The Science of Analytic Reporting

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Original Article

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Abstract The challenge of visually communicating analysis results is central to the ability of visual analytics tools to support decision making and knowledge construction. The benefit of emerging visual methods will be improved through more effective exchange of the insights generated through the use of visual analytics. This article outlines the major requirements for next-generation reporting systems in terms of eight major research needs: the development of best practices, design automation, visual rhetoric, context and audience, connecting analysis to presentation, evidence and argument, collaborative environments and interactive and dynamic documents. It also describes an emerging technology called Active Products that introduces new techniques for analytic process capture and dissemination.
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Keywords: visual rhetoric; graphic design; analytic product; reporting; collaboration; communication

This article is a product of a workshop on the Future of Visual Analytics, held in Washington, DC on 4 March 2009. Workshop attendees included representatives from the visual analytics research community across government, industry and academia. The goal of the workshop, and the resulting articles, was to reflect on the first 5 years of the visual analytics enterprise and propose research challenges for the next 5 years. The article incorporates input from workshop attendees as well as from its authors.

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Introduction

Typically, the goal of an analysis activity is to create new understanding and communicate it to others. Even if the audience is unknown, knowledge must generally be translated from the analyst's mind and the software environments he or she uses into a report that summarizes, to varying degrees of detail, the analysis process and results. These reports may use multiple media – typically text and image, but interactive components are also possible. The challenge for visual analysis tool users is to efficiently and effectively capture their analysis processes and findings, and represent these results in a compelling manner, to support the communication of knowledge between producer and consumer. The roles of producer and consumer are flexible, such that one who consumes a source report might create a derivative representation of it, and in collaborative environments, producer–consumer relationships can be recursive.

Creating effective representations of analytic findings that can be easily digested or contested is at the heart of the science of analytic reporting. Analytic accuracy depends on enabling analysts to create authoritative, useful representations of their work. In this article, we will review progress made toward the reporting recommendations in *Illuminating the Path*: *The Research and Development Agenda for Visual Analytics*,[1] discuss in detail the results of a Composition Workshop[6] held to begin clarifying the needs for next-generation visual communication technology and provide recommendations for the future.

Background

In the visual analytics research agenda, the major purpose in the chapter entitled 'Production, Presentation, and Dissemination' was to

outline the needs for new research in support of visual communication. The production, presentation and dissemination challenges focused on conveying analytical results rapidly and in meaningful ways to a wide variety of audiences, including peers, decision makers and emergency responders, and facilitating two-way communication with team members, including the public. The goal was to spur development of technology that supports the immediate communication of well-analyzed results in emerging and emergency situations.

Typically, advanced visualization and analytic tools remain separate from reporting tools. For instance, many analysts use word processing or presentation software to both capture content from analysis tools (for example, as screenshots and commentary), and later format it into communicable reports. Creating customized reports to meet user needs is time-consuming and difficult. More recently, some visualization tools have added 'export' functions that help move content such as views or data from the tool into a format that can be used as the basis for a report. While worthy advances, these capabilities are restricted to use in a single visualization system and do not accommodate the wide range of tools in use; moreover, they may inconsistently apply user preferences and report customization, leading to a lack of standardization in how reports are constructed and shared.

Review of Illuminating the Path recommendations

The production, presentation and dissemination vision is to achieve a seamless integration of reporting tools with the analysis process to produce timely outputs that are relevant to the target audience and that allow the audience to interact with the reports and their producers in new ways. *Illuminating the Path* identifies five research recommendations for production, presentation and dissemination. Modest advances have been made toward some of these goals, while others remain areas for high-value research.

Create systems that provide shared real-time situational awareness to teams of analysts

Visual analytics systems for the first responder community (such as Pike *et al.*[2]) have enhanced the ability of collaborating teams to collect and share information. However, such systems are typically constructed for synchronous collaboration and data sharing rather than the sharing of deeper analytic processes over long time periods. A central outstanding challenge that remains is representing the state of a team's collective knowledge.

