REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
17-12-2007

2. REPORT TYPE
FINAL

3. DATES COVERED *(From - To)*
01-10-2004 - 31-03-2008

4. TITLE AND SUBTITLE
EWall - Electronic Card Wall:
Computational Support for Decision-Making in Collaborative Environments

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-04-1-0569

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
PAUL KEEL

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY
77 MASSACHUSETTS AVENUE, BUILDING 32, CAMBRIDGE, MA 02139

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
OFFICE OF NAVAL RESEARCH
ATTN: MICHAEL LETSKY, ONR CODE 341
ONE LIBERTY CENTER
875 NORTH RANDOLPH STREET, SUITE 1425
ARLINGTON, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified, Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Our work focused on conceiving and prototyping technologies for supporting individual and collaborative sense-making activities in distributed and decentralized work environments. We developed an experimental computational environment referred to as the EWall system. The EWall system is designed to be used for users to conduct, for researchers to investigate, and for computational systems to support individual and collaborative sense-making activities. The EWall system engages users in the visual organization of information through the spatial arrangement and modification of graphical objects. Computational agents infer from spatial information arrangements and the collaborative use of information as a basis for directing the flow of information among collaborating users and computational systems. The goal of the agents is to direct the distribution of information in ways that brings together people with complementary backgrounds, expertise, interests and objectives and that improves team shared understanding. Individual agents represent unique cognitive and collaborative concepts, combine their analyses, and autonomously adapt to particular users, tasks and circumstances. The primary contribution of this work lies in the design of concepts and mechanics that enable a noninterruptive interchange of contextual discoveries between humans and computational systems.

15. SUBJECT TERMS
Collaboration, Knowledge Interoperability, Knowledge Management, Distributed Cognition, Interpretation, Sense-Making, Computational Agents, EWall

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	24	PAUL KEEL 617 252 1866

Reset

EWall - Electronic Card Wall
Computational Support for Decision-Making in Collaborative Environments

Final Report
Grant Number: N000140410569
December 2007

Submitted to:

Office of Naval Research
Life Sciences Division
One Liberty Center
875 North Randolph Street, Suite 1425
Arlington, VA 22217-5660

Principal Investigators:

Patrick H. Winston, Ford Professor of Artificial Intelligence and Computer Science
Massachusetts Institute of Technology
Computer Science and Artificial Intelligence Laboratory
The Stata Center, Building 32, Room 251
32 Vassar Street, Cambridge, MA 02139, USA
phw@mit.edu

William Lyman Porter, FAIA, Leventhal Professor of Architecture and Planning
Massachusetts Institute of Technology
Design and Computation Group
Building 9, Room 224
77 Massachusetts Avenue, Cambridge, MA 02139, USA
wlporter@mit.edu

Project Manager:

Paul Keel, PhD
Massachusetts Institute of Technology
Computer Science and Artificial Intelligence Laboratory
The Stata Center, Building 32, Room 258
32 Vassar Street, Cambridge, MA 02139, USA
keel@mit.edu

TABLE OF CONTENTS

1. SUMMARY

Our work focused on conceiving and prototyping technologies for supporting individual and collaborative sense-making activities in distributed and decentralized work environments. We developed an experimental computational environment referred to as the EWall system. The EWall system is designed to be used for users to conduct, for researchers to investigate, and for computational systems to support individual and collaborative sense-making activities. The EWall system engages users in the visual organization of information through the spatial arrangement and modification of graphical objects. Computational agents infer from spatial information arrangements and the collaborative use of information as a basis for directing the flow of information among collaborating users and computational systems. The goal of the agents is to direct the distribution of information in ways that brings together people with complementary backgrounds, expertise, interests and objectives and that improves team shared understanding. Individual agents represent unique cognitive and collaborative concepts, combine their analyses, and autonomously adapt to particular users, tasks and circumstances. The primary contribution of this work lies in the design of concepts and mechanics that enable a non-interruptive interchange of contextual discoveries between humans and computational systems.

In this report, we discuss the objectives underling the design of the EWall system, explain user interfaces and agent operations, and elaborate on how agents can support particular sense-making processes. Furthermore, we reference publications resulting from this effort, highlight potential benefits four our technologies, and inform about the current implementation status of our software prototype.

2. CHALLENGES

The creative and incremental discovery of relationships among pieces of data, information and knowledge is commonly referred to as sense-making. Typical sense-making tasks such as brainstorming, decision-making and problem-solving include the collection and visualization of task-relevant information, the analysis and comprehension of information, and the subsequent investigation of possible solutions and strategies. Sense-making produces new knowledge through the application of existing knowledge and information to unique situations, tasks and circumstances. The successful execution of sense-making tasks not only depends on the creative interpretation and application but also the availability, fast accessibility and diversity of knowledge and information. Thus, sense-making tasks are commonly conducted in groups of people with different backgrounds and expertise as well as through the use of computational tools for the search, visualization and organization of information. The challenge is to effectively coordinate available knowledge and information as well as to bring together the human capacity for intuitive problem solving and the computer's capability for processing and visualizing large amounts of information.

