Chapter 1

Introduction

Make analytic provenance a chosen approach rather than a default one, so only introduce sensemaking

Introduce to sensemaking

sensemaking here doesn't only apply to interactive exploration of data using visualization/visual analytics systems; it also includes browser-based online sensemaking of everyday tasks as our last two papers

Challenges in support sensemaking

1.1 Research Problem and Approach

The overall goal of this research is to **examine how to support users in their sensemaking process**.

Introduce analytic provenance approach and why it's a potential direction. Also visualization.

Introduce the 3 fundamental stages of an analytic provenance pipeline: capture, visualize and utilize

The overall research problem is broken down into the following research questions, each maps to a stage above.

Elaborate each question and explain why it is challenging

1. **What provenance information has the potential to support sensemaking and how to capture it?**
2. **How to design interactive visualizations of the captured provenance to support sensemaking?**
3. **How can the visualized provenance be used to support sensemaking?**

This is to answer the question "How do you go about solving your research question?". Is there any methodological approach that is the same as what I have done?

We investigate both manual and automatic approaches in capturing analytic provenance. We develop visualizations to explore different aspects of the captured data including temporal, categorical, hierarchical, spatial and causal information. We characterize the sensemaking support into three processes in the sensemaking loop of PCM including schematization, case building and presentation. Finally, besides direct sensemaking support, we also examine whether and how can analytic provenance help one to understand the sensemaking process completed by others. The proposed solutions are designed and validated using the nested model proposed by Tamara Munzner [6]. We break down the work in each stage and combine them into a visualization system. Requirements – Design – Implementation – Evaluation. We choose two domains to target: intelligence analysis, which is the original context for Pirolli and Card's sensemaking model and online browser-based, which is more applicable.

make sure there's a strong link between the research problem/questions and subsequent chapters. Make it as explicit as possible so that readers know what come next and why

Missing figure

summarize what will come next and how they map/link to the research questions

1.2 Research Contributions

1.3 Thesis Outline

1. How do we structure the sensemaking support provided by AP?
   - the sensemaking loop in Pirolli – Card's model: schematize – build case – present
   - collect – curate – communicate

2. Where to include SM−VAST?
 – The case building (and a bit of presentation) support in SM−VAST and SenseMap is the same
3. Can the design requirements in SenseMap be generalized for the entire thesis?
4. Chapter structure and title
5. Is it all about information visualization rather than visual analytics?
6. Literature Review: what to include? things that not obviously related to SM and AP such as set visualization and qualitative analysis

– sensemaking
  – overview
  – PCM
  – DFM
  – sm on the web?
– visualization
  – overview
  – how vis can help support sm
– analytic provenance:
  – modeling
  – capture
  – visualize
  – use
– challenges, gaps in the literature and we're addressing them in this thesis.

Specific related work such as details of timeline/set vis and qualitative analysis put in corresponding chapters

7. It seems to me that the current SenseMap is quite incomplete with a few critical problems. So, I want to do a second phase to address them. Also, it will be easier for me to report in the thesis if I take the leading role in all major parts of SenseMap.

– bad window management: use two monitors?
– lost track:
  – make newly added nodes visible
  – regain awareness of recently added nodes since the last time looking at the history map?
  – show temporal information
– lost trust/reassurance: fix linking problem and cricitcal bugs
– suggested features: add a free note, a label attaching to a node/link

– support more communication?

Table 1.1: Analytic provenance in my work.

Name	Capture	Visualize	Support
SchemaLine	manual note	aesthetically pleasing yet compact **timeline**	– interactive temporal schema construction from user notes – interaction for sensemaking activities in DFM
SM-VAST	manual finding, able to revisit, multiple sources	**node-link** diagram	– auditability (revisit captured vis) – overview and replayability of the sensemaking process – hypothesis generation: users to assign supporting and contradicting arguments – interactive narrative construction – collaborative sensemaking (both sync. and async.)
TimeSets		timeline with **set** relations	
SAVI		TimeSets to show tweets, findings(?)	
SenseMap	auto actions with semantic extraction	– **tree** for auto collection – node-link diagram for curation	– collection: overview of the process, relevance assessment – curation: spatial organization, casual relationship, reasoning – communication: complete picture, raw data, varied audience, share
SensePath		timeline of actions with type and duration (compact **time**/**set**)	– help understand the sensemaking process of others – support transcription and coding in qualitative data analysis

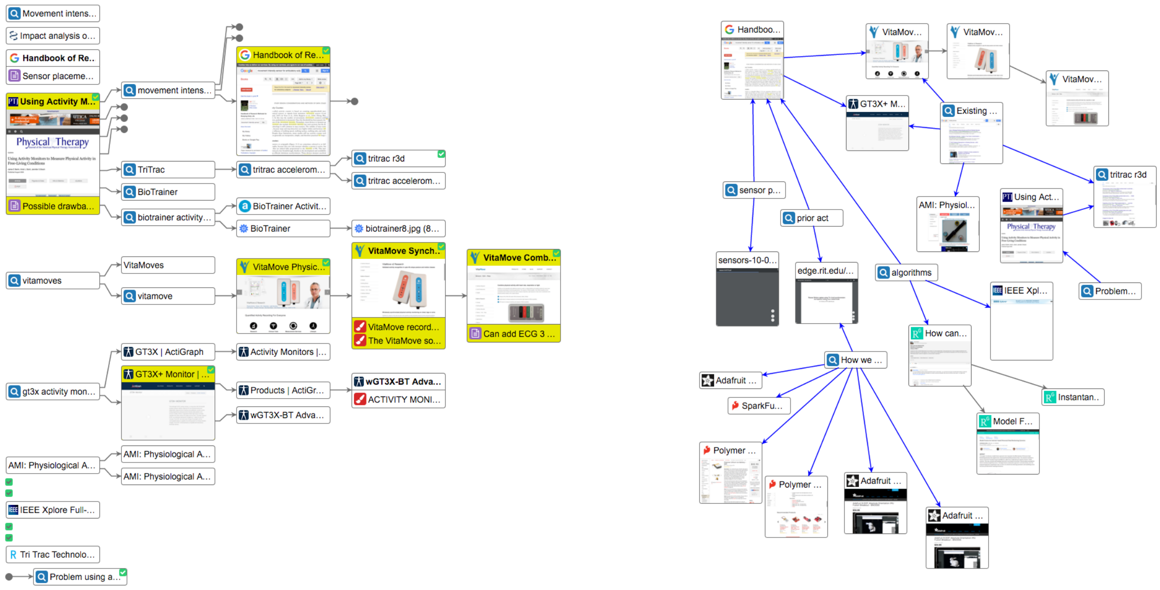
Table 1.2: An analytic provenance approach to support sensemaking.

