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DESIGN FOR SYNTHESIS IN GEOVISUALIZATION

A Dissertation in

Geography

by

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ABSTRACT

Visually-enabled analysis of geographic information with interactive geovisualization tools is increasingly common in domains like disease surveillance, crisis management, and intelligence analysis. As geovisualization tools evolve to support more sophisticated analytical capabilities, the results that emerge from these systems are becoming more abundant and intricate. Current tools provide basic mechanisms for collecting, organizing, and making sense out of multiple results, but little basic research has been done to characterize this task – the synthesis of geovisual information.

This study explores the topic of synthesis in the context of infectious disease surveillance. Expert analysts from the Pacific Northwest National Laboratory (PNNL) and experts from the Penn State Center for Infectious Disease Dynamics (CIDD), and the Geographic Visualization Science, Technology, and Applications Center (GeoVISTA) were recruited to take part in interviews and experiments to characterize geovisual synthesis. These participants are likely to use, or are already using geovisualization tools to develop analytical results – therefore they stand to benefit from new synthesis support tools.

This research employs a mixed qualitative method study to characterize and design for geovisual synthesis. Interviews were conducted with analysts at PNNL to characterize how synthesis is conducted currently and to elicit opinions about how synthesis should be supported in the future. Individual and collaborative synthesis experiments were conducted with participants from PNNL, CIDD, and GeoVISTA to observe synthesis in a simulated real-world scenario. Analysis of experimental and interview data provides insight into the process of geovisual synthesis. Results show that synthesis involves the application of a wide range of organizational metaphors, and that it requires flexible tools that support creative approaches. These results are distilled into a set of empirically-derived design guidelines for new synthesis support tools.

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Chapter 1 – Introduction

The process of analysis with geovisualization tools is frequently described as a steady transition from exploration, to analysis, through synthesis of results, and ending in presentation (DiBiase 1990). The research reported here focuses on the topic of synthesis. While a great deal of effort has gone into developing tools and design methods for facilitating exploration, analysis, and presentation, relatively little is known about what characterizes the act of synthesis or how to design synthesis support tools.

As the study of visual analytics matures and productive tools emerge for analysts, the results they generate will become more prolific and detailed. In his model of visualization in support of the process of science, DiBiase (1990) proposed that: “Synthesis...entails summarizing and generalizing the results of exploratory and confirmatory analyses, and articulating a new, integrated conception of how the components of the research problem interrelate. It is a bridge from the private to the public realms.” In this study, the focus is on supporting a wider range of information analysts. In that context, synthesis is conceived of as a process that includes the actions of organizing, annotating, and assigning meaning to collected results.

Geovisual analytic tools in development promise to make it possible for users to tackle complex tasks across heterogeneous types of spatial data. Photos, news articles, and video clips will be interactively linked to tabular geospatial databases (Andrienko et al. 2007; Thomas and Cook 2005). As geovisual results become increasingly intricate, there is a need for research to examine how domain experts collect, organize, and assign meaning to their results, as a basis for the conceptualization and development of synthesis-support tools. The research reported here focuses on infectious disease surveillance and bioterrorism intelligence, domains that require the synthesis of many types of geographic information.

1.1 Problem Area

This research focuses on synthesis characterization and synthesis tool design for public health analysts monitoring biological and chemical threats at government agencies, non-governmental organizations (NGOs), and private consulting firms. Users at each type of organization currently apply GIS and geovisualization tools to monitor the spread of infectious diseases.

The real-world problem that this research responds to is illustrated through the following scenario depicting a prototypical situation in which geovisual result synthesis tools are needed:

Samantha, a communicable disease epidemiologist at an international health organization, uses a geovisualization toolkit to explore the geographic and temporal dimensions of the mortality associated with avian influenza in Southeast Asia. The toolkit she uses offers a choropleth map, a scatter plot, a time-oriented graph, and a parallel coordinate plot all showing a common set of disease outcomes (mortality and incidence rates) and indicators (socioeconomic measures, access to screening, etc...) that are regularly updated and linked to statistical models of avian influenza. Every week she receives new datasets and she must make regular reports to her supervisor about what she has found with each new dataset. The current state of the art in geovisualization tools allows her to save screen captures during data exploration, and to save data loading configurations as projects for later use. To build her report, Samantha must rely on generic office productivity software to organize the screen captures together with her notes, relevant email messages from other expert colleagues, relevant RSS newsfeeds from PubMed detailing the latest research, and relevant RSS feeds of other news articles that may indicate how the data she is exploring reflects life on the ground in her study area.

Now, Samantha has been asked to recall several of her recent analyses to help create a report on a new flu outbreak in Taiwan. Additionally, Samantha is now required to use a new version of the geovisualization toolkit that has been extended to support additional data resources – notes, news articles, photographs, and audio/video clips.

This additional complexity makes it more difficult for Samantha to synthesize information in a separate software environment. Samantha needs new tools to help her marshal the information at hand within the geovisualization toolkit itself. Allowing synthesis to take place inside the analytical software provides the opportunity to preserve interactive connections to real data and particular states of the geovisualization. This would make the task Samantha is facing (to recall prior work and develop a summary) far more efficient – an important goal considering the time-critical task she is trying to accomplish.

Understanding synthesis and designing for it is a near-term priority because there are many geographic and information visualization tool development efforts underway that are focused on enabling exploration and analysis through space and time using traditional table-based digital databases that coordinate in interesting ways with diverse data types like notes, photos, and articles (Andrienko et al. 2007; Thomas and Cook 2005). The problem-solving goals of these projects are ambitious, and the problem domains they support are of high-importance (disease epidemiology, crisis management, threat assessment, etc.). Analysts need to explore and analyze massive databases rapidly, all the while capturing and synthesizing their results in ways that will be easy to return to at a later time, in a format that supports collaboration with others. It is essential for analysts to be able to explain precisely how they arrived at a conclusion, and to re-use portions of prior work when similar situations arise and there is a need for comparative analyses.

It is also important to understand synthesis more fully as an analytical process in order to shape the direction of new synthesis tools that are currently in development. Examples of tools that are being used to collect, organize, and add meaning to analysis artifacts currently include Oculus Info nSpace (Wright et al. 2005, 2006), i2 Analyst's Notebook (i2 2007), and GeoVISTA ConceptVISTA (Gahegan et al. 2007). These tools and others like them stand to benefit from research that empirically explores the process of synthesis and distills knowledge gained from that exploration into design guidelines for future synthesis support tools.

1.2 Defining Synthesis

This research focuses on synthesis in the context of geovisualization. Geovisualization tools are designed to support highly-interactive visual exploration and analysis of geospatial data. Geovisualizations are Geographic Information Systems (GIS) that are focused on user-driven, interactive visual exploration and analysis of spatio-temporal data. GIS provides critically important tools for developing spatial datasets and analyzing/modeling spatial processes, and geovisualizations often integrate multiple data sources that were developed in GIS analytical tools into interactive, exploratory environments. Geovisualization tools enable analysts to look at geospatial data from multiple perspectives and explore complex data relationships that may exist over a wide array of spatial and temporal scales. Current areas of research on geovisualization include integrating cartographic approaches with representation and analysis methods from scientific and information visualization, supporting exploratory data analysis, user-centered design of custom toolkits, and developing collaborative environments (Kraak and MacEachren 2005; Dykes, MacEachren, and Kraak 2005).

The theory driving geovisualization development connects geovisualization tools to a research process proposed by DiBiase (1990), and elaborated upon later by MacEachren (1994; 1995). DiBiase describes a research process that begins in the private realm of the individual analyst exploring data, developing hypotheses, and iteratively carrying out analysis tasks to assess and refine the hypotheses, to the public realm of synthesizing results and evidence to support the results and presenting those results along with supporting arguments (Figure 1). In DiBiase's model synthesis is presented as a fusion of information and a, "...generalization of findings." In this process, the scientist switches from an initial focus on visual thinking to a focus on visual communication. Contemporary geovisualization tools provide strong support for analytical tasks that occupy the visual thinking realm – the result of much emphasis in early geovisualization research on supporting that realm. In contrast, synthesis as the bridge between knowledge construction and its application has received limited attention so far. The research study presented here seeks to fill that gap by characterizing how synthesis should be supported.

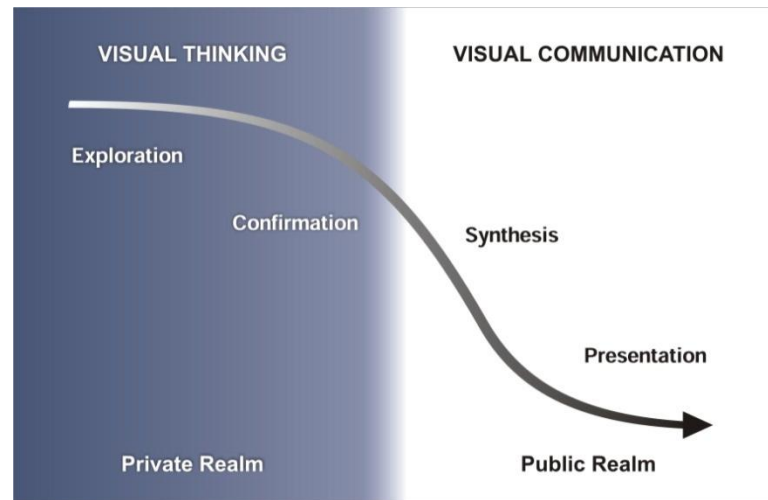


Figure 1: The geovisualization research process as conceived by DiBiase, 1990.

When viewed from the **(cartography)**³ framework of geographic visualization (Figure 2), (MacEachren 1995) this research is positioned to design strategies for composing and generalizing exploratory and analytical results, as the task shifts from knowledge construction over to information sharing. These strategies will support the formative stages of condensing what has been discovered using geographic visualization, as analysts change goals from revealing unknowns to presenting knowns (e.g., from uncovering unexpected patterns to interpreting and explaining those patterns). Support for synthesis will help analysts make scientific results relevant to and useful for policy and decision-making, and ensure that research results are made more accessible to outside collaborators, students, and experts in other domains.

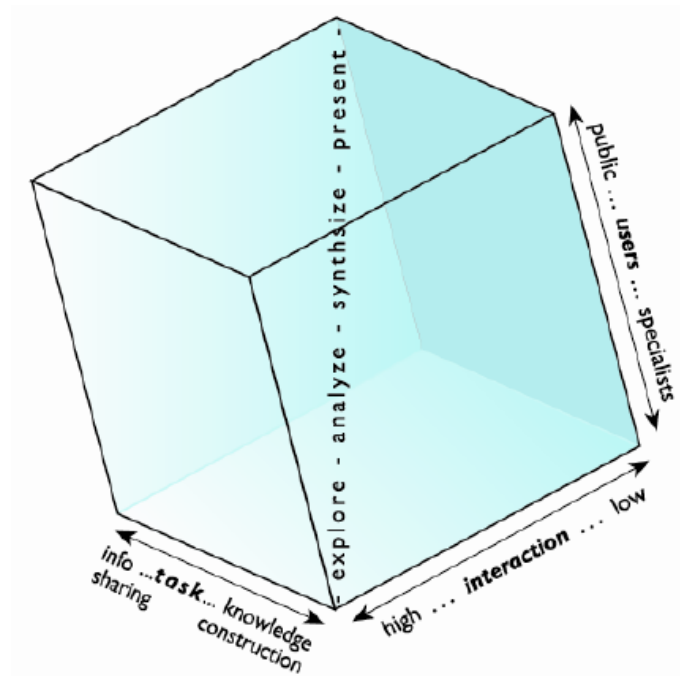


Figure 2: The (cartography)³ diagram depicting the basic functions of geovisualization proposed by MacEachren (1995, 2004).

A commonly referenced theoretical framework in GIScience by Gahegan and Brodaric (2002) describes synthesis in somewhat different manner than our proposed focus. In their framework of geoscientific discovery, synthesis involves creating taxonomies from data – often in the form of classification schemes. As an example of synthesis, Gahegan and Brodaric describe how analysts could visually explore and identify suitable classification schemes with landcover data – making synthesis an activity that occurs quite early in the scientific process.

In generic terms, the Oxford English Dictionary assigns a variety of meanings to synthesis (Simpson and Weiner 1989). Synthesis refers to the transition from causes to effects when used in logic. In chemistry and physics, synthesis is creation of a compound from individual constituents. Immanuel Kant described synthesis as the cognitive understanding acquired by combining perceptual inputs and prior experiences. The common popular definition of synthesis is the, “...putting together of parts or elements to make up a complex whole.”

Because the definition for synthesis varies in the literature, it is important to define how the term is used in this study. The focus here is on the results integration, generalization, and organization stage of the scientific process – a (thus far) largely unexplored topic in geovisualization research. Therefore, this study uses the term “synthesis” in the sense articulated by DiBiase (1990) and MacEachren (1995; 2004). Synthesis is defined in this study as *the stage of an analytic process in which analysts select, generalize, organize, and combine individual analytical results into coherent groups that are used to assign meaning and/or encapsulate complex ideas.*

1.3 Research Questions

To characterize and design for synthesis of geovisual results, this research project focuses on answers to the following questions through a longitudinal mixed qualitative method study of analysts and experts on biological and chemical threats.

1. How do analysts currently synthesize the results of geovisual exploration?
2. What do analysts wish they could do to better synthesize the results of geovisual exploration?
3. How do analysts synthesize results in a simulated real-world situation, and what does this tell us about how synthesis is conceptualized?
4. What design guidelines for new synthesis tools emerge from analysts’ current, projected, and demonstrated synthesizing behavior?

Answers to these questions have come from work with analysts monitoring infectious disease and biological/chemical threats at Pacific Northwest National Labs (PNNL) and experts from the Center for Infectious Disease Dynamics (CIDD) and GeoVISTA Center at Penn State. This study combines evidence from knowledge elicitation activities (interviews and synthesis experiments) to define general synthesis strategies and to develop specific tool design guidelines that can be used to design synthesis tools for future geovisualization environments.

Exploration of these research questions has several wider implications for the study of Geography. First, it begins to fill the gap in understanding of synthesis as proposed in existing theory about the process of geovisual analysis. Specifically it addresses the broad challenge of characterizing the schema that people use when working with geovisual information (MacEachren and Kraak 2001). It also addresses a more recent and more specific challenge to develop new methods for supporting knowledge capture and manipulation in geovisual spatial decision support systems (Andrienko et al. 2007) where we expect users will need to assemble and share the “big picture” based on collections of discovered results. Second, the design guidelines developed in this work are based on an experimental approach that focuses on a realistic geographic problem, using data that contain various types of spatial references and a scenario that requires participants to develop an understanding of these spatial references in order to develop hypotheses. Finally, the experimental approach presented here provides an empirical method for future work to understand how synthesis is influenced by spatial information and spatial thinking.

1.4 Dissertation Structure

This dissertation is presented in eight chapters. Chapter one introduces research questions related to synthesis in geovisualization. Chapter two provides background information on relevant topic areas. Chapter three outlines the research methodology used to complete this study. Chapter four presents results from structured interviews of analysts at PNNL to characterize the current state of synthesis support tools. Chapter five presents results from a simulated synthesis activity with individual analysts at PNNL and PSU. Chapter six presents results from a simulated collaborative synthesis activity with analysts at PSU. Chapter seven provides a set of empirically-derived software design guidelines for the development of synthesis support tools. Chapter eight concludes the dissertation with reflections on the significance, limitations, and future work suggested by the results of this study.

Chapter 2 – Background

This study is intended to characterize and design for synthesis as a component of the geovisual analysis process where analysts construct knowledge from heterogeneous information. This chapter discusses relevant prior work that has influenced the research questions and methodology applied to this problem. It begins with a review of geovisualization and the new field of geovisual analytics, as they both relate to the need for synthesis research. Next, prior work to design and evaluate geovisualization tools is examined to position this study among an array of methodological approaches from HCI, cartography, and geovisualization. This is followed by a literature review about deriving hypotheses from visualization – an important aspect of the experimental methodology used in this study. Finally, current advances in software synthesis support tools are reviewed to show possible beneficiaries of the empirically-derived design guidelines developed in this study.

2.1 Geovisualization and Geovisual Analytics

Geovisualization tools have been developed to support exploratory and analytical tasks for application domains like epidemiology (Edsall 2003; Robinson 2007), crisis management (MacEachren and Cai 2006; Tomaszewski et al. 2007), and environmental analysis (Cliburn et al. 2002; Cova, Dennison, and Kim 2005; Harrower, MacEachren, and Griffin 2000). Geovisualization tools typically emphasize user interaction and the ability to view spatio-temporal data from multiple, coordinated perspectives.

Geovisualization environments like GeoVISTA *Studio* (cite) and GeoViz Toolkit (cite) allow application designers to develop custom toolkits tailored to different domain needs. These environments place emphasis on supporting exploratory tasks (MacEachren et al. 2003) and coupling visual geographic representations with computational analysis methods (Guo et al. 2005).

Motivation for this research comes in part from the need for integrative geovisualization applications that move beyond support for exploration and analysis and connect those actions to knowledge construction and representation. A criticism of many current geovisualization tools is that they are too data-centric, providing few functions intended to help users develop concepts and higher-level understanding from the results of visual

exploration (Gahegan 2005). Therefore it is important to design and implement new geovisualization tools that bridge this gap.

Gahegan suggests that users are likely to move back and forth between exploration, analysis, synthesis, evaluation, and presentation tasks in a non-linear fashion. Because it is unreasonable to expect that all of these tasks will be fully supported in a single toolkit, geovisualization tools should instead be engineered to easily coordinate with one another through a common framework. This would allow users to discover patterns in one tool, and pass this information into another tool that helps them organize and make sense of these discoveries without losing provenance. Much attention in recent geovisualization research focuses on visual analysis of data from diverse sources like text, video, imagery, numerical tables, and spatial information (Andrienko et al. 2007). In that scenario it will be even more important to preserve provenance information in a way that lets analysts browse representations of their knowledge and easily recall prior work. Such systems would allow users to preserve important metadata about their results, and this metadata could include the information necessary to recreate the exact scenario in which they were generated.

While there is considerable interest in the challenge of developing tools to collect, organize, and add meaning to analytical results from exploratory geovisualization, little has been done to empirically explore the process of synthesis itself. However, prototype tools have been developed that connect exploratory methods to knowledge construction using concept graphs for synthesis support (Gahegan and Brodaric 2002; Tomaszewski et al. 2007). These tools allow users to develop node-link graphs that represent the knowledge they have gathered from their work with geovisualization tools. These graphs can then be compared among multiple users, or to formal domain ontologies. It remains to be seen if user evaluations of concept graph synthesis tools confirm their utility and/or usability. The research presented here empirically examines synthesis in order to suggest designs for synthesis support tools in geovisualization, which may include the use of concept graphs as well as other organizational metaphors.

Recent research in geovisualization indicates a shift toward geovisual analytics (Andrienko et al. 2007) – following the development of visual analytics work by a

community of visualization, cognition, HCI, and other experts concerned with various aspects of visually-driven analysis. Visual analytics is defined as the science of analytical reasoning facilitated by interactive visual interfaces (Thomas and Cook 2005). Visual analytics calls for a close integration of analytical methods with visualization tools, and focuses attention on handling massive datasets that may include information in a variety of formats and of varying quality. Geovisual analytics targets these goals from the perspective of geographic datasets and spatial analysis methods (Kraak 2007). This trend can be seen as a response to the earlier call by Gahegan (2005) to move toward tools that support a broader set of science goals beyond simple visual exploration of spatial data.

Examples of geovisual analytics applications include the exploration of historic hotel registry data from the 1900's by Weaver et al. (2007). Their study uses geographic and temporal data to reconstruct patterns of traveling salesman and entertainers around several hotels in New York and Pennsylvania. Another study by Andrienko et al. (2007) focuses on geovisual analytic exploration of synthetic data from route models designed for evacuation decision support. Their tools help users explore possible evacuation routes in advance of a real disaster, so that they can simulate roadblocks and other real-world constraints and evaluate how those impact evacuation route choices.

2.2 Design and Evaluation of Geographic and Information Visualization

Design and evaluation studies are necessary to develop geovisualization tools that satisfy user needs and perform efficiently (Robinson et al. 2005; Slocum et al. 2003b). Design studies help decide the tasks that need to be supported in software, and can reveal interface metaphors that fit well with the target user domain. Evaluations of prototype tools and finished products can provide guidance for tool refinement and debugging.

There are many recent examples of design and evaluation efforts to create and refine geovisualization tools. These efforts span a wide array of application domains, including epidemiology (Edsall 2003; Robinson et al. 2005; Koua, MacEachren, and Kraak 2006), decision support (Aggett and McColl 2006; Andrienko et al. 2002; Haklay and Tobon

2003), and crisis management (Schafer et al. 2005; MacEachren et al. 2005). In terms of methodology, these studies typically make use of iterative design techniques that incorporate multiple methods (Figure 3). They share a sharp focus on incorporating the evaluated needs of end-users as primary inputs to design.

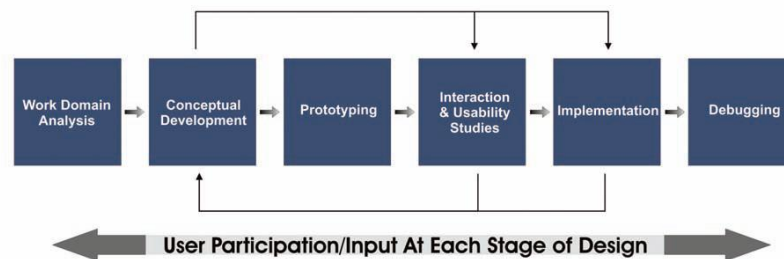


Figure 3: Iterative design process for geovisualization tools (Robinson et al. 2005).

Many design methodologies employed in contemporary geovisualization research are rooted in traditions from usability engineering and human-computer interaction (HCI) studies - sub-disciplines of computer science. Jakob Nielsen's *Usability Engineering* (Nielsen 1993) outlines the standard set of methods for refining and evaluating software interfaces. Nielsen's work, which is focused on producing quantifiable improvements in utility and efficiency has provided the foundation for a vast array of software evaluation efforts. With respect to the evaluation of visualization tools, Shneiderman and Plaisant (2005) offer a thorough review of knowledge elicitation and usability techniques that can be used. Some early work to explore the design and evaluation of GISystems was presented by Medyckyj-Scott and Hearnshaw in their book *Human Factors in Geographical Information Systems* (1993).

Usability engineering and HCI are not the only domains that have provided design and evaluation methodologies to geovisualization development efforts. Cognitive science approaches are also frequently used to evaluate how people work with tools. Ware (2004) outlines a comprehensive approach to visualization design that focuses on basic visual design principles founded upon evidence from cognitive (largely perceptual) studies. McNeese (2004) describes a work analysis and tool design approach built around cognitive systems engineering called the living laboratory framework. This

framework contrasts with Ware's by focusing instead on studying the situated actions of users as they attempt to solve realistic problems.

The cartographic literature also provides a broad set of methodologies for studying how people use maps (Furhmann and Pike 2005; Slocum et al. 2001), early work on that topic having begun decades ago with Arthur Robinson's *The Look of Maps* (Robinson 1952). These studies can be broken down into three major categories: map-design research, map-psychology research, and map-education research (Montello 2002). Map-design research is the most relevant to the research presented here, as it examines use and usability. Studies of map-design have often focused on individual visual elements and how they quantitatively influence map use (Gilmartin 1981; Montello 2002). In recent years, qualitative map-design studies have become common for projects focused on how maps are used in real world situations (Suchan and Brewer 2000). Qualitative methods are often used in combination to triangulate results – a practice described by Battenfield (1999).

Evaluation efforts of geovisualization tools have often followed the quantifiable utility and efficiency goals outlined by Nielsen (1993). As the tasks envisioned for visualization tools have increased in complexity, so have tool evaluations. Recently, there has been a detectable shift away from one-off evaluations of task time and performance to larger efforts that are iterative and longitudinal in nature (Shneiderman and Plaisant 2006). Shneiderman and Plaisant propose a set of twelve guidelines for conducting multi-dimensional, in-depth, long-term case studies (MILC) of information visualizations. These guidelines connect principles from ethnography to the context of design and evaluation for visualization software. In geovisualization research, there are recent design efforts that could be considered MILCs (Slocum et al. 2003a; Griffin 2003; Robinson 2007). The research reported here builds upon prior work to design and evaluate information visualization and geovisualization tools. Its methodology comprises a MILC designed to characterize synthesis in the context of disease surveillance.

2.3 Hypotheses and Visualization

A central assumption of this study is that visualization tools enable users to generate insights about their data – the input that will feed into synthesis support tools. A primary

goal of visualization is to help users generate new hypotheses or refine those that already exist (Spence 2007). Identifying and characterizing instances in which visualization facilitates hypothesis development are challenging tasks. Griffin (2003) studied the insights generated by disease experts as they used a geovisualization tool to model the spread of Hantavirus. In Griffin's study, participants were asked to verbally report and describe their hypotheses. This information was analyzed with session logs to identify the specific visualization tools that were relevant to each discovery. Saraiya et al. (2004) applied a somewhat different approach to examine insights generated by biologists working with five different gene-expression microarray visualization tools. In their study, Saraiya et al. coded think-aloud protocol data from user sessions to identify and characterize insights. Quantitative measures were used to compare the tools to one another in terms of how many insights they facilitated and how quickly they supported discovery.

The mechanisms through which analysts develop hypotheses from information have been described in a number of different theoretical frameworks. The sensemaking process presented by Pirolli and Card (2005) is particularly relevant to the research reported here. Based on cognitive task analysis of intelligence analysts, their framework describes hypothesis development as the product of two complementary processes – an information foraging loop, and a sensemaking loop. In information foraging, analysts search and filter relevant information from various data sources. Then, in the sensemaking loop, analysts take information gathered from foraging and schematize it in some way. This latter process is most relevant to the synthesis study described here. In Pirolli and Card's terms, the act of collecting, organizing, and adding meaning to multiple pieces of information is a bottom-up (from data to theory) process of schematizing.

There is substantial room for improvement in visualization tools with respect to their support for developing hypotheses. Current systems provide limited support for connecting dissimilar data sources, exposing sources of uncertainty, and revealing causal relationships (Amar and Stasko 2005). Additionally, the discoveries that analysts make with visualizations are not usually captured or integrated with the data they are derived from (Thomas et al. 2001). Discoveries and the reasoning behind them are often only stored in the mind of the analyst. This makes it difficult to determine what aspects of

visualization afford the most potential for hypothesis development, and what improvements should be made to reduce barriers to hypothesis development. By connecting visualization tools with visual synthesis support tools, hypotheses can be stored and made explicit. This will enhance our ability to evaluate and improve visualization tools to support real-world analytical situations.

2.4 Recent Advances in Synthesis Tools

Researchers in the information visualization community have begun to tackle the problem of supporting synthesis with new visually-driven environments for collecting and adding meaning to analytical results. The study reported here is intended to augment this work with empirically-derived design guidelines. Current synthesis support tools include Analyst's Notebook (i2 2007), nSpace (Wright et al. 2006), GeoTime (Eccles et al. 2008), Scalable Reasoning Systems (Pike, May, and Turner 2007), EWall (Keel 2007), and Jigsaw (Stasko et al. 2007). A common theme driving the development of such systems is that providing users with interactive, visual interfaces for constructing knowledge from analysis artifacts will help them develop compelling stories about their findings that can be presented to decision makers (Gershon and Page 2001).

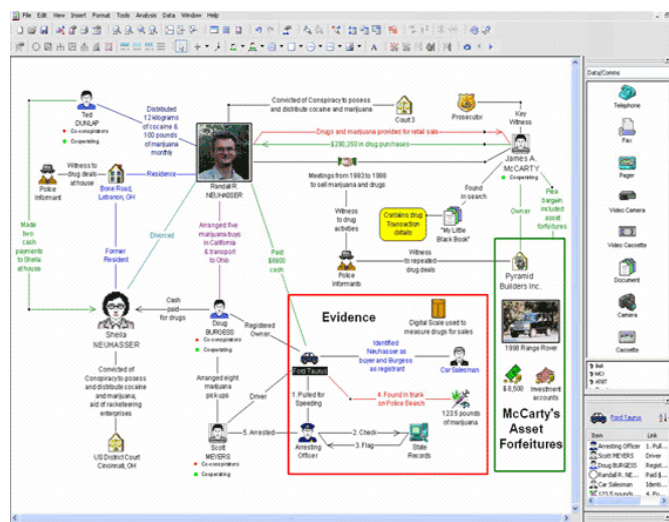


Figure 4: A sample screenshot from Analyst's Notebook.

Analyst's Notebook (i2 2007), a tool developed by i2 Inc. is commonly used in intelligence analysis and law enforcement settings to organize and add meaning to

collections of information (Wright et al. 2005; Xu and Chen 2005). Analyst's Notebook allows users to assemble multimedia and construct layouts that describe complex scenarios. Its interface provides a large, blank canvas on which users can arrange individual pieces and assign text, photos, or graphics to represent information and the links that may exist between multiple fragments (Figure 4).

Recent work by Oculus Info has resulted in the development of a tool called nSpace – a “sandbox for analysis” where analysts can assemble and organize information in both formal and ad-hoc structures (Wright et al. 2006). In nSpace, the post-it note is used as a flexible metaphor for developing and connecting analysis artifacts. The interface features a large blank canvas on which notes, graphics, and other information can be flexibly arranged (Figure 5). Information can include evidence taken directly from other tools, or it can be added in the form of questions or concepts recorded by the analyst – allowing combinations of direct and derived evidence.

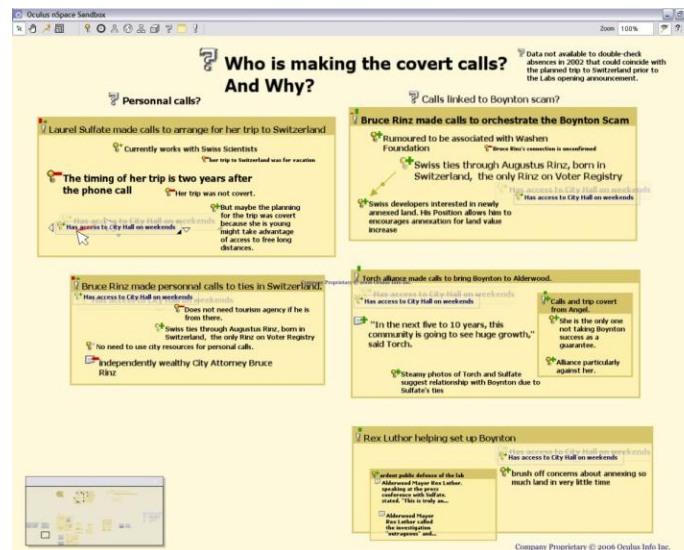


Figure 5: Synthesis demonstrated using the nSpace Sandbox tool (Wright et al. 2005).

Oculus has also recently developed a storytelling extension for GeoTime, their space-time visualization environment (Eccles et al. 2008). With their tools, analysts can take snapshots of the visualization and associate these snapshots with text descriptions that contextualize their findings in a way that is understandable to decision makers. Links to the snapshots from the storyboard allow users to return to the visualization to explore

referenced patterns at any time (Figure 6), eliminating the typical separation of visual analytic environments and the tools used to add meaning to their results.

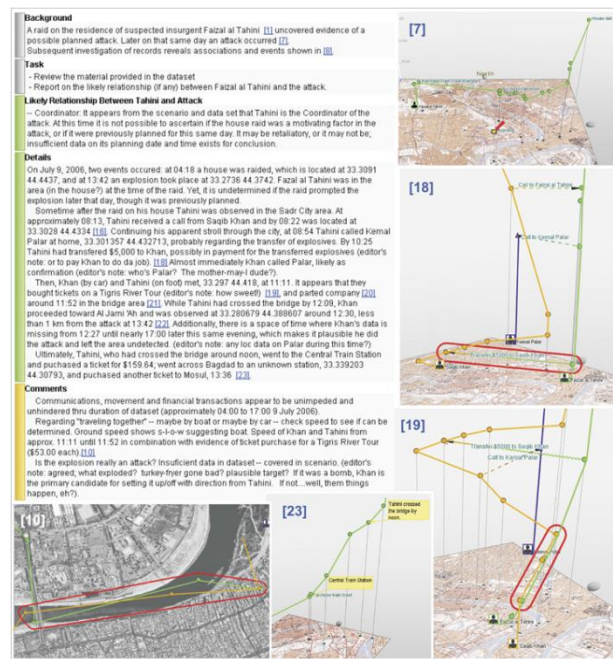


Figure 6: Storytelling tools in GeoTime, showing how direct links to the visualization can be embedded in analytical narratives.

Eccles et al. situate support for storytelling in GeoTime as part of a process to bridge the gap between patterns derived from data and presentable narratives (Figure 7). They describe current systems as good at performing the former task and weak at supporting the latter. It is possible to see similarities in this framework to earlier theoretical processes described by DiBiase (1990) and MacEachren (1994, 1995). In both cases specialized synthesis tools are called for to transition from analysis to presentation.

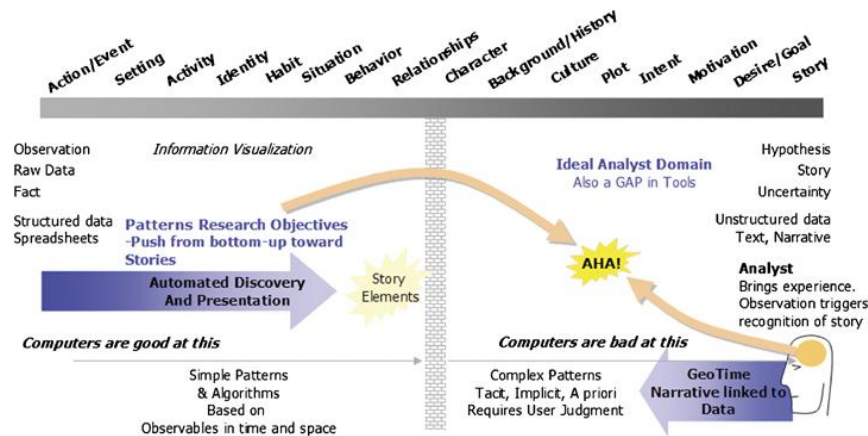


Figure 7: Model of the transition from data to storytelling proposed by Eccles, et al. (2008).