The key problem in regards to sense-making activities is that a lot of knowledge is processed in the minds of humans and thus remains invisible to collaborators, observers, and computational systems. The externalization of knowledge and exchange of information among humans and computational systems is often time-intensive and interruptive. This is particularly true for the early stages of sense-making processes where individuals explore the availability and location of task-relevant knowledge and information. Commonly, sense-makers bypass this problem by collaborating with people they previously collaborated with and by accessing information from known sources. This approach has become ineffective within the highly dynamic, de-centralized, globally distributed, and information loaded environments enabled by information technologies. Individuals increasingly collaborate asynchronously and remotely, contribute to multiple tasks and work groups simultaneously, dynamically regroup based on their availability and expertise, and deal with large amounts of heterogeneous, distributed and dynamically changing information. To deal with these challenges it is necessary to explore new means for helping sense-makers to effectively coordinate and harvest the knowledge and experience of humans and computational systems.

The EWall system was designed in response to these challenges and provides a basis for the observation of decision-making processes, the demonstration and comparison of current and new decision-making processes, as well as the implementation and testing of intelligent computational agents for the support of decision-making processes. The following chapter introduces and explains essential components, functions and concepts of the EWall system.

Note: Some of the function and agents described in this report have not yet been implemented. Eight character codes in brackets (XX-XXX-XXX) provide references to Appendix B where detailed information about the implementation status of individual functions and agents can be found.

3. APPROACH

This section introduces objectives, concepts and implementations relevant for understanding the EWall system as a means to explore and support cognitive and collaborative sense-making activities. The section on the “EWall User Interface” introduces technologies for users to conduct and for researchers and computational agents to monitor sense-making activities. The section on the “EWall Agent System” details the utilization of computational agents for representing and supporting particular sense-making processes.

3.1. EWall User Interfaces

Sense-making activities commonly accumulate large amounts of data, information and knowledge, a lot of which is represented through external visual representations such as notes, graphics, diagrams, sketches, and documents. Sense-makers develop a contextual understanding through the decomposition, combination, comparison, organization and analysis of such representations. The external representation and visual organization of information reduces the cognitive burden by helping sense-makers to comprehend, evaluate and reflect on what they know, to quickly access specific information when needed, to remember relevant thoughts and ideas, as well as to exchange knowledge and develop a shared understanding with other people. The primary problem with the external representation and visual organization of information is that relevant information is commonly extracted from different sources, represented in different formats, and stored in different locations (Marshall 2005). For example, an idea may be written down on a Post-It, a hyperlink may be stored in the bookmark section of a web browser, an email may be copied into a mailbox of a mail handler, and a digital text document may be stored in a shared file system on a server. Effective sense-making requires people to quickly compare and relate task-relevant information items uninfluenced and unhindered by information formats and locations. The EWall user interfaces are designed to help people quickly collect, organize and compare pieces of information.

3.1.1. Cards

The EWall system allows for the external representation of data, information and knowledge in a standardized and visually abstract format referred to as Cards (Figure 1, Layout). Cards help users to quickly overview, compare, organize and contextualize information (Robertson et al. 1998) as well as to memorize and recall associated contents. Cards are intended to remind of information rather that to present information in detail. In other words, Cards are supposed to omit all information that is unnecessary to compare Cards or to remember the contents associated with Cards. The object-like nature of Cards is intended to engage a human’s cognition in ways that allows for the processing of large amounts of information (Byrne 1993; Marcus, 2003) and that enables people to think of information as something more tangible and personal that they can possess, understand, collect, trade, and exchange (Winnicott 1982).

