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Vitalizing cultural memory with immersive data storytelling

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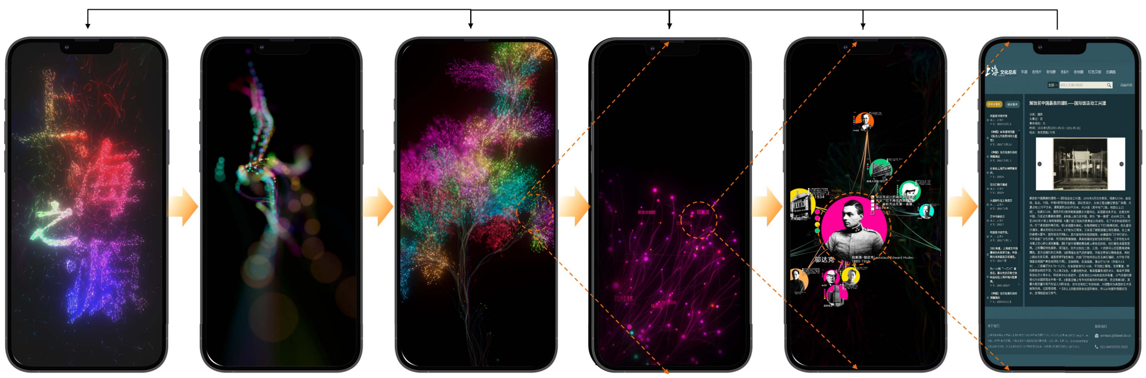

a) starry night | b) growth | c) exploration | d) keywords | e) details | f) GKB platform

Figure 1: Interactive storytelling and visualization of Culture Chronology. a) Stars representing history events float in the sky. Some starts to gather and illustrate the story title. b) Some of the stars are triggered and grow to form a tree of historical events. c) The users interactively navigate through the 3D scene of the tree. d) The users may zoom in to find hierarchically structured detailed information including the keywords, the relationship graphs and eventually the semantic web pages leading to the General Knowledge Base.

Abstract

Through decades of cultural heritage and cultural memory digitization, a massive amount of data has been collected and organized. There is an increasing interest in and demand for making the data approachable, explorable, and usable to the public audience, visualizing the data with multiple scales, and expressing humanity knowledge with aesthetically appealing images.

In this paper, we review media space design and research to vitalize the cultural memory resources and present a design framework for immersive data storytelling and multiscale knowledge data visualization of cultural databases.

Based on Shanghai Memory, a collection of cultural heritage and cultural memory knowledge bases, an interactive and immersive system of Cultural Chronology was designed and implemented to visualize event data with hierarchical and heterogeneous structures. Multiple versions of implementation, including a desktop application and a touch-screen virtual environment interactive installation, were presented for library and archive researchers, humanities scholars, public audiences, and other general-purpose users. The designed virtual environment is implemented with the procedural development workflow in Houdini and the interactive media art platform TouchDesigner, supporting data-generated modeling with a designer-friendly workflow. To further test the usability and evaluate the above design effect and efficiency of the design, a questionnaire-based investigation was conducted, showing the interests and challenges in immersive and hierarchical HCI design in digital humanities research.

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1 Introduction

With the accumulation of cultural heritage digitization and the rapid development of interactive technologies, interactive media technologies and visualization methods have become widely used tools for revitalizing cultural heritage and have been proven to create presence, provide an aesthetically appealing and realistic experience, and increase narrative engagement [26]. Meanwhile, massive amounts of intangible data, such as cultural memory data [2], stored and maintained in galleries, libraries, archives, and museums (GLAM) also contain an important component of digital humanities research. Big data technologies are used to support a large amount of knowledge and valuable information that is rarely revealed. Not enough attention is paid to cultural memory data as the information they present is often abstract, with complicated structure and inherent correlation. It is an interesting challenge to visually reveal the knowledge excavated from the massive data, and make it approachable, explorable, and usable to public audiences and humanities scholars.

