VISUAL ANALYTICS FOR SENSE-MAKING IN CRIMINAL INTELLIGENCE ANALYSIS

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Analytical Provenance for Criminal Intelligence Analysis

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I N T E N T I O N A L L Y B L A N K

ABSTRACT

In criminal intelligence analysis to complement the information entailed and to enhance the transparency of the operations, it demands logs of the individual processing activities within an automated processing system. Management and tracing of such security sensitive analytical information flow originated from tightly coupled visualizations into visual analytic system for criminal intelligence that triggers huge amount of analytical information on a single click, involves design and development challenges. To lead to a believable story by using scientific methods, reasoning for getting explicit knowledge of series of events, sequences and time surrounding interrelationships with available relevant information by using human perception, cognition, reasoning with database operations and computational methods, an analytic visual judgmental support is obvious for criminal intelligence. Our research outlines the requirements and development challenges of such system as well as proposes a generic way of capturing different complex visual analytical states and processes known as analytic provenance. The proposed technique has been tested into a large heterogeneous event-driven visual analytic modular analyst's user interface (AUI) of the project VALCRI (Visual Analytics for Sensemaking in Criminal Intelligence) and evaluated by the police intelligence analysts through it's visual state capturing and retracing interfaces. We have conducted several prototype evaluation sessions with the groups of end-users (police intelligence analysts) and found very positive feedback. Our approach provides a generic support for visual judgmental process into a large complex event-driven AUI system for criminal intelligence analysis.

Keywords

Analytic Provenance, Visual Analytics, Transparency, Visualization Design, Sensemaking.

INTRODUCTION

Provenance is a broad topic that has many meanings in different contexts. The Oxford English Dictionary defines provenance as "the source or origin of an object; its history and pedigree; a record of the ultimate derivation and passage of an item through its various owners." In scientific experiments, provenance helps to interpret and understand results by examining the sequence of steps that led to a result, we can gain insights into the chain of reasoning used in its production, verify that the experiment was performed according to acceptable procedures, identify the experiment's inputs, and, in some cases, reproduce the result. In criminal intelligence it has a greater impact to understand the process by which the decision has been made. Now-a-days the large and complex event-driven systems around us are computationally intense where data flows from one process to another as it is transformed, filtered, fused, and used in complex models in which computations are triggered in response to events. Provenance capturing and representing to support judgmental process of criminal intelligence analysis by using such computation systems with hundreds of interconnected services that creates huge volume of data at a single run is a matter of obvious challenge.

Wong et al., (2011) proposes a three-layer provenance model which describes the relationship between the provenance and the intelligence process i.e, the data provenance, process provenance and reasoning provenance. The process and reasoning provenance are termed as "Analytic Provenance" at it's broader category. Criminal intelligence analysts are likely to benefit from the ability to review the way in which the data they collected evolved during the intelligence process (data provenance) and from the possibility to track back various activities in which they engage (analytic provenance). This is likely to help them in dealing with the complexity of the intelligence process considering the limited capability of the human mind to store all relevant details. As explained by Shrinivasan et al., (2008) to keep track of the data exploration process and insights, visual analytics systems need to offer history tracking and knowledge externalization to the analyst. This will reduce the cognitive overload imposed on the analyst and by freeing essential mental resources and offering a new perspective on the recorded information. According to North et al., (2011) provenance "has demonstrated great potential in becoming a foundation of the science of visual analytics".

Visual Analytics for systematic scientific analysis of large dataset has opened up a new era for criminal intelligence analysts to understand the process through which a crime or criminal situation has occurred. The project VALCRI aims to develop a semi-automated visual analytic system that will help find connections in criminal intelligence that often humans miss. It's provenance recording system will keep track of analytical reasoning processes to minimize human errors. Significant amount of research have been carried out to capture analytical provenance into science, engineering and medicine computation systems. For handling provenance information into event-driven large visual analytic systems, it requires research for developing system specific generic approach. In the context of criminal intelligence our research work mainly contributes to-

- A system design to identify requirements and understand the problems of capturing, representing analytical provenance data, usability and management for criminal intelligence analysis.
- Development of visual analytic system and protocol to capture and manipulate analytical provenance data in a generic way for large complex criminal intelligence analysis system.

