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Arizona Literature Mapper: An Integrated Approach to Monitor and Analyze Global Bioterrorism Research Literature

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Abstract

Biomedical research is critical to biodefense, which is drawing increasing attention from governments globally as well as from various research communities. The U.S. government has been closely monitoring and regulating biomedical research activities, particularly those studying or involving bioterrorism agents or diseases. Effective surveillance requires comprehensive understanding of extant biomedical research and timely detection of new developments or emerging trends. The rapid knowledge expansion, technical breakthroughs, and spiraling collaboration networks demand greater support for literature search and sharing, which cannot be effectively supported by conventional literature search mechanisms or systems. In this study, we propose an integrated approach that integrates advanced techniques for content analysis, network analysis, and information visualization. We design and implement Arizona Literature Mapper, a Web-based portal that allows users to gain timely, comprehensive understanding of bioterrorism research, including leading scientists, research groups, institutions as well as insights about current mainstream interests or emerging trends. We conduct two user studies to evaluate Arizona Literature Mapper and include a well-known system for benchmarking purposes. According to our results, Arizona Literature Mapper is significantly more effective for supporting users' search of bioterrorism publications than PubMed. Users consider Arizona Literature Mapper more useful and easier to use than PubMed. Users are also more satisfied with Arizona Literature Mapper and show stronger intentions to use it in the future. Assessments of Arizona Literature Mapper's analysis functions are also positive, as our subjects consider them useful, easy to use, and satisfactory. Our results have important implications that are also discussed in the paper.

Keywords: bioterrorism, literature resources, knowledge mapping

1. Introduction

The fallout of the September 11th and the subsequent anthrax attacks have made bioterrorism a top priority of national security (Lane, LaMontagne, & Fauci, 2001; Richmond & McKinney, 2007). Biodefense, the defense against bioterrorism agents domestic or foreign, is now drawing enormous attention from governments around the world as well as from various research communities (Lane et al., 2001; Richmond & McKinney, 2007). Central to biodefense is biomedical research that targets the development and testing of pharmaceutical products, vaccines, or technologies for various illnesses or diseases, which can be used to counter bioterrorism threats or to develop deadly biological weapons (CDC & HHS, 2005; Lane et al., 2001; Richmond & McKinney, 2007). The U.S. government has been closely monitoring and regulating biomedical research activities, particularly those studying or involving bioterrorism agents or diseases. Effective surveillance requires a comprehensive understanding of extant biomedical research and timely detection of new developments or emerging trends (CDC & HHS, 2005; Lane et al., 2001; Richmond & McKinney, 2007).

Research publications represent a critical scientific knowledge repository, thereby documenting scientific investigations, research activities, and key findings. The development of science and technology has advanced rapidly, as manifested by the accelerating growth in the number of research publications (Börner, Chen, & Boyack, 2003; Chen, 2003). Scientific collaborations among researchers also strengthen and are increasingly important in the field of biomedical research (Bruijn & Martin, 2002). The rapid knowledge expansion, technology advancements, and spiraling collaboration networks demand greater support for literature search and sharing, a crucial prerequisite for further scientific advancements and technical breakthroughs (Huang, Chen, Wu, & Pan, 2003), particularly in the biomedical domain (Bruijn & Martin, 2002; Cohen & Hersh, 2005; Jensen, Saric, & Bork, 2006).

The sheer volume of biomedical research articles is overwhelming and will continue to grow at a fast pace (Bruijn & Martin, 2002; Cohen & Hersh, 2005), thus making conventional literature search mechanisms increasingly ineffective. With conventional search support, researchers now have great difficulty keeping up with the fast-growing literature, even in well-defined specialized areas (Jensen et al., 2006). This underscores the need for advanced knowledge mapping systems that seamlessly integrate vast amounts of data and documents, and provide effective search functionalities and visualization designs.

Several techniques are fundamental to supporting effective literature search and sharing; i.e., content analysis, citation network analysis, and information visualization. Content analysis aims at identifying important underlying themes, patterns, or trends by collecting and grouping articles on the basis of authors, institutions, topic areas, countries, or regions (Chen & Roco, 2008). Citation network analysis, premised in network theory (Börner et al., 2003), analyzes citation information from different perspectives that may include author, journal, institution, and country (Newman, 2001; Watts & Strogatz, 1998). Information visualization displays search results through static or interactive visual presentations of abstract phenomena, such as bibliographic data sets or Web access patterns (Börner et al., 2003; Chen & Roco, 2008). Effective visualization can convey analysis results in a manner that is cognitively efficient, intuitive, or transparent (Zhu & Chen, 2005). Although distinct, these techniques are central to knowledge mapping and should be integrated to develop advanced knowledge mapping systems.

The current study addresses the following questions: (1) How can we develop an integrated approach to monitor and analyze global bioterrorism research?; (2) Is a knowledge mapping system built upon this integrated approach more effective for global bioterrorism research analyses or surveillance than existing

systems?; and (3) Will users assess such a system more positively, exhibit higher satisfaction with it, and show stronger intentions to use it in the near future, as compared with existing systems?

We propose an approach that seamlessly integrates advanced techniques for content analysis, network analysis, and information visualization. Specifically, we design and implement Arizona Literature Mapper, a Web-based portal that allows users to gain a timely, comprehensive understanding of bioterrorism research, including leading scientists, research groups, and institutions, as well as to obtain insights about current mainstream interests or emerging trends. We conduct two user studies to evaluate Arizona Literature Mapper.

The remainder of this paper is organized as follows: We first provide an overview of knowledge mapping analysis and its core enabling techniques, summarize important studies examining knowledge mapping systems, review representative work in knowledge mapping for bioterrorism, and highlight our motivation. We then describe the design and implementation of Arizona Literature Mapper, followed by details of two evaluation studies examining its search function and analysis functions respectively, including hypotheses, study design, measurements, subjects, tasks, and data collection. Finally, we conclude the paper with a summary and discussion of the study's contributions and important implications, together with some future directions.

2. Literature Review and Motivation

In this section, we provide an overview of knowledge mapping analysis and summarize its core enabling techniques – i.e., text mining, network analysis, and information visualization. We review previous

knowledge mapping research in bioterrorism and review representative knowledge mapping systems in other domains. In light of prior work, we highlight our motivation for the current study.

2.1 Overview of Knowledge Mapping and Core Enabling Techniques

The advancement of scientific knowledge, to some extent, can be attributed to a relatively small group of visionary scientists and highly prolific researchers (Crane, 1972). They often form networks of collaboration to advance their fields of study (Newman, 2001). Knowledge mapping, as an important emerging research area, provides a mechanism for supporting effective and efficient searches of essential collaboration networks among researchers and their seminal works and publications (Börner et al., 2003; Shiffrin & Börner, 2004). Several techniques are fundamental to knowledge mapping, including text mining, network analysis, and information visualization (Börner et al., 2003; Chen, 2003; Chen & Roco, 2008). A summary of each technique follows.

Text Mining: Text mining involves the process of structuring input text documents, extracting patterns within the structured data (i.e., documents), and evaluating and interpreting the output (Chen & Chau, 2004). In knowledge mapping, text mining can be used to identify important subjects or topic areas embedded in the title, abstract, or main body of documents. Different text mining techniques have been developed and can be broadly categorized as natural language processing (NLP) or content analysis (Chen & Roco, 2008). Examples of NLP include automatic indexing (Salton, 1989) and information extraction (Chen & Roco, 2008). Automatic indexing is a common NLP technique that represents document contents using a vector of keywords or terms. Compared with the baseline Bag of Words (BOW) representation, noun-phrasing techniques for automatic indexing are capable of capturing richer linguistic semantics in the (input) documents. Most noun-phrasing techniques depend on a combination of part-of-speech-tagging (POST) and grammatical phrase-forming rules for extracting semantics from documents. Prevalent noun-phrasing

tools include MIT's Chopper, Nptool (Voutilainen, 1997) and Arizona Noun Phraser (Tolle & Chen, 2000). Information extraction is another salient NLP technique, which is computationally efficient for identifying important concepts from text documents (Shiffrin & Börner, 2004). It can effectively and efficiently extract from structured texts essential entities of interest; e.g., names of individuals or locations. Entities embedded in unstructured textual narratives (e.g., date, time, number expressions, dollar amounts, email addresses, and URL) can also be extracted using NLP techniques that follow a rule-based or statistical approach. Chinchor (1998) shows that effective NLP-based systems can extract persons, locations, organizations, date, time, currencies, and percentages from newspaper articles with an accuracy exceeding 90% in both recall and precision rates.

Content analysis represents another approach for text mining, thereby grouping documents on the basis of author, institution, topic area, country, or region, and analyzing them to identify important themes, patterns, or trends (Börner et al., 2003; Chen & Roco, 2008). Examples of prevalent content analysis-based techniques include clustering algorithms, self-organizing map (SOM), multidimensional scaling (MDS), principal component analysis (PCA), co-word analysis, and PathFinder Network (PFNET) [1] (Chen & Roco, 2008). Clustering algorithms organize and group similar documents or topics in a hierarchical structure. A dendrogram is often generated to represent a hierarchy of points and their associated clusters. In particular, a hierarchical agglomerative clustering (HAC) algorithm is commonly used for document clustering (Willett, 1988). SOM, developed by Kohonen (1989; 1995), consists of an unsupervised, two-layered neural network and can be used for clustering or dimension reduction. SOM is advantageous over other clustering algorithms (Börner et al., 2003) because it offers comprehensible visualizations of high dimensional data (i.e., a two-dimensional grid) while preserving the similarity between data points. Chen et al. (1996) develop

[1] The outputs of these content analysis-based techniques (e.g., SOM, MDS, PCA, and PFNET) are often displayed in a 2D format. However, these techniques are primarily used for text mining rather than merely visualization tools. Therefore, we categorize them as essential content analysis-based techniques for text mining, although they are often used for visualization purposes as well.

a multi-layered SOM to categorize 110,000 Web pages according to their contents. Kohonen et al. (2000) map 6.8 million patent abstracts onto a one million-node SOM. MDS and PCA are classical techniques for dimension reduction and have been widely used in different applications. Both techniques use a low-dimensional Cartesian coordinate space to approximate the corresponding high-dimension vectors. Co-word analysis depicts a network of concepts by calculating a matrix of term co-occurrence probabilities between any two terms. PathFinder algorithms take as input estimates of the proximity between pairs of items and define a network representation of the items by preserving only the most important links. The resulting PathFinder network (PFNET) consists of the items as nodes and a set of links, directed or undirected for symmetrical or nonsymmetrical proximity estimates, which connect pairs of the nodes. White et al. (2004) employ both SOM and PFNET to create "localized" mapping of 24 most relevant terms given a single input term, a medical subject heading, a co-cited author, or a co-cited journal from the *Proceedings of the National Academy of Sciences (PNAS)*, 1971-2002. Mane and Börner (2004) apply Klienberg's burst detection algorithms, PFNET, and graph layout techniques to generate maps for supporting the identification of important research topics or trends in *PNAS*, 1982-2001.

