

HistoGlobe

Teaching History Visually

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Abstract: HistoGlobe is an interactive historical geographic information system (HGIS) that provides students with gathered and curated historical information for self-study and aids teachers during history classes. The system visually integrates temporal and spatial aspects of historical events, as well as affiliations and alliances of states, routes of historic people and groups, and finally, detailed multimedia information. HistoGlobe relies on familiar interfaces such as globes and timelines but augments them with new techniques including directly manipulable moving entities such as troops and a direction-preserving presentation of treaties and other collaborations based on routing lenses. A field study with 12th graders revealed an overall solid usability of the system and inspired the development of further features.

1 INTRODUCTION

Traditional books and static maps about history mostly rely on elaborate knowledge transfer in prosaic manner, but often they do not adequately survey long-term, dynamic and complex processes and temporal changes visually. In contrast, HistoGlobe is a historical geographic information system (HGIS) combining the sciences of history – the study of *when?* – and geography – the study of *where?*. It employs modern web technologies to show historical development in society, politics, and economics at given times and periods in history (see Figure 1).

HistoGlobe is aimed at two specific target groups: history teachers and students. It helps teachers to present the content of their history lessons in an interesting, informative, and interactive way and students to better understand events and their context in history. Overall, our major contributions are:

- An advanced map interface that is capable of visualizing changing border and region information on either a 2D map or a 3D globe.
- The hivent concept of visually incorporating major historical happenings in time and space, including detailed information and multimedia.
- Advanced timeline concepts incorporating time periods concerning historical topics and individual hivents.

- Moving entities is a direct manipulative glyph-based approach of providing route information about individual people and groups.
- Interactive and static routing lenses are an appealing approach to presenting treaties and other collaborations globally by preserving direction information.

History teachers from a public school were involved during the design and implementation process and, ultimately, invited us to conduct a field study on 12th grade users during classtime, as well as during self-study. Overall, most students were satisfied with HistoGlobe because they found it easy and fun to use and reported that it provides a good overview of history topics. The results encouraged us to proceed with our approach, yet also revealed shortcomings and a lack of some capabilities that were considered in the further development process.

2 RELATED WORK

Best-known for visually embedding time-related information onto a static map is Charles Minard's flow map of Napoleon's 1812 Russian Campaign (Minard, 1869) featured by Edvard Tufte (Tufte, 2001). Time has only one dimension; however, it can be linear