RELATED WORK

Significant amount of research have been carried out for developing a usable and manageable provenance tracker along with the user interface for representation, access to provenance information. We describe and summarize few of this research under three different areas to focus on - 1) Capturing provenance of analysis process, 2) Visualizing captured information and 3) Utilizing visualized provenance.

Provenance Capture and Management

Groth et al., (2004) developed an implementation-independent protocol for recording of provenance. They described the protocol in the context of a service-oriented architecture and formalize the entities involved using an abstract state machine or a three-dimensional state transition diagram. To track events processing stream provenance for workflow driven system, Vijayakumar et al., (2007) described an information model and architecture for stream provenance capture, collection and evaluated the provenance service for perturbation and scalability for the Linked Environments for Atmospheric Discovery (LEAD) project. Prov4J is a semantic web framework for generic provenance, proposed by Freitas et al., (2010). This work describes a framework which uses Semantic Web tools and standards to address the core challenges in the construction of a generic provenance management system. The work also discusses key software engineering aspects for provenance capture and consumption and analyzes the suitability of the framework under the deployment of a real-world scenario. Problem of systematically capturing and managing provenance for computational tasks have been receiving significant attention because of its relevance to a wide range of domains and applications. Freire et al., (2008) have presented a survey on concepts related to provenance management for computational tasks, so that potential users can make informed decisions when selecting or designing a provenance solution.

Provenance Visualization

GeoTime developed by Eccles et al., (2007) is a commercial geo-temporal event visualization tool that can capture a screen shot of the tool and perform text or graphical annotation. It also allows users to construct a report of the analysis. Tableau Public offers a story telling feature, which consists of several pages or story points, each is a captured visualization with annotation. To reuse captured states, the Human Terrain Visual Analytics system (HTVA) proposed by Walker et al., (2013) allows the analyst to drag and drop captured visualizations automatically onto an empty space and add narrative to each visualization to build the story. To visualize captured information, LifeLines developed by Plaisant et al., (1998) is a visualization for personal histories, which uses icons to indicate discrete events and thick horizontal lines for continuous ones. Typically, the system begins with an initial state (node). When the user performs an action, a new node is created for the current state, and a new edge is added to connect the previous node with the current node. VisTrails introduced by Bavoil et al., (2005) colour-codes the background of visualization nodes according to when they are created and Aruvi introduced by Shrinivasan et al., (2008) uses the length of edges to represent the distance in terms of time between two states. For visualizing the reasoning process, the Scalable Reasoning System developed by Pike et al., (2009) provides a more formal method to document the reasoning process. A captured visualization can be added into reasoning space to create a node as a miniature and can be tagged as an evidence artefact.

Provenance Utilization

SensePath developed by Nguyen et al., (2016) is a tool for understanding sensemaking process through analytic provenance. SensePath provides four linked views of i.e, a timeline view that shows all captured sensemaking actions in temporal order, a browser view that displays the web page where an action was performed, a replay view that shows the captured screen video & can automatically jump to the starting time of an action when it is selected in another view, a transcription view that displays detailed information of selected actions. "Vistories" introduced by Gratzl et al., (2016) is a visual stories based history exploration system by following the CLUE (Capture, Label, Understand, Explain) model. This tool has an authoring mode, a provenance graph view, a story view for showing the history of the analysis and a Vistory being created.

ROLE OF ANALYTICAL PROVENANCE

Analytical provenance is the means for providing insight into data processing operation in question. So, for criminal intelligence analysis it is one of the best means to provide necessary support to explain in a clear way how decisions or choices were made, what they were based on, how steps in a selection process were made, provide information grounds to justify and answer claims of bias or discrimination, and show compliance. All these are enabler of fairness and lawfulness of the data processing activities from the legal framework. *Transparency* in criminal intelligence analysis is an important requirement for maintaining respective LEP (Legal, Ethical, and Privacy) guidelines. This is the property that all operations on data including legal, technical and organisational setting and the correlating decisions based on the results can be understood and reconstructed at any time. So, Transparency can be regarded as the underlying foundation of the analytical provenance. As well as analytical activities performed by analysts should be recorded for supporting *Accountability* for particular action of analysis process. Analytical provenance data has got greater influence in this regard.