Network Analysis: Social network analysis (SNA), particularly those techniques for analyzing complex networks, represents another stream of research central to examining researchers and their collaboration networks. As Chen & Roco (2008) and Shiffrin & Börner (2004) note, SNA can be used to segment subgroups of scientists and researchers, identify key people in a network, reveal their interaction patterns, and uncover the network organization or structure. Burt (1976) applies hierarchical clustering methods to identify subgroups in a social network, on the basis of some structural equivalence measure (Lorrain & White, 1971). Several studies use blockmodel analysis, an SNA technique, to explore patterns of interaction between subgroups in a network (Wasserman & Faust, 1994; Xu & Chen, 2005). Blockmodel analysis can be used to examine a collaboration or co-author network, thereby revealing patterns of inter-

group interactions and associations as well as depicting the overall network structure. Several important measures have been developed to characterize individuals' roles in a network, including degree, betweenness, and closeness (Wasserman & Faust, 1994). The degree of a node denotes the number of direct links it has. The betweenness of a node is the number of geodesics, the shortest path between any two nodes, which passes through it. The closeness of a node denotes the number of all the geodesics between that node and every other node in the network. Together, these measures portray the importance of each individual in the network.

Previous research has used the random graph theory (Albert & Barabasi, 2002) to study complex networks consisting of individuals and other entities. However, many real-world complex networks, such as collaboration or co-authorship networks in bioterrorism, are not random; rather, they are often organized or governed by some underlying principles (Chen & Roco, 2008). Prior studies examine real-world networks in terms of topology (Newman, 2001; Watts & Strogatz, 1998), evolution and growth (Jeong, Neda, & Barabasi, 2003), robustness and attack tolerance (Albert & Barabasi, 2002), and other network properties (Xu & Chen, 2005). For example, according to Newman (2001), the average shortest path length between co-authors in the MEDLINE collection (with 1.5 million nodes) is 4.6, showing that large networks often have small path lengths between their nodes. Yet, the MEDLINE co-authorship network has a coefficient of 0.066 which is several orders of magnitude higher than its random counterpart, suggesting that real-world networks tend to have relatively high clustering coefficients as compared with random graphs. Further, the degree distribution function of the network follows the power law scaling with exponent of 1.2, showing the growth and evolution of the network by measuring the degrees of nodes.

Information Visualization: Knowledge mapping requires information visualization for presenting search or analysis results to users in a cognitively efficient, intuitive, easily comprehensible, and transparent manner

(Börner et al., 2003). Information representation and user-system interaction designs are crucial (Zhu & Chen, 2005). Shneiderman (1996) examines various information representation methods and classifies them as one-dimensional (1D) representation, two-dimensional (2D) representation, three-dimensional (3D) representation, multi-dimensional representation, tree representation, network representation, and temporal representation (Shneiderman, 1996). Most 1D methods represent abstract information using one-dimensional visual objects and display them on the screen in a linear or a circular manner (Eick, Steffen, & Sumner, 1992; Hearst, 1995). Such methods have been applied to display the content of single documents (Hearst, 1995) or provide an overview of a collection of documents (Eick et al., 1992). With a 2D representation, information is represented as two-dimensional visual objects. The visualization of many SOM-based systems adopts a 2D representation to display the output (Chen et al., 1996; Huang, Chung, & Chen, 2004; Kohonen, 1995; Kohonen et al., 2000). Typically, these systems display the categories extracted from a large collection of documents and the layout of each category is defined by its location in the two-dimensional output of an SOM. Spatial proximity on the user-interface represents the semantic proximity of the extracted categories. A central challenge then is how to help users deal with a large number of categories extracted from vast volumes of textual data. A 3D representation reveals information as three-dimensional visual objects, wherein common metaphors that include rooms (Card, Robertson, & York, 1996), bookshelves (Card et al., 1996), or buildings (Andrews, 1995) are often used to convey the abstract information to be communicated to users. Multi-dimensional representations use a three-dimensional or a two-dimensional space, often projecting document clusters or themes into that space using some dimensionality reduction algorithm. As such, textual documents are represented as a set of key terms analyzed to identify important themes in the documents. Both the Spatial Paradigm for Information Retrieval and Exploration (SPIRE) system[2] (Wise et al., 1995) and the VxInsight system (Boyack, Wylie, & Davidson, 2002) employ multi-dimensional representations. A tree representation is usually employed to

[2] SPIRE has been updated over time and currently is known as InSpire.

show hierarchical relationships among objects. Common examples include tree-map (Johnson & Shneiderman, 1991), cone tree (Robertson, Mackinlay, & Card, 1991), and hyperbolic tree (Lamping, Rao, & Pirolli, 1995). Network representations are often used when a simple tree structure is insufficient for depicting complex relationships. Such representations can help users to visualize the citations among published articles (Chen & Paul, 2001; Mackinlay, Rao, & Card, 1995) or to understand the linkages among interconnected Web pages on the Internet (Andrews, 1995). A temporal visualization can organize information according to the temporal sequence. Location and animation can be used as visual variables to augment the presentation effectiveness by revealing the temporal aspect of information. In general, visual objects are listed along one axis (denoting time) as they occurred, while the other axis may be used to display key attributes of each temporal object (Eick et al., 1992).

These different representation methods can turn abstract text-based documents into visual objects that are easily understood by users. To be effective, a representation method has to be integrated with user-system interactions. Recent breakthroughs in computer hardware and software allow much faster user-system interactions, and enable novel visualization and interaction designs. Two prevalent interaction approaches are “overview + detail” and “focus + context” (Card, Mackinlay, & Shneiderman, 1999). Overview + detail provides multiple views, of which the first is an overview depicting overall patterns to users. Details about the specific parts of interest to the user can then be displayed in a drill-down manner. When a detailed view is requested, two types of zooming are usually involved; i.e., spatial zooming and semantic zooming. In contrast, focus + context provides detail (focus) and overview (context) dynamically on the same view. Examples of focus + context include the 3D perception used in information landscape (Andrews, 1995) and cone tree (Robertson et al., 1991), wherein visual objects at the front appear larger than those at the back. Another example is the fisheye view in hyperbolic tree (Lamping et al., 1995), a distortion representation

method that acts like a wide-angle lens to amplify part of the focus, thus, providing greater granularity on the region of interest and reducing neighboring information details simultaneously.

2.2 Review of Knowledge Mapping Systems

Knowledge mapping has been studied in several domains that include business and health care. For example, Marshall et al. (2004) develop EBizPort, a knowledge mapping system for business intelligence, and evaluate the system in terms of usability, information quality, and user satisfaction, using a prevalent system for performance benchmarking. Chung et al. (2004) develop a similar knowledge mapping portal, CBizPort, which supports business intelligence analyses in Chinese document environments. They experimentally examine CBizPort's information quality, cross-regional searching capability, and the associated user satisfaction, and report encouraging results. In health care, Zhou et al. (2006) design and implement a Chinese medical portal (i.e., CMedPort), which allows users to search for Web pages from local collections and meta-search engines, together with an encoding conversion between simplified and traditional Chinese to support cross-regional search and document summarization/categorization. They conduct an experiment to evaluate the effectiveness, efficiency, error recovery, interface, and functionality of CMedPort, reporting that the use of CMedPort can result in significant improvements in users' search performance, compared with three benchmark regional search engines that include Sina, Yahoo! Hong Kong, and Openfind.

Some studies focus on examining the visualization components of knowledge mapping. Chung et al. (2005) assess users' satisfaction with a visual framework for knowledge discovery. According to their findings, users exhibit higher satisfaction with their proposed system's display format, interface, visualization function, and navigation function than those of the benchmark systems that are associated with a notable information overload. Zhu and Chen (2005) develop an image retrieval system to address a challenge

common to conventional retrieval models; i.e., requiring users to have complete knowledge about low-level features of an image. They use recall and precision rates to assess the system's performance and compare it with those achieved by human subjects. According to their results, the system can perform comparably with humans in image analysis and categorization.

2.3 Knowledge Mapping Analysis for Bioterrorism

Terrorism is generally difficult to research because of the clandestine nature of terrorist groups (Merari, 1991; Silke, 2001). It is therefore challenging to identify essential intellectual structures or characteristics of contemporary terrorism literature (Reid & Chen, 2007). Biodefense is critical to bioterrorism because its research and practice can be used for biological weapon developments or counter attacks. Increasingly, governments around the world are paying closer attention to biodefense research and practice, disclosing the urgency for monitoring, regulating or controlling these activities. Swanson (1986) pioneers the work of mining implicit knowledge (information) from biomedical literature to discover the association between fish oil and Raynaud disease. He uses a literature-based method to infer new relationships; e.g., fish oil helping patients suffering from Raynaud disease; magnesium deficiency playing an important role in migraine headache; arginine intake affecting the level of somatomedin C in the blood; and oestrogen protecting against Alzheimer disease. These results shed light on the underlying cause of a particular disease or illness, and new treatment approaches or methods. Various biomedical informatics tools have been developed to combat bioterrorism attacks. Jensen et al. (2006) study prevalent online biomedical informatics tools and identify common resources for information retrieval, entity recognition, information extraction, and text mining. Hu and his collaborators (Hu, Yoo, Rumm, & Atwood, 2005; Hu, Zhang, Wu, Zhou, & Rumm, 2006; Hu, Zhang, Yoo, Atwood, & Rumm, 2005) take a text mining approach to identify from PubMed literature candidate viruses and bacteria as potential bioterrorism weapons. For example, they caution the U.S. public health system and primary healthcare providers to be prepared for pathogens,

which are rare in the United States historically. Their findings guide future studies and enlighten some promising defense measures in public health. Morris et al. (2003) use a time line method to analyze a set of literature related to Anthrax, a bioterrorism agent. They identify and visualize temporal changes in research activities of different research fronts related to Anthrax. For example, they find that the earliest research front of Anthrax, dealing mostly with immunology and some preliminary topics on toxins, is the origin of basic information for research that followed. In addition, there is some flow of information from documents in the vaccine research domain to research involving Anthrax bioterrorism.

