Workshop on Visualisation in Environmental Sciences (EnvirVis) (2015)
A. Middel, G. Weber, and K. Rink (Editors)

A Collaborative Web-Based Environmental Data Visualization and Analysis Framework

J. Lukasczyk[1], X. Liang[2], W. Luo[2], E. D. Ragan[3], A. Middel[2], N. Bliss[2], D. White[2], H. Hagen[1], and R. Maciejewski[2]

[1]TU Kaiserslautern, Germany [2]Arizona State University, USA [3]Oak Ridge National Laboratory, USA

Abstract

We present an environmental data visualization framework that features synchronous and asynchronous multi-user interaction with all the benefits of modern web-based applications, such as easy accessibility and cross-platform compatibility. In contrast to outdated web-based network protocols, the proposed framework uses HTML5 Web-Sockets to enable full-duplex communication between server and clients. To demonstrate the framework, we chose the ecological problem of water scarcity in Africa. In this case study, water scarcity is calculated and visualized using various models and parameters, which can easily be shared among users and devices. Hence, we show the potential and the utilization of web technologies for collaborative environmental data exploration on distributed desktop and mobile devices.

1. Introduction

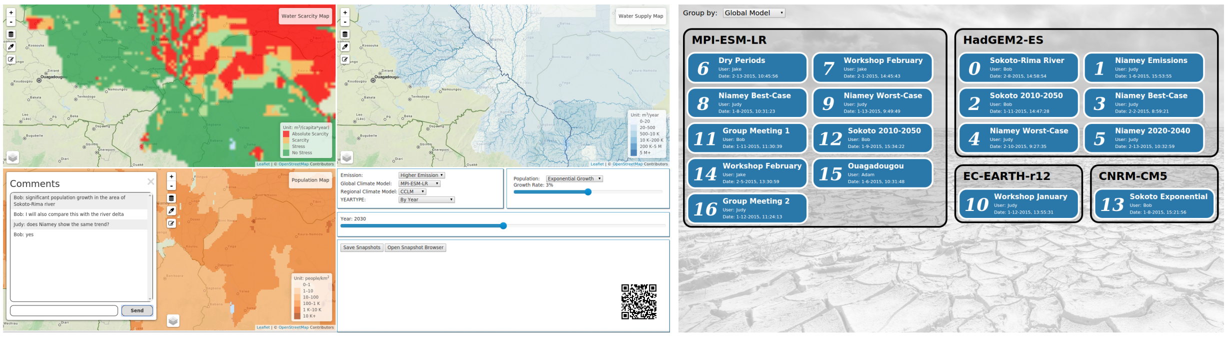
The coupled effects of global climate change and population dynamics on water systems are widely considered to be among the greatest urban sustainability challenges facing humanity in the Anthropocene - an era that recognizes the indelible signature and long-term impact of human influence on the Earth system [VMG*10]. Semiarid and arid regions will be at particular risk. Meanwhile, the world's urban population is projected to double in the next generation [Uni12], with much of this urban growth occurring in arid or semiarid environments. Indeed, the nonclimatic stressors on water resources may outweigh the climate impacts for some regions [STN09, GMBW14, VMG*10]. Taken together, these interrelated pressures pose unprecedented challenges for urban sustainability and environmental governance. To develop solutions, environmental governance is increasingly focused on improving linkages between scientific knowledge and decision making through collaborative problem solving. In this process, stakeholders communicate options, make plans, monitor events, and often politically strategize [SGH09]. Given that such planning must engage multiple stakeholders in the problem formulation, there is a need for ways in which stakeholders can engage with data analysts, modelers, and simulations to define problem threats and solutions through multiple perspectives. One means of doing this is through computer-supported collaborative visualization environments in which decision-makers can run models and simulations to explore the impact of various policy choices. To this end, we have been working with domain experts from policy planning and sustainability to explore potential design spaces that can facilitate collaborative analysis and decision making. While much work in visualization has focused on collaboration [WHHA11,MST12,Rob08,WSM13], there are still challenges [IES*11] ranging from engaging new audiences to developing hybrid collaborative platforms.