Capturing analytical provenance has also got significant role in criminal intelligence analysis, because the legal directive foresees an obligation to provide competent legal authorities with information about the processing operation upon request. Competent authorities are any public authority or any other entrusted body by national law to exercise public authority and public powers for the purposes of the prevention, investigation, detection or prosecution of criminal offences or the execution of criminal penalties, including the safeguarding against and the prevention of threats to public security. Analytical provenance data can help to validate the processing operation in such case.

ANALYTICAL PROVENANCE REQUIREMENTS

To have a better understanding of the requirements for analytical provenance in criminal intelligence analysis, we organized a focus group discussion with police analyst end users of the project VALCRI. Based on our initial understanding of capturing analytical provenance, we developed an analytical state capturing prototype and demonstrated to police analysts during the focus group. We adopted Walker et al.'s, (2013) proposed technique of saving analytical states as bookmarks for implementing our prototype. The purpose of such prototype demonstration in the focus group was to gather requirements for a much larger system as well as to evaluate the prototype. The focus group involved three groups of police analysts and each group had two people.

We tested two techniques of capturing analytical states by using our developed prototype - 1) Capturing a URI, and 2) Capturing event properties to save and restore analytical states automatically. We also tested these techniques on two separate visualizations, using the Canadian Crimes by Cities 1998-2012 dataset for Geo-Spatial Temporal (GST) crime analysis and VAST Challenge 2015 dataset for Call Data Records (CDRs) analysis. This system automatically logs information about the user's interaction with system as well as saves corresponding state data into database and shows the preview of the analytical state at front-end along with meta information on tooltips by using which a captured state can be restored again. The event based approach out of these two techniques that we followed to develop our initial prototype, provided us better results for capturing analytical states even at a granular level.

System Requirements

Based on the prototype development experience and realization from the focus group demonstration, we identified following system requirements for supporting criminal intelligence analysis.

SysReq1: different techniques should be supported for capturing and recording analytical provenance information.

SysReq2: a standard mechanism should be referred to the discovery of an analytic provenance state object and a representation model should be used.

SystReq3: different levels of granularity should be used in describing analytical provenance of complex state objects.

SysReq4: analytical provenance data needs to be stored, logged, and versioned to allow capturing of states.

SysReq5: the system needs to scale with large amounts of recorded analytical provenance data and lots of analyst end-users.

SysReq6: analytical provenance information needs to be able to be easily queried.

SysReq7: different levels of security are needed to provide access to analytical provenance data.

Police Analyst Requirements

The police analysts currently record their thoughts in their diaries or spreadsheet manually and found this process cumbersome and ineffective. The police analysts found the demonstrated concept of analytical states capture and restore, and automatic state suggestion system could be effective for their work-flow. Based on the focus group we identified five potential end-users for an analytical provenance capturing system to support criminal intelligence. These include police analysts, analyst trainers, researchers, managers, and auditors. We now outline the identified requirements of the five-end users based on the focus group.

AnaReq1: analysts need to see different representation techniques for visualizing analytical provenance data.

AnaReq2: analysts need to be able to compare different analytical provenance information.

AnaReq3: analysts need to validate whether captured analytical provenance information is of adequate quality for evidence.

AnaReq4: the provenance information needs to show whether laws, rules and regulations have been correctly adhered to.

AnaReq5: analysts must be able to step-back and step-forward through the states they have captured in the past to see what actions they performed in the system.

AnaReq6: analysts need to be able to record a set of macro states to perform a collection of operations on different sets of data. We also call this Repetitive Replicating Playback.

AnaReq7: analysts need to be able to annotate provenance information about different states.