Some prior studies use bibliometrics to analyze terrorism research publications, thus providing an evolutionary perspective of the development of the field (Kennedy & Lum, 2003; Reid, 1983, , 1997). Reid (1983) applies both content analysis and citation analysis to identify the most frequently cited (MFC) terrorism publications. Gordon (1999) assesses the status of terrorism research by conducting a content analysis of a large collection of masters and doctoral dissertations in the terrorism domain. The abstract and bibliographical details of the theses and dissertations, published between 1969 and 1997, are retrieved from Dissertation Abstract International (Gordon, 1999). Schmid & Jongman (1988; 2005) collect and analyze survey data to generate insights about terrorism of different categories; e.g., whether it is specific individuals, politically-based, or state-supported. They also define a set of theories that may assist in combating terrorism. Silke (2001) studies terrorism research from a psychology perspective, performing content analysis on a large set of articles published between 1995 and 2000 in major terrorism journals. Through basic bibliographic analysis, content map analysis, and co-citation analysis, Reid & Chen (2007) develop a knowledge mapping framework for identifying leading researchers and salient knowledge creation approaches in terrorism. They analyze the articles about terrorism from ten major databases, published between 1965 and 2003, and identify the top 42 core terrorism researchers, together with their research focus and representative work. Reid and Chen also find clusters of terrorism researchers

interested in similar areas. However, our literature review shows that few (if any) studies examine the use of knowledge mapping to monitor and analyze the current status of global bioterrorism research. In addition, most prior studies predominantly use terrorism publications as data sources and therefore fail to explore the use of bioterrorism research publications for biodefense.

2.4 Motivation

Our literature review points to several notable gaps in research. First, the efforts for monitoring and analyzing global bioterrorism research are limited. Second, few studies have investigated the use of knowledge mapping to monitor and analyze global bioterrorism research. Further, evaluations of bioterrorism knowledge mapping systems have received little research attention. To address these gaps, we take an integrated approach to monitor and analyze global bioterrorism research literature. Specifically, we develop Arizona Literature Mapper, a knowledge mapping system for identifying researchers in the field of bioterrorism agents or diseases, the collaborations between or among them, and the emerging topics and trends in bioterrorism agent or disease research. We conduct two evaluation studies. One study is system-centric, focusing on the system's search function and comparing it with that of PubMed, a well-known system widely used globally. Another study is user-centric, targeting the system's three analysis functions: bibliographic analysis, co-authorship analysis, and topic trend analysis. Our evaluations are methodologically rigorous and are designed to test hypotheses developed through our review of salient theories and synthesis of extant literature. In the following section, we describe the design and implementation of Arizona Literature Mapper.

3. Design and Implementation of Arizona Literature Mapper

As shown in Figure 1, the design of Arizona Literature Mapper includes several main components; i.e., data acquisition, data parsing and cleaning, and data analysis, described as follows.

<Insert Figure 1 here>

Data Acquisition: We use research articles from the MEDLINE database[3], which contains approximately eleven million records from over 7,300 journals published between January, 1965 and November, 2005 (http://medline.cos.com/). All related articles are collected by using keyword filtering. We compile two test data sets about human and animal related bioterrorism agents or diseases, respectively. To construct the human bioterrorism agents or disease data set, we retrieved 178,599 publication records from MEDLINE (1964-2005), by searching article abstracts and titles using keywords from CDC's list of agents by category (http://www.bt.cdc.gov/agent/agentlist-category.asp). We used all the keywords (including those shown in parentheses) provided on the Web page, resulting in a total of 58 keywords. For the animal bioterrorism agents or disease data set, we retrieved 135,774 publication records from MEDLINE (1965-2005) by searching article abstracts and titles using keywords from OIE's list of diseases by species (http://www.oie.int/eng/maladies/en_classification.htm). By removing the redundancies among the listed animal diseases, we obtained a total of 58 different keywords related to animal diseases.

Data Parsing and Cleaning: We parse the title, abstract, author information, and publication date of each article, and store the parsed structured data in a relational database. Authors' institutions and countries are parsed using dictionaries of countries, states, cities, and institutions. By using these dictionaries, we can assure the correctness in entity, location, or institution names. All the authors' names associated with an

[3] Compiled by the U.S. National Library of Medicine (NLM) and published on the Web by Community of Science, MEDLINE is the world's most comprehensive source of life science and biomedical bibliographic information.

article are also parsed, however only the first author's institution is retained for subsequent analyses. Some variations exist in foreign institution names and city names; we spot check and consolidate them manually. For example, both "University Tokyo" and "University of Tokyo" appear in authors' institutions; they refer to the same institution, the University of Tokyo. In this case, we reconcile the difference by using "University of Tokyo" as the institution name. Author names may also create ambiguity. For the first authors, we use their institutions (addresses) for disambiguation. If two authors with the same name are from different institutions (addresses), we consider them different authors. However, authors with the same name and the same institution (address) are treated as one (the same) author. This disambiguation approach is not perfect because it cannot distinguish different authors who have identical names and work in the same institution (address). However, we believe that such cases are rare and therefore consider this disambiguation approach acceptable. The MEDLINE database only allows us to extract institution information for first authors. For the non-first authors, there is little additional information available for disambiguation. Hence, we perform disambiguation only for first authors.

Data Analysis: To understand the status of global bioterrorism research, we use knowledge mapping techniques to perform bibliographic analysis, co-authorship analysis, and content map analysis. In the bibliographic analysis, we examine the productivity of each author, institution, and country on the basis of the number of articles published. We also assess emerging trends and the evolution of the bioterrorism agent or disease research field. We conduct co-authorship analysis to explore the collaborations among researchers. By building co-authorship networks, we can identify a set of independent, isolated research groups (i.e., independent networks), where researchers only have intra-group collaborations but no inter-group collaborations. We use SOM to examine major research topics and to discover emerging themes in different time periods.

We implement Arizona Literature Mapper using a three-layer system architecture: presentation layer, logic layer, and database layer. The Web pages are developed using Java Server Pages (JSP). The Web server is implemented using Apache Tomcat and the database is implemented using Microsoft SQL Server 2000. Arizona Literature Mapper is designed to support multiple users accessing the system and performing analyses simultaneously. Our system implementation allows Web-based access, analytical functionality, and visualization. It has four main functions: search, bibliographic analysis, co-authorship analysis, and topic trend.

Figure 2 shows the home page of our Web-based system with the search function that focuses on two types of search: human and animal disease related bioterrorism publications. To search articles on human or animal diseases, a user can specify the title, author' first name, author's last name, the publication institution, the publication country, the publication year range, or their combinations. The user-provided article title, author's name, and institution name can be partial or complete. In response to a user-submitted query, the system will return a list of articles, including titles and publication dates, which allow users to select particular articles and review their details.

<Insert Figure 2 here>

Figure 3 shows a sample bibliographic analysis. By clicking the hyperlinks, a user can view the productivity analysis at three levels: country, institution, and individual. In response to a query about the productivity of different countries in human disease research, the result table lists the countries and their number of publications related to human diseases in decreasing order, with the most productive country at the top. As shown, the United States has the most publications, more than four times that of Japan, which is ranked second. United Kingdom, Germany, and France complete the top five most productive counties. Institution-

or individual-level productivity queries will yield results displayed in a format with the most productive institutions or individuals at the top of the result table.

<Insert Figure 3 here>

Figure 4 provides a sample co-authorship analysis. Users can view the collaborations among researchers by disease or region. Figure 4 shows the collaborations among researchers on Anthrax, a human related bioterrorism disease. We use NetDraw, a popular social network analysis tool (available at: http://www.analytictech.com/Netdraw/netdraw.htm/), to create the co-authorship networks. Each node represents a researcher. The larger the node, the more articles the researcher has published. The link between two researchers means that these two researchers have published an article or articles jointly. The thicker the link, the more articles these two authors have published together. We only include researchers who published more than five articles to make the network not overly crowded. As shown in Figure 4, there are several notable groups. The largest group in the center consists of researchers from the United States and the second largest group is from France. Most of the smaller groups are from India, Israel, Italy, and United Kingdom. In each group, researchers collaborate closely with one another but have little collaborations with those outside this group. In addition to analyzing the collaborations associated with a particular disease, we also examine the collaborations in different regions, including countries that have substantial direct state-funded terrorism research (e.g., Iran, Cuba, Sudan, Libya, North Korea, and Syria) as well as countries in the Middle East or North Africa. We find that researchers in state-sponsored terrorism research engage in more collaborated efforts on E. Coli, whereas researchers in the Middle East or North Africa show more collaborations in studying Q fever and Brucellosis.

<Insert Figure 4 here>

Figure 5 provides a sample topic trend in human disease research between 2001 and 2005. We use the multi-level self-organization map algorithm developed by the Arizona Artificial Intelligence Lab (Chen et al., 1996). The algorithm has been used to map nanotechnology patents in previous studies (e.g, Huang, Chen, Chen, & Roco, 2004; Huang, Chen, Li, & Roco, 2006; Z. Huang et al., 2003). Although they all adopt the Arizona Topic Map algorithm, this study is different from the prior work in some ways. First, Arizona Literature Mapper implements the algorithm as a core component of the knowledge mapping system to make the analysis/search results accessible online and to support various system evaluation studies. In contrast, the prior studies, including Huang et al. (2004; 2006; 2003), use this algorithm to only analyze the nanotechnology literature. It is not implemented in a real-world system. The resulting Arizona Literature Mapper system can readily be used to support online searches of the bioterrorism literature. Second, Arizona Literature Mapper targets bioterrorism research, an area critical to public health and national security that needs effective knowledge mapping support. This target application domain involves datasets and search words distinct from those for nanotechnology literature analyses. Therefore, the content maps in this study show the emerging research topics about bioterrorism; the content maps included in Huang et al. (2004; 2006; 2003) describe topics about nanotechnology. To make the analysis/search results accessible online and to support various system evaluation studies, we implement this algorithm as a core component of the knowledge mapping system targeting bioterrorism research, an area critical to public health and national security that needs effective knowledge mapping support. The nodes in the folder tree and colored regions represent topics extracted from the input documents. The topics are organized by a multi-level self-organization map algorithm. The more related two technology topics, as revealed by their co-occurrence, the closer they are positioned on the map. The number of papers pertaining to a particular topic is indicated after the topic's label. The size of a topic region corresponds to the number of documents pertaining to the topic. Region color indicates the growth rate of the associated topic—the warmer the color, the higher the growth rate. We measure the growth rate of a particular topic (or region) by dividing the

number of articles published in a time period by the number of articles published in the previous time period. As shown in Figure 5, the dominating topics are "Yersinia pestis," "Centers of Disease Control," "Protective antigens," "Francisella tularensis," and "Botulinum neurotoxin." Some emerging topics are also observed, such as "Biological weapons," "Anthracis spores," and "Smallpox vaccination." Our analysis results suggest a shifting research interest toward the use of Anthrax spores and biological weapons after 2000.

