A 3D Virtual Environment for Spatio-Temporal Analysis: Theoretical Approach, Proof of Concept, and User Study

R.N. Stewart[1], C. Wilkerson[1], E. Ragan[1], M. Agreda[1], D. White[1], S. Duchscherer[1], J. Piburn[1]

[1]Oak Ridge National Laboratory, P.O. Box 2008, 1 Bethel Valley Rd, Oak Ridge, TN 37831
Email: stewartrn@ornl.gov, cwilker7@vols.utk.edu, eragan@tamu.edu, mdagreda@yahoo.com, whiteda1@ornl.gov, piburnjo@ornl.gov

Abstract

We present a 3D virtual environment leveraging 3D game dynamics for statistical analysis on spatio-temporal (ST) data. We present a theoretical construct, a proof-of-concept implementation (STWorld), and preliminary results from a human-computer interaction (HCI) study. Results include a novel integration of the Unity game engine with open source tools PostGreSQL, R, and the D3.js graphics library. Preliminary results suggest that STWorld may be judged more enjoyable and incur better procedural memory retention than traditional dashboard interfaces. We conclude with findings on gender bias and the gap between gamers and non-gamers.

1. Introduction

Applying statistical tools to spatio-temporal (ST) data using traditional statistical packages requires access and understanding of statistical routines, data manipulation, navigation of user interfaces, and basic programming skills. These are obstacles for casual analysts impeding education and application. Web-based tools such as the World SpatioTemporal Analytics and Mapping Project Tool (Stewart *et al*. 2015) have helped in mitigating these. Alternatively, educational gaming research has demonstrated a strong and positive connection between gameplay, enjoyment, learning, and memory retention of new content and procedures. Jabbar and Felicia (2015) provide a review of the extensive body of work in this domain, and Armes *et al*. (1999) explored engaging statistical visualizations in virtual 3D space. In this paper, we examine the potential for leveraging first-person gameplay dynamics for analysing spatiotemporal data and raise the following questions:

1) Can we leverage benefits of 3D gaming for the study of ST data?
2) How does efficiency in learning and exploration compare to a traditional interface?
3) How does memory retention compare to a traditional web-tool?
4) Are effects influenced by gender or gaming experience?

We present a novel theoretical construct for analytics in 3D space, implement a novel proof-of-concept called STWorld, and report on a small user study aimed at these questions.

2. Theoretical Approach

We propose a 3D virtual environment populated with familiar objects whose real-world purpose and behaviour are replaced by abstract data and analytical operations. The user enters a room with a first-person perspective, where cardboard boxes represent PostGreSQL databases, a gun used to query data sets, a magnifying glass that performs statistical analysis, and walls that become interactive graph and map spaces (Figure 1). The intent is for these repurposed objects to serve as comfortable, memorable metaphors for otherwise abstract data operations. By distributing abstract analytics as objects in a room, we aim to improve memory retention of how to locate, access, and analyse data (Ragan *et al*., 2012). While not a game in the strictest sense, we repurposed foundational game knowledge for ST analytics by adopting common 3D game dynamics including spatial navigation, selection of tools, pursuit of end goals, and typical game controls (Figure 1f). We developed a proof-of-concept to implement and test these concepts.

3. ST World: A Proof of Concept

The desktop 3D virtual environment, STWorld, was built using the Unity engine to incorporate and connect mainstream open source assets including the PostGreSQL database, the D3.js visualization library, and the R statistics package (Figure 1a). To our knowledge, the introduction of these approaches in a first-person environment is completely novel. Global ST data from the CIA World Factbook (1989-2012) was added to a PostGreSQL database and served to STWorld along with R statistical functions via a RESTful API. The D3.js library presents interactive visualizations. A standard controller (Figure 1b) allows users to move about the room, pick up tools, connect to data, and choose from available countries, attributes, years, and statistical functions. In typical game play, users enter the room and use a tool (gun or magnifying glass) to choose a database (shelved boxes, Figure 1c). The box is placed on a table and opened to provide access to CIA data organized by geographic regions shown as labeled spheres (Figure 1d). Selecting a sphere and projecting it onto the wall reveals its content in graph and map forms (Figure 1e). Users can then select areas of the map to view and compute statistics (Figure 1f).