Capture	Visualize	Support
– manual highlight/note – manual finding, able to revisit, multiple sources – auto actions with semantic extraction	– aesthetically pleasing yet compact timeline – timeline with set relations – hierarchical – spatial – causal	Schematization – temporal schema (SchemaLine) – temporal/categorical schema (TimeSets – **not used to show findings yet**) – hierarchical schema (SenseMap – History Map) – spatial/causal schema (SenseMap – Knowledge Map) – interaction for sensemaking activities in DFM (**only in SchemaLine**) Case Building (both SM-VAST and SenseMap) – hypothesis generation: users to assign supporting and contradicting evidence – hypothesis verification: access raw data – alternative hypothesis: access live data allowing trying different things Presentation – interactive narrative construction (both SM-VAST and SenseMap) – complete picture, varied audience (multiple level: result – process – data), share **ALL** – auditability (revisit captured vis) – overview and replayability of the sensemaking process (SM-VAST) and the data exploration process (History Map) – collaborative sensemaking (both sync. and async.) **OTHER** – help understand the sensemaking process of others – support transcription and coding in qualitative data analysis

Chapter 2

SenseMap

Sensemaking is described as the process of comprehension, finding meaning and gaining insight from information, producing new knowledge and informing further action. Very often, users get lost when solving a complicated task using a big dataset over a long period of exploration and analysis. They may forget what they have done, are not aware of where they are in the context of the overall task, and do not know where to continue. In this paper, we introduce a tool, *SenseMap*, to address these issues in the context of *browser-based online sensemaking*. We conducted a semi-structured interview with nine participants to explore how they search, manage, and synthesize online information for their daily work activities. This was followed by a series of design workshops to walk the user scenarios, generate design questions, and formulate solutions relating to user interactions, tool features and manifestation. A simplified model based on Pirolli and Card's sensemaking model is derived to better represent the browser behaviors we found and to guide the development of design requirements: users iteratively *collect* information sources relevant to the task, *curate* them in a way that makes sense, and finally *communicate* the findings to others. SenseMap automatically captures a user's sensemaking actions, i.e., *analytic provenance*, and provides multi-linked views to visualize and curate the collected information, and communicate the findings. To explore how SenseMap is used, we conducted a user study in a naturalistic work setting with five participants completing the same sensemaking task related to their daily work activities. Most of the participants found the tool intuitive to use. It helped them to organize information sources, to quickly navigate to the sources they wanted, and enabled them to effectively communicate their findings. A process model is also derived based on both quantitative and qualitative data analysis.



(a) History Map: visualizes captured user sensemaking actions to provide the overview of the sensemaking process.

(b) Knowledge Map: curates and makes sense of the most relevant information to the task.

Figure 2.1: SenseMap interface.

2.1 Introduction

Sensemaking is described as the process of comprehension, finding meaning and gaining insight from information, producing new knowledge and informing further action [9]. Very often, users get lost when solving a complicated task using a big dataset over a long period of exploration and analysis. They may forget what they have done, fail to find the information they have discovered before, and do not know where to continue. One approach is to capture and visualize user interactions in such a way that provides an overview of the sensemaing process to the user. The information that describes such interactive data exploration and the human reasoning process that accompanies it is termed *analytic provenance* [8, 11].

In the World Wide Web context, the aforementioned problem is known as the *disorientation* problem [3]. One approach to address this problem is through a graphical browser history [1, 4, 5]. It visualizes visited web pages and the linking relationships among them to help users to quickly see where they are in the network and to navigate to the page they want. However, when solving a sensemaking task online, which requires gathering, restructuring and reorganizing lots of information to gain insight, the disorientation problem becomes more severe and difficult to address. They do not just get lost in the hypertext space but also get lost in the task space. What has been done so far? Where am I in the context of the overall task? What information should I search for next?

In this paper, we introduce a tool, *SenseMap*, to support *browser-based online sensemaking* through analytic provenance. We targeted this domain because many everyday sensemaking tasks such as travel planning, are now performed online [10]. To explore how users search, manage, and synthesize online information for their daily work activities, we conducted a semi-structured interview with nine participants and observed their web browsers. Then, a series of iterative design workshops were conducted to walk the user scenarios, generate design questions and formulate solutions relating to user interactions, tool features and manifestation. We derived a model simplifying the sensemaking model proposed by Pirolli and Card [9] to better represent the browser behaviors we found and guide the development of design requirements: users iteratively *collect* information sources relevant to the task, *curate* them in a way that makes sense, and finally *communicate* the findings to others.

Based on the elicited requirements, we develop the SenseMap tool consisting of three components: a *Browser View* that is a standard web browser with additional sensemaking support, a *History Map* that provides an overview of the sensemaking process, and a *Knowledge Map* that allows users to curate the collected information. Communication is made possible in all three components.

To explore how SenseMap is used, we conducted a user study in a naturalistic work setting with five participants completing the same sensemaking task related to their daily work activities. Both quantitative data about user activities with SenseMap and qualitative data through semi-structured interviews were collected. Most of the participants found the tool intuitive to use. It helped them to organize information sources, to quickly navigate to the sources they wanted, and enabled them to effectively communicate their findings. A process model is also derived based on data analysis

SenseMap is freely available as a Chrome extension [1]. In summary, our main contributions are:

1. A user study exploring how users search, manage and synthesize online information for their daily work activities; and a series of workshops followed up to generate design questions and formulate solutions.

[1]https://chrome.google.com/webstore/detail/sensemap/agljnpanahlilmpipaeflmnjkiiecfjb/

2. A visual analytics tool SenseMap supporting browser-based online sensemaking addressing all the requirements above.
3. A user evaluation exploring how SenseMap is used in a naturalistic work setting and a process model derived from the data analysis.

2.2 Design Research and Requirements

2.2.1 Design Research

We conducted a semi-structured interview with nine participants to explore how they search, manage and synthesize online information for their daily work activities. We took video of each interview with the camera showing the interviewee's laptop screen and their hand gestures. We also made screen recordings of each laptop while the interview was taking place.

The semi-structured interview was designed to elicit behaviors exhibited by the participants when conducting online sensemaking. Each interview began with the general question: "*How do you search and what to you do with the information that you have found?*". Subsequent probes were used to focus the ongoing conversation into six browser functions, which were then used to tag the videos: browser choice, starting searches, tabs, windows, bookmarks, and history. The user behaviors associated with these functions were used to elicit their sensemaking approach and strategy, which informed the design requirements for SenseMap.

Starting Searches Opening a new tab preceded most searches. Users spoke about managing information, keeping things separate and the ability to go back to other pages that were relevant to their work activities and ongoing investigations.

Tabs Eight of the nine participants had a number of tabs open and categorized them as either: collections of tabs relating to current investigations or single points of access to commonly accessed services, e.g. social feeds, email etc. In further probing about the tab collections a number of shared behaviors emerged.

1. Opening a new tab if "significant" information is found enabling the page to stay live in the browser.
2. Opening Google search result links in a series of new tabs from one search page. Subsequent tabs were reviewed and then kept or closed based on their significance.

3. Reordering tabs to develop a narrative. In all cases the narrative was described as flowing from left to right. The narrative was used by the participants to make sense of the information found, to develop more refined search strategies and terms where information was lacking, and to communicate their findings to others.
4. All participants expressed anxiety about losing tabs when they were inadvertently closed or lost due to a system error and they all described the same recovery procedure using the recently closed tabs section of the History menu.
5. The number of tabs in browser windows varied greatly across the participants. One participant diligently closed all tabs at the end of each "work episode" although sometimes they kept them open in a non-active window when at home and used a new window for domestic/private web browsing. Most described groups of seven to eight tabs that were currently in use for active projects. One user had over fifty tabs open in their main browser and twenty in their second browser, but they gave the same explanation for their presence, use and organization.

Windows Only one user described the use of more than one window in the web browser. This behavior (described in 5 above) enabled them to keep active work related tabs separate from domestic/private browsing.

Bookmarks There was considerable variance in the use of browser bookmarks although most had moved away from using them and relied instead upon tabs to keep relevant information live and accessible. Two participants had no bookmarks at all. One participant saved some bookmarks, but these were not organized into groups, categories or folders. One participant described a behavior where they bookmark the contents of tabs at the conclusion of a project and organize these into named folders. However, they rarely revisited these bookmarks to use them to access information again, instead preferring "Pinterest" or relying on Google to find it again from a search term.

History None of the participants made use of the history menu to revisit pages or to make sense. However, all participants used it to reestablish a tab if it had been inadvertently closed.