<Insert Figure 5 here>

These functions of Arizona Literature Mapper can help individuals or government agencies to monitor and analyze global bioterrorism research. The system can provide users with the bioterrorism research articles published by a particular author from an organization located in specific country within a specified time horizon (in years). The three analysis functions enable users to get a high-level understanding of the research and development status or important trends in bioterrorism research. Most existing knowledge mapping systems designed for other domains (such as business and general health care) focus only on the search function. In contrary, Arizona Literature Mapper offers additional analysis functions crucial to users' obtaining a comprehensive understanding of the bioterrorism research domain.

4. Search Function Evaluation Study and Results

We conduct a study to evaluate the effectiveness, usefulness, and ease of use of Arizona Literature Mapper's search function and the associated user satisfaction and intention to use the system. To select an appropriate benchmark system for comparative purposes, we focus on the following criteria: (1) the system is freely accessible online, (2) the system is widely used for searching or analyzing the biomedical literature, and (3) the system offers a search function similar to that of Arizona Literature Mapper. According to these

criteria, PubMed (http://pubmed.gov) is chosen to be our benchmark system[4]. PubMed is a search engine for accessing the MEDLINE database of citations and abstracts of biomedical articles. It is made available by the U.S. National Library of Medicine and consists of nearly eleven million records from over 7,300 journals from 1965 to November 16, 2005 (http://medline.cos.com/). PubMed is arguably the most widely used system in medicine and biomedicine related areas. Given that no existing knowledge mapping systems are specifically designed for bioterrorism, PubMed presents an appropriate benchmark knowledge mapping system that also provides search services related to biomedical research. Our choice of PubMed is also advantageous because the articles accessible by both PubMed and Arizona Literature Mapper are from the MEDLINE database[5].

PubMed is designed to assist searches of published articles in medicine and biomedicine. In contrast, Arizona Literature Mapper provides not only the article search function but also additional advanced analysis functions. For comparison purposes, one evaluation study focuses on Arizona Literature Mapper's search function and includes PedMed as the benchmark system. We perform another evaluation study to examine the analysis functions of Arizona Literature Mapper. In the following, we detail each study's design, targeted questions or hypotheses, dependent variables or measurements, subjects, and tasks.

[4] We acknowledge one anonymous reviewer's suggestion of InSpire and PubNet as potential benchmark systems. However, InSpire is a commercial tool and is not specifically designed for biological and medical science areas and PubNet's architecture and core functions are considerably different from those of Arizona Literature Mapper. These issues, combined with our selection criteria, indicate that InSpire and PubNet are not more appropriate benchmarks than PubMed.

[5] The collection of research articles accessible to Arizona Literature Mapper is a subset of the MEDLINE database, to which PubMed can access as well. Although in total, PubMed has a much larger collection than does the datasets in Arizona Literature Mapper, we, when designing the search tasks, are particularly mindful about ensuring that the two systems will return comparable numbers of potential articles in response to the user query. Our search tasks focus on bioterrorism related publications, each entailing some specific keywords. Our use of these keywords essentially restricts the number of publications (from PubMed) accessible or returned to the subjects in our evaluation study. Thus, both systems, Arizona Literature Mapper and PubMed, share the same data source (i.e., the MEDLINE database), and therefore involve a highly similar set of bioterrorism articles. In addition, recent advancements in computing, including hardware performance and database management capabilities, have greatly mitigated the time and computational requirements for online searches against enormous data sets or document repositories. At this level of processing, most users, with adequate Internet connections, would hardly experience delays when using online search systems, such as PubMed.

4.1 Hypotheses

In this evaluation study, we compare the search function of Arizona Literature Mapper with that of PubMed. Overall, we posit that the effectiveness, usability, user satisfaction and intention to use associated with Arizona Literature Mapper are greater than those of PubMed. In developing these hypotheses, we draw on the literature in technology acceptance (see Venkatesh, Morris, Davis, & Davis, 2003 for a review). The specific hypotheses to be tested in this evaluation study are as follow:

- H1: Users are more likely to successfully complete their search tasks when using Arizona Literature Mapper than using PubMed.
- H2: Users can successfully complete their search tasks faster when using Arizona Literature Mapper than using PubMed.
- H3: Users will perceive Arizona Literature Mapper to be more useful than PubMed.
- H4: Users will perceive Arizona Literature Mapper to be easier to use than PubMed.
- H5: Users' satisfaction with Arizona Literature Mapper is higher than that with PubMed.
- H6: Users exhibit a higher intention to use Arizona Literature Mapper than PubMed in the near future.

4.2 Evaluation Design

Experimental design: To test our hypotheses, we adopt a repeated-measures factor design, which is appropriate for testing our hypotheses because it gives greater precision than alternative designs that employ only between-subjects factors (Myers & Well, 1995). In our design, system is a repeated-measures factor defined at two levels: Arizona Literature Mapper and PubMed. Each subject uses one system to complete all the tasks and then repeats these tasks using the other system. We randomize the sequence of system use to ensure a comparable number of subjects starting with each system. For example, a subject could be randomly assigned to use Arizona Literature Mapper first and PubMed second. In this case, the subject would complete all of the tasks with Arizona Literature Mapper first, then complete the same set of tasks using PubMed. The tasks to be performed are identical for both systems. Other subjects performed the tasks in the opposite order, with PubMed first and Arizona Literature Mapper second.

Dependent variables: We assess each system's effectiveness in terms of task performance accuracy, which refers to how well a system supports the user to complete a search task correctly. We adopt an accuracy measurement commonly used in previous knowledge mapping and information retrieval research (Chung et al., 2005; Chung et al., 2004; Marshall et al., 2004; Zhou et al., 2006). Specifically, task performance accuracy is measured as $Accuracy = \frac{Number\ of\ correctly\ answered\ parts}{Total\ number\ of\ parts}$. An expert uses both Arizona Literature Mapper and PubMed to derive a gold-standard answer for each search task, and then reviews subjects' search results and assign scores on the basis of respective gold-standard answer and the accuracy formula. We measure efficiency using the amount of time a subject took to complete a search task, consistent with prior knowledge mapping or information retrieval research (Chung et al., 2005; Marshall et al., 2004; Zhou et al., 2006). To keep the experiment within a reasonable time span, we implement a time limit of 15 minutes for performing each task using either system, which is appropriate as all the subjects in the pilot study were able to complete each of the search tasks in a total of 12 minutes or less. We adapt items from Davis (1989) to measure each system's usefulness and ease of use as perceived by subjects. These items also have been used to assess knowledge mapping or information retrieval systems (Chung et al., 2005; Chung et al., 2004; Marshall et al., 2004; Zhou et al., 2006). We adapt items from Bhattacherjee (2001) to measure users' satisfaction and intention to use each investigated system. These items have been used to examine online services; e.g., (Hu et al., forthcoming). The specific items used in the study are summarized in Appendix A, together with their respective sources.

Subjects: Our subjects are undergraduate students who enrolled in a sophomore- or junior-level information systems class at a major public university located in the southwest United States. The instructors assisted our recruiting by providing extra course credit as an incentive for student participation in our study.

Tasks: With the assistance of several domain experts, we design six scenario-based search tasks related to bioterrorism agents or diseases. An example task is: "Foot-and-mouth disease (FMD) is one of the most devastating animal diseases. It occurs throughout the world and is a significant hazard to agriculture. In 2001, the epidemic in United Kingdom led to the loss of six million livestock. Please identify one research article published by United Kingdom after year 2001 (2001 excluded), talking about FMD. Please write down the title of the article, the institution and country that published this article, and the publication year of it." All the tasks used in the experiment are listed in Appendix B.

Experimental Procedure: In the experiment, a subject uses each of the two investigated systems to perform all the tasks. The order in which each system is assigned to the subject is random, thus allowing us to avoid potential bias introduced by the system sequence. After completing the tasks using a system, each subject is asked to assess the system by completing a questionnaire soliciting his or her evaluative responses to the system's usefulness and ease of use, as well as the satisfaction with the system and intention to use the system in the near future. Subjects can provide additional comments on each system based on their experiences.

4.3 Evaluation Results

A total of forty-three subjects took part in the experiment; all of them completed the experiments and filled out the post-experiment survey. Our subjects average 22.1 years of age, with a fairly balanced gender distribution; i.e., 22 male subjects and 21 female subjects. As a group, the subjects have used computers for approximately 12 years. In the experiment, twenty-two subjects used Arizona Literature Mapper first and the remaining used PubMed first.

We first perform ANOVA to test the main effect of system on each dependent variable. According to our analyses, the search system has a significant effect on the likelihood of successfully completing a search task ($F(1,84) = 8.74$, p-value = 0.0040), the amount of time required to complete a search task ($F(1,84) = 52.52$, p-value < 0.0001), perceived usefulness ($F(1,84) = 50.96$, p-value < 0.0001), perceived ease of use ($F(1,84) = 63.58$, p-value < 0.0001), user satisfaction ($F(1,84) = 46.75$, p-value < 0.0001), and intention to use the system in the near future ($F(1,84) = 51.33$, p-value < 0.0001). Our findings suggest that the choice of system matters for users' search performance in terms of accuracy and time efficiency, perceptions of the system's usefulness and ease of use, and their satisfaction and intention to use the system.