Over the past decades, cultural institutes have digitized a massive amount of cultural heritage resources such as archaeological sites, buildings, and relics. These intangible resources, known as cultural memory, are attracting more and more attention. These include books, films, photographs, audio, and video recordings that are specified to fit the memories, knowledge, and information of a social group. [24]. Big data technologies including Linked Data, Resource Description Framework (RDF), Semantic Web, etc. are used to uniform, mark, and filter the data. As a result, platforms are created to expose information to researchers and the general public. Web-based services such as search engines, websites, and recommendation systems are developed for personal exploration and sharing over social media. Excavated data is open to the public and calls for creative usage. 3-dimensional visualization based on e.g. web3d is widely used to interactively visualize individual data sets [26]. The immersive narrative is introduced in the design of public media space to incorporate artistic design, data-driven visualization, visual narration, knowledge exposition, and data communication in immersive environments [21].

With the development of 3D technologies, especially general-purpose GPU and real-time realistic rendering, real-time massive generative model rendering with high-resolution details becomes possible . However, there is still a considerable cost in rendering large amounts of data-driven models and textures. Meanwhile, designing humanities data visualization [9] requires collaboration among artists, engineers, and humanities scholars, and a rapid prototyping and design framework with the capability of stable data extension is required [4].

In this paper, we contribute:

- A design framework for massive data visualization, narrative design, generative design, interactive exploration, and artist control.
- A novel generative modeling approach that integrates procedural artistic design with data-driven modeling.
- A correlation evaluation algorithm is propose to construct event relationship graph from the knowledge bases.
- Interactive and immersive installations and applications that provide accessible, explorable, and inter-operable visualization of chronological cultural memory knowledge.

2 Background

2.1 Cultural heritage and cultural memory

While cultural heritage emphasis on material resources, ***cultural memory***(CM) [2] is typically embedded in intangible resources including books, films, archives, photographs, and audio and video recordings. In 1992, UNESCO launched the Memory of the World Program to protect cultural memories. Since then, there have been continuous efforts to digitize cultural memory resources, and process the data derived from them [1]. In 2011, Shanghai Library started the project Shanghai Memory project to connect dozens of databases and knowledge bases about local chronology and geography, and provide a generalized platform service [6]. This platform provided direct searching services through the original databases of archives, photos, audio and videos, and knowledge bases were constructed on specific topics, such as the Old Film, Historical and Classical Archives, World Expo, etc. [1]. Despite the increasing amount of intangible cultural heritage data, there is a significant shortage of interfaces enabling its access, exploration and usage [26].

2.2 Digital experience and interfaces

After decades of digitization, massive cultural heritage (CH) data are open and available on the web. New types of interactive interfaces based on visualization technology are fostering novel cultural heritage experiences, including web-based interfaces [14], augmented reality interfaces [20], virtual reality interfaces [27], and immersive installations [11]. The advantage of enhancing cultural heritage experience with Augmented Reality and Virtual Reality lies in improving the quality of knowledge dissemination and enhancing the immersive experience of users [5]. An immersive interactive virtual tour application [1] is designed to provide users with an immersive and interactive cultural heritage experience, by using 360-degree immersive video applications for Head Mounted Display (HMD) devices. Indraprastha et al used AR and HoloLens to provide a promising tool for 3D visualization and experience, wherein computer-generated objects are enhanced into real and physical objects [8]. With these new interactive interfaces, different interaction methods can be used. For example, TombSeer, an augmented reality application, can vividly restore the cultural heritage in the museum into virtual space through gesture interaction. In addition, new and combined multimedia can also enhance the experience of cultural heritage [18]. Koeva et al integrates comprehensive information including high-resolution spherical panorama, various maps, global navigation satellite systems, sound, video, and text information to display the cultural heritage data of spherical or cyclical images [12]. A more generous alternative is proposed: a rich and browsable interface that shows the scale and complexity of the digital heritage collection, including pictures, text, charts, and other forms [25].

2.3 Data representation and visualization

Visualization technology provides an effective way to explore the complex and comprehensive information space of cultural heritage and cultural memory [26]. Visualization methods for cultural heritage and cultural memory include lists and slideshows, grids and mosaics, hierarchical diagrams, word clouds, charts, plots, clusters and sets, maps, and networks, such as a knowledge map based on paper data [10] Nishanbaev et al. transformed geospatial cultural heritage data into machine-readable and processable RDF data [17]. McKenna et al published the libraries' metadata as Linked Data (LD) [13]. 3D models have gradually become popular in the field of cultural heritage, enriching the types and formats of data and combining spatial and non-spatial data wells, such as MayaArch3D [3].