2.2.2 Model and Design Requirements

We followed the video interviews with a series of iterative design workshops to walk the user scenarios, generate design questions and formulate solutions relating to user interactions, tool features and manifestation.

We began by searching for an existing sensemaking model that would represent the browser behaviors as described and guide the development of design requirements. The "sensemaking loop" for intelligence analysis by Pirolli and Card [9] provided an excellent fit.

The model's two major loops effectively encapsulate the observed tab behaviors:

- The Foraging Loop: behaviors 1 and 2
- The Sensemaking Loop: behavior 3

Behaviors 4 and 5 indicate possible tool features rather than a step described in Pirolli-Card model.

The synthesis of our observed behaviors with the Pirolli-Card model indicates a browser-based sensemaking process, during which information sources are held in a *collection* of browser tabs [Foraging Loop], with each tab containing the provenance for the source. An ongoing *curation* process takes place [Sensemaking Loop] where tabs are ordered into categories and a narrative sequence unfolds within such categorized groups. These groups and relationships represent the underlying schema. The results of the curation is then used to guide further more refined searches and, on completion, as a support to *communicate* the findings to others. Our process model for browser-based sensemaking became:

The model led to the following requirements.

2.2.2.1 Collection Requirements

1. **Provenance visualization**: enrich and make the provenance of information sources more visible to users. Currently, the provenance of tab contents is only accessible when the tab is active and then only by a list of page titles (press and hold browser back button), which requires the user to build their own schema that is external to the browser.
2. **Easy revisitation**: ensure information sources are organized and saved; also, allow quick and easy revisitation. Currently, tab contents are represented by a favorite icon and a truncated page title, which is a poor abstraction from the original source. This abstraction becomes poorer as more tabs are opened.

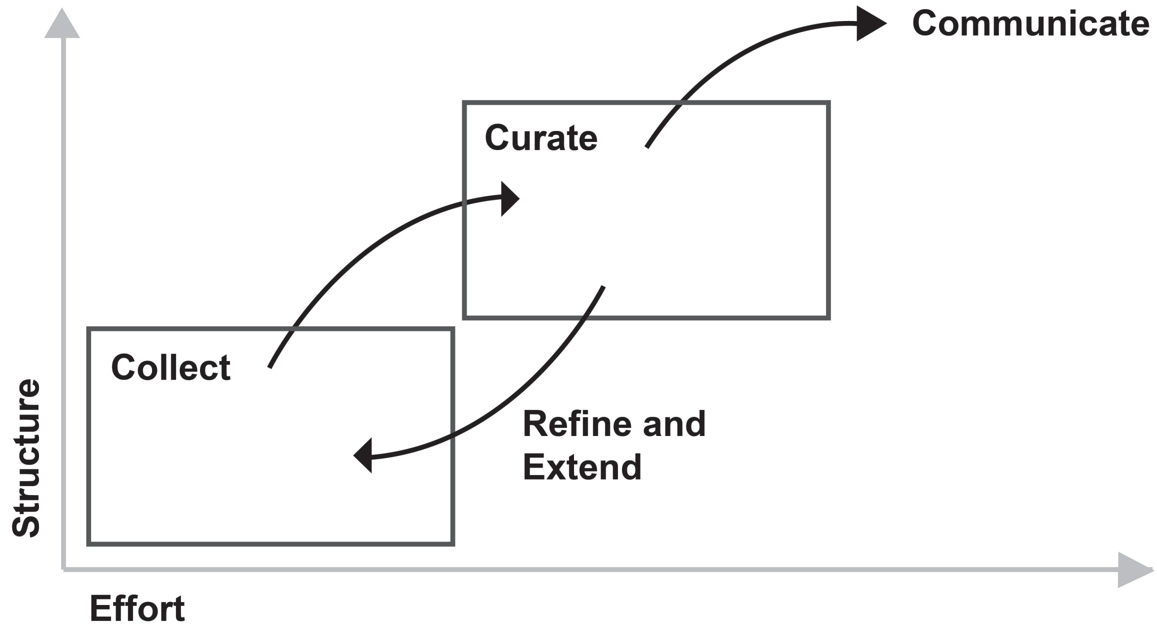


Figure 2.2: Our refined sensemaking model for user behaviors on the web.

3. **Location awareness**: provide a good overview of the sensemaking process. What has been done so far? Where am I in the context of the overall task? Where may I go next?
4. **Preparation for curation**: enable quick relevance assessment of the information source and represent with different levels of richness depending on the relevance.
5. **Interruption & Separation**: enable task switching without compromising the collection process.

2.2.2.2 Curation Requirements

6. **Rich representation**: provide a rich abstraction of the information source allowing the user to quickly recognize it. This also relates to the "Easy revisitation" and "Location awareness" requirements for Collection.
7. **Free movement**: enable users to freely arrange information sources in both x and y dimensions to address the limit of a one-dimensional sequence of tabs.
8. **Causal relationship**: enable further curation of these sources by establishing links.

9. **Reasoning**: enable users to apply their reasoning strategies such as using supporting and counter evidence, or alternative hypotheses.
10. **Collection – Curation**: enable users to see connections between the curated and collected sources, and to use these to inform further searches.

2.2.2.3 Communication Requirements

11. **Complete picture**: provide a complete picture of the curated sources and the relationships that a user ascribes to them via their curation activity. Currently it is difficult to see an overall picture of the curated sources and their categorization from the sequence of tabs.
12. **Raw data**: enable users to use these sources and the relationships that they have ascribed to them to communicate their findings using both the curated picture and by accessing the original sources.
13. **Varied audience**: enable users to customize the curated set of information to suit various needs and backgrounds of the audience.
14. **Share**: enable users to share both raw and curated sets of information with others.

2.3 SenseMap

2.3.1 Design

Considering all the requirements listed above, SenseMap needs to:

1. Capture web pages that the user visited, the sensemaking actions that happened there, and how the user arrived at those pages.
2. Visualize the captured information in such a way that the user can understand what they have done, how things are connected, and what else they may do next.
3. Support the user to curate the collected information according to its relevance, facilitate their reasoning, and communicate the findings. Also, this should not interfere with the original relationship among collected information so that the user can always use it as a reference.

2.3.2 Overview

SenseMap consists of three views:

- A *Browser View* that is a standard web browser with additional sensemaking support and provenance capture of actions happening there
- A *History Map* (Fig. ??) that shows captured sensemaking actions with their page linking provenance while preserving their temporal order as much as possible to provide an overview of the sensemaking process (Point 2 above).
- A *Knowledge Map* (Fig. ??) that allows users to curate the collected information. This map is separate from History Map to preserve the semantic, temporal structure of the captured information (Point 3 above).

Communication is made possible in all three views. Fig. 2.3 shows the relationship between the views and the supports they provide.

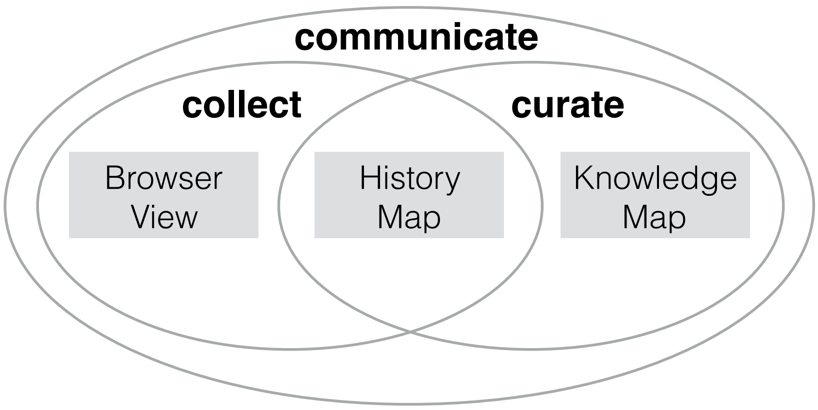


Figure 2.3: Three views and their supports.

