

VAST Challenge 2016: Streaming Visual Analytics

R. Jordan Crouser, Kristin Cook, John Fallon, Georges Grinstein, Kristin Liggett,
Danko Nebesh, Diane Staheli, Mark A. Whiting and Kirsten Whitley

Abstract — The 2016 VAST Challenge returns to the (fictional) island of Kronos to pose three Mini-Challenges. In Mini-Challenge 1, participants must design an innovative interactive visual interface that enables security investigators from the Euybia Island Resort and Conference Center to conduct real-time analysis of streaming data. In Mini-Challenge 2, the GAStech Corporation returns from the 2014 kidnapping disaster more committed than ever to tighten up operations at its new headquarters in Abila. Using data from stationary and mobile sensors of multiple types, participants must help the company to understand both operational issues as well as security issues. In Mini-Challenge 3, participants are asked to try their hand at the most complex VAST Challenge scenario to date: 2.5 days of live, streaming operational data. The VAST Challenge 2016 received 29 submissions and had participation from 72 reviewers.

Index Terms — Visual Analytics, Human Information Interaction, Streaming Analysis, Evaluation, Contest

INTRODUCTION

Each year, the IEEE VAST Challenge poses problems for visual analytics researchers. The VAST Challenge is designed to help researchers understand how their software would be used in a realistic analytic task and determine if their data transformations, visualizations, and interactions would be beneficial for particular analytic tasks. VAST Challenge problems provide researchers with realistic tasks and data sets for evaluating their software, as well as an opportunity to advance the field by solving complex problems in both data analysis and design. **Design challenges** pose a specific analytic scenario, and participants are asked to design a visual analytics solution. This is the second time that VAST Challenge includes a design challenge, a goal being to widen and diversify participation. **Data analysis challenges** provide participants with a scenario, collections of synthetic data with known ground truth, and a series of analytic questions to address. Participants are then asked to create or apply visual analytics tools to analyze the synthetic data and identify plausible answers to the questions posed.

The 2016 VAST Challenge focused specifically on problems in the emerging area of **streaming visual analytics**. It consisted of three Mini-Challenges. Mini-Challenge 1 posed a design challenge in which participants were asked to design a visual analytics tool to support analysis of streaming data in an operations center. Mini-Challenge 2 and 3 were data challenges. Mini-Challenge 2 provided two weeks of static data from various building sensors and asked participants to create or apply visual analytics tools to characterize patterns and anomalies. This challenge was specifically designed to provide participants with an opportunity to practice streaming visual analytics without having to work with a live stream. Mini-Challenge 3 provided a live stream of 60 hours of building sensor data, and participants were asked to build a visual analytics solution that would permit users to rapidly orient themselves to emerging events as well as to be able to reconsider past data as circumstances change.

THE CHALLENGE OF STREAMING VISUAL ANALYTICS

Streaming visual analytics is an open question for the visualization research community. Understanding streaming data is often a matter

• R. Jordan Crouser is at Smith College, and is the corresponding author on this publication. E-mail: jrcrouser@smith.edu.

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of comprehending changes over time, changes that may occur at different resolutions, changes that not be readily visible to a human, and changes that require multiple passes to comprehend, as well as understanding how that change alters a user's understanding of the past and the expected future. For example, consider the jobs of journalists, law enforcement personnel, and emergency responders, who monitor social media streams to understand rapidly evolving situations. To support such tasks, visual analytics solutions must move well beyond systems that simply provide real-time monitoring of streaming data with playback (e.g., a timeline with controls to replay sections of time). Instead, we must ask what is required is a direct way to represent change to help a user orient and reorient to rapidly changing and evolving situations. We must also imagine the potential for streaming data that is too large for storage, and yet still needs to be visually reviewed.

Performing analysis of rapidly changing, high-volume streaming data poses problems at multiple levels. Users may consider multiple competing lines of reasoning, each with its own assumptions, and test this reasoning on multiple data streams that are sampled or filtered, error-prone, and uncertain. They must address problems requiring human intellect, but they must adapt to machine speeds. We refer to this set of activities as **orientation**. In the most challenging cases, users must quickly identify and react to important developments that contradict their assumptions and expectations. They must rapidly refine their understanding of the situation and create new hypotheses. Users must be able to swiftly interpret and reinterpret incoming and historical data in light of these changes and be able to use new situation models to consider potential futures states they did not previously anticipate. We refer to this set of activities as **reorientation**.

In a streaming context, the user expends much time and cognitive effort orienting and reorienting to changing situations in a complex data environment that is ripe for misinterpretation. Sampling and filtering mean that data are incomplete in the best of circumstances. Initial results provided by fast approximations may be contradicted by slower, more accurate computations. Data may arrive out of order, with data about later phenomena showing up before data about precursor events that provide important context. These complexities in change and certainty add to a user's cognitive load. The challenge of streaming visual analytics concerns direct representations of change in the context of the user's understanding of the evolving situation. For example, analogous to video key frames, could effective **analytic key frames** provide a user with succinct change points in both data and analytic thinking? Could analytic key frames be designed to provide both fast orientation as well as a compact change path over a long window of time?

This year's VAST Challenge encourages researchers to consider the problems of visual representation of change and support for orientation and reorientation in streaming data. Mini-Challenge 1 presented an operations center in which security analysts needed to consider and re-consider data in real time to keep visitors safe. Mini-Challenge 2 presented streams of building sensor data for participants to visualize; it also asked participants to create techniques that would permit users to catch up on important changes they missed while not at the computer. Mini-Challenge 3 was intended as a "warm-up" for Mini-Challenge 2; it provided static collections of the same type and format as Mini-Challenge 3 that participants could use to familiarize themselves with the data.