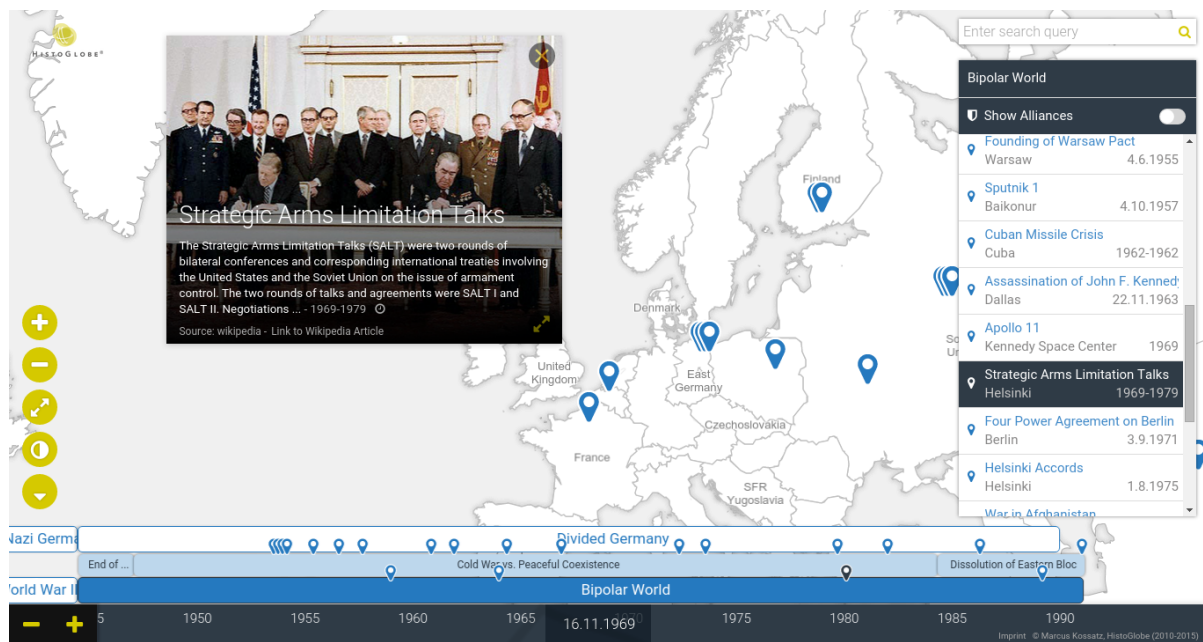


Figure 1: HistoGlobe’s user interface currently focusing on Central Europe during the bipolar world era with its local and particular manifestation of divided Germany (see below). The hivent list on the right outlines all historical events being crucial during the Cold War such as the selected Limitation Talks (see also corresponding hivent box containing further information).

for a set of singular events or cyclical for recurring events (Ott and Swiaczny, 2001). The preferred technique for displaying linear time is the use of a timeline; either in vertical (the World History Timeline (Frank E. Smitha, n.d.)) or in horizontal direction that allows dragging and zooming, e.g. The Life of Nelson Mandela (Time Magazine, n.d.) created with *Timeline.js* (Northwestern University Knight Lab, n.d.). Google Earth can be used to show historical imagery (Google Inc., n.d.). Retrospectively, social indicators are often visualized using maps and timelines, e.g. GapMinder World (Stiftelsen Gapminder, n.d.) and the World Bank Maps (World Bank, n.d.). TimeMaps (TimeMaps Ltd., n.d.) shares some basic concepts with HistoGlobe: at specific time points the geopolitical state of the world is depicted and certain historical events can be seen on both the map and timeline. However, TimeMaps lacks linking and interaction. A very interesting concept is the space-time cube, which extends a regular planar map into a third time-representing dimension (for example Kraak (Kraak, 1988)). The idea of the contained space path that connects two-dimensional location information to three-dimensional movement representation dates back to Lenntorp (Lenntorp, 1976).

A matter related to moving entities is direct manipulation of objects on screen (described later in Section 5). Kimber (Kimber et al., 2007), Dragicevic (Dragicevic et al., 2008), and also Karrer (Kar-

rer et al., 2008) introduced a complementary space-centric technique where an object trajectory is detected during a video sequence and visualized as a hint path on selection. Then the user can drag the object along the trail constrained by its trajectory, which sets the global time and thus moves all other objects along. Kimber’s approach, mainly dealing with surveillance videos, additionally provides draggable glyphs on a floor plan. DimpVis by Kondo (Kondo and Collins, 2014) investigated this direct manipulation approach in the field of information visualization. While the pointer remains connected to the data, smooth manipulation within spatiotemporal value domain can be made.

3 BASIC CONCEPTS

HistoGlobe is intended to convey historical knowledge and geopolitical development in an informative, fluent, and interactive manner. Several aspects of historical data have to be addressed regarding this purpose including date, place, involved parties, movement profiles, alliances, and additional background information. The user interface is carefully designed by enhancing and mixing established linked methods such as the map (or globe) interface for spatial dimensions (latitude and longitude) with novel approaches, such as a hivent (historical event) concept or the topic-

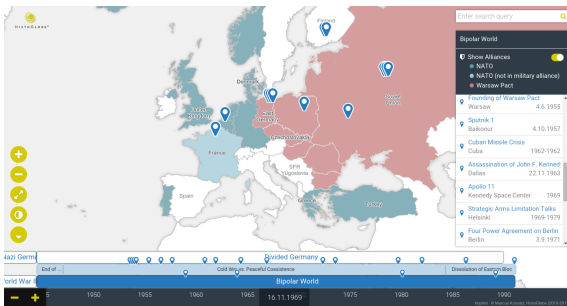


Figure 2: Countries colored due to their membership in NATO (blue) or Warsaw Pact (red).