Develop technologies that enable analysts to communicate what they know through use of appropriate visual metaphor and accepted principles of reasoning and graphic representation

Tools such as ProSPECT[3] have advanced the state of diagrammatic reasoning and uncertainty representation. Using such tools, hypothesis structures can be represented visually. Additional research in the links between visual representation and cognition, however, will ensure that reasoning aids use schemas that match those of their users as closely as possible – or better yet, employ flexible schemas that allow different users to express knowledge in different visual forms, yet map between them for ease of communication.

Create visual analytics data structures that support seamless integration of tools so that data requests and acquisition, visual analysis, note-taking, presentation composition and dissemination all take place within a cohesive environment

Little effort has been devoted to infrastructures that can connect the wide range of tools at an analyst's disposal into a seamless workflow. Some domain communities, notably bioinformatics, have advanced the state of workflow research such that distributed analysis components can be flexibly linked into provenance-preserving networks. The visual analytics community should look to these examples for inspiration in constructing standardized analytic architectures. Within the visual analytics community, Oculus has provided initial well-liked capabilities in this area. For example, their Sandbox allows colleagues to interactively review interim results, and final reports can be generated by moving selected elements to Microsoft® Office or by making an interactive final report in the Sandbox itself.[4]

Write a handbook for communicating risks in emergency situations

The National Visualization and Analytics Center™ (NVAC™) has been engaged in user studies and task analyses with first responder communities, particularly law enforcement, with the goal of producing widely shared handbooks on user requirements. However, these handbooks are designed for the research community, not to help end users create effective visual messages. As best practices and perceptual principles are established, they should be distributed both as written guides and as defaults in visualization tools.

Develop technologies that capture the results of an analysis, decision recommendations and first responder actions into information packages that can be tailored for each intended receiver

Recent research, notably Dou *et al.*[5] has focused on the problem of capturing analysis processes automatically, helping to free analysts from the burden of manually reconstructing their reasoning strategies during the reporting phase. This work was limited to a single domain, and it is still unclear whether there are general principles that relate events in a software application to insights generated by human analysts. Even if selected insights can be captured either automatically or with user input,

additional research is needed to determine how best to package these findings automatically. Can report skeletons be generated that reflect the major steps an analyst took, requiring him or her to merely supply additional details? How can summarization research and role-based user models be used to tailor information presentation to different users?

Composition Workshop Results

To successfully meet the need for rapid communication of analytical outcomes to diverse audiences, graphic design and rhetoric must be incorporated into report composition. In early 2007, a multi-disciplinary team was mobilized to accomplish this goal through a Composition Workshop,[6] which produced a report that laid out the necessary steps to achieve the vision and assessed their difficulty and resource requirements. The workshop participants drew a distinction between those visualizations useful for discovery and those for illustration; however, there was still a relationship that had to be explored. The most significant result of the workshop was an enumeration of eight major topics required to advance the state of visual reporting.

Topic 1: Best practices

To maximize their utility to the consumer, presentations of information acquired through analysis should follow best practices in utilizing visualization. The right choice of the type of visualization and the methods for clearly communicating through the depiction of data are a part of best practices.[7] A cooperative effort within the visual analytics community should be the articulation of these best practices and the promulgation of standards that give visualization developers a set of clear guidelines for display usability. These standards can also inform the representation choices given to end users, ensuring that the displays they produce for communication purposes are usable by their intended audiences.

Topic 2: Design automation

Most analysts are not experienced designers. While written composition is a staple of education, graphic design principles typically are not. The impact of design on engaging an audience and communicating effectively is not widely appreciated, and where it is appreciated, is not always widely practiced because of limitations in tools, training or time. Visual design, oral and mixed-media presentation and narrative skills (such as would be useful for creating videos to tell the story of an analysis) are not dominant cultural themes despite the increasing movement away from textual toward more visual and aural communication.[8]

Compounding the problem, many popular presentation creation tools do not do enough to help users make good design choices. There is enormous room for improvement in design tools that people use every day, including tools for oral presentation, document creation, graph and chart creation and report generation. Edward Tufte argues that 'slideware' tools in fact often weaken the analytical quality of presentations.[9] Because visual analytics asserts the importance of visual information in knowledge discovery and decision making, presentation techniques that preserve and enhance the visual impact of communication are needed.