Our work builds upon the platform of Lukasczyk et al. [LMH14], which highlighted the creation of visualizations that are easily accessible and cross platform compatible. These advantages enable collaborators to easily share their work and reach out to a large audience. Here, we specifically facilitate another feature of web-based applications, the potential of easily interconnecting users and devices. This enables collaborative data exploration on distributed and mobile devices. Our domain task focuses on exploring the effects of population growth and climate change in the Niger River Delta. We present our system architecture, a case study, and feedback from domain scientists.

2. Related Work

Isenberg et al. [IES*11] defined and explored basic concepts and challenges of combining collaboration and visualization techniques. They predicted that collaborative software tools will become more standardized and that researchers will be confronted with the challenge of integrating useful multi-user capabilities into data analysis environments. For instance, a basic concept of collaboration is saving and sharing the current state of a visualization. Mahyar et al.

DOI: 10.2312/envirvis.20151087



(a) Workspace Window (b) Snapshot Browser

Figure 1: The collaborative visualization framework. (a) The Workspace Window is used for exploring water availability, population growth, and water scarcity. (b) The Snapshot Browser allows users to annotate, discuss, and share scenario information.

[MST12] explicitly emphasize the importance of recordkeeping. Their observations showed that users extensively took notes and saved visualization snapshots during the collaborative decision-making process. Another research issue is the synthesis of such result records. Robinson [Rob08] presented results of experiments where teams consisting of participants with various backgrounds had to combine visual analytic results. Their study showed that collaboration tools benefit from a platform where users can easily comprehend the history of records, their common features, and their relationship. Synchronized visualization also facilitates data exploration. A user study conducted by Wallace et al. [WSM13] indicated that collaborating users perform better using a shared device on which they can combine information and collaboratively interact with the same visualization. An example of a collaborative visualization tool for environmental planning is the distributed collaborative geovisualization environment proposed by Brewer et al. [BMA*00, MB04]. The tool enables the exploration of climatic time series via interactions and animations, while offering support for collaborative sensemaking. Other examples for the use of collaborative visualization tools can be found in the Decision Theater at Arizona State University [EL09]. As described in Section 3, our framework design follows these previously described concepts.

From a technical standpoint, there are various ways to implement these concepts and there exist a large number of collaborative visualization tools [Har09, SBO*08, WHHA11, HVW07, VWvH*07, BMZ*06, IF09, VBA*11]. However, most of the tools require the user to install software, use outdated technologies, or are limited to basic multi-user interaction. For example, Hardisty [Har09] and Stock et al. [SBO*08] introduced geovisualizations that support synchronous communication over different locations, but require the users to install toolkits, which is not suitable for interconnecting and reaching out to large and diverse audiences. Willet et al. [WHHA11], Heer et al. [HVW07], and Viegas et al. [VWvH*07] proposed web-based tools that are easy accessible, cross-platform compatible, capable of saving visualization states, and storing structured notes, but the underlying communication protocol does not provide synchronous collaboration. For instance, most tools use *AJAX* to actively request in short time intervals updates from a server, or use exploits such as *long-polling* to keep a pseudo connection to the server, which causes in both cases a high network overhead and is not truly synchronous [PHJsM14, Cha13]. On the other hand, modern web technologies, such as *HTML5* and *WebSockets*, can be used to easily augment visualizations with synchronous and asynchronous multi-user interaction. Marion and Jomier [MJ12] proposed a prototype that combines the *Web Graphics Library (WebGL)* and *WebSockets* to enable synchronous collaboration on a medical data visualization. In particular, they used *WebSockets* to synchronize the views rendered by *WebGL* across all connected devices. However, *WebSockets* are capable of much more than simply synchronizing camera parameters. In our application, we use *WebSockets* to communicate database queries, annotations, and model features.

