for most EB-Visualizations is the timeline (Tufte, 1983)



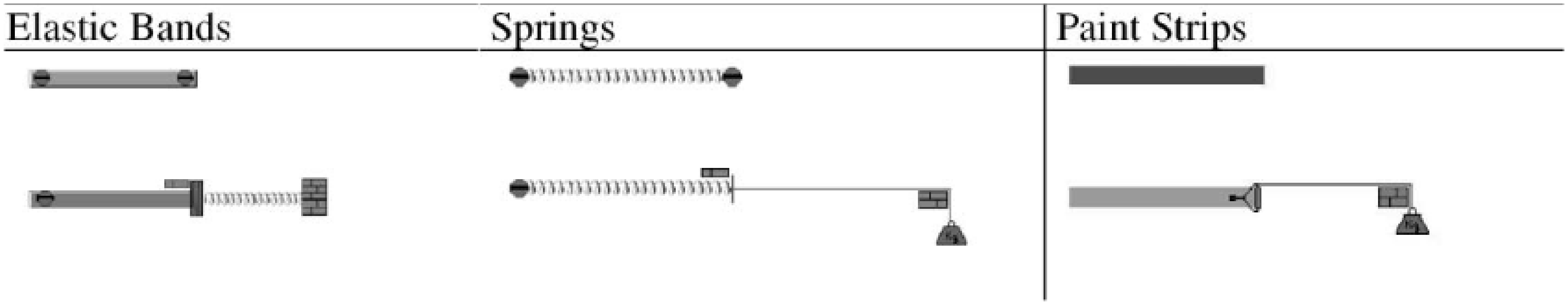
(From: Link)

Most time lines are horizontal (from past to present), they may be segmented and events are categorized.

Event-based Visualization: Overview

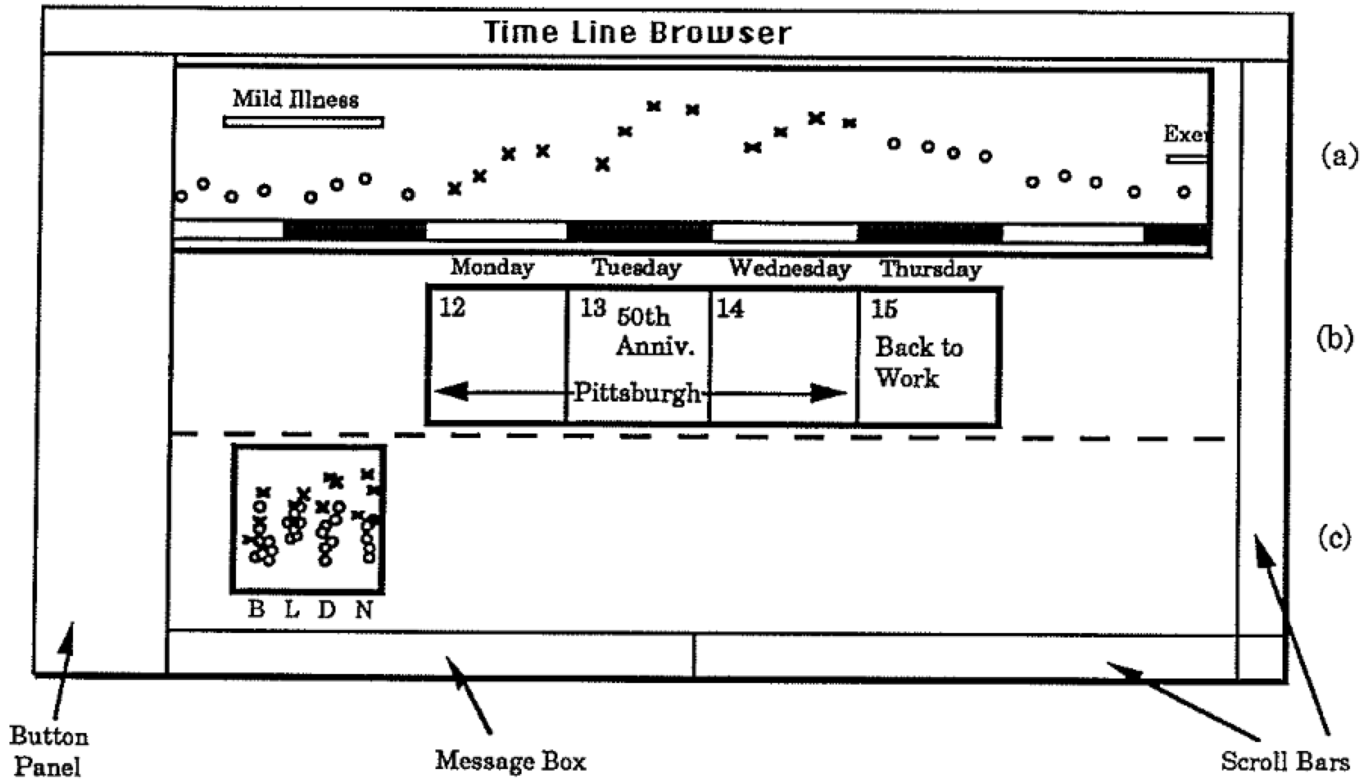
Metaphors:

- Visual representations may convey intervals as fixed or dynamic (to reveal uncertainty).



