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# Spotting temporal co-occurrence patterns: the *historySkyline* visual metaphor

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**Abstract** – When trying to depict how architecture gets transformed over time, it is important to try and spot and analyse temporal relations between architectural changes on one hand and facts or events that may have triggered or at least impacted on these changes. In this contribution we introduce a visual metaphor called *historySkyline* aimed at aligning in time architectural events (any changes, including destruction or extension) and facts that may have impacted these events (in short, pieces of information about historical contexts). Visual metaphors are commonly used to uncover temporal patterns in the field of information visualisation (Infovis). Our experiment, carried out on the historic centre of the city of Cracow, shows that such an approach can be worth trying out in the context of historical sciences, and underlines some of the specific challenges this application field raises.

## I. INTRODUCTION

When trying to understand and recount how pieces of architecture get transformed as time passes by (may we observe one particular historic edifice or a whole urban structure), analysts pull together a variety of documentary hints helping them to spot and depict changes over time, and to order (if not date) those changes. The word “changes” means here of course morphological or structural modifications such as extensions or demolitions, addition of new architectural components or removal of deprecated technical solutions, replacement of a material by another, *etc.*. But it may also refer to successive functions devoted to a piece of architecture or to successive ownerships and role in the city for instance. At the end of the day, analysts try to end up with a sort of “chain of events” where periods of stability and changes are assessed and ordered in time, and where the actual physical layout of pieces of architecture is likely to be represented in 2D or 3D through contemporary geometric modelling platforms (typically, VR applications). But when looking at it from closer, what exactly are architectural changes? A random, accidental,

phenomenon, a sort-of matter of chance? What initiates them? Why do they occur? Why do they occur in one place at one time? In this contribution we base on the claim that it can be worth considering architectural transformations as consequences – and accordingly to try and cross-examine the underlying possible causes.

More modestly and pragmatically, the research is aimed at relating architectural changes to potential causal factors by correlating information on architectural changes (in terms of morphology, structure and function, following a description framework introduced in [1]) with information on a global context (legal issues, natural phenomena, demography, wars and rulers, *etc.*).

Trying to link cause and effects is obviously nothing new in historical sciences: the written works of many major authors in that field are packed with such attempts (may the causal chains proposed be known, assumed, or hypothetical). But when it comes to local facts, when it comes to correlating multi-granular and strongly heterogeneous indications, what solutions can analysts rely on in order to put architectural changes into a context? They can naturally rely on their own knowledge and culture and provide an educated and useful discourse. Our claim is that when the amount of data and information reaches a significant level, analysing and synthesising these heterogeneous inputs may benefit from the support of visual solutions helping to spot temporal co-occurrence patterns.

We wish to correlate potentially ill-defined data sets (events that cannot be precisely dated for instance), and to handle time indicators that strongly vary in terms of granularity (ranging from an architectural transformations that lasted several years or decades to a fire, or a new law, that can be tagged as occurring on one specific day). Accordingly it should be made clear that our approach targets early stages of a reasoning process, before more formal approaches, typically based on Allen’s [2] methods of temporal reasoning, can be applied [3]. It aims at helping analysts get a better overview of potential temporal interactions – and as such basically aims at uncovering new research questions.

## II. METROLOGY AND THE TIME PARAMETER

Metrology, pointed out in Wikipedia as the “the science of measurement”, has paved its way on top of the research agenda when facing the necessity to acquire and spatial data, with technologies like photogrammetry and laser scanning nowadays widespread in archaeology. But beyond spatial features, measuring the *time parameter* is also an issue, with well-established “absolute” methods like radiocarbon dating or dendrochronology to human centered observation methods on for instance a stratigraphy. These examples in fact illustrate some of the *models* of temporal data that are summarized in [4] :

- *Time primitives* (what results from radiocarbon dating – a date with a “fork” *i.e.* an *interval*)
- *Granularity* (dendrochronology dates per year, *i.e.* *single granularity*)
- *Scale* (a stratigraphy says  $t_1$  before  $t_2$ , even when neither  $t_1$  nor  $t_2$  are dated, *i.e.* *ordinal time*).

In other words, beyond the field of archaeology, measuring and modelling the time parameter is common in many research fields, like medicine or climate for instance, and contributions like [4][5] can be of great use in processing temporal metrology-based information.