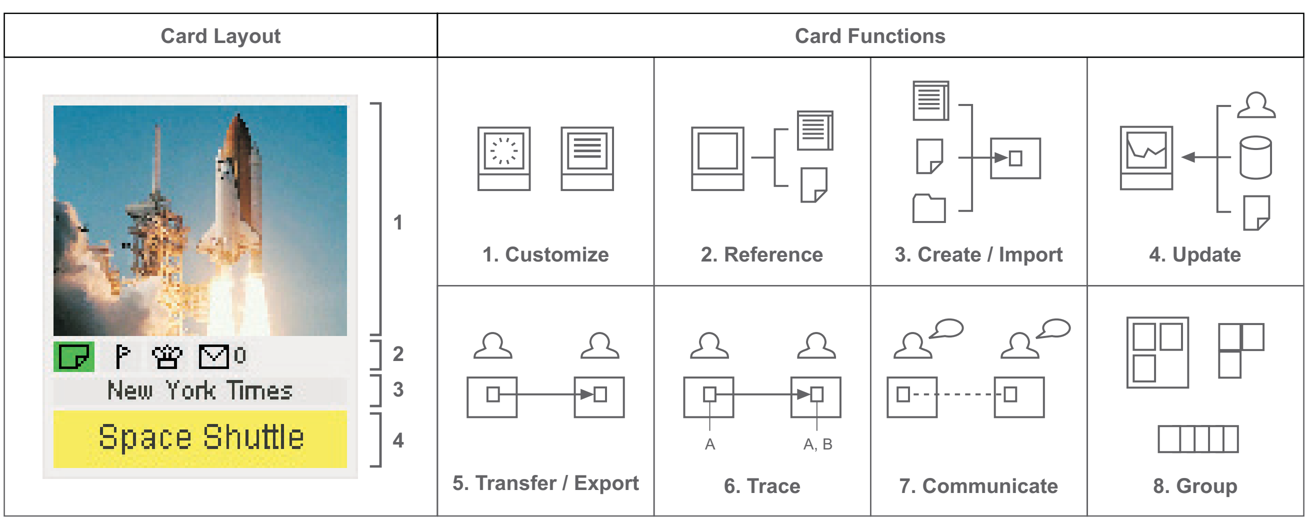


Figure 1: Card Layout (Left) and Functions (Right)

The Card layout consists of four components (Figure 1, Left):

1. The Icon Area allows for the placement of a representative picture and/or descriptive text to support the easy memorization and recollection of the information referenced by a Card (Lewis et al. 2004; Pena and Parshall 2001).
2. The Function Area contains the Card's control panel allowing users to monitor Card states and to operate Card functions such as instant messaging and voting.
3. The Information Area is used to display secondary Card information such as document type, modification date, author name, and geographic location.
4. The Heading Area allows for the placement of a keyword or a heading which provides an additional and complementary option for the access, memorization and recollection of Card contents (Haramundanis 1996).

Cards combine a large amount of functionality with intuitive operations. The following list outlines a selection of essential Card features (Figure 1, Right):

1. The Card layout and functions are customizable allowing individual users to view shared information in a familiar format as well as to complement Cards with custom functionality for particular work tasks (CF-G01-SKI). For example, information may be represented with very small Cards that only display an Icon and a Function Area and that include a custom function for the categorization of Card contents.
2. Users can hyperlink information to Cards (CF-L01-HYP, CF-L02-ATT). A mouse-click on a Card can open a web page, a file, a folder, or an executable. This particular option allows users to easily manage information in different formats and locations.
3. Cards can easily be created and imported (CF-G03-IMP). Information (such as web sites or files) to be displayed, embedded, or hyperlinked can simply be dropped onto Cards or the EWall interface. Cards can also be copied from other users and EWall interfaces. The small effort involved in creating and importing Cards encourages and simplifies the external representation of knowledge and allows users to combine and compare their contributions with information from other sources.
4. Cards can be static or dynamically adapt modifications from remote information sources (CF-L03-DYN). For example, a Card may synchronize itself with a Card on another user's EWall interface, a Card in a database, or an Internet based resource such as security camera, weather forecast, stock quote or news update. The dynamic nature of Cards is essential for user to deal with the decreasing permanency of information as well as to remain responsive to changing circumstances.
5. Cards are not confined to one particular location but can be transferred among different user interfaces and computer applications (CF-G02-EXC, CF-G06-SHA). For example, users can remotely collaborate in the development of a Card arrangement by copying Cards between their individual or shared interfaces. Cards can also be converted into files and transferred through traditional means such as file sharing and email.
6. Cards maintain a log about where they have been, by whom they have been modified, and what other Cards they encountered on their journeys (CF-L04-HIS). This information helps researchers and computational systems analyze the history and collaborative use of information.
7. Users can remotely discuss Card contents through a Card's instant messaging feature (CF-L05-INS). A Card indicator informs of instant messaging activity thus allowing users to easily monitor and simultaneously participate in a large number of discussions on different subjects and with different groups of users.
8. Cards can be grouped and hierarchically structured by placing Cards within the spatial boundaries of bigger Cards (CF-G04-GRO). Furthermore, a magnet function automatically joins together Cards that overlap or are being positioned in close proximity (CF-G05-MAG). This particular functionality allows users to group Cards in absence of visual indicators. Cards that are grouped or hierarchically structured automatically attach to each other so they can be moved and manipulated as a unit.

3.1.2. Workspace View

The Workspace View (Figure 2 and 3) is a canvas for the creation and spatial organization of Cards. The spatial positioning of Cards on the Workspace View suggests a dependable reference system that helps users distinguish, relate and establish the relative importance of information items as well as to develop a contextual understanding of an information space (Kirsch 1995; Pena and Parshall 2001). A collaboratively developed Card arrangement additionally serves as a shared representation or group memory that can enhance group interaction and shared understanding (Pena and Parshall 2001). The Workspace View reduces the cognitive burden by enabling users to externally consolidate, spatially arrange and comprehend task-relevant information (Figure 2 Arrow 1). The use of the Workspace View also presents an opportunity for observers, researchers and computational systems to harvest valuable clues about a user's mental consideration, knowledge, expertise and foci during sense-making activities without establishing a direct and potentially distracting and time-consuming dialogue with the users (Figure 2 Arrow 2). For example, recently modified Cards might indicate the current focus of attention while Cards in close spatial proximity might hint discovered relationships. Furthermore, the transfer of Cards between users and user interfaces provides hints about the evolution and collaborative use of information which allows for various investigations such as the determination of shared understanding, mutual interests and distributed cognition.