2016 VAST CHALLENGE: SCENARIO AND SCOPE

The 2016 VAST Challenge consisted of three distinct Mini-Challenges, each emphasizing visual analytics within a streaming data environment. Mini-Challenge 1 was a design-only challenge, which meant that participants submitted an interface concept that could be applied against the data that was described in the Mini-Challenge instructions, but no dataset was supplied and no software was expected to be built (or used) to support the design. Mini-Challenge 2 was a traditional VAST Challenge problem, where the data and analytic problem were presented to contestants up front. The setting for the problem was the new headquarters for the fictitious GASTech corporation, in the imaginary city of Abila on the invented island of Kronos. For those familiar with the VAST Challenge, the GASTech Corporation and the island of Kronos were used in the VAST Challenge 2014 kidnapping scenario [2,3]. From the problem description posted online:

After the successful resolution of the 2014 kidnapping at GASTech's Abila, Kronos office, GASTech officials determined that Abila offices needed a significant upgrade. In 2015, the growing company moved into a state-of-the-art three-story building near their previous location. The new office is built to the highest energy efficiency standards, and it is fully instrumented with sensors that identify everything from building temperatures to concentration levels of various chemicals.

GASTech has recently introduced new security processes. Staff members are now required to wear proximity (prox) cards while in the building, so that incidents like the 2014 kidnapping cannot occur again. As an expert in visual analytics, you have been hired to help GASTech understand its steady stream of operations data. This includes data from stationary and mobile sensors of multiple types. The company needs your help in operational issues as well as security issues.

Historical building data and prox card data were supplied to contestants to investigate potentially strange behaviors in both the building operations and the personnel movements. Mini-Challenge 3 boosted the analytic difficulty by providing this same data as a stream (temporally after Mini-Challenge 2), and participants were asked to perform real-time analysis on this information as it was received.

Mini-Challenge 1: Design Challenge

Mini-Challenge 1 focused on systems to support security and operational analytics at the Euybia Island Resort and Conference Center, a busy convention resort hotel and casino off the coast of Kronos. Participants in this challenge were asked to design an innovative interactive visual interface to enable the facility's security investigators to conduct real-time analysis of streaming data. In particular, the investigators have articulated the need for an analytic environment that will allow them to "quickly understand new

situations, think deeply to develop and test their theories, and rapidly reorient their investigation when data or assumptions change."

The goal of Mini-Challenge 1 was to solicit novel approaches for streaming visual analytics that push the boundaries for what constitutes a visual analytics system, and to explore new human-computer interaction paradigms for streaming data. In particular, this challenge encouraged submissions that envisioned an analysis environment (rather than a standalone system) and incorporated emerging interaction modalities into that environment. By eliminating the constraint of accurate data analysis, participants were free to come up with creative solutions with the potential to shape future research. From the problem description posted online:

[Your design] should push the current understanding of human and computer interaction and explore new possibilities in visual interface and user experience design.

You are free to design the most creative interface that you can imagine. Alternate interaction and display modalities are welcomed. Euybia Island is looking for bold new ideas and want you to take creative risks. You are encouraged to push the boundaries and recommend fundamentally new approaches.

Participants were given some additional detail about the role of the investigators that would ultimately use their systems.

Investigators face the challenge of analyzing streaming data to understand changing conditions and investigate suspicious activities as they occur. Situations can unfold rapidly. The data may appear to support one hypothesis, but further data may invalidate that hypothesis and call on the investigator to develop fundamentally new hypotheses on the fly.

It was noted that investigators have access to a wide variety of streaming data sources, such as:

- Reports from uniformed and plain-clothes security officers moving throughout the hotel and casino
- News reports about current and planned events
- Up-to-the-minute weather conditions and forecasts
- Current police reports of crime in the area
- Closed-circuit security camera feeds
- Financial and game information from the casino
- Automated analytics of many types
- Reports of crowd control issues, overcrowding, fights, and suspicious behavior identified by operators who monitor the closed-circuit cameras.

They were also given the following information about the physical constraints of the analytical environment:

The investigators share a 12'x20' room. The investigators have individual desks, each outfitted with three high-resolution displays. Euybia Island tells you that the resort is willing to use the current setup or consider alternatives, including other desktop configurations, wall displays, tablets, and augmented or virtual reality interfaces.

Successful submissions to Mini-Challenge 1 will provide investigators with the ability to understand current situations as they evolve, look at past data that puts current data in context, and anticipate what might happen next. They should also allow investigators to reconsider recent data in light of new events.

Mini-Challenge 2: Static Analysis

The analytic challenges for 2016 were set in the GASTech headquarters, a new three story building on Kronos Island. To acquire operations data for this building, the Challenge development team used the U.S. Department of Energy's Energy Plus building simulation software system [1]. The team created the floor plans and specifications for the GASTech headquarters and engaged PNNL's building energy group to create and model energy zones; typical building usage parameters; and general building schedules for electricity, heating, and lighting, and occupancy. Following this, the team introduced insider threat behavior (suspicious movements about the building and prox card manipulations) and developed the corresponding building control system manipulations that resulted in the building energy anomalies. The Energy Plus software was also able to model amounts and dispersion of carbon dioxide and other user specified gases often found in buildings. We incorporated the CO₂ component and introduced our own fictitious gas called Hazium, which had unspecified hazardous effects on people.