The Information Interfaces Group at Georgia Tech has recently developed a text report visualization toolkit called Jigsaw (Stasko et al. 2007). This toolkit features multiple, coordinated views designed to explore entities derived from large collections of text reports. It also features coordination with Microsoft's OneNote annotation software. Jigsaw users can write down observations and take snapshots of the Jigsaw interface and organize these inside OneNote while working with the visualization (Figure 8). It is unique among recent synthesis support tools in that it uses a tablet interface to facilitate synthesis, enabling users to develop personalized knowledge representations.



Figure 8: The Jigsaw visualization toolkit features multiple coordinated views and a tablet interface for recording and adding meaning to discoveries.

The National Visualization and Analytics Center (NVAC) at Pacific Northwest National Laboratory (PNNL) has recently presented a synthesis tool called the Scalable Reasoning System (SRS). The SRS is a web-based environment for organizing bits of information represented as individual post-it notes on a flexible canvas (Figure 9). Users can conduct web searches and use web services to retrieve information, and then represent findings as notes or links between notes (Pike, May, and Turner 2007). Automated methods can be applied to information in SRS to develop simple visualizations for both text and numeric data – opening the door for subject matter experts to integrate visualization into their work without requiring substantial training investments. Additionally, artifacts and links in SRS can be given confidence and quality ratings using interactive sliders.



Figure 9: SRS lets users synthesize information in a web browser interface (Pike, May, and Turner 2007).

Researchers at the Massachusetts Institute of Technology have introduced a synthesis support environment called the Electronic Card Wall, or EWall for short (Keel 2006, 2007). The EWall is designed to support collaborators working at a distance as they search for, retrieve, and share information artifacts with each other in a dynamic workspace. Information artifacts are represented in the form of cards that can be arranged on a blank workspace (Figure 10). EWall users can assemble information in personal workspaces and share pieces of their individual workspaces on a global, collaborative workspace.



Figure 10: The EWall workspace and a closeup view of a prototypical information card (Keel 2007).

2.5 Discussion

The preceding sections situate this study within current research trends in geovisualization and information visualization. Prior work has shown that visualization tools can generate insights, but that current systems are just beginning to tackle the problem of collecting, organizing, and adding meaning to those insights so that they can be passed forward into presentation formats that are useful for decision making. Developers of these systems will benefit from the characterization of synthesis and empirically-derived design guidelines that are the products of this dissertation – important research that has been left undone until now.

The next chapter describes the mixed qualitative method approach used to complete this study. It describes interview and experimental procedures that were developed to characterize synthesis and suggest design guidelines for future synthesis support tools.

Chapter 3 – Research Methodology

This chapter describes the methodological elements selected for this study of synthesis in geovisualization. Three primary research efforts were combined to develop answers for the research questions outlined in Chapter 1. First, interviews with disease surveillance and biological/chemical threat analysts at PNNL were conducted to elicit knowledge about the current state of synthesis, and to envision possible new synthesis support tools. Second, a synthesis experiment was completed where individual PNNL analysts synthesized information from artifacts in a prototypical analysis scenario. This experimental method was repeated with a group of expert biologists and geographers at PSU who completed the task in both individual and collaborative settings. Finally, the results from interview and experimental data were distilled in order to develop a set of design guidelines for future tool development.

This chapter begins with a description of the general methodological approach used in this research. Next, it provides details about the analysts and experts who were recruited to take part in interviews and experiments. Then it explains the procedures used to conduct the interviews and experiments. The final section describes how the resulting data was analyzed to develop a design framework for synthesis support tools.

3.1 General Methodology

Exploring the process of synthesis in geovisualization poses two key methodological challenges. First, there are no prior examples of empirical work that characterize synthesis that could suggest appropriate experimental methods. Second, the theory that describes synthesis describes it as a transitional activity that takes place somewhere between exploration/analysis and final presentation – providing a somewhat vague guideline for how to situate an experiment to explore synthesis. Because the process of synthesis is poorly understood a qualitative approach is an appropriate choice for revealing the character of synthesis.

This research uses a mixed qualitative methodology (Creswell 1998) for characterizing synthesis activities and developing design guidelines for tools to support geovisual synthesis. Mixed qualitative method approaches combine multiple research methods

(e.g. interviews, experiments, and document analysis) in order to develop a comprehensive understanding of complex phenomena. They also allow results to be triangulated from multiple angles to judge their validity. Mixed qualitative investigations have been used in the past to design and evaluate geovisualization tools (Robinson et al. 2005; Slocum et al. 2003b; Andrienko et al. 2002) as well as information visualization tools (Seo and Shneiderman 2006; Saraiya, North, and Duca 2004).

Design research like the work described here can be classified as one of two types – formative and summative. These two types of design research were first discussed in the HCI community (Hix and Harston 1993). Battenfield (1999) later described these two types of evaluation in terms of an effort to design a geospatial digital library. According to Battenfield, formative design involves the development of new design ideas through knowledge elicitation activities, usually with a small group of end-users. Summative evaluations are designed to compare specific tools against each other to assess how well they work, often with the goal of obtaining generalizable results. Mixed qualitative methodologies are particularly useful for formative design efforts (Shneiderman and Plaisant 2006). The research reported here is a formative design effort intended to characterize synthesis and develop our understanding of it into design guidelines for new synthesis tools.

The experiment design used in this research was intended to simulate real-world analytical work. The goal was to observe realistic work, with realistic constraints, in an activity that encouraged participants to draw upon their previous experience. This was achieved by developing a prototypical analysis scenario and presenting participants with the scenario and set of information artifacts representative of the heterogeneous mix they would encounter in a real analytical situation. Scenarios as used in the design and evaluation of software tools are envisioned depictions of user needs and activities, usually embedded in a narrative (Carroll 1994, 1995). They are useful for design and evaluation to explore current and/or envisioned situations – and they are usually implicit in design efforts that rely on other design/usability methods. Scenarios can be based on observing analysts at work and/or on critical incidents identified in debriefing sessions.

The scenario developed for this research focuses on disease surveillance epidemiology as the primary domain of interest. Epidemiology can be defined generically as a medical science that seeks to characterize, explain, and control the incidence of disease in populations (Last 2001). Research in epidemiology generally falls into one of two main traditions; descriptive and analytic (Gordis 2000). Descriptive epidemiology seeks to characterize the spread of disease in a particular population. Analytic epidemiology seeks to test hypotheses about the causes of diseases in particular populations, usually by testing intervention strategies to evaluate their effectiveness. The domain of interest for this study is descriptive epidemiology, and more specifically disease surveillance, where epidemiologists and other analysts systematically monitor a variety of data sources to describe and track disease outbreaks.

Secondary domains of interest for this study include biological/chemical threat surveillance analysts, disease biologists, and geographers. Users from these domains are likely to work in teams to monitor and mitigate disease outbreaks, making their perspective on synthesis relevant to the primary area of interest.

3. 2 Participants

A total of eighteen analysts and experts were recruited to take part in this research. Eight disease surveillance and biological/chemical threat analysts were recruited from Pacific Northwest National Laboratory to participate in interviews and individual synthesis experiments. These analysts were recruited with assistance from members of the National Visualization and Analytics Center (NVAC) at PNNL who were asked to identify disease and biological/chemical analysts who would be likely end-users of advanced geovisual analytic tools currently in development. Each analyst was provided with a stipend by NVAC to compensate for their time spent participating in the research.

Five GIScience experts from the Penn State GeoVISTA Center and five infectious disease experts from the Penn State Center for Infectious Disease Dynamics were recruited to take part in individual and collaborative synthesis experiments. These experts are all postdoctoral research associates or senior PhD candidates in their respective laboratories. They were recruited with email solicitations and were provided with a \$50 stipend for their time.

The strategy guiding participant selection was to explore potential differences between real world analysts and those who have expert training who might become analysts in the future. It is important to know not only what is needed to support current analysts, but also to have insight into how synthesis support tools may need to function once people currently receiving education and training enter the workforce in the years to come. It is also of interest to note whether or not analytical training for those in different disciplines has an impact on how participants synthesize results in an experimental setting. Additionally, broadening the participant group made it possible to conduct multiple experiments with sample sizes large enough to derive useful results.

3.3 Interviews

In July of 2007 the analysts recruited at PNNL were interviewed with the goals of eliciting knowledge about the current state of synthesis support tools, and to develop possible design directions for future synthesis support tools. Recruited participants from the Penn State group were not interviewed because the goal here was to find out about how analytic synthesis is currently carried out in the workplace – a task that is not common to research-oriented experts like those recruited from Penn State.

An hour long structured interview was developed to shed light on primary research questions one and two, which focus on how analysts currently conduct synthesis as well as how they envision future synthesis support tools.

A structured interview format was chosen to ensure that all participants received the same questions and that answers across the group could be more directly comparable. Structured interviews require all questions to be preselected, placed in a pre-determined order, and asked without modification or adlib follow-ups (Creswell 1998; Silverman 2004). They do not provide for flexibility like semi-structured or unstructured interviews where the questions can be created or modified during the interview to probe potentially interesting avenues. They do provide for more readily comparable answers and help to alleviate problems with interviewer bias that can occur when questions are open to modification. In this research, the interview was intended to collect basic and comparable knowledge about the character of current and projected analytical synthesis,

making a structured format more appropriate than an open-ended approach. This structured input was complemented by the more open nature of synthesis experiments in which participants were free to approach the problem (within its constraints) using their own strategies.

3.4 Synthesis Experiments

To adequately design and develop synthesis support tools it is necessary to observe how synthesis takes place. For that reason an experiment was designed to simulate the real-world task of determining who or what was responsible for an Avian Influenza outbreak in the Pacific Northwest.

Participants were instructed that an avian influenza outbreak had occurred in the Pacific Northwest and that their task was to develop hypotheses for the source of the outbreak using the artifacts and tools they had been provided. The experiment design features a synthesis activity in which participants organize and annotate a set of physical artifacts (provided on 3.5" x 5" laminated cards) on a paper-covered workspace. Participants were also provided with markers, pens, adhesive tags, and post-it notes of multiple sizes and colors to modify the workspace as desired. The use of physical artifacts and tools was intended to explore how synthesis occurs without the constraints imposed by current software tools, which typically limit the types of organizational metaphors one can use. Previous work in human-computer interaction studies suggests that analog tools like paper and office supplies can be useful means for eliciting new technological ideas and designs by exploring how the people use the affordances provided by such tools (Sellen and Harper 1997).

Participants at PNNL had one hour to complete the activity, and participants at PSU had 40 minutes (albeit with a smaller set of artifacts). During the activity, participants were asked to state what they were doing. This technique, called verbal protocol analysis (Ericsson and Simon 1993), was used to help provide context for individual actions during the experiment, so that they could be accurately coded in post-experiment analyses. There are two basic variations of verbal protocol methods; talk-aloud, and think-aloud. In the talk-aloud variation, participants are instructed to simply state what they are doing, and to not attempt to explain their actions. In the think-aloud setting,

participants are asked to explain what they are doing and to describe their goals. The talk-aloud method is typically used in experiments designed to explore cognitive processes where explaining actions may interfere with performing the task. A talk-aloud variation of verbal protocol was chosen because the experiment required substantial cognitive attention - a situation in which a think-aloud protocol could interfere with the task (Boren and Ramey 2000).

Participants completed a short training example with the lead investigator at the beginning of the experiment to ensure that they understood these instructions. When using verbal protocol methods it is important to choose a strategy for prompting users to continue their verbal reports (Boren and Ramey 2000) and the simple method of consistently saying “keep talking” was used for these experiments. This prompt was used when participants failed to speak for more than 30 seconds.

In addition, participants were instructed to inform the lead investigator whenever they had an emergent hypothesis, and to then briefly describe this hypothesis so that it could be recorded. This was done to evaluate two things: whether or not the experiment as designed was successful in eliciting real analytical behavior from our participants, and to examine any patterns that might emerge from the types of actions that participants complete before, during, and after arriving at a hypothesis. Participants were not given specific criteria for what constitutes a hypothesis, rather it was left to their judgment to decide if they had developed one or not. The term hypothesis has a variety of meanings, ranging from speculative assumptions to testable theses (Simpson and Weiner 1989). Because the target domain for this work is the descriptive side of epidemiology where the focus is on characterizing the spread of disease in a population (Gordis 2000), the experiment and its materials were designed to elicit hypotheses about the possible source of the disease outbreak. This stands in contrast to what would be expected in a scenario that focuses on analytical epidemiology, where the focus is on testable hypotheses to evaluate population risk and the effectiveness of intervention strategies.

The use of hypothesis development as the goal for the synthesis task reflects several important considerations. First, the focus here on descriptive epidemiology calls for an approach that has participants develop a characterization of the spread of disease

based on available evidence – a task that involves synthesis as defined in this research (organizing and adding meaning to multiple pieces of information) and results in the development of one or more hypotheses that describe the source of the avian flu outbreak. Secondly, in a more generic sense the scenarios in which we envision synthesis feature situations where the analyst begins with a collection of interesting analytical artifacts (which themselves have been developed based on *a priori* hypotheses) and then develops the “big picture” that takes what is currently known and molds it together to create a higher-level understanding of the current situation. Unless and until this conceptualization has been proven to be true, the outcome of such work is best characterized as a descriptive hypothesis.

A variety of relevant theories of scientific and information analysis point to hypotheses as the possible outcome of synthesis. DiBiase’s (1990) depiction of the research process associated with geovisualization describes synthesis as, “...summarizing and generalizing the results of exploratory and confirmatory analyses, and articulating a new, integrated conception of how the components of the research problem interrelate.” In other words, from a variety of individual analytical results, one or more hypotheses will emerge to explain how those results relate with one another.

Another theoretical framework for the process of science facilitated by geovisualization places hypothesis generation in between the actions of exploration and synthesis (Gahegan 2005). The framework proposed by Gahegan features exploration, synthesis, analysis, evaluation, and presentation as key stages of scientific activity, and it suggests that the path one takes through these stages is not necessarily one-way or even linear. Figure 11 shows one potential path through these stages of work, where the imagined user does take a linear path through those activities. Figure 12 shows the potential paths a user might take once they have developed a set of results to return to the initial constraints of their work and try alternatives. In this scenario, one possible outcome of assessing analytical results is to return to and modify initial hypotheses. While this theory does not suggest that synthesis itself results in hypotheses in the way that DiBiase’s (1990) framework suggests, it does support the notion that once analytical results have been generated, one possible outcome is for users to revise and/or propose new hypotheses.

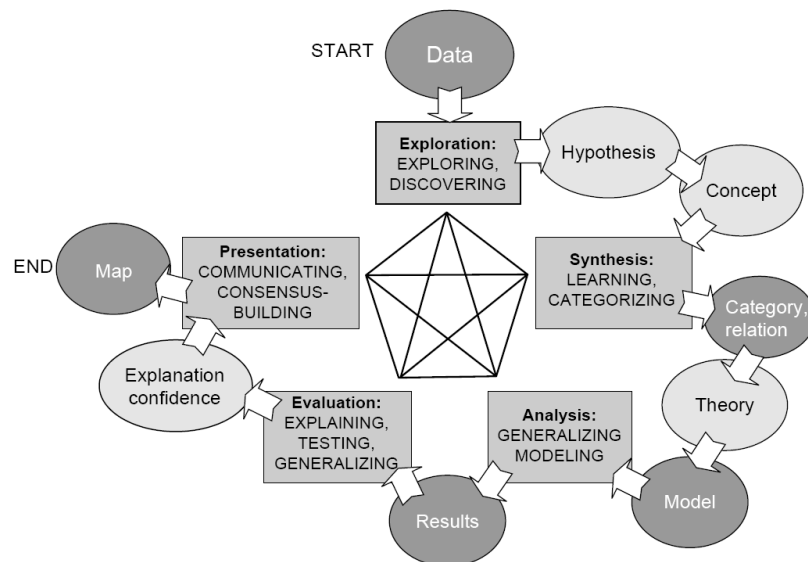


Figure 11: One potential path through the core scientific activities proposed by Gahegan (2005).

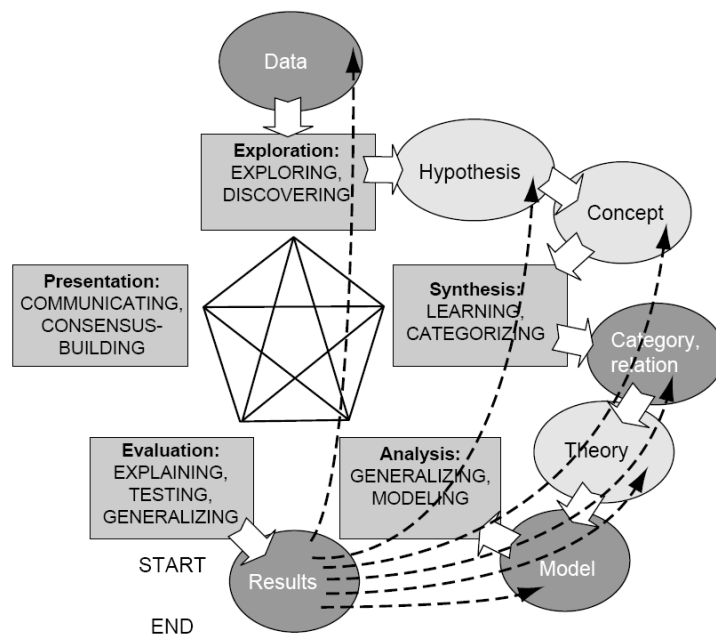


Figure 12: Potential paths that a user could take once they have generated results (Gahegan 2005).

The sense-making process proposed by Pirolli and Card (2005) suggests a loop of activity that involves schematizing information, building a case, developing hypotheses, and searching for support for those hypotheses in the schematized information again

(Figure 13). These parts of the sense-making process (steps 10-13 shown in the diagram below) complement theories of analysis with geovisualization proposed by DiBiase (1990) and Gahegan (2005), elaborating a conception of synthesis that matches the definition used in this research where analysts structure and add meaning to collections of information. In the sense-making loop, the act of schematizing evidence is analogous to the act of synthesis as defined in this study. The sense-making loop proposes that the result of schematizing information is a hypothesis, which can then itself be fed back into subsequent refinement of the evidence collection.

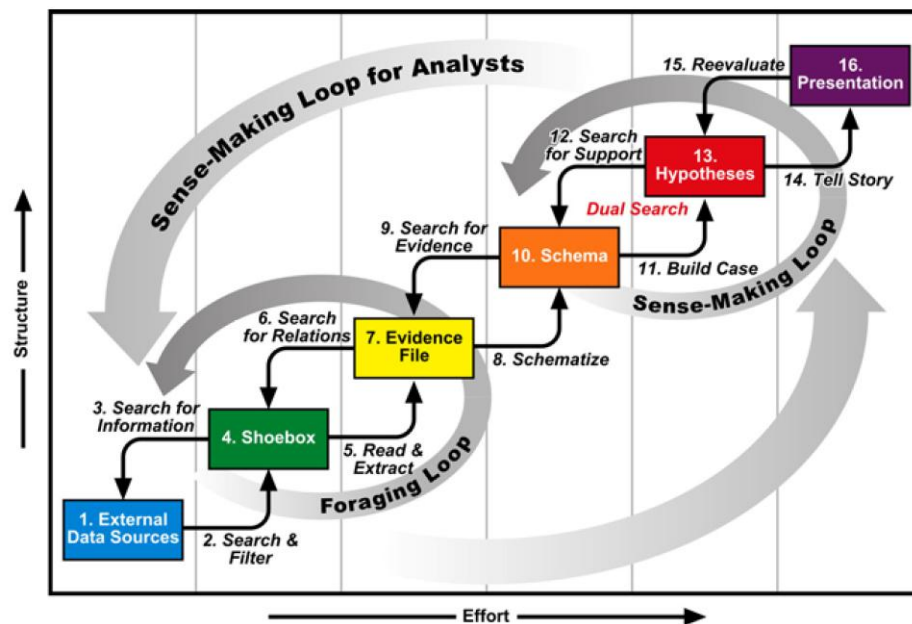


Figure 13: The sense-making process proposed by Pirolli and Card (2005).

At the conclusion of each experiment, a short debriefing session was conducted on-camera between the lead investigator and the participant(s). At that time, the participant was asked to describe how they had organized their information and what they had done to indicate their hypotheses on the workspace. This evidence was gathered to help evaluate coding results and to have the participant identify the organizational methods they had applied.

The first synthesis experiments were carried out in a video conferencing room at PNNL in Richland, Washington in July of 2007. After the completion of these experiments, a

previously planned additional study with individual experts at PSU was modified to include a collaborative component to explore synthesis in multiple-user settings as well. Participants at PSU completed a slightly shorter version of the experiment that had been completed at PNNL using overlapping sets of 36 of the 48 total artifacts, split so that each participant had 12 unique and 24 common artifacts.

Five collaborative experiments were conducted in October of 2007 with pairs of analysts from PSU. One analyst in the pair was recruited from the GeoVISTA Center, while the other was recruited from CIDD (thus individuals having expertise in geovisual analytics methods and tools were paired with individuals having expertise in disease dynamics). Each analyst completed two activities. First, each PSU participant completed an individual experiment with the same instructions provided to PNNL participants – their goal was to determine the source of the outbreak. Second, the participants worked together with their results on a blank workspace situated between their individual workspaces to develop a ranked set of plausible hypotheses to provide to a decision maker. The choice to mix participants from different backgrounds for the collaborative experiment was made to ensure that the collaborative synthesis setting accurately reflected how collaboration was likely to occur in real-world situations, where analysts from a variety of backgrounds will work together on a multi-faceted problem. For the collaborative experiments, the artifact sets were selected so that each participant in a paired group had the information that the other was missing – creating a situation where participants had partially overlapping information, a condition also likely to occur in a real-world analysis situation.

The full set of instructions given to PNNL and PSU participants for the individual experiments are available in Appendix A. The instructions given to PSU participants for the collaborative synthesis experiment are provided in Appendix B.

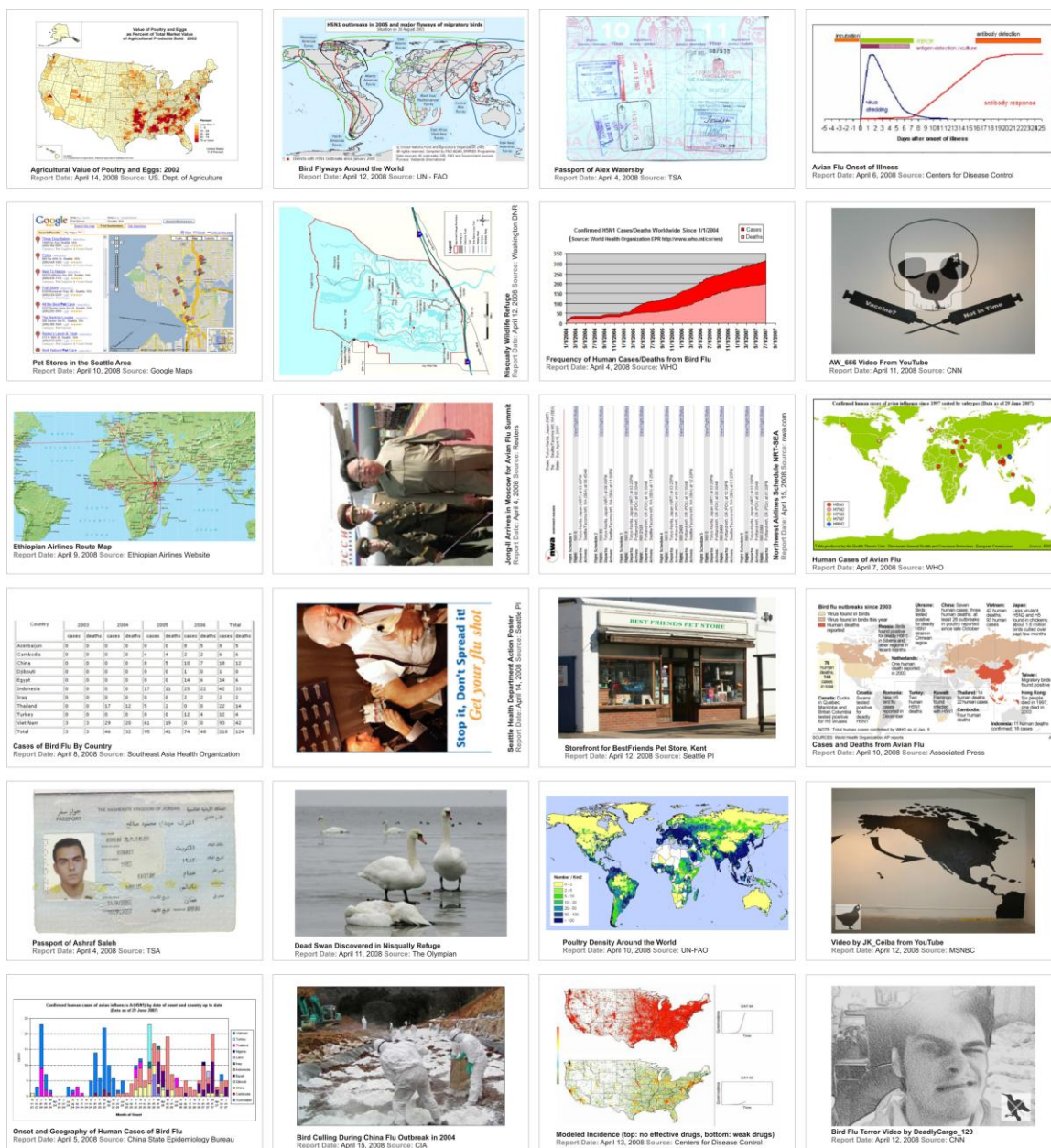
3.4.1 Analysis Artifacts

The objective of the synthesis experiment was to provide a realistic analytical task for participants to complete. A model for this type of task exists in the form of training activities developed to teach analytical methods to new intelligence analysts. One such training activity called The Sign of the Crescent (Hughes and Schum 2003) has been

developed by the Joint Military Intelligence College. It contains a set of text reports that include source information and time stamps. The goal of the activity is for analysts to determine the most likely hypothetical outcomes of a terrorism scenario based on the information they can gather from these reports. The Sign of the Crescent is commonly used as a training exercise for intelligence and crime analysts (Booker et al. 2007). Because there is little guidance for the development of analytical artifacts for synthesis experiments, the Sign of the Red Crescent activity was used as a model for the information included in each artifact. In total, 48 analytical artifacts (Figure 14) were developed for use in synthesis experiments.

The artifacts used in the reported synthesis experiments differ from those in the Sign of the Red Crescent activity in that they include maps, photos, and other graphics as well as text reports. This was done to more accurately simulate the many types of analytical artifacts that analysts are likely to generate using geovisualization tools. A 2-to-1 ratio of graphic artifacts to text artifacts was used to develop the complete set. This choice reflects the fact that geovisualization tools typically generate graphical rather than textual results. The complete set of artifacts is provided in high-resolution format in Appendix C.

The artifacts were designed to weave a multi-threaded story regarding an avian influenza outbreak in the Pacific Northwest. Each artifact features source information and a timestamp, and there are photographs, video captures, maps, data graphics, and text reports included in the set. While many images were borrowed from Google image search results for items related to avian influenza, all time, source, and other text information (including all of the text reports) was contrived to develop the story and potential hypotheses. Appendix D provides a table showing each of the graphical artifacts (since all of the text reports were fabricated), its original source, and whether or not the image was modified from the original for the experiment. To simulate a realistic scenario, the artifacts feature different types of information, including background data, maps of relevant areas, reports and speculation from news and official government sources, and simulated social media. Through the use of different purported sources and report times, elements of uncertainty were also included to simulate varying data quality in real situations.



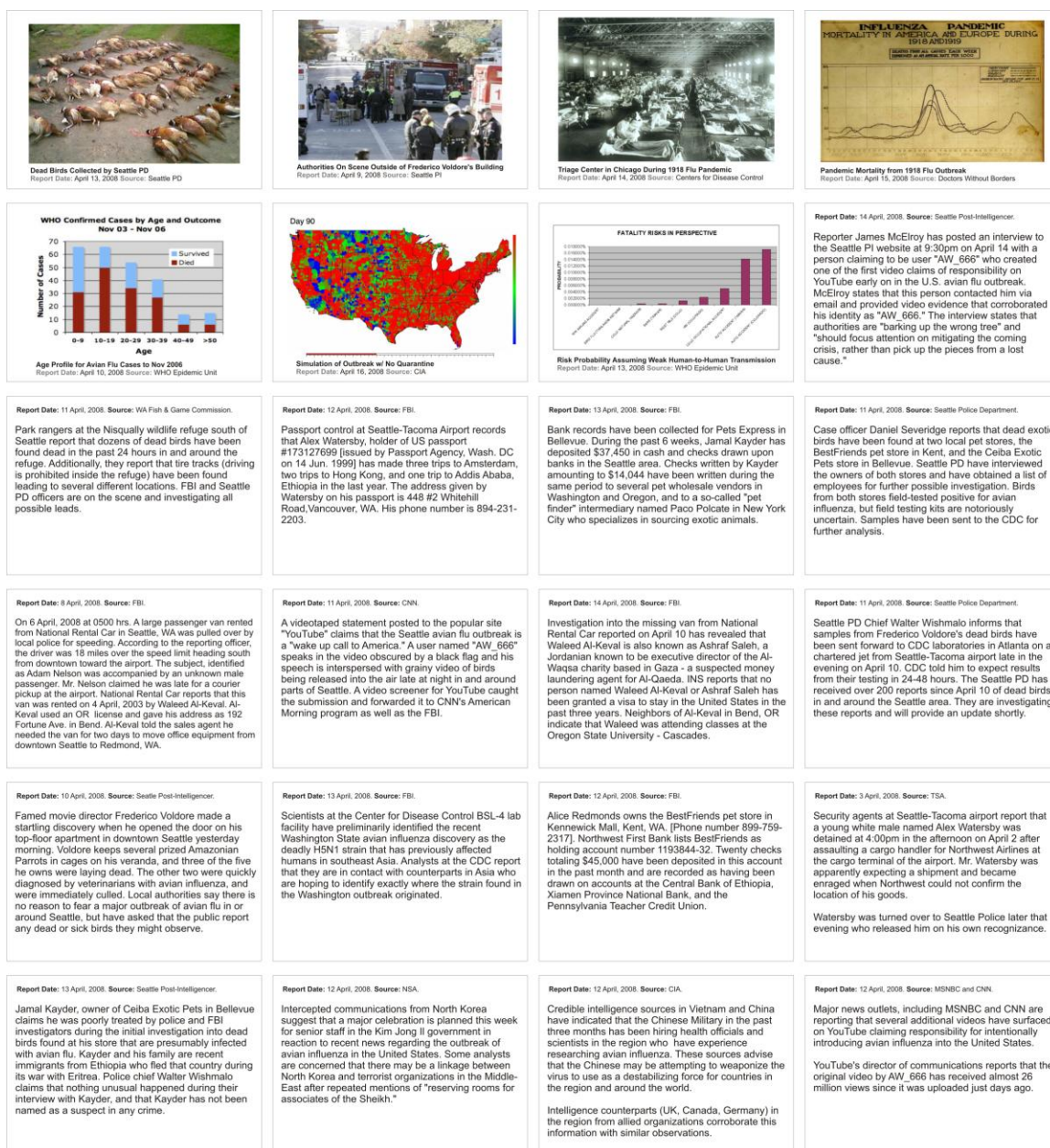


Figure 14: The set of analytical artifacts developed for synthesis experiments.

Particular attention was paid to including a variety of spatial references in the data to require participants to make judgments about hypotheses in terms of how likely they fit the relevant geography. Flight schedules, financial transactions, and flu incidence/mortality data provide contextual geographic references to help participants determine whether or not the local geographic extent of the outbreak made sense in

relation to where avian flu existed previously, how it could get to the region, and where the funding to support that effort would likely come from.

Based on the information provided, there are at least five potential sources for the outbreak, and there are many more permutations possible given combinations of those potential sources. The five threads devised for the experiment include: a natural occurrence based on bird migration, a person named Alex Watersby who intentionally spread the flu to wild birds and through pet stores, an Al-Qaeda operative named Waleed Al-Keval who infected wild birds, an unintentional outbreak caused by illegal pet trade activity by local pet stores, and a plot by North Korea and China to spread avian influenza to disrupt poultry commerce in America. All of the embedded hypotheses require the participant to develop some understanding of the geography involved and gauge evidence based in part on spatial plausibility (e.g. is it reasonable that Alex Watersby could have spread infection at pet stores near Seattle as well as the wildlife refuge south of Seattle in a few days time?). The number of artifacts that provide direct or indirect evidence for each hypothesis is summarized here in Table 1. Some artifacts provided evidence to support multiple hypotheses, so totaling numbers in the table does not match the complete set of 48 artifacts. Additionally, ten of the artifacts did not provide direct or indirect evidence to any of these hypotheses, rather they supplied historical or other contextual information about avian influenza in general.

Hypothesis	Direct Support	Indirect Support
Naturally occurring outbreak due to infected bird migration	3	3
Alex Watersby intentionally spread infected birds in pet stores and a nearby wildlife refuge	4	6
Al-Qaeda operative Waleed Al-Keval infected birds in a nearby wildlife refuge	2	4
Unintentional outbreak caused by black market pet trade	4	4
North Korea and China to introduced avian flu to disrupt U.S. poultry industry	3	2

Table 1: Experiment scenario hypotheses and the number of artifacts in the collection that directly or indirectly support them.