extended timeline for orienting and navigating within the temporal dimension. The map presents information regarding a given date e.g. current region and country borders, hivent that occurred at about that time, moveable entities, etc. The countries' color mapping is primarily used to emphasize affiliation information (see Figure 2). Of course, not every single country label can be shown at once, which is why the countries are ranked size-wise and lower priority labels that would overlap are hidden. Besides navigating and zooming the map in regular mode, as well as in full screen mode, a high contrast mode can be toggled when working under problematic light conditions in the classroom (see control buttons on the left in Figure 1).

Timelines are a traditional yet appropriate way to provide temporal orientation and navigation. We enhanced it to a topic bar. Temporal information is depicted in the lower part as an interactively zoomable timeline (with levels of annual, multi-annual, decade, and century intervals). The current date of the visualization, the *now marker*, is marked in the center of the timeline. Changing the current date by moving the timeline or manually setting the date updates the map by revealing territorial changes by animated transitions. Topic information is attached in an additional upper layer to provide supplemental context about global epochs, as well as longer lasting matters on a local scale in the geographic regions currently visible. We implemented a hierarchical approach where each topic (e.g. "World War 2") can have sub-topics (e.g. "Blitzkrieg" or "Turning Point of the War"), as seen in Figure 3. Some topics show additional features, for example coloring of the countries based on their affiliation with a military alliance (as seen in Figure 2).

Providing a proper and legible labeling of the topics turned out to be a surprisingly difficult problem on a zoomable and moveable bar. Writing the topic name in more than a single line would destroy the intended layout since it reduces the space that should ultimately remain on the map. Dynamically resizing

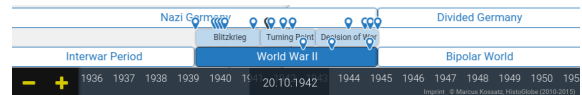


Figure 3: The upper row shows consecutive epochs of local German history. The lower row consists of global eras that provide their hierarchical structure in between. Below the topics the zoomable timeline is attached.

the topic areas in a horizontal direction would result in historically incorrect information due to visually wrong ending times or overlapping topics. Leaving out vowels or the middle of words and replacing the letters with "...", if necessary, for the current zoom factor.

Linking elements of the topic bar and the maps are the so-called hivent representing a spatio-temporal relationship on a single occasion as historically significant incidents at a certain point in time and space. They are visualized at the location of occurrence on the map, as well as on the timeline, using a small blue glyph. Hivent occurring close to each other on the map are grouped into a cluster marker that can expose (on demand) the clustered hivent in a radial layout and makes them selectable. Furthermore, they can be filtered and searched for by for names, people, places, and time in the upper right box that instantly presents matching hivent. Below the search box, the regular hivent list depicts all hivent of the current topics of the given time periods. Hivent list and search box share the space on the right side, i.e. if the search box is used, the hivent list folds down (not depicted).

Detailed information about the events are presented on demand in hivent boxes: the location, the date, a short description about the event, and an affiliating background image. Additionally and optionally a link to the related Wikipedia article, as well as directly-playable multimedia content, is available.

4 PILOT STUDY

A pilot test should give an impression whether HistoGlobe is suitable as a teaching aid in the classroom while imparting the historical context of a hivent – in our example, the content and the consequences of four major conferences at the end of World War II: Casablanca and Tehran 1943, Yalta and Potsdam 1945. The lecture was video recorded for observation and a semi-structural interview with the teacher was conducted afterwards to gain more insight. During the lecture the teacher alternated between his own

prepared teaching slides and HistoGlobe to explain the context of the conferences by using the map. Although the teacher needed only a limited subset of the prototype's features, he stated later that there was a big advantage to having a navigable and zoomable map for visualizing the territorial development of countries and membership in alliances for other historical topics.