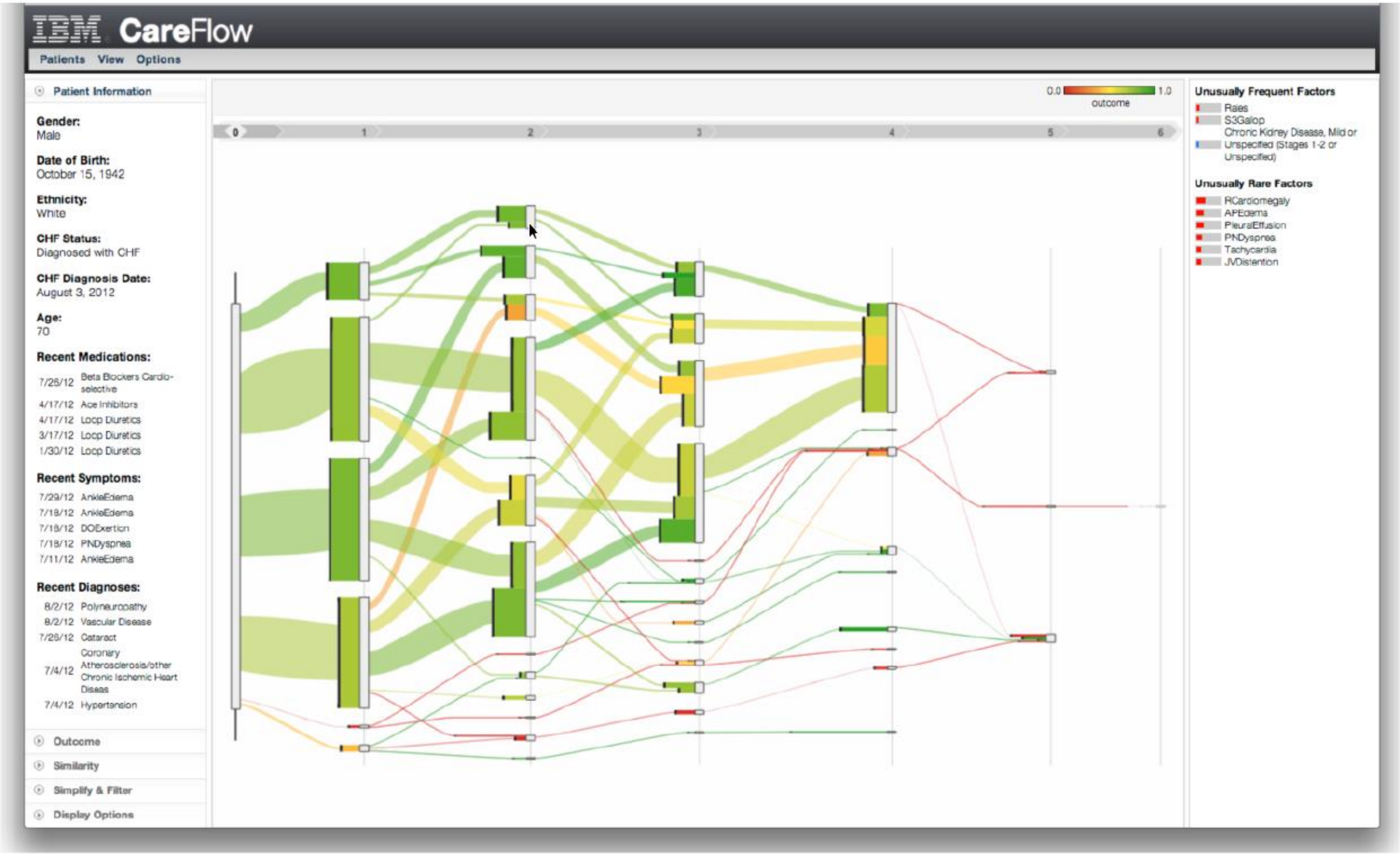
- Elastic bands, springs and paint strips as metaphors for interval events (From: Chittaro, 2003). Bands are fixated with screws (fixed intervals), whereas springs with wires reveal a range of possible positions.

Event-based Visualization: Overview



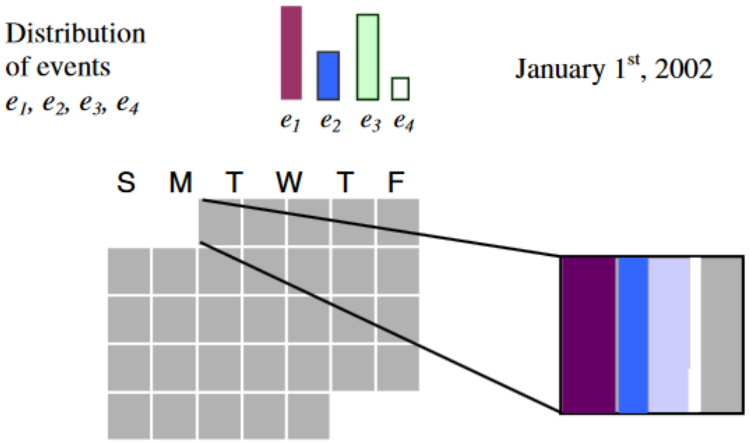
Basic concept of a time line browser (for displaying patient data) displaying point and interval events with facilities for filtering (left), scrolling. (a) diabetes logbook, (b) personal calendar of the patient (From: Cousins, 1991).

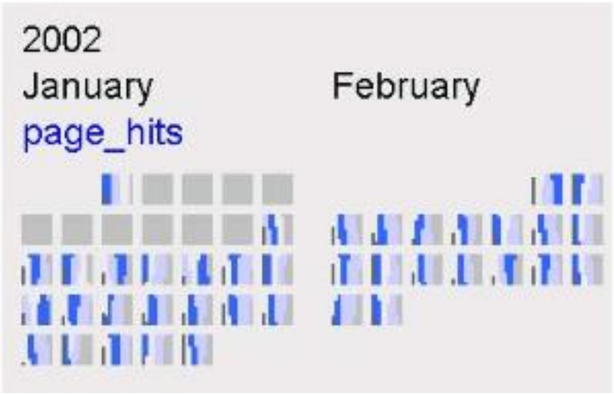
Event-based Visualization: Overview



Treatment plan and associated textual information (left). Color indicates patient state. Basic infovis technique: Parallel sets (From: Perer/Gotz, 2013)

Event-based Visualization: Overview





A calendar view to display the distribution of (point) events in days. The calendar metaphor enables good recognition of working days and related patterns. Start and end of individual events cannot be depicted. (From: Ankerst, 2008).

Event-based Visualization: Interaction

Major Interaction Tasks (Rind, 2013):

- Selection of subsets (of records, time, event types)
- Exploration (navigation in time, pan and zoom)
- Reconfiguration (sorting, adjustments)
  - Temporal alignment as essential example
- Encode (adapt color mapping, glyph mapping, …)
- Abstract/Elaborate (show/hide details, aggregate similar consecutive events, …)
- Filter (according to event attributes, event sequences, trends, such as rising values)
- Connect (show related contextual data, e.g. an X-ray for a patient)