But when trying to pull together pieces of data corresponding to strongly heterogeneous acquisition processes, another methodological challenge is raised: coping with unevenly defined data sets. When talking about spatial data, this can occur for instance when handling on one hand a contemporary photogrammetric survey and on the other hand a human witness report saying “*three minutes away from...*”. In the same way this can happen when handling temporal data, with for instance a one year match for artefacts made from wood, only relative dating like contextual seriation for a piece of stonework, or even human reports. This is precisely what happens when wanting to cross-examine a large amount of information on the changes over time of a large site like Cracow's market square, with hints ranging from archival material to contemporary archaeological findings. Our focus in this paper is put on the cost and constraints of reasoning on such data sets, an issue that we believe is a relevant one in historical sciences at large where gaining insight does not only depend on the accuracy of an instrument, but is impacted by the heterogeneity of the temporal data. What we therefore investigate is not the temporal data acquisition itself, but the way diversely acquired temporal data can at the end of the day be merged so as to spot temporal co-occurrences.

## III. THE CONTRIBUTION

We introduce a visual metaphor called *historySkyline* aimed at aligning in time architectural events (any transformation, including destruction or extension) and facts that may have impacted these events (in short, pieces of information about historical contexts). The

visualisation combines a recount over time of architectural transformations (by type) with indications on the amounts of historical evidence available and with a variety of contextual information such as wars, natural disasters, reign of rulers, demography, new laws, *etc.*. The visualisation does not actually mention causality: it barely puts facts that occurred at the same period side by side. It is applied to architectural transformations on Cracow's Main Square (over 40 edifices at one time, 3 left today – 371 architectural transformations recorded, 538 bibliographic sources, 478 pieces of information about various elements of contextualisation). It builds on an infovis-birtherd mantra: *using vision to think* [6], with here a specific bottleneck – highly heterogeneous data sets. The contribution introduces the methodological and technological choices behind the *historySkyline* visual metaphor, and discusses its practical benefits and limitations in terms of information discovery on the abovementioned test field.

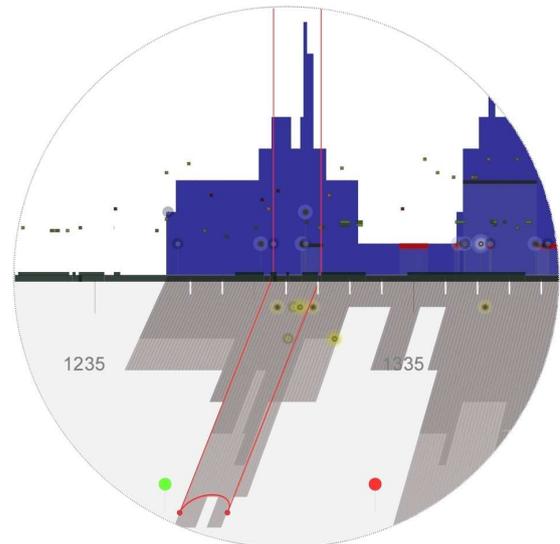


Fig. 1. A zoom on the *historySkyline* visual metaphor. The building activity on the Market Square in Cracow (blue vertical bars, year per year) is correlated with the Czech occupation (symbol composed of a red arc and two dots showing the time interval)

## IV. VISUAL METAPHORS

The notion of visual metaphor stems from the Infovis and visual analytics communities. The information is displayed using a real-world equivalent, like for instance the image of a tree with branches to convey an information about a genealogy, a long time used metaphor as shown in [7]. Visual metaphors are, as mentioned in [8], one of the three fundamental units of visual representation in Infovis, along with formalisms (a pie chart for instance) and models (when the information itself is based on a real-world equivalent like in the “Brockhaus Planetarium” space Atlas [8]). Most often the

design of a visualisation implies combining these units – and the *historySkyline* visualisation does include both a main metaphor – the image of an urban skyline, and its reflection in the water, and visual formalisms – diagrammatic shapes in the bottom part.

Visual metaphors are commonly used in the above mentioned communities in the handling of the time parameter. A great number of historic examples for genealogies (tree, chain, hand, *etc.*) or time charts (ladder, river, temple, game of snakes and ladders, *etc.*) are illustrated in [7] and [9] (*conf.* Fig. 2).