2.3.3 Browser View

This is a standard web browser with the following additional features.

2.3.3.1 Sensemaking Support

Highlighting and annotation are essential editing support. They allow users to mark relevant/important information and to assign their own interpretation to the reading material (Requirement 4). A new option “Highlight” is added to the context menu when a passage of text is selected allowing the user to highlight it. That text becomes clickable enabling the user to either write a note or remove the highlight.

When a web page is visited, SenseMap takes a screenshot and use it to represent the page in the history map (Section 2.3.4). It is intended to help the user quickly recognize web pages that have been visited (Requirement 2). However, that screenshot may not reflect perfectly the main content of the web page, especially when it contains lots of text. To address this issue, we allow the user to assign a custom representative image to a web page. This can be done by simply right-clicking on any images in the web page and select "Set as Page Image" option in the context menu.

2.3.3.2 Provenance Capture

To be able to provide an overview of the sensemaking process (Requirement 3), the following aspects of actions are captured:

Type: We used the action type taxonomy described in SensePath [7]. The default action when the user opens a web page is *browsing*. More specific action types are *search* and *filtering*. Actions captured when the user reads a web page include *highlighting* and *annotation*.

Timing: This is the time when an action happens.

Context: The contextual information provides additional clue when looking at individual actions. It varies according to its action type such as the keyword for search and the selected text for highlighting. Also, title, URL, favorite icon, and a screenshot of the rendered web page are always recorded as part of the context.

Relationship: If a web page was opened by clicking on a link in the previous page, this source is captured.

2.3.4 History Map

This map provides an overview of the sensemaking process using the captured actions and their provenance (Fig. **??**).

2.3.4.1 Visual Representation

An action is represented as a bar with an icon indicating its type and a text for the contextual information. Icons help users to recognize action types faster and we use the same icon set as shown in Fig. 2 of the SensePath paper [7]. If the action type is the default *browsing*, the favorite icon of its web page is used instead. The contextual text is important to understand what the action is about and it is truncated up to a certain length because of the limited space. Fig. 2.4 shows an example of a keyword search action.

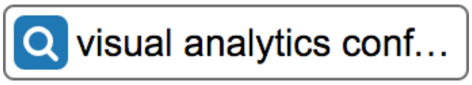


Figure 2.4: Action bar for a search with keyword "visual analytics conference".

Highlights and annotations of the same web page are grouped together as in Fig. 2.5. They are placed in separate rows below the web page title. By default, just a few highlights and annotations are shown to ensure a reasonable height for the page. All of them can be revealed using a menu available when hovering on any highlight or annotation.

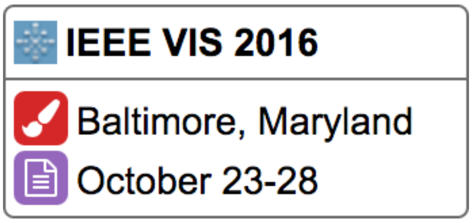


Figure 2.5: A page with one highlight and one note.

To help provide a connection between the history map and the browser view, the action bar corresponding to the active browser tab is highlighted with cyan color. Pages that have been opened but have not seen yet (could be the result of opening links in new tab) are shown with a dashed border, which may help remind the user on reading them. Fig. 2.6 shows an example of pages with those two states.

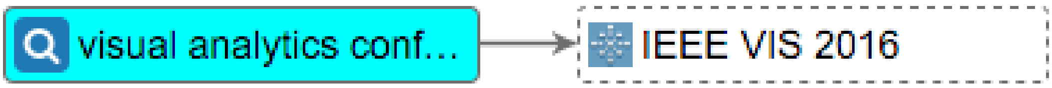


Figure 2.6: The user is active on a search result page (left bar) and opens a link in a new tab (right bar).

2.3.4.2 Layout

Seeing the provenance of a web page is important to the user. Currently, it can only be seen if the user presses and holds the browser's back button. This features is not even available if a page is open in a new tab. In the history map, linking relationships between two pages are always visible and illustrated by an arrow pointing from the source to the target (Fig. 2.6). For example, if the user clicks on a link in page A yielding to page B, an arrow from A to B will be added to show this relationship. Showing links among pages can reveal branching structures such as when multiple pages are opened in new tabs from the search result page. This provides richer provenance information and easier access for the user compared to the current browser support (Requirement 1).

Technically, all pages and links in the history map form a *forest*, where tree roots are pages that do not have a parent page including search actions or pages opened by entering the URLs manually. Temporal information of sibling pages are indicated by the order of them: earlier opened pages are placed above later ones. This also helps to maintain the mental model for the user about their process: the order of pages are never changed; and a new page is added either on the right side of the page triggering its opening or at the bottom of the map when such linking does not exist. A virtual node is then added and connected to all tree roots to form a single tree. We use the compacted tree layout in *jgraph* library [2] to produce the location of pages (Fig **??**).

Temporal information shows the order of actions the user has taken, and the branching/linking information reveals their semantics. At a lower level, highlighting the active tab in the layout as described above helps the user know where the page they are focusing is in the context of the overall process. Both these supports address Requirement 3.

2.3.4.3 Preparation for Curation

History Map displays all captured actions; however, probably not all of them are equally important and relevant to the sensemaking task. Therefore, it is necessary to allow users to assess the relevance of the collected information. We use the term *node* to refer to either a simple search action bar or a page containing many highlights. Three levels of relevance are provided, all through the menu available when hovering a node.

1. If a node is completely irrelevant, the user can *remove* it.
2. If a node is not quite relevant but the user wants to keep it to have a look at some point, they can *minimize* it.
3. If a node is very relevant, the user can *favorite* it.

[2]https://www.jgraph.com/

When a node is removed, it and all links connecting to it are simply removed from the map. When a node is minimized, it is collapsed into a small circle. This allows the user to focus on other nodes and also helps in saving the display space. Favorite nodes are displayed with a yellow background and a thumbnail of the captured screenshot to increase their recognizability. Fig. 2.7 shows an example of minimized and favorite nodes.

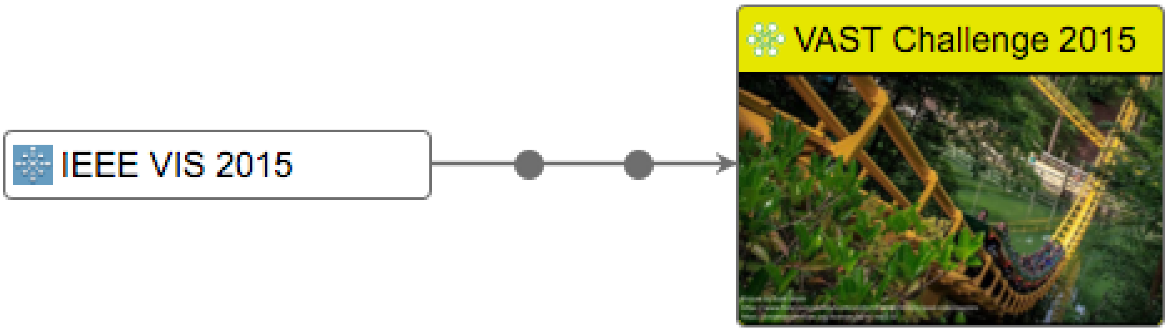


Figure 2.7: Nodes are pre-curated: two middle nodes are minimized and the last one is set favorite.