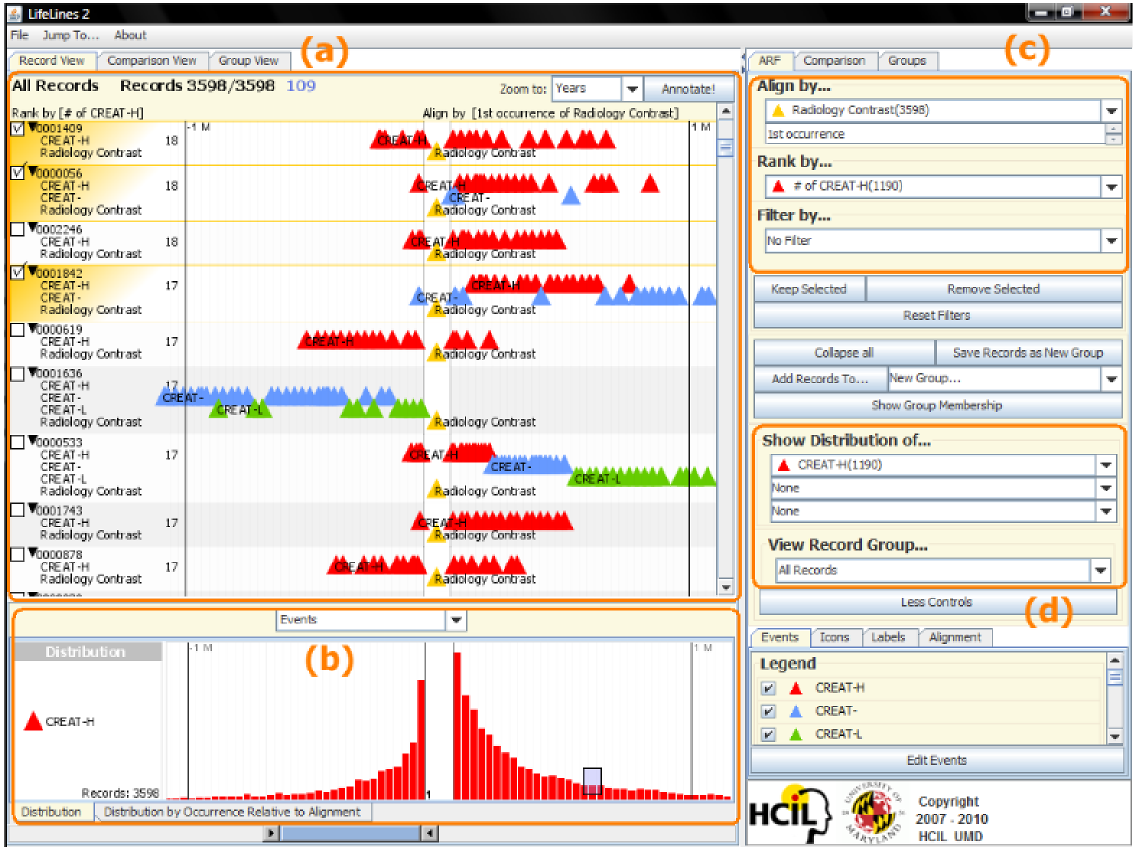
Event-based Visualization: Alignment

Temporal alignment:

- A series of data is compared according to temporal behavior relative to a marker/sentinel event.
- Instead of presenting data along an absolute time scale, it is relative to the chosen event, e.g. profes-sional development 10 years after graduation.
- Often combined with filtering: Data are only displayed if they contain the marker event.
- Combined with temporal windowing: only a certain period before and after the marker event considered.

Use of this strategy: supports the search for cause-and-effects. If something occured shortly after something else, it *may* be caused by the previous event.

Event-based Visualization: Alignment



Categorical temporal patient data aligned by an event (patient received examination with contrast enhancement). In (b) a histogram, a *temporal summary*, indicates frequency of events before and after event (From: Wang, 2009).

Event-based Visualization: Focussing

„Visual analytics is likely more rapid when data is reduced and patterns are more discoverable when data variety is trimmed“ (Shneiderman, 2015).

Focussing may be achieved by applying and combining:

- Selection of subsets of the data,
- Simplification strategies,
- Folding strategies,
- Partioning

Selection of subsets may be performed by a visual query interface or by automatic techniques, such as *feature selection*, *instance selection*, or f*requent pattern mining*

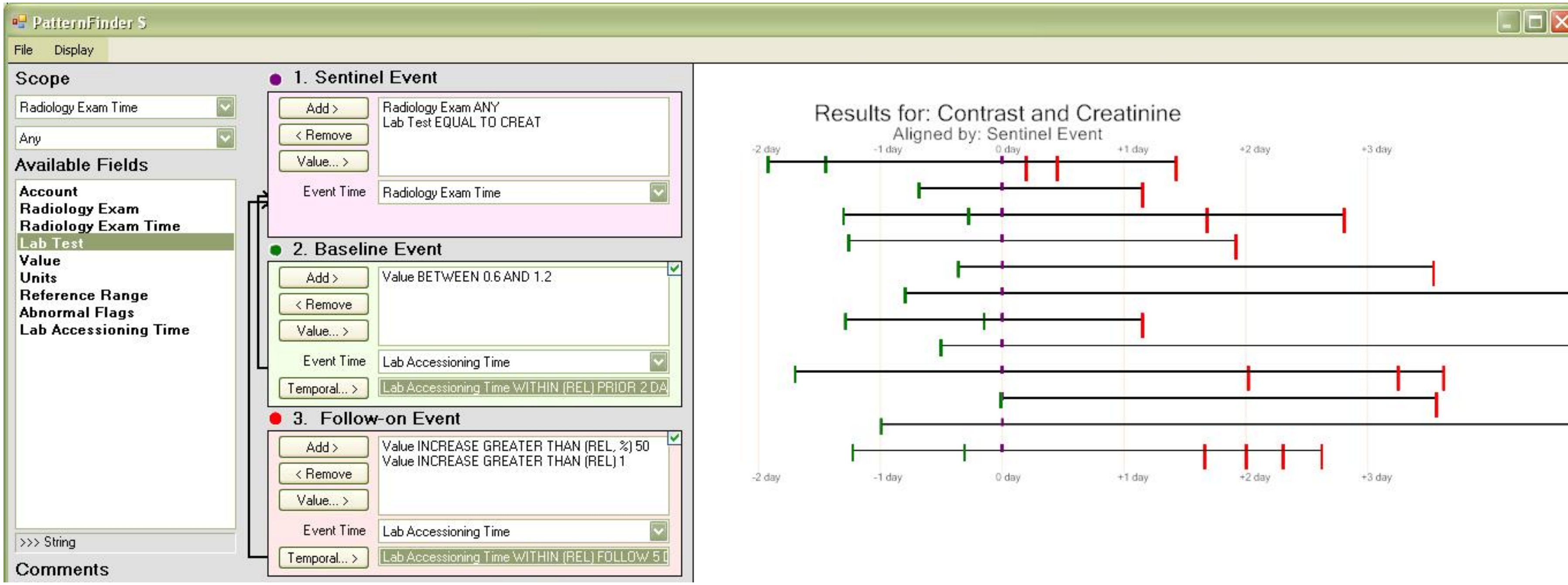
Event-based Visualization: Focussing

Linking event records to outcomes

- Select subsets of records that exhibit a particular outcome, e.g. clients purchased something, patient was re-admitted to hospital within a period

Strategy often used in the beginning of analysis to *form hypotheses* and *guide* further strategies, e.g. selection of temporal windows and event types

Event-based Visualization: Selection



- Form-based query interface to search for an event sequence with sentinel, base line and follow up event.
- Display of the results aligned according to the sentinel event.
- Patients with Hemoglobin level increasing by 50% within 10 days then decreasing 30% within 10 days.
- PATTERNFINDER integrated in a commercial system (Screenshot from Amalga).

