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Gestural Interaction with Spatiotemporal Linked Open Data

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Abstract

Exploring complex spatiotemporal data can be very challenging for non-experts. Recently, gestural interaction has emerged as a promising option, which has been successfully applied to various domains, including simple map control. In this paper, we investigate whether gestures can be used to enable non-experts to explore and understand complex spatiotemporal phenomena. In this case study we made use of large amounts of Linked Open Data about the deforestation of the Brazilian Amazon Rainforest and related ecological, economical and social factors. The results of our study indicate that people of all ages can easily learn gestures and successfully use them to explore the visualized and aggregated spatiotemporal data about the Brazilian Amazon Rainforest.

Keywords: Gestural interaction, spatiotemporal phenomena, Linked Open Data.

1 Introduction

In recent years, gestural interaction has been successfully used to enable untrained users to control different types of applications. Some operations arguably map naturally to certain types of gestures. Examples of this are pointing at an item to select it or moving a body part to trigger a similar motion of the screen content. These properties of gesture control are typically used to facilitate access to simple data such as photographs, media or basic maps. Given this, our hypothesis is that gestural interaction is equally well suited to enable the exploration of more complex (linked) spatiotemporal data. The goal is thus to create methods for communicating results of the field of Geographic Information Science to the public, for example in an exhibition, in a science museum or science center, where large surfaces are important for better visibility.

Gesture control is a promising approach to enable interaction with large surfaces in particular since it can improve ease of learning and help overcome reachability issues [15] and due to its high level of learnability [7, 23]. While previous work has shown this for basic spatial operations (panning, zooming, re-arranging objects), it is not clear whether gestural control can work equally well when interacting with spatiotemporal data.

Interfacing research on Human-Computer Interaction with recent Linked Open Data and visualisation techniques for complex spatiotemporal data is a contribution towards Linked Open Science [14] to support transparency and openness of science via facilitating the exploration of scientific observations. Clearly, Linked Open Science needs Linked Open Data (LOD)[8] to allow for publishing of very different kinds of data on the web, and to interconnect them together and to space and time. Additionally Linked Open Science needs Open Source Software, to make its results reproducable and freely available.

In this paper we present and evaluate an application based on open source technologies enabling the exploration of Linked Spatiotemporal Data integrated into an exhibit. We present a set of gestures that visitors to a science fair can use to explore large amounts of linked data related to deforestation on large screens and we also report on results from an initial survey. In the following, we first briefly describe the background before presenting the prototype system, the linked open spatiotemporal datasets [13], their visualizations and the gestures we have implemented. We then describe the survey we conducted and summarise the results we obtained. The penultimate section discusses possible implications of our findings on the design of similar systems. The paper closes by summarising the main contributions and giving a brief outlook on future work.

2 Related Work

There is a broad range of previous work investigating the use of different types of gestures (e.g. arm-, body-, or headgestures) to facilitate interaction with various types of systems (e. g. desktop computers, mobile phones or public displays). The recent intro-

[8] http://linkeddata.org

duction of affordable off-the-shelf solutions to track gestures [16] led to the development of gestural interfaces for a variety of application scenarios. Gestures have thus been used successfully as a means to enable laypeople to control different types of applications (e. g. simple map exploration, motion games, remote control of TVs, or art installations [1, 2, 21]). Bhuiyan [1] provides a chronologically ordered overview of gesture-controlled user interfaces. Wachs [21] surveys possible application scenarios for gestural interaction but also compiles a set of basic requirements for gesture-based systems. Technically, the cited systems either make use of multi-touch surfaces [8], near-or on-body sensors [4], or contactfree/camera-based technologies [3].

Frequently, a skeletal model is used to further improve recognition [12]. Since there now are several viable options to detect gestures fairly reliably, the design and use of specific gestures has recently become an important area of research. Wobbrock [22] presented initial research into what gestures people produce naturally and identified a set of common gestures for use on multi-touch surfaces. Jokisch carried out a survey on how users discover gestures for map interaction on large multi-touch surfaces [10]. In his study, adults (20-30 years old) easily discovered simple gestures (i.e. pinch-to-zoom) but had great difficulties finding complex ones, while children (8-9 years old) had more difficulties discovering both.