To create the occupancy behavior, the development team modeled each employee's daily routine throughout the duration of the simulation. Some employees demonstrated more detailed behavior than others, particularly if they had some role in the insider threat or if they had some specialized role in the organization's daily operations (e.g., the facilities personnel who arrived and left throughout the day according to their building management roles). Workers executed three shifts throughout the week, and occasionally, some employees would come to work on the weekend.

Proximity card (prox) zones, where the prox card reader would record an employee's location, were scattered around the building to correspond to work zone or special access areas (e.g., the computer server room). Prox zones were aligned with energy zones, so participants had to be quite clear on which zones were being analyzed in any part of their work. Worker movements were simulated throughout the entire data run by an agent model, with every staff member represented by an independent agent. Agents followed their schedules as best they could, given constraints imposed by problems such as crowded elevators. However, contestants were only provided with prox zone locations, not specific coordinates for any individual at any particular time.

In addition to the static sensor data, the Mini-Challenge data included data from a mobile sensor known as *Rosie the Robot*. Rosie was a mail-delivering robot that traversed the entire building twice a day. Employees only knew her as a mail delivery system, but the GASTech management had installed an on-board prox card reader, so that she recorded prox cards that appeared within 5 meters of the reader. Data from Rosie, combined with other data, allowed contestants to hypothesize the insider threat employee, as well as how and when inappropriate activities were occurring.

In summary, the following data was provided for this challenge:

- A **building layout** for the GASTech offices, including the maps of the prox zones and the HVAC zones
- A current list of **employees, roles, and office assignments**
- A description of the data formats and fields provided
- Proximity sensor data for each of the **prox zone regions**
- Proximity sensor data from **Rosie the mobile robot**
- HVAC sensor readings and status information from each of the building's **HVAC zones**
- **Hazium readings** from four sensors

Using this data, along with any external sources that might be relevant to their analysis, participants were asked to address the following four areas:

1. What are the **typical patterns** visible in the prox card data? What does a typical day look like for GASTech employees?
2. Describe up to ten of the most interesting patterns you observe in the **building data**. Describe what is notable about the pattern and explain what you can about the significance of the pattern.
3. Describe up to ten **notable anomalies or unusual events** you see in the data, including when and where the event or anomaly occurs and describe why it is notable. If you have more than ten anomalies to report, prioritize those that are most likely to represent a danger or serious issue for building operation.
4. Describe up to five **observed relationships** between the prox card data and building data elements. If you find a causal relationship (e.g. a building event or condition leading to personnel behavior changes or personnel activity leading to building operations changes), describe your discovered cause and effect, the evidence you found to support it, and your level of confidence in your assessment of the relationship.

Ideal solutions included direct representations of important change. Successful solutions directed user attention (for example, to change that exceeded safe thresholds). Smart solutions supported a user's need to directly juxtapose current status in historical context and to directly compare different sensors for testing hypotheses about correlated data streams.

MINI-CHALLENGE 3: STREAMING ANALYSIS

Participants in Mini-Challenge 3 were provided with the same type of building and proximity card data that provided in Mini-Challenge 2, with one twist: instead of providing a static dataset, 60 hours of this data was streamed to the contestants for analysis. All of the metadata (data fields, data formats, and background) remained the same. There was increased concern with the Hazium concentrations in this data, so the contestants were allowed to "place" an additional sensor (i.e., receive additional data) after approximately 2 days of data were ingested to better detect Hazium during the remainder of the data set run. From the challenge instructions posted online:

The goal of the challenge is to develop new approaches to allow people to understand current data, as well as to catch up on events that took place while the system was not being monitored.

The challenge organizers do not expect or want teams to monitor the data stream constantly throughout the 2.5 days (60 hours)!

Check the data streams periodically as needed to ensure your software is working as expected and you are able to identify patterns of interest. Capture screen shots to include in your submission when you identify items of significance.

One example of an issue that appeared during the streaming data period was a sharp temperature rise in the Floor 3 server room. Prox card data would note several IT staff going into the server room, presumably to shut down machines due to the extreme temperature.

During this challenge, participants were asked to address the following four areas:

1. Describe up to 10 unusual or unexpected patterns and anomalies you observed during the **first two days of streaming data (June 14-15)**.

2. Which **additional sensor** did you choose to add to your data stream? What was the rationale for your selection? Did it provide additional insight?
3. Describe specific anomalies or unusual events you saw in the **last four hours** of the data stream. Which of these anomalies is of greatest concern? What is your rationale?
4. Describe how your team approached the challenge of catching up on events that took place **while you were not monitoring the stream**. What features of your software helped you to review past events and catch up on things you missed? How could these features be used to help you reconsider recent data in light of new events?

Successful entries to Mini-Challenge 3 indicate how the proposed tools would aid the analyst in understanding the dynamics in the data streams; for example, slowly or quickly changing conditions. They would also illustrate deft handling of the complex data over a multi-day period, supportive of streaming analysis. Finally, successful entries would illustrate interactions when adding an information stream, in this case a new Haziium sensor, and the impact to the analytical task.

REVIEW PROCESS

The VAST Challenge relies on an anonymous peer review process to provide feedback to the participants and to recommend submissions for award consideration. All submissions are reviewed by researchers in the visual analytics community. In addition, all submissions are reviewed by subject matter experts who do not typically participate in visual analytics research but understand the application areas being addressed. This year, participants in the design-oriented challenge also received reviews from professionals in the human-computer interaction and user experience design fields, most of whom are not participants in the visual analytics community. A total of 72 reviewers provided feedback on between one and seven of the 29 submissions. Each Mini-Challenge 1 submission received eight to ten reviews. Each Mini-Challenge 2 submission received between five and eight reviews. Each Mini-Challenge 3 submission received eight reviews. For consistency, each reviewer was asked to evaluate submissions for a single Mini-Challenge only.