Event-based Visualization: Selection

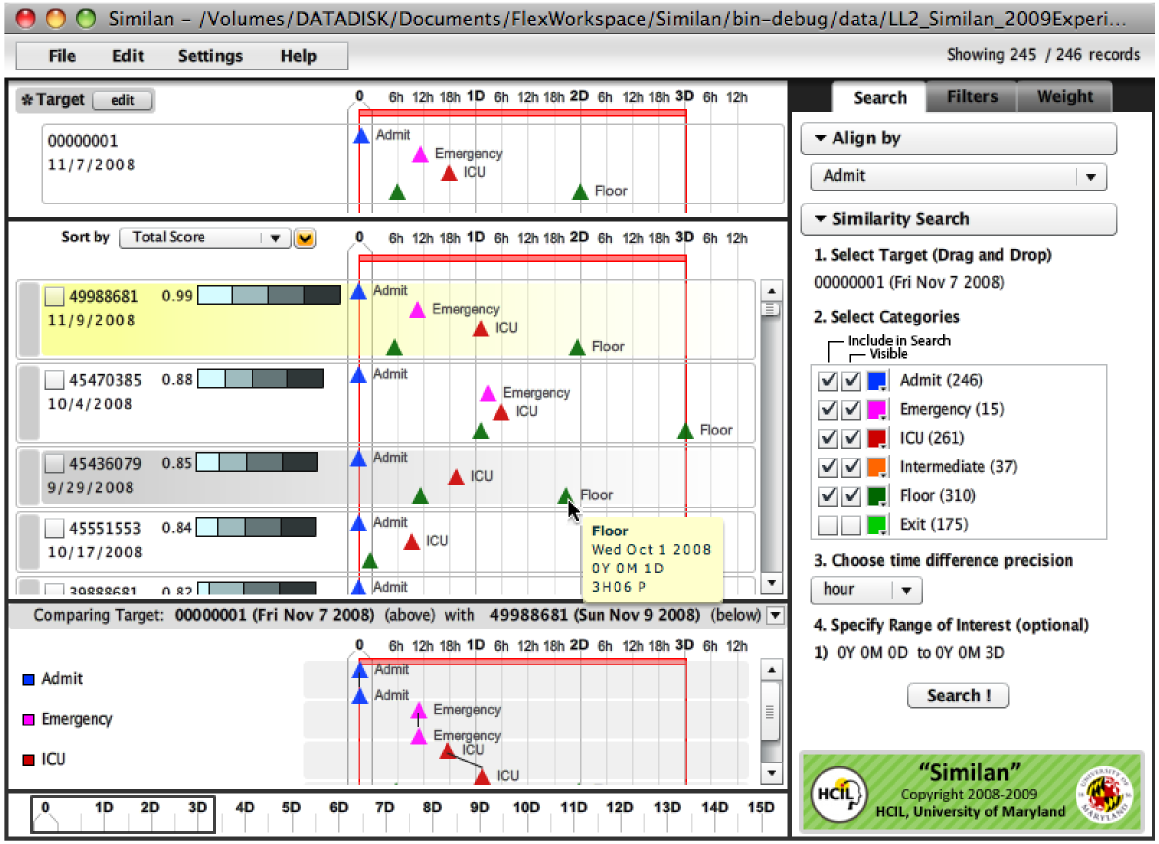
Filtering involves either SQL-like textual commands or using a query interface where sliders, checkboxes and radioboxes specify time intervals, value intervals or specific values (for categorical and ordinal data).

Drawback: only datasets that fully satisfy the filtering condition are returned and displayed.

Alternative: rank datasets with a similarity metric w.r.t. distance to the query.

Alternative concept: Select one dataset (target) and ranks others w.r.t. similarity. Present for example, the top 10 most similar datasets.

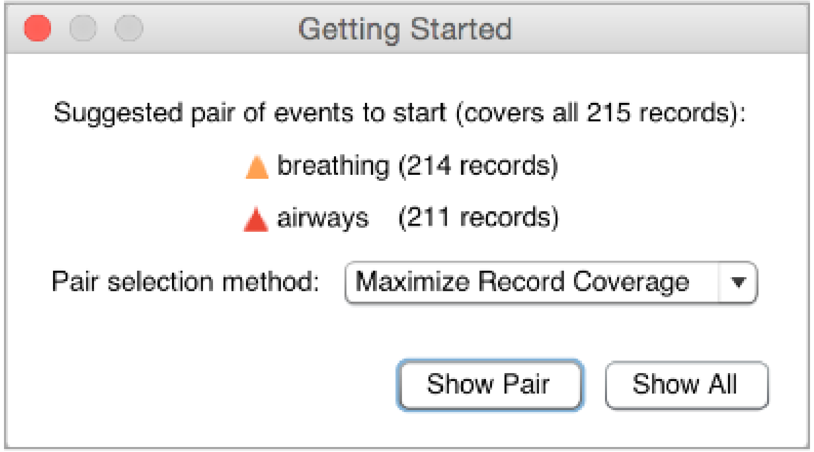
Event-based Visualization: Selection



SIMILAN employs a match and mismatch measure to select datasets that are very similar or very unsimilar to the target (From: Wongsuphasawat, 2009). Focus categorical data; other data need to be categorized first.

Automatic selection:

- To support selection, frequent event sequences may be detected (above a minimum coverage, compare A-rules)



(From: Du, 2016)

Event-based Visualization: Selection

Random sampling (Du, 2016)

- In case of very large data with high variety, the previous selection strategies may be insufficient
- Random sampling of records may enable focussed analysis, reveal trends and interesting patterns to guide the use of other focussing strategies
- Random sampling is the „last resort“ and should only be applied to records, not to event types

Event-based Visualization: Simplifcation

- Event visualization get complex when many records, event types and event sequences are involved, e.g. there are thousands of diagnostic codes (ICD), drugs, …
- Common practice:
  - Employ (advanced) filtering w.r.t. event types, specific events, temporal intervals, records, event attributes or combinations thereof
  - Clustering of event sequences according to a similarity metric
- Filtering „leaves control in the users hand“ but may be difficult.
- Clustering is used as a black box method not creating trust in the results.

Event-based Visualization: Simplifcation

Simplification strategies (Monroe, 2013):

- Inspired by related tasks, e.g. simplification of polygons, meshes, vector fields
- Lossless:
  - A certain simplification is possible without loosing any detail, e.g. replacing a set of planar triangles by a smaller set.
  - Summary of records with the same event sequences
- Lossy:
  - Strong simplifications → loss of details