AnaReq8: analysts (based on role) must be able to turn off automatic logging of the provenance capture method.

AnaReq9: trainers should be able to use the system to train new analysts.

AnaReq10: auditors should be able to use the system to examine the kinds of activities analysts are performing and to generate reports.

AnaReq11: managers need to be able to monitor what their police analyst colleagues are working on and see summaries of information.

AnaReq12: researchers need to be able to use the system in conjunction with analysts to understand how to effectively perform criminal intelligence analysis.

PROVENANCE VISUALIZATIONS

ProvVIZ

To support police intelligence analysts (end-users) for their visual judgmental process of crime analysis, we designed a new system called "ProvVIZ" based on our identified requirements from earlier focus group and prototype. We adopted UIMD (Understand, Ideate, Make, Deploy) design process model introduced by Mckenna et al., (2014) to implement this Provenance VisualiZation system "ProvVIZ". This system has several visual interactive panels for analytical captured states representation, multi-ways querying, workflow playing back and analytical process mapping. These visualizations have been built on our developed provenance data manipulating protocol to query/access database and event based analytical states capturing method. The widget visualizations for crime analysis inside Analyst's User Interface (AUI) system have been built on anonymized real crime dataset. We applied the same methodology as our earlier study prototypes on AUI system for analytical states capturing through ProvVIZ visualizations that link back to the requirements for criminal intelligence analysis.

States Representation – Currently, our developed provenance visualization system can capture analytical states of the AUI (Analyst's User Interface) and shows snapshots as previews (Figure 1). Annotations can be added and all other meta-information of a state has been shown into tooltips (Figure 2). Provenance can be captured either manually by the analysts or automatically by the system as log.

Repetitive Replicating Playback (RRP) System – Group of states can be captured as a macro to use them all again on another dataset and see the results to compare among result sets as shown in Figure 2. This was one of the important requirements gathered from focus group discuss with the police analysts during our case study. We've named it Repetitive Replicating Playback (RRP) into our provenance visualization system.

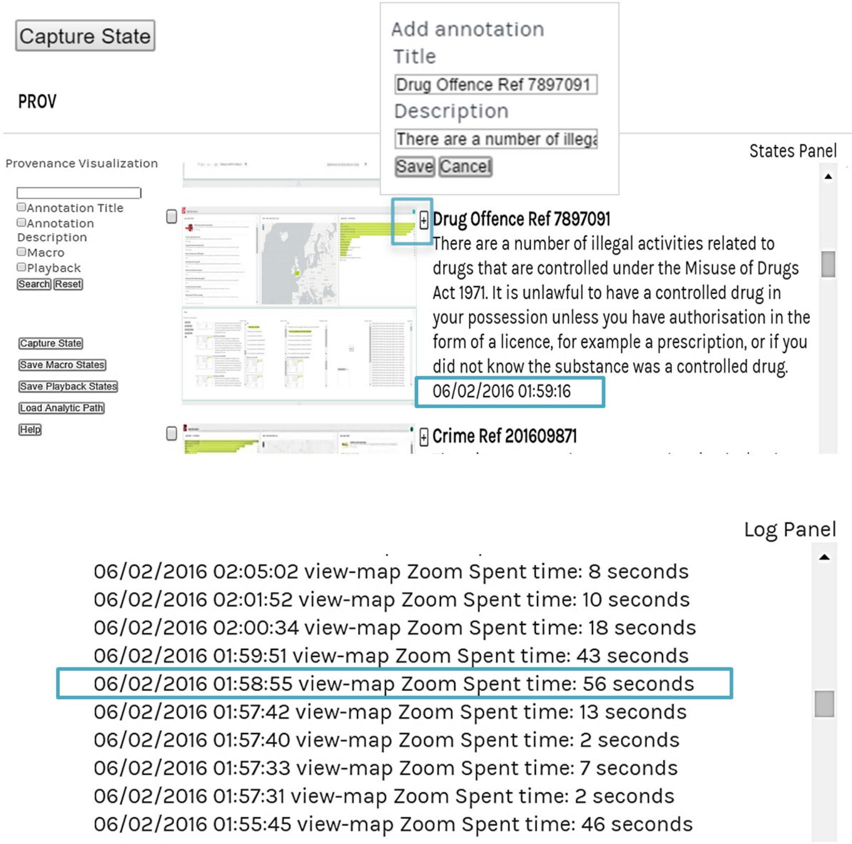

Figure 1: Manually captured states panel with annotation add/edit and automatic log panel for Analyst's User Interface (AUI).