2.3.4.4 Scalability

Nodes can reduce their size through zooming to accommodate for more nodes within the visible part of the history map. By default, all nodes have the same width and the same maximum height, which allow a few words of the contextual text to be visible and a reasonably large thumbnail image to help the user recognize the visited web pages. For each smaller level, both the node width and the number of highlights are reduced. The maximum height should be adjusted so that the ratio between it and the node width remains unchanged. At the smallest level, only the action type icon or a small thumbnail image is shown. Fig. 2.8 shows an example of different zoom levels applied onto the same node.

Node zoom level is explicitly controlled by the user using simple plus/minus buttons. When the collection of nodes exceeds the visible area, the user can pan the map to see them.

2.3.4.5 Revisitation and Interruption

When an action is captured, its web page's URL is also recorded. Clicking on a node opens its associated web page. This releases the user from worrying about losing browser tabs. Moreover, we think that the additional branching/linking structure of

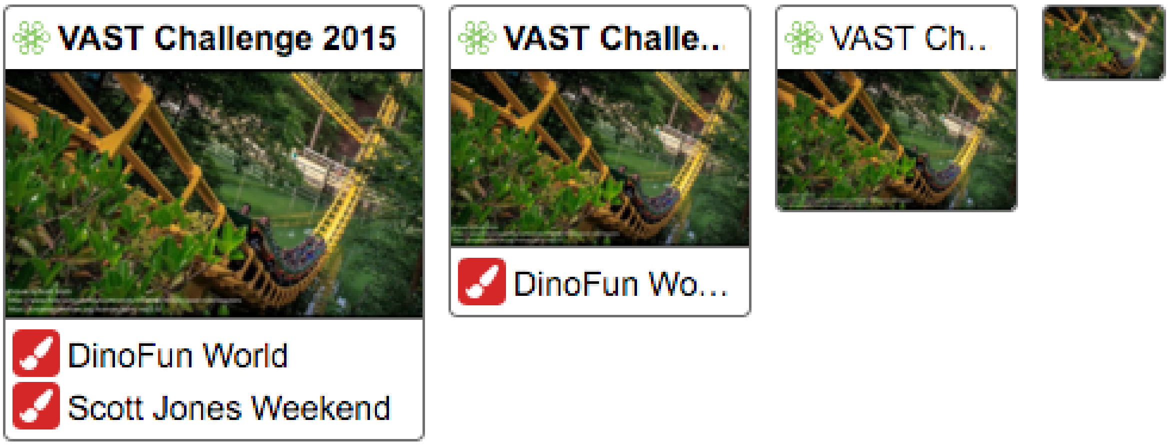


Figure 2.8: The same node with four zoom levels.

the layout will help the user to find information faster than the History feature of the browser (Requirement 2).

To provide a finer grained navigation than the web page URL level, revisiting a captured highlight brings the user to the exact text being highlighted. This is made possible by capturing the relative location of the highlight with respect to the root of the web page.

In the real world environment, the user may have many sensemaking tasks happening at the same time (Requirement 5). Even when working in a single task, the user may do some other things irrelevant to the task such as checking email and social feeds. Therefore, always capturing user actions and putting them into a single place will result a huge mix of unrelated information. To address this issue, we allow the user to create separate collections of information for different tasks. The user can also pause the information capture and resume when needed.

2.3.5 Knowledge Map

This map allows users to curate the information displayed in the History Map (Fig. **??**).

2.3.5.1 Visual Representation

The curation process starts by adding nodes from the history map to the knowledge map. This is done via the *Curate* button in the menu available when hovering over a node. Nodes in the knowledge map have the same visual representation with those in the history map. The only difference is that thumbnail images of curated nodes are always made visible to improve its recognizability (Requirement 6).

2.3.5.2 Free Movement

The limit of single dimensional ordering tabs from left to right is addressed in the knowledge map through the spatial organization of nodes (Requirement 7). The user can freely move nodes by simply dragging them around. This allows the user to spatially group nodes and assign different meanings to them. Fig. 2.9 shows an example of a knowledge map with three clear groups based on their locations.

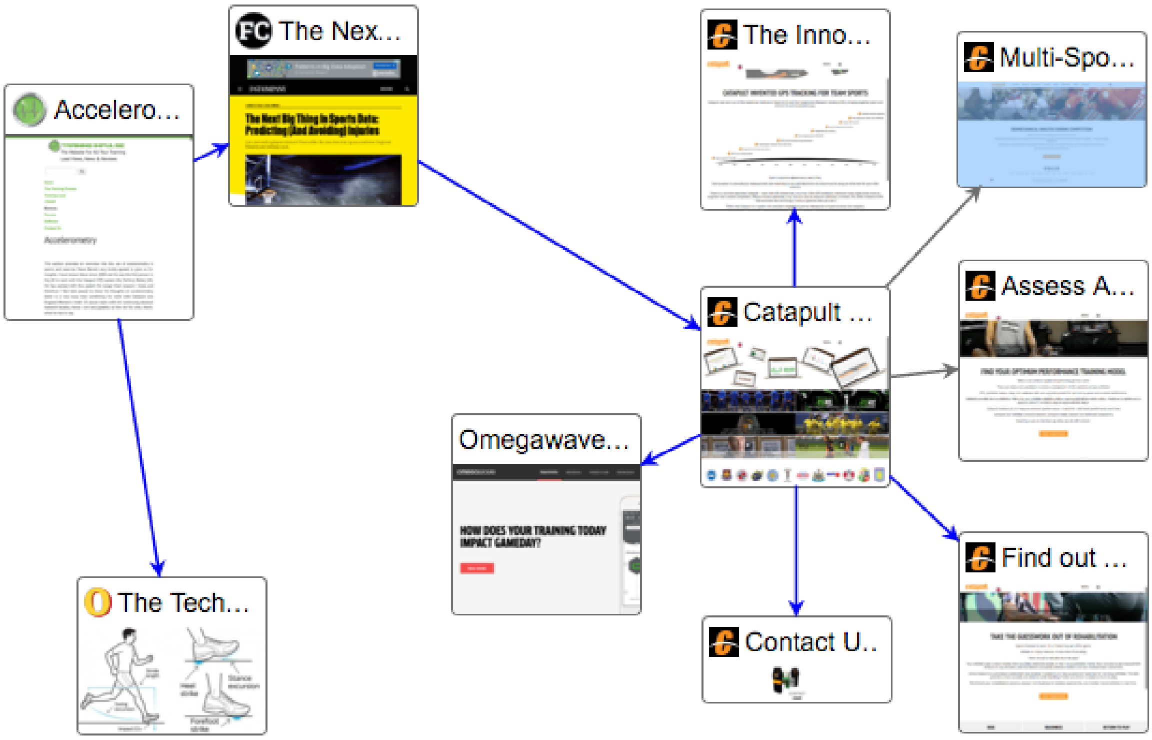


Figure 2.9: A knowledge map with three clear groups of nodes as the result of free movement.

2.3.5.3 Casual Relationship

Besides spatial grouping, seeing the casual relationship among collected information is also important to users in supporting sensemaking (Requirement 7). A conventional representation is used to show this relationship: an arrow pointing from the cause to the effect. The user can add a casual relationship by clicking on the "cause node", holding it for half a second until the cursor changes to an arrow, then releasing the mouse on the "effect node".

When nodes are added to the history map, the provenance links among them are also copied to the knowledge map to provide an initial understanding of existing relations. Different colors are used to distinguish user-added links from provenance links.