3 Design Framework

Through years of digitization and research by cultural scholars, the General Knowledge Bases(GKB) are created with Big Data technologies and laid the foundations with huge valuable humanities data(see Figure 2. Shanghai Memory is a database extracted and reconstructed from GKB [6]. Over 13000 cultural events are extracted. Each event entity is defined by the title, keywords, influence, key entities and related entities. Key entities include figures and affiliations, geographical sites, locations and architectures, cultural field types and descriptions. Unstructured data are stored with other media archives including videos, audios, books, etc (see Table 1).

Prior to the development of visualization systems for Shanghai Memory, we, a group of designers, artists, humanity researchers and software engineers reviewed the related research and design, and set up our design framework.

- Immersive: In immersive environment, users construct their spacial imagination and understanding about data via navigation, exploration and interaction. The process is a continuous and personalized experience.
- Explorable: Free exploration promotes engagement and arouses interest.
- Narrative: Storytelling draws the users to establishing the setting and helps the users understand the navigation logic.
- Generative: The scene created is generated from existing database and knowledge base, that are responsive to data correction, knowledge completion, information update and live news information.
- Multiscale: Massive data viewing at different scale reveals different structures and value. Hierarchical design with integrity and consistency cross scales provides informative experience.
- Clear: When visualizing massive data, too much information visualized at one time without balanced design leads to overwhelming cognitive load and failure to deliver information effectively.

[1]http://scc.library.shanghai.cn

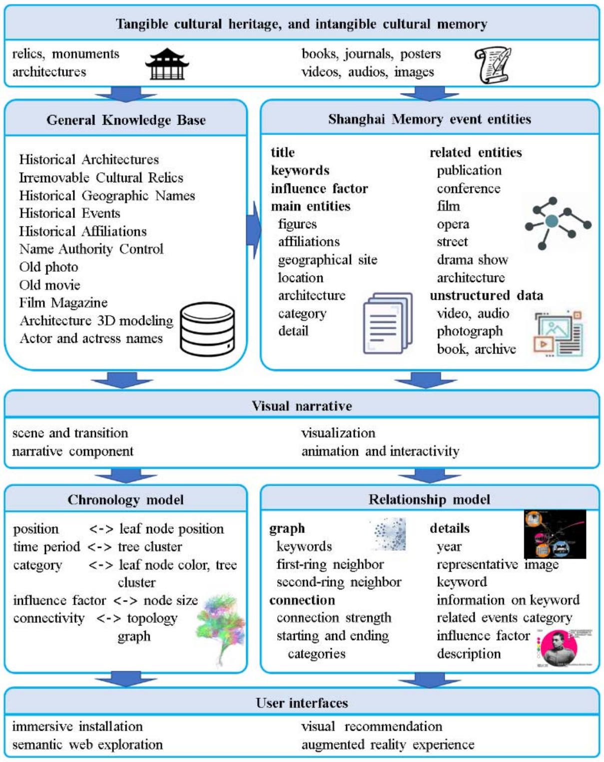

Figure 2: Design framework and data infrastructure supporting Culture Chronology

4 Generative design

Based on the proposed framework, we designed and implemented a data visualization and storytelling system: Culture Chronology, exposing the contemporaneous events along a chronically timeline. In this section, we explain the design, the interaction and graphics algorithms. An introduction story is presented. The user then explores freely in the immersive virtual space, and zooms in step by step to reveal the hierarchical information starting as a simple sphere in the tree, then keywords, and finally as fine details panels. The detail panels illustrate the event times, the keywords, the detailed description, the relationship graph, and the related web pages from GKB(see Figure 1).

Multiscale visualization have been used to effectively represent heterogeneous data structures with different scales and different levels of details. We follow graphical user interface design guideline introduced by Shneiderman [22] "Overview first, zoom and filter, then detail-on-demand". Our target users include humanity scholars, visitors and public audiences, library users and readers. Our designed data visualization is presented as an application on library daily usage desktops, and a public space digital installation.