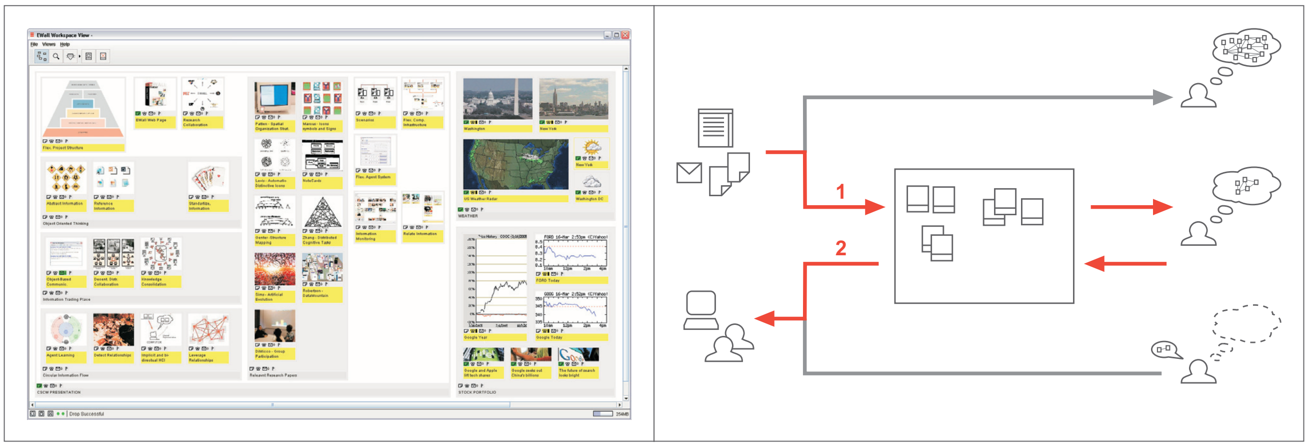


Figure 2: Workspace View

3.1.3. Kiosk View

The Kiosk View (Figure 3) provides users access to information from internal and external information sources such as information available on web sites, in databases or the Workspace Views of other users. The Kiosk View represents all information as Cards and offers a variety of visualization options that help users estimate the relevance and discover relationships among information items, learn about other users that may be able to provide expertise on subjects of current consideration, or explore the shared use of information during collaborative sense-making activities. Cards of interest can be copied from the Kiosk View to the Workspace View for further consideration and comparison with previously accumulated information.

3.2. EWall Agent System

Sense-making depends on an effective exchange of knowledge and information among humans and computational systems. The goal of the EWall agent system is to help individual users navigate vast amounts of shared information effectively and remotely dispersed team members combine their contributions, work independently without diverting from common objectives, and minimize the necessary amount of verbal communication. The key challenge for the agent system lies in determining who needs to know what and from where or whom this information may be acquired. More specifically, the agent system must learn about the expertise, knowledge and task foci of individuals as a basis for effectively managing the flow of knowledge and information among users as well as users and computational systems.

The agent system is managed by two types of computational agents (Figure 3): Interpretation Agents (Chapter 3.2.1) and Transformation Agents (Chapter 3.2.2). Interpretation Agents unobtrusively capture some of the users' mental considerations by inferring from the spatial and temporal organization and collaborative use of information on the users' Workspace Views. Interpretation Agents also synchronize and combine the contributions of multiple users in a shared database. Transformation Agents analyze the database contents as a basis for directing the flow of information among collaborating users and for bringing together people with complementary backgrounds, expertise, interests and objectives. Transformation Agents communicate their conclusions by providing individual users with a customized selection of potentially task-relevant information in their Kiosk Views. In other words, Transformation Agents do not directly communicate their analyses with users but only adjust the flow of information so as to influence the sense-making process in ways that facilitates collaboration and information sharing. Users may copy information from their Kiosk Views to their Workspace Views thus providing the agent system with feedback about its performance and subsequently trigger additional suggestions based on similar considerations. Agents responsible for correctly determining information of interest for particular users become more influential during subsequent iterations. The dynamically changing influence of individual agents allows the agent system to improve the accuracy of its suggestions as well as to incrementally adapt to particular tasks, users and circumstances. The influence of individual agents is temporary meaning that past successes of agents are only recognized for a certain amount of time. This is to ensure that the system remains adaptive to new users and agents as well as to allow for a more active participation of agents that represent less commonly used concepts.

Every agent emulates one unique intuitive or explicit human sense-making activity. For example, one agent might focus on collecting contributions from people that have made effective contributions in the past. This particular activity reflects a typical human response in dealing with information uncertainty yet might contradict with various other considerations (represented by other agents) such as, for example, whether the contributor's expertise corresponds with a particular problem domain. The collective application of multiple agents may lead to incompatible results that subsequently require a conflict-resolution strategy. The agent system offers several conflict resolutions options: By default, the agent system favors complementary conclusions shared by the majority of agents. System operators may manually adjust the influence of particular agents over other agents. Alternatively, the agent system can automatically adjust the influence of individual agents based on indirect user feedback (the adaptation of Cards from the Kiosk Views). This process offers similarities with the human mind where different evaluation methods are considered based on past experiences.