2.3.5.4 Reasoning

SenseMap does not provide support for any specific reasoning techniques. However, we think that the flexibility of free movement and casual relationship can help the user apply their reasoning strategies. For instance, the user can draw a link from a "hypothesis" node to its evidence. Then, they can move all supporting evidence nodes to one area and all counter evidence nodes to a different location to distinguish the two groups.

2.3.5.5 Collection – Curation

All nodes in the knowledge map appear in the history map, but the other direction may not be true because typically, only relevant and important nodes are curated. To help the user quickly recognize which nodes in the history map are already curated, a green "tick" icon is superimposed at the top right hand corner. Also, hovering a node in one map will highlight that node, if it exists, in the other map.

2.3.6 Communication

The final organization of curated information provides a complete picture of solving the sensemaking task, which makes it ideal for the user to present their findings (Requirement 11). If the process is of interest, the history map can be used alongside the knowledge map. Moreover, the user can refer to raw data, via node revisitation, to support their presentation (Requirement 12).

Both the history and knowledge maps can be saved as local files and loaded. This allows users to share their maps (Requirement 14). Also, the user can create multiple copies of knowledge maps based on the same history map allowing customizing for various presentation purposes (Requirement 13).

p: not implemented yet!

2.3.7 Implementation

SenseMap is implemented as a Chrome extension using standard web technologies including HTML5, CSS3, and JavaScript, together with D3 library [2] for visualization. Highlighting and annotation require modifying the structure of a web page, thus they must be implemented as content scripts in a browser plugin. We decided to target Chrome first due to its popularity. Also, in the initial interview, the majority of the interviewees used Chrome (seven out of nine).

To capture user sensemaking actions, we apply the same mechanism as in SensePath [7]. The detection of “search” actions is based on URL parsing. The web page URL is compared against a set of query templates to extract search type and parameters if it matches some template. Detecting “filtering” actions is based on a heuristic that if two URLs share the same domain and path name but have different query parameters, the second page should be the result of a filtering action on the first one.

The three views communicate using *messaging passing* mechanism provided by Chrome extension API. When an interaction occurs in one view, it sends a message to notify all other views. Each view constantly listens and responds to such messages.

2.4 Evaluation

We conducted a user-centered evaluation of SenseMap in order to:

- Evaluate its effectiveness in providing the desired support for searching, managing and synthesizing information through our collect, curate, communicate process model;
- Identify significant features relating to user behaviors, interactions and outcomes in the use of this new tool; and
- Describe any processes that these behaviors, interactions and outcomes might infer.

2.4.1 Design

Our evaluation was undertaken in a naturalistic work setting with a number of users completing the same task. We recruited five participants who are all working as junior designers and engineers in an innovation center. The participants were all introduced to the tool, trained in its operation and given thirty minutes to try out the tool with support, before being given the task. Each participant installed the tool on their own device; all participants were using laptops -– three Apple Macs and two Windows — and one participant had a second larger monitor connected. The participants conducted the task in their normal working environment over a two-hour period.

The task was devised to reflect normal work activities for these participants in the early research phases of an innovation project. We focused the task on technology selection and deployment, requiring them to collect and curate information on a variety of interrelated areas and then to communicate their findings. Participants were given the task in written form and it was discussed to clarify any points of confusion or ambiguity. They were asked to complete the below task while using SenseMap to record and present your findings. The task was: "We need to use accelerometers to measure *movement intensity* in ambulatory subjects, in naturalistic settings, for up to 1 week. We need to find out about (in no order of priority): prior art, placement of devices, algorithms, commercial products and APIs, bespoke approaches, and anything else you feel is relevant."

2.4.2 Data Collection and Analysis

2.4.2.1 Quantitative Data

During the trial we collected quantitative provenance data to establish 'Interaction profiles' for each of the participants. These profiles enable us to understand how our participants interacted with SenseMap in their sensemaking activities over time. We captured provenance information showing which view (Browser, History Map, Knowledge Map) the participants were using and what their interactions were.

The low level provenance events collected included window focus and mouse/keyboard interaction. The provenance of all sensemaking actions supported by SenseMap are also captured, including the timing (when), content (what), position (where), and associated interaction (how).

2.4.2.2 Qualitative Data

At the end of the two-hour period we conducted an individual, semi-structured interview with each of the five participants, which was recorded. The participants were asked to: present their findings; describe the process that they used to reach these findings using SenseMap; and to reflect upon their experience. The five videos were viewed to identify and describe significant features from each participant.

These features were then categorized and these categories used to identify recurrence across all participant trials. Using the feature categories, their recurrence, the quantitative data and any recurring concomitance, we then explored whether any processes could be inferred.

2.4.3 Findings

2.4.3.1 Interaction Profiles

The quantitative data showed two distinct interaction profiles, i.e. how the participants engaged in the sensemaking process and interacted with SenseMap. We have characterized this as *Curate early, Curate often* and it relates to the interplay between collect and curate in our model of browser-based sensemaking, through refining searches and extending the schema. Fig. 2.10 shows the histogram of curation activities for all participants.

Positive interaction profiles: P5 had most of this interplay. Table 2.1 shows the number of nodes and links of the knowledge map for all participants. P5 was the first to curate and had the most detailed knowledge map with 35 nodes and 35 links. P2 had a similar profile with early and regular interactions with their window contents. P2 had the second most detailed knowledge map with 26 nodes and 26 links (Fig. **??** shows part of it). P1 began the trial with uncertainty due to a lack of technical knowledge of the task. The task was contextualized for P1 helping them to relate it more closely to their expertise. P1 began productive engagement with SenseMap at a later stage resulting in a similar interaction profile to P2 but compressed into a shorter timeframe. P1 had the third most detailed knowledge map with 10 nodes and 12 links.

Table 2.1: Knowledge Map produced by participants.

Participant	Number of nodes	Number of links
P1	10	12
P2	26	26
P3	6	7
P4	5	2
P5	35	35