For a second test we tried to gather impressions about the usefulness of HistoGlobe as a self-education tool for students. In a computer pool the students were instructed to write an overview about the bipolar world between 1945 and 1993 with a focus on the cold and hot phases of the time. We observed the students during the test and interviewed them later on, asked about advantages and disadvantages, collected suggestions for improvement of the visualization, and again had the students complete a questionnaire. Several interesting aspects were revealed. No questions were asked by the students regarding the usage of the software – everyone was able to use it from the beginning. The hivent list was the main navigation element primarily used by all students. It was considered to be very helpful to know which event happened where and when in order to get detailed information. Hence, the usage of the map was surprisingly more passive, mostly driven by selecting the hivents in the list. The information on the map was widely understood, and the colored alliances were considered especially helpful. One requested feature was to introduce cities, rivers, etc. on the map for better orientation. The timeline and the topics bar were used less, maybe since the “Bipolar World” topic only spans four decades.

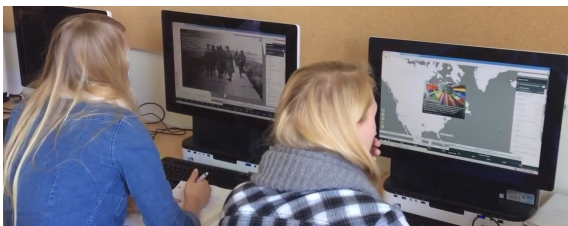


Figure 4: The usage of HistoGlobe as learning material for the students.

Due to the exploratory task, the search function was not used at all by the students. The students did not have any specific keyword to search for. The hivent boxes were highly appreciated as the main source of information. Often students copied the content from the box directly into their notes (although they were not allowed to). Interestingly, nearly half of the students favored the high contrast mode even if it was not really necessary with respect to the lighting

conditions and the monitors. Overall, the vividness of the visualization and the chronology and visual impressions of the hivents (especially in the list) were considered by the students to be very helpful.

5 INTERACTING WITH MOVING ENTITIES

As revealed by our evaluation, one important shortcoming of the early prototype was the lack of (as we call it) moving entities. These include the whereabouts or the habitations of a certain person during his/her lifespan. It also means movements of groups of persons in a shorter time period, such as troop movements during armed conflicts, as well as massive migration of entire tribes or nations. Minard's (Minard, 1869) maps visualized time varying attributes of a single entity (most prominently the size of the troops) as width along its path.

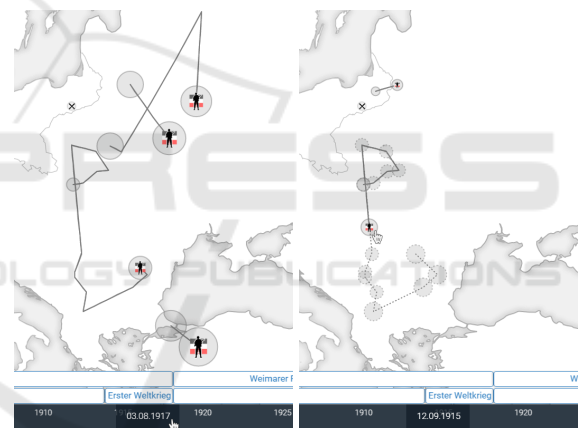


Figure 5: Troops moved by (left) time bar manipulation or (right) by dragging directly on map.

We aimed at visualizing multiple entities at once by using a glyph-based approach in order to avoid occlusion by widths of different paths. Thus, the paths themselves have a constant width, whereas the changes of attributes are addressed by modifying the appearances of the circle-shaped glyphs representing the troops. We introduced the idea of using “glyph footsteps” at particular locations along the path. This eases estimating and comparing glyph sizes while following a path.