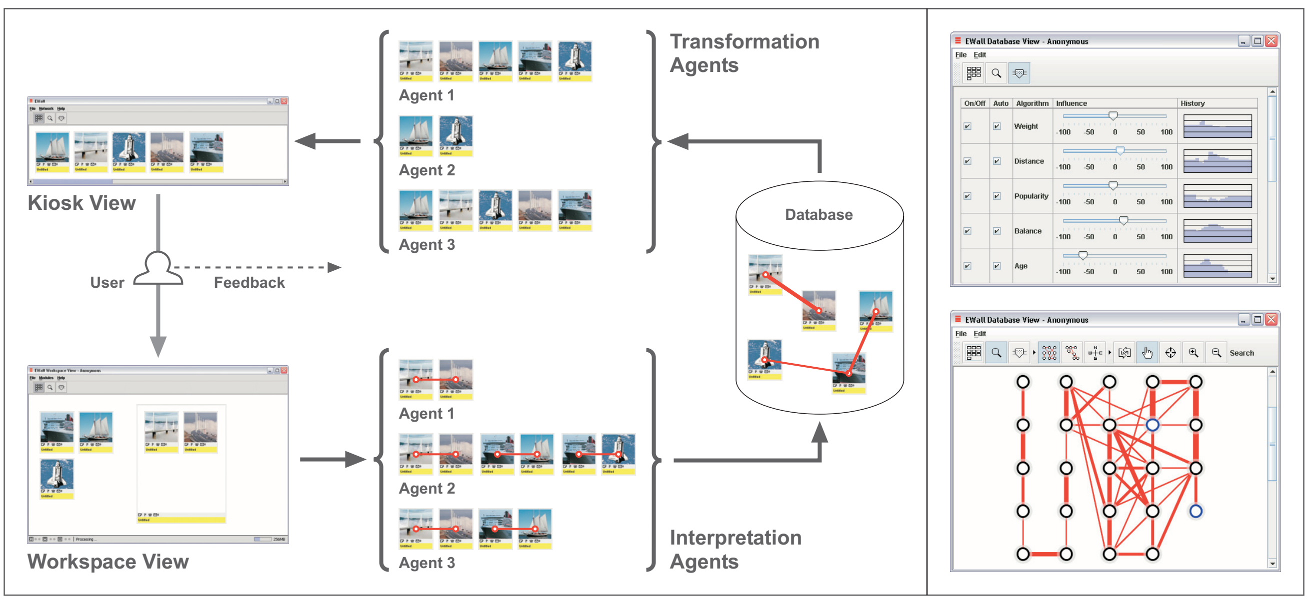


Figure 3: Agent System (Left: Information Flow; Right: Administrator Interfaces)

3.2.1. Interpretation Agents

Interpretation Agents are responsible for creating and maintaining a network of relationships among Cards in EWall's database. The network of Cards emerges and dynamically changes with every new addition. Every Card in the database may be associated with other Cards, authors, modification dates, documents, and geographic locations. The task of the Interpretation Agents is to collect Cards from the Workspace Views of users, create relationship among Cards, and save the Cards and relationships to the database. Relationships among Cards reflect human mental considerations that can be inferred through the users' spatial and temporal organization and collaborative use of Cards. Every individual Interpretation Agent specializes in creating one particular type of relationship. For example, one Interpretation Agent might establish a relationship between two Cards because the two Cards have been positioned in close proximity on a user's Workspace View. Another Interpretation Agent might create a relationship between two Cards that were created during similar time frames. Yet another Interpretation Agent might create a relationship between a Card pair that is used by multiple users. As individual Interpretation Agents focus on specific aspects only the combination of multiple Interpretation Agents may produce a particular result.

Figure 4 compares a Card arrangement as seen by the users with a Card arrangement as seen by the Interpretation Agents. The relationships created by the Interpretation Agents are not meant to be seen by the users but exclusively used to structure the database contents. Contradictory relationships conceived by different Interpretation Agents are not resolved but are added to the database assuming that at a later point in time the accumulation of additional relationships will put an end to the conflict. Consider, for example, an assembly of objects separated into three groups. Each group contains red and white objects. One Interpretation Agent could consider relationships among objects of equal color while another Interpretation Agent could recognize relationships based on the grouping of the objects. The Interpretation Agents do not have the capability to determine whether neither, only one or both assumption are true but simply add their concluding relationships to the database with the anticipation of other Interpretation Agents supporting their assessments in the future. Consequently, the database is an assembly of both, conceivably correct and conceivably incorrect relationships. Interpretation Agents can construct either dynamic or static relationships. Dynamic relationships reflect the current state of the database and are reevaluated after every event. Static relationships accumulate over time and never change or expire. Thus, the sum of all static relationships represents a database's history or long-term memory while the sum of all dynamic relationships represents a database's current state or short-term memory. The number of relations between two Cards can increase over time consequently producing varying weights (strength, importance) among the relationships between different Card pairs. Every weight change may affect the network balance in part or as a whole. Equivalent relationships conceived by multiple Interpretation Agents are likely to become more influential within the database.