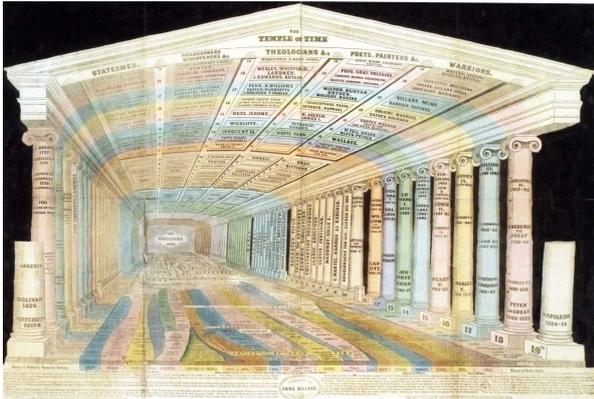


Fig 2. Emma Willard's 1846 "Temple of Time" : a three-dimensional projection of historical chronography [10]

Contemporary, computer-born, 2D or 3D examples are also quite numerous such as Infosphere [11], Datavases [12], TimeWheel or Perspective walls, [4] *etc.*.

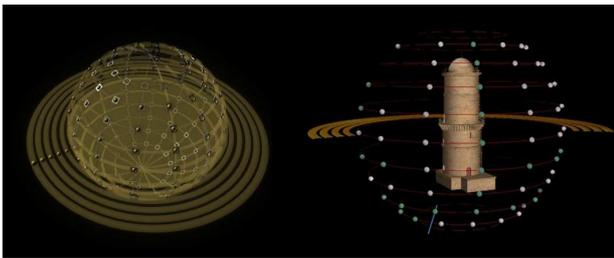


Fig. 3. The Infosphere visual metaphor uses the image of a globe, with parallels and meridians used to sort pieces of information, and rings that correspond to periods.

A key aspect in the design of any temporal data visual metaphor is to understand the model of time corresponding to the underlying data. For instance, a tree metaphor for genealogies uses an "ordinal time" scale, as defined by [4], *i.e.*  $t_1$  appears before  $t_2$  whether or not  $t_1$  and  $t_2$  are actually dated. By contrast, time charts use a "discrete time" scale where time is mapped to a continuous series of Integers (typically, a year, a day, *etc.*), implying that each piece of data is dated. Similarly choices are made in terms of granularity: a smallest unit (called chronon) needs to be fixed, for instance a day in classic calendars. The choices we have made are

discussed in the next section with regards to the data we handle.

## V. THE DATA

The baseline objective of the *historySkyline* visual metaphor is to allow the spotting of temporal co-occurrences between architectural changes and broadly speaking a *context*. In the list below we show the various types of data that we pulled together, and for each of them the main corresponding models.

1. architectural changes (in terms of morphology, structure, function or ownership),  
> *time intervals, in years*
2. certainty of dating for morphological changes (a 3 values scale) indicating to which extent the left and right bounds of the above interval are trustworthy indications,  
> *time point, a year*
3. period of reign of rulers,  
> *time intervals, in years and days*
4. amount of sources used to document the changes (grey reflection of the skyline)  
> *time intervals, in years*
5. military events (siege, occupation, assault, invasion, *etc.*),  
> *time points or time intervals, from days to years*
6. natural disasters (floods, fires, epidemic, gale, famine, *etc.*) – unevenly dated in sources beyond their intrinsic heterogeneity,  
> *time intervals, from days to years*
7. legal matters (decrees, limitations, privileges, *etc.*) with in sources an accuracy of dating ranging from a day to a year,  
> *time point, a year*
8. global military context in the country (significant battles, sieges, *etc.*),  
> *time intervals, from days to years*
9. population in Kraków,  
> *time point, a year*

The variety of the models themselves, but above all the variety in terms of precision of the data we handle made it clear that the most reasonable choice to adopt was to stick to a discrete time model, with a one year chronon. Limits of this choice are discussed in the conclusion section. The choice of a discrete time model with a one year chronon does not impact the way we store the data itself: it impacts the way the results of queries on these databases are exploited: each piece of data has to be "translated" to match the model.

## VI. FROM THE DATA TO THE VISUALISATION

The visualisation is calculated in real time, not drawn once for all (infrastructure RDBMS/Perl/SVG). It uses

inputs from various databases collected over the years, from architectural information to elements of general historic context. The visualisation is computed in response to a user selection of buildings: it can be used to analyse changes one building alone (Fig 4) or on any user selection of buildings (Fig 5, the whole Market Square).

