Constructing Narrative Visualizations as a means of Increasing Learner Engagement

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ABSTRACT
Increasingly visualization systems are using storytelling to present complex data. However, many approaches neglect enabling users to independently explore details within the story. The research presented in this paper provides an overview of the implementation and discusses the evaluation of a novel framework (VisEN), which aims to allow users to construct narratives containing multiple exploration paths. The narratives are told through dynamically generated visualization techniques, which are personalized for individual end users, and where every visualization technique in the narrative can be further explored. The evaluation described assesses the role personalized visual narratives had in increasing engagement of weaker students with an online database SQL course. It was found that weaker students who regularly interacted with their personalized visual narratives showed an improvement in engagement.

Categories and Subject Descriptors
H.3.5 [Online Information Services]: Web-based services; H.5.2 [User Interface] Graphical User Interface; H.5.4 [Hypertext/ Hypermedia]: Architectures

General Terms
Design, Experimentation, Human Factors, Performance

Keywords
Visualizations, Personalized Visual Narratives, Visual Interaction and Exploration

1. INTRODUCTION
Research in the field on Information Visualization has largely been focused on visual analytics and exploration, whereas research in visual presentation and storytelling has recently started to gain momentum. Storytelling in information visualization, or narrative as it is referred to in this work, can be defined as an ordered sequence of steps consisting of visualizations, which are linked or connected to make the communicated message more memorable [1]. Stories provide effective ways of highlighting facts, making points and passing on information [16], while visualizations facilitate a simple means to understand digitized data as they map data attributes to visual properties [6]. The research addressed in this paper presents a framework, VisEN (Visual Exploration with Narrative), which aims to provide a novel way to extract knowledge and meaning from data. VisEN supports users in the role of narrative composers to analyze potentially complex data through advanced web based interfaces to construct narratives. The narratives include explorations paths to facilitate data drill downs and viewing related data. The narratives are automatically transformed into personalized visual narratives for end users, who can analyze and explore sections of the narrative through multiple interactive visualization techniques and gain a deep understanding of the data.

This paper discusses the implementation overview, evaluation and preliminary results of two key components of the VisEN framework: the Narrative Builder and the Visual Narrative Explorer. The aim of the Narrative Builder is to enable narrative composers to construct explorable narratives through an advanced web–based interface, which enables the analysis of potentially complex data without dealing with data complexity issues. The aim of the Visual Narrative Explorer is to personalize the visual narratives for end users and facilitate analysis and exploration of these narratives. VisEN was deployed to the AMAS [20] Personalized Learning Environment (PLE), to provide personalized visual narratives to 108 students who participated in an online SQL course. Two evaluations were completed with the first analyzing how effective the AMAS course professor found the user interfaces provided by the Narrative Builder to build explorable visual narratives. The second evaluation focused on weaker students' level of engagement ("participation in educationally effective practices" [17]). In particular, it analyzed how effective the personalized visual narratives were in allowing weaker students to extract meaning from their activity data, in order to motivate them to engage with the course. The results of both evaluations were very encouraging and it was found that these learners were drawn to their visual narratives in order to understand and improve their engagement with the course.

The remainder of this paper is structured as follows: Section 2 discusses the VisEN framework approach. Section 3 presents a review of the related work. Section 4 describes an implementation overview of VisEN. Section 5 presents two use cases; the first describing a domain expert using VisEN to construct visual narratives, and the second describing a learner using her personalized visual narratives to gain a thorough understanding of her personal course log data. Section 6 evaluates effectiveness of VisEN when deployed to a PLE and discusses preliminary results. Finally, section 7 discusses conclusions and future work.

2. VISEN APPROACH
VisEN automatically transforms narratives into explorable visual narratives. This transformation requires data characterization and

mappings to transform data to appropriate visualization techniques. Data characterization or data transformation [6] involves analyzing data to facilitate automated mappings to visualization techniques. To enable this mapping or visual encoding [6], the affordances and characteristics of visualization techniques are required, for example, through a matrix. VisEN narratives consist of data slices, which are constructed using data fields, metadata, filters and aggregations. Data slices form the chapters or sections of the narrative.