The design of our Interpretation Agents emerged from a variety of cognitive and psychological theories and observations. We implemented an initial set of Interpretation Agents that primarily create relationships based on the spatial and temporal organization of Cards. We decided on a selection of Interpretation Agents that reflect human mental considerations during sense-making activities, take advantage of our computational infrastructure, make a unique contribution, and demonstrate compatibility with other methods for creating relationships among information items such as, for example, the semantic comparison of information contents (Foltz, 1996) or the analysis of information access patterns (Sarukkai, 2000). Our Interpretation Agents have not yet been tested for their effectiveness and were primarily deployed to ensure the proper operation of our computational infrastructure as well as to demonstrate the integration and utilization of Interpretation Agents.

A first group of Interpretation Agents focuses on detecting implicit relationships among spatially arranged Cards and is inspired by Wertheimer's (2000) research on perceptual organization. Wertheimer's work provides valuable insights into how humans perceive relationships among spatially arranged objects and suggests a set of eight factors that influence our cognitive perception when considering relationships among objects. The "Factor of Proximity" (IA-I01-PRO) suggests the emergence of relationships among objects in close spatial proximity. The "Factor of Direction" (IA-I02-DIR) proposes relationships among a sequentially aligned sequence of objects such as, for example, an alignment of objects in rows or columns. The "Factor of Objective Set" (IA-I03-OBJ) considers the human ability to remember incremental changes to an arrangement of objects and suggests that previously perceived relationships among objects may dominate even after the emergence of contradictory perceptual concepts. The "Factor of Closure" (IA-I04-CLO) focuses on the visual recognition of object clusters. Object clusters commonly emerge through the spatial grouping of information based on specific criteria. The "Factor of Similarity" (IA-I05-SIM) refers to the emergence of relationships among similar looking objects. Color, shape and iconographic representations are among the most influential aspects in regards to this particular perceptual concept. The "Factor of Common Fate" (IA-I06-COM) deals with the effects and the resolution of conflicting perceptual concepts. For example, two objects might be in close proximity yet offer distinct differences in their visual representation. The "Factor of Past Experience" (IA-I08-PAS) elaborates on how a human's background might influence his/her visual perception. For example, people educated in western cultures develop a tendency to start exploring object arrangements from left to right and top to bottom. Finally, the "Factor of the Good Curve" (IA-I07-GOO) discusses the effects of visual ambiguities that may emerge through the intersection of object clusters or the shapes of empty spaces between object clusters. Our current collection of Interpretation Agents in this group establishes relationships between Cards based on Wertheimer's Factors of Proximity, Direction, Objective Set, Closure and Common Fate. We plan on implementing additional Interpretation Agents so as to be able to demonstrate and test all of Wertheimer's principles within the context of our computational environment. Subsequently we will consider complementing this group with Interpretation Agents that represent other research findings. For example, the work Albert Zobrist and William Thompson (1975) focuses on the recognition of object clusters and introduces concepts such as curvilinear continuity, good closure, and overall goodness grouping. Ullman (1966) investigated the cognitive perception of spatially arranged objects based on shapes and colors. Johnson (2001) introduced the concept of "habituation", the tendency to devote more attention to novel stimuli such as, for example, objects that have not been noticed previously, objects that appear suddenly, or objects that are located in odd or wrong locations.

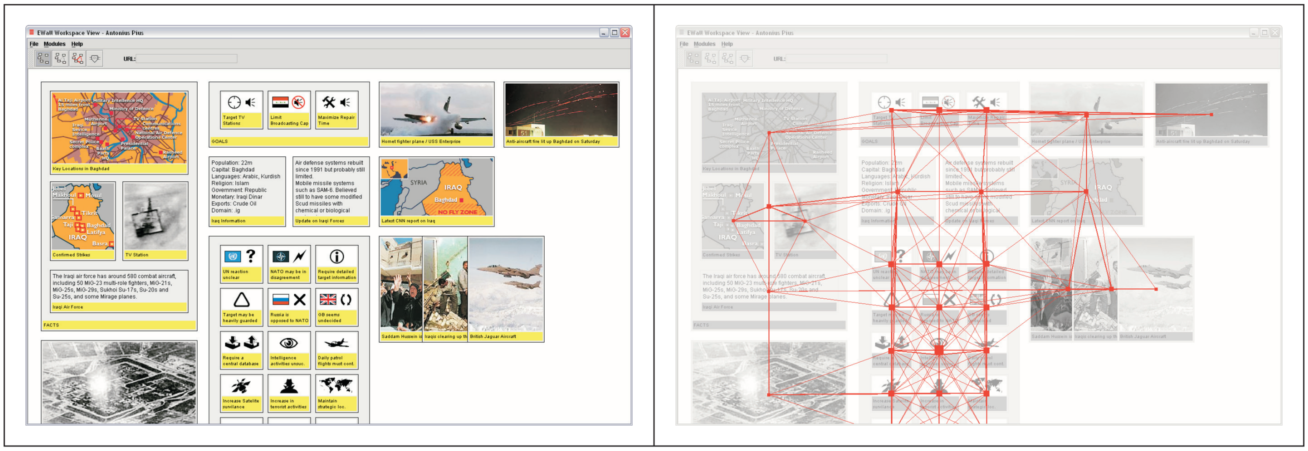


Figure 4: Generated relationships: Interpretation Agents infer possible relationships (right) among information items through the analysis of the spatial and temporal organization and collaborative use of information on the Workspace Views of individual users (left).