Query System – One of the challenges for captured analytical states is to be able to formulate queries that retrieve and employ traces and other artifacts in order to fulfil an analyst's information needs, user-friendly ways of formulating ad-hoc traceability queries, involving traces and all their relationships and allow interactive filtering of retrieved data and ad-hoc query refinement. We visualized all captured states on a timeglider and saved macros as group of states (Figure 3). States can be searched/filtered by types & users. As well as states sequences can be represented (highlighted in yellow colour) as shown in Figure 3 in temporal order to show the process of analysis, followed by an analyst. Also states can be traced back by using temporal information (gliding the timeline or using calendar).

Analytic Path – Intelligence analysis is not practiced exclusively as a solitary activity. Analytical provenance adds considerable value for collaborative analytics, where it must be communicated and shared among teams. Additionally, by allowing communication and sharing of information, visual representations of analytic provenance data will support analyst's ability to identify and work with the desired information. So far the application of analytic provenance system supports sensemaking for individuals. In case of more than one analyst working together for a specific problem, demands to record all their interactions automatically for understanding their thinking process. We also have implemented "Analytic Path" (Figure 4) as a tool for visualizing analyst's activities through interactions with the visualizations. The tool supports adding, deleting, editing or rearranging different branches with users' colour codes, consisting of annotations set by analysts along with captured states. As well as mapping of analytic states can be saved into or loaded back from data storage to combine multiple maps together for making story of the visual group analysis process to support transparency or to visualize different captured analytical data versioning.

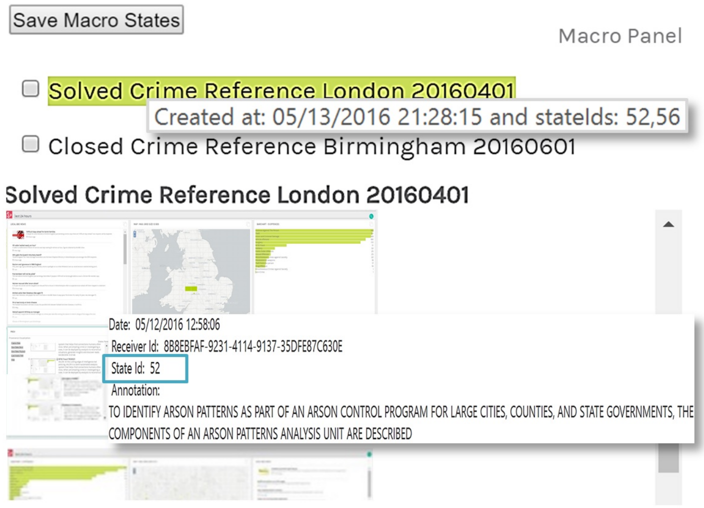

Figure 2: Repetitive Replicating Playback (RRP) System shows results with source state id information after runningmacro operation on saved group of states.