The individual experiment results discussed in Chapter 4 includes additional discussion about the specific hypotheses that participants developed, and a table that summarizes the similarities and differences in hypotheses developed between different participant groups at PNNL and PSU.

3.4.2 Experiment Setup

The experiment was set up using a 36 inch by 36 inch square workspace. This workspace size was chosen because it provided ample space for all 48 artifacts to be arranged, and because in a trial run it was found not to be too large for a user to reach across easily. The workspace was covered in plain white paper. Colored markers, pens, adhesive tags, and post-it notes of multiple sizes and colors were provided nearby so that participants could alter the workspace and artifacts as desired (Figure 15). These tools were chosen because they are commonly used in office environments to keep track of and organize information. They were also used because together they provide a very flexible creative palette with which participants can modify the workspace and artifacts during the experiment. Given that the goal of the synthesis experiments is to characterize how participants organize and add meaning to information artifacts, it is important to provide flexible means for doing so in the analog setting.

Standard Post-It Notes	Colors indicate categories, allows substantial writing, sticky but movable
Small Post-It Notes	Colors indicate categories, allows limited writing, sticky but movable
Colored Tags	Colors indicate categories, allows very limited writing, sticky but movable
Colored Arrows	Colors indicate categories, sticky but movable, linkages or directions indicated with arrowhead
Colored Markers	Colors indicate categories, supports annotation
Ballpoint Pens	Colors indicate categories, supports annotation
Paper Workspace	Supports annotation

Table 2: Affordances offered by analog tools provided for synthesis experiments.

The properties of an object that determine how it can be used are called affordances (McGrenere and Ho 2000). The basic affordances that each of the analog tools selected for synthesis experiments provide are summarized in Table 2. These tools were selected to provide flexible and topic-neutral means for organizing, annotating, and adding meaning to the artifacts. Similar flexible tools could be engineered in software, and in such environments some of the analog limitations with respect to object size (post-it writing area, for example) and permanence (annotations cannot be undone or moved, for example) could be removed. Despite the limitations of analog materials, analog experiments have been shown to elicit new ideas for digital technology through observations of how participants make use of affordances provided by paper and other real-world tools (Sellen and Harper 1997). It has also been observed that analog methods still tend to elicit greater creativity among users when compared to their closest digital counterparts (Stones and Cassidy 2006) – and a key goal of this study is to allow for creative approaches to the synthesis task as much as possible.

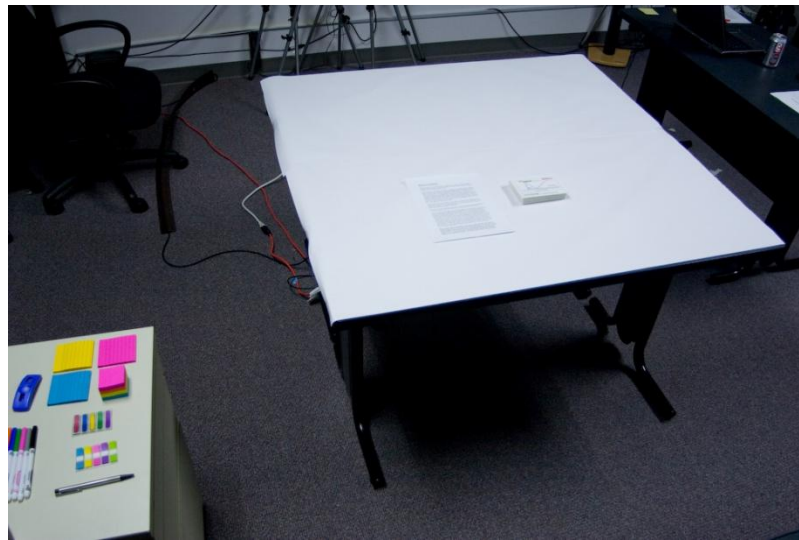


Figure 15: The synthesis experiment setting.

Artifacts were re-sorted for each participant using a random permutation provided by the website www.randomization.com. This was done in order to minimize potential order effects (see Eisenberg and Barry 1988). The randomized artifacts were placed on the workspace in a stack at the beginning of each experiment.

A video camera set on a tripod was set facing the participant during the experiment. This camera recorded the duration of the experiment to allow for later analysis of actions and verbal reports. During the experiment the lead investigator remained in the room to record emergent hypotheses reported by participants and to prompt them to keep talking if they were quiet for more than thirty seconds. Figure 16 shows a screen capture from one of the videos recorded at PNNL.

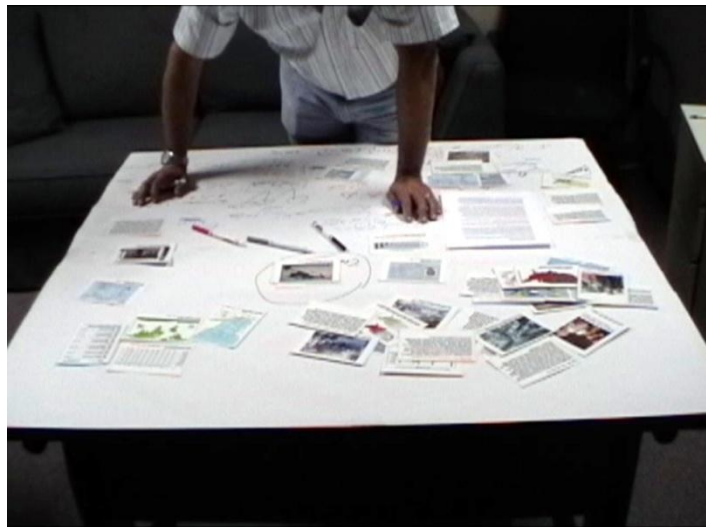


Figure 16: Sample screen capture from PNNL synthesis experiments.

3.5 Experimental Result Coding and Analysis

The synthesis experiments generated a total of twenty-three video recordings. The goal was to extract useful information from these recordings in a systematic manner that would enable the development of specific software design guidelines. The focus here was on defining which software tools and functions would be necessary to support what the user was doing with the artifacts during the experiment. To that end, a coding scheme was developed to describe the low-level events that users initiated to complete the synthesis experiment. The problem of deciding what is a separable action in this case is non-trivial, and a conservative approach was taken here to identify actions that involved the actual use of artifacts, tools, or the workspace. The decision was made that coding would apply only to actions that were separable and obvious, using the verbal protocol of the user as well as the context of the action (for example, the work

immediately prior to the action in question) to help guide choices. More subtle actions like gestures or verbal declarations (outside those that indicated emerging hypotheses) were not set aside for coding in this study.

The first coding scheme was developed by the lead investigator after watching a sample video from each of the three experiment types (individual experiments at PNNL and PSU, and a collaborative experiment at PSU). These videos were examined to identify what software tools would be required to support what participants did with artifacts, tools, and the workspace to complete the synthesis task. This scheme was then further refined by a group of seven interface and software developers from the GeoVISTA Center during a meeting in which the experiment and a sample of the videos were reviewed. A final round of refinement then took place after the lead-investigator completed sample coding of three of the videos with the working coding scheme (one from PNNL, one individual and one collaborative from PSU). The final coding scheme is presented here:

A1 - Annotate (text): *Text written on the workspace or a tag.*

A2 - Annotate (drawing): *Graphics drawn on the workspace or a tag.*

C1 – Collapse Group of Artifacts: *After grouping artifacts, placing them in a stack where only the top artifact can be seen.*

C2 - Expand Group of Artifacts: *Taking a collapsed group of artifacts and spreading them out again for viewing.*

G1 - Group Artifacts (unknown): *Placing artifacts in close proximity on the workspace, but without verbal or non-verbal communication to suggest what they have in common.*

G2 - Group Artifacts (hypothesis): *Placing artifacts in close proximity on the workspace, with verbal or non-verbal communication that they are part of the same hypothesis.*

G3 - Group Artifacts (category): *Placing artifacts in close proximity on the workspace, with verbal or non-verbal communication that they are part of the same category (e.g. people, places, and other qualitative attributes from the evidence).*

G4 – Group Artifacts (type): *Placing artifacts in close proximity on the workspace, with verbal or non-verbal communication that they are the same generic type of artifact (picture, text, video, etc.).*

G5 – Group Artifacts (time): *Placing artifacts in close proximity on the workspace, with verbal or non-verbal communication that they are arranged according to time.*

G6 – Group Artifacts (read or un-read): *Placing artifacts in close proximity on the workspace, with verbal or non-verbal communication that they have or have not been read.*

H1 – Stated Hypothesis: *A participant verbally indicates to themselves or the experiment proctor that they have developed a hypothesis, and they describe this hypothesis.*

L1 - Link Artifacts (network): *Placing artifacts or drawing an arrow or other graphic in such a way that it is clear from verbal and/or non-verbal communications that the artifacts are part of a node-link diagram.*

L2 - Link Artifacts (hypothesis): *Placing artifacts or drawing an arrow or other graphic between them in such a way that it is clear from verbal or non-verbal communication that the artifacts are linked through a common hypothesis.*

- S1** - Sort (time): *Quickly arranging artifacts according to time.*
- S2** - Sort (category): *Quickly arranging artifacts according to category.*
- S3** - Sort (type): *Quickly arranging artifacts according to type.*
- S4** - Search (category): *Verbal or non-verbal communication that suggests a search for artifacts on the workspace that are part of a particular category.*
- S5** - Search (time): *Verbal or non-verbal communication that suggests a search for artifacts on the workspace that are from a particular time.*
- S6** - Search (for read or un-read artifacts): *Verbal or non-verbal communication that suggests a search for artifacts on the workspace that have or have not yet been read.*
- S7** - Search (keyword): *Verbal or non-verbal communication that suggests a search for artifacts on the workspace that mention a specific keyword.*
- T1** - Tag (hypothesis): *Placing a physical tag (post-it or other sticky tag) on an artifact to indicate it is part of a particular hypothesis.*
- T2** - Tag (category): *Placing a physical tag (post-it or other sticky tag) on an artifact to indicate it is part of a particular category.*
- T3** - Tag (certainty): *Placing a physical tag (post-it or other sticky tag) on an artifact to indicate certainty.*
- T4** - Tag (follow-up): *Placing a physical tag or writing a question on or near an artifact that indicates something for future follow-up.*
- T5** - Tag (time): *Placing a physical tag (post-it or other sticky tag) on an artifact to indicate it is part of a particular timeframe.*
- T6** - Tag (place): *Placing a physical tag (post-it or other sticky tag) on an artifact to indicate it corresponds to a particular geographic location.*
- T7** - Tag (network): *Placing a physical tag (post-it or other sticky tag) on an artifact to indicate it is part of a particular social or other network.*
- Z1** - Zoom (single item): *Picking up a single artifact from the workspace to inspect it closely.*
- Z2** - Zoom (group of items): *Picking up multiple artifacts from the workspace to inspect them closely.*

For collaborative videos, the prefix A, B, or C is used to denote actions by the GeoVISTA participant, the CIDD participant, or both participants together.

The videos were coded with the help of Transana (Woods and Fassnacht 2007), a software tool designed for qualitative analysis of audio and video data. In Transana, timestamps can be added to transcripts that serve as live links back to that moment of video or audio. During coding, events were timestamped, and then assigned a letter and number code from the coding scheme. This allowed the time of the event to be recorded along with its description, and these timestamps were used later during code reliability evaluation.

In any qualitative analysis it is important to ensure investigator bias is reduced as much as practical. One typical way of assessing the credibility of coding data is to gauge code reliability (Yawn and Wollan 2005). To that end, a sample of ten videos out of the twenty-three total available videos was selected to test coding reliability. Four videos each from PNNL and PSU individual experiments were selected, as well as two videos from PSU collaborative experiments. Project funding did not allow for a full recode by multiple

independent coders – a more ideal code reliability test. Two independent graduate student coders were recruited from the GeoVISTA Center who had not participated in the experiment and who did not have substantial prior knowledge of the work. The coders were each given five videos (two from PNNL/PSU individual experiments, one from collaborative experiments at PSU), which had transcripts including event markers but stripped of the specific code that the lead-investigator had previously assigned. They were given basic training on how to use Transana to navigate videos and add codes to their transcripts, and provided with the full set of codes and their corresponding definitions.

Code reliability was assessed using a percent agreement measure, a commonly used method of inter-rater reliability (Yawn and Wollan 2005). Percent agreement simply measures the percent of coded entries that match between coders. It is not a perfect measure, as it does not account for the chance that a coder will guess when assigning a code and be correct (Fleiss, Levin, and Paik 2003). However, in this case because there are 28 possible codes (and coders were allowed to combine them together if they felt two things were happening concurrently), the chance of guessing a correct code at random is small (3.6%). The percent agreement values are presented in Table 3. Rates above 87% indicate high levels of code reliability for the results reported in this research.

	Coder A	Coder B	Combined
Percent Agreement	87.64	89.15	88.4

Table 3: Percent agreement between two independent coders and the lead investigator after sample recoding.

The coded results were converted into Microsoft Excel tables that were then manipulated using Tableau desktop visualization software (Mackinlay, Hanrahan, and Stolte 2007) to create time series graphs for each user and summary graphs for each user group. These materials were further edited using CorelDRAW to enhance readability, to assign an appropriate color scheme (courtesy of www.colorbrewer.org), and to develop page layouts for presentation.

Chapter 4 – Characterizing Geovisual Synthesis

In July of 2007 eight analysts at PNNL were interviewed with the goals of eliciting knowledge about the current state of synthesis support tools, and to gather input on possible design directions for future synthesis support tools. A one hour structured interview was conducted with eight analysts from disease surveillance and bioterrorism domains. The full questionnaire is provided as a supplement in Appendix E. Interview data in this chapter comes from digital audio recordings that have been transcribed using Transana qualitative analysis software (Woods and Fassnacht 2007). The transcripts of all eight interviews total 22,057 words. Answers for each question were compiled and evaluated as a group to derive the results reported in this chapter. The goals for interview data analysis were to identify areas of agreement and disagreement between analysts. Table 4 shows how each section in this chapter corresponds to specific interview questions.

Section	Interview Questions
4.1 - Participant Background	1a,1b,1c,1d
4.2 - Analysis Artifacts	1e, 2
4.3.1 - Organizing Results	3
4.3.2 - Developing the “Big Picture”	4, 13
4.3.3 - Recalling Prior Work	6
4.3.4 - Collaborating With Results	7, 8
4.3.5 - Explaining Results	11, 12
4.3.6 - Result Provenance	10
4.3.7 - New Synthesis Support Tools	5, 7, 10

Table 4: Correspondence between sections in this chapter and interview questions.

The first of the following sections describes participant background information and analytical expertise. This is followed with a discussion of interview results that describe the common types of analytical artifacts that participants generate in the course of their regular work. Then separate sections present results that describe how synthesis is currently conducted, the context of synthesis, and how synthesis is envisioned.

4.1 Participant Background

Four male and four female analysts participated in this study, working in various roles as analysts at PNNL. Three are research program managers, focused on biological and chemical monitoring and security issues. The remaining five are research scientists, three working in biology and medicine, and two working in chemistry. All of these participants are actively engaged in providing analytical products for clients in a wide array of U.S. government agencies. Projects are typically initiated by client agencies, who issue contracts to PNNL analysts for reports or other analysis products. Participants in this study stated they were currently working on specific topics like avian influenza surveillance, disease modeling, and chemical and biological weapons proliferation.

The problems that analysts in this study undertake are dynamic and intricate – problems that typically involve collaboration among many analysts, each of which has a particular area of expertise. The products they generate are often reports for decision makers, which link together individual analyses into a coherent story. The nature of their work makes these participants likely future users of synthesis support tools.

4.2 Analysis Artifacts

A key area of interest in terms of supporting synthesis is to develop an understanding of what types of artifacts are most common. Toward that goal, participants were asked to describe the typical analytical results that emerge from their work. Responses indicate that artifacts can take many forms, including tables, graphs, images, schematics, and text reports. The program managers in this study indicated that text reports were the most common results they worked with, while the research scientists mentioned that other types of artifacts were more common.

When asked to describe how artifacts are stored, participants indicated that operating system file folders, Excel spreadsheets, and PowerPoint presentations were typical mechanisms for collecting artifacts. Participants also mentioned that email archives are important as they often contain results in the form of attachments from colleagues. According to participants in this study, shared network storage is the most common

method of collaborative artifact storage, and in some cases email is used to share artifacts among multiple users.

4.3 Current and Envisioned Synthesis at PNNL

The primary purpose of conducting interviews with analysts at PNNL was to elicit knowledge about how synthesis is currently conducted, and to find out what analysts envision for future synthesis support tools. To explore how synthesis is currently conducted, analysts were asked to talk about the following key areas of interest:

1. How results are organized
2. How they develop the “big picture” from their results
3. How they handle the problem of recalling prior work
4. How they collaborate with results
5. How they explain their results to others
6. How they handle issues with result provenance

For each of these question topics, interview participants were asked to follow-up their answers with suggestions about how they would envision improving the current state of the art. The following sections cover responses on each issue, and a final section summarizes analysts’ ideas for future synthesis support tools that would improve upon current means.

4.3.1 Organizing Results

Multiple questions in the interview were designed to elicit the current process of synthesis at PNNL. These questions began with a request for analysts to describe the strategies they use to organize their results. Participants responded that they would typically organize results by projects or topics. PNNL 2 stated that they would develop “piles” of results:

I generally tend to assemble things into an administrative pile, which you know I can ignore...except for that are we running out of money sort of deal.

A reference pile, if you will, and then one for the project or one for the technical work specifically, and then normally kind of a reporting pile. And so things will generally flow out of the reference into the project, then into the reporting one.

When asked if these strategies change depending on the type of project they are completing, analysts indicated (with one exception) that they tended toward a single common strategy for organizing results. Analysts cited the need for consistent reporting and communication with clients as reasons for using the same strategy regardless of the context. PNNL 8 differed from the others, stating that different project goals typically require different strategies for handling results, as some projects they work on deal with only a few key pieces of information, while others may involve many more.

4.3.2 Developing the “Big Picture”

Participants were asked to describe methods and tools they use to evaluate the “bigger picture” that situates their results, a portion of synthesis that shifts simple collections of results into coherent information that can be used for reporting. This question revealed some differences between how those who work on disease and biological threats approach this task versus those who work primarily with chemical threats. The former group cited their domain expertise as the main mechanism for this portion of synthesis. PNNL 5, an infectious disease expert described how they situate their results:

I think I have some kind of ability to see where things are going, you know? And I think I draw a lot of those thoughts from, you know, reading the newspaper, watching CNN, um, I've got a book...on the plague...one of the best books on epidemics I've read was "History of the Plague Years." I mean there's the same patterns that flow, from historical knowledge and other media, giving context.

In contrast, analysts who work on chemical threats indicated that they rely on statistician colleagues to help situate their findings. PNNL 6 describes one such scenario:

The statisticians. <laughs> Verifying it with someone else, right. But the graphs typically give you the bigger picture to see what is happening over a time period or whatever you're measuring.

In terms of tools for supporting this task, participants stated the PowerPoint, Word, email clients, and file sharing software are most commonly used. Two participants indicated that in addition to those tools they also make use of Starlight (Risch et al. 1997) and INSPIRE (Wong et al. 2004) visualization systems to create representations of data that provide overviews of their work.

When it comes time to present the “big picture” in report form, PNNL 6 stated that this task requires the use of outlines:

That's the difficult part, trying to figure out what to include, what's important. Ah, usually we try to create an outline and then fill in the outline as we go, trying to determine how to tell the story in the best possible manner. And I struggle with that. It's not easy.

One participant described how presenting synthesized results requires careful attention to defining the relationships between particular results. As PNNL 4 says:

I think that takes a careful analysis of each of those pieces. What they mean, and how they relate, and I think you really have to demonstrate the relation. I think it needs to be very cohesive when it's presented in order to look like it's...a serious result that should be considered as a whole, I think. Because...they all sometimes have to depend on each other. I think especially in the business that we're in, we're trying to get to a root cause or a particular type of technical thing...then you need to be careful with how you present the pieces together.

4.3.3 Recalling Prior Work

An important aspect of synthesis pertains to the ability for analysts to recall and reuse prior work when that becomes necessary. For example, a risk analysis describing the economic and social impact of a potential avian flu outbreak might need to be revisited in the wake of an actual outbreak to evaluate the predictions. For the purpose of better situating the current state of synthesis support, analysts were asked to talk about how they approach this problem.

PNNL 7, an analyst who frequently deals with chemical spectra and other associated data mentioned that in addition to laboratory notebooks, automatically encoded metadata is a useful aid to analytic recall:

Oh I guess that's sort of changed over time but, you have a lab book or sort of like an instrument book. And so you've written down something, maybe what you did that day. And a lot of the instruments these days, depends on the instrument, they'll store a lot of the metadata. Store all of the conditions and all of that sort of stuff. So then you can go back and see what conditions you actually used.

PNNL 3 stated that recalling prior work is a non-trivial task, but that it can be aided by keeping track of items by date:

I would say that's a difficult game. Because a lot of times what I find here is that... I'll work on a project for say 3 or 4 months, then we're pretty much done...and I will work on IRS work for 3 or 4 months and somebody will bring me back and say, "Oh we need to do more work in this area." So I've gotten pretty good at organizing where I put stuff and I try to organize it by date and I'm trying to keep track of all the emails that came to me by date so that I can actually track back through and say OK, "so we were here when I quit."

Several participants indicated that this task is approached most often as a mental exercise, suggesting that tools do not currently play a significant role in aiding this type of synthesis-related task. PNNL 1 described their method for recalling prior analyses this way:

Retracing your steps back to those places, you find the file if it's electronic or paper copy, or it's the papers on your desk...you're trying to find where you were. When you're there you're trying to retrace your steps to catch up and think about where you were. Suppose I built a simulation of a hospital, even a simple one, I'd have to remember what my thoughts were at the time.

4.3.4 Collaborating with Results

Typically analysts at PNNL work on problems that require the work of multiple experts, including collaborators who may be working from multiple locations. To characterize how collaboration impacts synthesis, participants were asked to describe both the tools and methods they use to handle collaboration when it involves managing collections of results.

In terms of tools for managing results among collaborators, participants indicated that they were using the same tools they used for their personal collections. Word documents, PowerPoint presentations, Excel spreadsheets, shared network folders, and email are all commonly used for collecting and distributing results among collaborators. PNNL 5 specified how these tools are used in combination, with email as the means for distributing files created in Excel, PowerPoint, and Word:

I have to tell you, the best thing I really have for sharing results, both here but even you know if you're working globally, you know if you're telling your friend at CDC... is really just email. Just email. Here's the email, here's this, here's the bottom line, here's the enclosure.

With respect to more general collaborative methods, participants stated that conference calls, regularly scheduled in-person meetings, and email conversations are typically used to manage collaborative synthesis. Once a collaborative project has been coordinated, reports are often developed asynchronously using shared documents and file resources, as PNNL 2 describes here:

There's a couple things. One is that we all collect data and put it in a repository but then we also have a shared synthesis activity where again you think about the page...we all are on travel at different times and whatnot and sometimes it's hard to coordinate and have us all seated in the same place...but if we all have access to the document we can be updating it and adding to it and editing it and so you know there's kind of a timeless collaboration that can occur on the actual product.

4.3.5 Explaining Results

Because synthesis is a transitional stage between analysis and presentation, it is important to examine how results, once synthesized, are moved into the realm of presentation. To explore this portion of synthesis, analysts were asked to describe situations in which results were particularly easy to communicate, and how they were communicated. They were also asked to describe a time when results were particularly difficult to communicate, and how they overcame that problem.

Analysts consistently reported that the easiest results to communicate to their clients were those that the client had expected to see. And the most difficult results to explain are those that the client did not anticipate. Participants indicated that they were usually aware how their work would be perceived (either expected or unexpected) before developing their final report, and that their approach to the report would differ depending on this knowledge. PNNL 4 described the two different scenarios this way:

Yeah I would say if it's an expected result. That's probably the easiest, when they're unexpected is probably when it's gonna be most difficult and then you have to properly surround your results with the supporting information. Go back to references and things.

Similarly, PNNL 2 explained what they have found to be the key factor involved in explaining results to clients:

It's actually kind of more the expectation. He expected that we were gonna come back and reinforce what he thought, it was the fact that we were not reinforcing it that made it difficult, that made it more important that we had data to back it up.

One participant mentioned an alternative scenario in which the results are not easily interpreted by non-experts, making the issue less about whether or not the client agrees with the answer so much as how well the client can understand the science itself. PNNL 7 talked about how this situation occurs:

You know it always depends on who you're trying to talk to. It depends on their background and what they understand and, I mean that's what I've always noticed nowadays because usually the client has a very different background than you, and... what keeps you excited about doing work is going to be very different than what keeps the client excited about doing work.

Software tools were not mentioned by participants in their responses on the issue of explaining results, perhaps indicating that this aspect of synthesis is not dependent on tools as much as it is on the content itself. It shows that there may be a place here for tools to support this task, perhaps by allows users the ability to quickly attach metadata, credibility measures, or other information to results so that clients can drill down into reports when necessary.

4.3.6 Result Provenance

A crucial aspect of supporting synthesis with software tools is to ensure that results can be linked back to the tools and methods responsible for creating them. When asked to describe how this problem is currently handled, all participants stated that current tools do not typically allow them to easily determine who, how, or when results were generated. This is a particularly difficult issue considering that analysts tend to collect results in office productivity software – environments that do not normally recognize analytical results in a way that allows their metadata to be maintained (if they have metadata at all). As PNNL 3 mentions, accessing information that describes result provenance is particularly problematic in situations where analysts are returning to previous work:

I mean we typically run into that a lot, especially from what we did years ago, we went back and looked at some stuff and were like, "how did that get from point a to point b?" You can see it in the write up we did, but the write up isn't as detailed as what happened. So we can probably guess how we got there but...

Participants stated that a promising avenue for future software development would be to support better linkages between results and the tools (and analysts) that generate them. PNNL 4 supported this direction with the following statement:

You know I really don't think I have much in the way of tools to try to maintain that link. I may make a note somewhere possibly if it's...not recorded somewhere in the electronic file or the email traffic. You know "so and so did this and it was based on so and so's work." But ...a lot of times I don't even receive that information I think. There is a lot of value in going back to the originator of the work...who actually had the original thoughts and the original process of developing something, a method or a tool or something. There's a lot of value there that can definitely be tapped.

In general, interview responses indicate that analysts are aware and uncomfortable with the reality that their results are often distilled into small portions of reports for decision makers. When this happens, information about who developed a particular result or how it was developed is rarely included, and current tools do not support automating this task.

4.3.7 New Tools for Synthesis Support

To suggest directions for future synthesis support tools, participants were asked to identify changes they would make to what they currently use. They provided several different suggestions for future tools, including easy-to-use visualization environments, keyword searchable databases, and synchronized file sharing tools that do not require substantial training. PNNL 1 described one hypothetical solution for quickly locating results in a collection:

When I want to find this file in the file structure I've got to click and click and click and why can't I just say I want this file and there's some artificial intelligence or something that can think like you do and "here it is" instead of me, going to click and scroll down to this folder on my email, and from that down. And I think this whole time, "why can't I at least even say what I'm clicking for." You know that's very simple.

One participant indicated that current visualization tools are useful for collecting results and ultimately presenting them to clients, but that they are currently too awkward to support regular use, or use by analysts who cannot dedicate substantial time to training:

Well, IN-SPIRE is pretty easy to use, Starlight is adequate from an output perspective, but it is a huge learning curve when you learn how to operate it. In a perfect world I would make it so that it incorporated data much easier than it does now and allows you to structure it without having to...go in and structure the data so that Starlight would actually read it...I mean it was not an easy process. So there's sort of a disconnect, you have to have somebody who's sort of an expert at putting it in, but they don't necessarily know what you want, so... we did a little bit of back and forth stuff and then I finally said you know why don't I just do it. But I mean that's a huge learning curve. The tool should be easier to work with.

When it comes to collaborative synthesis activities, most participants indicated that using email can introduce problems. Email conversations tend to branch into multiple threads, file attachments are not easily managed, and it is unreasonable to expect analysts to spend time trying to manually organize those things, as PNNL 4 states here:

Email is just a very kind of a mish-mosh of a bunch of different things and I just don't have the time to sit down and file through it and try to say ok this is on disease, this is on bioterrorism, you know and have my separate folders.

PNNL 4 envisioned a new software environment that would help coordinate collaborative synthesis in terms of result management as well as project communications:

You've got your communication side of it, and you've also got...are we all working on the same paper...where are we with that? Maybe a tool where you would go in and it records essentially what you have done in this session, and then in an adjoining folder or adjoining area it also has a log of our communications. And also to maybe somehow link in to email for people who are not as technically adept, you know it automatically synchronizes things. I think something like that would be awesome.

Interview participants envision new synthesis support tools that make it easy to retrieve important information, and that coordinate that information with related project communications. Additionally, they require that these tools are immediately usable given analysts current technology skills. Document sharing and visualization tools are already in use, but their applications are limited as long as usability remains a barrier, and as long as they do not connect in meaningful ways to project communication streams.

4.4 Discussion

Interview responses from analysts at PNNL indicate that synthesis is currently supported through the use of office productivity software and shared network resources. Office productivity tools like Word and PowerPoint are commonly used to organize and share results, both in individual and collaborative settings. Visualization tools are used by some to develop synthesized overviews of information for presentation to decision makers. Email is often used as a method of moving these resources around among multiple people. In general, current tools and methods do not adequately support analysts when they need to revisit and/or revise past analyses.

Client expectations are the deciding factor for the degree to which results are particularly easy or particularly difficult to explain. When analysts know their results will conflict with a client's expectations, they develop reports that saturate their findings in corroborating details. Current tools do not help analysts easily develop reports with varying levels of detail to match these circumstances.

Participants envision synthesis tools that coordinate project communications with the results they have generated. This would also help alleviate problems noted with determining/maintaining result provenance information. New tools should be usable with minimal training and assumed technological expertise, so as not to impede work progress. Visualization tools are promising candidates for further development in this direction, as their outputs are generally easy for decision makers to interpret.

The next chapter presents the results of synthesis experiments conducted with participants from PNNL and PSU. These results provide empirical evidence to further characterize and understand the problem of synthesis in geovisualization.

Chapter 5 – Individual Synthesis Experimental Results

This chapter describes the results from eighteen coded videos from individual synthesis experiments conducted at PNNL and PSU. Eight videos came from experiments conducted at PNNL, and ten videos came from experiments conducted at PSU (experiment details are described in Chapter 3). These videos were coded to identify and characterize low-level events initiated by participants to complete the synthesis experiment. The following sections describe cumulative coding results, results for individual videos, common patterns of activity across multiple videos, and the organizational metaphors were used by participants. Where relevant, differences between groups at PSU and PNNL are highlighted.

The graphical data presented in this chapter can be interpreted using the annotated legend provided in Figure 17. Choosing colors to indicate glyphs for 29 different codes required the use of two glyphs for each coded event. The primary glyph carries with it the color of the major category it is associated with (e.g. Annotate, Group, Sort, etc...), and the smaller glyph attached to its bottom indicates which particular subtype of that category was assigned. A qualitative color scheme was used from www.colorbrewer.org (see Brewer, Hatchard, and Harrower 2003; Harrower and Brewer 2003). Grayscale ramps were also used from ColorBrewer to fill the subtype glyphs. In this case, although the codes are qualitatively different, visual clarity was not possible using a qualitative scheme for the higher level categories as well as the individual subtypes.

Where noted, individual participants are referred to using the generic name for the site where the experiment took place, along with a number. A letter suffix is included with PSU participant data as those experiments were grouped into five sessions that each featured three activities, hence a letter and number designation for those participants.

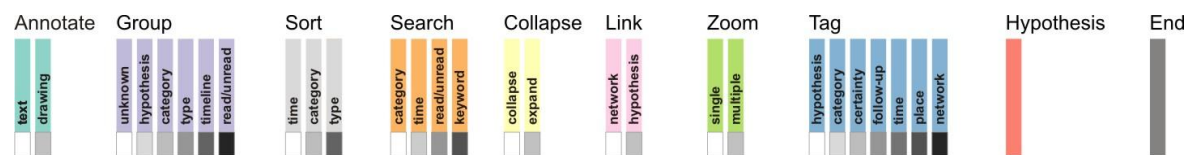
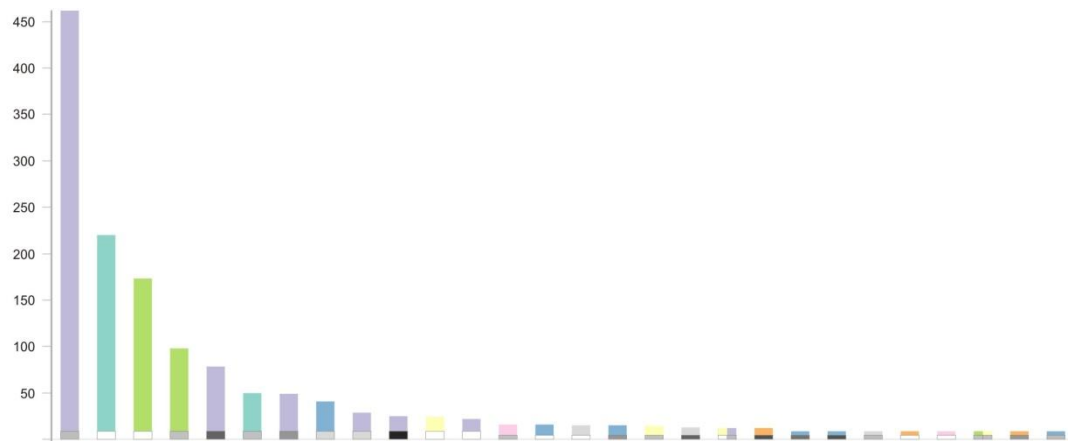


Figure 17: Legend for use with code results presented in this chapter.