Table 1: Databases in GKB

Knowledge base		Data base	
Old music records	66026	Old Photos	32953
Historical Affiliations	21869	Old maps	10574
Historical Events	13916	Film persons	5700
Historical Geographic Names	10162	Musician	1592
Old Chinese Film	4130	Film magazine	385
Irremovable Cultural Relics	3452	Film music	44
Historical Architectures	1086	Old film video	44
News Papers and Journals	521	Old theatre	10

4.1 Interactive storytelling

Storytelling has been an effective approach to introduce the audiences and users to the background environment. This story reveals an understanding and imagination of the researchers about the historical space rendered by individual events. The audiences are first introduced to a starting scene of a starry night, with the stars flowing like in a liquid fluid. Some of the starts start to grow like seeds in the land. Vines rise up, seek for the light, twist together and fall apart to eventually form a tree. After that, more curved lines start to grow and connect the leaf nodes from different node clusters. The tree is a metaphor of history threads supported by the historical events, and the secondary vines represent other relationships excavated from the event data. Now, the users are free to explore, experience, dive in step by step for more and more detailed information, until they reach the web-based services provided by GKB. At any step, they can also trace back and return to the original view without losing the global picture(see Figure 1).

4.2 Event entities

Shanghai has been culturally active in Chinese history, where multiple cultures join, collide, blend, merge, and interfere with each other. Cultural memory records in this period often appear with a blend of cultural facets and categories. For example, educator Huang Yanpei show multiple identities of an educator, a news and media journalist, and a writer through a sequence of cultural memory events. Based on the primary attribute, event entities are classified into 12 main categories: Publication, News, Theater, Opera, Literature, Film, Fine Arts, Dancing, Music, Architecture, Education, and Library and Museum(see Figure 3). Each category is represented by one color.

4.3 Generative model with artistic design

As mentioned before, academic scholars decided to use a tree model to represent the history trend. Designers searched over the traditional painting and presented figurative drafts and 3-dimensional rough models for the tree(see Figure 4.a). However, the designer's model is inconsistent with the statistical data (see Figure 4.b). We take the procedural modeling approach and develop an human-computer interactive workflow for the designer to balance between data-generated model and artistic model.

First, the reference mesh A(see Figure 4.a) and the statistical model B(see Figure 4.b, c) are imported. In the statistical model, each cylinder represents a historical period p. Its height and y-position are aligned with the time period h_p and starting year y_p. The cylinder's radius r_p was resolved, such that the volume of each cylinder $\pi h_p r_p^2$ is proportional to the event counts N_p. Each cylinder was then cut into sectors with the fractions proportional to the event count $N_{p,c}$ for each given category c in the given time period p. The cylinder sectors are then manually horizontally translated to align with the designed model(see Figure 4.d).

While L-system is frequently used for generating realistic tree [19], shortest path is another approach to generate vine models [15]. We find the second approach directly controllable from pre-designed surface model. Hence we take the shortest path approach.

We further refine the aligned model, and prepare the surface model with an organic shape of a tree. First, we used CGAL [1] to remesh each cylinder sector, and displace the vertices along the normal directions with random noise(see Figure 4.e). To fix penetrating polygons from the perturbed mesh, we generate a levelset function of the explicit mesh using OpenVDB [16]. With this levelset function,

[1] https://doc.cgal.org/latest/Surface_mesher

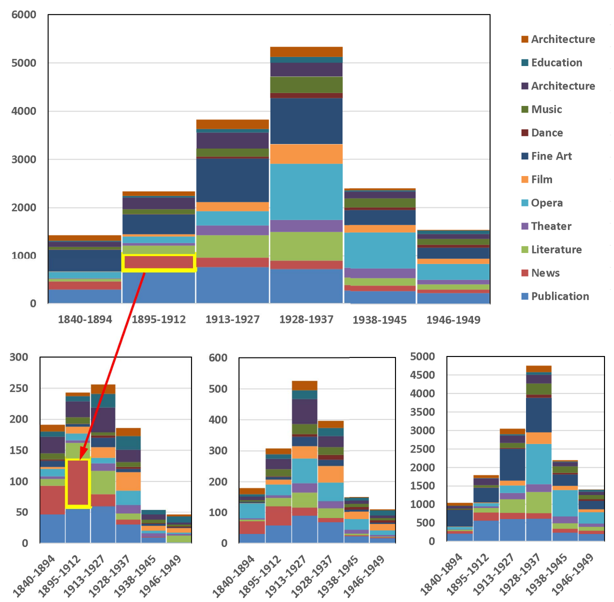

Figure 3: The primary cultural events categories in Shanghai Memory and their distribution in the 6 culture periods(Top). Based on the impact factor, the events are classified into 3 groups: high(bottom left), medium(bottom middle) and low(bottom right). The distribution of each group varies. For example, only 18% of events in between 1895 and 1912 are pertaining to architecture, but 36% of high impact events are architecture events. This means more architecture events are significant, compared to other time periods and categories.