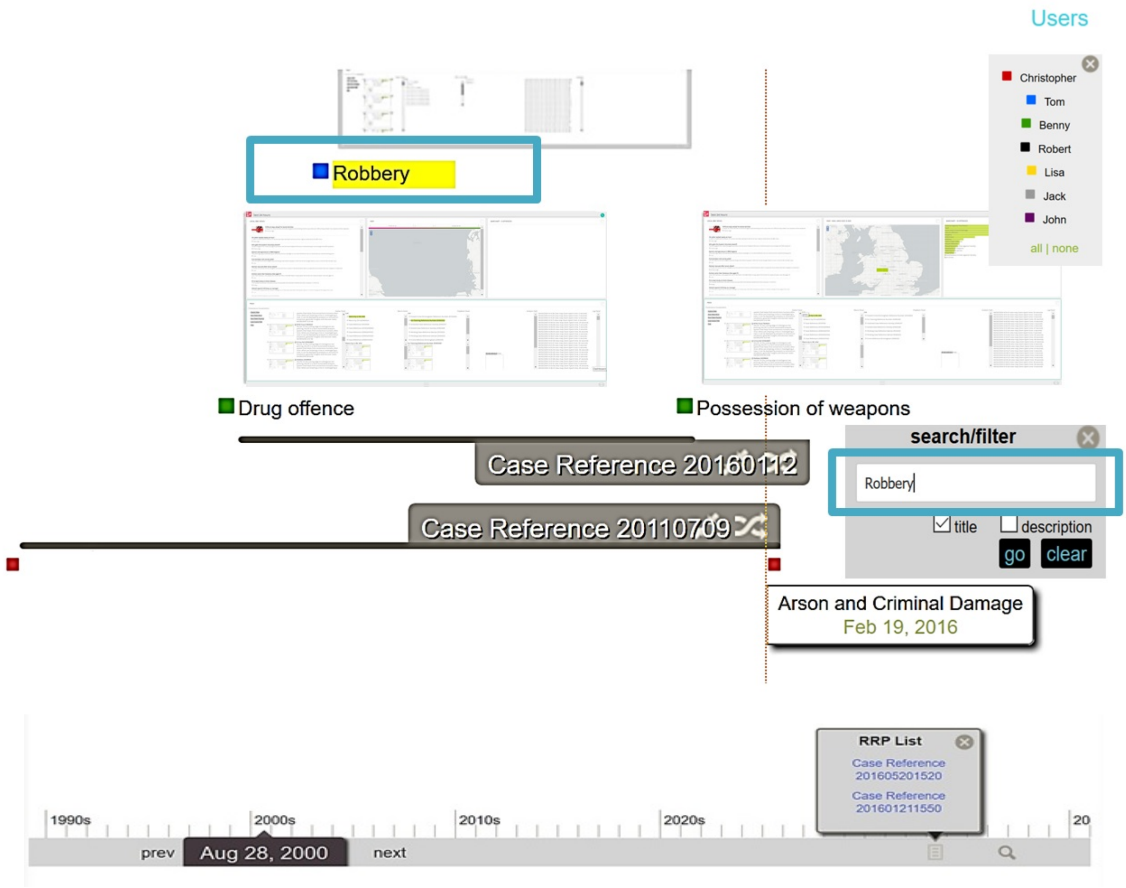

Figure 3: Visual representation of saved RRPs into macro panel to trace states back by time gliding, colour coded users (analysts) filtering, keyword searching and selecting from RRP list