Reviewers were supplied with review guides containing background on the Mini-Challenge and descriptions of the types of responses the committee anticipated. The evaluation process relies on the reviewers' expert judgment, supported by these review guides. Each reviewer was asked to provide an overall rating for the submission on a 1-5 scale, along with a written rationale for the rating. In addition, reviewers were given an opportunity to nominate deserving submissions for awards. Reviewers were given freedom to identify any aspect of the submission that they deemed worthy of recognition. When nominating a submission for recognition, the reviewer was asked to suggest an award title and to provide a rationale for their nomination.

The remaining review questions were tailored to correspond to a specific Mini-Challenge. Mini-Challenge 1 reviewers were asked to comment on the level of innovation in the design and the level to which the solution would be applicable to a streaming analysis task. Mini-Challenge 2 and 3 reviewers were asked to assess the submission's answers, as well as the application of visual analytics to the problem. In addition, Mini-Challenge 2 and 3 reviewers responded to a series of questions as to whether the submission demonstrated desired characteristics needed to support static (Mini-Challenge 2) and streaming (Mini-Challenge 3) analysis.

MINI-CHALLENGE 1: DESIGN

University of Konstanz - dynamite (#118)

Award: *Notable Support for Streaming Analysis*

SAS Institute - CORE (#120)

Honorable Mention: *Compelling Vision*

University of Konstanz - IRSIS (#116)

Honorable Mention: *Excellent Storyboard*

MINI-CHALLENGE 2: STATIC ANALYSIS

giCentre, City University London (#124)

Award: *Outstanding Presentation of Patterns in Context*

KU Leuven (#117)

Award: *Robust Support for Visual Anomaly Detection*

University of Maryland / INRIA-Saclay (#111)

Honorable Mention: *Clear Analysis Strategy*

VRVis Research Center (#123)

Honorable Mention: *Effective Support for Building Management*

Purdue University (#127)

Honorable Mention: *Quality Aesthetics*

TCS Research (#130)

Honorable Mention: *User-Friendly Anomaly Detection*

MINI-CHALLENGE 2+3: STREAMING ANALYSIS

Peking University / Qihoo 360 (#102)

Award: *Outstanding Comprehensive Solution*

Table 1: Recipients of Awards and Honorable Mentions for the VAST Challenge 2016

Upon receiving the reviewer feedback, the VAST Challenge committee held a one-day meeting to consider the submitted award nominations and finalized the selection of submissions for recognition. Three types of recognitions were selected: awards, honorable mentions, and notable submissions. Notable submissions are not recognized with formal awards, but receive special mention in the committee's presentation at the VAST Challenge workshop.

2016 AWARD WINNERS AND HONORABLE MENTIONS

The submissions recognized for awards and honorable mentions in 2016 are listed in Table 1. Additional information about all completed entries can be found in the VAST Challenge papers included in the electronic proceedings of the 2016 IEEE Conference on Visual Analytics Science and Technology (VAST) and in the Visual Analytics Benchmark Repository.

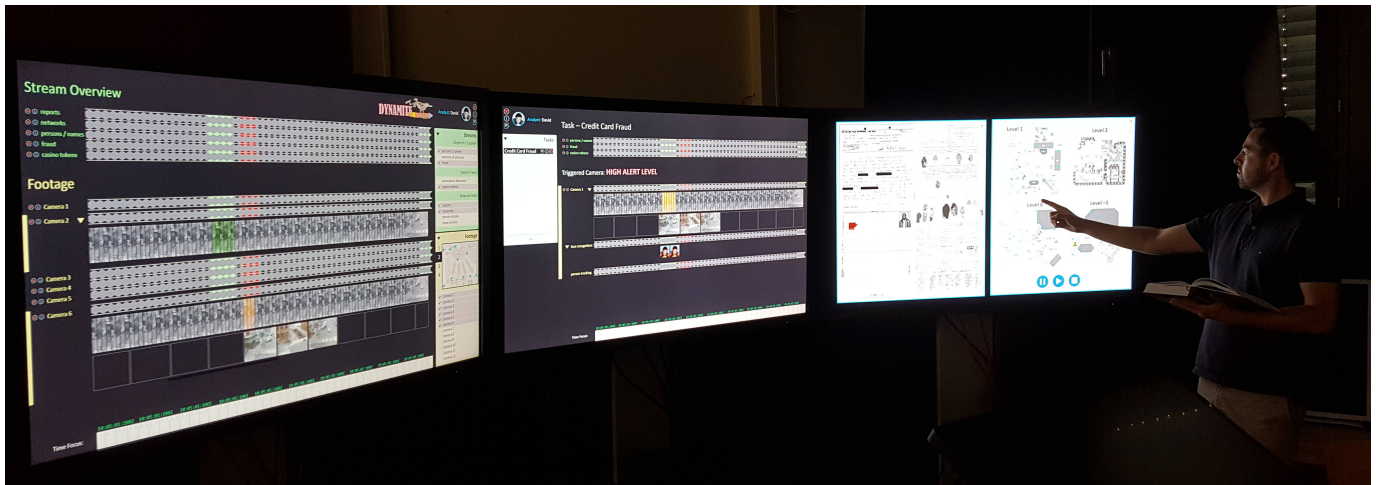


Figure 1: University of Konstanz - dynamite (#118) analytic environment mock-up.