we smooth the implicit surface by levelset advection, and reconstruct the mesh with non-penetrating polygons(see Figure 4.f). The point attributes denoting event categories are transferred to the new grid by averaging from the closest points in the original mesh. In order to trace the shortest paths through the interior volume of the mesh, we prepare internal edges by generating interior tetrahedrons as proposed in [23]. The Dijkstra algorithm [7] are then used to traverse through all edges and find the shortest paths between the specified starting and ending point groups. We define the starting points as the first 5 points in each event category, and define the ending points by sampling $N_{p,c}$ points on the tree surface. As a result, each generated path is mapped to one event in category c and period p(see Figure 4.g).

4.4 Correlation extraction

Events occurring within relatively close periods of time are important components in constructing the historical memory. In this paper, we propose a model to evaluate the events correlation from their related entities' correlation in the knowledge graph.

First, each event is connected to entities of subject keywords including related people, architectures, publications, films, performances, cultural affiliations, etc. Each entity is related to other entities in the GKB. By extracting keywords relationship in the Knowledge Graph, we can find the connectivity among events. Figure 6 illustrates an example. The event "In 1934, the Park Hotel designed by Hudec opened." has a subject keyword "Ladislav Hudec", the name of the architect. He designed a sequence of important theatres and hotels in Shanghai. In these architectures, films, plays, and operas were presented. Therefore, contemporary playwrights, performers, historical figures, and other visitors could be related with shared experiences and trips. Hence, these events are connected.

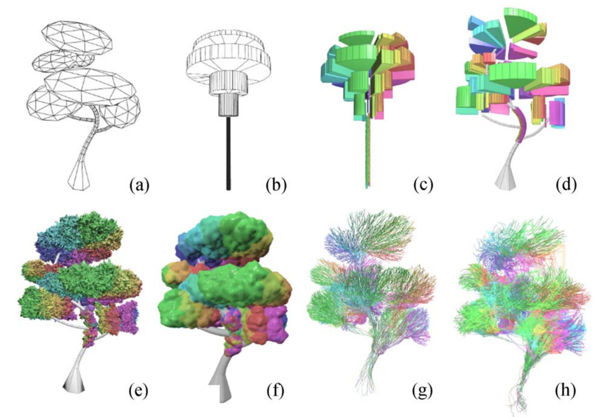

Figure 4: Culture Chronology generative model. (a) Artist-designed model. (b) Statistical model. (c-d) Modified design model. (e) Perturbed mesh. (f) Regenerated mesh from level set function. (g) Shortest path model. (h) Relationship graph.

To quantify the strength of the events' bond, we define a correlation score between each pair of events. Consider an event e in year y_e and with the period of influence I_e. Its keywords k_e can be found in the General Knowledge Base(GKB). By tracing k_e related entities in GKB, we find a sequence of related keywords k_r. We then search for all events e_r related to k_r. The year y_r and period of influence I_r of each related events are also extracted. The correlation score f_{e,e_r} is related to the distance between the two keywords in the Knowledge Graph $\text{dist}(k_e, k_r)$ and the correlation factor between the two events $\text{corr}(e, e_r)$. The distance between two keywords is defined by the number of steps to reach from one entity to the other. From the chronological view, the correlation factor is dependent on both events' occurrence time and influence periods.

$$f_{e,e_r} = \text{dist}(\text{k}_\text{e}, \text{k}_\text{r})^{\alpha} \text{corr}(\text{y}_\text{e}, \text{y}_\text{r}, \text{I}_\text{e}, \text{I}_\text{r}).$$

A kernel function evaluating the influence of one event to another event is defined as:

$$\ker(d_y, I) = \max(0, d_y e^{-\beta d_y / I}).$$

where I is the influence period of the first event, and the d_y is the time difference between the two events. And the correlation factor is defined by their mutual influences.

$$\text{corr}(y_e, y_r, I_e, I_r) = \max(\ker(y_r - y_e, I_e), \ker(y_e - y_r, I_r))$$

4.5 Graphical design

The correlation scores define the weight and connectivity bond in the relationship graph. Only edges with a score above a specified threshold is connected.