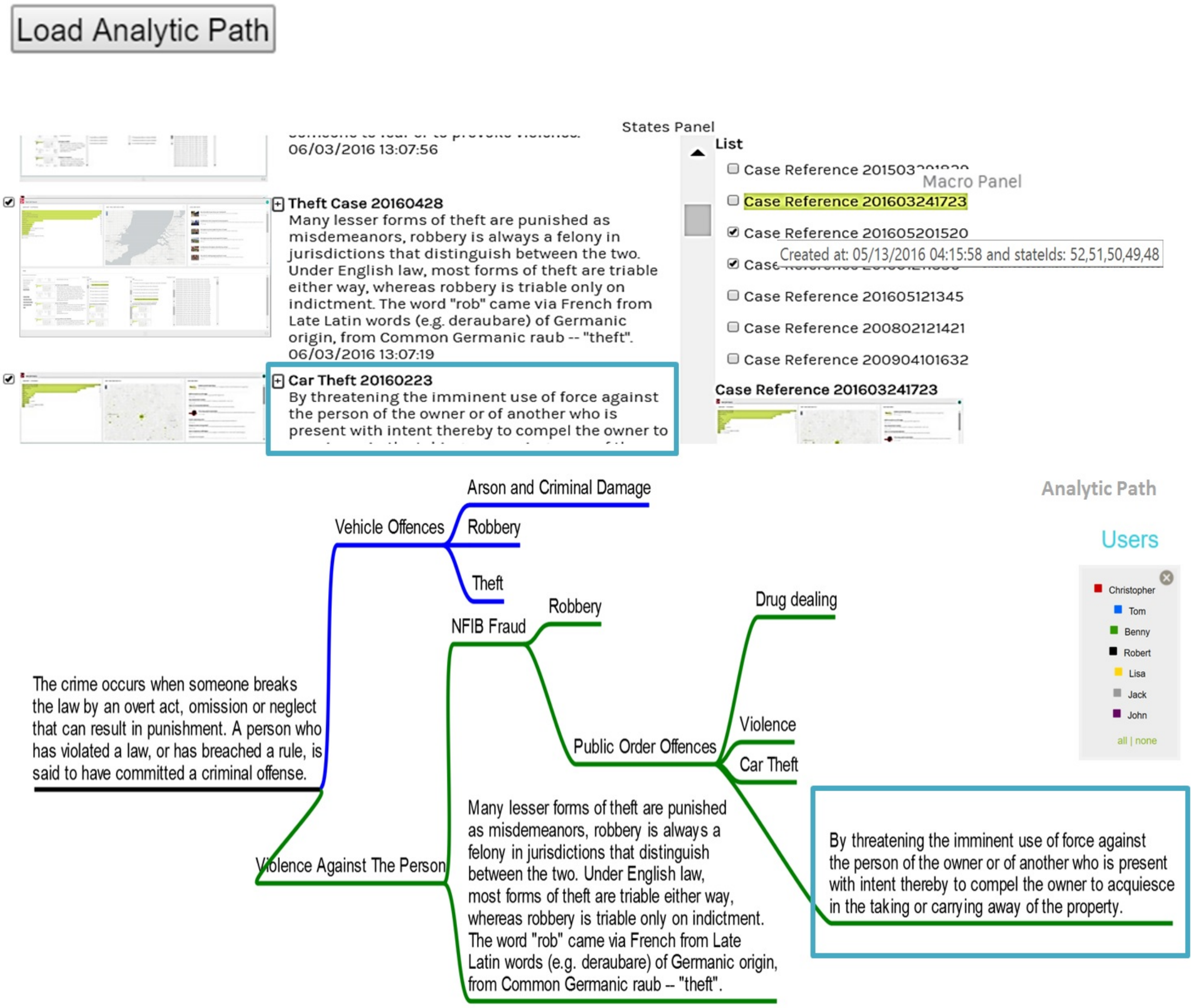

Figure 3: Visual representation of saved RRPs into macro panel to trace states back by time gliding, colour coded users (analysts) filtering, keyword searching and selecting from RRP list

FEEDBACK

To elicit subjective feedback of ProvVIZ we conducted focus groups by demonstrating our prototype to police analysts. We wanted to understand how provenance visualizations could support analysis and reasoning about data for deriving relevant information in criminal intelligence. Three groups of analysts participated in pairs. Each pair was from

Figure 4: Analytic Path showing annotations set by analysts with captured states & their relationships based on interactions with colour coded users (analysts) information. States can be selected from States Panel & RRP List of Analyst's User Interface (AUI) to load analytic path for understanding intersections of analytical states captured by different analysts during their analysis process.a different police organization and country (UK and Belgium). The procedure used in the focus group involved demonstrating the prototype, illustrating the visualizations for different tasks, and obtaining feedback. Each group had 30 minutes for the demonstration and feedback. The end-users did not get to experiment with the prototype on their own as this was demonstrated by one of the researchers. We had separate observers during the focus group that recorded notes, ideas, and feedback from the end-users.

Purpose and value- All the end-users understood the purpose of the prototype to log and track analytic workflow in the VALCRI system. They claimed that this task would add value to what their current workflow processes are, as it would allow them to track what they were doing on a daily basis and analyse what they had done previously. They deemed these tasks to add value, as it is necessary to explore different analytic pathways, or to even pick up and validate the work of others.