In this manner the main challenge was aligning glyphs on their paths and on the global time slider accordingly. Obviously, any manipulation on the time bar must entail an immediate and automatic movement of all glyphs along their respective paths. Therefore the previously covered distance is depicted as a

solid path line (see Figure 5a). We decided that, for the sake of orientation and also for forecasting the future parts of the path towards its destination (beyond the current date on the time bar), the future segments are drawn as dashed lines (see Figure 5b).

Controlling the position of the entity via the timebar while looking at a particular path was an indirect task that resulted in unnecessary context switches. We favored and implemented a direct manipulation approach (inspired by Dragicevic (Dragicevic et al., 2008), Karrer (Karrer et al., 2008) and also Kimber (Kimber et al., 2007)), who introduced the metaphor for controlling video playback directly by grabbing objects depicted within the video frame) that enables the user to drag the glyphs directly along their paths which instantly affects the global date and hence the positions of all other entities. Precise input movement along the path is not necessary; the user is guided by the path's constraints.

Due to the lack of more precise routing information, a path consists of a discrete minor number of known locations that have to be interpolated temporally and spatially in order to create a continuous path and to determine an entity's position for every time step inbetween the dates of the known locations. Two different possibilities for coping with this situation were tested: first, simply condoning interpolated, yet inaccurate, positions when interaction is discontinued (as implemented for the timebar). In contrast, releasing the mouse when directly dragging a glyph entails an automatic animation to its next valid position, which again changes the global time and causes the movement of other entities that once more might end up in an inaccurate position, at which point we stop the recurring calls and allow interpolated positions. Interrupting this cyclical behavior might appear inconsequential; however it prevents the system (in the worst case) from moving all glyphs one after another.

At best, this issue might be solved by gathering more information about the entities and their movements, which revealed to be barely possible since the necessary information is rarely available in a reusable form. Usually the information is unstructured, scattered, and embedded in numerous text documents, many of which cannot be processed with standard information retrieval tools.

6 ALLIANCE ROUTING LENSES

HistoGlobe already provided a possibility showing affiliations with alliances by coloring countries accordingly. From suggestions during our field study we

noticed that this approach lacked in supporting bilateral treaties. We implemented a solution for depicting higher information density referring to historical treaties and conflicts in combination with the three-dimensional globe, which serves as advanced map representation. "Correlates Of War" (Maoz, n.d.) offers a wide variety of data concerning international relations such as bilateral alliances among states and countries between 1816 and 2012. Edges represent bilateral treaties. Every active incoming edge increases the radius of circular nodes accordingly so the user can easily spot and distinguish very actively linked countries and lesser ones.

The number of simultaneously active alliances drawn onto the globe is tremendous (even for selected epochs) and produces crossings, as well as occlusion. Of course, every directly connected component is going to be highlighted if the pointer is hovered above a particular node. This includes every outgoing edge and its corresponding alliance partner node (see Figure 7 left). Additionally the user can turn off all non-involved edges of the whole graph by clicking a node or even selecting two alliance partners consecutively.

Although such filtering makes the graph less dense, crossings between edges and non-associated nodes still occur if an uninvolved third country node lies underneath the direct path between two alliance partners. In order to avoid such incorrect visual impressions, Holten (Holten, 2006) or Buchin et al. (Buchin et al., 2011), for example, proposed bundling techniques by using or generating control points for spline-based paths which result in a sort of branched structure that is considered to be more visually appealing. Unfortunately, bending and bundling edges eventually entails losing their direction information. Reliable predictions that limit the area of possible target locations are only possible if the direction towards a treaty partner remains straight. Even if the target is out of sight while looking at another region, we can count on our mental model in such a familiar environment like the Earth's globe.



Figure 6: Interactive lens-based edge distortion. (a) All nodes out of scope. (b) Incident ignored edges on node inside scope.

Therefore, we developed two techniques for avoiding false implications by maintaining the basic direction of an edge, globally, yet introduced a local repelling mechanism in the proximity of third country nodes. First, we evaluated an interactive lens-based approach that distorts all edges around the mouse cursor (see Figure 6a). The user can alter the repelling strength and thereby change the lens' scope. For having the opportunity to focus on a particular node and its alliances while moving the lens above it, neither the node nor its adjacent edges are affected (see Figure 6 b). Using this property, one can easily distinguish true from false incidences when hovering over a node.