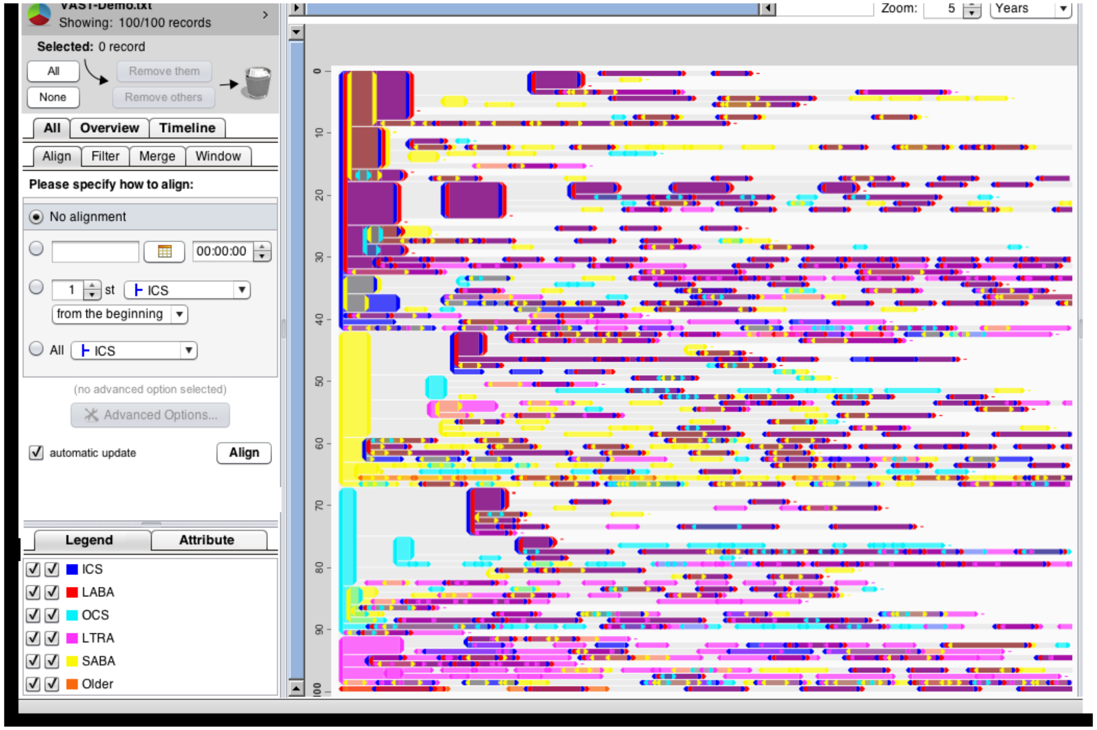
Lossless techniques are of limited use when there are many unique sequences. → exactly the same sequences are rare

Event-based Visualization: Simplifcation

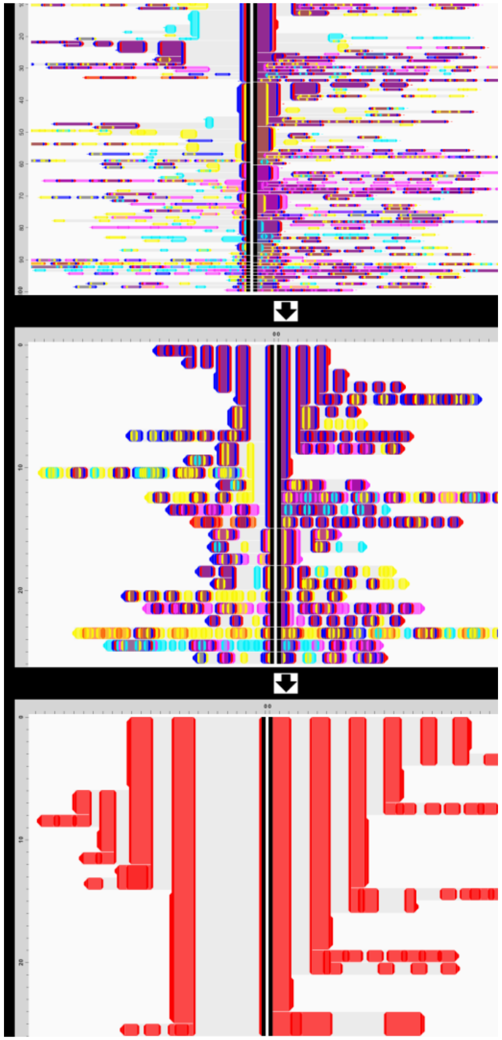
Measures to simplify huge event sequence data

- Instead of exact, *similar* sequences need to be identified and summarized.
- Depending on the analytic question, irrelevant records may be detected and excluded.
- Filtering event categories (compare EventFlow,)
- *Temporal event merging*: Merge overlapping events of the same/similar type and events of the same type with a limited gap. → a technique for temporal data abstraction
  - Patient gets drug from day_1 to day_{14} and from day_{16}

Event-based visualization: Simplifcation



An event visualization related to Asthma treatment. With 2700 visual elements, the display is too complex to interpret (From: Monroe, 2013). The interface provides visual query mechanisms to simplify the display.

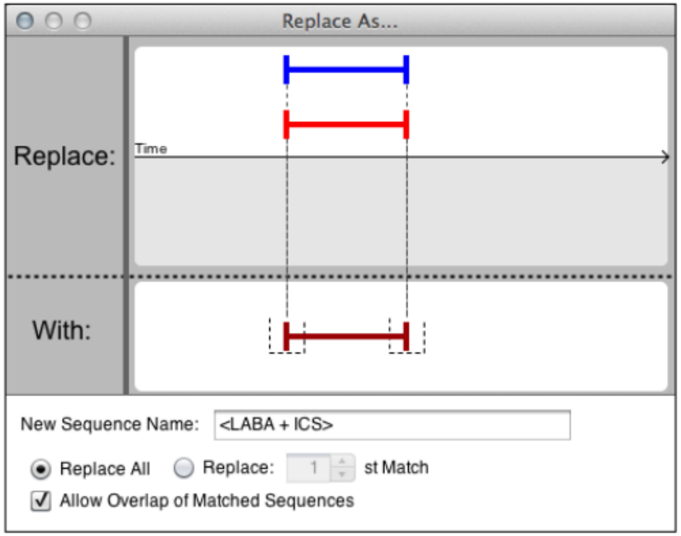


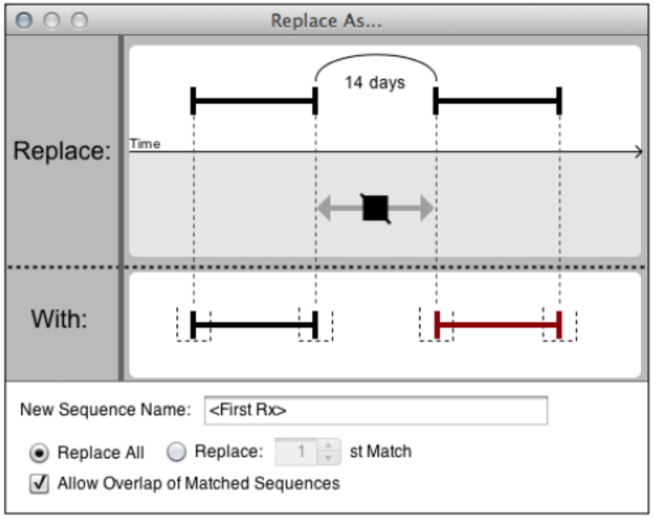
Sequence of simplification steps:

- Filtering by record: Only a certain event sequence is relevant
  → number of records strongly reduced.
- Reducing the number of event types increases the chance that remaining event sequences can be summarized.
- Also the time considered is filtered.
- Overall, 99 elements result after simplifying from 2700 elements (Monroe, 2013).