It is important that the visual communication principles that are the foundations of the graphic design community are translated into usable tools for nonexperts. Analysts who have no prior knowledge about what properties characterize good graphic designs or how design contributes to the clarity and usability of a presentation still need to communicate effectively. Tools that embody well-known design principles should be developed to support authors in the design process, helping guide them toward good choices. Educational curricula to teach design principles and the effects of different design choices, already part of design programs, should be translated into courses and practices for information analysts.

We can identify a pathway from simple to more sophisticated design support tools. The simpler tools would help authors improve their designs, for instance, when converting from one format to another within a presentation or for increasing or reducing the amount of information shown. These include ideas such as a consistency checker that evaluates the design consistency across different parts of a presentation or report. For example, such a tool might check that style and formatting parameters are consistent that alignments between elements are consistent and so on. In general, it will check that the design principles produce consistent effectiveness ratings across the entire report. Another example is an aesthetics checker that adjusts a design to correct problems that violate a culture's or an audience's notion of aesthetics. Switching from one format to another (for example, from a scientific audience to a business audience) requires changes in the style as well as the content of the presentation; however, switching from one predefined style format to another often results in small problems such as line-splitting, improper centering or figures whose background colors change and make the text unreadable; all of these problems may require time-consuming corrections. Another set of tools would provide suggestions for automated figure captioning and automated formatting of figures within documents to keep the visual material near the textual material that references it. More general automated layout tools could be especially helpful with multi-authored presentations.

More sophisticated tools would be applicable earlier in the design process. For example, design rules can lead to report templates that suit the task and audience. Another line of tools would make sophisticated

suggestions about how to convert content for different communication needs. As a particularly ambitious example, we can envision a tool that converts an analysis session into a framework written report or oral presentation. One can envision a language analysis tool that has a model of 'presentation grammar' and helps authors create effective reports for various communication modes.

Topic 3: Visual rhetoric

Visual rhetoric is the way visual images persuade the viewer. How images, text and interactive components interact in a report is an open area of research. When a news article contains both text and information graphics, what is the persuasive effect of each? When interactive exploration components are also provided, how do consumers create understanding as they move between text, image and interaction? It is critical to understand such details as the meaning of motifs, visual argumentation and the relationship between text and figures in discourse. The relationship between verbal and visual rhetoric is critical for the effective use of visual analytic results in presentation. Composition tools can help broaden the bandwidth of communication by enabling analysts to embed more interactive, dynamic components in their reports. Awareness of visual rhetoric should be part of the analyst's toolkit.

Topic 4: Context and audience

Presentations are valuable only insofar as they actually convey their meaning to their intended audiences. As such, presentations must be tailored to their audience by adapting to its cognitive capabilities, deficits and devices.

The primary research problem in this domain is that of 'adaptable presentations' – how presentations can be authored in such a way that they can be adapted to different situations, pulling in additional context that might be required (for example, from web services), and adapting to different output devices and viewing situations. A secondary research problem is determining what a particular viewer's needs might be. This determination may be accomplished by assessing the viewer's comprehension of previous presentations based on statements made or questions asked during and after the presentation. Perhaps a profile of the viewer could be assembled on the fly or the viewer could be allowed to explicitly control parameters of the presentation. We will know that we have achieved something significant in this area when tools and reports actively bridge the presentation and the viewer's understanding of the topic area.

Topic 5: Analysis to presentation

Analytic tools support the discovery of insight. A presentation conveys this result with supporting evidence to a particular audience. Characterizing the difference between the path of arriving at the result and the presentation of an argument for the result will provide the theoretical underpinnings for the relation of visual analytics to presentation.

A scientist performs research to obtain a result but may alter the written account of the research to clarify it when reporting the result. For example, the scientist may have gone down useless paths or obtained negative results along the way to the reportable result. Those paths do not necessarily need to be included in the initial report of the result to the broader scientific community. They may only be communicated to colleagues or students for educational reasons.