A second group of Interpretation Agents focuses on explicit relationships among spatially arranged Cards. Explicit relationships may be assumed among objects that are grouped with a bounding box (IA-E01-BOU), that are interconnected with rubber lines (IA-E04-LIN), that are stacked (IA-E03-SEQ), overlap or touch each other, and that are hierarchically organized in a file system. Our computational infrastructure provides users with some means to create explicit relationships. For example, multiple smaller Cards can be located within the spatial boundaries of a bigger Card (CF-G04-GRO). The corresponding Interpretation Agent (IA-E01-BOU) creates a hierarchy of relationships that reflects the spatial nesting of Cards. Furthermore, a magnet function (CF-G05-MAG) automatically joins together Cards in close proximity. This function allows users to group Cards in absence of visual indicators. The associated Interpretation Agent (IA-E02-MAG) creates a relationship for every joined Card pair. At present we refrain from offering functionality for interconnecting Cards with rubber lines. Such functionality can lead to a vast visual complexity that is often ineffective and confusing in dealing with information items during time-constrained and creative tasks (Prante, Magerkurth, Streitz, 2002).

A third and more experimental group of Interpretation Agents is currently in the design stage. These agents create relationships based on the analysis of previously created relationships (independent of external activity) and are primarily active during system idle times. For example, one of these Interpretation Agents randomly explores the network structure for weakly related Cards (Cards that only maintain few relationships with other Cards) (IA-P01-DIS). These Cards are temporarily related with more recent additions so as to stimulate their discovery. The goal of this particular Interpretation Agent is to ensure that past knowledge is not prematurely discarded as well as to instigate a more explorative discovery of information during sense-making activities. Another Interpretation Agent strengthens interconnections among heavily related network segments in the database (IA-P04-HIG). Imagine, for example, a heavily interconnected group of Cards that were created in relation to Apple stocks and another heavily interconnected group of Cards related to Microsoft stocks. If the Interpretation Agent were to detect a significant number of relationships that interconnect Cards in both groups then it would add one strong relationship (a so-called Highway) between the most heavily related Cards in each group. Subsequent database retrievals of Apple related information would subsequently become more likely to carry along information about Microsoft and vice versa. We also work on an Interpretation Agent that creates relationships among Cards in the database based on Card activity (IA-P03-FOO). Card activity is registered whenever a user selects a Card on his/her Workspace View, whenever a Card is added or modified in the database, or whenever a Card in the database is accessed, traversed or retrieved. Temporary relationships are created among Cards that experience activity during similar time frames. The goal of this Interpretation Agent is to foster a distribution of information that reflects and potentially intersects individual user foci. Yet another Interpretation Agent is specialized on creating shortcuts among indirectly related Cards in the database (IA-P02-SHO). For example, a sequential connection of Cards A, B, C and D could produce a relationship between Cards A and D. With this particular agent we expect to foster a more explorative retrieval of database contents that is less focused on strong or direct relationships among information items.

3.2.2. Transformation Agents

The Transformation Agents are responsible for providing individual users with a customized selection of potentially relevant information. The relevance of information is determined through the analysis and comparison of the contents in EWall's database and the contents on a user's Workspace View. Because EWall's database reflects and interrelates current and past contributions from different users it provides a rich source of information for Transformation Agents to learn about the knowledge and expertise of users, the current foci and interests of users, the interactions among users, as well as the collaborative use of information. Every individual Transformation Agent specializes on one particular aspect when determining the relevance of information. For example, one Transformation Agent might search the database for Cards that maintain relationships with Cards on the user's Workspace View. Another Transformation Agent might increase the relevance of Cards that were created by authors from whom the user previously copied Cards. The relevance of information does not necessarily satisfy the interests of one particular user but a community of collaborating users as a whole. For example, if a Card were to be used by all but one collaborating user then a particular Transformation Agent might increase the relevance of this Card for the one user who is not yet using this Card. The conclusions from multiple Transformation Agents are combined and the resulting selection and sequence of Cards sent to the user's Kiosk View. Hence, Transformation Agents do not directly communicate their conclusions with users but only adjust the flow of information so as to influence the sense-making process in ways that corresponds with the assigned objectives of individual agents.