Awards and Honorable Mentions for Mini-Challenge 1

The University of Konstanz - dynamite team focused their design submission on the user interactions with a visual analytics system. They used their design mockups (Fig. 1) to explore how an analyst might use their system to interact with streaming data to complete monitoring and analysis tasks. Of all the challenge submissions, this entry came the closest to addressing many of the challenges associated with streaming data (multiple streams, focusing analyst attention, etc.), demonstrating that this design activity was an effective way of reasoning about the problem. For this, they earned award recognition for their *Notable Support for Streaming Analysis*.

The SAS Institute - CORE team (Fig. 2) and the University of Konstanz - IRSIS team (Fig. 3) took a systems perspective and produced submissions that described their future vision for what a real-time analysis environment might look like. They focused not just the visual analytics displays, but also imagined the analytics, human processes, scenarios, real-world interactions, and outcomes that might result of deploying such a system in the real world. These envisioned worlds have many dependencies and complexities; by describing a vision, a designer can provide a framework and a starting point for how to decompose into smaller, more manageable

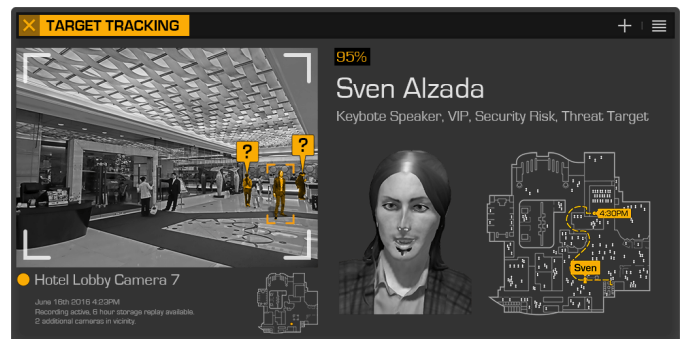


Figure 2: Target Tracking View from SAS Institute - CORE (#120).

issues (what analytics would need to be developed, what data sources might need to be brought together, what personnel would be needed, et cetera). For this, the SAS Institute - CORE team earned an honorable mention for their *Compelling Vision*, and the University of Konstanz - IRSIS team earned an honorable mention for their *Excellent Storyboard*.

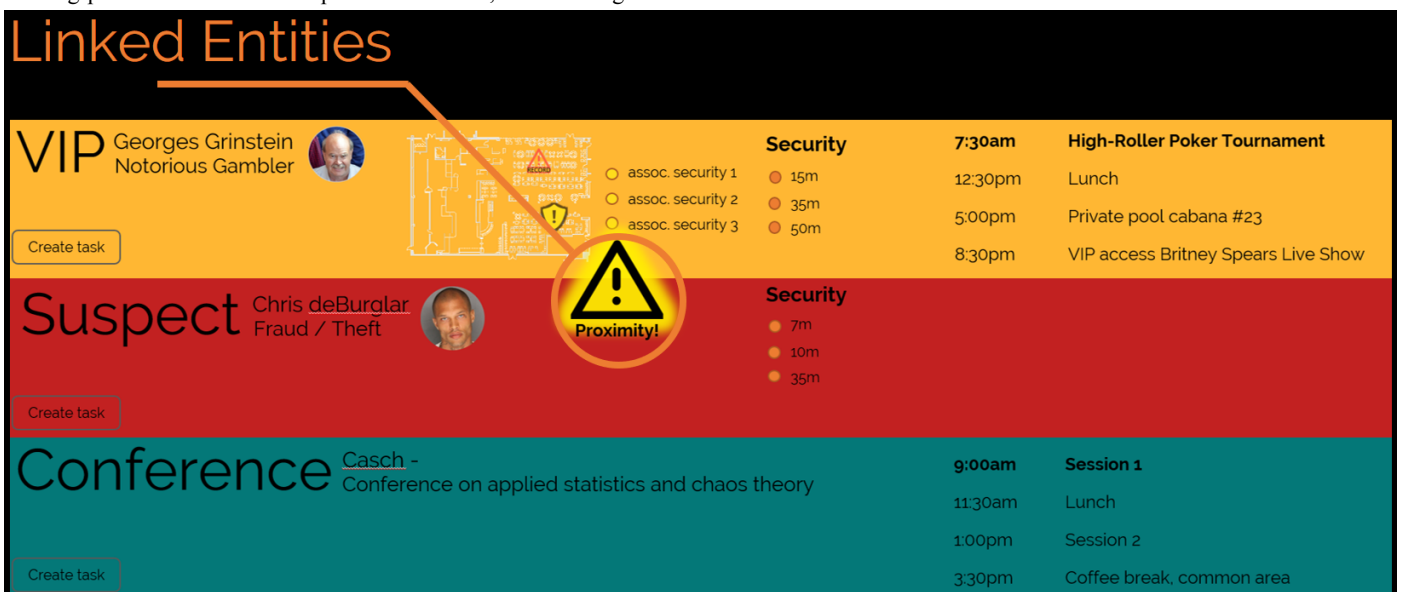


Figure 3: Entity View from University of Konstanz - IRSIS (#116) storyboard.