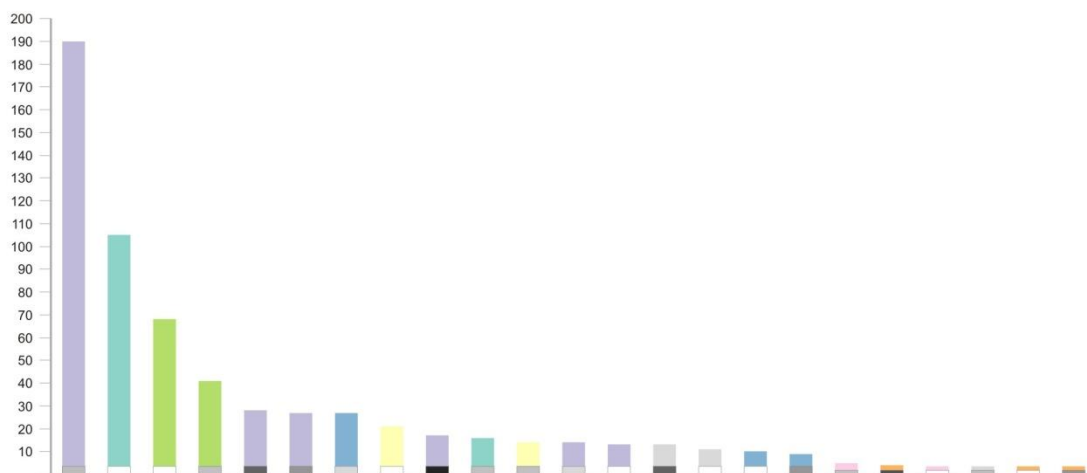
5.1 Cumulative Results

Charts showing the cumulative results from experiments conducted at PNNL and PSU are shown in Figure 18. These graphs reveal several interesting insights about how synthesis was conducted during the experiment sessions. The top five most frequent events are, group (category), annotate (text), zoom (single), zoom (multiple), and group (timeline). These five codes are consistent for both PNNL and PSU groups, not indicating a difference between domain backgrounds in this case.

Total Number of Events (PNNL and PSU)



Total Number of Events (PNNL)



Total Number of Events (PSU)

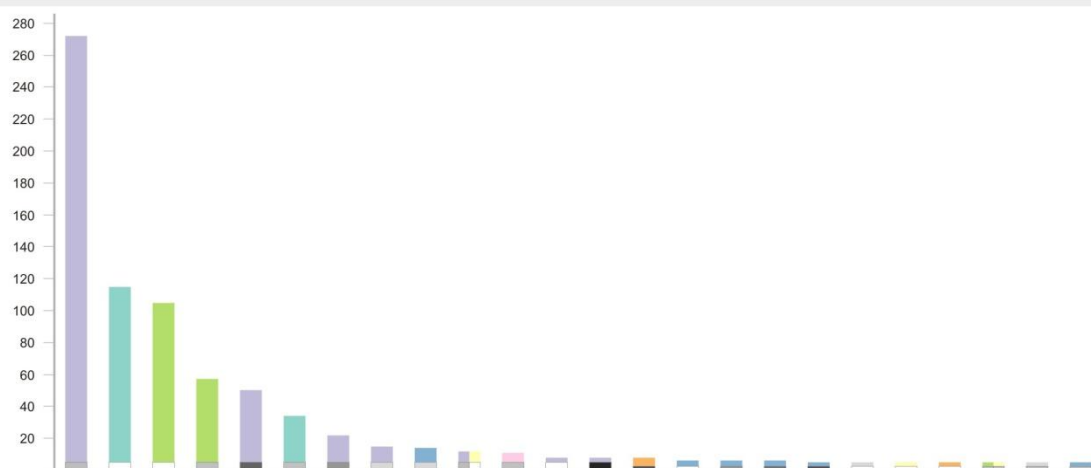


Figure 18: Cumulative charts showing total number of coded events for both experimental groups.

5.1.1 Grouping

A bias toward the group code is expected considering that participants were provided a stack of randomly sorted artifacts at the beginning of the experiment. However, the type of grouping is of interest, as the most common methods for doing this are by category or by timeline. The categories users assigned to artifact groups varied widely, from broader categories like “historical information” to specific categories like “information about Alex Watersby.” They included references to locations and other qualitative features of the evidence – as opposed to grouping by timeline which involved the use of a metric for organization.

Grouping by timeline was the second most common coded grouping method. Since source information and dates were provided on each artifact, it was easy for participants to sort through and group items along a timeline. The way the timelines were arranged on the workspace is of interest, as there was no single dominant strategy for this. Some users arranged past to present from top to bottom, others from bottom to top, and some used left-to-right.

We might have expected more participants to group artifacts by hypotheses, considering the task was to develop hypotheses, but this was an infrequently coded event in our

experimental evidence. Every participant developed at least three hypotheses (see section 5.2.3 for a discussion about these), but few chose to group items using hypothesis membership as a criteria.

5.1.2 Annotation

Textual annotation was the second most commonly coded event from the individual experiment data. Participants from both PNNL and PSU added text annotations more often than graphical annotations, with PSU participants using graphic annotations slightly more often than PNNL participants. Text annotations were frequently carried out to record key information about artifacts, to add information to tags, and to identify working hypotheses.

Drawn annotations usually took the form of regions around groups of artifacts, or arrows drawn between particular items that are related in some way. It is worth noting that not all users engaged in annotation of one kind or another, PNNL 7, PSU 2B, and PSU 5B did not choose to annotate their workspaces.

5.1.3 Zooming

Zoom events were quite common among participants from both groups. Zoom events were coded when a participant closely inspected an artifact or multiple artifacts that had been placed on the workspace. Most of the time participants picked up artifacts and brought them closer to their face to interrogate them closely. In general zooming takes place later in the process of synthesis after artifacts have already been grouped on the workspace. Participants favored looking at one item at a time over multiple items, but this is probably because there is a physical limitation involved with holding a substantial number of artifacts in your hands. The most common multiple item zoom was to examine two artifacts to compare their information.

5.1.4 Other Events

While grouping, annotation, and zooming are the most common events that occurred during synthesis experiments, participants initiated a wide array of additional actions to develop hypotheses using the artifacts. Colored tags were used to indicate categories,

hypotheses, certainty, and other attributes. These events did not occur as frequently, but frequency alone is not necessarily an indicator of importance with respect to supporting synthesis. Participants also initiated searches and sorts through artifacts to find references to particular people, and to quickly organize data based on time or other criteria.

Link events were coded whenever participants stated that artifacts were linked to each other and/or when arrows were drawn indicating as much. Most of the time, links were used to indicate direct or suspected relationships between artifacts in a hypothesis. Graphical and textual artifacts were linked in similar proportions, indicating that different artifact types may not have a strong influence on how participants apply links (at least in instances like this where all artifacts are the same size and shape).

Finally, some participants collapsed artifact groups on the workspace. Most of the time collapse events occurred with data artifacts that were judged to be useful as background or historical information. One analyst at PNNL chose to begin with collapsed groups organized on a timeline, and then systematically expanded each group one at a time from past-to-present to analyze the information.

5.2 Individual Results

Summarized coding results reveal insights about the frequency of events during synthesis, but do not provide detailed characterizations of strategies that participants used to synthesize information. This section focuses on patterns of events that are observable by looking at the coded results for individual participants. It also presents observations on the organizational methods that participants used to complete the synthesis task.

Coded results for each participant are collected together in Figure 19 (PNNL) and Figure 20 (PSU). Each “track” of results has been resized so that it takes up the same width of the page to avoid overprinting issues. The legend in Figure 17 should be used with these graphics as well. Section 5.4 provides detailed graphical results for participants from the PNNL and PSU individual experiments. There each coded result is presented along with

a graph that summarizes the most frequently coded events, a photograph of the final workspace, and a brief text summary of what occurred during the experiment.

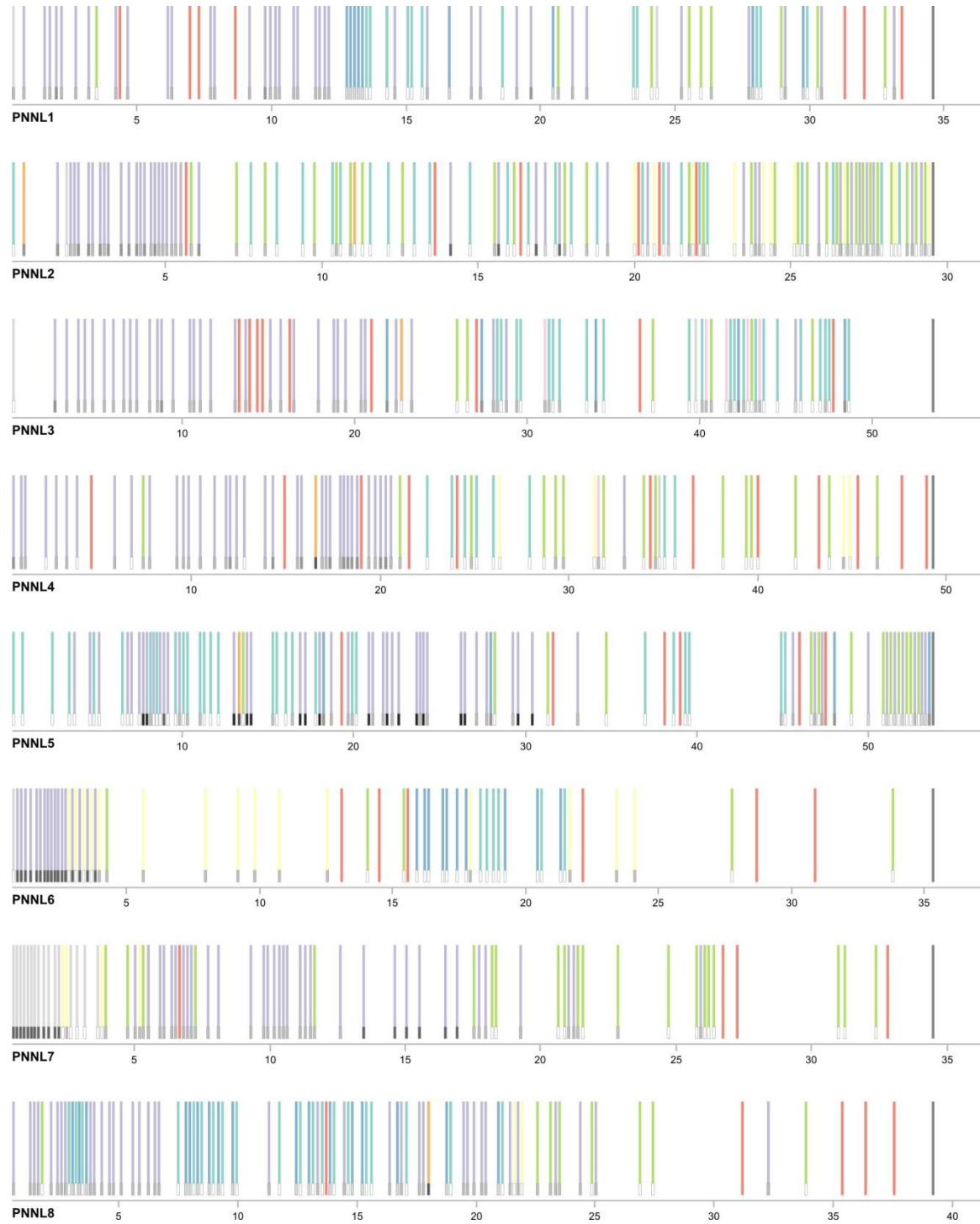


Figure 19: Coded results from PNNL experiments.

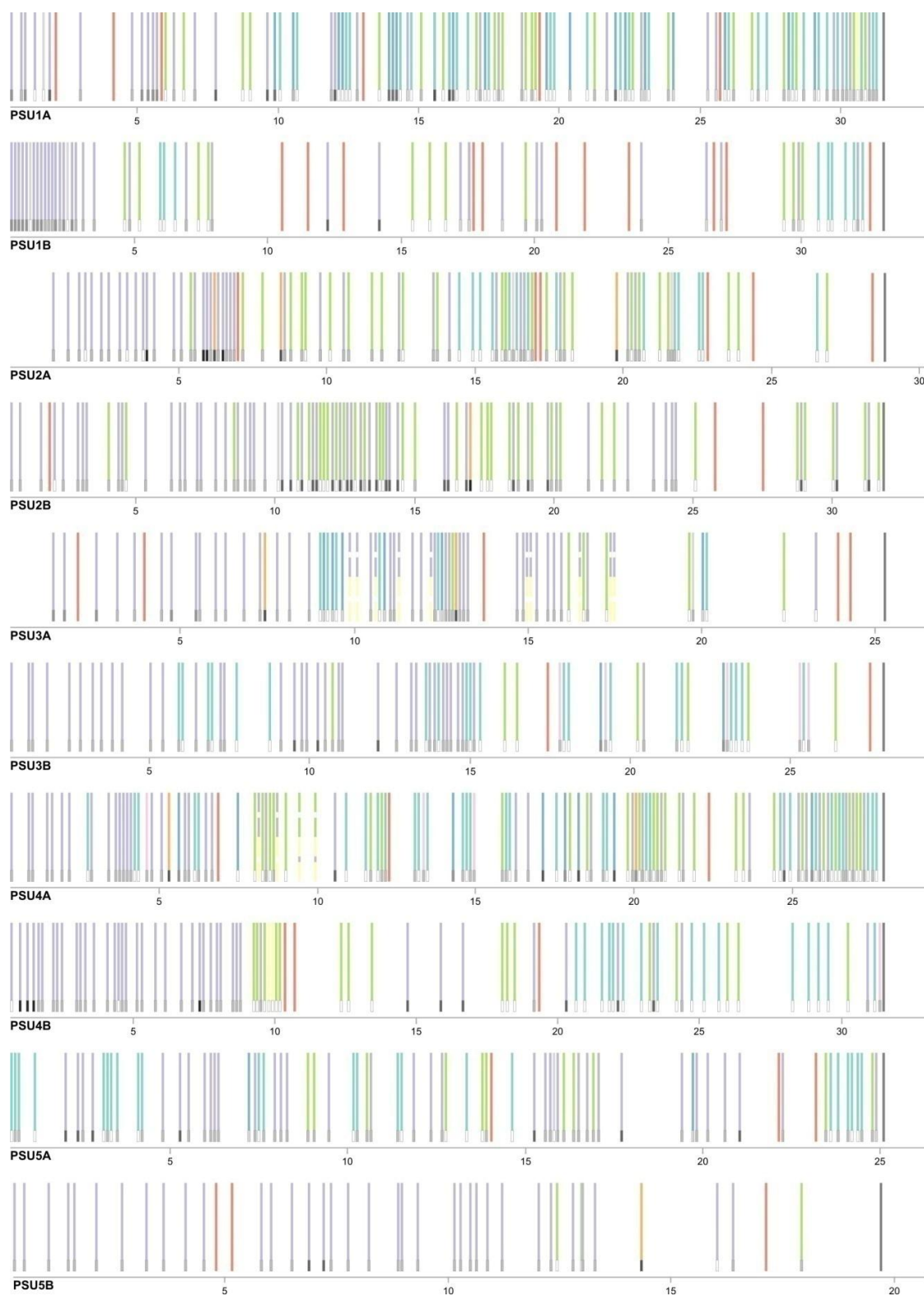


Figure 20: Coded results from PSU experiments.

5.2.1 Synthesis Strategies

Participants engaged in several different basic strategies for completing the synthesis task. The most common strategy (Figure 21) begins with grouping all of the artifacts following a brief examination of the artifacts one-by-one. Then after the workspace has been initially organized, a deeper look at the artifacts takes place, often involving cycles of zooming one or more items, annotating about them, and regrouping into new categories or hypotheses. Participants tended to announce hypotheses shortly after the initial grouping, and then announce new or refined hypotheses during close examination of artifacts. In this synthesis approach, annotation and tagging occur after most grouping has been completed.

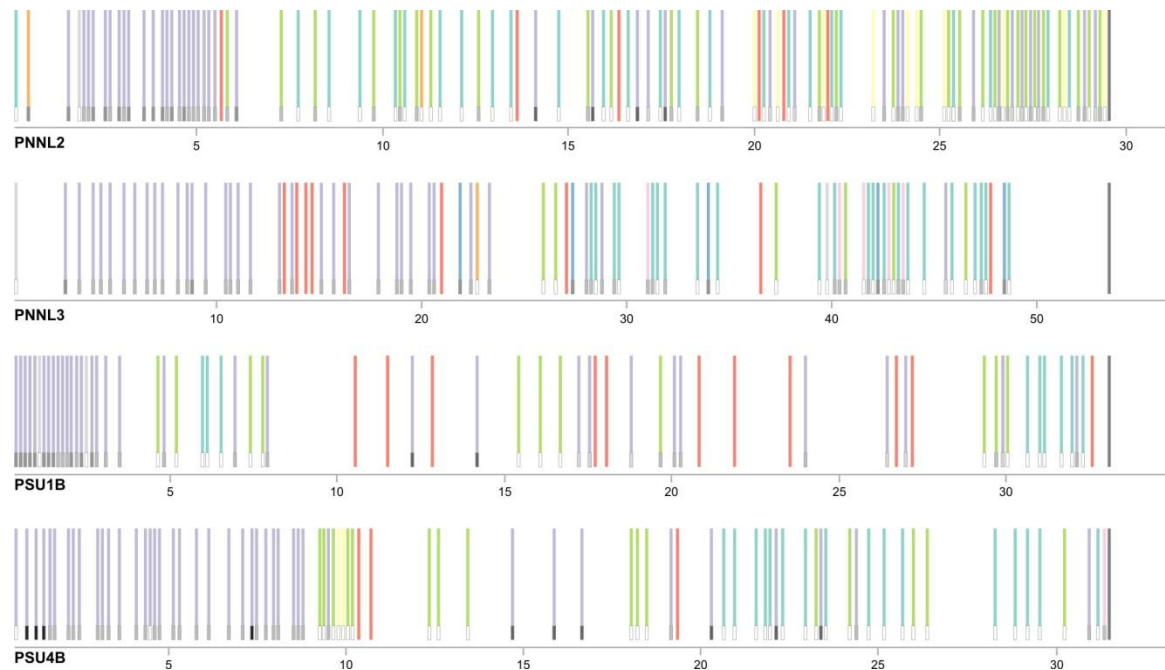


Figure 21: Coded results showing a group first, then examine and annotate strategy.

Variation exists within this strategy in terms of how much time it takes participants to complete the initial grouping task. PSU 1B and PNNL 2 complete this phase in roughly half the time that PSU 4B and PNNL 3 require. Note here that differences do not appear between the analysts at PNNL and experts from PSU.

Another discernable strategy from experimental evidence begins with thorough examination of each artifact, annotation of key information, and then collection of artifacts into groups. Figure 22 shows two sets of coded results that demonstrate this strategy. It is not clear in these cases how hypotheses might be related to sequences of events during synthesis. From video evidence, PSU 5A could be described as methodical in terms of how much time he spent carefully examining and annotating each artifact, and he appeared surprised that substantial time had passed by the time all artifacts had been examined. This could explain why PNNL 5 identified more hypotheses with the same strategy. PNNL 5 asked to know how much time was left with 40 minutes expired and decided then that it would be a good idea to step back from the task and think while laying on a couch that was in the experiment room. After a short break, PNNL 5 returned to the task and completed several cycles of re-examination of particular artifacts while refining hypotheses.

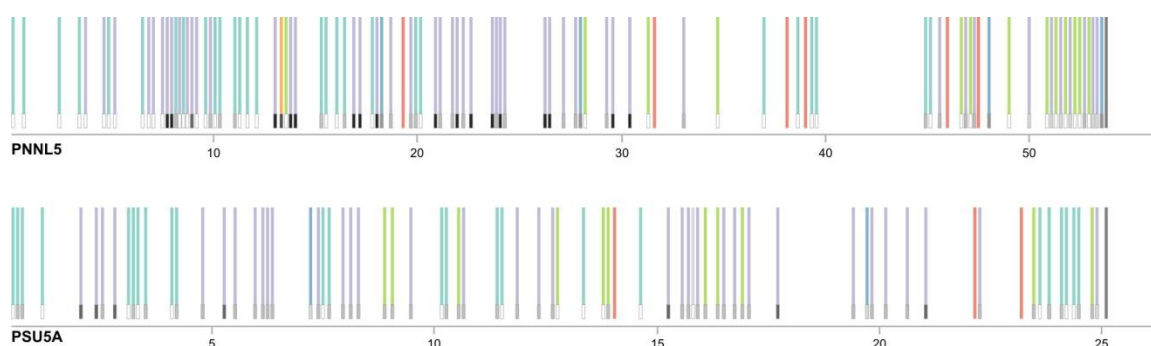


Figure 22: Coded results showing an examine first, then annotate and group strategy.

A third approach focused on a rapid initial sort or grouping of artifacts according to generic attributes (Figure 23). This was followed by different secondary strategies to evaluate information. PNNL 6 began by quickly grouping artifacts onto a timeline that had collapsed stacks for each day in the dataset. Then, she expanded each day one by one from past to present to evaluate the information in detail. Later, colored and annotated tags were added to indicate artifacts that were important to particular hypotheses, but artifacts were kept in place according to the timeline.

PNNL 7 used a similar approach in the sense that he began by quickly sorting the stack of artifacts by the type of information they showed (text, graphic, photo, video capture,

etc...). In this case the objects were sorted while in hand, not grouped on the workspace. After the rapid sort was complete, PNNL 7 began evaluating the text items to create groups by category.

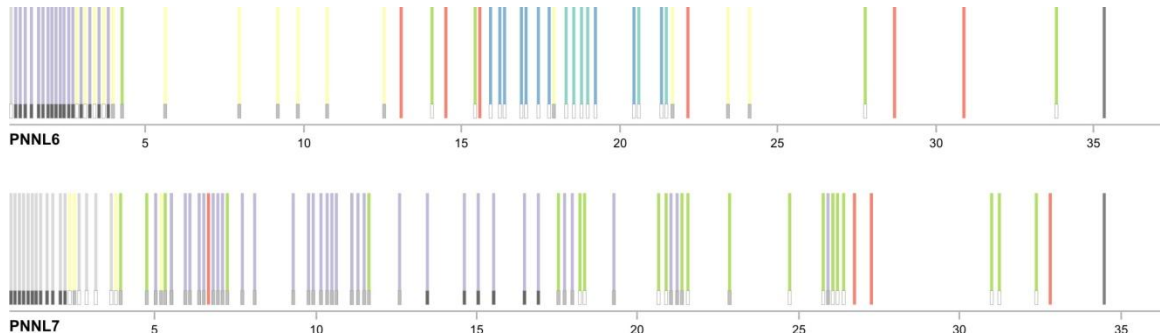


Figure 23: Coded results showing a rapid initial sort/group strategy.

5.2.2 Organizational Metaphors

The individual events initiated by participants during synthesis provide substantial insights into the process of synthesis and how it might be supported with interactive visualization tools. It is also important, however, to examine the basic organizational metaphors that participants made use of to organize their information. Video recordings of the experimental sessions, the debriefing conducted immediately following each experiment, and photographs of the final workspaces form the basis for the following sections discussing how participants organized information. During the debriefing, the lead investigator asked participants to explain how they had organized information during their work and how they had indicated hypotheses.

In general, it was common for participants to mix together multiple organizational methods during synthesis. Participants often chose to group artifacts in multiple ways on their workspace, augmenting some of them with tags or annotations, rarely in a consistent manner across all of them. This may be due in part to the fact that it is not easy with physical artifacts to quickly try out several different methods of organization. It may also indicate that complex analytical problems require multiple views onto information in order to develop hypotheses. Information that provides context or historical background may not need to be in a timeline along with events and reports from authorities.

Figure 24 shows a photograph of the workspace that PSU 4B developed that has been marked up to show the different organizational metaphors that he used. Here, a timeline has been established across the top of the workspace and hypotheses have been arranged from left to right according to where they fit in terms of time. At bottom left an emerging hypothesis with sparse information has been gathered, but deliberately not included in the main timeline. At the center of the workspace a text report from the CDC that confirms an H5N1 virus outbreak has been placed near several artifacts that describe recent data about the spread and impact of avian flu around the world. Finally, along the bottom right of the workspace a number of artifacts have been gathered that serve as contextual and historical information.

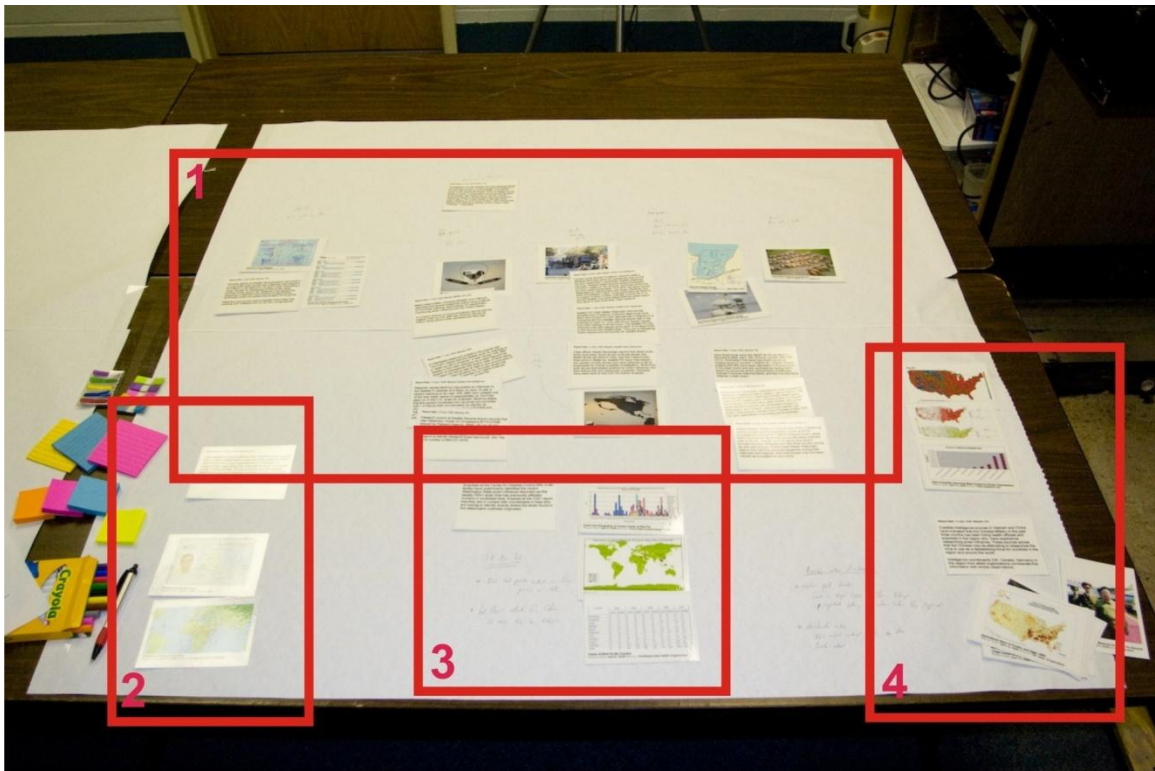


Figure 24: Workspace of PSU 4B, showing multiple organizational methods. 1) Timeline from left to right used to organize hypotheses. 2) A hypothesis that is less certain. 3) Report confirming of an avian flu outbreak and data on its spread. 4) Contextual and historical information about avian flu.

Another example of the use of multiple forms of organization can be seen in the workspace developed by PNNL 7. Figure 25 shows a photograph of this workspace that has been marked to point out areas that use different organizational metaphors. At the top left the participant placed artifacts that provide contextual and historical information. Across the top center and right a set of category groups is laid out using graphical artifacts and associated text. Each graphical artifact corresponds to a different category group, and the set of artifacts to the right of each graphic has been arranged according to time. At bottom left are artifacts corresponding to a pair of hypotheses that the participant viewed as uncertain and unlikely. Finally, at bottom right maps and other data artifacts about avian flu have been loosely gathered together.



Figure 25: Workspace of PNNL 7, showing multiple organizational methods. 1) Contextual and historical information about avian flu. 2) Category groups, led by an image and arranged into individual timelines from left to right. 3) Artifacts of two hypotheses that were seen as uncertain. 4) Maps and other data on avian flu.

One aspect of organization common to most of the final workspaces was an area on the periphery of the workspace dedicated to historical or contextual information. Figure 26

shows how participants PSU 4A and PNNL 8 did this on their workspaces. PSU 4A drew a region around the artifacts and labeled the region “Context,” while PNNL 8 used annotated tags to create subgroups of maps, historic information, and data. PNNL 5 moved artifacts related to YouTube videos (that claimed responsibility for the outbreak) into a portion of the workspace that had been circled in black marker and had the word “crook” written above. PSU 3A chose to collapse a large group of artifacts that contained contextual and historical information and wrote the word “attic” on a post-it that was placed above the stack. While most participants developed a place to store artifacts that were not necessarily immediately related to their hypothesis development, only one chose to completely eliminate an artifact - PNNL 1 moved one contextual information artifact to the top right edge of the workspace and wrote the word “delete” underneath it.

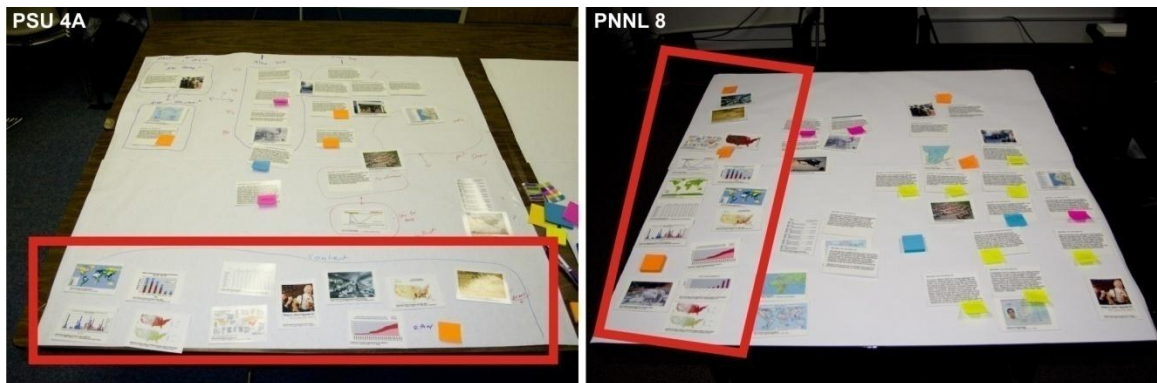


Figure 26: Areas of the workspace set aside for historic and/or contextual information.

5.2.3 Hypotheses

Participants in the reported synthesis experiments were asked to develop at least two hypotheses for the source of an avian flu outbreak in the Pacific Northwest. Every participant was able to do this, and only one participant (PSU 3B) arrived at exactly two hypotheses. All others developed three or more. Participants were responsible for announcing when they had a hypothesis, ensuring that coding that particular event was not subjective. The character of the resulting hypotheses depends on how each analyst or expert personally defines a hypothesis – something that is likely to be quite variable from person to person. The artifacts developed for the synthesis experiment facilitated the discovery of hypotheses that would be common in a descriptive epidemiology scenario, where the goal is to characterize the spread of disease among a population, in

contrast to testable hypotheses one would expect in an analytical epidemiology scenario where the goal would be to evaluate specific disease intervention strategies (Gordis 2000). The hypotheses that resulted from synthesis experiments show that in general participants interpreted the instructions to mean that they should develop reasonable propositions for the source of the outbreak rather than more formal statements that could form the basis of investigation for scientific theory building.

The specific hypotheses reported by participants from both groups are summarized in Table 5. Hypotheses that were common among both groups are highlighted in purple at the top of the figure, and unique hypotheses are summarized in the columns beneath. Overall, PNNL participants generated a slightly larger number of unique hypotheses than PSU participants. This may be due to the fact that PSU participants had a shorter amount of time to complete the activity, and that they had a smaller set of artifacts to evaluate. It also may reflect a distinction between analysts who are trained to deal with scenarios like the one presented in the experiment, and experts who have not received such training.

The relationship between coded event results and the announcement of emergent hypotheses is somewhat obscure. Some participants announced one or more basic, emergent hypotheses when they had finished examination of the entire set of artifacts, prior to deeper examination and annotation. Others only announced hypotheses after subsequent close inspection of the artifacts in a second run through the set. Variation across participants may be due to different personal definitions of what constitutes a hypothesis.

Five key hypotheses for the source of the avian flu outbreak were embedded in the artifact collection: a natural occurrence based on bird migration, a person named Alex Watersby who intentionally spread the flu to wild birds and through pet stores, an Al-Qaeda operative named Waleed Al-Keval who infected wild birds, an unintentional outbreak caused by illegal pet trade activity by local pet stores, and a plot by North Korea and China to spread avian influenza to disrupt poultry commerce in America.

The fact that all participants were able to develop multiple hypotheses, and that these hypotheses were focused on the plot threads (and combinations of them) that had been embedded during the development of the artifacts, provides verification for the experimental design and execution. Participants had sufficient time, information, and tools to complete the task as intended. Even with a random reduction of a dozen artifacts for the shorter individual PSU experiments (participants in each pair having 36 artifacts that overlapped partially to ensure the pair ultimately had the whole set), those participants were able to develop multiple hypotheses to complete the task.