The same is true in using visual analytic software to arrive at an analysis of a body of data. Some paths along the way are worth retelling and will be part of convincing an audience of the validity of the analysis. Some paths will not be valuable to the audience in assessing the result. Sometimes the analysis path is a part of what will be presented in a structured presentation; however, often it will not be helpful to the audience.

Another characteristic of visual analytic software is that the visualizations can contain more data than is needed for a presentation. The presentation must guide the audience's attention through the data, emphasizing what the producer deems important but allowing the consumer to still explore its context. In the future, visual analytics systems' output should be in a format that allows editing or the software should have built-in presentation support.

Topic 6: Evidence and argument

Keeping track of the confidence and strength of evidence, change in evidence and the relationship between the evidence and the argument have been achievable since the early 1980s; however, visualization tools and explanatory logical techniques such as natural deduction are more current and provide an impetus for improving presentations and making them dynamic. In addition, the evidence-analysis-collection chain can be automated to allow quick response to situations.

In studying human reasoning, it is instructive to look at the range of logics needed to represent the content of linguistic expressions. Although there is much unsaid in a discourse, there is also much that is packed into it because each speaker not only has a shared context but also knowledge of the full language. Speakers and writers rely on both to communicate their point. Analysts must also be able to express their analysis results clearly. Providing a reasoning environment for performing the analysis will also support the clear communication of the results.

For instance, the work of Byrnes *et al.*[10] on proof presentation illustrates the need for the integration of reasoning and presentation. The desiderata of a presentation of the reasoning, that is, the proof or the explanation, has both machine- and human-centered value. The most common

solution to machine reasoning is to use resolution and ignore the presentation to the user. Byrnes' novel solution was to study the structural properties of natural deduction to create an algorithm suitable for automation directly in natural deduction. Such an approach lends itself more readily to user–consumable presentations.

More extensive research in the area of argumentation and cognition would improve multimedia presentations. User studies of deployed products would quickly suggest improvements. Deeper research into the automation of logics that approximate human reasoning would have longer-term effects on the ease and quality of argumentation and its presentation.

Topic 7: Collaborative environments

Collaborative shared-data environments, such as Intellipedia, have shown tremendous adoption and potential in the intelligence community, and more broadly, collaborative authoring tools are seeing wider deployment. New advances in information-centric, collaborative visualization environments as demonstrated in the Army's Command Post of the Future (CPOF) program offer tremendous opportunity to create new cooperative environments for analysis and presentation. Such systems exploit shared information spaces and rich visualization capabilities in a novel 'shared work product' metaphor, allowing users to perform analysis and share visualizations and workspaces with one another.

Collaborative authoring environments, such as Wikis, work because of fast, easy contribution, evolution of others' content, easy linkage to other content and revision control. Extending the Wiki format with information-centric visualizations and direct manipulation techniques can introduce new 'deep collaboration' capabilities:

- Information is shared in real-time and continuously at multiple levels of abstraction with users in distant locations, both synchronously and asynchronously.
- Users are able to abstract, organize and extend data from feeder systems, structuring source documents into knowledge.
- Data become liquid, moving seamlessly among all users' analysis tools across all visualization and analysis contexts.
- All systems are inherently collaborative – no separate collaboration tool is required – allowing analysts and decision makers to concentrate on their work, not driving multiple separate software systems.
- Expressiveness, immediacy and understanding of face-to-face communications are combined with the depth of knowledge afforded by data-rich tools.
- Results are presented in an evolving knowledge-rich environment that offers a 'better than being there' experience.

New analytic reporting techniques can spur 'stigmergic collaboration,' where users' visibility into each other's work products allows participants to anticipate the needs of others. Seeing another's results can prompt an analyst to refine his or her own thinking, perhaps updating his or her own products in response. In essence, work products become continually evolving, cooperatively constructed resources. Even in solo activities, preserving analysis strategies for collaboration is important; indeed, all analysis is collaborative, even if that collaboration is simply with one's future self.