3. Collaboration Framework

The main window of our application, called the workspace window, is the actual visualization and enables multiple users to interactively explore data (Figure 1a). The window consists of three maps and a parameter menu. The parameter menu is used to adjust visualization and model parameters, and contains a dynamic QR code in the bottom right corner. This code could, for example, encode a hyperlink to the current visualization or to a website with detailed information about the dataset and models. Since this is a standardized method to supply web links, users can simply scan the QR code with their mobile devices and immediately participate in the visualization.

The three maps visualize one scenario according to parameters controlled through the parameter menu. To support the user in comparing the different overlays, the views of all three maps are synchronized. Hence, a user can examine the same spatial domain with three different overlays without occlusion. We use *Leaflet* [Lea15] as our map engine, since it is light weight, and offers mobile-friendly interactions, such as zooming, area selection, and pop-ups, which make collaboration much easier and faster between handheld and desktop devices. The actual data is stored on a *GeoServer* [Geo15], which responds to requests from clients and provides the data queries as map overlays via a *Web Map Service* (WMS). *Leaflet* can add these overlays by including the service as a tile provider and therefore reduce workload on the client side.

To enable multiple users to interact with our web application, we use the *Socket.IO* [Soc15], *Express.js* [Exp15], and *Node.js* [Nod15] libraries. We created a *Visualization Room*, which can be compared to an ordinary chat room. Users who would like to collaborate can join the same *Visualization Room* by following a link to a website from a device of their choice. Each user can interact with their individual visualization, share their findings, and view information provided by other users of the same *Visualization Room*. In particular, the users can share and synchronize their camera positions, selected data subsets, comments, and used models. These features are stored in a so-called snapshot, which also contains a title, a description, the time of creation, and the users who contributed to the snapshot. This follows the basic concept of record-keeping presented in [MST12]. Furthermore, each snapshot stores a history of comments, similar to the approach proposed in [WHHA11]. All snapshots are displayed on a separate window, the so-called *Snapshot Browser* (see Figure 1b). The user can search for snapshots with specific keywords, or group them by their features, such as used model, year, and user. As proposed in [Rob08], this facilitates the understanding of the history of records, their common features, and their relationships among each other. If a user enables the *synchronize flag* in the parameter menu, their visualization is synchronized with a chosen master device. Updates on the master device, such as view and model parameter changes, are sent to the server, which in turn sends the updates to all clients who want to synchronize with that master device. This allows users to work on a simulated shared device, as has proven to be beneficial in Wallace et al. [WSM13]. Moreover, one user could open the visualization multiple times in different browsers or devices with distinct parameters, and then synchronize the instances with each other to compare different scenarios.

4. Case Study

To demonstrate our framework and the provided multi-user interactions, we visualize water scarcity in the Niger River Basin in Western Africa. Users can select and combine several climate, water supply, and population growth models. The climate models are derived from different combinations of global and regional climate models developed through the Coordinated Regional Climate Downscaling Experiment (CORDEX) database. Sponsored by the World Climate Research program, CORDEX aims to develop advanced Regional Climate Models to dynamically downscale the latest set of global climate scenarios and predictions produced within the 5th Coupled Model Intercomparison Project (CMIP5). A basic water supply model quantifies and predicts "Blue Water" as a sum of the local water runoff plus the river corridor discharge [VLR05]. Population growth can be simulated exponentially or by shared social pathways from 1960 to 2100. To visualize the different model aspects, our tool features a map ensemble of predicted water scarcity, water supply, and population (Figure 1a).

Figure 2: Users collaborating in the Decision Theater at ASU.

Figure 2 shows users interacting in the Decision Theater at ASU. Here, students explored the models locally on their tablets and used the large displays to discuss and share their findings. In this scenario, the population model was fixed, and the main task was to examine the effects of different climate and water supply models at Sokoto and Niamey from 2010 to 2050. The goal was to understand potential water threats and to discuss these with respect to various scenarios of population growth. Sokoto and its urban area is highly dependent upon agriculture, and therefore highly dependent on the water supply provided by the Sokoto River. Niamey, on the other hand, is surrounded by a dense river system and is the largest city in Western Africa. With our collaboration framework, users explored future climate and population scenarios across these regions, commented on findings in the browser, and shared and loaded model parameters, both from their analysis and those of our water modeling experts. Figure 3 shows population, water supply, and water scarcity predictions around Niamey and Sokoto for 2050. The first row indicates that although Niamey is surrounded by a dense river system, the urban spread in 2050 will cause water scarcity in the north-eastern regions. The model also predicts that areas around Sokoto that are not close to the Sokoto River will have massive water problems in 2050.