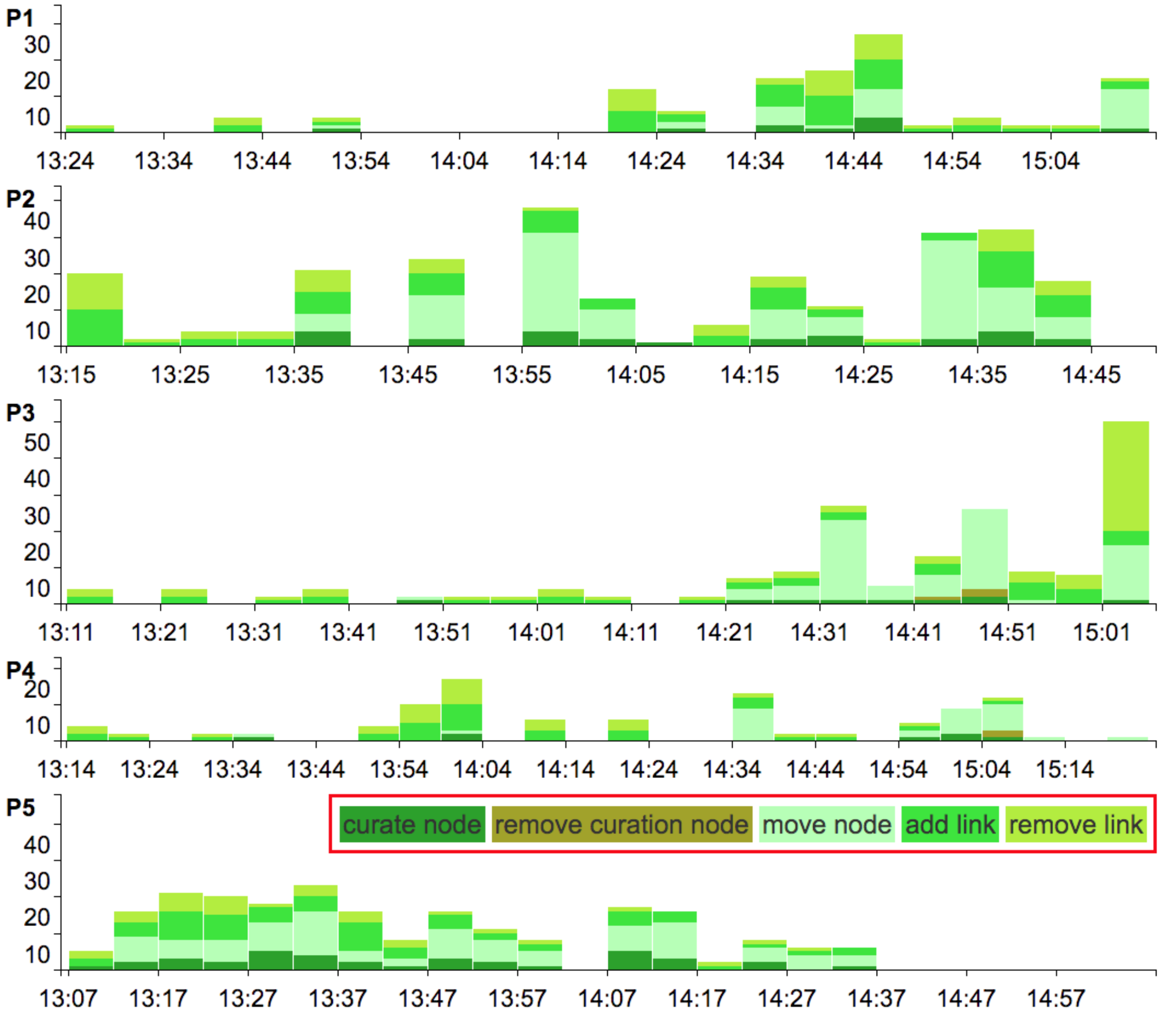


Figure 2.10: Histogram of curation activities for all participants.

Negative interaction profiles: P3 did some minor curation activities early in the sensemaking process, but there was a considerable rise in the last third of the task time. There were only 6 nodes and 7 links in the final knowledge map with an indeterminate linking structure. P3 had moved nodes in the knowledge map 78 times, added 12 links and deleted 34, indicating some level of confusion, indecision or potential playing with the interface.

P4 did some minor curation activities with a short focus after an hour and more towards the end of the task. P4's interaction profile is notable for long and frequent periods of inactivity. P4 had only 5 nodes and 2 links in their final knowledge map with an indeterminate linking structure (Fig. 2.11).

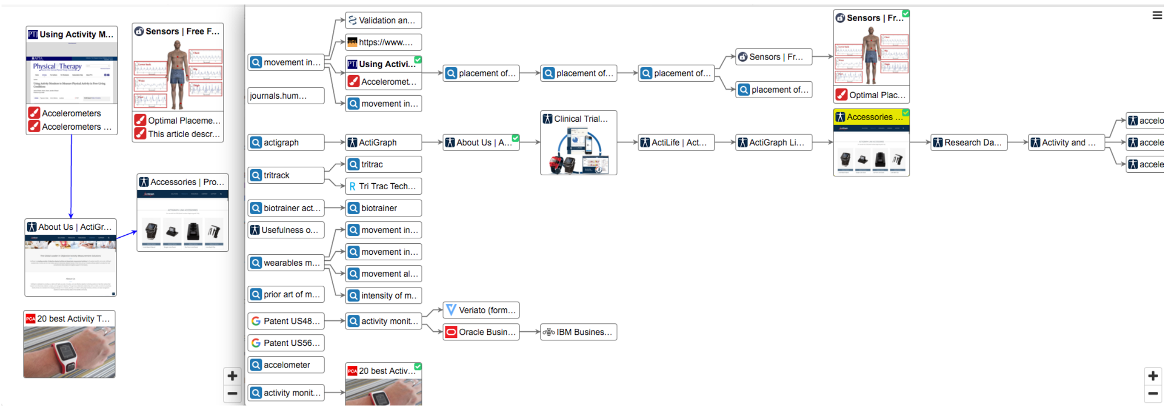


Figure 2.11: P4: Knowledge Map (left) and History Map (right). P4 successfully moved a key document into the curation space, but subsequent schema is scant.

2.4.3.2 Qualitative Features

Following the analysis of quantitative data, we went through the interview data looking for confirmation and potential reasons for the different interaction profiles.

F1 Communication The way that the participants communicated their findings is the principle feature that maps to the interaction profile. We considered the following questions for communication: Did the participants use the knowledge map to communicate their findings? Had they successfully curated their schema through linked clusters, linked branches or other coherent structures? Had they constructed a narrative to explain their schema? Did this narrative unfold in expected ways (left to right, top to bottom)?

Positive: P1, P2, P5. All had arranged their detailed knowledge maps as linked clusters from a key document. P1 and P2 were both able to provide a very coherent narrative about their findings. They confidently used the knowledge map to explain their findings, using links and clusters to explain relationships and recommendations and clicking on nodes to access the original information sources in the browser window. P2 felt confident that he had completed the task in the time allowed and felt that the tool had helped him to be thorough, systematic and organized. P1 had low confidence in his technical expertise when he began the trial. After the task was recontextualized for him he made confident progress. He was pleased with the manifestation and tool features of the knowledge map referring to it as a 'mind map'; a knowledge mapping process that he often uses. P5 was less able to provide a narrative of his findings even though he had the most detailed knowledge map. He felt that he had not completed the task and was unsure about some of the technical aspects of it, which may have had some bearing on this. He was very positive about the use of the tool.

Negative: P3, P4. Neither of them were able to use their knowledge map to communicate their findings, referring instead to their history maps. Both saw much the potential in the tool to assist in sensemaking activities, but were less positive about their experience of it.

During the qualitative analysis, we identified and described four further features that could potentially cause the different interaction profiles.

F2 Window Management Were participants able to work with their desired browser window size and effectively display or switch between windows during the task?

Positive: P1, P2, P5. P5 had a second monitor connected and was able to work with a full-screen browser window on his laptop as his point of focus. The two maps were arranged on the second monitor, each taking half of the screen, and the monitor was behind his laptop. He enjoyed this relationship and referred to the external monitor as his back-up and like having a second-brain. P1 and 2 both resized windows, but were adept at switching between them and demonstrated fluidity in this during their interview and in their interaction profiles. P2 had arranged all three windows to be nearly full-screen and arranged them as an overlapping stack, so he could see the edges of all windows at all times. He also used the three-finger swipe on his mac to minimize and show all windows and to switch between them.

Negative: P3, P4. Both reverted to full-screen browser width. Both of them expressed a strong preference for this. P3 ignored the collection view after losing reassurance that the tool could support them in their task and returned to their preferred full-screen browser window. P4 reset the browser window-to full screen, ignored the history map and then lost track of the meaning of the collection when they returned to it.

F3 Loosing Track Did the participant loose track of the building collection through ignoring the history map?

Lost track: P4. Early in the task P4 decided to reset the browser window to full-screen and to ignore the history map. When she returned to the history map she found she had, lost track and did not satisfactorily regain it throughout the rest of the task.

Maintained track: P1, P2, P3, P5. P5 had a second monitor attached so could see the history map at all times. He said that the tool really began to make sense for him when he connected the second monitor and he felt his pace increased. P1 said he had resized the browser to full screen and ignored the history map, but it continued to make sense to him. He characterized his use as having regular periods of interaction with the history map rather than regular observation of it building up. P3 maintained track in the early phases of the task and did extensive preparation for curation by minimizing nodes to help him keep track and to guide his searches.