A frequent example application scenario for gestural interaction is the exploration of two-dimensional maps or simple spatial data (e. g. [6, 17]. Map interaction was also a frequent example scenario to demonstrate FTIR-based surfaces [8]. Daiber [4] introduced a set of physical multi-touch interaction primitives and let user groups choose corresponding spatial interaction tasks. Recently, the manipulation of a virtual globe has also received some attention [4, 11, 19]. Boulos [11] introduced a system for gestural interaction with Google Earth and Google Street View by describing gestures for the basic functionalities. Stannus [19] reported on a comparison study, where they asked participants to perform different common navigation tasks with a virtual globe using either a mouse, a 3D-mouse or gesture control. They found that users often prefer classical input methods, i. e. a standard mouse for finding places in Google Earth, only displaying the standard imagery and no complex data. The gestural interaction was rated and commented positively in terms of naturalness. The study was of a qualitative nature, having only 10 paricipants and reported about technical problems in the prototype for the gestural interaction.

The work presented in this paper also investigates gestural interaction with a virtual globe but extends previous work by enabling interaction with the temporal dimension (to explore historical data and trends). In contrast to previous work, the prototypical application we used relied on linked spatiotemporal data on deforestation in South America. To the best of our knowledge our effort to provide exploring Linked Data with gestural interaction methods is first of its kind.

3 Exploring Data about the Brazilian Amazon Rainforest

In order to investigate the suitability of gestural interaction for the exploration of linked spatiotemporal data, we designed an interactive system aimed at enabling untrained users to explore linked data sets and visualizations on the deforestation of the Amazon region in South America. The system was exhibited at a science fair, where we gathered feedback from visitors. The physical setup of our system was based on a triangular construction with three rear projection surfaces (see Figure 1 and Figure 2).

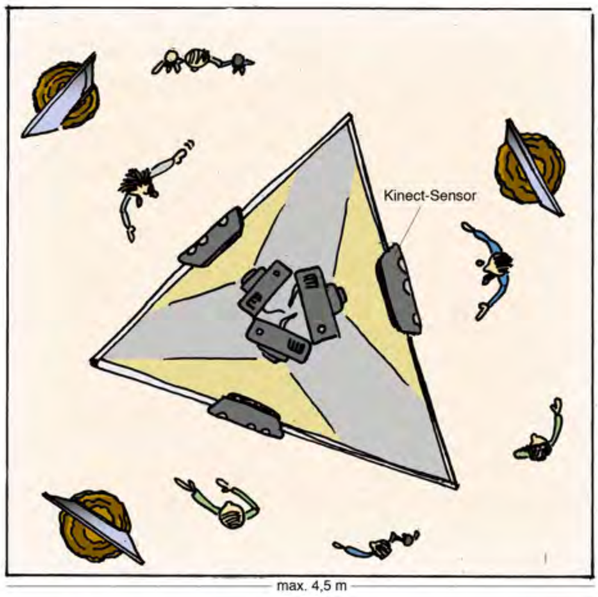

Figure 1: Physical setup of prototype: three back-projection screens arranged in a triangular configuration; each screen is controlled by a Kinect motion tracking device.

Figure 2: Gestural Interaction with the prototype on two sides providing access to different facets of the complex data se.

Each of the three screens was controlled by a dedicated gesture tracking device (i.e. a Kinect sensor). The data was rendered on the screen using a modified version of the free open source system NASA World Wind Java SDK[9] (a virtual globe system). Gestural interaction was implemented via the open source API for natural interaction OpenNI[10], a computer vision middleware NITE[11] and time series analysis [20].

The Linked Data in use represents deforestation observations from the Brazil Amazon Rainforest. Moreover, there are related social, economical and ecological data from selected Open Data sources. The social, economical and ecological dimensions were selected following the Triangle of Sustainability concept [18]. The software supports several operations to explore the data: panning—i.e. moving the map—, zooming in and zooming out, as well as moving forwards and backwards through time. The temporal operation is particularly important to support understanding of the effects and spread of the deforestation over time, and correlated phenomena like increased GDP and increased population.

The approach is completely based on free and open source software technologies and open data, making the exploration of the Brazilian Amazon Rainforest deforestation available to a broad audience in science, education, politics and society. In the next sections we introduce the open datasets and describe their visualization in NASA World Wind and the user interface with its gestural interaction.

3.1 Linked Brazilian Amazon Rainforest Data

Linked Open Data (LOD) is a set of standards and practices for exposing data on the web. LOD also allows to explicitly store the various connections in the data. We made use of our earlier contribution to open up and link the data [13] about the Brazilian Amazon Rainforest for the visualization. These statistical and spatial datasets were described and structured using mainly two vocabularies, namely the Open Time and Space Core Vocabulary (TISC)[12] and the Open Linked Amazon Vocabulary (OLA)[13] . The entire dataset originates from official sources of the Brazilian Government, namely from IBGE[14] (Brazilian Institute of Geography and Statistics) and INPE[15] (Brazilian National Institute for Space Research).