An interactive approach is nice; however, wouldn't it be better to provide this capability for all nodes at once? Advancing our approach automatically generates a lens around every graph node whereas the nodes' radii are used to determine the scope of the so-called local control points. Again, incident edges associated with a node are not affected. All other alliance connections circumvent each node along the edge but follow their primary direction out of the scope again (see Figure 7 right).

Besides a proper path construction itself, additional attributes had to be visualized: for instance, the type of alliance (defense, neutrality, non-aggression, entente, or a combination of them). Since less than six combinations occurred in the dataset, we ultimately used a simple additive color model based on respective base colors. Thus, one can easily spot the appearance of enacted alliance types by observing whole color regions on the map. However, we are aware that this may not suffice for some future data sets consisting of more types and combinations of alliances. Furthermore, the user is provided with details about making use of the hivent information windows.

Another important attribute that might be of interest is the endurance of such a relationship between two countries mapped onto the elevation of an edge whose highest point is then at the center of a connection. In order to avoid edges elevated at the same level following identical paths (if two states enact multiple alliances during the same time period), arcs are unfolded on both sides of the initial connection (see Figure 8, top). The arcs can even be merged with our lens-based approach; however, they are currently only useful for certain viewing angles (see Figure 8, bottom). Further development is going to improve the concept by readjusting the lenses along their edges to provide optimal view every time the point of view is changed due to navigation.

7 DATA AND IMPLEMENTATION DETAILS

The prototype is almost entirely implemented on client side in Coffeescript/Javascript. For depicting the map, the Leaflet library was integrated, whereas all other components were developed from scratch. All three-dimensional and globe-related interface elements are realized by using Three.js, a web-based, plug-in free, and a high level library which provides the use of WebGL. We organized perspectively-distorted and screen-space based interface elements into different rendered scenes. By casting rays from the mouse pointer into these multiple scene layers, selection and object manipulation is achieved. Shader materials were employed to parallel process the connections of the graph layer on the GPU.

Starting from *Natural Earth Data* (Natural Earth, n.d.) we created and edited a novel dataset of historical countries of most parts of Europe from 1871 until 1990. Available historical maps were first geo-referenced onto present coordinates and then the country borders were extracted using *QGIS* and stored as individual JSON files. The labels are stored separately due to independent changes of names and geometries. Each one is assigned to a priority that determines the label's bounding box. Thus a label is only shown if it does not collide with any bounding box.

HistoGlobe uses an event-based spatio-temporal data model (Peuquet and Duan, 1995) for changing country areas: for example, changing the membership of a country (e.g. Alsace-Lorraine 1919 from the German Empire to France) or for changing or introducing country borders following the splitting of two countries (e.g. the border between Czech and Slovak Republic after the dissolution of Czechoslovakia in 1991). Animated transitions lead the users' attention. Areas, labels, and transitions are preprocessed on the server and loaded directly onto the client to avoid client-server interaction during transitions. However, if the date changes on timeline, the server is notified to send all hivent that have occurred since the previous request. For each hivent the changes are executed: on the map, transition areas and borders are faded in and the related old and new areas and labels are queued and processed by adding new areas and labels while the old ones are faded from the map. In order to prevent large amounts of changes on the map if the timeline is moved far, a rule-out mechanism is implemented. Areas and labels that would be added in one change but deleted in another one are removed from both lists because they would not contribute to the current state. With this mechanism it is possible to move the timeline at a high speed there and back and