When a data slice is constructed, visualizations that can render the data are automatically generated and presented to the narrative composer as a set. The narrative composer decides which visualizations to keep in the set. This action introduces humans into the visual matching process. This results in a refined set of visualizations for a data slice, and takes place before the narrative is transformed into a visual narrative. VisEN automatically generates personalized exploration paths to allow end users to select elements within visualizations and view details or view related data through other visualizations. The exploration paths are generated based on users preferences and consists of visualizations showing details and related data to the narrative viewed.

To complete the narrative, the narrative composer connects the data slices to each other in a chronological order and publishes it. Figure 1 shows a simplified view of the process used by VisEN to produce personalized explorable visual narratives.

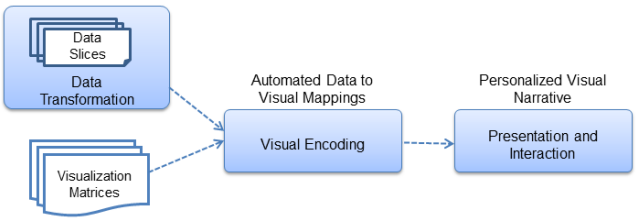

Figure 1: VisEN Flow

3. RELATED WORK

Interaction, exploration and visual storytelling are important aspects of presentation in information visualization as they allow users to gain a deeper understanding of data. This section analyses the state of the art to determine how adequately generating dynamic visual narratives and enabling personalized visual explorations of these narratives have been addressed.

Visual narratives have been effectively used in journalism [9, 15, 24] to tell stories with data. These have ranged from presenting several visualizations with annotations in one view to slides containing interactive visualizations to tell a story. Contextifier [15] for example, provides visualizations embedded in news articles and provides visualizations of related articles allowing users to navigate and explore these. Tools such as Gapminder [22], GED Viz [8] and SketchStory [18] provide users with interactive visual storytelling. However, the interactions are limited to hovering the mouse over data points to reveal details and filtering regions of the data. StoryFlow [19] allows users to explore data in a second layer of the story through its bundling operation, which reveals a level of detail beneath a bundled line. Spotfire [27] provides users with data drill down capabilities, where visual structures can be clicked by users and the system loads another visualization that also provides a drill down of the data. A user can choose to drill down further and view the selected data through a further visualization. However, with drill downs, users reach an end point where their exploration must. Exploration paths provided by VisEN are linked to elements in the visual narrative and when these elements are clicked, visualization techniques are generated rendering a drill down view or a related data view of the element selected. Drill down views show the details surrounding a selected element, whereas related data views show data which shares relationships with the selected element. When a user reaches the lowest point in a drill down, she always has the option to view related data. Visualizations have been used in Technology Enhanced Learning (TEL) to present student activity data and peer comparisons [11, 22] to motivate students. However, these are not represented through visual narratives, where users can explore the data presented.

Personalized visual narratives can aid the process of understanding complex data as they can present personalized data and provide visualizations that suit individual preferences. In Tableau Story, Tableau [26] selects the most suitable visualization for the story point and this can be changed by the analyst. Similarly Google Fusion Tables [10] uses a suitable visualization for the data. However, we find on many occasions, a number of visualization techniques are suitable to render the same data. The visualizations generated by these systems are not personalized to end user preferences. In TEL, a number of systems [2, 3, 21] provide personalized visualization forming part of the learning module. VisEN's architecture consists of a Personalization Engine, which generates personalized exploration paths for end users. User data preferences are stored in a user model, which are used to personalize the exploration paths.

From the visualization tools that support visual interactions and explorations, Spotfire [27] supports drill down explorations, however, the exploration path is fixed and an end user has the option to either view the details behind a data point or not. The exploration is not independent of the path constructed by the analyst. VisEN provides multiple exploration paths from each data slice, allowing end users to explore various tailored paths through the data set. Hence the exploration is independent from one end user to another and this allows users to derive personal conclusions.

From the analysis above, it can be seen that VisEN progresses the state-of-the-art by introducing three novel factors which focus on allowing end users to: 1) explore related data through exploration paths; 2) view visual narratives; and 3) analyze tailored exploration paths.

4. IMPLEMENTATION OVERVIEW

The VisEN architecture uses principles discussed in 1) the visualization pipeline [6]; 2) the visual information seeking mantra [25]; 3) the Template Editor and Shelf Configuration visual interface design approaches [13]; and 4) sequencing in visual narratives [14] to generate explorable personalized visual narratives. Figure 2 shows VisEN architecture, which consists of the Narrative Builder, the Visualization Engine and the Visual Narrative Explorer components.