Substitution-based simplification:

- In addition to filtering time, records and event types, *replacement* operations may be used.
- Complex event sequences get replaced with simpler ones, e.g. several parallel events or a sequence of events is replaced by a single (highlevel) event

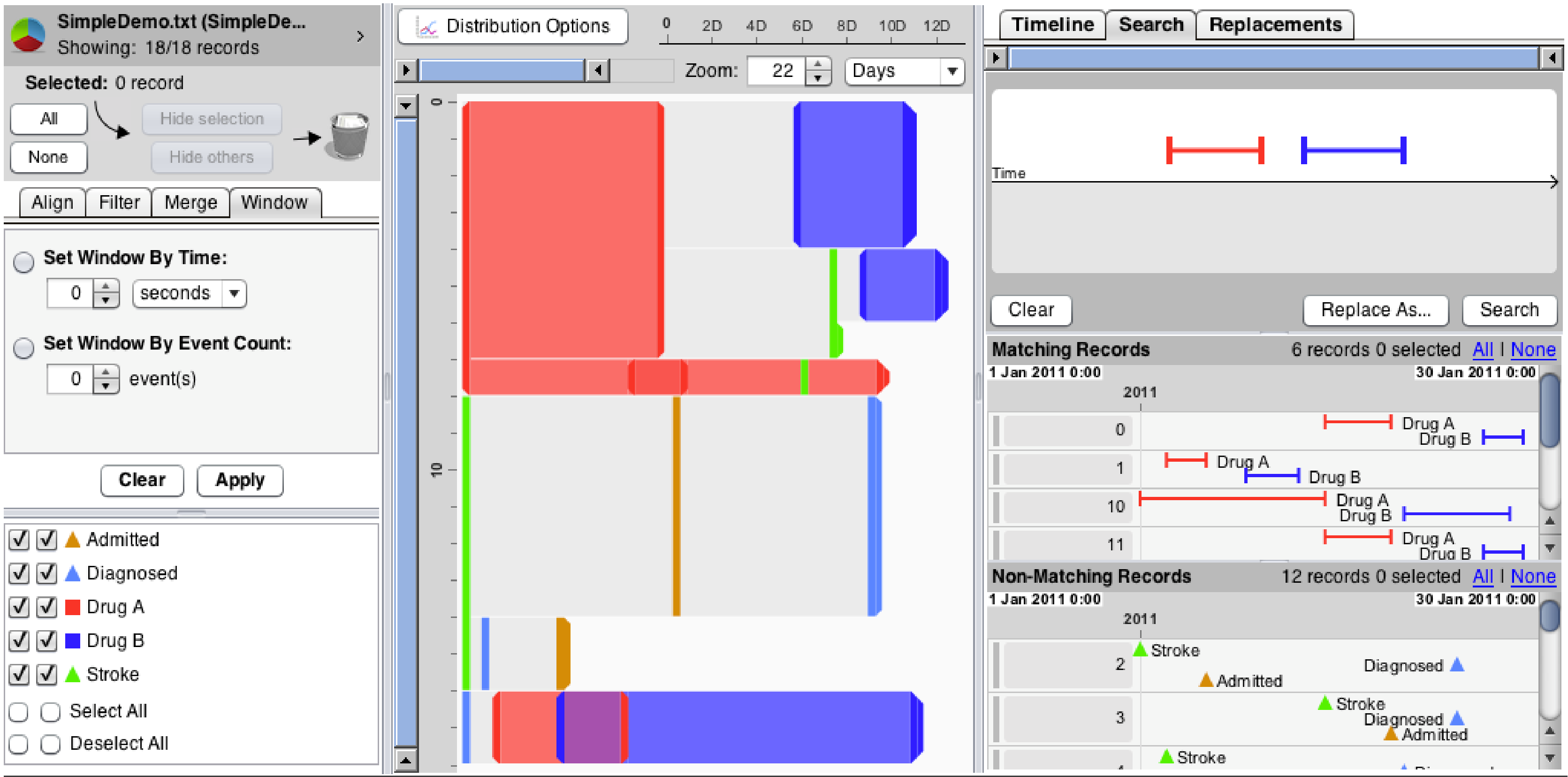




(From: Monroe, 2013)

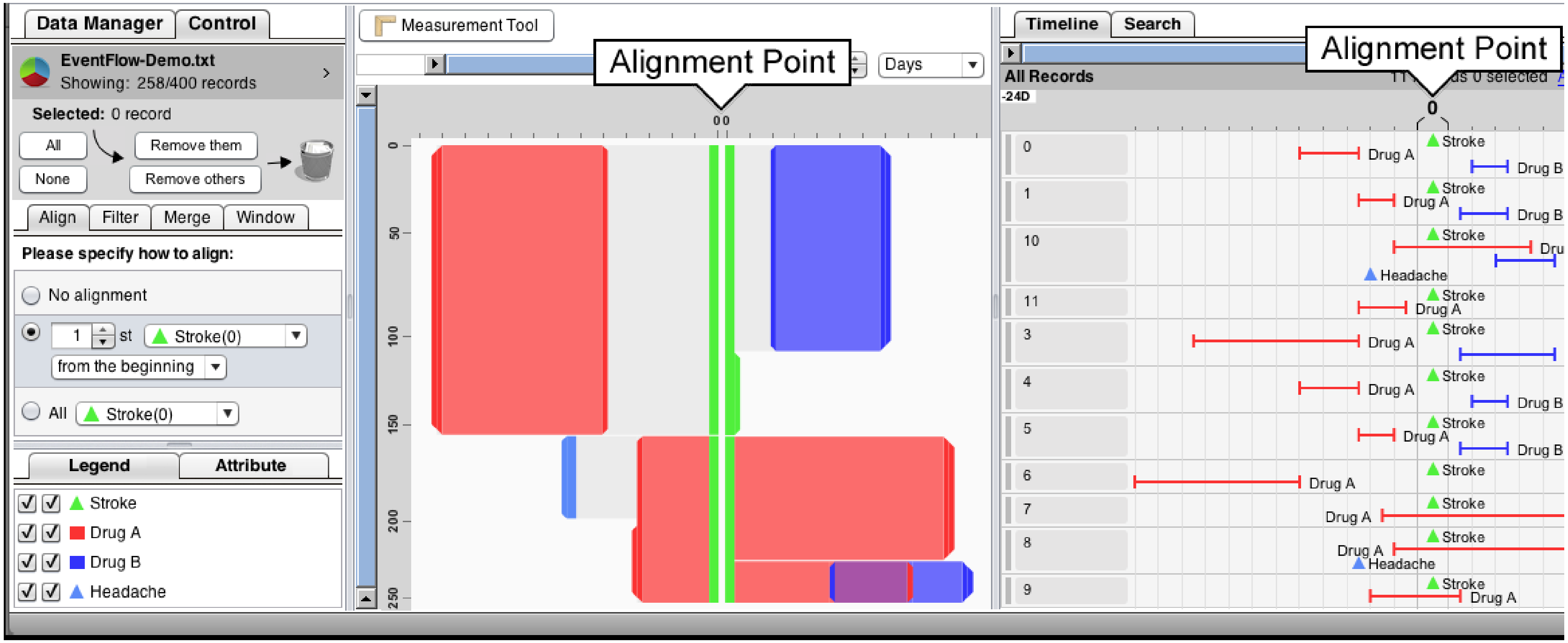
Event-based Visualization: Simplifcation

Control Panel Aggregated Record Display Individual Record Display



EventFlow: Categories enabled/disabled. Filtering for event count, time. Search for a certain sequence. Generation of a simplified overview (middle) (From: Link)

Event-based Visualization: Simplifcation



Summary of 250 records of stroke patients.