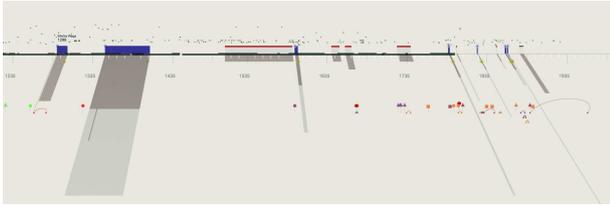


Fig. 4. HistorySkyline calculated for one edifice alone, the "Grand Scales".

In the examples below we show its application to the collection of artefacts that refurbished Cracow's Market Square: in other words what is shown is the *global activity over time* on this area. The design of the visualisation uses the metaphor of an urban skyline, with the horizon line acting as a timeline (Fig 5a). Time goes from left to right, one pixel represents one year.

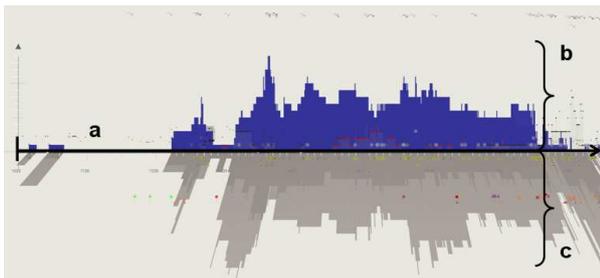


Fig. 5. General structure of the visualisation. Height of bars show the amount of transformations, year per year (graduation on the y-axis)

Above the horizon line vertical bars show the building activity (Fig 5b), *i.e.* architectural changes, using three colours: blue for morphological transformations, and in the foreground, superimposed with transparency, red for structural changes and black for destructive changes (Fig 6a,b,c). The width of a bar corresponds to a time interval, and certainty of dating of the left and right bounds are figured using a "street lamp-like" shapes (Fig 6d). The grey reflection of the skyline below the horizon line (Fig 5c) shows the amount and type of sources that document the building activity (Fig 6e). This can help for instance to contradict the common sense assertion that would say "the more changes the more sources" (Fig 6f). Shades of grey are used to differentiate types of sources: light grey correspond to the total number of sources, while dark grey underlines the proportion of visual material.

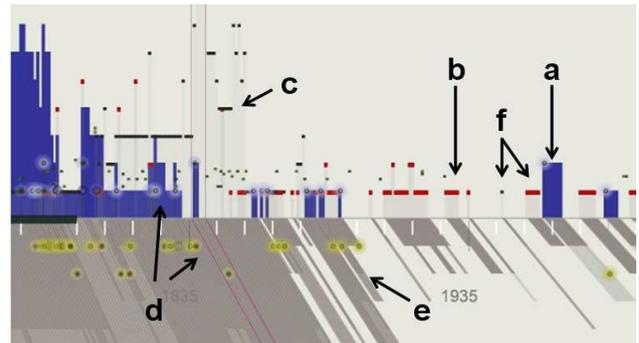


Fig. 6. A detailed view centred on the turn of the 19th century. Note the relative lengths of reflections of bars. The amount of transformations in both cases is the same, but the building activity of the left bar (black, destructive transformation) is far more documented than the building activity of the right bar. The a bar shows a higher number of transformations, yet the amount of sources is inferior.

A time scale is shown on the horizon line, graduated every 10 years. Above it the periods of reign of rulers are represented by small rectangles.

The underlying information is available (and highlighted in the graphics) interactively, as shown in Fig 7.

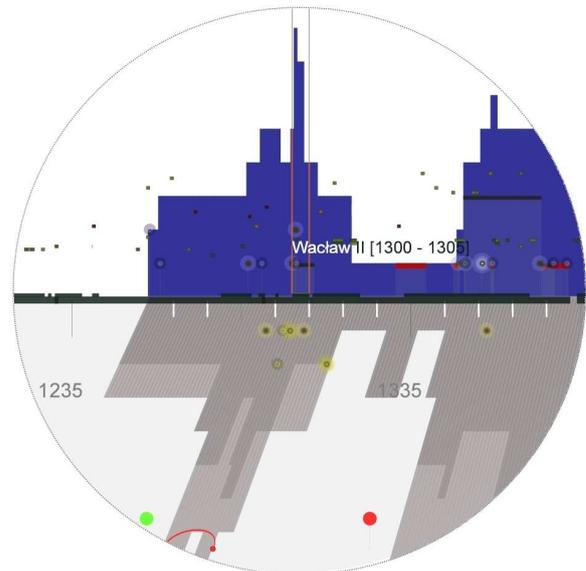


Fig. 7. The reign of king Wenceslas II co-occurs with a high building activity.