4.1 Narrative Builder

The Narrative Builder enables narrative composers to easily construct narratives from complex data. Visualizations are not introduced into the narrative during the narrative building phase.

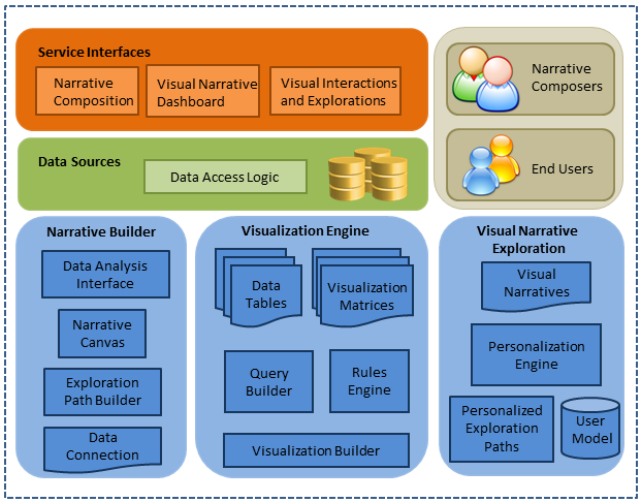

Figure 2. VisEN Architecture

4.1.1 Data Connection Component

Narrative Composers use the Data Connection component to connect to heterogeneous data sources to construct narratives. Data connections are established by selecting data sources or specifying connection parameters. Preconfigured data source parameters are stored in configurations files and new data source parameters supplied by narrative composers are also saved to these files.

4.1.2 Data Analysis Interface

Data slices form the individual pieces of narratives and are constructed by the narrative composers via the web based Data Analysis Interface. In addition to constructing the data slice, the Data Analysis Interface allows narrative composers to analyze data sources. The interface consists of a number of buttons which run general queries such as "*select count..*", "*select <field>..*" etc.; this simplifies the process of constructing narratives as the raw data values can be analyzed by narrative composers. The Data Analysis Interface uses the jQuery Accordion widget to show source tables and fields and uses the jQuery Draggable widget to facilitate dragging and dropping of data fields to construct data slices. The interface provides a canvas with panels for fields and filters. The data fields from the Draggable widget can be dropped onto these panels to construct data slices. The drag and drop design approach has been used effectively in state of the art [26]. When a field is dropped onto a filter panel, VisEN runs queries to fetch data to allow narrative composers to specify which values to use in the filter.

4.1.3 Encoded Exploration

An important and novel aspect of VisEN is exploration paths, which are automatically constructed and connected to data slices. Exploration paths consist of a series of visualizations linked to each data slice or section of the narrative. End users can view and analyze exploration paths by clicking on elements in a data slice to drill down into sections of a narrative or explore related items to obtain a deeper understanding of the data. Exploration paths are constructed by VisEN using data slices that have common elements or derivatives in the narrative. The narrative composer can view the automatically constructed exploration paths and can remove and visualization to the path via the available add/remove options on the Data Analysis Interface.

4.2 Visualization Engine

The Visualization Engine transforms narratives into visual narratives by mapping data slices from the narrative to visualization techniques.

4.2.1 Query Builder

The Query Builder uses the data and metadata provided by the narratives composers in the data slices to generate and execute SQL queries against the specified data sources. The query results are formatted by data type, size (data sizes and number of series of data) and coordinates (data points) to aid the Rules Engine in selecting appropriate visualizations for the data slice.

4.2.2 Rules Engine

The Rules Engine uses the formatted query results and the data slice metadata to determine appropriate visualization techniques for each data slice of the narrative. Instead of building visualizations, VisEN utilizes JavaScript visualization libraries to source visualization techniques. Extensive research [4, 5, 7, 12] has evaluated the affordances and characteristics of visualization techniques and compared the suitability of various techniques for data sets. This research has been used by VisEN to allow developers to build matrices that specify the characteristics, affordances and constraints of the supported visualizations. The matrices are stored as XML files and new visualizations can be seamlessly incorporated into the framework by creating a new XML file (matrix) and importing the JavaScript library.