Height represents number of records with this event.

Marker event for alignment: stroke

Display of summary and details is restricted to the prescription of two specific drugs (From: Monroe, 2013).

Event-based Visualization: Simplifcation

Grouping events (Du, 2016)

- Events of a certain subcategory may be summarized by the parent category.
- Existing ontologies may be employed.
  - In the international code of diseases, there are > 400 types of lung cancer and > 200 types of bone cancer.
  - To detect that lung cancer often leads to bone metastasis, whereas bone cancer very rarely leads to lung metastasis, the aggregation to just lung and bone cancer is beneficial.
- Complex event sequences may be summarized, e.g. all diagnostic and immediate treatment steps related to heart attack.

Event-based Visualization: Simplifcation

Discussion:

- Combination of interactive filtering and automatic summarization tools is most promising

Applications:

- Network security analysis (large logfiles)
- Electronic Health Records, drug prescription (lecture on Visual Analytics in Healthcare)

Event-based Visualization: Folding

- Temporal folding means that events for a certain period are summarized by one event, e.g. the most important event, the most frequent event, the interval event with longest duration, …
- Folding/unfolding is an essential focussing strategy (Du, 2016).

Event-based Visualization: Partioning

- As a divide-and-conquer strategy, large event-typed data may be partioned, e.g. by event category, age group of customers, or subspace clustering
- Instead of the whole dataset, subsets are analyzed
- Strategy is reported to be used often by practioners (Du, 2016)

Event-based visualization: Uncertainty

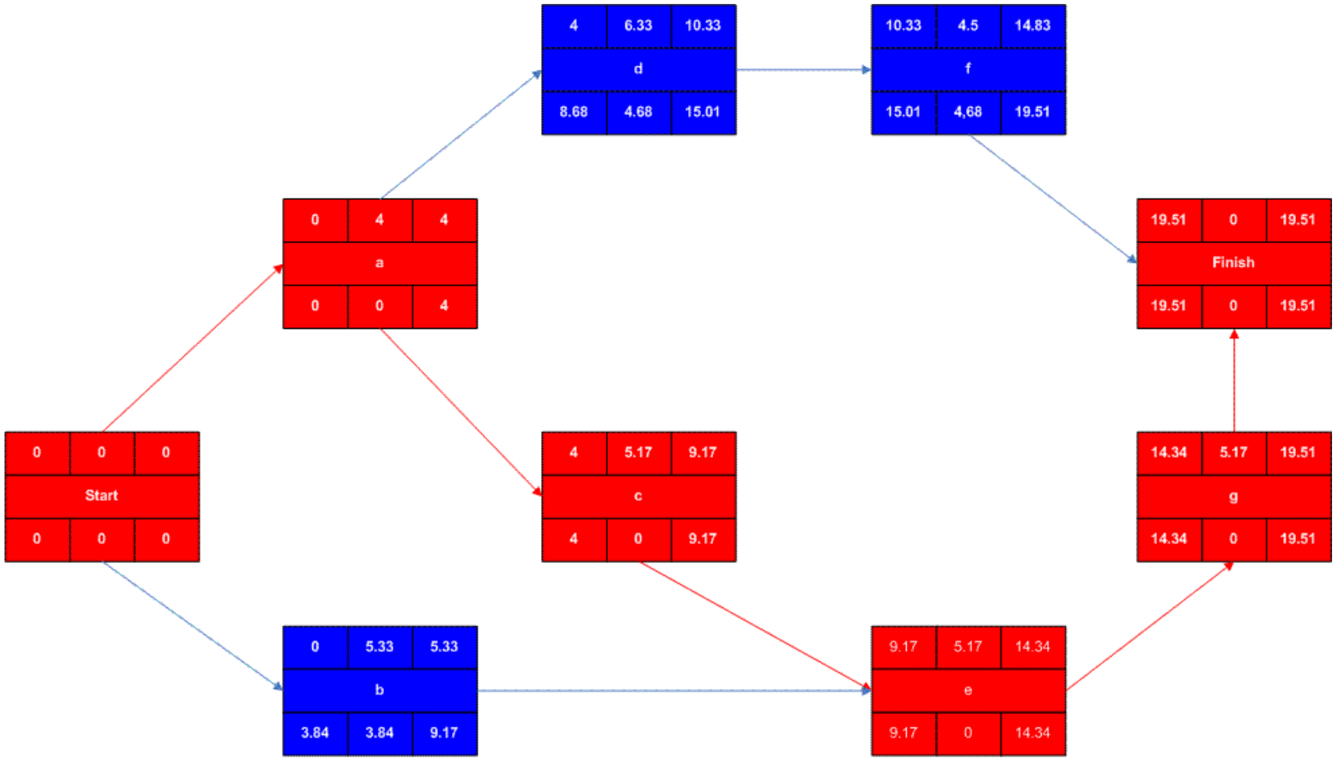
Early Start	Duration	Early Finish
	Task Name	
Late Start	Slack	Late Finish

In project management with PERT (Program evaluation and review technique) tasks are assigned optimistic start and end time (ES, EF) and pessimistic start and end times (LS, LF).

PERT events are start and end of tasks (activities).