Above the horizon line other elements of context are also shown, and represented as squares (one year) or rectangles (several years): natural disasters, legal matters, global military context in the country. They can be highlighted interactively one by one (Fig 8), or highlighted type by type – for instance in order to observe the co-occurrence of famine and epidemics.

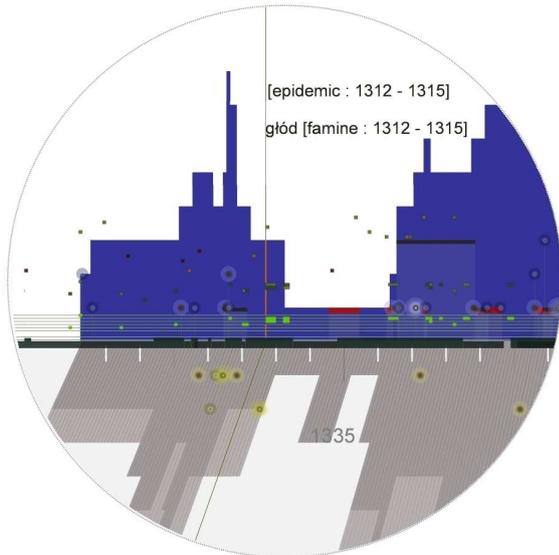


Fig. 8. Highlighting of events of type “disaster”: Six years of combined epidemic and famine during the 1312-1315 time interval.

Under the horizon line, superimposed over the grey reflections, rows of diagrammatic figures run in parallel, corresponding to various types of military events that impacted the city: sieges, occupations, invasions, etc..

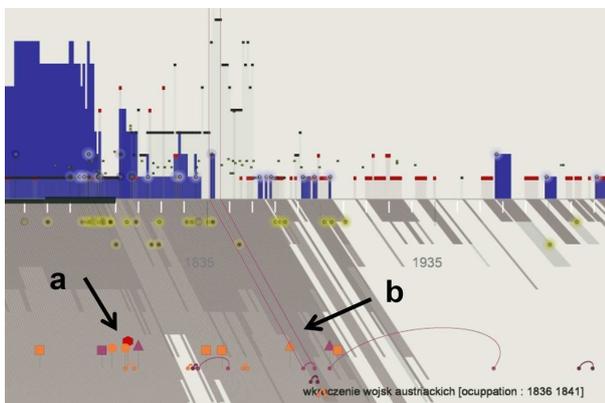


Fig. 9. Symbols used to position major military events in time – in this example the 1836-1841 Austrian occupation is highlighted. Purple lines are displayed up to above the horizon line so as to read potential co-occurrences with the information displayed there.

Those that lasted several years are represented by an arc that joins two dots (Fig 9b). Each colour corresponds to a given “foreign actor” - red for Czechs for instance (Fig 1), and purple for Austrians (Fig 9). The interactive highlighting of one these symbols opens coloured lines that can help users spot potentially significant co-occurrence patterns (conf. Fig1). Finally, the “population size” information is shown in the upper part of the visualisation, represented as a “flock of birds” in the sky (Fig 10). The idea is simple: the lower the bird the bigger the population. What the visualisation helps to spot is not

really numbers, but *contradictions* in numbers (Fig 10a).

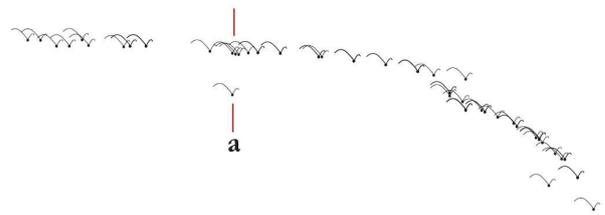


Fig. 10. The population size symbolic representation.

## VII. EXAMPLES OF USE

At this stage the *historySkyline* visualisation is basically a proof-of-concept prototype, experimented on a specific case study. It would definitely require a thorough evaluation effort before stating whether the approach can be generalised. It has however been tested in the context of workgroup discussions in order to evaluate to which extent the visualisation can support information discovery (e.g. identifying unexpected temporal co-occurrence patterns). As an illustration, three interesting patterns spotted during these workgroup discussions are presented below, along with the open questions they helped raise.