Strengths and Weaknesses- The biggest strength as reported by all the end-users was that the tool tracked the tasks they were performing as well as the ability to bookmark certain parts of the interface they were working with. The tracking and book-marking feature was found to be useful as they could come back to a previous state where they had been working and continue to work from that state.

Improvements- Different features were suggested by some of the analysts for addition to the prototype. They would like to see a team leader login part, which can monitor the activities of all analysts. The purpose for doing so is they can see at what stage an analyst is working on within a crime investigation and to get reporting features based on the progress of analysts. They would also like to be able to add outcome reports to different stages of the analytical path. Being able to summarize information through annotations and free text will enable analysts to record some of their thoughts when investigating a crime.

Satisfaction- The overall assessment of the prototype by all the end-users was very positive and they were satisfied with the progress of the prototype. All the analysts felt that the different provenance features could add value to what they are currently doing and to help make more effective decision making for criminal intelligence analysis.

DISCUSSION & CONCLUSION

The key to this research on analytic provenance is the belief that by capturing user's interactions with a visual interface, some aspects of the transparency of user's reasoning processes can be retrieved. To correlate analyst's interactions with the visualizations for his/her reasoning process, the analytic provenance research needs to start with the understanding of how information is perceived by the user. We conducted a focus group discussion meeting with the police analysts to understand their needs for analytic provenance visualization. As the user interacts with visualization, the series of interactions can be considered as a linear sequence of actions. So, how can these analytic provenance information be captured – is still an open challenge. We have implemented our proposed protocol for managing huge analytic provenance dataflow for a large complex system like Analyst's User Interface (AUI) of the project VALCRI. Once the user's provenance data has been captured, the challenge becomes making sense of the provenance. As noted by Jankun-Kelly et al., (2007) history alone is not sufficient for analyzing the analytical process with visualization tools. Often, there are relationships between the results and other elements of the analysis process which are vital to understanding analytic provenance. Our provenance visualization system can also capture analytical relationships automatically. We have developed an analytic process mapping system named as "Analytic Path" to visualize those related process sequences for multiple analysts working in a group. One of the research goals in analytic provenance is to be able to automatically reapply a user's insights to a new data or domain. It refers to the utilization of specific knowledge of previously experienced, concrete problem situations or cases. By employing such repetitive process, the analyst can solve a new problem by finding a similar past case, and reuse it in the new problem situation. We have developed a Repetitive Replicating Playback (RRP) system, where analysts can use their previously saved group of analytic states, apply to new dataset and see the results. We have tested our proposed way of capturing event-driven analytical provenance by developing visualization prototypes based on police intelligence analysts' requirements and found it supports the challenges of five interrelated stages of analytic provenance generically, as suggested by North et al., (2011) i.e, perceive, capture, encode, recover and reuse.

According to Gotz et al.'s, (2008) hierarchy of analytic behaviour, the sub-tasks at higher-level have more concrete states with rich semantics into provenance-aware analytic process comprising of interactions for understanding human intention and computational elicitation. Semantics of interactions that occur during switching among multiple visualizations hasn't been addressed into this work. Also this work hasn't addressed the coupling between cognition and computation through interactions during analytic processes. As well as for sensemaking or computational problem solving during crime analysis in criminal intelligence and the analytic processes, require insightful alignment with the visualizations for supporting analyst's thought processes. The current developed visualizations have got limited support in this regard, which we are still working on.

Our future endeavour for this work is to add few more features with our current system i.e, creating case specific new provenance capturing space with pluggable annotation system and tag them. Also developing a document trail system by using attached crime reports with the annotations will be useful as identified by the police intelligence analysts. We also aim to develop an ontology for analytical provenance, which is currently absent into W3C standard for describing and integrating analytical states from different sources. As well as visualizing evolution of ontology is a crucial issue to understand the way knowledge evolves form one state to another during analyst's analytical process and that is a potential area of research.

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