Hypotheses in Common

It is being brought in through black market pet trade
 Alex Watersby is involved in an intentional spread of the virus
 North Korea is intentionally spreading flu to birds
 Federico Voldore purchased infected birds from a pet store
 Naturally occurring outbreak of avian flu
 Potential terror plot to bring avian flu to the U.S.
 North Korea is colluding with Al-Qaeda to spread the virus
 China is spreading a weaponized version of the flu
 Alex Watersby and AW_666 are the same person
 AW_666 who claims responsibility on YouTube is in fact the source
 Jamal Kayder is importing infected birds to his pet store
 Alex Watersby traveled to Ethiopia and Hong Kong and picked up the virus
 Unknown person smuggled birds and spread flu to pet stores and the Nisqually wildlife refuge
 Terror plot may be attempting to make outbreak appear natural

PNNL

An intentional release to birds so that it spreads to humans
 Alex Watersby and Waleed Al-Keval imported infected birds to pet stores
 An unknown person accidentally brought infected birds into the country
 Ashraf Saleh is a terrorist and is spreading the virus intentionally
 Federico Voldore is not the source of the outbreak
 Unknown person is working for other countries to spread the virus
 It did not occur via an insect vector
 It is not a terrorism event
 Terrorists are using flu outbreak to distract authorities from another attack
 Pet stores might self-report dead birds to hide involvement
 North Korea and China not involved as they gain little from the outbreak
 Two outbreaks are happening at the same time, natural and intentional

PSU

Money is being laundered from Ethiopia to support intentional spread
 The outbreak is intended to damage the american poultry industry
 Waleed Al-Keval is intentionally spreading flu to birds
 Adam Nelson and Waleed Al-Keval have released infected birds in Nisqually refuge
 Alex Watersby is not responsible for starting the outbreak
 Waleed Al-Keval imported infected birds to pet stores
 North Korea is spreading a weaponized flu virus provided by China
 Alex Watersby is importing infected birds to pet stores
 Federico Voldore's parrots started the outbreak

Table 5: Shared and unique hypotheses generated by PNNL and PSU groups during synthesis experiments.

While all participants' hypotheses required at least some attention to spatial reasoning to decide their plausibility, none in the individual experiments attempted to draw a map on the workspace to develop an explicit spatial representation of their information. A few chose to tag artifacts to indicate spatial information, but for the most part, participants did assign separate methods for spatial references. Written notes on the workspace and post-it notes that were used to summarize findings integrated spatial references with other information.

5.3 Discussion

Synthesis experiment results with analysts from PNNL and experts from PSU indicate that participants conduct synthesis in a variety of ways. Participants may choose to group artifacts first, then examine them closely and annotate their findings. Others showed a pattern that begins with close examination of each item, and transitions from there into the development of artifact groups. A third observed strategy was when participants conducted a rapid initial sort or grouping of the entire set of artifacts and then proceeded to examine artifacts closely to group them by categories or hypotheses.

The most common events initiated by experiment participants were grouping, annotation, and zooming. Other less frequent, but important actions included tagging artifacts to indicate attributes about them, searches through artifacts to identify matches to keywords or other attributes, and linking artifacts together using drawn lines or arrows to indicate relationships.

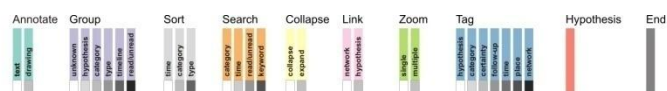
The results presented in this chapter point out the complexity of synthesis, even when conducted in a limited experimental setting. Supporting synthesis in software will require attention to the diversity of approaches described here, in a form that is scalable to many more than 48 artifacts. Differences between groups at PNNL and PSU are not readily apparent, despite an expectation that analysts at PNNL would be trained to interrogate information more systematically than academics at PSU (see Heuer 2005 for an overview of common intelligence analysis strategies).

Evaluating how individuals synthesize information provides an important but incomplete understanding of synthesis. Many real world situations will require multiple analysts to

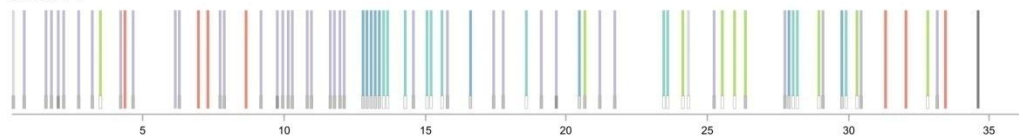
collaborate on synthesis tasks. The next chapter presents coded results from collaborative synthesis experiments conducted with experts from GeoVISTA and CIDD at PSU.

5.4 Detailed Graphical Results

This section presents detailed graphical results for the experiments discussed in this chapter. Individual experiment code results are shown in timeline and summary graph form, along with a photograph of the final workspace and a short narrative description.

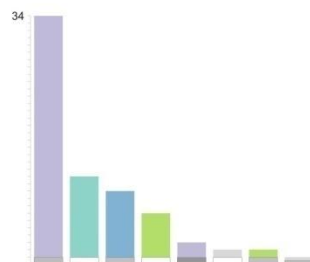


PNNL 1

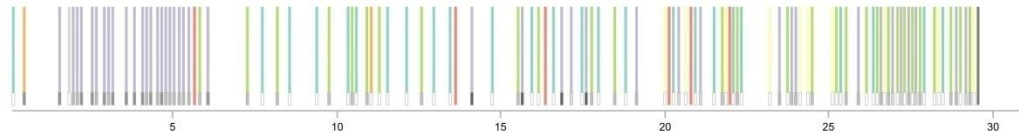


Summary:

This participant began by grouping artifacts into categories. Then, they created post-it headings (a "folder tree" according to the participant) that were placed on the workspace to encapsulate subgroups of related topics & categories.

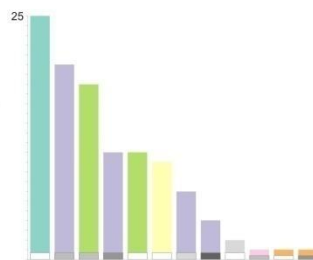


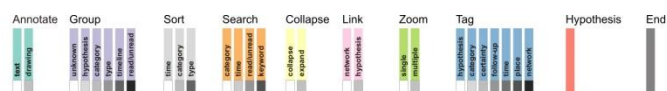
PNNL 2



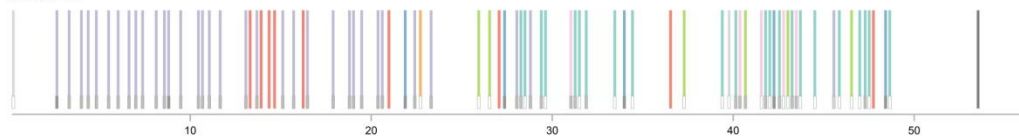
Summary:

This participant began by grouping artifacts by category and hypotheses. After examining the artifacts, some groups were ordered by time. Later, groups of artifacts were collapsed into hypotheses and topic groups, and annotations were placed on the workspace to indicate these groups. These annotations included a variety of details about key information and questions relevant to the artifacts.



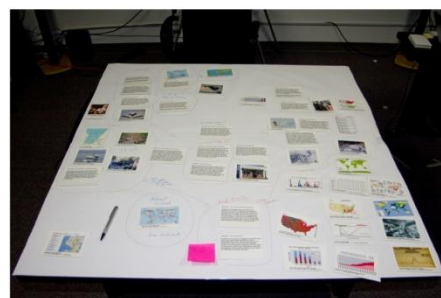
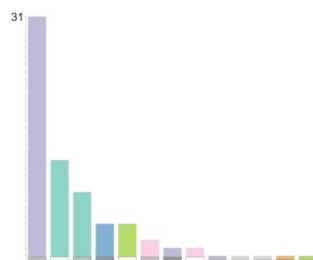


PNNL 3

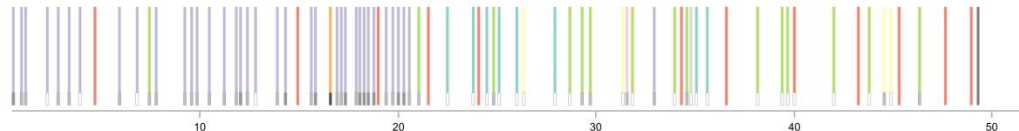


Summary:

This participant began with groupings by category and hypotheses. These were later circled using a marker. Then, links were drawn between groups and individual artifacts that were related to particular hypotheses. Questions were then written adjacent to artifacts for future follow-up.

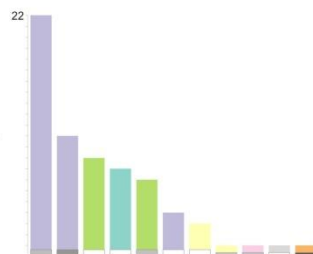


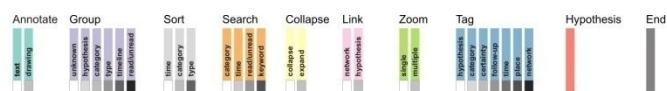
PNNL 4



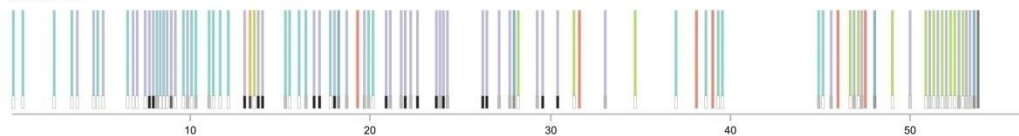
Summary:

This participant began by creating groups by category, by type, and a background knowledge section. Annotations were added to the workspace to identify key information from particular artifacts. Some groups were later collapsed into stacks after deeper analysis had taken place.



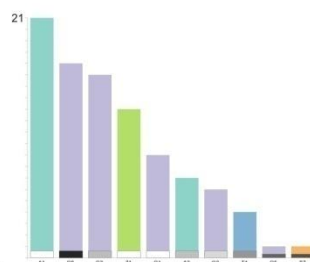


PNNL 5

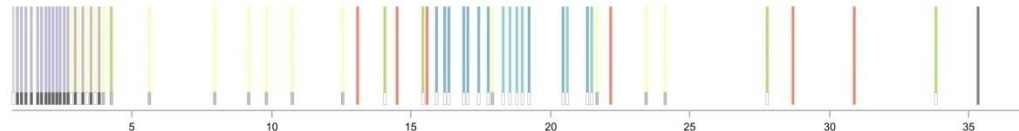


Summary:

This participant began by writing down notes about the task. At first, there was no obvious artifact grouping. Each artifact was read and notes were added to the workspace, then artifacts were placed into a "read" pile. Later, groups were created by category and hypothesis. Finally, they made a second pass through previously-read artifacts as they refined hypotheses.

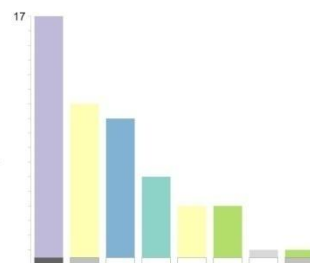


PNNL 6

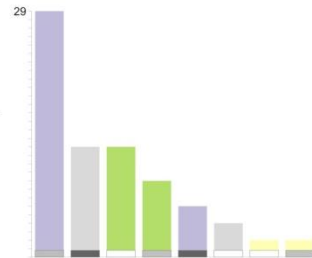


Summary:

This participant began by creating a timeline with all of the artifacts. If there was more than one artifact for a particular day, they were collapsed into stacks. Later, the participant systematically expanded and evaluated each day to develop hypotheses. Colored tags (with small annotations on them) were placed on items in the timeline that form parts of particular hypotheses.



This participant began with an initial sort by artifact type (text, graphics, pictures). Then, they began grouping artifacts into categories. After careful examination, these categories were each sorted into timelines. This participant chose not to use any markers or other tools to alter the workspace.



This participant began by creating category groups of artifacts. These groups were then tagged using different colored post-it notes to identify categories, hypotheses, and to show keywords that summarize the content of text artifacts. Some groups were later collapsed to hide graphics/photos underneath text.

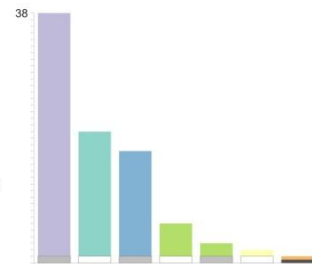
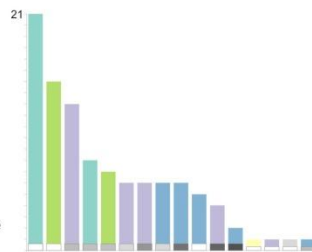
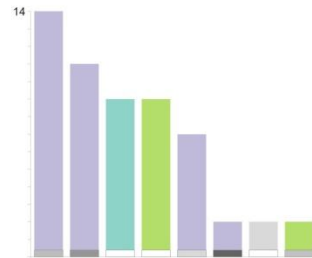


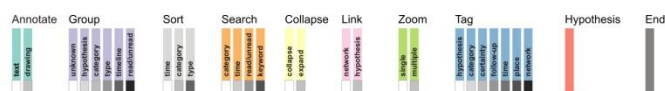
Figure 1: A horizontal bar chart showing the number of genes in each of the 32 clusters. The x-axis is labeled from 5 to 30. The y-axis lists 32 clusters. The bars are color-coded: red, purple, green, blue, and black. The number of genes per cluster is indicated by the length of the bar and the number of vertical lines within it.

This participant began by creating groups by type and category. Some items were then grouped into timelines. Tags were used to indicate time, certainty, hypotheses, places, and categories. A separate "pool" of data was developed for reference information. Post-its were then linked together to create a simplified timeline graphic. Drawn regions were added later to surround hypotheses.

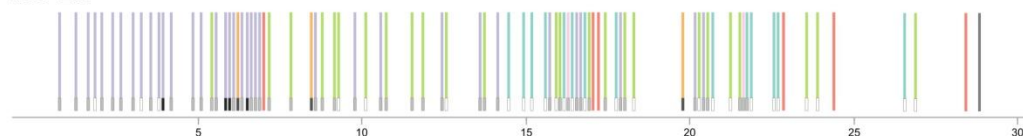


This participant began with an initial rapid sort into groups by type and category. The groups were then sorted by time. Groupings into hypotheses occurred afterward following a close examination of the artifacts. Some artifacts were placed on the periphery of the workspace. These showed historical and contextual information, or hypotheses that were deemed unlikely.



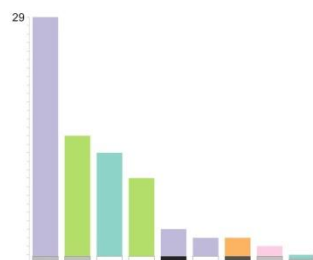


PSU 2A

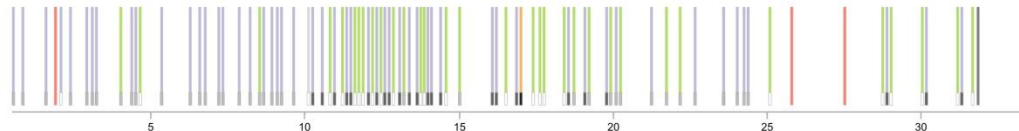


Summary:

This person began with a quick initial grouping by category for some items and a generic "read" group for the others. Then they began close examination of each artifact to refine groups and develop hypotheses. Groups were then collected and annotated with category names as headings. Some groups and individual items were later connected to one another using a link annotation.

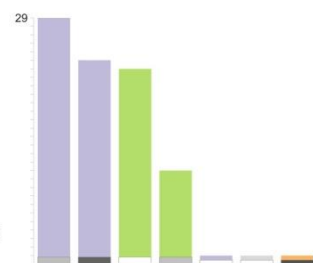


PSU 2B

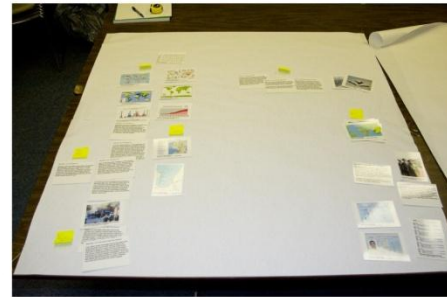
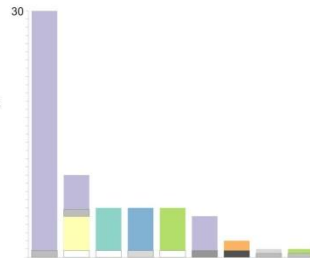


Summary:

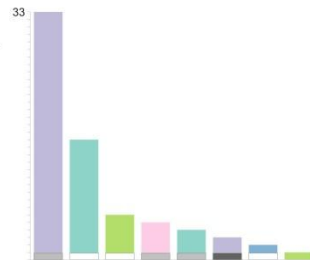
This participant began by grouping artifacts into categories. They then grouped artifacts into a large timeline that spanned most of the workspace. Artifacts that were not part of the timeline groupings were gathered into a section on the periphery of the workspace that was reserved for background information and other relevant data.



This participant began with an initial organization by artifact type. Then they switched to grouping by individual actors, an outbreak in the PNW, and global/local data. An "attic" was developed to store things considered irrelevant to the problem at hand but potentially useful later. Category tags were placed as headings for groups of artifacts.

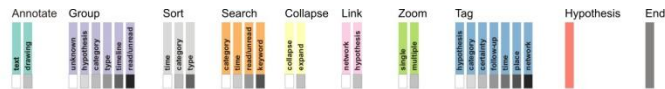


This person began with and initial organization by source. Then, groups were assigned by category. Later, regions were drawn around groups, labeled with a category heading. Some groups of artifacts were then linked to each other using drawn arrows. Dotted arrows were also used for links that were judged to be less certain.

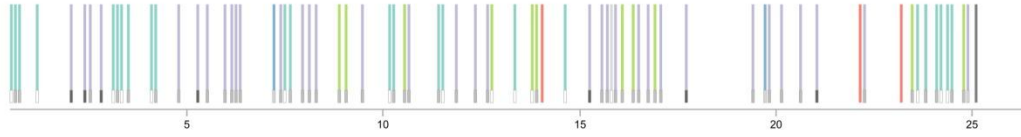


Year	Number of Publications
2000	35
2001	28
2002	28
2003	22
2004	12
2005	8
2006	7
2007	5
2008	5
2009	3
2010	3
2011	2
2012	2
2013	2
2014	2
2015	2
2016	2
2017	2
2018	2
2019	1



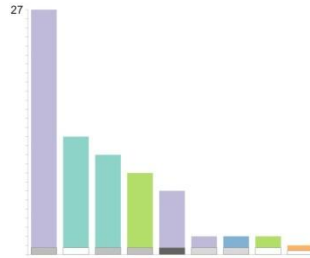


PSU 5A

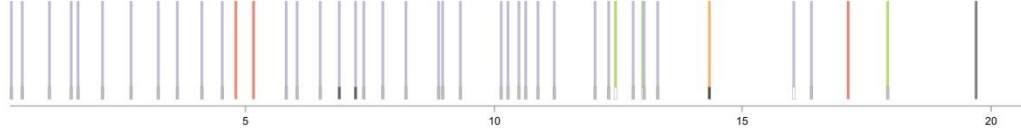


Summary:

This person began by drawing a concept map to describe the task. Each artifact was then carefully read and annotated nodes were added to a concept map drawn on the workspace. Later, artifacts were grouped by category and some groups were arranged within by time.

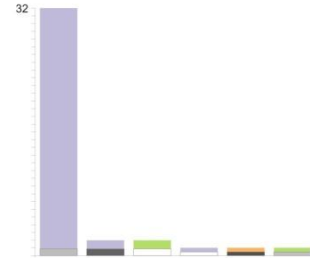


PSU 5B

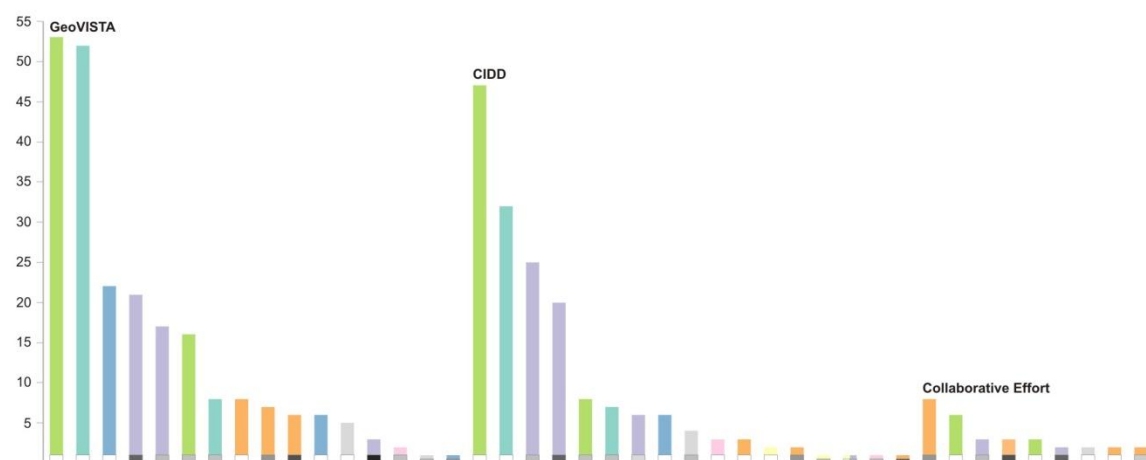


Summary:

This participant began by organizing artifacts into categories (data, maps, pet stores, etc...). Some of these groups were later arranged into timelines. This person did not choose to use any of the tags or writing tools to modify the workspace.



Total Number of Events (by Participants)



Total Number of Events (Participant Code Omitted)

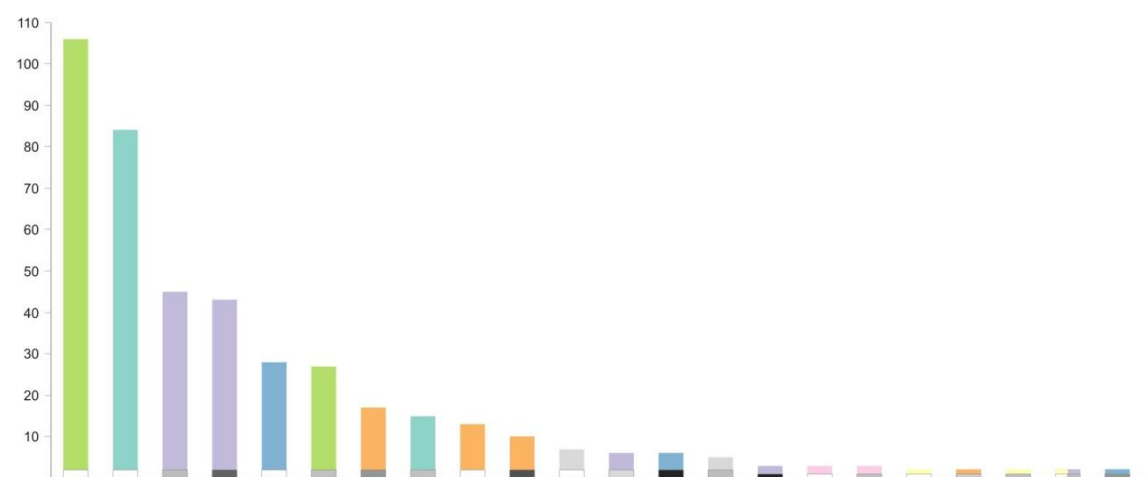


Figure 28: Cumulative coding results from collaborative synthesis experiments conducted at PSU.

Cumulative summaries of the coded events (Figure 28) from collaborative synthesis experiments provide several important insights. If all coded events are summarized irrespective of who initiated them, the five most common events are zoom (single item), annotate (text), group (category), group (timeline), and tag (hypothesis). When code results are broken down according to who initiated them, GeoVISTA and CIDD participants differ in a few interesting ways. GeoVISTA participants annotate more frequently, and the 3rd most common event for GeoVISTA participants is tagging hypotheses – a code that appears substantially lower down the list for CIDD participants. A small number of events were coded as collaborative actions, where both participants

worked together to complete an action. The most common collaborative actions are search (read/unread), and zoom (single).

6.1.1 Zooming

It comes as no surprise that the most common coded event from collaborative synthesis experiments is zooming a single item. The collaborative experiment followed shorter individual experiments where participants worked independently with an incomplete set of artifacts to develop hypotheses. Instructions for the collaborative experiment asked participants to rank the hypotheses they had found independently. Therefore the collaborative setting encouraged participants to revisit their work and to explore their colleagues work for additional evidence to support or refute their hypotheses – things that require individual artifacts to be closely examined.

6.1.2 Annotation

Annotation in the form of text on the workspace was another common collaborative synthesis event. In many cases one of the participants took on the role of being the “reporter” and would write down hypotheses, key facts, and other information while the session progressed. The coding results indicate that GeoVISTA participants were responsible for more text annotations than CIDD participants. Graphical annotations were also created during collaborative synthesis, albeit to a much lesser extent than textual ones. These annotations were typically in the form of regions drawn around groups or arrows drawn between related artifacts.

6.1.3 Grouping

As participants continued to refine and develop hypotheses, a substantial amount of artifact grouping took place - usually in the form of category groups or timeline groups. Typically participants would develop these new groups with parts of existing groups from their workspaces that had been organized prior to the collaborative experiment. These results indicate that grouping is not only important as an initial stage of synthesis when artifacts are first evaluated, but that groupings will evolve over time in collaborative settings.

6.1.4 Tagging

Of the most frequent coded events, tagging was much more common by GeoVISTA participants than CIDD participants. Three groups; PSU 1C, 3C, and 4C used tagging on workspaces and artifacts. GeoVISTA participants primarily used tags to identify hypotheses. In practice these tags were used in two ways. Large post-it notes were annotated with short descriptions of different hypotheses. Small post-its and colored arrow tags were placed on specific artifacts to indicate their presence in particular hypotheses.

6.1.5 Collaborative Events

Although a relatively small portion of events were identified as purely collaborative, the character of these actions is noteworthy. Participants would often choose to work together to search for artifacts in several ways, a strategy that has shown benefits over independent searches in studies of teamwork with tabletop user interfaces (Morris, Paepcke, and Winograd 2006). Most of the time these searches sought to identify artifacts that they had in common versus those that only one of them had. Searches for artifacts related to particular categories or keywords were also conducted as hypotheses were refined. Usually one participant would recall seeing artifacts from a category or containing a specific keyword, and then both participants would work together to try and find those artifacts.

6.2 Individual Pair Results

The cumulative coding results outlined in the previous section described general findings based on the relative frequency of events. This section focuses on some of the unique strategies that participant groups used to conduct collaborative synthesis. It also describes the organizational methods that participants used to complete the task of ranking synthetic hypotheses.

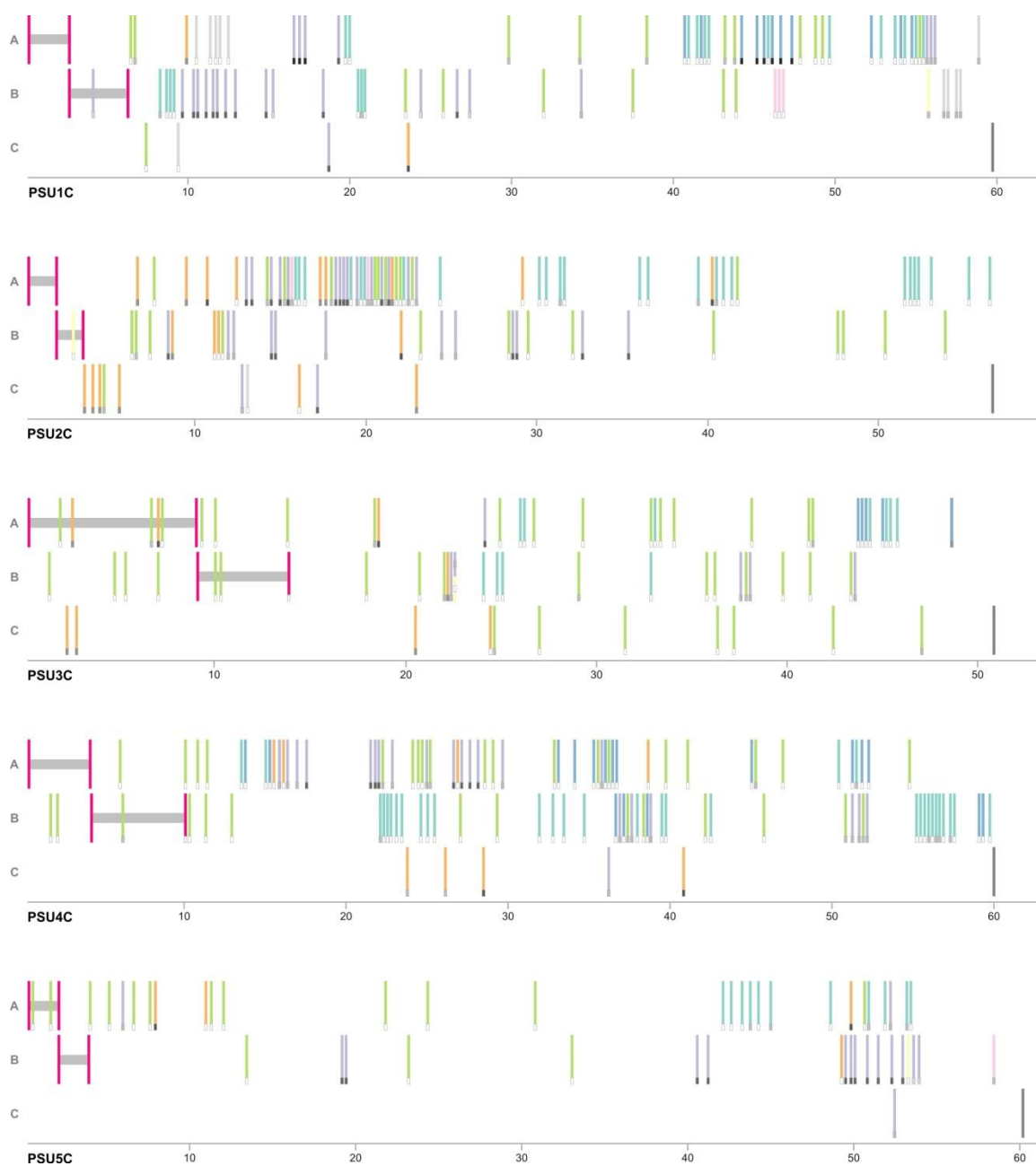


Figure 29: Coded results for the five collaborative synthesis experiments.

Coded results for the collaborative synthesis experiments are provided in Figure 29. Each session is represented with a three-part track, split into events according to who initiated them. Events in the *A* and *B* tracks refer to GeoVISTA and CIDD participants respectively, and *C* events are those that both participants conducted together. The legend in Figure 23 applies to these results as well. Section 5.4 provides detailed results

for each pair of participants, where each set of coding results is shown with photographs of the final workspaces, a graph that summarizes events, and a short written summary.

6.2.1 Establishing Common Ground

Collaboration often involves an initial period in which collaborators must develop their understanding of each other's work (Chuah and Roth 2003; Convertino et al. 2005). Participants came into the collaborative experiment having just completed their own individual work with the artifacts. They knew they would be participating in a collaborative activity, but they were not told that they would be using their individual results, so participants found out at the beginning of the experiment when the instructions were explained that they would need to evaluate each other's previous findings. Participants were not instructed to establish common ground in a particular way, but each group chose to do so in the same way for all five groups. After the start of the session, the GeoVISTA participant would begin explaining how he or she had organized their workspace. After this was completed, the CIDD participant would do the same. As shown in Figure 29, groups differed in terms of how much time was spent on this activity. PSU 2C and 5C took only a few minutes to establish common ground, while PSU 3C took the longest with almost fifteen minutes of explanation. During these explanations there were occasional zooms and other actions as particular artifacts were pointed out by one participant to the other.

A key aspect of establishing common ground for participants in these experiments was to assess which information they had seen before and which they had not. Participants quickly discovered during their personal workspace explanations that they had partially overlapping information. Groups varied from one to the next in terms of how systematic they were in then setting off to identify which pieces they had in common. All groups discussed this issue, but only PSU 2C and 3C conducted searches for read and unread artifacts in a sustained effort.

6.2.2 Collaborative Synthesis Strategies

The coded results for each group are largely unique from one another. It is difficult to discern clear patterns in terms of the sequence of events that may be considered a clear

strategy. The most obvious pattern is evident when examining which participant initiated which sorts of actions. This can be seen by looking at the cumulative graphs of coding results for each participant group. Participants in PSU 1C, 2C, and 4C chose roles during the experiment, assigning one member with the responsibility of annotating the workspace (Figure 30). In two instances, the GeoVISTA participant was in charge of annotation, while in the remaining instance the CIDD participant took that role. This strategy of role assignment has been noted in previous research as an important aid to collaboration (Hathorn and Ingram 2002; Zhu 2003).

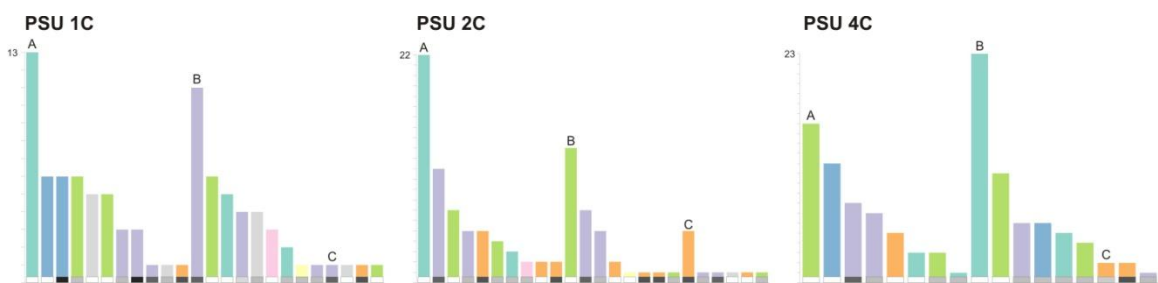


Figure 30: Cumulative graphs for PSU 1C, 2C, and 4C experiments, showing how participants adopted roles to handle annotation responsibilities.

The code results for PSU 5C show a similar pattern with different types of events figuring more heavily for each participant. But, in this case, it was clear from video evidence that they worked separately as a result of conflict rather than collaboration. The remaining group, PSU 3C, did not use role assignment to approach the collaborative task. This group relied heavily on verbal discussion to complete the task, choosing not to develop new organizations of their information or substantially modify their prior work.