4.2.3 Visualization Builder

The current set of visualization techniques supported by VisEN requires data to be formatted as JSON objects. The Visualization Builder creates JSON objects using the query results and metadata and populates the set of visualization techniques (currently nine techniques are supported including: bar chart, bubble chart, gauge, line chart, pie chart, scatterplot, stacked bar chart, area chart and parallel coordinates). It also makes the populated set of visualizations available to the narrative composer to view through a web interface as a dropdown list, where visualizations can be removed from the set. The remaining set is used for the visual narrative.

4.3 Visual Narrative Explorer

The Visual Narrative Explorer personalizes the visual narratives for end users by generating tailored exploration paths for each narrative based on individual preferences. It provides a web-based interface where end users can analyze visual narratives and view exploration paths to understand data.

4.3.1 Personalization Engine

The Encoded Exploration component generates derivatives from data slices for exploration paths, which can be accepted or rejected by the narrative composer. Accepted derivate data slices and data slices related to the narrative are used to form personalized exploration paths. The Personalization Engine personalizes the exploration paths using user data preferences, set in the user model. These preferences are set when end users asked to select data tags (taken from data slice metadata) they are interested in exploring when viewing visual narratives. Selected tags are stored in the VisEN user model and these are used to personalize the exploration path.

4.3.2 Narrative Dashboard

Published visual narratives are made available to end users through the web based Narrative Dashboard. End users are presented with the first data slice of visual narratives and the remaining data slice can be access by clicking the titles at top of the interface. When an end user wishes to explore an element in the data slice, she can click it and this generates the first visualization in exploration path, which is shown in a popup window on the web browser. Clicking an element in the visual narrative fires an AJAX request and the linked exploration path is made available to the end user. At any point the end users can close the exploration path popup window and continue analyzing the visual narrative or alternatively continue with the exploration.

5. USE CASES

This section discusses two use cases; the first use case describes a university professor using VisEN to construct two narratives. The second use case describes a student using personalized visual narratives to understand and improve her course engagement.

5.1 Use Case One – University Professor

John is a Professor lecturing Database Management System to final year university students. His students need to use the AMAS [20] portal to study SQL. John understands the challenges learners' have engaging with online learning modules and wishes to provide visual narratives to improve engagement by allowing them to visually analyze and explore their individual log data.

John logs into VisEN and assumes the role of a narrative composer. He connects to the AMAS data source containing learner log data from the last time the course was run. This data source consists of thousands of entries with all the interactions learners had with the course over a three months period. After analyzing the data he wishes to construct two narratives. He starts constructing data slices by dragging data fields onto the Narrative Builder interface.. He clicks on the "Visualize Data" button and views the set of visualizations for each data slice and also views the automatically generated exploration paths. Finally he disassociates the narrative with the previous log data and connects it to new data source (this consists of test entries as the course is yet to commence) and publishes the narratives.

5.2 Use Case Two – Final Year Student

Michelle is a final year Computer Science student and has received an average grade of below 50% each year during the first three years of her course. However, she is determined to improve her grade in her final year. As part of one of her modules she needs to study SQL using the AMAS portal. During the first month of the three month module, Michelle has occasionally used the portal. At the end of this month she receives a notification from the portal informing her of her poor engagement with course activities and advises her that in previous years the students who continued to engage at this level performed poorly.

Following on from this notification, Michelle wants to understand how she can improve her engagement and estimate how much time she must commit to this module to perform well. She views her personalized visual narratives and analyzes her engagement score and how it was calculated. She analyzes peer engagement comparisons using her visual narratives which allow her to determine how to improve engagement. By analyzing peer comparisons and exploring her visual narratives, Michelle is able to predict how long it will take her to complete her next five activities. Michelle now feels motivated and determined to work hard and obtain a good grade. As she completes each activity, she explores her visual narratives and estimates the time the next activity would take.

6. EVALUATION

VisEN was deployed to the AMAS [20] PLE during the 2013-2014 academic year to provide learners with personalized visual narratives to allow them to analyze their engagement score, view time spent on activities and analyze peer comparisons. AMAS provides a dynamic and adaptive framework for composition and assignment of personalized learning activities [20]. It has been used over the past three years to deliver an SQL database course to final year university students in Trinity College Dublin. Two evaluations were carried out in conjunction with the delivery of the AMAS SQL course. The first evaluation involved a university professor using VisEN to construct visual narratives for his students. The second evaluation involved participating students of the course using personalized visual narratives in order to understand their performance and engagement from their log data.