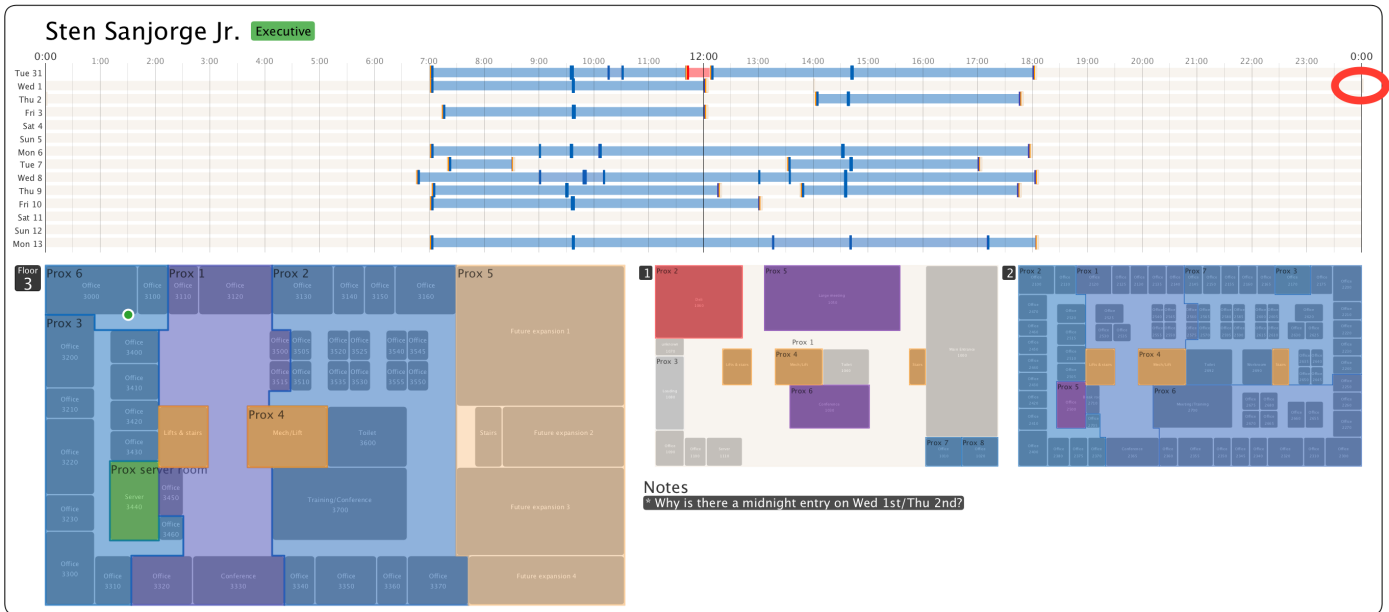


Figure 4: Detail view from giCentre at City University London (#124) showing unexpected midnight activity in the dataset.

Awards and Honorable Mentions for Mini-Challenge 2

Mini-Challenge 2 received the largest share of submissions to the 2016 VAST Challenge. Many submissions were nominated by reviewers for recognition, and these recommendations were consolidated by the committee into two awards and four honorable mentions. Jo Wood of the the giCentre at City University London (Fig. 4), whose Processing-based tool supported a deep retrospective analysis, received an award for *Outstanding Presentation of Patterns in Context*. Students from KU Leuven developed a suite of web-based tools to explore various aspects of the data, with a particular emphasis on temporal patterns and relationships (Fig. 5). This team's submission earned an award for *Robust Support for Visual Anomaly Detection*.

A joint effort by the University of Maryland and INRIA-Saclay presented a thoroughly-documented analysis. Their submission included an explicit declaration of their assumptions, as well as made use of external data to provide real-world context to their analysis. This earned the team an honorable mention for their *Clear Analysis Strategy*. A submission from the VRVis Research Center also made effective use of external data about normal CO₂ levels, and provided a common-sense analysis that earned them an honorable mention in *Effective Support for Building Management*.

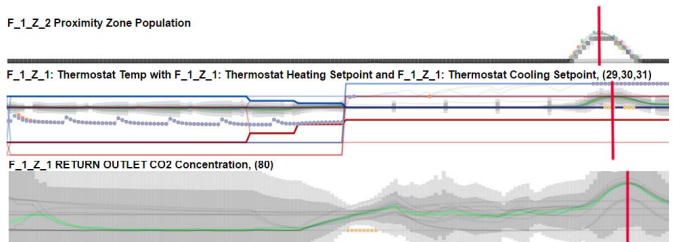


Figure 6: Purdue University's (#127) detection of pattern-of-life for the Deli on Floor 1: population increase during the lunch rush (top), elevated CO₂ cause by increased population density (middle), and subsequent increase in ventilation (bottom).

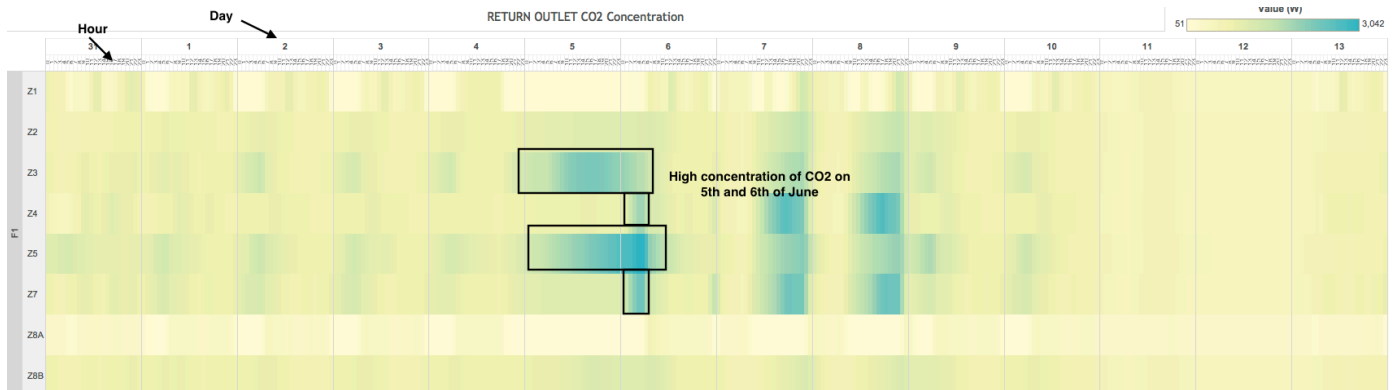


Figure 5: Detection of an anomaly by KU Leuven (#117) involving elevated CO₂ levels on June 5th and 6th.