The strategies that groups pursued to complete the collaborative task differed in terms of how they were begun. There were three observed strategies for approaching the task after establishing common ground: one group chose to address the timeline of events first, two groups chose to identify common and uncommon information first, and two groups decided to lay out their hypotheses first.

Participants in PSU 1C approached the collaborative task by devoting particular attention to the temporal dimension of the evidence. After establishing common ground, participant B began constructing a timeline while participant A searched for artifacts

based on time of occurrence. They situated their timeline around the idea that hypothesis plausibility depended on whether or not the events made sense compared to the time it takes for H5N1 to build up in a host and begin shedding (at which point it becomes contagious to others).

The PSU 2C and 3C groups approached the task by first determining which information they shared and which they did not. After establishing common ground, participants in PSU 2C went to each other's original workspace to identify which artifacts they had not seen before. From there, they focused their attention on modifying participant B's workspace to complete the task. PSU 3C used a very similar strategy, choosing to modify A's workspace instead.

PSU 4C and 5C focused on hypotheses first. After explaining their prior work, participants in PSU 4C began by writing hypotheses on post-it notes and placing them on the collaborative workspace. From there, they constructed hypothesis groups and timelines to refine their work. Participants in PSU 5C also began by focusing on their hypotheses, choosing instead to discuss them at length in place of using the artifacts on the workspace.

6.2.3 Ranking Hypotheses

The stated goal for participants in the collaborative synthesis experiment was to rank the hypotheses they had developed according to which were the most plausible, assuming they would then work afterward to communicate their results to decision makers. Participants were not instructed to use any particular type of ranking, as it was of interest to see what groups would do without specific guidance.

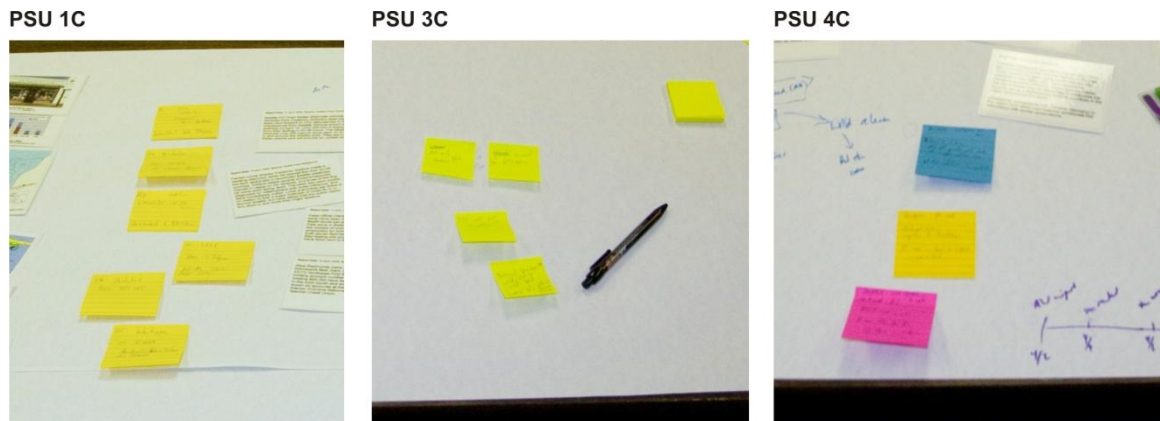


Figure 31: Ranking hypotheses using movable post-it notes.

Groups chose two ways to rank their final hypotheses. Three groups: PSU 1C, 3C, and 4C used post-it notes to record hypotheses (Figure 31). Then, each participant had an opportunity to rank them according to preference. Those groups then finished by negotiating a final ranking. Participants stated that this method was particularly effective because the post-it notes could be moved around easily to develop the final ranking. Two groups: PSU 2C and 5C did not record a set of final ranked hypotheses on the workspace. Instead, their ranking was entirely based on verbal discussion. These groups spent less time ranking hypotheses and did not discuss or debate the intricacies of their hypotheses in as much detail as the groups that chose to rank them using post-its on the workspace.

6.2.4 Collaborative Deadlock

One group's results stands out as an outlier. PSU 5C initiated the fewest events out of all of the groups, and failed to develop a collaboratively-ranked set of hypotheses. The participants in this group did not agree with each other about which information was most important and which hypotheses were most plausible. This group spent the majority of the session period discussing their differences. A risk associated with conducting any type of collaborative research is that the participants may approach a problem from very different perspectives that are difficult to reconcile in a time-limited situation, as happened in this case.

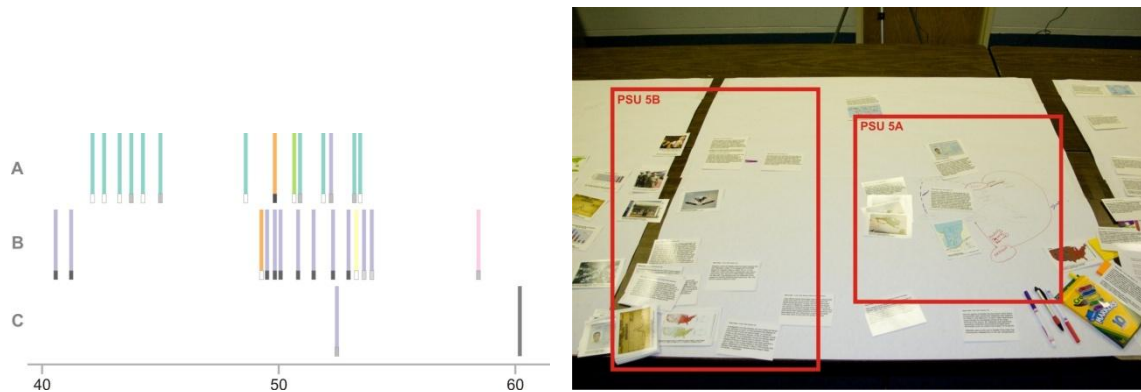


Figure 32: Detail of PSU5C showing where the participants chose to work separately from each other on the collaborative workspace. The picture at right is marked to where each participant completed their work.

In the last twenty minutes of their session, the participants of PSU 5C began working separately from one another to try and satisfy the requirement of the task to develop a ranked set of hypotheses. They did not discuss this as a solution to their conflict, rather the transition to this behavior was unstated. Participant A worked on a concept-map style of organization for the primary hypotheses he felt was most likely, while Participant B created groups on another portion of the workspace separate from participant A's work (Figure 32). Following an extended period of independent work, the participants then talked about the relative merits of their respective hypotheses, but did not reach a consensus about a ranking. The root of their disagreements appeared to be participant A's insistence on a single hypothesis that involved assumptions about data that was not actually present in the artifacts. Participant B was not willing to commit to hypotheses that were based on those assumptions. Participant B strongly advocated sticking to what she knew as a basis for hypotheses, not what might be true.

6.2.5 Organizational Metaphors

An important reason for conducting synthesis experiments with physical artifacts on a blank workspace is to see what types of organizational metaphors participants employ in the absence of a pre-determined method. Results from these experiments indicate that a multitude of methods are often mixed together.

The participants in PSU 4C mixed together four metaphors to develop their collaborative workspace (Figure 33). Along the top of the workspace they created hypothesis groups that were tagged to indicate relevant times, places and other attributes. At bottom left a social network was drawn to determine which people were related to each other in some way. At bottom center the set of final hypotheses were summarized onto separate post-it notes and ranked. At bottom right the participants drew a graphical timeline and plotted key events along it to try and discern the validity of a particular hypothesis.

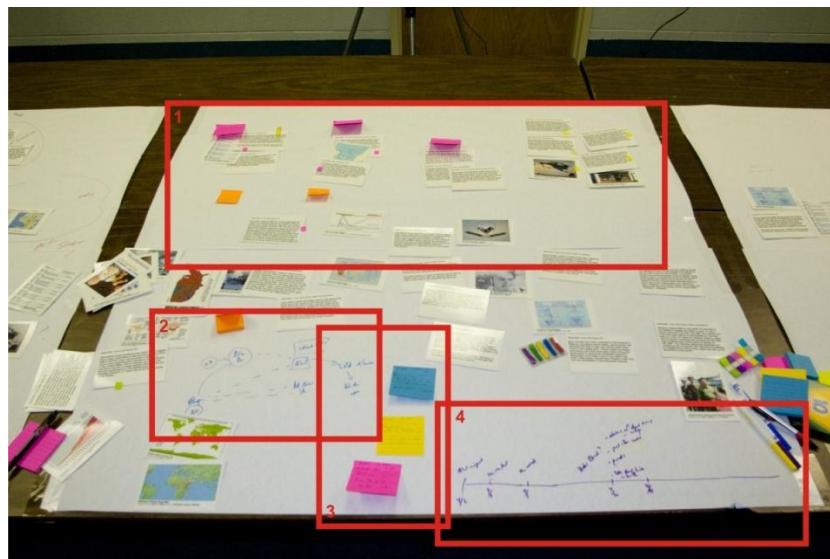


Figure 33: Collaborative workspace of PSU 4C, showing multiple organizational methods. 1) Hypothesis groups with tags to indicate times, places and other attributes. 2) A sketch of a social network. 3) Hypotheses summarized on post-it notes used for ranking. 4) A graphic timeline of important events.

PSU 1C used post-it notes at the top left of the workspace to represent hypotheses. At top right, post-it notes were annotated and arranged with drawn links between them to develop a representation of a social network. Across the bottom, participant B drew a large, simplified version of a virus growth and shedding artifact to use as a timeline reference for artifacts from their hypotheses (Figure 34).

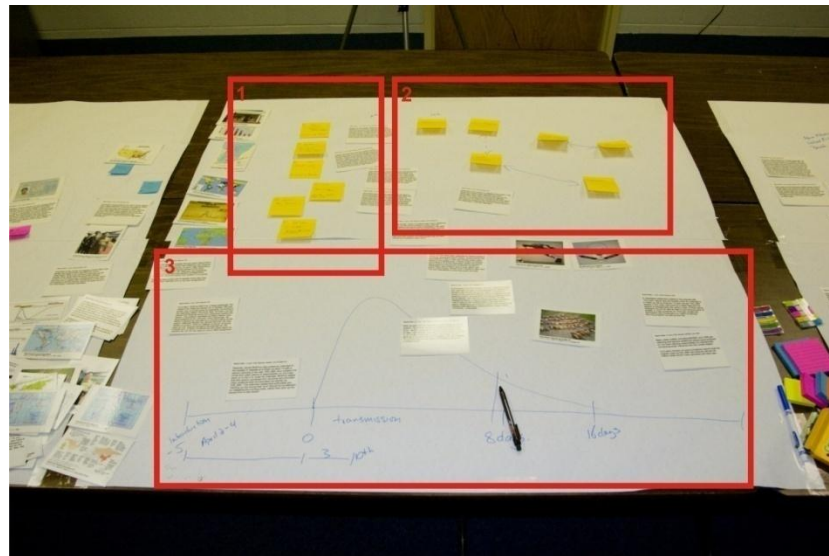


Figure 34: Collaborative workspace of PSU 1C, showing multiple organizational methods. 1) Ranked hypotheses on post-it notes, with adjacent supporting artifacts. 2) Social network using annotated post-it notes. 3) Drawn graphic intended to replicate an artifact that shows virus growth and shedding over time.

Another important aspect of general collaborative synthesis organization is the use of pre-existing organizations. In the experiment, participants were provided with a complete duplicate set of artifacts and a blank workspace to use if they so desired to complete the hypothesis ranking task. All groups except for PSU 3C chose to use all or part of the duplicate artifact set to create new artifact groups on the blank collaborative workspace. PSU 3C participants used the collaborative space only to write down a timeline of events and to rank post-it notes that represented hypotheses.

Groups PSU 1C, 3C, and 4C verbalized their desire to maintain their individual work in its original state, to make it easier for them to remember their findings later. PSU 3C deviated from this stated goal over time, poaching artifacts from participant A's workspace over to B's workspace, which was where the pair worked from during most of the experiment. In the debriefing where participants were asked to discuss their work, those groups that chose to alter their original work mentioned this as an unwise decision, as it made it hard for them to recall their findings once their personal space had been substantially altered.

6.2.6 Spatial Information

One of the collaborative pairs, PSU 2C, drew a map of the Pacific Northwest on the collaborative workspace to help develop a sense of the places related to various hypotheses (Figure 35). The geographer in the pair initiated this action, but the disease expert helped him find and add spatial references from the artifacts. For the other participant groups, attention to spatial information did not take the form of maps or other spatial representations, instead those references were included with and represented like other keywords, categories, or temporal information.

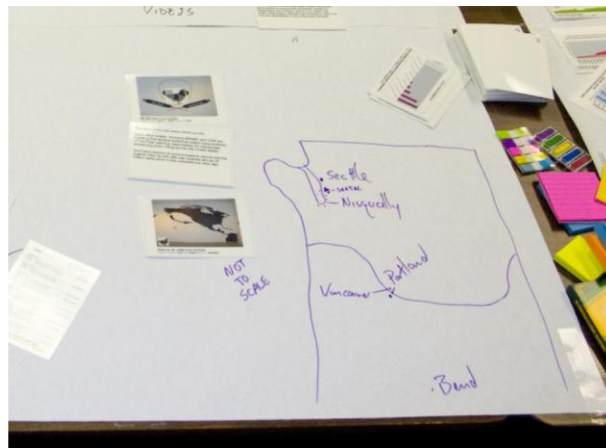


Figure 35: Map developed by participants in PSU 2C.

The lack of much special treatment for spatial information may simply indicate the difficulty associated with drawing a map from memory to represent the geography associated with various hypotheses – so it may be possible that had this experiment been attempted with the help of a reference map, participants would have made more explicit references to geography. Participants did discuss and reason about the spatial plausibility of their hypotheses, so that information did appear to factor into their overall information synthesis.

6.3 Discussion

While some of the results discussed here indicate the influence of the choices associated with designing the experiment (zooming and grouping artifacts are required given the situation posed by partially overlapping artifact sets on different workspaces), it

is reasonable to assume that real-world collaborative synthesis would take place in similar conditions. Users will bring their prior work to the task at hand, which has already been organized, and which includes items that other collaborators will not have.

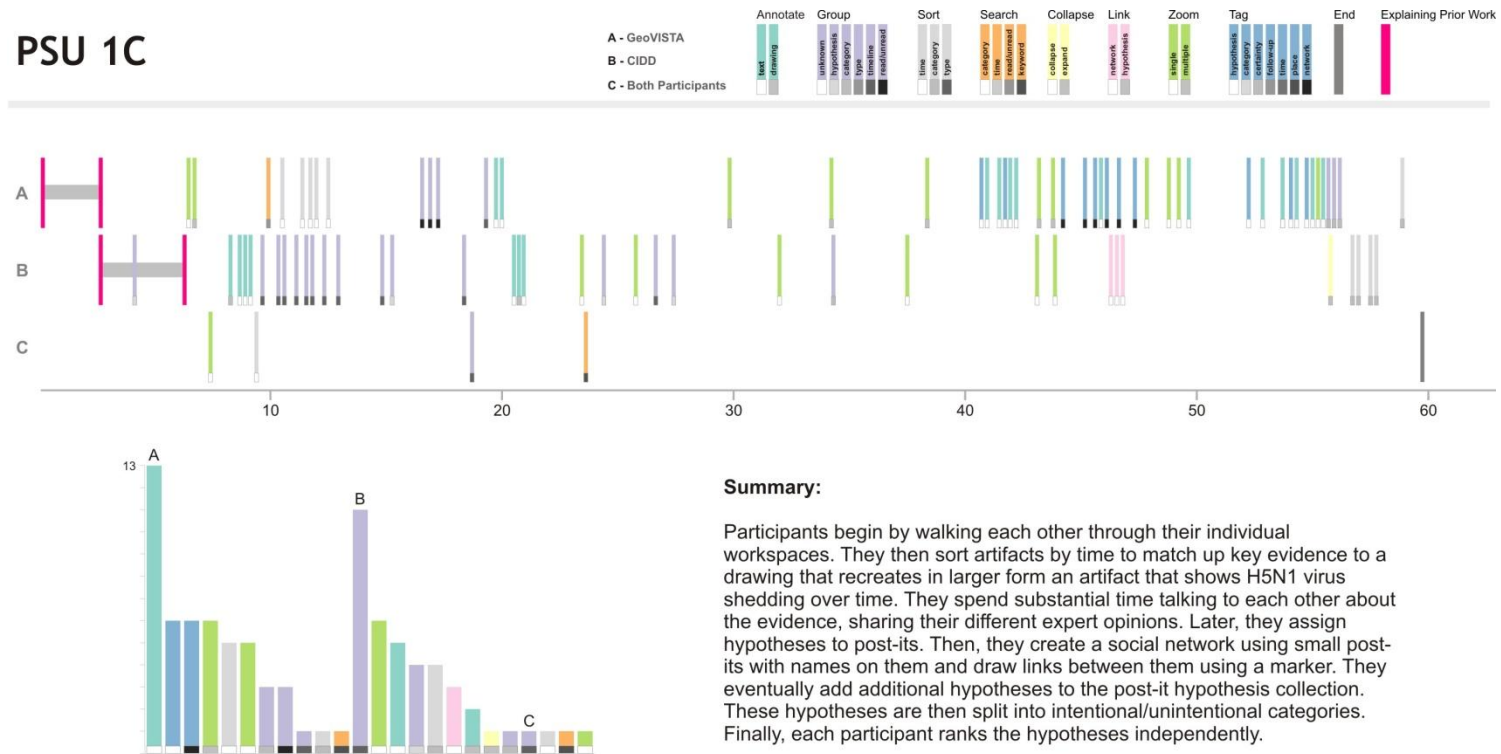
Results from collaborative experiment evidence suggest that supporting collaborative synthesis will require flexible tools that begin by helping users establish common ground. They will need to support a wide range of organizational types (timeline, network, category groups, etc...) and allow for open forms of annotation and tagging. It is also important to consider that groups will choose different strategies for approaching collaborative tasks. Some will begin with an emphasis on previously developed hypotheses, others might focus attention on which information overlaps and which does not, and still more may begin by reframing all of the information by some measure such as time, source, or certainty. Finally, it is also important to support collaborative role assignment, as participants in experiments often chose to split tasks among them to complete their work.

Chapter 7 presents design guidelines for synthesis support tools based on the collaborative results discussed here and the individual results discussed in Chapter 5.

6.4 Detailed Graphical Results

This section presents detailed graphical results for the experiments discussed in this chapter. Individual experiment code results are shown in timeline and summary graph form, along with a photograph of the final workspace and a short narrative description. Much like the detailed figures presented in the previous chapter on individual experiments, these figures show coded events on timelines to indicate how participants worked with the artifacts. Their verbalizations were not coded, but the figures do mark a time span to show the initial discussion for each session when participants worked to establish common ground.

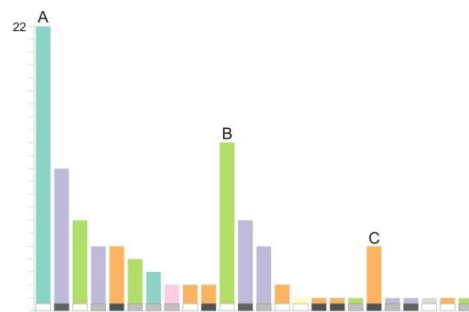
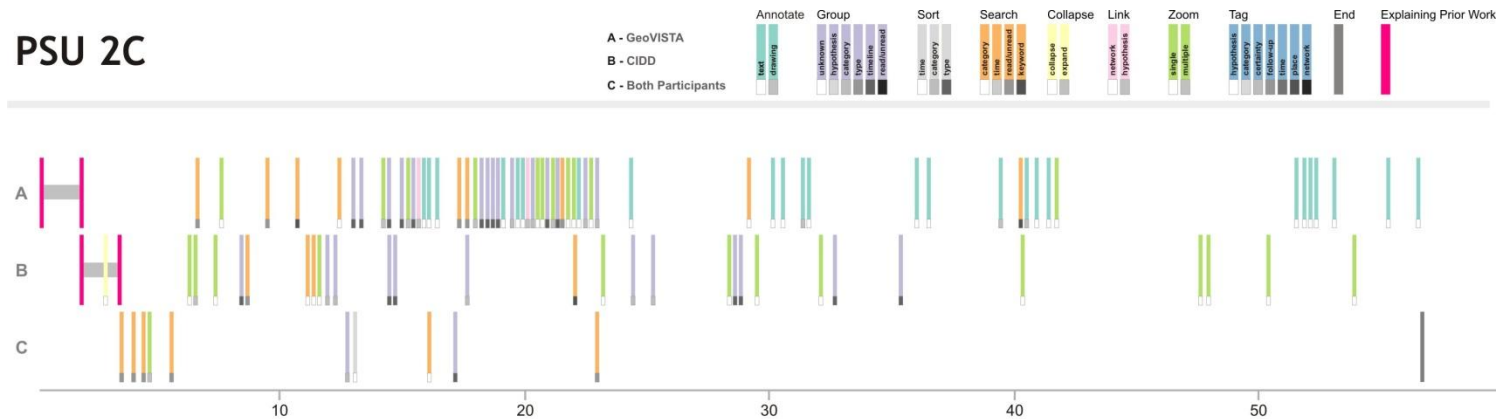
PSU 1C



Workspaces At End of Session



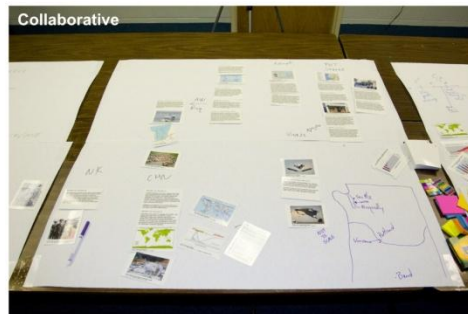
PSU 2C



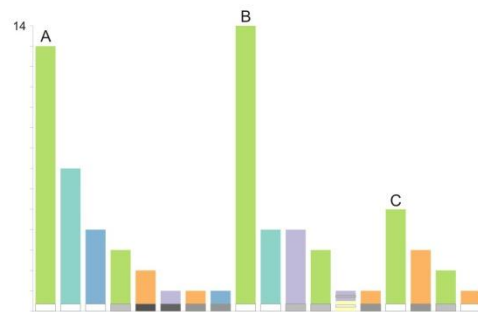
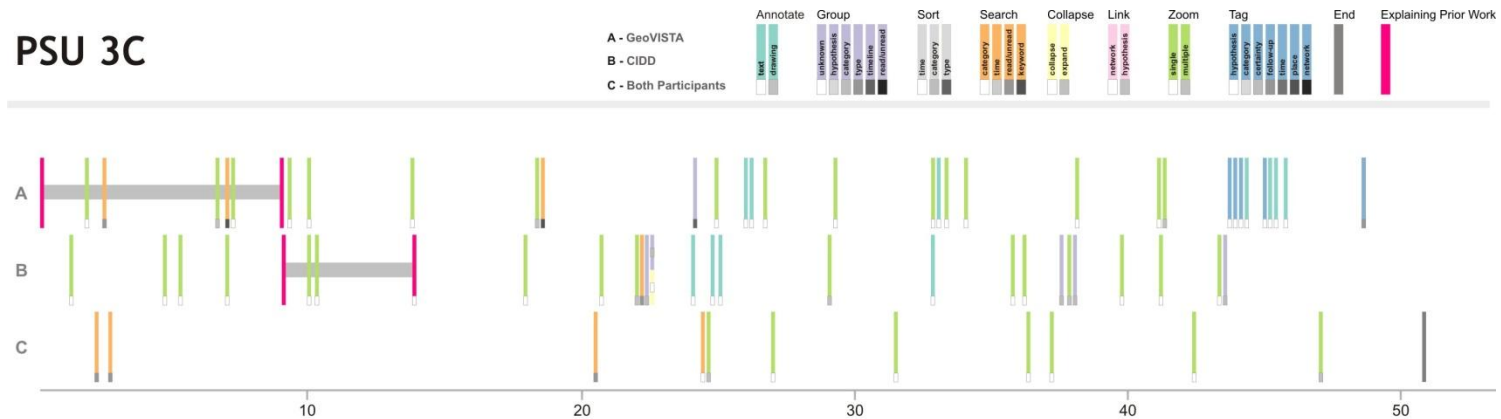
Summary:

Participants begin by explaining their findings to each other. Then they search each other's information to find the artifacts that are new to them. Timelines by topic are then created on the center table using artifacts from each participant's original work. Later, a graphical timeline is created on participant A's workspace that summarizes events but does not use the artifacts themselves. Participant A draws a map then of the Pacific Northwest region to help situate events in terms of geography. They finish by writing down likely hypotheses on a portion of participant A's workspace.

Workspaces At End of Session



PSU 3C



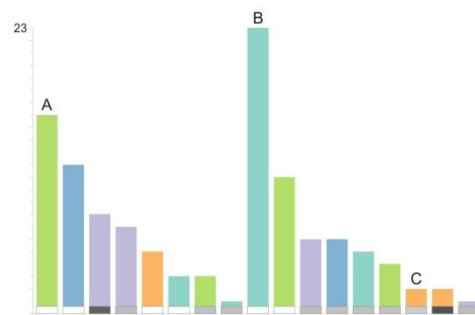
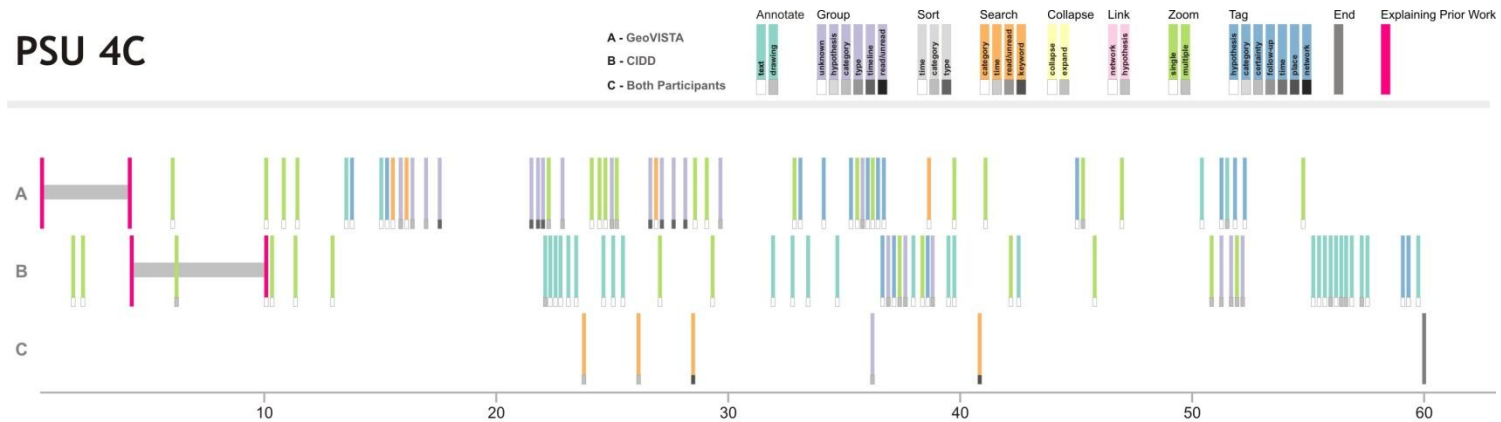
Summary:

Participants begin by explaining their work to each other, and then decide to look through the full set of artifacts to find what information they did not have in their first experiment. They initially decide to avoid altering their original work and use the new set of artifacts to create the collaborative view. Later, they change strategies and participant B brings over some of their artifacts to add to participant A's workspace. To organize their thoughts they write down events and key information in chronological order in the collaborative workspace. Participant A uses a different color marker to write down place-related information in the timeline. They eventually decide to write down hypotheses on post-it notes that can be moved around to indicate their ranking.

Workspaces At End of Session



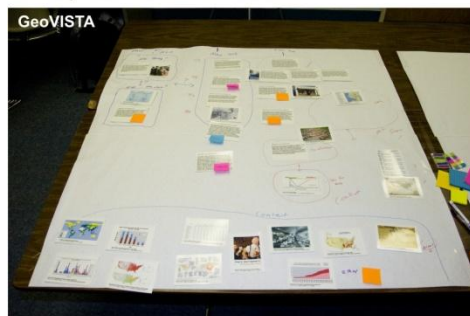
PSU 4C



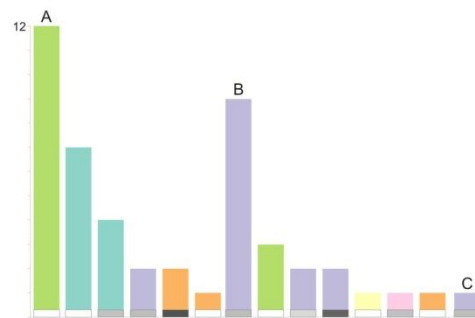
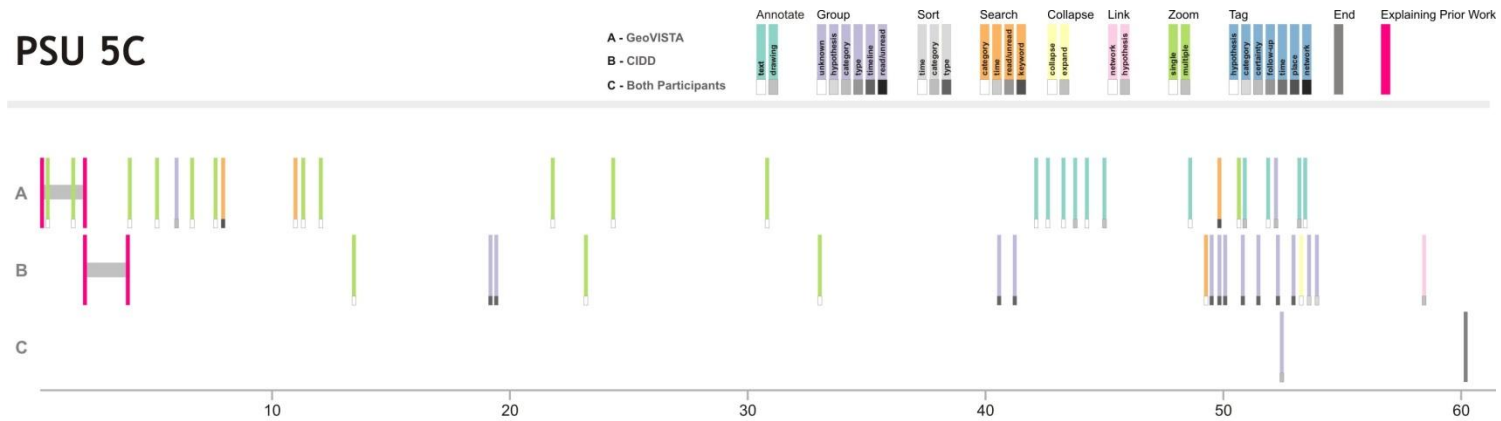
Summary:

Participants begin by showing each other their work. Participant A uses the common workspace to place tags that correspond to hypotheses and important events, mentioning that tags work better than committing drawing on the paper which cannot easily be changed. They agree to use artifacts from the duplicate set instead of altering their original work. Both participants use time to organize artifacts and to create a graphical timeline on the common workspace. They use color tags to indicate which artifacts pertain to which hypotheses. Participant B draws a network to indicate linkages between key events and players to try and crystallize the hypothesis he finds most credible. At the end, participant B ranks the hypotheses after discussion with participant A by placing tags with hypotheses written on them in rank order.

Workspaces At End of Session



PSU 5C



Summary:

Participants begin by explaining their work. They disagree on the relevant information/hypotheses and appear to struggle through the activity much more than the other groups. After 25 minutes, they re-read the activity instructions and each identify the hypotheses they think explain the source of the outbreak. For most of the activity they work from participant B's workspace. Participant A writes down hypotheses there using concept maps. Participant B states that A should show which parts of the concept maps are based on known facts and which are conjecture. Participant A and B work separately to complete the rest of the activity (concept maps on one side for participant A, artifacts grouped by hypothesis on the other side for participant B), as they do not agree on what information is important.

Workspaces At End of Session



Chapter 7 – Design Guidelines for Synthesis Support Tools

As the results generated from geovisualization become more intricate and numerous, support for synthesis in geovisualization software is becoming more important. Analysts working on long-term efforts to tease apart complicated problems currently have little in the way of interactive visual tools to help organize, annotate, and make sense out of their collections of evidence. To begin addressing that need, research results from individual and collaborative synthesis experiments are distilled here into design guidelines for synthesis support software. The following sections describe interface metaphors, necessary tools and functions, and general design guidelines based on evidence gathered from interviews and experiments with analysts and experts at PNNL and PSU. This chapter concludes with a section describing design considerations for moving synthesis support tools beyond individual work into collaborative environments.

7.1 Synthesis Interface Metaphors

Interview and experimental results indicate that there is a wide array of organizational metaphors that can be used to synthesize analytical results. Analytical needs dictate the use of different organizational strategies at different times, for example, timelines may be useful to orient artifacts in order of occurrence, but a node-link organization may be required later during the same synthesis activity to develop a deeper understanding of the social network involved. Evidence points to organization by category, hypothesis, timeline, hierarchy, report outline, and node-link methods (Figure 36). These are described in further detail in the following sections. Each section also includes a reference for a representative workspace for each organizational method from the detailed graphical result sections of Chapters 5 and 6.

7.1.1 Category

The most common organizational method used by participants in synthesis experiments was to group items by category on the workspace (see PSU 3B for an example). Categories vary in terms of specificity – from relatively broad areas like “background information” to more specific topics like “news reports about dead birds.”