Due the recently announced policy of the Brazilian government to publish all their statistical data on the web[16] it was possible to retrieve this data and integrate it into the existing Linked Data about the Brazilian Amazon Rainforest. We realized the retrieval via a custom-made application, which connected to the IBGE's servers, downloaded the relevant data and transformed it into Linked Data to be used for the visualizations and exploration.

3.2.1 Statistical Dataset

The statistical dataset, containing a time-series from 2004 to 2009, includes the following information:

Soybeans – Soybean crops classified by hectares of planted and harvested area, value in thousand of reais (Brazilian Currency), metric tons and kg hectare. Those crops are linked to an observation and additionally linked to their respectively entries in DBPedia.

GDP – Gross Domestic Product from each municipality of Pará state.

Cattle – The total head of cattle grouped by municipality.

[9] http://worldwind.arc.nasa.gov/java
[10] http://www.openni.org
[11] http://www.primesense.com/solutions/nite-middleware
[12] http://observedchange.com/tisc/ns
[13] http://observedchange.com/amazon/ns
[14] http://www.ibge.gov.br/english/
[15] http://www.inpe.br/ingles/
[16] http://acessoainformacao.ibge.gov.br/en/

Population per municipality – Census 2000 and 2010, and population projections from 2001 to 2009.

3.2.2 Spatio-temporal Dataset

Observations of deforestation were made using remote sensing techniques, i.e. satellites. Similarly, land use data and natural and social factors of change were collected. All these data, structured and provided by INPE[5], were aggregated to grid cells of 25 km x 25 km. In Figure 3, a visualization of the dataset can be seen, where the deforestation values from cells, which spatially overlap the municipalities of Pará in Brazil, were aggregated and were plotted together with the corresponding population on the virtual globe. The spatial dataset, also containing a time-series from 2004 to 2009, has the following information:

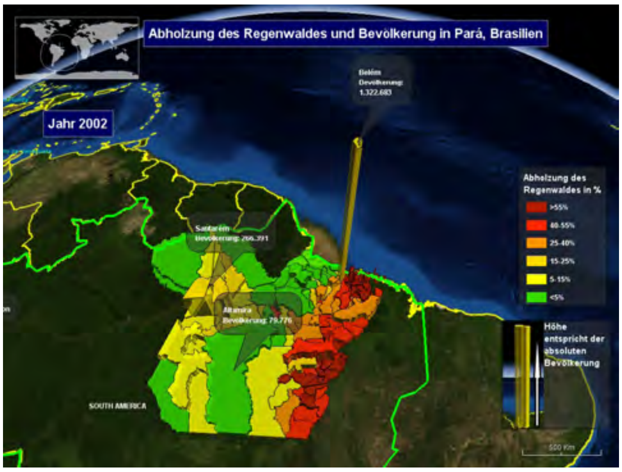

Figure 3: Visualization of the LOD Datasets on Population (height) and Deforestation (color) in NASA World Wind.

Deforestation – The observed amount of deforestation aggregated to grid cells.

Municipalities and Federal States – A complete compound of Brazilian Federal States, which belong to the Amazon area (according to the legal definition) and their municipalities, together with their geographical location and covered area.

Mesoregions – Spatial dataset that contains the mesoregions[17] area in Pará state. With this variable it was possible to group the statistical variables, originally grouped by municipality, to their corresponding mesoregion.

3.2 Visualization

The Brazilian Amazon Rainforest Dataset was visualized in NASA World Wind, divided in three different variables with the deforestation phenomena, namely GDP, Population and Head of Cattle. Each variable can be projected on the screens of the triangle and correlated with the yearly amount of deforestation, so the user can navigate year by year through the spatio-temporal datasets and observe its correlation with the deforestation phenomena. Figure 4 shows an example of the deforestation correlated with the GDP of each state of Pará in the year 2005, where the geometries height represents the GDP per person and their colour the amount of deforestation.