Overall, users found that these tools performed well and showed enthusiasm for working together to explore complex problems. Feedback from the domain expert indicated that such collaboration allows users to implement anticipatory approaches to decision making by: a) characterizing and exploring uncertainty in a transparent manner by creating

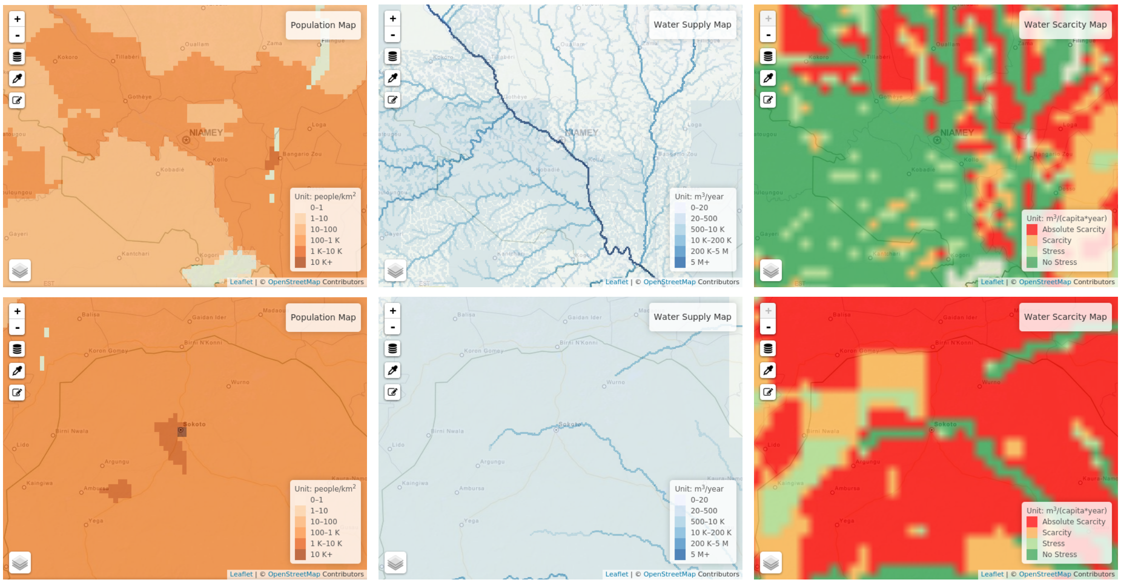


Figure 3: Visualization of the predictions according to the HadGEM2-ES model around Niamey (first row) and Sokoto (second row) in 2050. The first column shows the population, the second column the water supply, and the third the water scarcity.

multiple scenarios of water supply and demand futures with varying assumptions about climate and population dynamics; b) defining a problem space for complexity using a systems approach to modeling that incorporates interactions and feedbacks between system elements; and c) outlining a decision space using policy options to explore interests of varied stakeholders. Future work could use such collaborative processes to identify examples of sustainable or resilience development patterns that may differ from existing trends and would entail different water use patterns. These potential development pathways could then be categorized by the components that affect the water balance, and users could deliberate on development interventions necessary to achieve desirable futures and avoid undesirable ones.