There is tremendous potential for collaborative analysis, composition and presentation in such environments. Presentations can be given to large audiences distributed across space (and time). Analysts can act as 'native guides' to lead decision makers through complex problem domains, data spaces and reasoning chains.

In such environments, analyses and presentations are live visualizations reflecting the current state of information, allowing audience members to drill down into details of the data or presentation structure for supporting information. Presentations occur in a live environment allowing audience members to explore detailed supporting information. They could allow audience contribution, turning presentations into a two-way dialog. Other analysts can share their impressions and annotations, which allow adding supporting or contradicting evidence.

Topic 8: Interactive and dynamic documents

Documents need to be represented with an internal structure that supports interaction and changes. The evidence that supports the arguments or the data that were interpreted need to be accessible to the reader and the writer from within the document. The evidence needs to be linked to the presentation to allow reach-back and alerts upon updates. Accessibility to the linked structures must be controlled by permissions for security and privacy purposes.

Rather than compose static documents at the end of a work session, the authoring process, if tightly coupled to analytic tools, can allow analysts to embed live visualizations into their reports. These interactive components can allow the consumer to 'see what the analyst saw,' evaluating the quality of the findings directly and even exploring the data for alternative hypotheses.

Toward New Reporting Models

NVAC has sponsored research on Active Products that attempts to respond to many of the above production, presentation and dissemination challenges. The Active Products environment is intended to provide an example of what future reporting environments could look like. The aims of the Active Products approach are to enable rapid authoring, reduce the amount of time that might be spent reconstructing earlier work during the reporting

phase and craft new modes of presentation that are more tightly coupled to analysis tools themselves.

These products are designed with four characteristics in mind. First, products must be auditable; they need to carry with them provenance information that reflects not just the origin of source data but the analytic operations that were performed over it and the background knowledge that the analyst brought to the task. Second, products must be dynamic; as data, or analysts' confidence in it, change, products should update automatically so that recipients of the updates are assured that they are working with the most up-to-date analysis. Third, products must be interactive; to support evaluation and reuse of analytic strategies, products should contain live visual components so that consumers can better understand – and have the tools to challenge – others' findings. Fourth, context sensitivity should allow products to take different forms customized for their audiences, from actionable alerts for first responders to longer reports for policymakers that articulate the full reasoning behind hypotheses.

Collecting, authoring, and disseminating analytic content

To create analytic reports with these characteristics, NVAC is developing new technology in three areas: collection, authoring and dissemination. For reports to become dynamic resources, analysis tools need to be their users' partners in the production of report content. The Active Products 'collection widget' is a desktop sentinel that can connect to existing analysis tools and enable the capture of high-value analytic snippets. A snippet is a small piece of digital content that describes both an information unit (such as a piece of evidence) and the discovery processes that were used to find it. Snippets contain automatically generated provenance information about the analysis steps that the analyst took. An initial 'snippet specification' is being developed that will allow any third-party tool to generate these snippets in a form that can be included in smart reports. This specification enumerates both the metadata elements that describe a snippet (such as the source application, user, time of capture and so on), as well as the snippet content itself (the 'view,' which could be text, visual depiction or other representation), and provenance information that lists the interaction steps the user took to construct the view. Snippets can be as simple as clips from a web page, in which case the provenance information captured would include the sequence of links followed to reach the source of a clip. In the case of a visualization application, the analytic provenance sequence would include the chain of application events from loading of data to marshaling it into a view that reflects an insight-generating moment. Currently, users of the Active Products system are required to manually capture snippets, dragging content from their tools onto the collections widget. Research is needed in automatically identifying user insight and capturing relevant content from analysts' tools without their intervention.

Once snippets have been collected from analysis tools, the analyst must organize them into a report. The Active Products authoring environment lets the analyst focus on his or her story, crafting a message from the snippets collected along the way. Because this material has been captured as she worked, the process of organizing and refining it is much easier because she does not need to reconstruct her analysis strategies. A web-based editor (Figure 1) allows the analyst to associate the snippets she has collected (left side, boxes marked A and B) with passages in a document (center, box marked C), and she can tag the relationship with the precise role that the snippet plays in her argument. A consumer reading the document can follow passages that reference snippets all the way back to the source application used to generate them.