We then perform one-tailed t-tests to test H1 through H6. As summarized in Table 1, the likelihood of successful search task completion is significantly higher when users are supported by Arizona Literature Mapper than by PubMed (p-value = 0.0007). Thus, our data support H1. The difference between systems in the amount of time required to successfully complete a search task is also statistically significant (p-value < 0.0001). As shown in Table 2, on average, a user needs 2.88 minutes to complete a search task when using Arizona Literature Mapper but spends 4.41 when supported by PubMed. Therefore, our data support H2. Our analyses show that users perceive Arizona Literature Mapper to be more useful and easier to use than PubMed (p-value < 0.0001), in support of H3 and H4. Our subjects exhibit a significantly higher satisfaction when using Arizona Literature Mapper than PubMed (p-value < 0.0001). Their intention to use Arizona Literature Mapper is also significantly higher than that for PubMed (p-value < 0.0001). Thus, our data support H5 and H6. Table 1 summarizes our hypothesis testing results; as shown, our data support all the hypotheses, suggesting the crucial role of a knowledge mapping system in users' bioterrorism literature searches and the relative advantage and utility of Arizona Literature Mapper over PubMed. Further, subjects' evaluation responses of Arizona Literature Mapper are notably positive, as shown in Table 3,

averaging 6.16 in perceived usefulness, 6.50 in perceived ease of use, 5.81 in satisfaction, and 5.76 in intention to use, on the basis of a 7-point Likert scale with 7 being "strongly agree."

<Insert Table 1 here>

<Insert Table 2 here>

<Insert Table 3 here>

We also collect comments from some subjects about the search function of Arizona Literature Mapper and PubMed, respectively. Many comments are about users' experiences and assessments of the interface designs or data completeness. Most of our subjects point out that the search function of Arizona Literature Mapper is faster, easier to use, and more comprehensible than that of PubMed. Arizona Literature Mapper allows effective and efficient searches for specific details; but, it does not provide automatic spell checking and its display of detailed information needs improvement. In contrast, these subjects praise PubMed for effective categorization of searchers and automatic spell checking. We observe inconsistent and somewhat interesting assessments of Arizona Literature Mapper's separation of human and animal diseases. Some subjects are in favor of categorized searches but others value searching human and animal diseases simultaneously. Although the design of Arizona Literature Mapper separates the searches on human or animal diseases for increased ease of use and drill-down capabilities, we nevertheless need to further examine this design rationale[6]. Some subjects also comment on data completeness. Some perceive that PubMed can access more research articles than can Arizona Literature Mapper, which contains a condensed set of articles about bioterrorism agents or diseases. As one subject commented, "PubMed helps for searching medical articles; however, Arizona Literature Mapper is more helpful for searching bioterrorism articles." Such comments underscore the value of domain-specific knowledge mapping

[6] For example, without separating the searches on human and animal diseases, we may create confusion when providing specific details and their illustrations to users.

systems to facilitate users' literature searches. In this light, PubMed is effective for supporting general searches in medical literature but its utility seems diminished when users are searching for publications in other related domains, such as bioterrorism. In Appendix C, we list some representative comments by subjects.

5. Analysis Function Evaluation Study and Results

We conduct a second study to evaluate the core analysis functions of Arizona Literature Mapper; i.e., bibliographic analysis, co-authorship analysis, and topic trend analysis. No benchmark systems are included in this study because none of the existing knowledge mapping systems, including PubMed, offers such analytical functionality. Specifically, we use subjects' evaluative assessments of the usefulness, ease of use, satisfaction, and intention to use Arizona Literature Mapper's functionality instead of directly comparing Arizona Literature Mapper's analysis functions with those of a benchmark system. In the following, we describe the hypotheses to be tested, experimental design, subjects, tasks, measurements, and data collection used in this study.

Hypotheses: We test several hypotheses concerning the usefulness and ease of use of Arizona Literature Mapper's core analysis functions and the associated user satisfaction and intention to use these functions in the near future. Again, we draw on the literature in technology acceptance (e.g., Venkatesh et al., 2003) to develop our hypotheses. Specifically, we postulate favorable assessments by subjects in perceived usefulness, ease of use, satisfaction and intention to use by testing the following hypotheses:

H7: Subjects perceive positively the usefulness of Arizona Literature Mapper's analysis functions.
H8: Subjects perceived positively the ease of use of Arizona Literature Mapper's analysis functions.
H9: Subjects are satisfied with Arizona Literature Mapper's analysis functions.
H10: Subjects exhibit favorable intentions to use Arizona Literature Mapper's analysis functions in the near future.

Study Design: Each subject is asked to perform twelve tasks using Arizona Literature Mapper's core analysis functions. Six of the tasks are about research productivity, four of the tasks are on research collaborations, and the remaining two tasks target interesting trends in bioterrorism agent or disease research. We develop these tasks with the assistance of several domain experts and perform a pilot test to assure their appropriateness.

Subjects: Subjects are recruited from students enrolled in a junior-level information systems class at a major public university located in the south-west United States. The instructor assisted our recruiting by offering extra course credit as an incentive for student participation in the study. We excluded subjects who participated in the search function evaluation study.

Tasks: Each subject is asked to complete twelve tasks using Arizona Literature Mapper's analysis functions. These tasks target research productivity, collaborations, and trends in bioterrorism research. An example task on research productivity is: "Please find and write down the names of the 5 most productive countries (i.e., with the most research publications), related to human bioterrorism agents or diseases." An example task abut research collaborations is: "Please find the largest research collaborated group on Anthrax, a human bioterrorism agent or disease, and write down the names of any three researchers in that group." An example task targeting trends in bioterrorism research is: "Please find and write down three emerging research topics in human bioterrorism agent or disease research after 2001." All the tasks used in the experiment are listed in Appendix D.

Measurements: We measure usability, user satisfaction, and intention using items adapted from previously validated scales (Bhattacherjee, 2001; Davis, 1989), with minor wording changes appropriate for our

subjects and contexts. These items are identical to those used in the search function evaluation study described previously. All the items use a seven-point Likert scale, with 7 being "strongly agree," 4 being "neutral," and 1 being "strongly disagree." We use the midpoint (i.e., score of 4) as a cutoff distinguishing positive and negative assessments by subjects.

Data Collection: When completing all the tasks, a subject is asked to fill out a questionnaire survey designed to gather his or her assessment of the usefulness and ease of use of Arizona Literature Mapper's analysis functions, specify the satisfaction with these functions, and indicate the intention to use them in the near future. Subjects are also encouraged to provide comments about their use of and experience with these functions.

Results: A total of sixty subjects participated in this evaluation study; none of them had taken part in the search function evaluation study. Our subjects average 20.9 years of age, with the genders equally represented; i.e., 30 males and 30 females. As a group, our subjects report an average of 11.9 years of experience in using computers. Table 4 summarizes the average of subjects' ratings of perceived usefulness, perceived ease of use, user satisfaction, and intention to use these analysis functions in the near future. We perform one-tailed t-tests to asses whether subjects' assessments are significantly higher than the cutoff; i.e., 4 denoting the midpoint of the seven-point Likert scale used in the study. As shown in Table 5, subjects perceive these functions of Arizona Literature Mapper useful and easy to use, with an average rating significantly higher than 4, p value < 0.0001 and p value = 0.0002 respectively. Hence, our data support H7 and H8. User satisfaction is also positive, significantly higher than 4 (p-value = 0.0002), in support of H9. In addition, subjects indicate strong intentions to use the Arizona Literature Mapper's analysis functions in the near future; the average intention significantly exceeds 4 (p-value < 0.05) and therefore our data support H10. Table 5 summarizes our hypothesis testing results.

<Insert Table 4 here>

<Insert Table 5 here>

We also collect comments from subjects regarding their use of or experiences with the analysis functions of Arizona Literature Mapper. According to our results, subjects consider these functions fast and easy to use, and result displays organized and easily comprehensible. Overall, subjects are positive about their use of these functions, although few express some level of challenge in understanding a content map when using the topic trend analysis function. In turn, this suggests the value of providing additional detailed descriptions and enlarging the pictures in a content map for improved comprehensibility. In Appendix E, we list some representative comments by subjects.

6. Contributions and Future Research Directions

Monitoring global bioterrorism research is increasingly important and represents a crucial challenge to governments and research communities around the world. This research has made several contributions to addressing that challenge. First, we propose an integrated approach to monitoring and analyzing global bioterrorism research literature, which is becoming increasingly critical for biodefense and national security but has received little investigative attention. Our integrated approach provides an informative point of departure for continued research in knowledge mapping. Second, we make a research contribution by implementing Arizona Literature Mapper. The system, built upon advanced algorithms and techniques for search, bibliographic analysis, co-authorship analysis, and topic trend analysis supports effective and efficient knowledge mapping by allowing users to identify productive researchers or institutions studying bioterrorism agents or diseases, their collaborations, and emerging topics or trends in bioterrorism. Additionally, Arizona Literature Mapper can enhance user literature search performance and satisfaction.

To demonstrate the advantages of our system, we perform two rigorous evaluation studies. One study focuses on the search function of Arizona Literature Mapper and examines its effectiveness, efficiency, usefulness, ease of use, user satisfaction and intention for future use as compared with those of a prevalent benchmark system. The results of this study demonstrate that Arizona Literature Mapper is more effective, more efficient, easier to use and more useful than a comparison system (i.e., PubMed). In addition, the results indicate that users are satisfied with our system and have positive intentions toward using it. The second study examines Arizona Literature Mapper's functions for bibliographic analysis, co-authorship analysis, and topic trend analysis, using individuals' evaluations of these functions' usefulness and ease of use as well as their satisfaction and intention to use the functions in the near future. Again, the empirical results provide evidence to support positive user satisfaction and favorable intentions to use Arizona Literature Mapper. Together, these results indicate that the underlying algorithm provides valuable results and the system interface makes Arizona Literature Mapper accessible to the users.