When clicking on one keyword, the pertaining connectivity graph is released from the chronological model. We extract a sub-mesh connecting the keyword itself, its first-ring neighbors, and its second-ring neighbors. The tree fades and retreats, obscurely floating in the background, and the connectivity mesh protrudes and predominates in the view. With the extruded connectivity mesh, less nodes are visible, and detailed information about the corresponding events can be exposed.

In the detail view of each entity, a representative image with a background circle of the category color was placed in the center. Other brief information data was aligned to the left. It includes the time of the event, related event categories, the primary keyword, and

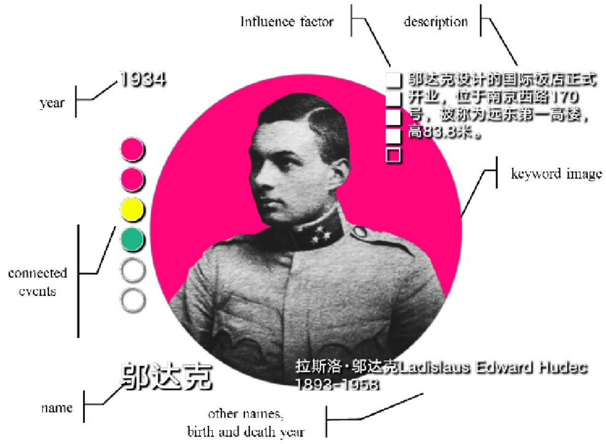

Figure 5: Detail view design for Culture Chronology.

details including names, affiliations, English names, starting and ending years, etc. in smaller font. A brief description of the event appears in the top right zone, in front of which is the influence factor of the event graded from 1 to 5.

As the users navigates through the virtual scene, and select keywords, this sub-mesh is updated according tho the new keyword. To dynamically balance the revealed detail information for sub-meshes with different complexities, we again take the graphical approach. First, we only reveal the detail panels for a number of nodes close to the camera. These panels are scaled based on the depth distances from the camera to the panels.

Finally, by clicking on each of the event detail panel, the web service page form the GKB pertaining to that event is exposed, showing to more complete information and media sources.

5 Results and discussion

We implement the presented visualization design of Culture Chronology on two platforms: a desktop version on the computers open to library visitors for free usage, and a tangible interaction installation in the public space (see Figure 7). The generative models are developed using the procedural generative tool Houdini. And the applications and installations are developed using the interactive media platform TouchDesigner.

5.1 Usability test

To verify the interactive design and evaluate the system's usability, we performed a usability test for the interactive installation Culture Chronology. The main steps of this test were as follows. First, we explained the purpose of the test and introduced the application with a video demonstrating the interactive steps and options. The participants were instructed to explore freely for 5 minutes. The host then asked the users to perform several tasks.

1 Zoom in to a specific time period, then find a cluster of nodes with a specific color shown by the host, representing a selected category of entities.

2) Navigate in that cluster zone to find a historical figure, site, affiliation, newspaper or journal.

3) Click on the history entity to review the event closely related to the entity, and talk about interesting relationships he or she find.

4) Click on the interesting entity to review the website with full description and multimedia digital resources.

All participants were observed, and their feelings and "thinking out loud" comments were recorded.

A total of 15 participants (3 male and 12 female) took part in the formal test, with an average age of 29. Regarding their knowledge background, 5 of all 15 participants are library staff, and 10 are visitors. 4 of all participants have history research experiences, 6 are interested, and the rest 5 are not familiar with history research. 8 of the participants have experience in interactive immersive performances or installations, and 7 are less experienced at all. It is interesting that 9 of the participants would come to visit a GLAM institute mainly for the purpose of experiencing the media space or interactive installations. Regarding the most interesting features of a GLAM experience, the top 3 features that would attract them to come are aesthetically appealing (10 participants), informative (9 users) and fun to play (8 users). We did a survey with questions in System Usability Scale (SUS). SUS is questionnaire with high reliability (alpha = 0.91). For all 15 participants, the average score is 71.5, which means the system is acceptable and good to use. 14 out of 15 participants are able to finish all 4 tasks. 13/15 participants feel they are more interested in finding the connection between history events after this experience. 10 of the participants feel they can easily find an interesting entity to start the navigation, however, 5 of them state that it is challenging to find a specific entity.

5.2 Future works

We are interested in investigating more and different types of culture memory resources, and build up more general design spaces and dimensions in immersive data storytelling. As several users have mentioned, our proposed system can be customized according to the humanities scholars' requirement, to facilitate researchers making better use of the Big Data treasure.