Documents created in this editor can keep track of the relationship between analytic steps (as represented through the snippets an analyst has collected) and components of the discussion contained in a report. Readers of these reports have access to this provenance information, allowing them to evaluate reports more effectively.

Finally, products created in the authoring tool can be transformed into various presentation modes using style sheets. Typical formats might include text documents, web pages, slide sets and mobile messages. Transformations for common distributed editing environments, such as MediaWiki, are also possible. Access rules can be placed on these media, controlling the degree to which recipients will be able to interact with them and drill down to underlying data. Products can be transformed into new formats on the fly as they are disseminated, reducing the burden on the analyst to customize them manually.

To be truly effective, community involvement is required to make new reporting paradigms a reality. The full range of tools available to an analyst needs to cooperate in report production. Rather than force tool developers to each implement their own publishing mechanisms (which is undesirable from the user's perspective), an ecosystem of cooperating providers for Active Product content is needed. The larger the number of visual analytics tools that are 'Active Product compatible,' the more rich interactive content can be embedded in new reports.

Recommendations for the Future

The topics described in the Composition Workshop Results section, which were defined by the creative and enthusiastic participants of the workshop, remain largely unexplored; only measured steps toward their accomplishment have been taken. Perhaps because the challenges of production, presentation and dissemination have been perceived as primarily engineering topics, the visual analytics community has devoted few resources to them. However, analytic reporting is more than an 'export to PowerPoint' capability (and even that would