Findings of this study have several important implications for research and practice. First, our evaluation results underscore the need for domain-specific knowledge mapping systems that are critical to obtaining a comprehensive understanding of the current status of a particular research domain (e.g., bioterrorism) in an effective and efficient manner but not well supported by existing general-purpose search systems (e.g., PubMed). Second, we demonstrate the viability of using a knowledge mapping system to analyze or monitor global bioterrorism research. Toward that, sources of publications are crucial and should include salient digital repositories with timely updates. A challenge then is to identify essential sources of bioterrorism articles (e.g., MEDLINE) and solve the technical or management issues associated with incorporating them into a knowledge mapping system, such as Arizona Literature Mapper. The range of bioterrorism agents or diseases is important as well. With expanded publication sources and bioterrorism

agents or diseases, knowledge mapping systems can become increasingly effective and useful for bioterrorism research analyses or surveillance. Third, many subjects commented on the visualization and information representation. Some sample comments include: "The content map and stats page were perfect, the network is – although the coding is probably amazing – too cramped of a picture, needs to become easier to read and derive results from;" "Try changing the fonts of the text for a more visual appealing design;" "The analysis functions simplify the information for users to understand;" "I really like the visual results. The colored map was my favorite;" and "I like seeing the map with colors indicating newer topics in red, which made it very quick to have a visual idea of the newest topics." Visualization is an area where knowledge mapping systems can benefit substantially from advanced analyses and designs. We anticipate visualization to play a more important role as knowledge mapping systems include additional publication sources and bioterrorism agents/diseases. Thus, the current study provides important guidance and implications for future domain-specific knowledge mapping system development for other domains.

The use of student subjects represents a limitation of this study[7], since the domain experts are going to be important users of Arizona Literature Mapper. Our subject selection was made for the following reasons. First, the use of Arizona Literature Mapper is not completely restricted to bioterrorism experts; rather it can be used by anyone interested in understanding or analyzing the bioterrorism literature. This necessarily includes students studying bioterrorism, security professionals with limited knowledge of bioterrorism, and citizen scientists who are simply inquisitive. Thus, in evaluating Arizona Literature Mapper, we wanted to be sure it was accessible by even naïve users. In addition, to fully test our hypotheses requires a reasonably large number of subjects. This would have been difficult to achieve had we relied entirely on experts. Based on these two reasons, we believe our use of student subjects is reasonable. The empirical evidence clearly indicates that Arizona Literature Mapper represents a solid foundation upon which to build more advanced

[7] We acknowledge the reviewer for pointing out the limitation of subject selection of this study.

functionality for bioterrorism research and for other important areas of inquiry. It would be valuable to obtains evaluations from domain experts in the future.

There are several possible directions for future research associated with both the underlying algorithm and the user interface. First, we used the number of papers published to represent the importance of a certain country, institution, and individual researcher. However, the number of papers is only one parameter to determine the importance. Future work should examine other parameters including the number of citations and the importance (e.g., impact factors) of the journals where the papers were published. This approach could lead to different search results that would need to be evaluated by domain experts in order to determine which underlying algorithm produces the most useful results. Second, we plan to extend our integrated approach to include a multilingual knowledge mapping system design. By incorporating a machine translation component, we plan to provide cross-regional (with multiple languages) literature search functionality. For example, users may submit their interested keywords in English to retrieve a related literature in other languages (e.g., Arabic, Chinese, French, Spanish, etc.). Given the increasing number of publications in non-English languages and the need to include all relevant publications when searching, particularly in the bioterrorism domain, this is an important extension of the current work. Determining how to design and implement the machine translation component with satisfactory accuracy and effectiveness is a significant research challenge. Finally, the knowledge mapping techniques used in this study have existed for some time. As technology users increase sophistication and expectations, developing interactive application with visual representation of data will become more and more important. Therefore, the need to develop new techniques to facilitate searching/analyzing scientific knowledge is increasing. Further work should develop and incorporate new information retrieval and visualization tools with more dynamic user-interactive features and higher information representation ability.

7. Conclusion

In this study, we proposed an integrated approach to develop an advanced knowledge mapping system for supporting analyses of the current status of or emerging trends in bioterrorism research involving various agents or diseases of human beings or animals. Our system, Arizona Literature Mapper, is a research portal that allows users to perform general literature search, bibliographic analyses, co-authorship analyses, and topic trend analyses. The search function of Arizona Literature Mapper supports searches of published articles about human or animal bioterrorism agents and diseases. The bibliographic analysis function shows the productivity of individual researchers, institutions, and countries. The co-authorship analysis function reveals the collaborations among researchers, whereas the topic trend function allows users to identify emerging topics and trends in bioterrorism research. Together, these functions enable users to gain an overall understanding of global bioterrorism research in an effective and time-efficient manner. We tested our implementation of Arizona Literature Mapper with two user studies, and the results demonstrated that users had favorable impressions of our system's functionality and preferred it to PubMed.

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Appendix A: Listing of Items Used in the Study

Perceived Usefulness (7-point Likert scale, ranging from strongly disagree to strongly agree) adapted from (Davis, 1989)
PU1. Using AZ Literature Mapper would help me more quickly to search for research articles on bioterrorism.
PU2. Using AZ Literature Mapper would be useful to help me search for research articles on bioterrorism.
PU3. Using AZ Literature Mapper would enhance my effectiveness in searching for research articles on bioterrorism.

Perceived Ease of Use (7-point Likert scale, ranging from strongly disagree to strongly agree) adapted from (Davis, 1989)
EOU1. I would find it easy to use AZ Literature Mapper to search for research articles on bioterrorism.
EOU2. Learning to use AZ Literature Mapper to search for research articles on bioterrorism would be easy for me.
EOU3. It would be easy for me to become skillful at using AZ Literature Mapper to search for research articles on bioterrorism.

Satisfaction (7-point Likert scale, ranging from strongly negative to strongly positive) adapted from (Bhattacherjee, 2001)
SAT1. Overall, my use of the search function of AZ Literature Mapper has left me feeling: Very dissatisfied/Very satisfied.
SAT2. Overall, my use of the search function of AZ Literature Mapper has left me feeling: Very displeased/Very pleased.
SAT3. Overall, my use of the search function of AZ Literature Mapper has left me feeling: Very frustrated/Very contented.
SAT4. Overall, my use of the search function of AZ Literature Mapper has left me feeling: Very terrible/Very delighted.

Intention of Use (7-point Likert scale, ranging from strongly disagree to strongly agree) adapted from (Bhattacherjee, 2001)
IOU1. If given the opportunity, I would use AZ Literature Mapper to search for research articles on bioterrorism in future.
IOU2. I intend to use AZ Literature Mapper rather than use any alternative means to search for research articles on bioterrorism in future.
IOU3. If I could, I would like to avoid using AZ Literature Mapper to search for research articles on bioterrorism in future.

Appendix B: Tasks Used in User Study 1

T1. "West Nile Virus" is an active research topic in human disease related bioterrorism domain. Please identify one research article related to this topic and write down the title of the article, the institution and country that published this article, and the publication year of it.

T2. Harvard University is an active institution in bioterrorism research domain. Please identify one research article published by Harvard University on bioterrorism, either human or animal disease related, and write down the title of the article, the author and the country that published this article, and the publication year of it.

T3. There is a research article talking about the threat of human bioterrorism disease, and it suggested that the medical community must educate both the public and policy makers about bioterrorism and build a global consensus condemning its use. The title of this research article is *Bioterrorism as a public health threat*. Please identify this paper and write down the author, institution, and country that published this article and the publication year.

T4. Bio-diseases might be used as bio-weapons in Bioterrorism. To understand and control the research status of bio-diseases can help to protect public health. Please identify one research article focusing on Anthrax, an acute human disease, published by Iran. Write down the author, institution, and country that published this article and the publication year.

T5. Foot-and-mouth disease (FMD) is one of the most devastating animal diseases. It occurs throughout the world and is a significant hazard to agriculture. In 2001, the epidemic in United Kingdom led to the loss of six million livestock. Please identify one research article published by United Kingdom after year 2001 (2001 excluded), talking about FMD. Write down the title of the article, the institution and country that published this article, and the publication year of it.

T6. Stanford University is one of the most prestigious universities in the world with a large number of publications each year. Please identify one research article related to human bioterrorism disease which was published by Stanford University in year 2005. Write down the title of the article, the institution and country that published this article, and the publication year of it.

Appendix C: Summary of Representative Comments by Subjects in the search function evaluation study

Search System	Comments	
	Pros	**Cons**
Arizona Literature Mapper	"The overall system is very useful to people when needing information about bioterrorism."	"I didn't like the format of viewing the detailed portions of the articles."
	"I found that this search function was fast and very helpful."	"I didn't like the fact you need to select an article. (better on PubMed)"
	"The interface was easy to use and very easy to understand. The minimal display of results was nice too."	"I kept going back to make sure I spelled everything correctly. It was a little frustrating."
	"I enjoyed finding articles, which I have been doing for many years, and find this information very helpful."	"The separation between humans and animals in search is a little unpleasing."
	"I liked this system better. Mainly because the human and animal diseases are separated. Also, the search page is clear and easier to use when trying to search indepth topics."	
	"The system was user friendly. And it was easy to narrow down searches."	
	"It was a very easy and quick system to use, and I would use it in the future if need be."	
	"Very useful for searching bioterrorism articles."	
	"Easier to get a condensed list of articles."	
PubMed	"The system was hard to use at first. But once you understand what you are doing, it becomes pretty easy."	"I use PubMed at my job to search for medical articles, and it helps for that. However, searching for bioterrorism articles is more helpful on Arizona Literature Mapper."
	"I would use PubMed for categorized searches."	"It was more difficult to use and narrow down a search."
	"I think it was more effective altogether."	"Much more complicated. Many features I didn't use."
	"PubMed would search for articles published in (place) + not about (place) if I simply typed it in the search field, using PubMed was very easy + useful."	"The interface wasn't as straight forward as the first (Arizona Literature Mapper)."
	"Overall found a lot of articles."	"The advanced search option in PubMed was not easy to use."
	"This search engine provides relatively more information."	"I had a little bit of hard time to get used to it."
		"Not as easy to use as Arizona Literature Mapper."

Appendix D: Tasks Used in User Study 2

T1-T6 are on research productivity.
T1. Please find and write down the names of the 5 most productive countries (with the largest numbers of research publications) related to human bioterrorism agents/diseases.

T2. Please find and write down the names of the 5 most productive countries (with the largest numbers of research publications) related to animal bioterrorism agents/diseases.

T3. Please find which of the following institutions are among the 20 most productive institutions (with the largest numbers of research publications) related to human bioterrorism agents/diseases.
Cornell University, University of California-Davis, Johns Hopkins University

T4. Please find which of the following institutions are among the 20 most productive institutions (with the largest numbers of research publications) related to animal bioterrorism agents/diseases.
Cornell University, University of California-Davis, Johns Hopkins University

T5. Please find and write down the names of the 5 most productive researchers (with the largest numbers of research publications) and their institutions related to human bioterrorism agents/diseases.