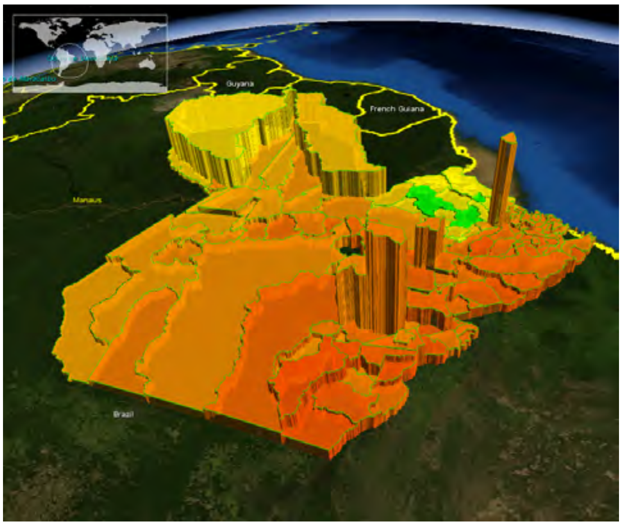

Figure 4: GDP (per person) and yearly deforestation in 2005.

Together with the variables and the deforestation visualization, several facts and pictures, related to each variable, were displayed in the application as annotations. These facts and pictures were programmed to be displayed according to the globe altitude, in a way that the user could have additional information to the application current view. Figure 5 shows an earth view of the Brazilian Amazon deforestation correlated with population in the year 2008. By this altitude the application was programmed to display in the left-hand side facts relevant to the current view. The facts displayed in the Figure 5 left side, written in German, say: "The pop-

[17]Mesoregions are subdivisions of Brazilian states. These subdivisions group various municipalities, based on neighboring municipalities and their common characteristics. They were created by the Brazilian Institute of Geography and Statistics for statistical purposes.

ulation of Pará represents approximately the same population of Switzerland with an area 36,75 times larger" and "Pará, population: 7.321.439, Total Deforestation: 24,13%, Population Growth: 255.920". This facts are hidden, giving place to other facts, if the user zooms the globe in or out. In the Figure 5 right-hand side, a legend is displayed to classify the geometries colours and and below it an image that explains the meaning of the geometries height, which in this case is population.

Figure 5: Earth view of the Brazilian Amazon deforestation correlated with population in the year 2008.

3.3 Gestures for Interacting with Spatiotemporal Data

Due to the importance of temporal control during the exploration of the datasets, we tried to come up with a gesture, which is easy to learn and to perform, and which also has a natural mapping to the temporal domain. Our initial approach was to use a clock metaphor, which would let the user move the hand of a virtual clock to control time by rotating their hand clockwise/counterclockwise. However, after some initial investigations we discarded this idea due to concerns about awkward and uncomfortable movements as well as difficulties in recognizing it reliably.

Eventually, we implemented three different gestures to control the spatial and temporal attributes of our map. In designing them, we tried to mimic known gestures for multi-touch enabled surfaces such as pinch-to-zoom and touch-and-drag-to-pan. While we were able to successfully apply this principle for the gestures controlling the spatial aspect, we did not find widely-used, well-known gestures for temporal control and thus designed them from scratch. The system currently supports the following gestures (cf. Fig. 6):

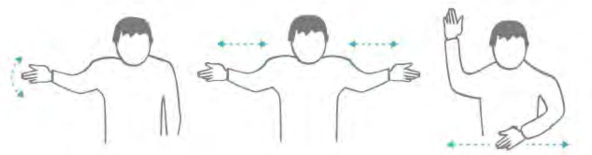

Figure 6: Complete gesture set implemented in the prototype (from left to right): one hand wipe (panning), two hand spread (zooming) and wiping with hand above head (controlling time).

One hand wipe – The first gesture is a wiping motion with one hand, which can be moved in any direction. This gesture allows the user to control which section of the map is shown, i. e. to pan the map in the direction of the hand motion. It is possible to perform this gesture with either arm, but not with both at the same time.

Two hand spread – The second gesture is used for zooming in and out of the map, i. e. to change the scale of the map. To perform this gesture, users have to move both hands and forearms simultaneously. If they move them closer together, the map is zoomed in, and if they move them further apart, it is zoomed out.

Wiping with hand above head – The third gesture controls the temporal aspect of the map. Users can carry it out by raising one hand over their head and – while keeping it above head – performing a horizontal wipe gesture with the other hand. Wiping to the left moves the timeline back by one year, wiping to the right moves it forward by one year. Visitors to the science fair could learn about the gestures by studying one of the posters we set up around the system, by observing other visitors interacting with the system, by talking to previous visitors to the exhibit, or by directly asking a member of staff continuously present near the system. The gestures can be seen in the project video[18].