New synthesis support tools should allow users to assemble groups of artifacts according to category designations. In experiments, participants indicated groups by collecting artifacts in close proximity on the workspace, and often chose to draw lines around the objects to develop “regions” to separate groups from one another. Synthesis software should detect groups of items in close proximity to one another and help users delineate them with boundary markers.

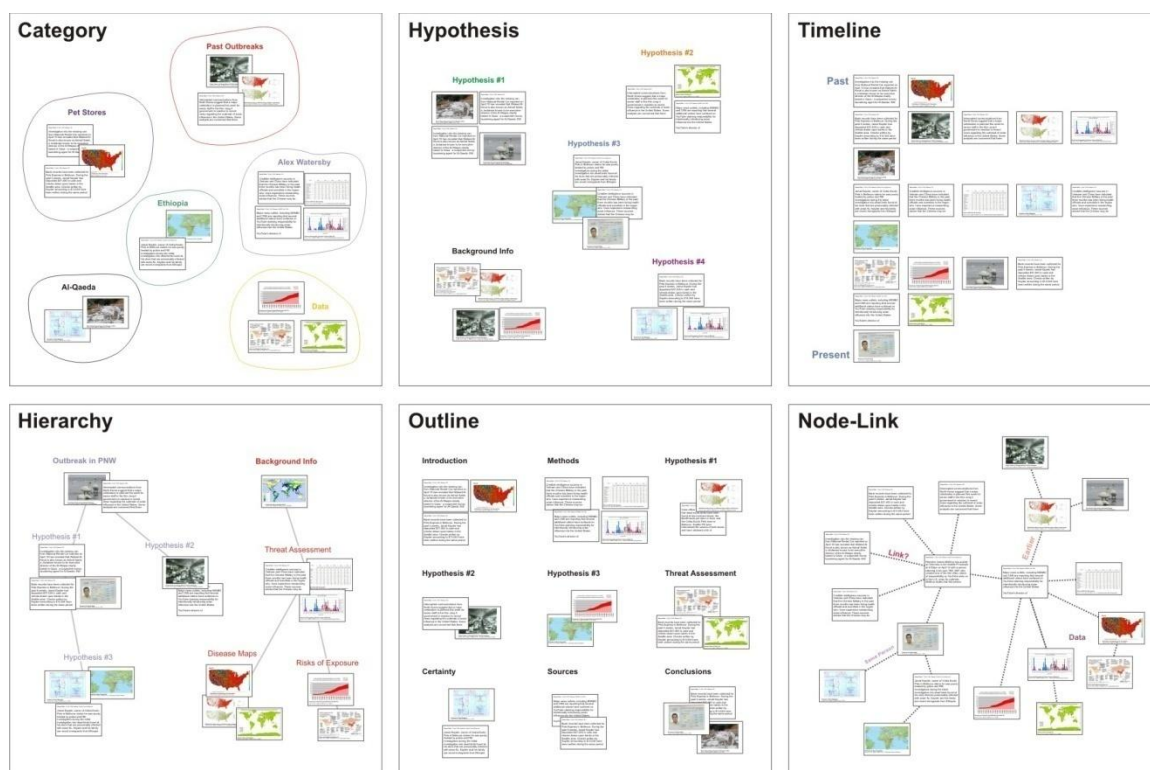


Figure 36: Synthesis organizational metaphors gathered from interview and experiment evidence.

7.1.2 Hypothesis

Another common organizational technique applied by participants in synthesis experiments was to group items according to hypotheses (see PSU 1C for an example). While the experiment conditions called for the development of hypotheses, this type of organization should be expected as a likely method for most real-world analytical scenarios. Few situations requiring the assembly of multiple analytical result artifacts will *not* have the goal of developing and/or refining hypotheses (Heuer 2005). This extends

to collaborative settings where teams may be asked to explore and critique competing hypotheses (Waltz 2003)

Users should be allowed to select a group of artifacts and indicate that they are part of one or more hypotheses. In synthesis experiments, participants placed artifacts in close proximity and provided annotations on the workspace or on tags to indicate different hypothesis groups. Synthesis support tools should help users quickly identify groups of artifacts as pieces of a hypothesis, and should reveal linkages between hypotheses based on time of occurrence, keyword/category similarity, or other measures. Cluxton et al. have implemented a visualization tool designed to support similar functions using a matrix in which multiple hypotheses can be compared across a variety of attributes (Cluxton, Eick, and Yun 2004). Their approach supports analysis of competing hypotheses (ACH), a methodology first proposed for intelligence analysis by Heuer (1999). ACH did not emerge as a strategy by participants in synthesis experiments. Analysts at PNNL have almost certainly been exposed to this method through training, so it is more noteworthy that they did not make use of it compared to PSU experts who are unlikely to have practiced ACH.

7.1.3 Timeline

Interview and experimental evidence indicates that time is an important mechanism for situating and organizing analytical results. This is consistent with recent research from the information retrieval community, which suggests that the temporal metadata can help users quickly find relevant information and to understand what “they could have known” when asked to audit prior work (Alonso, Gertz, and Baeza-Yates 2007).

Interview responses indicate that time is often used as a basic method for indexing projects and information, often in combination with project or category names.

Experiment results show that some participants begin a simulated synthesis task by sorting objects according to time of occurrence and building hypotheses around a global timeline (see PNNL 6 for an example). Most other participants make use of timelines as a way of examining their information from a different angle after they have developed one or more hypotheses using category or other organizational strategies.

Synthesis support tools should enable users to sort and align artifacts to a timeline. Because many experiment participants chose to apply timeline organizations to only a portion of their workspace, timeline organization should be applicable to subsets of items as users desire. Applying a global temporal organization to all items at once may be more useful when it is necessary to keep track of multiple collections of artifacts – a scenario participants described in interviews at PNNL.

7.1.4 Hierarchy

Participants in interviews and synthesis experiments show that hierarchical organizations, commonly used in office productivity software and operating systems are also useful ways of organizing analytical results. Interview responses suggested that keeping result collections in file trees is a common organizational strategy. Experimental results show that some users approach artifact grouping in a hierarchical manner (see PNNL 1 for an example), applying basic headings above groups of artifacts that have multiple sub-groups within them that represent specific sub-categories.

New tools to support synthesis should allow users to develop hierarchical organizations of their information. Hierarchies may be applied to results within a particular project, as well as the projects themselves when they are considered part of a knowledge base. Information structured in a hierarchy can be denoted by the placement of artifacts in a tree structure, including headings and sub-headings indicated by annotation on the workspace or on movable tags.

7.1.5 Node-Link

Another common organizational strategy shown in experimental data is the use of node-link diagrams to connect artifacts or summarize information contained in artifacts (see PSU 5A for an example). Participants at both PNNL and PSU used node-link organizational methods primarily to explore social networks. Artifacts were placed on the workspace in a way that allowed arrows or lines to be drawn between them to indicate relationships. Some users chose to summarize information on post-it notes and develop node-link diagrams using those.

Synthesis support tools should support the use of node-link organization to evaluate social networks in collections of artifacts. In synthesis experiments, participants used simple links between artifacts or artifact summaries, occasionally annotated to indicate the type of relationship that bound artifacts together. Synthesis tools should allow users to develop node-link organizations with subsets of information, as no participants in synthesis experiments applied this strategy to the entire workspace. Node-link organizations tended to emerge in the later stages of analysis as participants moved through multiple organizations of the information to evaluate and enhance their hypotheses.

7.1.6 Report Outline

A report outline structure was frequently mentioned during interviews with analysts at PNNL as an important strategy for organizing analytical results. Participants indicated that they would often try to situate artifacts according to where they would fall in a typical project report. Reports are also typically the first place analysts return to when asked to recall prior work, so providing tools to view artifact collections from this perspective (or to reach-back into them from the reports themselves) is particularly important for supporting analytical recall.

New synthesis support tools should allow users to organize objects according to report headings and outlines common to their domain. While experimental evidence does not show this type of organization, interview evidence suggests this is how results are approached in the final stages of work prior to presentation to a client. With that in mind, this type of organization may be best supported in synthesis tools as an alternative view designed for developing project reports, rather than a view intended to help analysts make discoveries or develop the “big picture” from their information.

7.2 Synthesis Support Tools

Basic organizational capabilities must be coupled with the appropriate set of corresponding tools to support effective and efficient individual and collaborative synthesis. Evidence from synthesis experiments with analysts and experts indicates an array of tools that are necessary to support synthesis in software. The following sections

provide guidelines for tools that group, annotate, zoom, tag, collapse, link, sort, and search artifacts.

7.2.1 Group

The most common action initiated by participants in individual synthesis experiments was to group items on the workspace. Artifact groups were developed with a wide array of strategies, including by category, time, and hypothesis. Experiment results show that participants often used different grouping strategies in the same session, and may mix methods on the same workspace.

Synthesis software should support the development of artifact groups by allowing artifacts to be moved around the workspace at will, and by providing users the ability to select multiple artifacts and assign a group tag or region to identify their association. To support multiple types of grouping, tools are required to help users create additional views of individual or multiple artifacts to reflect multiple perspectives, such as time, category, or hypothesis.

7.2.2 Annotate

Text and graphic annotation is a common event type noted from synthesis experiment results in both individual and collaborative settings. Participants frequently wrote keywords, hypotheses, questions for follow-up, and other notes on the workspace or on tags placed near artifacts. Graphic annotations included regions drawn around groups, sketch maps and other graphics, and arrows or lines to indicate linked artifacts.

New synthesis support tools should allow users to annotate workspaces and artifacts at will. Annotations in both textual and graphical formats should be supported, as experiment participants frequently mixed together both types. Pen and/or touch enabled interfaces are promising avenues for supporting easy annotation in synthesis toolkits. Sketch maps, timelines, and other graphics appeared in several synthesis experiment results – things that are impractical for users to create in software without using a stylus.

7.2.3 Zoom

Results from synthesis experiments demonstrate that participants frequently pick up artifacts to examine them closely. Artifacts were observed to be closely examined individually as well as in groups. When artifacts were examined together, participants were typically attempting to compare information between multiple items.

Synthesis support tools should provide zooming capability for users to closely examine one or multiple items at a time. Experiment evidence shows that users frequently wanted to examine artifacts in a particular group when they attempted to examine multiple artifacts at a time. Zooming tools should support this kind of “regional” zooming as well as individual artifact zooming.

7.2.4 Tag

Evidence from synthesis experiments suggests that identifying artifacts or groups of artifacts using colored tags is a commonly used technique. Participants frequently wrote short descriptions on tags to summarize different types of information. In collaborative activities, tags were used to represent hypotheses, at which point they were then arranged by participants to indicate likelihood ranking.

It is important for new synthesis support tools to enable artifact tagging to indicate keywords, time, certainty, membership in a hypothesis, and other information. Experimental evidence suggests that tagging happens to individual artifacts as well as groups of artifacts, so tagging tools should be agnostic to either case. Tags should be implemented in a way that allows them to be moved around the workspace to indicate rankings or to adapt to evolving methods of artifact organization.

7.2.5 Collapse and Expand

Participants in synthesis experiments occasionally collapsed groups of artifacts into stacks. Collapse events were initiated to reduce workspace clutter, and they were also initiated to indicate that one or more groups had been carefully examined, i.e. as a visual cue. Some participants alternated between collapsing groups and expanding them again later as their attention shifted from one group of artifacts to another. Graphical artifacts, colored tags, and annotations were used by participants to identify stacks. Some chose

to place graphical artifacts so that they were on top of the stack, or peeking out from the side of the stack to provide a visual cue.

New synthesis support tools should provide users with the ability to minimize groups of artifacts into stacks. Stacks should be expandable on-the-fly as users return to groups that they may have minimized to tidy the workspace or to indicate that they had examined those artifacts. Users should be able to use images, tags, or other conspicuous means to identify their stacks. Implementation of these capabilities might reflect recent work by Setlur et al. to design meaningful file icons (Setlur et al. 2005). The Setlur et al. approach uses computational methods to identify the content described in files, and then using that information simplified images that represent key topics are overlaid on the basic icon design. This method allows users to quickly recognize the type of file they are looking for, and then visually locate files based on their content.

7.2.6 Link

Evidence from synthesis experiments shows that participants place arrows and/or lines between artifacts and artifact groups to point out shared relationships and dependencies. Participants frequently used drawing tools and less frequently used arrow-shaped post-it notes to create links between objects.

Users should be able to indicate linkages between artifacts and artifact groups using line and arrow graphics in future synthesis support tools. Links may be used to indicate any kind of association between artifacts, including time, social connections, and hypothesis membership. Users should be able to annotate links to indicate these types of relationships as they see fit.

7.2.7 Sort

Participants in synthesis experiments were observed to quickly sort through artifacts to arrange them temporally, to split them into generic categories, and to isolate certain types of information (text reports from graphics, for example). This facility was particularly noted in collaborative synthesis experiments where participants made use of a duplicate set of artifacts to develop a collaborative workspace. Sorting actions were

observed to take place within particular artifact groups on occasion, as participants sought to arrange items in groups by time, type, or according to sources.

Synthesis support tools should allow users to quickly sort collections of artifacts by time, artifact type, category, or other attributes as needed. Sorting should be applicable globally as well as locally to specific groups of artifacts.

7.2.8 Search

Interview and experimental evidence indicates that participants require the ability to quickly search attributes and content associated with artifacts. Analysts at PNNL stated that a weakness of current tools is that they are not able to easily query collections of results to retrieve information. Experiment results show that participants frequently engage in search actions to find artifacts with specific keywords as well as those that belong to categories of information, particular time periods, and other attributes. Once artifacts were located, participants did not always necessarily move artifacts or change how they were grouped. This depended on whether or not searches revealed information that changed participants' hypotheses.

Users of synthesis support tools should be able to query artifacts to identify matches to keywords, categories, temporal references, and other attributes. Search results should simply identify and highlight matches and allow users to regroup artifacts as they see fit.

7.3 General Design Guidelines

Interview and experimental evidence reveals that there are several overarching design guidelines that contextualize the development of new synthesis support tools. First, it is important that new synthesis tools provide flexible tools and interfaces to support diverse approaches to synthesis. Second, synthesis tools need to allow for mixtures of organizational metaphors. Third, mechanisms are needed to coordinate communications and analysis to support synthesis. Finally, synthesis tools should provide users with methods to manage collections of background or contextual information.

7.3.1 Flexibility

Participants in interviews and experiments demonstrated a diverse array of approaches to the task of synthesis. There is no evidence that suggests a consistent, single strategy that synthesis tools can be shaped around. Even analysts who work on similar topics in the same workplace were not observed to synthesize information in the same way. Some analysts used annotations, tags, and other tools frequently to augment their workspaces, while others used only the physical arrangement of artifacts to indicate their thoughts.

Synthesis support tools will need to allow users to draw from a palette of common tools and organizational metaphors that are designed with flexibility and creativity in mind. The goal should be to create synthesis interfaces that afford all of the flexibility of real materials – yet enable advanced digital capabilities to quickly search, sort, duplicate, and reconfigure the workspace.

7.3.2 Mixed Metaphors

When this study was first conceived, it was assumed that it may be possible to identify one particular interface metaphor that would best support synthesis. Results of interview and experimental work show that in fact most participants choose to mix together multiple organizational methods as they synthesize information. New forms of organization are often brought into the workspace as hypotheses are revised and refined, as participants seek multiple perspectives on their information.

New tools for synthesis support must give users the ability to use multiple organizational methods. Additionally, they should allow users to apply different methods to different groups of artifacts as required. An obvious advantage that software synthesis tools could provide over real materials as evaluated in this study is that software tools should be able to easily support the creation of multiple workspaces with the same information. This would allow users to develop multiple synthesized collections, perhaps to systematically evaluate information from various perspectives. New synthesis support tools can also connect to computational methods designed to automate comparisons between the perspectives of multiple people who work with large sets of artifacts (Gahegan and Pike 2006).

7.3.3 Coordinating Communication

Interview respondents stated that an advance on the current state of the art of synthesis tools would be to couple project communications more tightly to analytical results. Email is frequently used to explain and transfer analytical results, but email software is not a satisfactory synthesis environment. Furthermore, the office productivity tools commonly used to collect and report on results do not recognize or generate links to relevant communications.

Synthesis support tools should allow users to couple analytical artifacts with related communications made through email and other means. This would particularly benefit analysts' ability to recall prior work when necessary. Synthesis software could index email in conjunction with analytical artifacts, allowing users to quickly search project communications and associate that information with artifacts. In the absence of satisfactory artifact metadata, related communications can also help users establish data provenance.

7.3.4 Managing Contextual Information

Results from synthesis experiments show that most participants devote a portion of their workspace to groups of artifacts that are considered background or contextual information. Usually located on the periphery of the workspace, these artifacts may not be part of particular hypotheses, but instead provide information that relates more generally to the analysis as a whole. Artifacts may also be placed in this area because their connection to the work at hand is as yet unknown. Studies of intelligence analysts have called artifact collections like these *shoeboxes* (Pirulli and Card 2005).

New synthesis support tools should allow artifacts to be designated as background, contextual, or unknown information. The shoebox metaphor can be employed here as a dedicated portion of the interface reserved for storing artifacts that are not yet in immediate use on the workspace. This place would be the starting point for many real-world synthesis activities, as users begin with a large collection of analytical artifacts and move them in small portions onto the workspace to evaluate information. A shoebox

display should allow users to quickly sort and search artifacts - actions that participants initiated with contextual artifact groups in synthesis experiments

7.4 Supporting Collaborative Synthesis

Different interview questions and experimental settings were employed in this study to explore differences between individual and collaborative synthesis. According to the PNNL project managers who participated in interviews, most real-world synthesis tasks will involve multiple analysts working together to develop reports for decision makers, a finding echoed in the intelligence analysis literature (Heuer 1999; Hutchins, Pirolli, and Card 2004). The following sections describe empirically-derived design guidelines that are particularly important for supporting collaborative synthesis. The first section suggests ways to support analysts as they establish common ground. The second section covers guidelines for supporting role assignment. The final section describes how new synthesis tools can help users align collaborative products to match client needs and expectations.

7.4.1 Establishing common ground

Interview and experimental evidence indicates that collaborative synthesis typically starts by establishing common ground between participants. Users' individual artifact collections must be compared to one another so that all involved understand what information is shared and what is not. Participants in collaborative synthesis experiments walked their colleagues through their prior work by verbally describing each part of their workspace. The experimental setting mandated that each participant had slightly different information, and after participants finished walking each other through their work, they often continued from there by identifying exactly which items they had in common. When given the choice to modify and re-use their independently developed workspaces, participants who did so stated in post-experiment debriefings that they regretted doing so because it was difficult to recall prior discoveries.

Synthesis tools should allow users in collaborative situations to quickly determine which artifacts they share versus which they do not. When users may want to draw all or part of their individual synthesized workspace into a new collaborative workspace, synthesis

tools should automatically save previous workspaces so that users can return to them later to more effectively recall their individual work. Collaborative synthesis tools should also provide users with tools to help them narrate to one another as they walk through their workspaces while establishing common ground.

7.4.2 Supporting role assignment

Collaborative synthesis experiment results show that participants adopted different roles to complete the task. Specifically, one participant would take responsibility for making annotations on the workspace, while the other participant focused more on retrieving information and feeding it to the reporter. It is realistic to expect that larger collaborative groups would also seek to split up responsibilities. This is especially likely in scenarios that require analysts from multiple domains work together to synthesize results, like natural disasters or disease outbreaks.

New synthesis support tools intended to function in collaborative settings should support role assignment. Easily configurable interfaces would enable this by allowing users to expose and organize tools according to the role they have adopted. Presets could be developed to save configurations for different roles, enabling quick transitions between roles when necessary. Recent work in the field of Computer Supported Cooperative Work (CSCW) proposes a research agenda for exploring the topic of role assignment (Zhu 2003; Zhu and Zhou 2006) – suggesting that role assignment aids collaborative productivity and results in higher levels of user satisfaction.

7.4.3 Aligning Synthetic Collections to Client's Needs

Interview results indicate that transitioning synthesized results from analysts to decision makers can be more or less difficult depending on what decision makers expected analysts to find. Analysts stated that they could usually anticipate difficult situations, and would develop reports accordingly. In such situations, analysts will include additional details and supporting evidence to bolster their arguments. In some circumstances analysts reported that results can be difficult to convey to decision makers because they require substantial domain knowledge to interpret.

Synthesis support tools will need to help collaborators transition synthesized results into reports that are adaptable in terms of the details they provide. Users should be able to easily embed metadata or other detailed information about their results to satisfy situations in which results are likely to be contested. Synthesis tools will also need to allow users to link their reports to background information in order to communicate their findings effectively to those who will make a decision with the information, but may not have substantial background in the relevant science.

7.5 Discussion

The preceding sections present a design framework useful for the development of new synthesis support software. These design guidelines are based on evidence from interview and experimental results gathered from analysts and experts in relevant task domains. They are intended to inform the formative design of new synthesis support tools for individual and collaborative applications. Previous research efforts have yielded similar frameworks for the design of geovisualization tools to support epidemiology (Robinson 2007), and to define the tasks that should be supported by visual analytics tools (Amar and Stasko 2005).

Generally speaking, synthesis support tools need to mesh well with the wide array of different approaches to synthesis that analysts have been observed to take. This means that synthesis tools need to provide flexible and easy-to-use features that afford all of the basic manipulations possible with real artifacts, paper, and office supplies. They also should leverage advantages that can be only found in software, which will enable rapid searches and sorts through data, as well as provide users with the ability to easily duplicate their workspaces, develop and compare multiple views onto the same data, and share collections of results with others.

Implementing synthesis tools using the guidelines presented here will provide the opportunity to conduct follow-up studies to explore how well they support synthesis as conducted in a purely digital realm. Prototype tools will also kick-start the difficult process of adapting current geovisualization tools so that they produce artifacts that can be understood by and shared through synthesis tools. In that sense the framework

presented here is an important portion of the larger effort to design and develop new geovisualization and visual analytic tools.

The next chapter concludes the dissertation with discussions on its significance and limitations, as well as outlines for potential future research projects that would expand upon what has been learned from this study.

Chapter 8 – Conclusions and Future Directions

This chapter concludes the dissertation with short discussions about the overall significance of the research, the limitations of its results, and ideas for future synthesis research.

8.1 Significance

The research reported here provides an important in-depth examination of part of the geovisualization research process that has until now remained unexplored. Prior to this work, synthesis has not received specific attention in tool design, development, or evaluations. The results of this research show that synthesis, the transitional stage between analysis and presentation in the process of science supported by geovisualization (DiBiase 1990), is an intricate and varied activity. Supporting it will require flexible tools that allow for diverse approaches and creativity.

This dissertation contributes to the existing body of Geography research that focuses on geovisualization as well as the newly formed area of geovisual analytics. It characterizes and suggests design guidelines for synthesis in geovisualization – filling a gap in the existing literature, and elaborating on a key portion of the theory that describes analysis with geovisualization. The findings from this work set the stage for the development of synthesis support tools that help analysts tackle complex, geographic problems with interactive visually-enabled interfaces. A realistic geographic problem was used in the design of the experiment materials, including artifacts that feature a variety of spatial references, and a range of hypotheses that each feature spatial components. Finally, the experimental approach itself provides an empirical method for future studies on how analysts collect, organize, and add meaning to spatial information.

The design guidelines from this work are significant because spatio-temporal problems like disease outbreaks and other crisis management situations will require sophisticated visualization tools that pull together different sources of geographic and non-geographic information. Synthesis support tools are also needed to help analysts assemble what they have discovered into actionable information for decision makers. Design guidelines

developed in this research will help shape new synthesis support tools to meet these challenges.

This study focused on four primary research questions:

1. How do analysts currently synthesize the results of geovisual exploration?
2. What do analysts wish they could do to better synthesize the results of geovisual exploration?
3. How do analysts synthesize results in a simulated real-world situation, and what does this tell us about how synthesis is conceptualized?
4. What design guidelines for new synthesis tools emerge from analysts' current, projected, and demonstrated synthesizing behavior?

Interviews with a group of disease surveillance and bioterrorism analysts at PNNL provided answers to questions one and two. Analysts currently collect, organize, and add meaning to their results by using office productivity software and in some cases visualization tools. When asked if these tools adequately support their work, analysts point out a number of weaknesses. They suggest new synthesis support should coordinate project communications with artifacts. They also indicate that new synthesis tools need to ensure that artifacts carry information with them to describe their provenance.

Research questions three and four were addressed by conducting synthesis experiments with analysts and experts at PNNL and PSU. Participants in these experiments showed that there are multiple approaches that can be used to synthesize results. Obvious differences between analysts at PNNL and experts at PSU were not observed, suggesting that domain expertise may not be a deciding factor in terms of how people synthesize information. In general, participants began the synthesis task by developing category groups from the artifact collection. From there, approaches varied substantially – often with participants applying multiple organizational metaphors in their workspace. Most participants made use of markers, tags, and other office tools to

augment their workspaces, and a few chose not to use anything besides the artifacts themselves.

Individual and collaborative tasks were assigned to explore differences between those types of synthesis. Collaborative synthesis as observed in five PSU experiments is a task that begins by establishing common ground, and from that point forward usually involves role assignment to split synthesis responsibilities among collaborators. When the goal is to develop a ranked set of hypotheses, most groups choose to summarize hypotheses on post-it notes and arrange them on the collaborative workspace. Groups did not attempt to match evidence across hypotheses and the sensitivity of their hypotheses to particular assumptions or evidence. This approach is known as analysis of competing hypotheses (ACH) and features prominently in the intelligence analysis literature as an important method for ensuring analytical quality (Heuer 1999; Waltz 2003).

This study is also significant because it provides an experimental methodology for studying synthesis that can be re-used and modified for additional research. Until now, there has been little in the way of specific guidance for developing experiments to observe synthesis. A hypothesis-centric approach allows experiment materials to be evaluated to see whether or not threads embedded in artifacts are in fact discovered and reported as hypotheses by participants.

Problem domains that we wish to support with geovisualization tools, such as disease surveillance and crisis management will require dedicated tools to help users synthesize collections of analytical results into meaningful information for decision makers. This research provides a set of software design guidelines based on experimental and interview evidence gathered from analysts and experts. These guidelines can be employed immediately to shape the design of new synthesis support tools.

8.2 Limitations

The experimental results reported in this research are focused on a particular type of synthesis – one that takes place in a short amount of time using information provided from outside sources. In that sense, it is focused on a tactical problem rather than a

strategic one. A wide variety of potential problem settings are possible. Jonassen has proposed a typology of eleven different types of problem solving situations for use in problem solving studies (Jonassen 2000). Problem solving situations vary in this typology in terms of their inputs, success criteria, context, structuredness, and abstractness. In this research, a case-analysis problem was used where the input is complex information, the criteria for success is arriving at multiple potential solutions, the context is the real world and its constraints, the problem itself is ill-structured, and the abstractness is case-situated. Furthermore, in many cases synthesis will take place over long periods of time, as analysts gradually develop and assemble large amounts of artifacts. Further study is needed to explore how synthesis might differ in a long term strategic scenario.

Additionally, this research centers on a synthesis task that pertains particularly to disease surveillance. The users we recruited are from disease surveillance, bioterrorism, disease biology, and geography backgrounds, and therefore do not necessarily represent the broader population of potential analysts who might make use of geovisualization tools. However, complex and uncertain problem scenarios like the one used in this research are not unique to those domains. So the results and guidelines reported here may be of use for other application areas. The experimental methods reported here should be repeated with analysts in other domains to develop further synthesis tool design guidelines and to refine those that have been proposed here.

The analog experimental method used in this research may also influence results because of the set of office tools that participants were allowed to use. It is important to separate the use of particular tools from the basic actions that participants were completing. For example, the use of post-it notes to represent hypotheses does not necessarily mean that tool developers should simulate a brightly colored post-it note in a future digital synthesis support environment. The task to develop hypotheses itself may not be the only appropriate means to observe and characterize synthesis. It is reasonable to expect that analysts who deal with thousands of artifacts in a long-term setting may develop subsets and add meaning to those subsets without necessarily developing much of a hypothesis that guides or influences that activity. The hypotheses embedded in the experiment artifacts are another limiting factor. They may have been

relatively easy to unravel compared to real-world situations, and their spatio-temporal complexity may not have been sufficient to elicit the most realistic analytical behavior from participants.

Finally, it remains to be seen what constitutes a typical analytical artifact. Interview responses indicate that artifacts can be graphs, maps, tables, text reports, and other items. Further study is necessary to characterize in greater detail what makes an artifact, and how that depends on analysis contexts, domain expertise, and other factors. It is also crucial to explore how artifacts can be developed from visualization tools when the result is dynamically displayed – for example, an animated model of an epidemic. Additionally, many current visualization efforts are focused on integrating interactive visual environments with analytical tools from GIS and statistical environments, and the artifacts used in this study did not attempt to provide detailed provenance information that would describe such linkages.

8.3 Future Work

A worthwhile addition to this research on synthesis using physical artifacts is to conduct similar experiments using a software synthesis environment that allows for quick sorting, searches, and other tasks that are difficult to do quickly with physical artifacts. The workspaces that users generate in a software environment may be quite different than those they develop with real materials on paper. The Scalable Reasoning System (Pike, May, and Turner 2007), currently in development at PNNL by the National Visualization and Analytics Center (NVAC) is one example of an existing system that could be used to conduct software-based synthesis experiments. The nSpace Sandbox in development at Oculus Info is another such tool that could be evaluated (Wright et al. 2006).

Plaisant et al. have recently called for innovative strategies for evaluating visual analytic tools (Plaisant et al. 2008). An interactive visualization tool for exploring code data gathered from synthesis experiments would be an efficient way to examine the frequency of events in relation to one another (for example, filtering to show the most common events that occurred prior to the first hypotheses), to search for complex patterns, and perhaps to coordinate code data with the videos from which they were derived. Such a tool could reveal patterns of analytical activity that could be in turn used

to automate the identification of similar patterns in future visual analytics tools that capture low-level interactive events like those observed in the experiments reported here. The coded data results from synthesis experiments could be explored by developing a custom toolkit using *Improvise* (Weaver 2004) or another similar visualization development environment. Recent work by Lam et al. (2007) visualizing browser session log data (event data, similar to coded synthesis experiment results) provides an example that can be built upon for further interactive analysis of coded synthesis experiment data.

This study focused attention on exploring differences between individual and collaborative scenarios, but there remains much to be explored with respect to collaborative synthesis. The experiments reported here focused on 2-person teams, who developed results in advance in an individual setting. Further experiments could focus on larger teams, and scenarios in which participants have not completed any work prior to collaboration. It would be particularly interesting to observe collaborative synthesis in a setting where teams are fed additional artifacts at regular intervals, allowing us to observe how teams manage streams of information. A future collaborative experiment might involve the use of software designed to support collaboration with information artifacts like the *EWall* (Keel 2007).

This study focused on short-term situations, and while many important problem areas will require short-term synthesis, long-term contexts warrant further exploration. User requirements for long-term projects may differ substantially from what is needed in short term situations. For one, it is likely that the number of analytical artifacts involved would be substantially higher. It is also unknown how users will organize their information if they have the opportunity to return to and refine their workspaces many times over a period of months or years.

Finally, many questions remain about how to create analysis artifacts, and what forms they might take. A particularly difficult challenge is to develop strategies for artifacts that are derived from dynamic representations. Many visualization tools in development integrate closely with analytical tools in GIS and statistical environments to support hypothesis testing and evidence contextualization, and future studies are needed to

explore how these linkages should be represented in artifacts, as well as how users incorporate this information in their analytical work. This study used physical cards to represent analysis artifacts, and there is little in the way of existing research to suggest how artifacts should be presented in digital forms. Related work in the computer science literature points to basic methodologies for constructing icons (Chen 2003), and some guidance exists for assigning preattentive encodings to icons (Deller et al. 2007). Support for the use of cards as a metaphor for information synthesis comes from the developers of EWall, a system designed to support collaborative sense-making (Keel 2007) that uses virtual cards to encapsulate and represent information. However, there appears to be no empirical data to suggest the use of one metaphor over another based on studies of user performance or satisfaction.

8.4 Conclusion

The theory that first proposed synthesis as a stage of the geovisualization-supported scientific research process identified synthesis as part of a transition from analysis to presentation that moves results from the private to the public realm (DiBiase 1990). This study shows that while synthesis is clearly part of this process, there are multiple stages of synthesis that typically occur before final presentation is possible. The first stage occurs when analysts begin to assemble results in collections to develop their findings into coherent groups that encapsulate meaning. From this point, multiple analysts may need to merge together their synthesized information to develop conclusions that can be passed on to decision makers. Once this has been completed, analysts need to move results into presentation materials, typically reports, where they are contextualized with narratives.

The research reported here shows that synthesis is a complicated portion of geovisual analysis. The parts of it that are observable through experimental and interview data reveal a wide array of approaches to the task. Supporting synthesis in software will require tools that allow for mixed organizational methods, flexible annotation and tagging, and support for creativity. Synthesis environments will need to be developed to handle at the three basic situations listed above and allow users to move between those tasks as seamlessly as possible.

The problem domains that geovisualization and other visual analytics tools seek to support are quite challenging. Disease outbreaks, natural disasters, economic crises, and other areas of interest typically require analysts from a variety of backgrounds to collaborate with each other. Additionally, relevant data may include a wide array of formats – maps, tables, photos, video, and text reports to name a few. Visually-enabled analytical tools will be key mechanisms through which analysts tackle these challenging problems and diverse datasets (Andrienko et al. 2007; Thomas and Cook 2005). However, such tools are only beneficial if they are coupled with equally sophisticated means for collecting, organizing, and adding meaning to the results they generate. This study contributes to that goal a detailed characterization of the process of synthesis and a set of empirically-derived design guidelines for the development of new synthesis support tools. This new understanding of synthesis and the future research it suggests can help meet the challenges posed by a future world certain to be full of diverse datasets and daunting analytical problems that must be solved.

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Appendix A – Synthesis Experiment Instructions

During the next hour you will be asked to organize and annotate a collection of maps, graphics, and text snippets –information “chunks” that taken together represent a typical analysis scenario for a bioterrorism analyst.