T6. Please find and write down the names of the 5 most productive researchers (with the largest numbers of research publications) and their institutions related to animal bioterrorism agents/diseases.

T7-T9 are on collaborations.
T7. Please find the largest research collaboration group on Anthrax (a human bioterrorism agent/disease), and write down the names of 3 researchers among the group.

T8. Please find the largest research collaboration group on Avian Influenza (an animal bioterrorism agent/disease), and write down the names of 3 researchers among the group.

T9. Please find the largest research collaboration group on human bioterrorism agents/diseases in state sponsors of terrorism, and write down which countries the members of the group are from.

T10-T12 are on trends in bioterrorism research.
T10. Please find the largest research collaboration group on animal bioterrorism agents/diseases in state sponsors of terrorism, and write down which countries the members of the group are from.

T11. Please find and write down 3 emerging research topics in human bioterrorism agents/diseases research after the year 2001.

T12. Please find and write down 3 emerging research topics in Avian Influenza (an animal bioterrorism agent/disease) related research after the year 2001.

Appendix E: Summary of Representative Comments by Subjects in the analysis functionality evaluation study

Comments	
Pros	**Cons**
“Much easier to use than expected.”	"Only did not understand the last (function). Otherwise very pleased."
“This website was easy and efficient for this research topic.”	"The pictures should be made larger."
“Very nice and well developed.”	"Need a legend to read the diagrams made."
“Very easy to use and understand. Can navigate quickly through site without hassle. I would be interested to fully explore how well it works.”	"Confusing at first if you don't know what services it provides."
"Once I used to how to use the site, I worked well."	
“Very organized!”	
“Organized and has up-to-date information. It was very user-friendly.”	
“Obviously the best source for this sort of information.”	
“I would recommend Arizona Literature Mapper because it was quick, easy to figure out and overall convenient.”	
“Easy to use interface and navigation.”	

Table 1. Results of hypotheses testing for hypothesis 1 through 6 in the search function evaluation study.

Hypothesis	*p* value	Result
H1. Users are more likely to successfully complete their search tasks when using Arizona Literature Mapper than PubMed.	0.0007**	Supported
H2. Users can successfully complete their search tasks faster when using Arizona Literature Mapper than PubMed.	<0.0001**	Supported
H3. Users will perceive Arizona Literature Mapper to be more useful than PubMed.	<0.0001**	Supported
H4. Users will perceive Arizona Literature Mapper to be easier to use than PubMed.	<0.0001**	Supported
H5. Users' satisfaction with Arizona Literature Mapper is higher than that with PubMed.	<0.0001**	Supported
H6. Users' intention to use Arizona Literature Mapper is higher than that for PubMed.	<0.0001**	Supported

Note. Significance levels * α = 0.05 and ** α = 0.01.

Table 2. Effectiveness and efficiency of the two search systems in the search function evaluation study.

Search System	Measure	Mean Performance	Std. Deviation
Arizona Literature Mapper	Effectiveness	85.76%	33.71%
	Efficiency	2.88	1.32
PubMed	Effectiveness	78.00%	39.43%
	Efficiency	4.41	2.24

Note. The performances of the six search tasks were averaged.
Effectiveness was measured as accuracy. Efficiency was measured in minutes.

Table 3. Results of users' subjective ratings on the two search systems in the search function evaluation study.

	Arizona Literature Mapper		PubMed	
Dimension	**Mean Rating**	**Std. Deviation**	**Mean Rating**	**Std. Deviation**
Perceived usefulness	6.16	0.99	3.96	1.88
Perceived ease of use	6.50	0.72	4.00	2.04
Satisfaction	5.81	1.04	3.79	1.78
Intention to use	5.76	1.46	3.35	2.04

Note. The range of rating is from 1 to 7 with 7 being the best.

Table 4. Results of users' subjective ratings on the analysis functions of Arizona Literature Mapper in the analysis functionality evaluation study.

	Arizona Literature Mapper	
Dimension	**Mean rating**	**Std. deviation**
Perceived usefulness	4.88	1.47
Perceived ease of use	4.73	1.56
Satisfaction	4.50	1.12
Intention to use	4.32	1.67

Note. The range of rating is from 1 to 7 with 7 being the best.

Table 5. Results of hypotheses testing for hypothesis 7 through 10 in the analysis functionality evaluation study.

Hypothesis	*p* value	Result
H7. Subjects perceive positively the usefulness of Arizona Literature Mapper's core analysis functionalities.	<0.0001**	Supported
H8. Subjects perceive positively the ease of use of Arizona Literature Mapper's core analysis functionalities.	0.0002**	Supported
H9: Subjects are satisfied with Arizona Literature Mapper's core analysis functionalities.	0.0002**	Supported
H10: Subjects exhibit favorable intention to use Arizona Literature Mapper's core analysis functionalities in the near future.	0.0493*	Supported

Note. Significance levels * $\alpha = 0.05$ and ** $\alpha = 0.01$.