4 Evaluating the Approach

In order to gain a first understanding of gestural interaction with spatiotemporal data, we carried out a

[18] http://goo.gl/oRTFO

questionnaire-based survey amongst visitors to the exhibit. Our goals were to get insights into how easy people found it to use and learn the gesture set, and whether it enabled them to get a deeper understanding of the complex spatiotemporal data they explored. In addition, we were interested in the fitness of the gesture set for the actions they were mapped to.

4.1 Procedure

We opportunistically asked visitors of the science fair, who had used our exhibit for several minutes (i. e. the gesture controlled exploration system for deforestation data) whether they would like to participate in our study. If they agreed, we asked them to fill out a short questionnaire. In addition, we informally observed the use of the system while noting any patterns, behavior, incidents and comments we became aware of. Participants were thanked for taking part in the study but did not receive any payments in return for their time.

4.2 Material

The questionnaire we used consisted of 28 open and closed questions in total. Participants were first asked to provide some demographic information about themselves such as their age, gender and their primary hand. We also gathered information about people's familiarity with common commercial systems that provide gesture control interfaces (e. g. Nintendo Wii, Sony Playstation Move/Eye). The second group of questions investigated task load for each gesture and were taken from the NASA TLX questionnaire [9]. We then asked participants questions relating to the use of gestures to control the spatiotemporal data. They had to rate how well gestures and specific map actions fit together, and to indicate whether they thought the gestural interaction interfered with the exploration and understanding of the linked Brazilian Amazon data being displayed. Finally, participants had to rank the three gestures overall.

4.3 Results

In total, we collected 43 responses. 28 of the participants were male and 15 female. The average age was 21.8 (mean deviation of 6.67); the youngest participant was 10, the oldest one 59. Seven of participants were left handed, 36 right handed. 19 participants stated they are familiar with gesture-based interfaces in general, while the other 24 stated the opposite. However, when asked about specific commercial systems (e. g. Nintendo Wii), it became apparent that some people had not considered these to be gesture-based systems when answering the previous question: 23 people indicated familiarity with Nintendo Wii, four with PS move, six with PS Eye Toy and eight with Microsoft Kinect. Two participants named other gesture-based systems. For this question, multiple answers per participants were allowed.

Figure 7 summarises the results for task load according to the standard NASA TLX questionnaire. The questionnaire uses a scale from zero to 20, where lower values correspond to lower work load, performance, effort or frustration, and higher values to higher work load etc. Participants rated all three gestures in a very similar way. Ratings for mental, physical and temporal demand ranged between 2.79 (std. dev. 3.23) and 4.07 (std. dev. 4.10), with the temporal control gesture generally being rated slightly worse than the other two. Performance ratings were highest for the two hand spread gesture (14.23, std. dev. 3.75), followed by the single hand wipe (13.12, std. dev. 4.2) and the wiping with hand above head gesture (12.67, std. dev. 4.6). The results in the effort category were nearly identical, whereas there were notable differences in the frustration category: here, the temporal control gesture attracted the worst rating (3.77, std. dev. 3.86), while the other two gestures were rated very similarly (single hand wipe: 3.79, std. dev. 3.51 and two hand spread: 3.93, std. dev. 3.81).

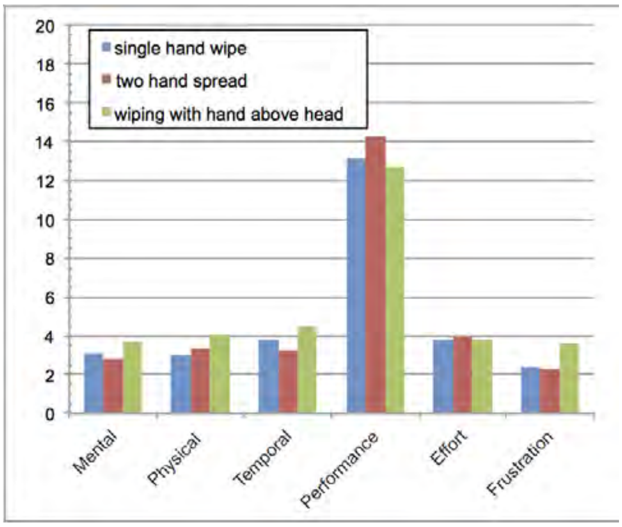

Figure 7: NASA TLX (task load) results for the three different gestures.