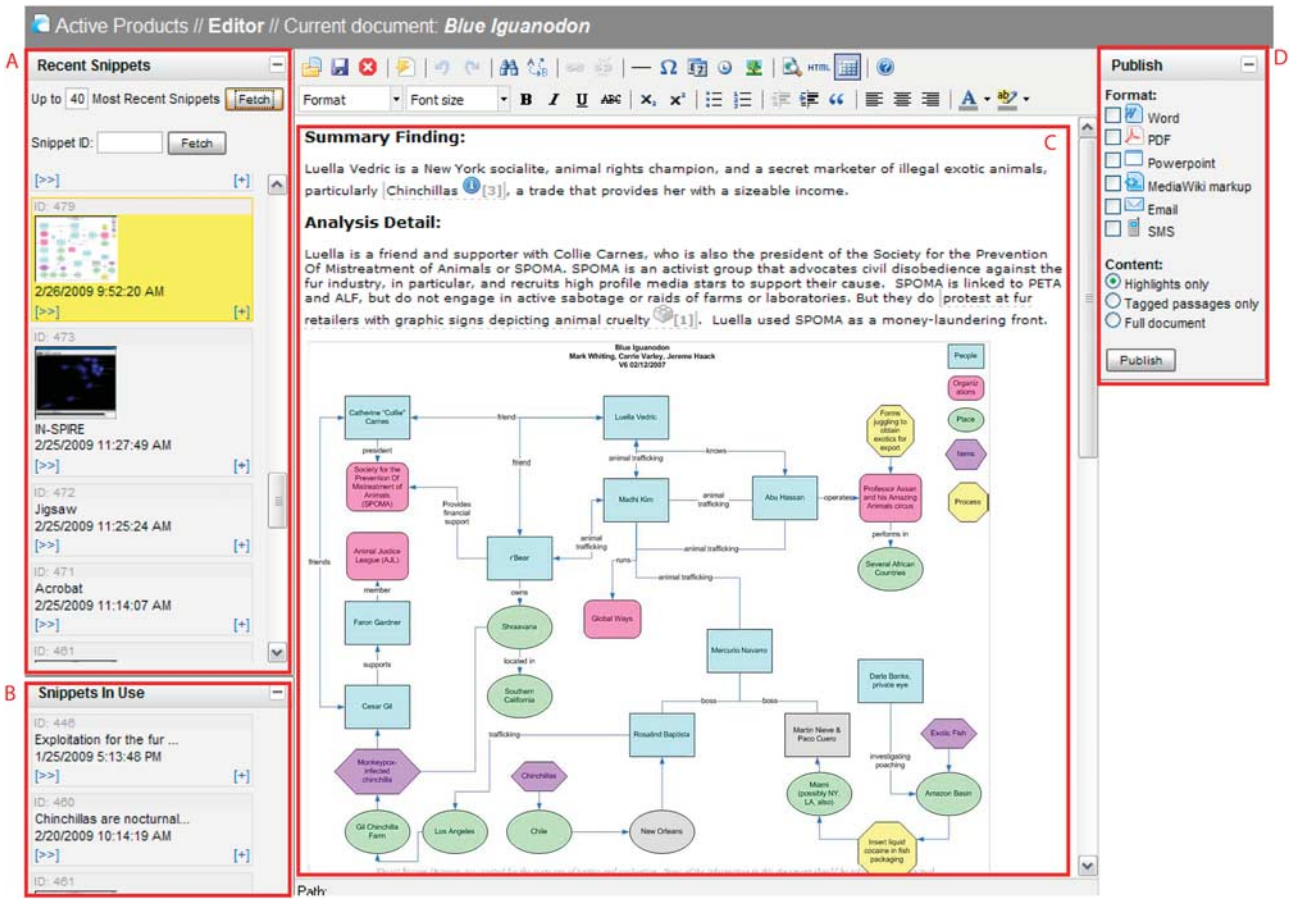

Figure 1: The Active Products authoring tool allows users to associate snippets (area A) with passages in their documents (area C). A running list of the analytic snippets that have been incorporated into a report is shown in Area B, allowing consumers to quickly identify analytic content that is accessible from a particular document. Reports can be published into different formats (area D).

raise difficult issues of summarization and translation of a nonlinear analytic process into a linear narrative). There are key research needs that require deep and prolonged exploration. How can analytic provenance be captured transparently? What are the principles of visual rhetoric and how can these be embodied in analysis tools? What interface design strategies can lead to tools that can migrate between analytic and presentation modes seamlessly?

Our experience with practitioners has indicated that the analyst community has become more aware of the needs in this area as other visual analytics successes have been deployed. As more sophisticated analytic capabilities are made available, the relative lack of sophistication in reporting capabilities is made all the more apparent. More importantly, the change in the communal use of the internet and technologies that make visual production easier have led to an overwhelming impact of visual media on analysts' daily lives.

Methodologies have been developed for the analysis of visual persuasion both in terms of the message and the originator and audience effects.[11] New methodologies in asking questions, framing and viewing analysis as narrative are being widely taught in the intelligence community. Analysts are increasingly using visualizations in products and are increasingly interested in developing best practices. The examples of visualization usage in the documentary *An Inconvenient Truth* have shown the rhetorical power of effective information graphics.

Within operational organizations, systems engineering groups have become open to change and open to analysts' needs to communicate successfully. New architectures are being developed that use web services and lightweight applications for creating mash-ups and improved working environments for analysts. Even so, analysts still have better communication systems at home than they do at work; management and sponsors have realized that major changes need to be made to retain younger analysts, and these changes include new ways of collaborating and sharing the results of their work. More workplace cultural change is still necessary. Consumers of analysis

need to be more savvy as to what is reasonable to demand of a presentation, and presenters need to be more willing to please consumers by showing them what is possible to provide if the technology is stepped up a notch.

We believe that the vision and substance put forth in the original research and development agenda along with the intervening workshop results should form the basis of a major program for funding by the government. The visual analytics community has matured sufficiently and has agreed upon common aims such that it may be ready to make the necessary changes to its tools and methods. It is critical for the visual analytics research community to develop techniques that support the differing aims of analytic visualization and report illustration. Just as the student learning to analyze visually persuasive media is taught to produce visually persuasive videos themselves, it is important for visual analytics to move into the generative mode as soon as possible. Better support for the end-to-end process of analysis, including the effective communication of analytic results, will cement visual analytics as a cornerstone of knowledge discovery.

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