6.1 Evaluating the Narrative Builder

In this evaluation, the professor whose students worked through the AMAS activities, assumed the role of a narrative composer and constructed narratives using the AMAS log data from the 2012-2013 academic year. The aim of this trial was to evaluate the end to end tasks of the narrative composer: analyze a complex data set; construct narratives with exploration paths; and critique the set of generated visualizations. The professor was provided with a 15 minutes training session on how to use the Narrative Builder and then asked to construct the two narratives using the Narrative Builder (shown on the left of figure 3): 1) A narrative showing learners' engagement score and how it was calculated; 2) A narrative presenting the time learners spent on activities, and allowing learners to compare activity times with their peers. Exploration paths were automatically generated, which showed a breakdown of selected students' engagement score (drill down). The other exploration path showed engagement scores of similar students (related data). Once both narratives were completed (which took 25 minutes with some assistance), the professor was asked to interact with the visual narratives, which were automatically generated and analyze the data through exploration paths. During the analysis, he was asked to answer questions by exploring and interacting with the visual narratives, which he did with ease and answered all the questions.

His final task was to critique the visualizations and the process of constructing the narrative through a questionnaire and interview. The questionnaire focused on how useful the professor found the process of constructing narratives and analyzing exploration paths. For example, one of the questions asked: "When viewing course engagement by activity, how useful was it to view students with similar engagement through an exploration path". The questions also addressed how well the framework and visualizations met his needs, such as "Did the framework support you in telling the story you wanted to tell" and "Where you ever frustrated with the limitations of the user interface", to which he offered useful suggestions such as providing tooltips and help options. From the feedback the professor found exploration paths very useful for gaining insight and was able to tell the story