Results of the ranking task are summarised in Table 1. Overall, participants slightly preferred the two hand spread over the one hand wipe; the wiping with one hand above head gesture was clearly the least preferred gesture amongst the three implemented. We recorded a similar trend in terms of how well participants thought the gestures mapped to the associated actions. The wiping with hand above head gestures was rated lowest at 13.07 (std. dev. 5.14), while the two hand spread received a 14.02 rating (std. dev. 4.18) and the one hand wipe a score of 14.23 (std. dev. 3.75). The question, if the gestural interaction was rather distracting or helpful in the exploration and understanding of the linked spatiotemporal data on the Brazilian Amazon deforestation was answered with an average score of 13.92 (std. dev. 4.52). Ratings were out of 20 from zero being worst to 20 being best.

Table 1: Overall ranking of three gestures (1: best to 3: worst); the table lists number of participant, who ranked each gesture either 1, 2 or 3.

Rank	**1**	**2**	**3**	**Average**
One hand wipe	18	16	6	1.7
Two hand spread	22	12	7	1.65
Wiping with hand above head	1	12	27	2.53

4.4 Observations

In addition to the formal survey, we were also observing visitors interacting with the system: after having used our system, a number of people reported that they found the controls mentally challenging during the first few minutes, and were only able to engage with the content after that period of time. Some visitors were confused by the direction of the temporal change as they were expecting a change in the opposite direction. One participant commented in the questionnaire that our gesture is the opposite of turning the pages in a calendar. In addition, were received several positive comments from older people, who found the system very accessible, particularly if compared to their first time use of a mouse. However, there were also a number of people were unwilling to try out the system at all.

Furthermore, we noted some technical issues. The time between recognising a user and registering them as the user controlling the system increased considerably with the number of bystanders/onlookers 'seen' by the Kinect sensor. We also observed some problems in recognising children, which depending on their arm length were not detected very well.

5 Discussion

Generally speaking, the results indicate that participants were able to easily learn and use all three gestures without excessive work load, effort or frustration. Possibly due to people's lack of familiarity with the gesture used to control time, the gesture consisting of wiping with one hand above head was rated slightly worse than the other two gestures. It was particularly encouraging that participants considered the gestures helpful to engage with the complex spatiotemporal dataset visualised by the application. In addition, several older users positively commented positively on the system and its interface, indicating that gestural control could hold some potential to reach this growing user group as well.

However, since we were not able to specify specific tasks or learning goals beforehand, it is unclear whether this self-assessment reflects actual learning performance. We also did not measure actual performance or error rates during the study so that in this area, further research is required to confirm whether ease of learning and use translate to good performance as well.

Finally, we would like to mention the challenge of displaying large amounts of Linked Spatiotemporal Data on virtual globes. In our solution we chose to use only the data from Pará state since it is an interesting and representable part of the complete dataset about the Brazilian Amazon Rainforest. The data from Pará state already has very interesting combination of each chosen dimension (ecological, economical and social factors). In addition we visualized links to other countries based on the export statistics. Given these experiences we see very potential research challenges emerging for visualizing larger datasets on virtual globes.

6 Conclusions

In this paper we investigated the use of gestural interaction with complex spatiotemporal data, aggregated from Linked Open Data sources. We introduce a prototype virtual globe application, based on open source software technologies. We proposed three gestures to explore multi-dimensional deforestation data, two of which were inspired by common multi-touch gestures, and one designed from ground up to control the timeline. In order to evaluate the gestures and the overall approach, we conducted a survey study at a science fair. The results indicate that the gestures were easy to learn and use (possibly after a brief initial learning phase), and were considered helpful in engaging with the complex data visualised by the application. This was true for the different age groups that participated.

In summary, our findings provide initial evidence that gestural interaction can also be successful in more complex scenarios, and thus deserves further research. One promising next step would be to conduct a study investigating naturally produced gestures (following the method pioneered by Wobbrock [22]). Additionally, modifying gestures by sensing hand and finger postures could be very useful when interacting with complex spatiotemporal data (e.g. controlling the number of years time is moved forwards or backwards, by extending the corresponding number of fingers while performing the gesture).

In terms of visualizing connections between very different phenomena —ecological, economical and social— Linked Data offered a good basis since connections could be made explicit via aggregation procedures, and via using time and space as major integrators. As a contribution the Linked Data about the Brazilian Amazon Rainforest we created and used is available also for others to use in visualizations and applications.

By interlinking aspects of Human-Computer Interaction, Linked Open Data approaches and novel visualization techniques for complex spatiotemporal data via open source software we contributed towards a Linked Open Science [14] to support transparency and openness of science.

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