In this exercise you will assume the role of an analyst at a government disease research agency. Instead of using software to help you complete the task, we want to see how you organize and evaluate information independent of technology. An outbreak of avian flu has occurred, and you are investigating the source of the outbreak. Your job is to assemble heterogeneous information from multiple sources and put together the pieces to develop actionable information for decision-makers. You are provided a set of colored markers, scotch tape, post-it notes, and other assorted office supplies. Please make use of these tools to help complete your work. You are provided a large, blank sheet of paper to use as your canvas. If at any time you wish to start over and reorganize your items, feel free to start again with a new sheet of paper.

We ask that you talk-aloud while you work. Please say what you are doing (but do not explain why) while you are working on this activity. There will be an opportunity at the end of the activity for you to explain your work. If you stop talking for very long, I will prompt you to resume by saying, “keep talking.”

The following scenario describes the situation in which the artifacts have been generated – use this scenario to guide your organization and annotation of the information:

You are a bioterrorism analyst at a government disease research agency. Your job is to assemble heterogeneous information from multiple sources and put together the pieces to develop actionable information for decision-makers. An Avian Influenza outbreak is underway in the Pacific Northwest and you have been provided information from many sources (including colleagues at CDC). Some of these sources are typically reliable, while others are not, but they represent the best information available at the time. Your ultimate task is to create a report to your supervisors that provides a situation assessment and possible hypotheses to explain the source of the outbreak, but for now

you first need to develop an understanding of the evidence you have at hand. Over the next hour use the tools that have been provided to organize and manipulate the evidence to develop this understanding. Consider that another, more pressing issue may emerge in the short term and require you to step away from this particular outbreak for awhile – think about how you can organize information so that you could easily return to it when necessary.

Please develop at least two hypotheses for the source of the outbreak. In the last few minutes of the activity I will ask you to describe the hypotheses you found and how you used the artifacts and tools to develop and evaluate the hypotheses. As you are working please announce when you have arrived at each hypothesis. Do this as soon as you think you have a working hypothesis – not after you have fully developed each one. I will ask you at that time to provide a very brief description of the working hypothesis.

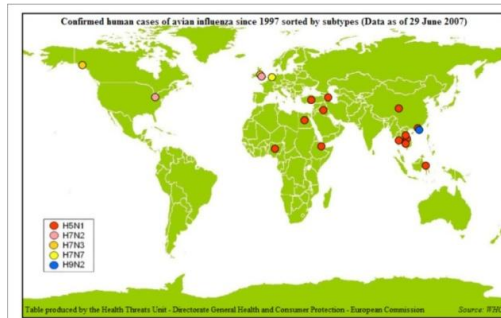
Appendix B – Collaborative Synthesis Experiment Instructions

During the next hour you will be asked to collaboratively organize and annotate a collection of maps, graphics, and text snippets –information “chunks” that taken together represent a typical analysis scenario for a bioterrorism analyst.

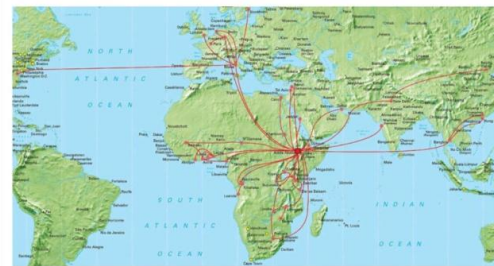
You have been paired with another expert who has also completed a short synthesis activity today. Your task now is to merge what you discovered individually into a collaborative product. You have already developed hypotheses on your own, now we would like you to further develop these hypotheses given the new knowledge you have from your collaborator.

Your goal now is to create a new collection of artifacts on a blank sheet of paper out of the two sets you have created individually. Develop at least three hypotheses (they may be modified versions of what you have already found individually) and rank them according to how likely you think they are to explain the source of the outbreak. Do so with the thought in mind that the next step you would take is to provide a report about your findings.

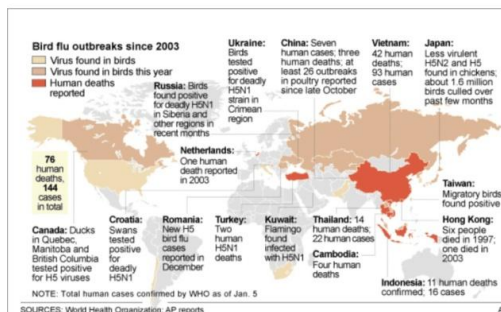
Appendix C – Synthesis Experiment Artifacts



Human Cases of Avian Flu
Report Date: April 7, 2008 Source: WHO



Ethiopian Airlines Route Map
Report Date: April 9, 2008 Source: Ethiopian Airlines Website



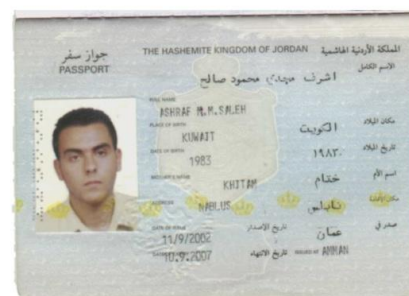
Cases and Deaths from Avian Flu
Report Date: April 10, 2008 Source: Associated Press

Country	2003		2004		2005		2006		Total	
	cases	deaths	cases	deaths	cases	deaths	cases	deaths	cases	deaths
Azerbaijan	0	0	0	0	0	0	8	5	8	5
Cambodia	0	0	0	4	4	2	2	6	6	6
China	0	0	0	8	5	10	7	18	12	12
Djibouti	0	0	0	0	0	1	0	1	0	0
Egypt	0	0	0	0	0	14	6	14	6	6
Indonesia	0	0	0	17	11	25	22	42	33	33
Iraq	0	0	0	0	0	2	2	2	2	2
Thailand	0	0	17	12	5	2	0	22	14	14
Turkey	0	0	0	0	0	12	4	12	4	4
Viet Nam	3	3	29	20	61	19	0	93	42	42
Total	3	3	46	32	95	41	74	48	218	124

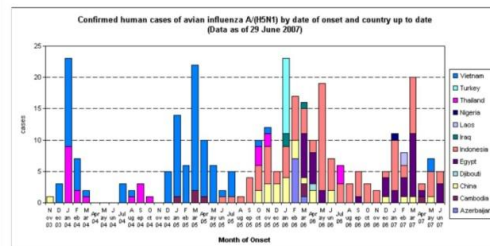
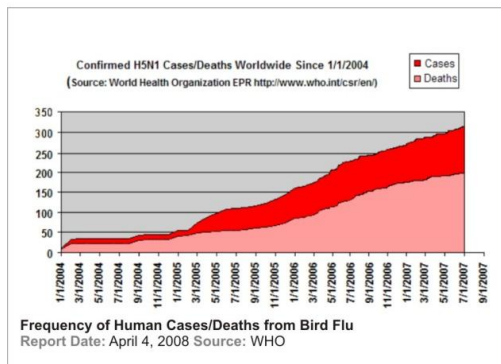
Cases of Bird Flu By Country
Report Date: April 8, 2008 Source: Southeast Asia Health Organization

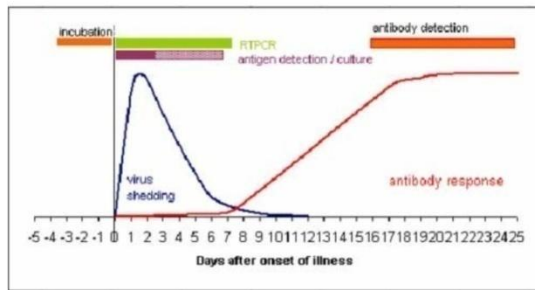


Passport of Alex Watersby
Report Date: April 4, 2008 Source: TSA



Passport of Ashraf Saleh
Report Date: April 4, 2008 Source: TSA





Avian Flu Onset of Illness
Report Date: April 6, 2008 Source: Centers for Disease Control



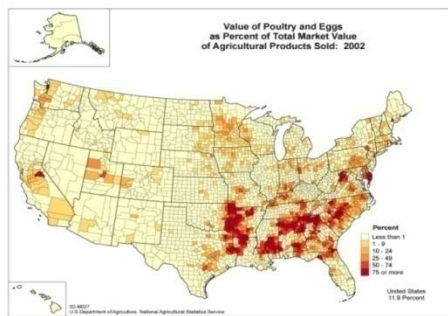
AW_666 Video From YouTube
Report Date: April 11, 2008 Source: CNN



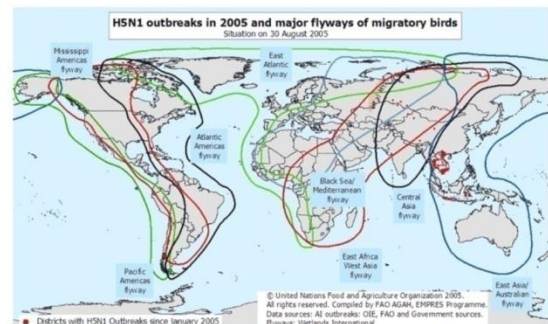
Bird Flu Terror Video by DeadlyCargo_129
Report Date: April 12, 2008 Source: CNN



Video by JK_Ceiba from YouTube
Report Date: April 12, 2008 Source: MSNBC



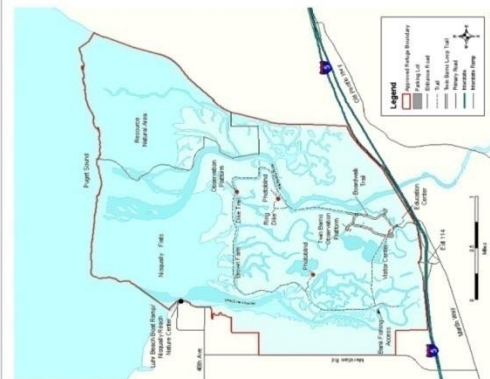
Agricultural Value of Poultry and Eggs: 2002
Report Date: April 14, 2008 Source: US. Dept. of Agriculture



Bird Flyways Around the World
Report Date: April 12, 2008 Source: UN - FAO



Pet Stores in the Seattle Area
Report Date: April 10, 2008 Source: Google Maps



Nisqually Wildlife Refuge
Report Date: April 12, 2008 Source: Washington DNR



Jong-il Arrives in Moscow for Avian Flu Summit
Report Date: April 4, 2008 Source: Reuters



Seattle Health Department Action Poster
Report Date: April 14, 2008 Source: Seattle PI

From: Tokyo-Haneda, Japan (NRT)	
To: Seattle/Tacoma Int. (SEA)	
Date: Sun, April 15, 2007	
View Flight Status	
Flight Schedule 1	
Departs: Tokyo-Haneda, Japan (NRT) at 03:45PM	
Arrives: Seattle/Tacoma Int. (SEA) at 08:45AM	
Flight Schedule 2	
Departs: Tokyo-Haneda, Japan (NRT) at 08:00PM	
Arrives: Seattle/Tacoma Int. (SEA) at 01:00PM	
Flight Schedule 3	
Departs: Tokyo-Haneda, Japan (NRT) at 03:25PM	
Arrives: Portland-Int. OR (PDX) at 08:30AM	
Departs: Portland-Int. OR (PDX) at 12:30AM	
Arrives: Seattle/Tacoma Int. (SEA) at 11:25AM	
Flight Schedule 4	
Departs: Tokyo-Haneda, Japan (NRT) at 03:25PM	
Arrives: Portland-Int. OR (PDX) at 08:30AM	
Departs: Portland-Int. OR (PDX) at 12:30AM	
Arrives: Seattle/Tacoma Int. (SEA) at 12:25PM	
Flight Schedule 5	
Departs: Tokyo-Haneda, Japan (NRT) at 03:25PM	
Arrives: Portland-Int. OR (PDX) at 08:30AM	
Departs: Portland-Int. OR (PDX) at 12:30PM	
Arrives: Seattle/Tacoma Int. (SEA) at 01:25PM	
Flight Schedule 6	
Departs: Tokyo-Haneda, Japan (NRT) at 03:25PM	
Arrives: Portland-Int. OR (PDX) at 08:30AM	
Departs: Portland-Int. OR (PDX) at 01:30PM	
Arrives: Seattle/Tacoma Int. (SEA) at 01:30PM	

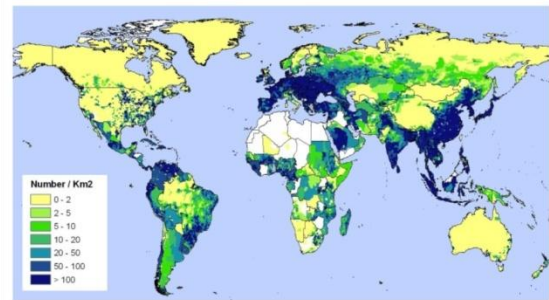
Northwest Airlines Schedule NRT-SEA
Report Date: April 15, 2008 Source: nwa.com



Storefront for BestFriends Pet Store, Kent
Report Date: April 12, 2008 Source: Seattle PI



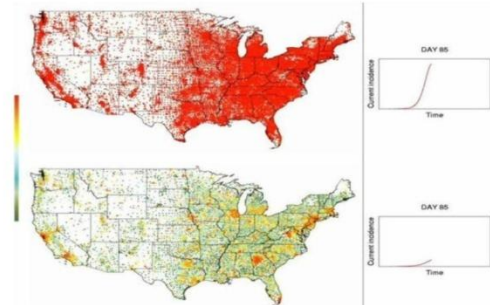
Dead Swan Discovered in Nisqually Refuge
Report Date: April 11, 2008 Source: The Olympian



Poultry Density Around the World
Report Date: April 10, 2008 Source: UN-FAO



Bird Culling During China Flu Outbreak in 2004
Report Date: April 15, 2008 Source: CIA



Modeled Incidence (top: no effective drugs, bottom: weak drugs)
Report Date: April 13, 2008 Source: Centers for Disease Control

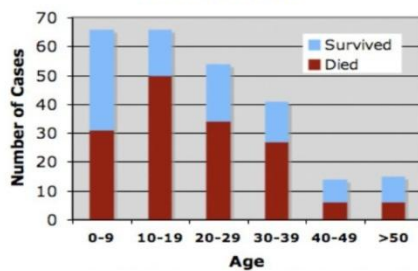


Authorities On Scene Outside of Frederico Voldore's Building
Report Date: April 9, 2008 Source: Seattle PI



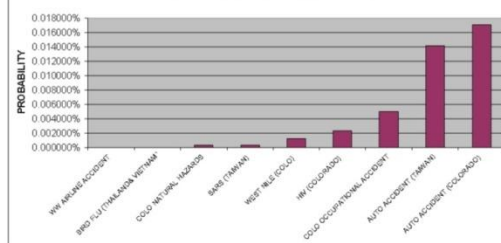
Dead Birds Collected by Seattle PD
Report Date: April 13, 2008 Source: Seattle PD

WHO Confirmed Cases by Age and Outcome
Nov 03 - Nov 06



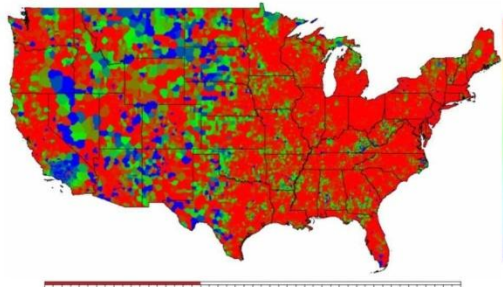
Age Profile for Avian Flu Cases to Nov 2006
Report Date: April 10, 2008 Source: WHO Epidemic Unit

FATALITY RISKS IN PERSPECTIVE



Risk Probability Assuming Weak Human-to-Human Transmission
Report Date: April 13, 2008 Source: WHO Epidemic Unit

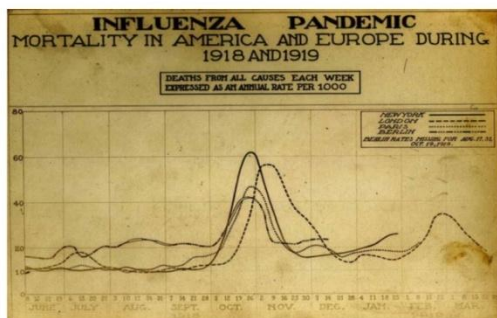
Day 90



Simulation of Outbreak w/ No Quarantine
Report Date: April 16, 2008 Source: CIA



Triage Center in Chicago During 1918 Flu Pandemic
Report Date: April 14, 2008 Source: Centers for Disease Control



Pandemic Mortality from 1918 Flu Outbreak
Report Date: April 15, 2008 Source: Doctors Without Borders

Report Date: 3 April, 2008. Source: TSA.

Security agents at Seattle-Tacoma airport report that a young white male named Alex Watersby was detained at 4:00pm in the afternoon on April 2 after assaulting a cargo handler for Northwest Airlines at the cargo terminal of the airport. Mr. Watersby was apparently expecting a shipment and became enraged when Northwest could not confirm the location of his goods.

Watersby was turned over to Seattle Police later that evening who released him on his own recognizance.

Report Date: 12 April, 2008. **Source:** FBI.

Passport control at Seattle-Tacoma Airport records that Alex Watersby, holder of US passport #173127699 [issued by Passport Agency, Wash. DC on 14 Jun. 1999] has made three trips to Amsterdam, two trips to Hong Kong, and one trip to Addis Ababa, Ethiopia in the last year. The address given by Watersby on his passport is 448 #2 Whitehill Road, Vancouver, WA. His phone number is 894-231-2203.

Report Date: 12 April, 2008. **Source:** FBI.

Alice Redmonds owns the BestFriends pet store in Kennewick Mall, Kent, WA. [Phone number 899-759-2317]. Northwest First Bank lists BestFriends as holding account number 1193844-32. Twenty checks totaling \$45,000 have been deposited in this account in the past month and are recorded as having been drawn on accounts at the Central Bank of Ethiopia, Xiamen Province National Bank, and the Pennsylvania Teacher Credit Union.

Report Date: 8 April, 2008. **Source:** FBI.

On 6 April, 2008 at 0500 hrs. A large passenger van rented from National Rental Car in Seattle, WA was pulled over by local police for speeding. According to the reporting officer, the driver was 18 miles over the speed limit heading south from downtown toward the airport. The subject, identified as Adam Nelson was accompanied by an unknown male passenger. Mr. Nelson claimed he was late for a courier pickup at the airport. National Rental Car reports that this van was rented on 4 April, 2003 by Waleed Al-Keval. Al-Keval used an OR license and gave his address as 192 Fortune Ave. in Bend. Al-Keval told the sales agent he needed the van for two days to move office equipment from downtown Seattle to Redmond, WA.

Report Date: 13 April, 2008. **Source:** FBI.

Scientists at the Center for Disease Control BSL-4 lab facility have preliminarily identified the recent Washington State avian influenza discovery as the deadly H5N1 strain that has previously affected humans in southeast Asia. Analysts at the CDC report that they are in contact with counterparts in Asia who are hoping to identify exactly where the strain found in the Washington outbreak originated.

Report Date: 10 April, 2008. **Source:** Seattle Post-Intelligencer.

Famed movie director Frederico Voldore made a startling discovery when he opened the door on his top-floor apartment in downtown Seattle yesterday morning. Voldore keeps several prized Amazonian Parrots in cages on his veranda, and three of the five he owns were laying dead. The other two were quickly diagnosed by veterinarians with avian influenza, and were immediately culled. Local authorities say there is no reason to fear a major outbreak of avian flu in or around Seattle, but have asked that the public report any dead or sick birds they might observe.

Report Date: 11 April, 2008. **Source:** Seattle Police Department.

Seattle PD Chief Walter Wishmalo informs that samples from Frederico Voldore's dead birds have been sent forward to CDC laboratories in Atlanta on a chartered jet from Seattle-Tacoma airport late in the evening on April 10. CDC told him to expect results from their testing in 24-48 hours. The Seattle PD has received over 200 reports since April 10 of dead birds in and around the Seattle area. They are investigating these reports and will provide an update shortly.

Report Date: 11 April, 2008. **Source:** CNN.

A videotaped statement posted to the popular site "YouTube" claims that the Seattle avian flu outbreak is a "wake up call to America." A user named "AW_666" speaks in the video obscured by a black flag and his speech is interspersed with grainy video of birds being released into the air late at night in and around parts of Seattle. A video screener for YouTube caught the submission and forwarded it to CNN's American Morning program as well as the FBI.

Report Date: 11 April, 2008. **Source:** WA Fish & Game Commission.

Park rangers at the Nisqually wildlife refuge south of Seattle report that dozens of dead birds have been found dead in the past 24 hours in and around the refuge. Additionally, they report that tire tracks (driving is prohibited inside the refuge) have been found leading to several different locations. FBI and Seattle PD officers are on the scene and investigating all possible leads.

Report Date: 11 April, 2008. **Source:** Seattle Police Department.

Case officer Daniel Severidge reports that dead exotic birds have been found at two local pet stores, the BestFriends pet store in Kent, and the Ceiba Exotic Pets store in Bellevue. Seattle PD have interviewed the owners of both stores and have obtained a list of employees for further possible investigation. Birds from both stores field-tested positive for avian influenza, but field testing kits are notoriously uncertain. Samples have been sent to the CDC for further analysis.

Report Date: 12 April, 2008. **Source:** MSNBC and CNN.

Major news outlets, including MSNBC and CNN are reporting that several additional videos have surfaced on YouTube claiming responsibility for intentionally introducing avian influenza into the United States.

YouTube's director of communications reports that the original video by AW_666 has received almost 26 million views since it was uploaded just days ago.

Report Date: 12 April, 2008. **Source:** CIA.

Credible intelligence sources in Vietnam and China have indicated that the Chinese Military in the past three months has been hiring health officials and scientists in the region who have experience researching avian influenza. These sources advise that the Chinese may be attempting to weaponize the virus to use as a destabilizing force for countries in the region and around the world.

Intelligence counterparts (UK, Canada, Germany) in the region from allied organizations corroborate this information with similar observations.

Report Date: 12 April, 2008. **Source:** NSA.

Intercepted communications from North Korea suggest that a major celebration is planned this week for senior staff in the Kim Jong Il government in reaction to recent news regarding the outbreak of avian influenza in the United States. Some analysts are concerned that there may be a linkage between North Korea and terrorist organizations in the Middle-East after repeated mentions of "reserving rooms for associates of the Sheikh."

Report Date: 13 April, 2008. **Source:** FBI.

Bank records have been collected for Pets Express in Bellevue. During the past 6 weeks, Jamal Kayder has deposited \$37,450 in cash and checks drawn upon banks in the Seattle area. Checks written by Kayder amounting to \$14,044 have been written during the same period to several pet wholesale vendors in Washington and Oregon, and to a so-called "pet finder" intermediary named Paco Polcate in New York City who specializes in sourcing exotic animals.

Report Date: 13 April, 2008. **Source:** Seattle Post-Intelligencer.

Jamal Kayder, owner of Ceiba Exotic Pets in Bellevue claims he was poorly treated by police and FBI investigators during the initial investigation into dead birds found at his store that are presumably infected with avian flu. Kayder and his family are recent immigrants from Ethiopia who fled that country during its war with Eritrea. Police chief Walter Wishmalo claims that nothing unusual happened during their interview with Kayder, and that Kayder has not been named as a suspect in any crime.






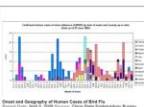







Report Date: 14 April, 2008. **Source:** Seattle Post-Intelligencer.

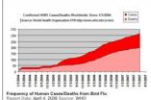


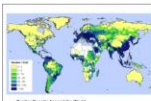

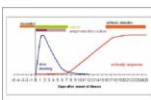


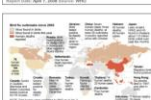



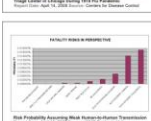
Reporter James McElroy has posted an interview to the Seattle PI website at 9:30pm on April 14 with a person claiming to be user "AW_666" who created one of the first video claims of responsibility on YouTube early on in the U.S. avian flu outbreak. McElroy states that this person contacted him via email and provided video evidence that corroborated his identity as "AW_666." The interview states that authorities are "barking up the wrong tree" and "should focus attention on mitigating the coming crisis, rather than pick up the pieces from a lost cause."

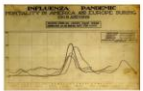


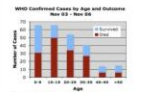

Report Date: 14 April, 2008. **Source:** FBI.

Investigation into the missing van from National Rental Car reported on April 10 has revealed that Waleed Al-Keval is also known as Ashraf Saleh, a Jordanian known to be executive director of the Al-Waqsa charity based in Gaza - a suspected money laundering agent for Al-Qaeda. INS reports that no person named Waleed Al-Keval or Ashraf Saleh has been granted a visa to stay in the United States in the past three years. Neighbors of Al-Keval in Bend, OR indicate that Waleed was attending classes at the Oregon State University - Cascades.

Appendix D – Artifact Source Information

	Original Source	Image Modified?
	http://www.nass.usda.gov/research/atlas02/Economics/Market%20Value%20of%20Agricultural%20Products%20Sold/Value%20of%20Poultry%20and%20Eggs%20as%20Percent%20of%20Total%20Market%20Value%20of%20Agricultural%20Products%20Sold.gif	No
	http://maps.google.com/maps?f=i&hl=en&geocode=&q=pet+stores&near=seattle,+wa&ie=UTF8&ll=47.603385,-122.32933&spn=0.294453,0.711365&z=11	No
	http://www.airlineroutemaps.com/Africa/img/Ethiopian_Airlines.jpg	No
	http://www.wpro.who.int/NR/rdonlyres/3084D395-48BB-49FA-93A9-A5697930E214/0/Table_1.jpg	No
	http://www.freewebs.com/ashrafmis/jordanane%20passport.jpg	Yes
	http://lunar.jrc.it/hedistools/OnsetCountryGraph.aspx?width=800	No
	http://www.lib.utexas.edu/maps/historical/EMPRES_Watch_global_flyways.gif	No
	http://www.fws.gov/nisqually/images/nisquallymap.gif	No
	http://lh3.ggpht.com/_pzfn3rHZug/Rs9iUJJP7MI/AAAAAAAAAGil/Qel7rCc2leg/koreja2_inline.jpg	No
	http://imagefruity.com/images/1fkv28w3g6ga2knsba6.jpg	No
	http://www.telegraph.co.uk/telegraph/multimedia/archive/00611/news-graphics-2006-_611756a.jpg	No
	http://china.org.cn/images/116244.jpg	No
	http://www.rogerwendell.com/images/travel/passport_pages.jpg	No

	Original Source	Image Modified?
 <p>Frequency of Human Cases/Deaths from Bird Flu Report from April 12, 2005 Source: WHO</p>	http://www.pandemicplanningcenter.com/AvianFluDeaths.gif	No
 <p>Flight Schedule Page</p>	http://www.nwa.com/cgi-bin/cgi_schedule.pro	No
 <p>Pet Shop</p>	http://www.alresford.org/images/pet_shop_600.jpg	Yes
 <p>Chicken Density Around the World Report from April 12, 2005 Source: WHO</p>	http://www.ilri.org/ilripubaware/uploaded%20files/Global%20Chicken%20Density.jpg	No
 <p>United States Map</p>	http://www.nigms.nih.gov/NR/rdonlyres/73ED934A-396D-4C2D-BAFE-C31A798F7466/0/flusimulationhi.jpg	No
 <p>Flu Cases</p>	http://www.picpanda.com/images/a8v1q0j6res1i393wbv.jpg	No
 <p>Avian Flu</p>	http://www.marshallastor.com/projects-art-stuff/avian-flu-awareness-project/	Yes
 <p>World Map</p>	http://ec.europa.eu/health/ph_threats/com/Influenza/ai_human_en.htm	No
 <p>United States Map</p>	http://imgedo.com/files/mmdu8vmtv8q6etfgho6j.jpg	No
 <p>Avian Flu</p>	http://www.marshallastor.com/projects-art-stuff/avian-flu-awareness-project/	Yes
 <p>Avian Flu</p>	http://tinypic.com/view.php?pic=11gudqa&s=3	Yes
 <p>Avian Flu</p>	http://www.public-health.uiowa.edu/ceid/images/Camp%20Fuston.jpg	No
 <p>Percentage of People Infected</p>	http://www.boingboing.net/images/ole1.gif	No

	Original Source	Image Modified?
 <p>Epidemic Curves Number of Cases vs. Time Source: CDC, April 12, 2020. (Source: CDC)</p>	http://www.mymdnw.com/bird/index.4.jpg	No
 <p>Dead Birds Collected by Seattle PD Source: Seattle PD, April 12, 2020. (Source: Seattle PD)</p>	http://www.fmt.net/archives/46brace/49TC0005.jpg	No
 <p>Historical Society Source: Historical Society, April 12, 2020. (Source: Historical Society)</p>	http://www.postyourimage.com/view_image.php?img_id=SB0ecOn38gDn501213841152	No
 <p>2020 Confirmed Cases by Age and Sex Source: CDC, April 12, 2020. (Source: CDC)</p>	http://afludary.blogspot.com/2007_05_01_archive.html	No
 <p>Map of the United States Source: CDC, April 12, 2020. (Source: CDC)</p>	http://www.sciencedaily.com/images/2006/04/060404084039.jpg	No

Appendix E – Interview Script

Opener:

Thanks for agreeing to participate in this interview, I'd like to ask you several questions today about kinds of information analysis you do and about how you store, organize, and evaluate your analytical results.

To start, I'd like to get some general background about your work.

1. Please provide a brief description of your job.
 - a. What general topic area(s) does your analysis work cover?
 - b. What general types of input data are common in your work (e.g., numerical data, text documents, maps, etc.)?
 - c. What methods do you use to analyze that data (e.g., statistical, office tools such as excel and word, document analysis tools, etc.)?
 - d. What form does a typical analytical result take in your work (e.g. maps, graphs, tables, etc.)?
2. How do you currently store your analytical results – those things you find during your work that are important evidence to support your findings?
3. What are some strategies you use to organize your results?
 - a. Do these strategies change depending on the type of project you are working on and/or type of results you generate?
4. What methods or tools do you use to get the “bigger picture” about your collections of results?
5. Are the tools you use to store, organize, and evaluate your results adequate?
 - a. If not, how could they be improved?
6. In those cases where you work on one or a set of related problems over a period of time (from days to months), how do you approach the problem of recalling your prior work to add to your existing knowledge?
7. When you collaborate with co-workers, what tools (software or otherwise) do you use to share your results?
 - a. Are these tools sufficient? Why or why not?
8. When you collaborate with co-workers, what methods (meetings, web repositories, etc...) do you use to share your results?
 - a. Are these methods generally successful? Why or why not?

9. Are there analytical methods you use that develop a particular type of result more often than others? For example, a particular disease modeling approach might always yield a threat matrix as the final output. A geographic analysis approach might yield maps and other graphics that take many forms.
10. Describe the connections that exist between the results you generate and the tools they come from.
 - a. Are these connections adequate, or could they be improved?
11. Tell me about a time when you had a particularly hard time explaining an analytical result (or set of results), and how you eventually succeeded?
 - a. How did you present this result or set of results to your colleagues?
12. Tell me about a time when one particular result or set of results was especially useful for explaining your results.
 - a. How did you present this result or set of results to your colleagues?
13. In situations where you generate several interesting results, how would you describe the process of going from individual results to a final report?

VITA

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Education

Doctor of Philosophy, Geography (2008)

The Pennsylvania State University
Dissertation: "Design for Synthesis in Geovisualization"
Advisor: Alan M. MacEachren

Master of Science, Geography (2005)

The Pennsylvania State University
Thesis: "Assessing Geovisualization Tools in Cancer Epidemiology: A Design Framework for an Exploratory Toolkit"
Advisor: Alan M. MacEachren

Bachelor of Science in Applied Geography (2002)

East Carolina University
Minor: Urban and Regional Planning

Selected Publications

Robinson, A. C., J. Chen, G. Lengerich, H. Meyer, and A. M. MacEachren. (2005) Combining usability techniques to design geovisualization tools for epidemiology. *Cartography and Geographic Information Science*. 32:243-255.

MacEachren, A. M., **Robinson, A. C.**, Hopper, S., Gardner, S., Murray, R., and M. Gahegan. (2005) Visualizing geospatial uncertainty: What we know and what we need to know. *Cartography and Geographic Information Science* 32:139-60.

Robinson, A. C. (2005) Geovisualization and epidemiology: A general design framework. *Proceedings of the 22nd International Cartographic Conference*, A Coruña, Spain, July 9-16.

Robinson, A. C., Weaver, C. (2006) Re-Visualization: Interactive Visualization of the Process of Visual Analysis. *Proceedings of GIScience 2006 Workshop on Visualization, Analytics, and Spatial Decision Support*. Muenster, Germany, September 20.

Weaver, C., Fyfe, D., **Robinson, A. C.**, Holdsworth, D., Peuquet, D., and A.M. MacEachren (2007) Visual exploration and analysis of historic hotel visits. *Information Visualization* 6(1): 89-103

Robinson, A. C., Koua, E., Hardisty, F., and Alan M. MacEachren. (2007) The G-EX Portal: Web-Based Dissemination of Geovisual Analytic Results. *Proceedings of the ICA Commission on Visualization and Virtual Environments Workshop "From Geovisualization Toward Geovisual Analytics"*, Helsinki, Finland, August 2 – 3.

Robinson, A. C. (2007) Synthesizing Results in Geovisualization. *Proceedings of the 23rd International Cartographic Conference*. Moscow, Russia, August 4th-10th.

Robinson, A. C. (2007) Synthesizing Geovisual Analytic Results. *Proceedings of the IEEE Visual Analytics, Science and Technology Conference Doctoral Colloquium*. Sacramento, CA, October 29 – November 1.

Robinson, A. C. (2007) A Design Framework for Exploratory Geovisualization in Epidemiology. *Information Visualization*. 6(3) 197-214.