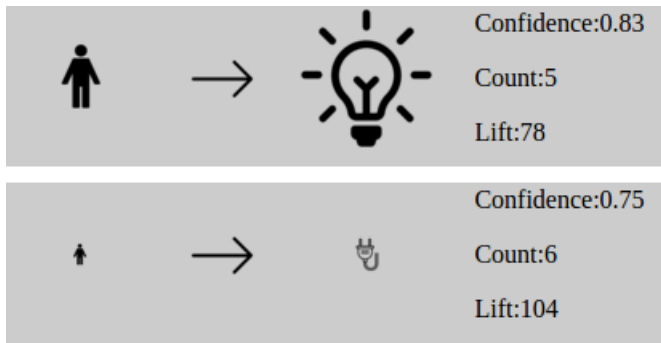


Figure 7: Iconic representation of patterns inferred by TCS Research (#130). Top: an increase in number of employees in a zone causes increase in the light power reading as lights come on. Bottom: a decrease in number of employees in a zone leads to a decrease in power consumption.

Award for Outstanding Comprehensive Submission

A joint submission from Peking University and Qihoo 600 received award nominations for both analytic Mini-Challenges. This team analyzed both static and mobile proximity sensor data, and explored patterns and anomalies in people's movement both as individuals and related groups (Fig. 8). Their visualizations provided substantial capacity for multiple views and drill-down, earning them an award for *Outstanding Comprehensive Solution*.

OBSERVATIONS FROM THE 2016 VAST CHALLENGE

In the following sections, we discuss the trends observed by the committee in this year's challenge submissions. In addition, we will also discuss the implications of observations on future exploration.

Observation 1: Streaming Visual Analytics

While this year saw strong participation in Mini-Challenge 2, the static data challenge, fewer participants attempted the streaming challenges in Mini-Challenge 1 and Mini-Challenge 3. Mini-Challenge 1 required participants to apply their creativity to envision a solution that supported orientation and reorientation in a streaming analytic environment. Some truly creative work was submitted, as noted previously. Many participants took a task-centered approach, focusing primarily on supporting the analysts' workflow. Fewer took data analysis-focused approaches, concentrating their efforts on developing techniques that would be computationally feasible in an on-line environment. This disparity underscores the need for further research in this area.

Many of the Mini-Challenge 2 participants used commercial tools such as Tableau or adapted their own existing visual analytics solutions. However, many of these tools were not well-suited to the live streaming environment in Mini-Challenge 3. We hypothesize that while Mini-Challenge 2 was conceived as a warm-up to Mini-Challenge 3, it instead redirected participants' efforts towards a static solution instead of focusing on a streaming one. This may explain the low number of Mini-Challenge 3 submissions.

Observation 2: User-Centered Design

This year's design challenge was intended to provide an opportunity to explore the integration of the practice of design into the development of visual analytics systems. Design affords a means of exploring an undefined problem space, communicating a future vision, reasoning about complex user-system interactions, and shaping the aesthetics of a visualization system. A user-centered design process shows progression from high-level design concept to illustrate how a system might work, to a high-fidelity design artifact that would specify how a user interface is developed. In this challenge, we saw teams that took both approaches.