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References

[1] L. Argyriou, D. Economou, and V. Bouki. Design methodology for 360° immersive video applications: The case study of a cultural heritage virtual tour. *Personal Ubiquitous Comput.*, 24(6):843–859, dec 2020. doi: 10.1007/s00779-020-01373-8

[2] J. Assmann and J. CzaplickaIn. Collective memory and cultural identity. *Suhrkamp*, 1988.

[3] M. Auer, G. Agugiaro, N. Billen, L. Loos, and A. Zipf. Web-based visualization and query of semantically segmented multiresolution 3d models in the field of cultural heritage. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, pp. 33–39, 2014.

[4] G. Avram and L. Maye. Co-designing encounters with digital cultural heritage. In *Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems*, DIS '16 Companion, p. 17–20. Association for Computing Machinery, New York, NY, USA, 2016. doi: 10.1145/2908805.2908810

[5] M. K. Bekele, R. Pierdicca, E. Frontoni, E. S. Malinverni, and J. Gain. A survey of augmented, virtual, and mixed reality for cultural heritage. 11(2), mar 2018. doi: 10.1145/3145534

[6] X. Cuijuan, W. Lihua, and L. Wei. Shanghai memory as a digital humanities platform to rebuild the history of the city. *Digital Scholarship in the Humanities*, 36(4):841–857, 03 2021. doi: 10.1093/llc/fqab023

[7] E. W. Dijkstra. A note on two problems in connexion with graphs. *Numerische Mathematik*, 1:269–271, 1959.

[8] A. Indraprastha. An interactive augmented reality architectural design model : A prototype for digital heritage preservation. In *2019 International Conference on Advanced Computer Science and information Systems (ICACSIS)*, pp. 83–88, 2019. doi: 10.1109/ICACSIS47736.2019.8979767

[9] K. I. Joy. Massive data visualization: A survey. *Springer Berlin Heidelberg*, 2009.

[10] C. Ke. Visualization analysis of library research in the context of big data based on knowledge map. In *2021 13th International Conference*

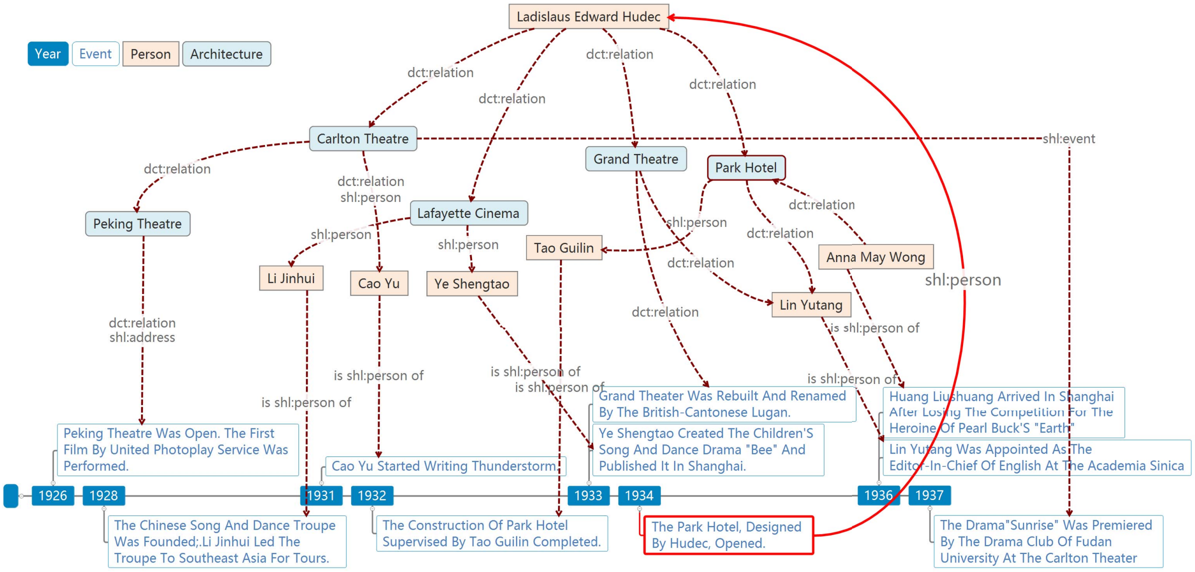

Figure 6: Knowledge graph and event connectivity.