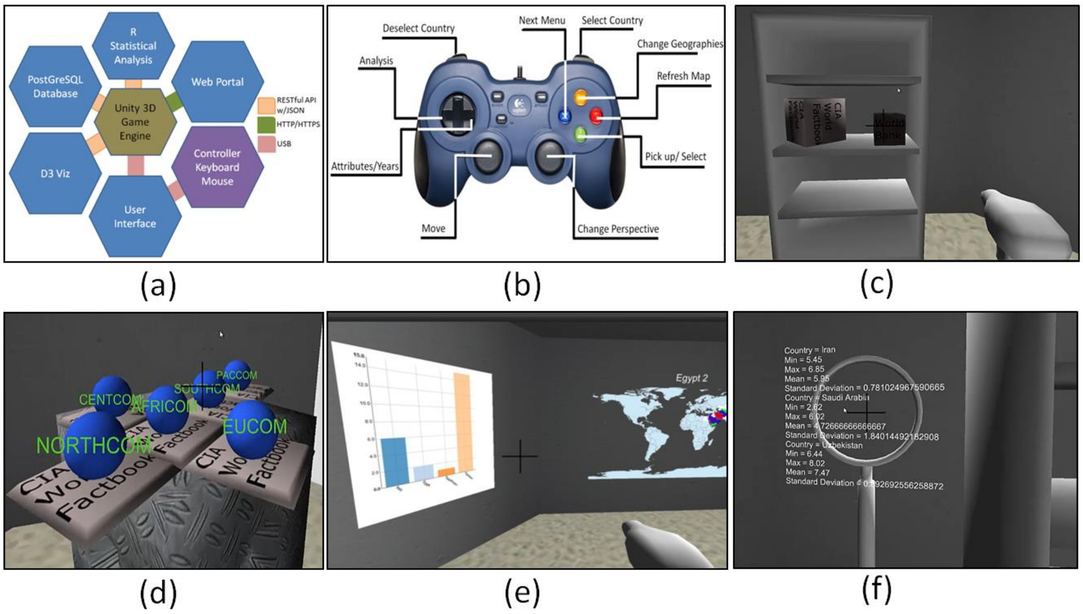

Figure 1. a) Architecture diagram, b) Game controller, c) Database representation, d) Data queries, e) Graphs and maps, f) R statistics

4. HCI Results

An HCI comparison of STWorld and WSTAMP (web tool interface) was designed to compare several factors including usability, recall, and enjoyment for users with STEM backgrounds (anticipated user community). Information was collected on participant age, gender, video game experience, education, highest math class completed, and confidence of data analysis. An open call for participants yielded 20 males and 10 females including staff and interns at Oak Ridge National Laboratory. Ages and gender skewed young (e.g. 90% under 30) and male (66%). We note the female ratio matched the national ratios for gender gaming (ESA, 2015). Participants first took a cube comparison test from ETS Kit of Factor-Referenced Cognitive Tests (Ekstrom 1976) to assess spatial ability. After a short tutorial, participants completed three tasks using both interfaces (ordering was counterbalanced). Tasks such as "*Produce a* *graph of Mexico's "birth rate" over time*" were designed to produce unambiguous outcomes. Completion time was recorded for each task. One week later, participants were asked to return to repeat the exercise to assess memory retention.

STWORLD users were initially slower and had higher variance in task completion times, but were able to learn quickly becoming competitive with WSTAMP by Task 3 (Figure 2a). Gamers (60% females, 90% males) found STWORLD more enjoyable while non-gamers preferred WSTAMP (Figure 2b). A week later, 10 males and 10 females elected to return to complete the study. Performance comparisons suggest retention in STWORLD was slightly better with 6% less average time per task compared to 6% longer in WSTAMP.

Within STWORLD, non-gamers narrowed the skills gap by Task 3 (Figure 2c) suggesting a tractable learning curve. Because females were unable close the gap (Figure 2d), task completion times were regressed against gender, age, game play frequency, self-reported data skills, and ETS scores to explain variation in performance. Self-reported video game skill (1-10) was also collected but collinear (variance inflation = 2.1) with gender, so not included. See Table 1 for results.

Table 1. Model Results

Independent Variable	Task 1	Task 2	Task 3
Intercept	38.40	53.71	83.30
Gender (0-female, 1-male)	-39.95	-41.25*	-31.06*
Age	5.21	2.58	0.63
Video Gaming Per Week	0.23	-0.57	-0.63
First-Person Gaming	0.38	1.62	-1.03
Data Skill (1-10)	1.77	3.08	3.09
EKT Score	0.68	1.30	-0.87
R-squared	0.18	0.22	0.28

No variables were significant in the first task—probably because users were still learning the particular interface. With more familiarity in Tasks 2 and 3, gender bias (as seen in Jensen and Castell, 2010) emerges even within a post-secondary STEM cohort.