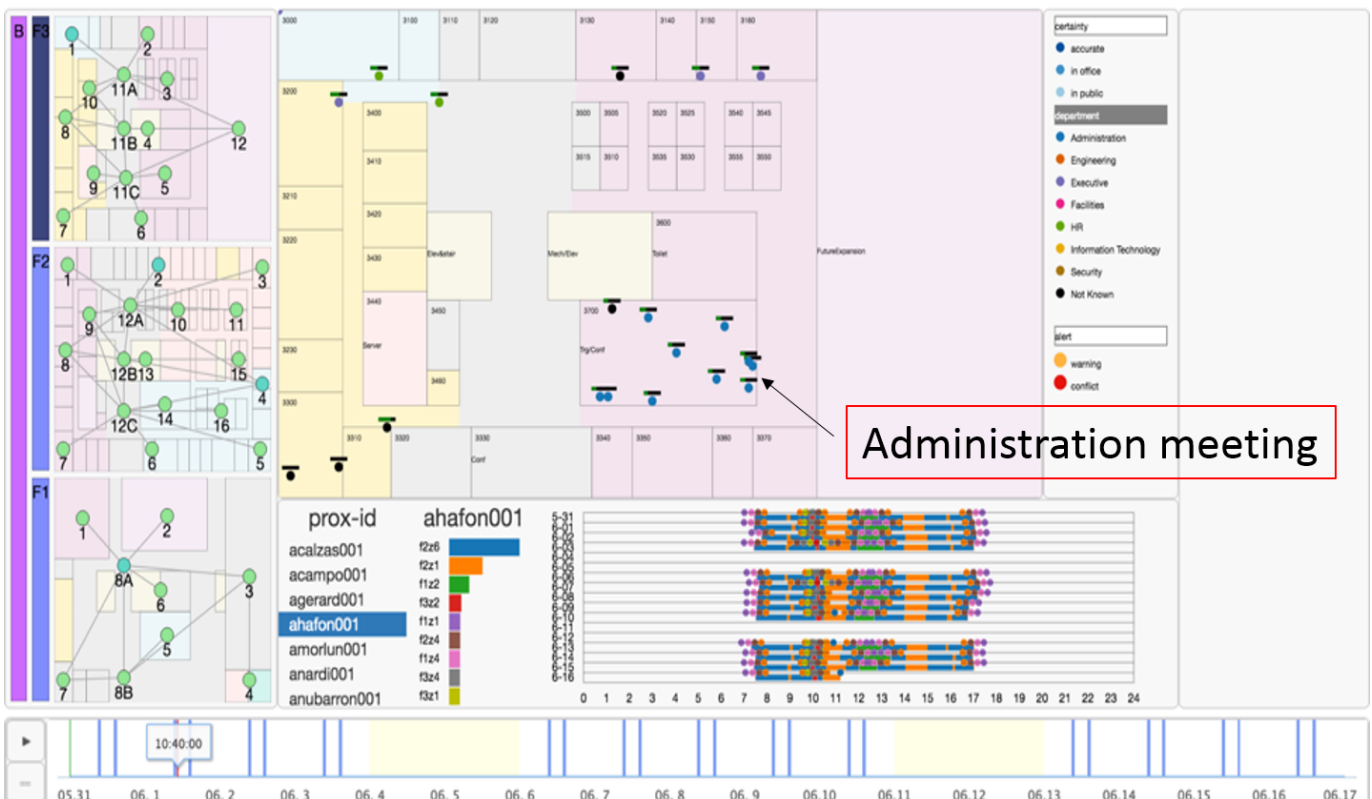


Figure 8: Administrative staff meeting, one pattern of collective behavior identified by Peking University and Qihoo 600 (#102).

Aesthetics is often overlooked in visual analytics, but plays important roles in improving cognitive processing of information and user engagement. The two Purdue teams crossed academic department lines to pair computer scientists and interaction designers for MC1 and MC2 and focused on the visual appeal of their designs with positive results. We encourage teams focus on aesthetic aspects of their submissions, and adopt similar multidisciplinary approaches.

Observation 3: Ergonomics and Use of Physical Space

This year's Mini-Challenge 1 design challenge submissions contained many ideas on how the analyst's working environment might extend into physical space. Along with a traditional multiple desktop monitor set-up, teams proposed the use of wall displays, tablets, augmented reality, virtual reality, ambient sound, and ambient light displays. While the committee really appreciated the consideration of such technologies for the overall design of the operations center, we wanted to see a rationale or justification of why these technologies were deemed necessary to better support analysts' tasks. These could include both perceptual and cognitive considerations (i.e., visual channel capabilities, short-term memory capacity, etc.). An example of one such rationale might be, "research has shown that an auditory alert gets a person's attention faster than a visual alert that is on a peripheral display; therefore, auditory alerts were incorporated when the visual display surfaces extended beyond the analyst's foveal vision."

Additionally, physical (ergonomic) considerations for these technologies should be addressed. For example, viewing distances, angles of monitors, seating and desktop heights, and weight and fit of head-mounted technologies all impact how effective an analyst can be in performing tasks while using some of these alternative display devices. In summary, the committee recommends that, when proposing alternative methods of information presentation, participants include the perceptual, cognitive, and/or ergonomic rationale for suggesting those methods. Additionally, a multidisciplinary team pairing computer scientists with human factors experts could improve the outcomes.

Observation 4: Role of Analytics in the VAST Challenge

Big data comes in many forms: thousands of variables, billions of records, collections of documents, images or videos, sensor feeds, and of course combinations of these. Big data has many descriptive definitions include the three, four or five Vs (volume, velocity, variety, veracity, value). Add complexity in data and tasks, and we now have numerous implications for visual analytics, one of which is that decisions need to be made rapidly, often in seconds or minutes (think trading on the stock market or air traffic feeds). The need to pair analytics with a visual solution becomes essential in a big data environment. With big data one cannot expect an analyst to simply comb through all of the raw data in a visual form.

Placing the burden squarely on the analyst for the analytical discovery or insight step works well when the data is small and the visualizations are interactive and linked, as many examples have been shown in the past VAST Challenges. This year, many put the burden on the analyst to make sense of the data without automated analytical support providing even initial pattern recognition and anomaly detection. Detailed individual visual exploration takes time and cognitive load. An analyst can do this reasonably well for one task, a few visualizations, a few interactions, a few instances. But there are limits, and many were reached in this year's challenge.

One quality measure in our submission evaluations involved scalability, namely whether the presented techniques scale. Clearly this was in anticipation of big data. One aspect of this quality measure we did take into account is scalability for human

consumption. This year's challenge highlighted this as many submissions used small multiples. These are visualizations all having common scale, color, axes, and other attributes often presented in a grid making it easier for the human to compare and search.

Small multiples can be helpful, but there are diminishing returns for small multiples and more generally even for multiple linked visualizations. Where should the analyst look? What interactions is the analyst required to perform? Based on a selection or interaction, what sequence of steps should the analyst perform next? We encourage use of automated analytic techniques to help identify relevant patterns, to help direct the analyst's attention with visual guides, and to support discovery and task solution.

CONCLUSION

Now in its eleventh year, the VAST Challenge has grown into a thriving resource for the visual analytics research community. Through the generous support of the University of Maryland in maintaining the Visual Analytics Benchmark Repository, archived datasets from the past decade of VAST Challenge competitions are freely available for use in student research projects and Visual Analytics courses worldwide. In addition, the research community is able to use these datasets along with the ground truth provided in the solution for evaluation and testing of new analytic approaches. Streaming data is an important challenge for the visual analytics community. Future VAST Challenges will continue to pose problems focusing on streaming data and other important emerging applications for the visual analytics research community.

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