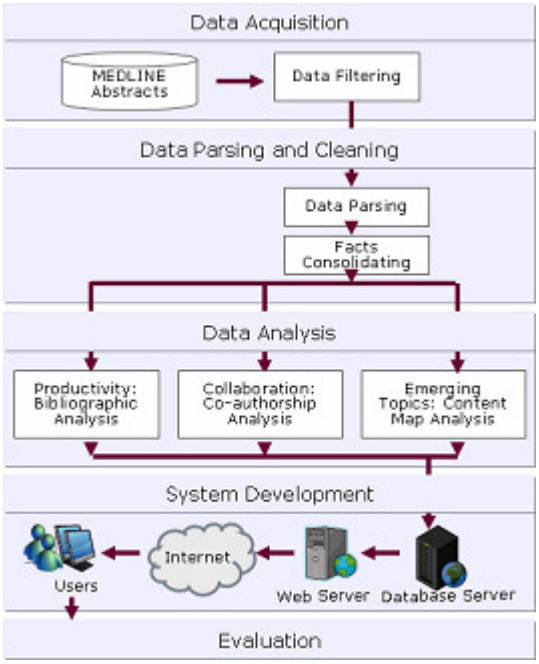

Figure 1. System design of Arizona Literature Mapper

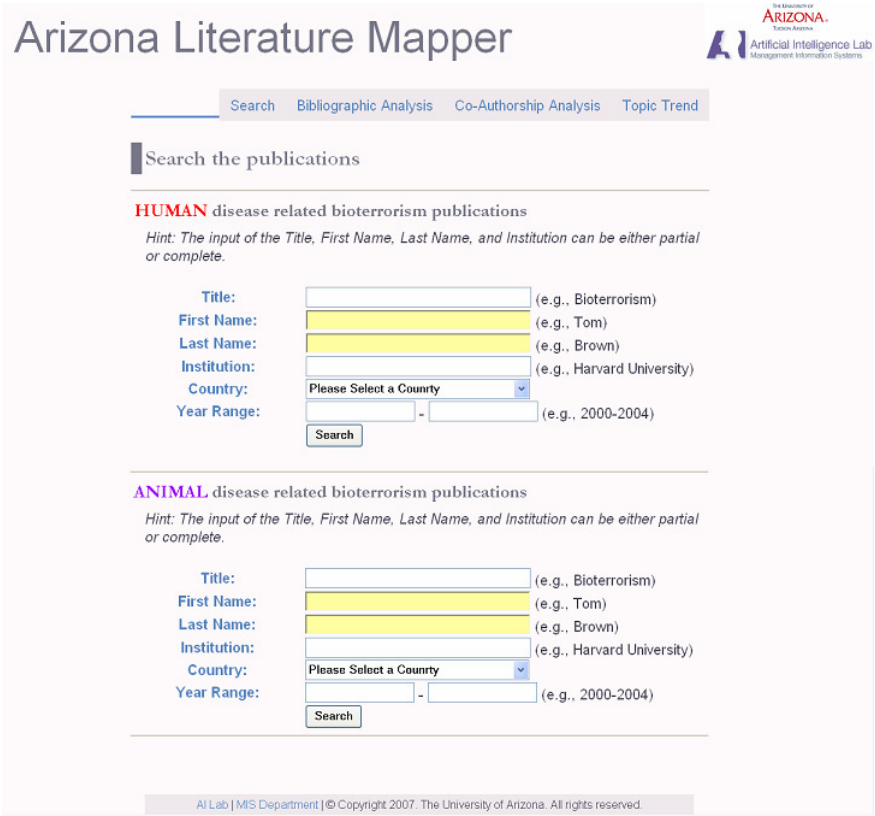

Figure 2. Search function of Arizona Literature Mapper

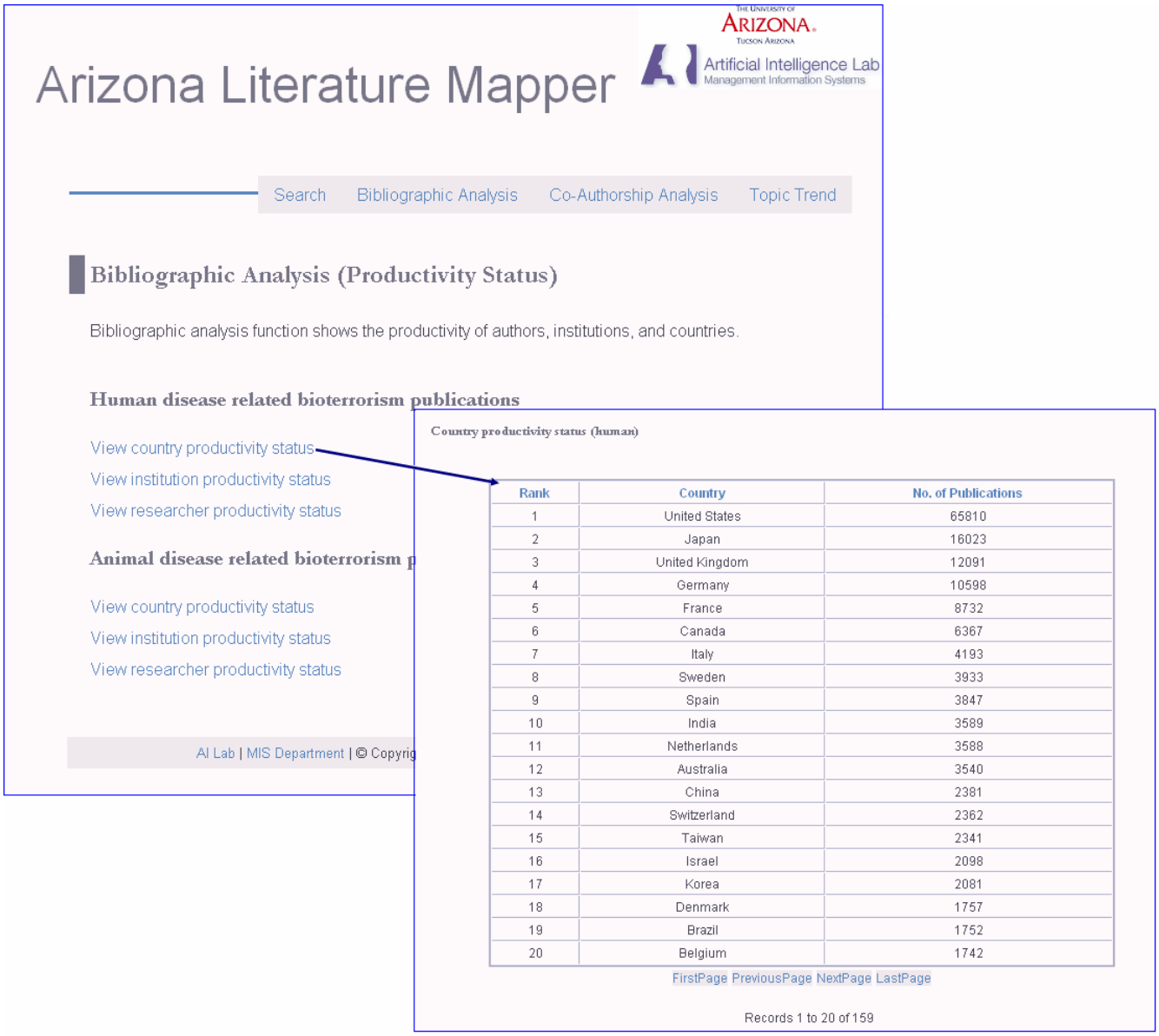

Figure 3. Screenshots of country productivity status on human disease research

This is a preprint of an article forthcoming in the Journal of the American Society for Information Science and Technology, 2009

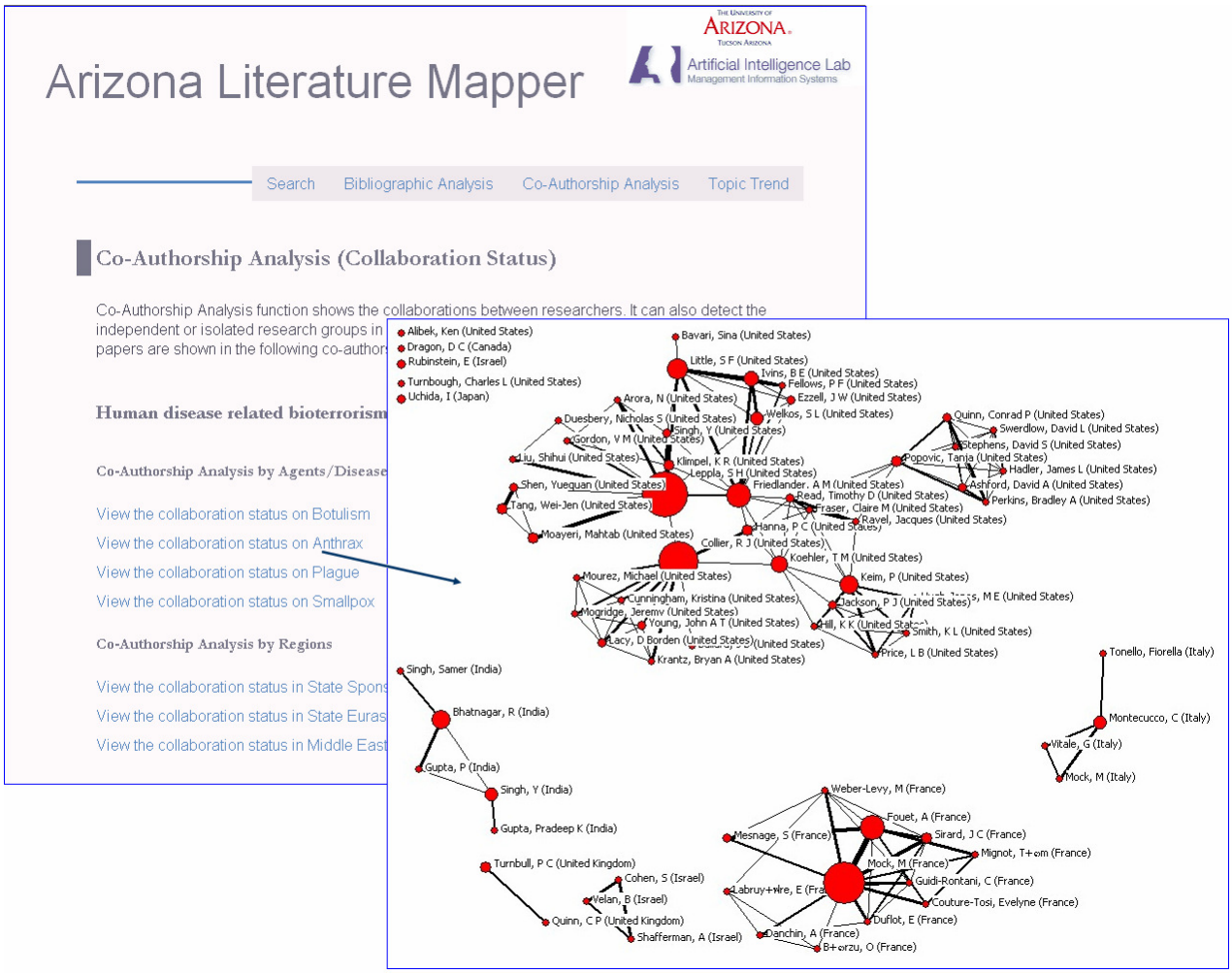

Figure 4. Screenshots of collaboration status of researchers on Anthrax

This is a preprint of an article forthcoming in the Journal of the American Society for Information Science and Technology, 2009

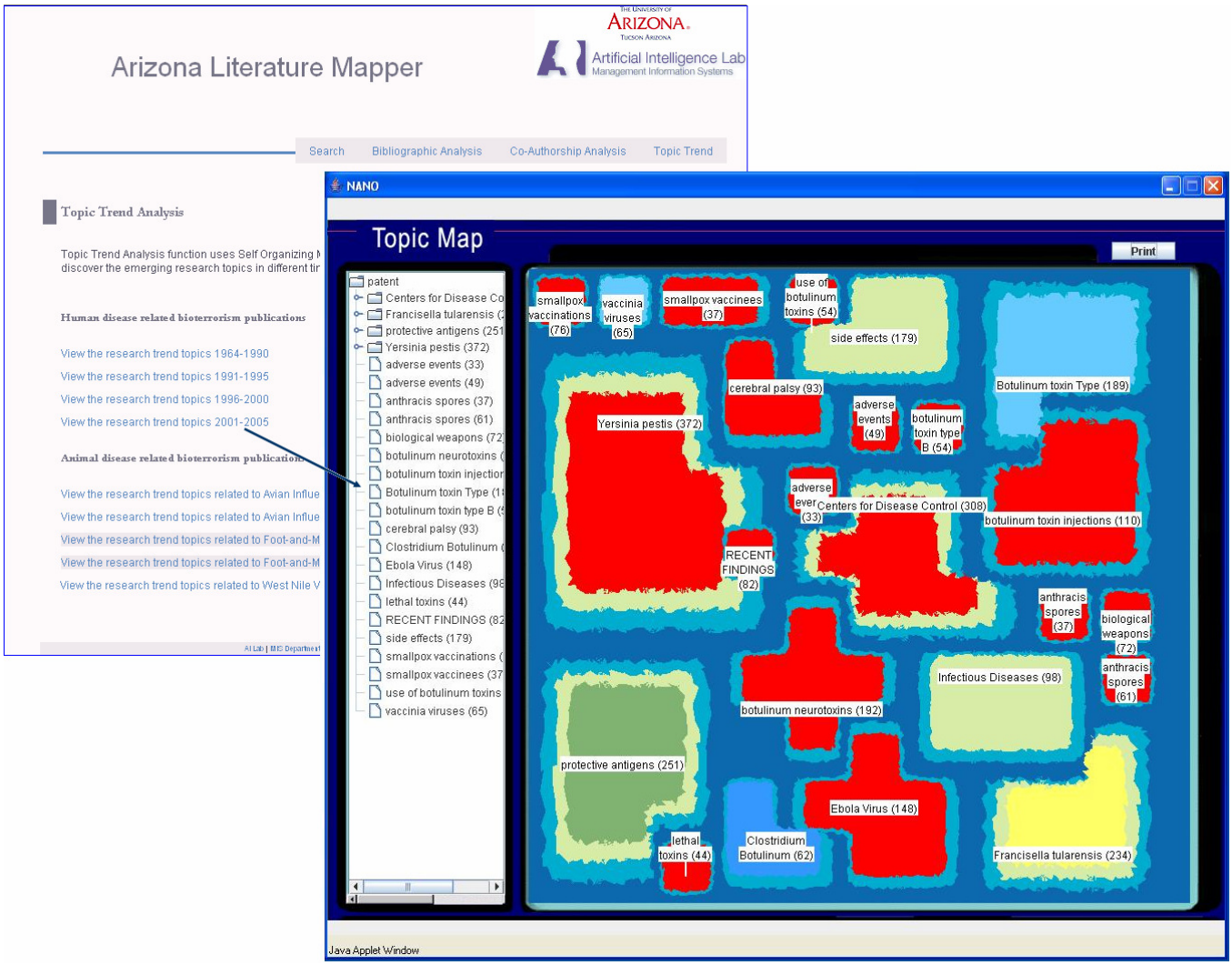

Figure 5. Screenshots of the hot and emerging research topics in human disease research from 2001 to 2005