5. Summary

STWorld represents a first step in developing a 3D interface for spatio-temporal analysis. Gamers were able to transfer existing gaming skills (navigation, tool selection, etc.) into a spatio-temporal analytics context with greater enjoyment and better memory retention than with the web tool. Non-gamers quickly closed the gap, but gender bias was detected even in this small study. Next steps include exploring mitigation of gender bias, incorporating game incentives (e.g., scoring), and web deployment for larger studies.

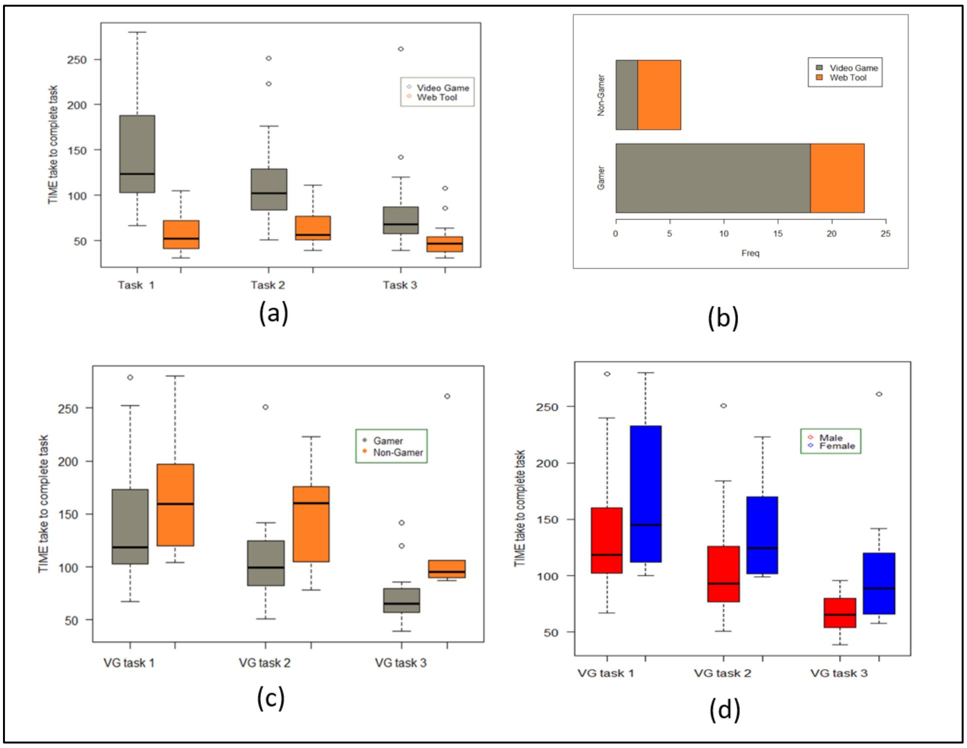

Figure 2. a) Task completion time, b) Enjoyment, c) Completion time by gaming, d) Completion time by gender

Acknowledgement

Support for this work was provided by the National Geospatial-Intelligence Agency and the U.S. Department of Energy SULI program.

References

Arms L, Cook D, and Cruz-Neria C, 1999, The benefits of statistical visualization in an immersive environment. In: Virtual Reality, Proceedings, IEEE.

Ekstrom, R.B., 1976. Kit of factor-referenced cognitive tests. Educational Testing Service.

ESA, 2016, Essential Facts: Sales, Demographic, and Usage Data. Entertainment Software Association.

Jabbar A and Felicia P, 2015, Gameplay Engagement and Learning in Game-Based Learning: A Systematic Review, *Review of Educational Research* 85(4): 740-779.

Jenson and Castell, 2010, Gender, Simulation, and Gaming: Research Review and Redirections, *Simulation and Gaming*, 41(1): 51-71.

Ragan E, Sowndararajan A, Kopper R, and Bowman D, 2010. The Effects of Higher Levels of Immersion on Procedure Memorization Performance and Implications for Educational Virtual Environments, *Presence: Teleoperators & Virtual Environments*, 19(6): 527-543.

Stewart R, Piburn J, Sorokine A, Myers A, Moehl J, and White D, 2015. World Spatiotemporal Analytics and Mapping Project (WSTAMP): Discovering, Exploring, and Mapping Spatiotemporal Patterns Across the World's Largest Open source Datasets In: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences II-4/W2.