5. Results and Future Work

This work introduced a web-based framework which is easily extendable, accessible, cross-platform compatible, provides synchronous and asynchronous multi-user interaction, and does not require the user to install software. We believe that such frameworks will enhance data exploration, analysis, and collaboration among researchers. In particular, we demonstrated the use of *Node.js*, *Socket.IO*, *Express*, and other modern web technologies to create a multi-user environmental data visualization, where users can share results, visualization states, and model parameters. The framework is designed to be easily extendable in the future. For instance, instead of storing a snapshot of a visualization state, it would be possible to archive the history of a visualization and enable the users to browse through time by showing the entire process that built up to the current representation. In addition to comments, users could also store more advanced annotations, such as free drawn shapes and external documents. To improve permanent record-keeping, the *Node.js* server can be combined with a database system that stores snapshots in a standardized format, such as *JSON*. This would also enable importing and exporting of snapshots to other visualization tools. In the future, we also plan to conduct a formal user study to evaluate and improve the usability and utility of our framework. While researchers have long recognized the need for collaborative visualization [IES*11,Rob08] and developed tools and techniques for collaborative analysis [WSM13,WHHA11,VWvH*07], there is still further need to integrate visualization into public-policy modeling [KNRB12].

Acknowledgements

This manuscript has been authored by UT-Battelle, LLC under Contract No. DE AC05-00OR22725 with the U.S. Department of Energy. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes. Some of the material presented here was sponsored by a grant from the DoD and upon work supported by the NSF under Grant No. (NSF 1350573). This research was supported by the DFG (IRTG 2057). Disclaimer: The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of ASU, DoD, or the U.S. Government.

References

[BMA*00] Brewer I., MacEachren A., Abdo H., Gundrum J., Otto G.: Collaborative geographic visualization: enabling shared understanding of environmental processes. In *IEEE Symposium on Information Visualization* (2000), pp. 137–141. 2

[BMZ*06] Brennan S., Mueller K., Zelinsky G., Ramakrishnan I., Warren D., Kaufman A.: Toward a Multi-Analyst, Collaborative Framework for Visual Analytics. In *IEEE Symposium On Visual Analytics Science And Technology* (2006), pp. 129–136. 2

[Cha13] Cha S.-H.: Developing a HTML5-Based Real-Time Monitoring System for Wireless Sensor Networks. In *Advances in Mechanical and Electronic Engineering*, vol. 178. Springer Berlin Heidelberg, 2013, pp. 241–245. 2

[EL09] Edsall R. M., Larson K. L.: Effectiveness of a Semi-Immersive Virtual Environment in Understanding Human-Environment Interactions. *Cartography and Geographic Information Science 36*, 4 (2009), 367–384. 2

[Exp15] Express.JS. http://expressjs.com/, 2015. Last Accessed: February 14, 2015. 3

[Geo15] GeoServer. http://geoserver.org/, 2015. Last Accessed: February 14, 2015. 3

[GMBW14] Georgescu M., Morefield P. E., Bierwagen B. G., Weaver C. P.: Urban Adaptation Can Roll Back Warming of Emerging Megapolitan Regions. In *Proceedings of the National Academy of Sciences (PNAS)* (2014). 1

[Har09] Hardisty F.: GeoJabber: Enabling Geo-Collaborative Visual Analysis. *Cartography and Geographic Information Science 36*, 3 (2009), 267–280. 2

[HVW07] Heer J., Viegas F., Wattenberg M.: Voyagers and Voyeurs: Supporting Asynchronous Collaborative Information Visualization. In *ACM Human Factors in Computing Systems* (2007), pp. 1029–1038. 2

[IES*11] Isenberg P., Elmqvist N., Scholtz J., Cernea D., Ma K.-L., Hagen H.: Collaborative Visualization: Definition, Challenges, and Research Agenda. *Information Visualization 10*, 4 (2011), 310–326. 1, 4

[IF09] Isenberg P., Fisher D.: Collaborative Brushing and Linking for Co-located Visual Analytics of Document Collections. In *Proceedings of Eurovis* (2009), Eurographics. 2

[KNRB12] Kohlhammer J., Nazemi K., Ruppert T., Burkhardt D.: Toward Visualization in Policy Modeling. *IEEE Computer Graphics and Applications 32*, 5 (2012), 84–89. 4

[Lea15] Leaflet. http://leafletjs.com/, 2015. Last Accessed: February 14, 2015. 3