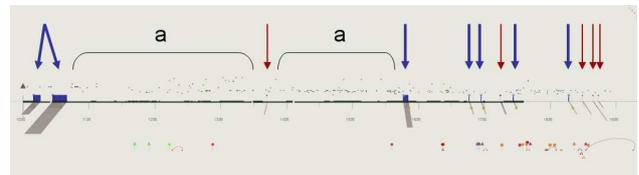


Fig. 11. The atypical temporal pattern of St Adalbert Church: short time intervals of transformations (blue – morphological, red-functional), significant inaction periods (a), highest amount of sources for the oldest transformations. An uncomplete documentation?

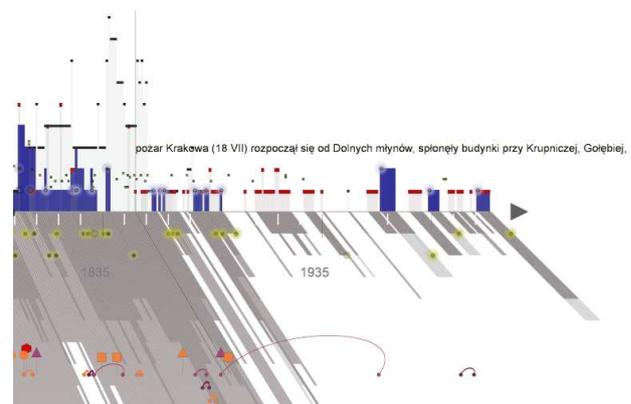


Fig. 12. A major fire occurs in 1850, and spreads to several quarters of the city. Although it did not directly impact the major structures of the Market Square’s heart, it is followed by a period of destructions (black vertical bars): An economic issue? An opportunity seized by the recent occupying power to refurbish the city centre?

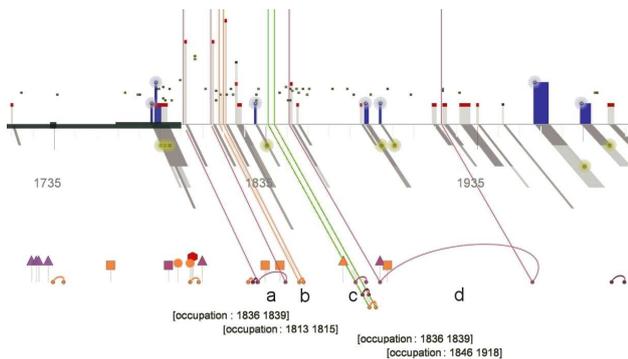


Fig. 13. *historySkyline* for the Town Hall ensemble (5 edifices), symbol of power in the city. Visible here is a “seizure of power” pattern (a,b,c,d) - numerous functional transformations on the arrival /leave of the occupying force. An exception is highlighted (c) three different occupying powers at the same time. The visualisation corroborates an intuitive assumption that in such a case a status-quo situation may prevent actors from intervening on a symbolic edifice.

These three examples underline what are probably the most beneficial results of the approach: highlighting, pointing out unaddressed research questions, needing further investigation, as well as corroborating assumptions and intuitions.

## VIII. CONCLUSION

The *historySkyline* visual metaphor has been designed as a tool helping analysts to cross-examine strongly heterogeneous temporal indications, allowing a bridging of the “quality gap” between metrology-based temporal data, and various historical hints. Temporal relations between facts and events can be observed, in order to spot temporal co-occurrences laid before the eye of the analyst as question marks.

To conclude, a number of limitations must be pinpointed. In terms of technology, such a visualisation requires a high level of interaction so as to allow users to dig deeply into the data displayed (selective zooming, multiple selections, etc.). Moreover, a key limit in terms of method is the time model we have adopted – discrete time, with a one year chronon. Such a choice implies for instance that we cannot visually discriminate an event that occurred in spring from an event that occurred in autumn. It also implies transferring qualitative temporal information such as “beginning of the 14<sup>th</sup> century” into quantified intervals. Finally, the uncertainty of dating, visualised through specific symbols, results in potentially deceptive time intervals, and thereby in possibly misleading temporal co-occurrence patterns. For all these reasons the *historySkyline* metaphor should be considered as a first step, needing further investigation.

Among the main perspectives ahead is the idea of testing

the ordinal time model. Ultimately, and because the objective is to support analysts in their reasoning tasks, we consider a key aspect in the development of such a visualisation is to allow a user monitoring of the interpretative steps – for instance giving each user the possibility to test alternative interpretations of uncertain dating. On the overall the approach appears promising, yet underlines to which extent merging heterogeneous temporal data sets remains a challenging issue.

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