F4 Trust Did the participant maintain trust in the tool throughout the process? Were they confident that nodes were appearing in the correct relationship and with the correct links to other nodes? Did they understand these relationships when looking at the history map?

Positive: P1, P2, P5. All had positive experiences with, and outcomes from, using SenseMap. They all expressed feelings of trust in the tool and were able to confidently shift their sensemaking activity focus from collections of tabs to the history and knowledge maps.

Negative: P3, P4. P3 had been managing the history map, but lost trust in the tool as they began to question the position and relationship of nodes generated in the history map to other nodes in that map.

P4 lost trust in the tool as they cold not understand the relationship of the nodes in the history map.

F5 Reassurance Was the participant reassured that the tool was providing support for their activity: Organization of information sources; Acting as an aide memoir; Allowing them to check or to navigate back to information sources; Removing anxiety over retaining and organizing tabs?

Positive: P1, P2, P5. P2 referred to the history map and the knowledge map as a good aide memoir allowing him to check completeness and to guide further searches. He felt reassured enough by the growing history map to close browser tabs. In his normal practice he often created reports based on his tab sets to communicate his findings. He was confident and enthusiastic that SenseMap could remove this burden. P1 saw much potential in the tool and asked if he could use it for a big design project that he would be competing in the following year. He had regular interaction with the history map and used it the most to revisit previous sources of information clicking on nodes in the history map (44% of web browser page reloads). P5 described the history map as "my thinking" and the knowledge map as "A neater view of my thinking". His reference to having a second brain was clearly reassuring to him!

Negative: P3, P4. P3 was initially reassured by the tool. However, this reassurance diminished over time as he began to feel that the management of the collection was impeding his ability to complete the task and gradually lost interest in the collection view, reverting to his typical sensemaking methods using tabs and a full width browser window. P4 had lost track and no longer felt reassured that the tool could support her activity.

Table 2.2 summarizes the status of each feature for all participants.

Table 2.2: Features derived from all participants.

	Communication	Window Management	Keeping Track	Trust	Reassurance
P1	✓	✓	✓	✓	✓
P2	✓	✓	✓	✓	✓
P3			✓		
P4					
P5	✓	✓	✓	✓	✓

2.4.3.3 Processes Model

Using the feature categories, their recurrence, the quantitative data and any recurring concomitance, we have constructed a process that indicates the dependence of the five significant features and the interaction profiles when using SenseMap.

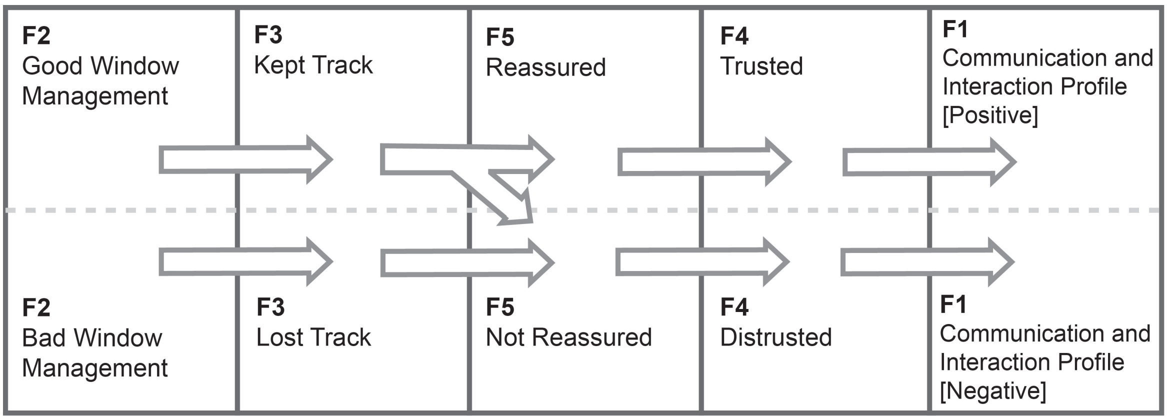


Figure 2.12: The process model derived from data analysis.

SenseMap has been designed as a tool to support browser-based, online sensemaking. Our evaluation validates our approach and provides a rich understanding of users' interaction with the tool and their responses to it. Importantly for us, and for other designers of such tools, it also highlights the significant features that lead to a positive outcome in the sensemaking process. These are valuable insights and design lessons.

In the current manifestation of SenseMap, window management (F2) is critical to a successful experience and outcome. Natural seamless interactions that do not impede workflow, but aid in keeping track (F3) and enabling important preparation for curation that takes place in the history map need to be supported. If users mange their windows well and keep track then they need to be reassured (F5) that the history map is building correctly and that they understand what it means. Our evaluation has shown that this reassurance is lost if nodes appear in questionable places to the user and they decide that the cognitive overhead of managing and interpreting the history map becomes too great leading to a lack of trust in the tool.

2.4.4 Opportunities for Further Development

There are two substantive immediate focus areas for further development of SenseMap and these areas also serve as design lessons for others.

The first is straightforward and perhaps something of an oversight on our part. In our evaluation all users mentioned that they would like to be able to add notes to the knowledge map; one had even invented a way to do this himself using search terms. They would like to be able label clusters and links to those clusters and also provide explanations about hypotheses and recommendations.

The second is more of a challenge. Our evaluation showed that there is potential to provide better integration between the browser and the history map. There is an opportunity to perform experiments with alternative window arrangements and interactions that naturally and seamlessly integrate the two views and that do not impede workflow. These arrangements and interactions must also aid in keeping track, reassurance and minimizing the cognitive overhead of managing and understanding the history map

Our participants are familiar with using full-screen web-browser windows and are discomforted by anything smaller. Indeed many websites are still fixed width and not responsive, so require resizing of the web browser window to view them correctly. We might overcome this difficulty quickly by placing the history map beneath the web-browser window and give it behaviors similar to a "dock". This short, wide window could be less obtrusive to the web browser, but big enough to see the currently active portion of the history map. The history map could also pan to ensure that the active node is always in view. A mouse hover could maximize and focus the window. A quick fix perhaps, but one that is worthy of investigation, however other less-obvious approaches may bring the desired seamlessness to this sensemaking process.

2.5 Conclusion and Future Work

In this paper, we present SenseMap, a visual analytics tool to support browser-based sensemaking through analytic provenance. A user study was conducted to explore how users search, manage and synthesize online information for their daily work activities and a series of design workshops was followed to generate design requirements. It also led to a model for browser-based sensemaking showing users iteratively go through the process of collect, curating and communicating findings to others.

SenseMap automatically captures user sensemaking actions in the Browser View, visualizes them in the History Map to provide an overview of the sensemaking process, and allows curation in the Knowledge Map. Communication is made possible in all three views. A user study was conducted to explore how SenseMap is used in a naturalistic work setting. Most participants found the tool intuitive to use. It helped them to organize information sources, to quickly navigate to the sources they wanted, and enabled them to effectively communicate their findings. A process model is also derived based on the data analysis.

SenseMap in its current state is in the middle of an iterative development process. The next step is to address the issues identified in the evaluation: adding note taking capability in the knowledge map and addressing the scalability issue. When the user changes the active tab, the corresponding node with that tab is highlighted in the history map. If that node is out of the visible area, the map needs to be panned to ensure its visibility. Also, in the evaluation, the link detection among pages occasionally produces the wrong result causing trust to be lost. This issue also needs to be investigated.

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