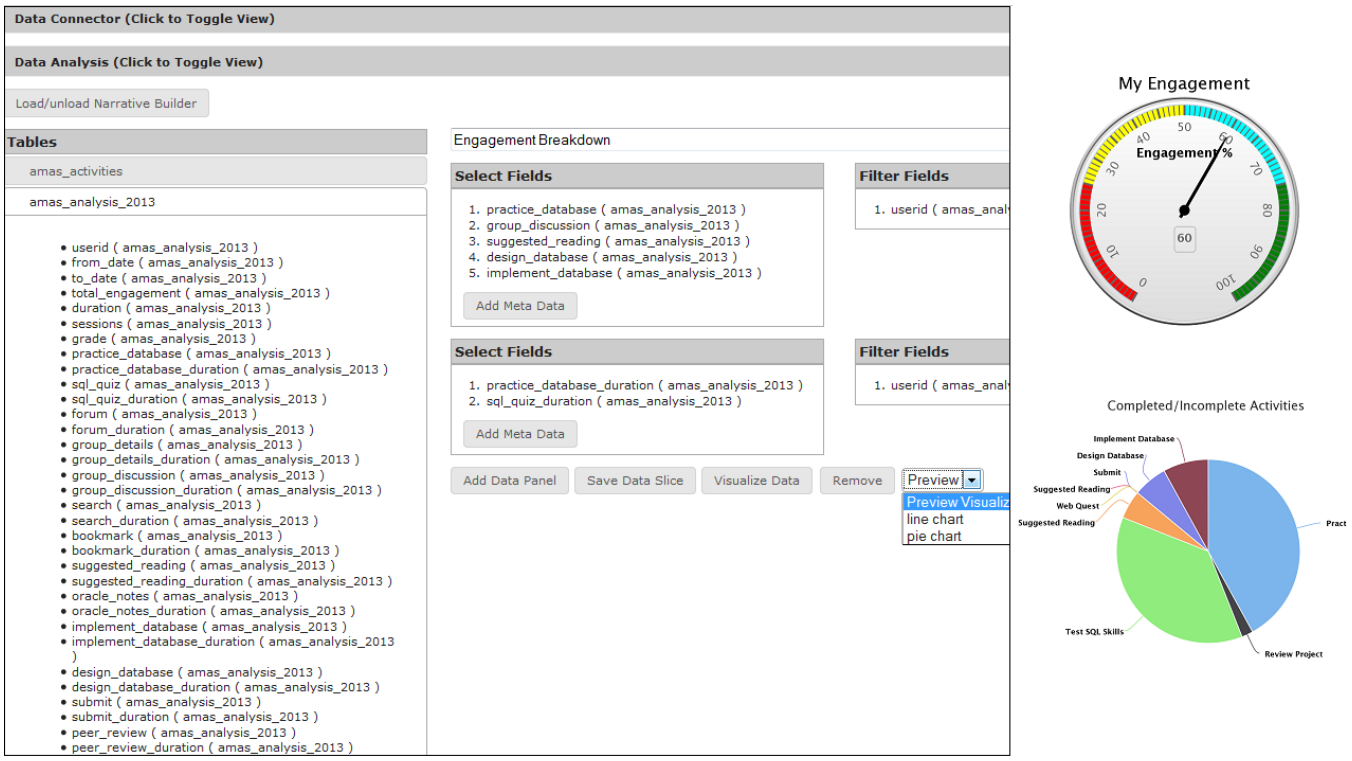

Figure 3. Narrative Builder Interface (left) and two sample visualizations from a Personalized Student Visual Narrative (Right)

requested. He expressed that the data slices and resulting visualizations represented his needs quite well. In the interview, the professor expressed that he was able to follow and interact with the visualizations easily and expressed confidence in constructing data slices and building the narratives. Examining the time taken to learn and construct the narratives, it was evident that the professor had a very positive experience constructing narratives using the Narrative Builder.

6.2 Evaluating Personalized Visual Narratives

One of the primary aims of AMAS is to support weaker students completing their course. The second evaluation focused on analyzing the impact the personalized visual narratives had on supporting weaker learners to improve course engagement. The right hand side of Figure 3 shows two visualizations from one of the narratives presented to learners. 108 students participated in the AMAS SQL course; 22 of these were identified as weak students as they had an average grade of below 50% for each of the previous three years of their course.

During the course, AMAS sent fortnightly notifications to learners informing them of their engagement levels. The first study analyzed the AMAS log data, (consisting of thousands of entries for three months of interactions from 108 learners), and found that all of the weaker students had at some stage received a below average engagement notification. The analysis of the log data of the 22 weaker students found that 17 of these students showed an improvement in engagement following this notification. It was found that 14 of these 17 learners were immediately drawn to their personalized visual narrative following a below average engagement notification. All of these 14 learners executed a minimum of 45% of their total narrative interactions on the first day after reading the notification. Following this notification (which did not explicitly direct them to their personalized visual narratives), these learners frequently returned to view their personalized visual narratives. Hence, it can be concluded that the personalized visual narratives assisted these learners in gaining a deeper knowledge of their performance data.

The second study analyzed if there was a correlation between weaker students interacting with their visual narratives and an improvement in engagement. The log data of the 17 weaker students, who showed engagement improvement following a below average engagement notification, was analyzed. It was found that all of these learners showed a minimum of a 70% increase in interactions with their visual narratives during the period in which their engagement improved. From this, it was concluded that weaker students who increased in interactions with their personalized visual narratives showed an improvement in their course engagement level.

7. CONCLUSIONS AND FUTURE WORK

This paper introduced VisEN as a framework to construct visual narratives and facilitate personalized visual explorations by allowing end users to: 1) explore related data; 2) analyze visual narratives; and 3) analyze personalized exploration paths.

Two evaluations were carried out; the first evaluation involved a university professor analyzing the log data of his students' course activities and constructing visual narratives. The results of this evaluation were positive, with the professor confidently creating data slices and narratives and positively commenting on his experience of executing the tasks required. The second evaluation involved analyzing the log data of weaker students who participated in an online SQL course. This evaluation found that the personalized visual narratives assisted these learners in understanding and improving their engagement and performance data.

Preliminary results have been obtained from both evaluations. Further work is required to evaluate the Narrative Builder through qualitative and quantitative analysis using several users. In the 2014 - 2015 academic year, it is intended to continue to provide learners with personalized visual narratives and compare engagement results with control groups, and quantify the increase in engagement levels, and verify the statistical significance.

8. ACKNOWLEDGMENTS

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