[LMH14] Lukasczyk J., Middel A., Hagen H.: WebGL-based Geodata Visualization for Policy Support and Decision Making. In *Workshop on Visualisation in Environmental Sciences (EnvirVis)* (2014). 1

[MB04] MacEachren A. M., Brewer I.: Developing a conceptual framework for visually-enabled geocollaboration. *International Journal of Geographical Information Science 18*, 1 (2004), 1–34. 2

[MJ12] Marion C., Jomier J.: Real-time Collaborative Scientific WebGL Visualization with WebSocket. In *Proceedings of the 17th International Conference on 3D Web Technology* (New York, NY, USA, 2012), ACM, pp. 47–50. 2

[MST12] Mahyar N., Sarvghad A., Tory M.: Note-taking in Co-located Collaborative Visual Analytics: Analysis of an Observational Study. *Information Visualization 11*, 3 (2012), 190–204. 1, 2, 3

[Nod15] Node.JS. http://nodejs.org/, 2015. Last Accessed: February 14, 2015. 3

[PHJsM14] Park J.-T., Hwang H.-S., Jun-soo Y., Moon I.-Y.: Study of HTML5 WebSocket for a Multimedia Communication. *International Journal of Multimedia & Ubiquitous Engineering 9*, 7 (2014), 61–72. 2

[Rob08] Robinson A.: Collaborative synthesis of visual analytic results. In *IEEE Symposium on Visual Analytics Science and Technology* (2008), pp. 67–74. 1, 2, 3, 4

[SBO*08] Stock C., Bishop I. D., O'Connor A. N., Chen T., Pettit C. J., Aurambout J.-P.: SIEVE: Collaborative Decision-making in an Immersive Online Environment. *Cartography and Geographic Information Science 35*, 2 (2008), 133–144. 2

[SGH09] Steinebach G., Guhathakurta S., Hagen H.: *Visualizing Sustainable Planning*, 1st ed. Springer Publishing Company, Incorporated, 2009. 1

[Soc15] Socket.IO. http://socket.io/, 2015. Last Accessed: February 14, 2015. 3

[STN09] Seager R., Tzanova A., Nakamura J.: Drought in the Southeastern United States: Causes, Variability over the Last Millennium, and the Potential for Future Hydroclimate Change. *Journal of Climate 22*, 19 (2009), 5021–5045. 1

[Uni12] United Nationals Development Programme: *The Sustainable Future We Want*. Tech. rep., United Nationals Development Programme, 2012. 1

[VBA*11] Vogt K., Bradel L., Andrews C., North C., Endert A., Hutchings D.: Co-located Collaborative Sensemaking on a Large High-resolution Display with Multiple Input Devices. In *Proceedings of the 13th IFIP TC 13 International Conference on Human-computer Interaction - Volume Part II* (Berlin, Heidelberg, 2011), Springer-Verlag, pp. 589–604. 2

[VLR05] Vorosmarty C. J., Leveque C., Revenga C.: Fresh water. In *Ecosystems and Human Well-being: Current State and Trends*. 2005. 3

[VMG*10] Vorosmarty C. J., McIntyre P. B., Gessner M. O., Dudgeon D., Prusevich A., Green P., Glidden S., Bunn S. E., Sullivan C. A., Liermann C. R., Davies P. M.: Global threats to human water security and river biodiversity. *Nature* (2010), 555–561. 1

[VWvH*07] Viegas F., Wattenberg M., van Ham F., Kriss J., McKeon M.: ManyEyes: a Site for Visualization at Internet Scale. *IEEE Transactions on Visualization and Computer Graphics 13*, 6 (2007), 1121–1128. 2, 4

[WHHA11] Willett W., Heer J., Hellerstein J., Agrawala M.: CommentSpace: Structured Support for Collaborative Visual Analysis. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2011), ACM, pp. 3131–3140. 1, 2, 3, 4

[WSM13] Wallace J. R., Scott S. D., MacGregor C. G.: Collaborative Sensemaking on a Digital Tabletop and Personal Tablets: Prioritization, Comparisons, and Tableaux. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2013), ACM, pp. 3345–3354. 1, 2, 3, 4