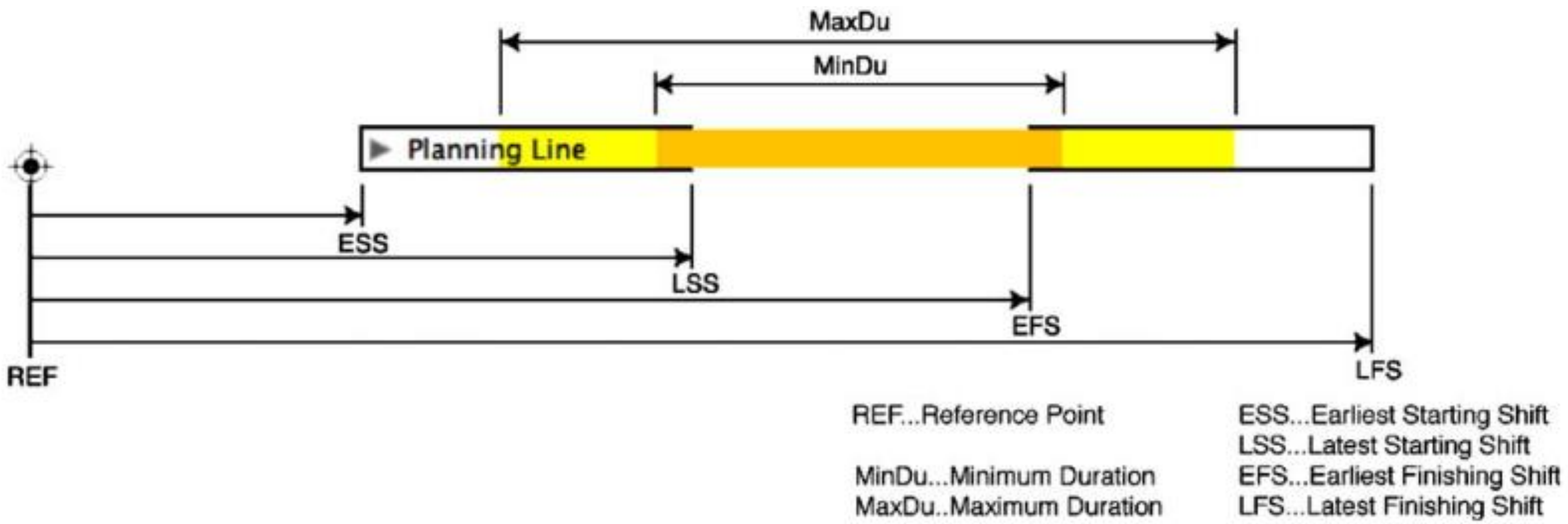
„It was able to incorporate uncertainty by making it possible to schedule a project while not knowing precisely the details and durations of all the activities. It is more of an event-oriented technique rather than start- and completion-oriented, and is used more in projects where time is the major factor rather than cost. It is applied to very large-scale, one-time, complex, non-routine projects." (Wikipedia page)

Event-based Visualization: Uncertainty



Project plan based on PERT. Red is the critical path. A drawback is that there is no timeline and thus no explicit visualization of parallelism and uncertainty.

Event-based Visualization: Uncertainty



Explicit visualization of the uncertainty of an interval event (From: Aigner, 2005)

Incorporation of Analytical Results

- Pattern detection is supported by temporal association rule mining (rules with minimum support and minimum accuracy are relevant) (Antunes, 2001)
- Temporal pattern specification supports search for most similar records
  - Requires flexible definition of a similarity metric and
  - Powerful methods for pattern specification
- Records are compared similar to gene sequences (where the sequence of amino acids are compared)
- Selected criteria:
  - Longest common sequence (LCS),
  - number of edit operations to change sequence ES_1 to ES_2

Examples for Temporal Event Data

- Electronic Health Records comprise test results, diagnosis, treatment with drugs and other means, allergies and complaints.
- Data is acquired for reimbursement and to give doctors an overview.
- It is not checked and improved substantially due to time constraints in hospitals.
- More on EHRs later (VA in Healthcare)

Examples for Temporal Event Data

Case study: security data (From Du, 2016):

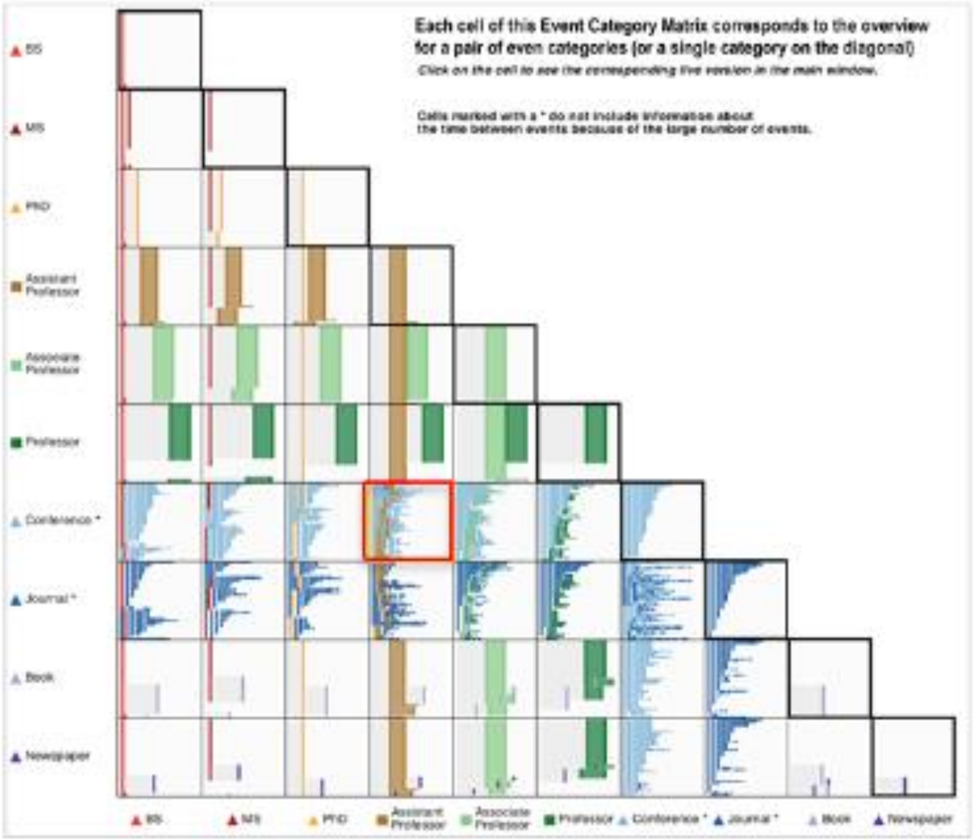
- Security researches want to analyze threats
- **Data**: 180 million events, ~ 33.000 per user related to login, e-mail use, web browsing
- **Preprocessing**: out-of-the box anomaly detection resulting in a suspiciousness score per user
- After removing events related to users with low scores, temporal windowing was performed (only a period around a suspicious behavior) and temporal folding was applied → reduction to 1.3 million events
- **Partioning** decomposed the data into 56 subsets
- When processing these, the same events within a 10 min. frame were substituted with one event.

Guided Analysis of Temporal Event Data

- Despite the focusing strategies, starting to analyze a new large and complex dataset is challenging and guidance is desired.
- CHOOSE2 is a set of strategies to guide novice and intermediate users (Mauriello, 2016)
  - For novices: suggest a pair of event categories that occurs most often simultaneously (or is the best w.r.t. another metric)
  - Show additional pairs of top-ranked event pairs
  - Show an event matrix where correlation between event categories is color-coded
- Implementation: wording of metrics and categories must be tested and aligned with the user‘s language

Guided Analysis of Temporal Event Data

- The diagonal is used for an overview on one event type; the other elements represent co-occurrence.
- The „professor data-set“ represents diffe-rent categories of pro-fessor (assistant, asso-ciate, full) with publica-tions in journals, confe-rences and books.



Event category matrix (Mauriello, 2016)

Summary

Temporal event sequences

- Represent behavior of customers, project activities, patient diagnosis and treatment and activities of authorities

Visual support is essential for

- Getting an overview of long/many records
- Comparison of records
- Restricting event-typed data to relevant portions
- Identification of further analysis of patterns

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