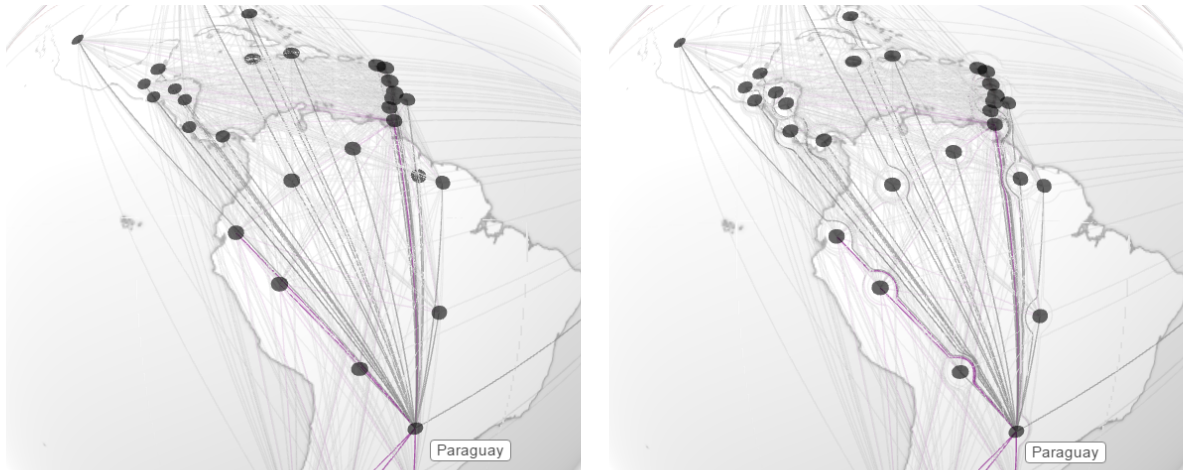


Figure 7: Highlighted alliance partners (left) without and (right) with location based repelling.



Figure 8: Arc groups (top). Combination of location based repelling and arcs(bottom). View dependent.

always get a fast and consistent update on the map.

8 CONCLUSION AND FUTURE WORK

HistoGlobe is intended to support teachers in explaining complex historical matters, as well as guiding stu-

dents with curated content during self-study. Therefore, the interactive web-based application integrates familiar interfaces such as globes and timelines with new visual concepts including hivents, directly manipulable moving entities, and direction-preserving route lenses.

The conducted pilot study with 18 students led to encouraging feedback, especially with respect to the fluent spatio-temporal coordination of map and timeline. The hivent concept, in particular, was greatly appreciated since the students used it in our observation to speed up knowledge transfer by focusing on the hivent list as kind of an overview (somehow bypassing the timeline with its eras), a behavior that was originally not intended.

Authoring capabilities have to be built in for teachers to develop their own courses, customize existing ones, compile different lessons, or derive web-based homework for the students. They should also allow students to put together stories, record them, and present them to others. However, even with proper authoring tools, most information has to be gathered and curated by people. We found that automatically extracting information suitable for our needs is barely possible since the necessary information is rarely available in a reusable form. Borders of states or realms that frequently changed in the past are traditionally depicted on historical maps that are mostly not even digitally available. In this regard, retrieving information that characterized moving entities such as locations, directions, durations, and number of people involved is also very important. Usually such information is unstructured, scattered, and embedded in numerous text documents and requires the development of custom information retrieval tools.

In conclusion, the current revision of HistoGlobe

covers both the questions *When?* and *Where?* very reasonably. An important issue to be solved in future work addresses the *Why?* (did a hivent happen?) question. This concerns both the automatic retrieval of facts as described above and the design and implementation of visualizations that could aid in clarifying what hivents are utilized or affected by others and to what extent. We believe that interactive visual history teaching systems such as HistoGlobe can significantly improve the knowledge transfer and the understanding of complex historical processes—besides being much more engaging and fun than traditional methods.