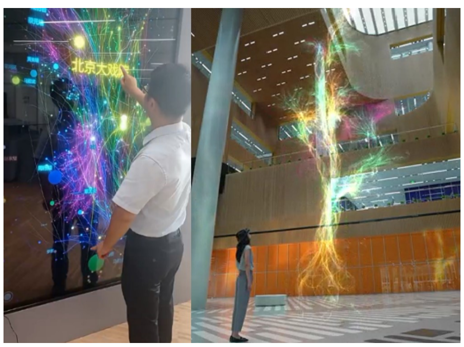

Figure 7: The visual installation Culture Chronology in the public space of Shanghai Library.

on *Machine Learning and Computing*, ICMLC 2021, p. 271–278. Association for Computing Machinery, New York, NY, USA, 2021. doi: 10.1145/3457682.3457775

[11] S. Kenderdine and T. Hart. marchive: Sculpting museum victorias collections. Proc. Museums Web, 2014.

[12] M. Koeva, M. Luleva, and P. Maldjanski. Integrating spherical panoramas and maps for visualization of cultural heritage objects using virtual reality technology. *Sensors*, 17(4), 2017. doi: 10.3390/s17040829

[13] L. McKenna, C. Debruyne, and D. O'Sullivan. Modelling the provenance of linked data interlinks for the library domain. In *Companion Proceedings of The 2019 World Wide Web Conference*, p. 954–958. Association for Computing Machinery, New York, NY, USA, 2019.

[14] C. Michele Valerie. *Preserving Our Heritage: Perspectives from Antiquity to the Digital Age*. ALA Neal-Schuman, 2014.

[15] Moritz. Special guest tutorial: Shortest path growth. Entagma, 2017.

[16] K. Museth. Vdb: High-resolution sparse volumes with dynamic topology. *ACM Trans. Graph.*, 32(3), jul 2013. doi: 10.1145/2487228.2487235

[17] I. Nishanbaev, E. Champion, and D. A. McMeekin. A survey of geospatial semantic web for cultural heritage. *Heritage*, 2(2):1471–1498, 2019. doi: 10.3390/heritage2020093

[18] I. Pedersen, N. Gale, P. Mirza-Babaei, and S. Reid. More than meets the eye: The benefits of augmented reality and holographic displays for digital cultural heritage. *J. Comput. Cult. Herit.*, 10(2), mar 2017.

[19] P. Prusinkiewicz and L. Aristid. *The Algorithmic Beauty of Plants*. Springer New York, NY, 1990.

[20] E. Y. Putra, A. K. Wahyudi, and C. Dumingan. A proposed combination of photogrammetry, augmented reality and virtual reality headset for heritage visualisation. In *2016 International Conference on Informatics and Computing (ICIC)*, pp. 43–48, 2016. doi: 10.1109/IAC.2016.7905687

[21] E. Segel and J. Heer. Narrative visualization: Telling stories with data. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):1139–1148, 2010. doi: 10.1109/TVCG.2010.179

[22] B. Shneiderman. The eyes have it: a task by data type taxonomy for information visualizations. In *Proceedings 1996 IEEE Symposium on Visual Languages*, pp. 336–343, 1996. doi: 10.1109/VL.1996.545307

[23] H. Si. Tetgen, a delaunay-based quality tetrahedral mesh generator. *ACM Trans. Math. Softw.*, 41(2), feb 2015.

[24] P. S. e. a. Varga. Communicative and cultural memory. *The Theoretical Foundations of Hungarian 'lieux de me ́moire' Studies*, 2013.

[25] M. Whitelaw. Generous interfaces for digital cultural collections. *Digital Humanities Quarterly*, 9, 2015.

[26] F. Windhager, P. Federico, G. Schreder, K. Glinka, M. Dörk, S. Miksch, and E. Mayr. Visualization of cultural heritage collection data: State of the art and future challenges. *IEEE Transactions on Visualization and Computer Graphics*, 25(6):2311–2330, 2019. doi: 10.1109/TVCG.2018.2830759

[27] R. Xie and S.-B. Tsai. Intangible cultural heritage high-definition digital mobile display technology based on vr virtual visualization. *Mob. Inf. Syst.*, 2021, jan 2021. doi: 10.1155/2021/4034729