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REFERENCES

- Buchin, K., Speckmann, B., and Verbeek, K. (2011). Flow map layout via spiral trees. *Visualization and Computer Graphics, IEEE Transactions on*, 17(12):2536–2544.
- Dragicevic, P., Ramos, G., Bibliowicz, J., Nowrouzezahrai, D., Balakrishnan, R., and Singh, K. (2008). Video browsing by direct manipulation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, pages 237–246, New York, NY, USA. ACM.
- Frank E. Smitha (n.d.). World History Timeline. <http://www.fsmitha.com/t-index.html>. [Online; accessed 2015-11-30].
- Google Inc. (n.d.). Google Earth Historical Imagery. <http://www.google.com/earth/explore/showcase/historical.html>. [Online; accessed 2015-11-30].
- Holten, D. (2006). Hierarchical edge bundles: Visualization of adjacency relations in hierarchical data. *IEEE Transactions on Visualization and Computer Graphics*, 12(5):741–748.
- Karrer, T., Weiss, M., Lee, E., and Borchers, J. (2008). Dragon: A direct manipulation interface for frame-accurate in-scene video navigation. In *CHI '08: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 247–250, Florence, Italy. ACM Press. Best CHI 2008 Note Award.
- Kimber, D., Dunnigan, T., Girgensohn, A., Shipman, F., Turner, T., and Yang, T. (2007). Trailblazing: Video playback control by direct object manipulation. In *Multimedia and Expo, 2007 IEEE International Conference on*, pages 1015–1018.
- Kondo, B. and Collins, C. (2014). Dimpvis: Exploring time-varying information visualizations by direct manipulation. *IEEE Trans. on Visualization and Computer Graphics (Proc. of the IEEE Conf. on Information Visualization)*, 20(12).
- Kraak, M. J. (1988). The space-time cube revisited from a geovisualization perspective. *Proceedings of the 21st International Cartographic Conference*, 1995.
- Lenntorp, B. (1976). *Paths in space-time environments: a time-geographic study of movement possibilities of individuals*. Meddelanden från Lunds universitets Geografiska institution: Avhandlingar. Royal University of Lund, Dept. of Geography.
- Maoz, Z. (n.d.). The Correlates of War Project. <http://www.correlatesofwar.org/>. [Online; accessed 2015-11-30].
- Minard, C. (1869). Carte figurative des pertes successives en hommes de l'Armee Francaise dans la campagne de Russie 1812-1813. <http://upload.wikimedia.org/wikipedia/commons/2/29/Minard.png>. [Online; accessed 2015-11-30].
- Natural Earth (n.d.). 10m-cultural-vectors — Natural Earth. <http://www.naturalearthdata.com/downloads/10m-cultural-vectors/>. [Online; accessed 2015-11-30].
- Northwestern University Knight Lab (n.d.). Timeline JS3 - Beautifully crafted timelines that are easy, and intuitive to use. <https://timeline.knightlab.com/>. [Online; accessed 2015-11-30].
- Ott, T. and Swiaczny, F. (2001). *Time-Integrative Geographic Information Systems: Management and Analysis of Spatio-Temporal Data*. Number v. 1 in Time-integrative Geographic Information Systems: Management and Analysis of Spatio-temporal Data. Springer Berlin Heidelberg.
- Peuquet, D. and Duan, N. (1995). An event-based spatiotemporal data model (estdm) for temporal analysis of geographical data. *International Journal of Geographical Information Systems*, 9(1):7–24.
- Stiftelsen Gapminder (n.d.). GapMinder. <http://www.gapminder.org/world>. [Online; accessed 2015-11-30].
- Time Magazine (n.d.). Nelson Mandela's Extraordinary Life: An Interactive Timeline. <http://world.time.com/2013/12/05/nelson-mandelas-extraordinary-life-an-interactive-timeline/>. [Online; accessed 2015-11-30].
- TimeMaps Ltd. (n.d.). TimeMaps. <http://www.timemaps.com/history>. [Online; accessed 2015-11-30].
- Tufte, E. R. (2001). *The Visual Display of Quantitative Information*. Graphics Press.
- World Bank (n.d.). Life expectancy at birth, female (years). <http://data.worldbank.org/indicator/SP.DYN.LE00.FE.IN?display=map>. [Online; accessed 2015-11-30].