We distinguish among three different groups of Transformation Agents: The first group (TA-C…) of Transformation Agents provides social networking services by distributing information in ways that facilitates team building as well as the convergence of individual user investigations and foci. These agents categorize Cards based on a verity of analyses such as, for example, the detection of Cards that are exchanged or shared among different users, the examination of similarities among Card arrangements, the analysis of the organization and modification frequencies of Card arrangements, as well as the evaluation of the popularity of particular Cards and Card authors. The second group of Transformation Agents is designed to minimize the promotion of Cards that are same or similar to Cards a particular user is already working with (TA-H…). These agents compare the history of Cards in the database with the history of Cards on a user's Workspace View to detect whether a particular Card was created or previously adapted by the user or whether a Card is a modified version of a Card the user is currently working with. The third group of Transformation Agents is concerned with the retrieval of Cards with same or similar properties as Cards on the users' Workspace Views (TA-A…). Examples of Card properties may include categories, geographic locations, authors, votes, references, modification dates, associated documents, headings, as well as Card appearances such sizes, shapes and colors. The three groups of Transformation Agents provide a framework for the organization of a potentially large number of possible agents. We implemented an initial set of Transformation Agents for each group to test and demonstrate the selection and prioritization of Cards for individual users. In this section we introduce a selection of four Transformation Agents that illustrate typical Transformation Agents operations and that emphasize the wide range of opportunities for leveraging the relationships in EWall's database. Every Transformation Agent is accompanied by an information visualization that reflects its analysis of the database contents (IV-…). The information visualizations are not supposed to be seen by the users but intended for researchers to demonstrate, test and monitor agent functions.

The first Transformation Agent prioritizes Cards based on user interactions (TA-C01-INT). An interaction is registered whenever a user copies a Card from another user, whenever two users communicate through a Card's instant messaging feature, or whenever an Interpretation Agent generates a relationship between two Cards created by different authors. Cards are prioritized based on how many interactions the Card recipients have with the Card authors. For example, if user A previously copied a Card from user B then user A would be more likely to receive promotions for other Cards created by user B. This Transformation Agent also considers indirect interactions. For example, if one interaction occurred between user A and B as well as one interaction between user B and C then one indirect interaction is assumed between user A and C. The reasoning for this is that user A might have shared information with user B that subsequently user B shared with user C. Alternatively, user B might have shared the same information independently with user A and C. This Transformation Agent is designed based on the assumption that the network of people interacting with each other indicates groups of users with potentially common foci, interests or work tasks. The analysis of direct and indirect interactions not only enables our Transformation Agents to provide users with potentially task-relevant information but also to make users aware of other users that may have similar interests, that may be experts on subjects of current consideration, or that might benefit from a direct collaboration. User interactions are visualized in a matrix with row and column headings displaying the names of users and the cells indicating the total number of interactions between users (Figure 5, Top Left) (IV-C01-INT). The number of interactions in the cells is represented with different shades of red color. The rows and columns are sorted to place users with many interactions near each other. This particular visualization is inspired by research in social networking (Sack, 2001) and organizational psychology (Varghese, Allen, 1993) and may be used for team managers to determine possible team arrangements for the resolution of sub-tasks.

The second Transformation Agent prioritizes Cards based on the orderliness and modification frequency of Card arrangements (TA-C02-BAL). The orderliness of a Card arrangement is determined by the ratio between the number of Cards created by a user and the number of relationships created by the Interpretation Agents. A small number of relationships and many Cards indicate a less structured and more arbitrary arrangement of Cards. A large number of relationships and few Cards indicate a well organized and structured arrangement of Cards. An unstructured arrangement of Cards is more typical during the beginning of sense-making sessions when people primarily focus on exploring and collecting information. A structured arrangement of Cards is more typical during the end of sense-making sessions when people conclude their analyses and organization of information. The goal is to encourage individual users to be broad and explorative at the beginning of sense-making sessions and increasingly focused and organized during the end of sense-making sessions. For example, if, at the beginning of a sense-making session, the Card arrangement of a particular user is very organized and only slowly receives new additions then this user is presented with contributions by other users whose Card arrangements are less organized or rapidly accumulate new information. This Transformation Agent uses line graphs to visualize the orderliness of Card arrangements for individual and groups of users (Figure 5, Top Right) (IV-C02-BAL). The visualization may be used to monitor progress during sense-making sessions and to recognize situations that allow for a broader exploration of issues or situations that suggest a more focused investigation.

The third Transformation Agent prioritizes Cards based on relevance (TA-C03-REL). The Card relevance is determined by the number of relationships that exist between a Card in the database and a Card on a user's Workspace View. In other words, the Card relevance indicates the number of relationships between a Card that the user is not using and a Card the user is using. For example, user A might align Card 1 and 2 on his Workspace in ways that prompts one of the Interpretation Agents to create a relationship between the two Cards. The adaptation of Card 1 by user B would subsequently trigger the promotion of Card 2. This Transformation Agent helps users detect potentially relevant information based on the contextual use of Cards by different people. The Transformation Agent offers a complimentary visualization that uses spring algorithms (Li, Eades, Nikolov, 2005) to represent the number of relationships among Cards through a spatial Card arrangement (Figure 5, Bottom Left) (IV-A01-REL). Cards in close proximity maintain more relationships than Cards located further apart. This visualization allows researchers to visually explore relationships among Cards as well as to monitor the evolution of the database contents.

The fourth Transformation Agent prioritizes Cards based on geographic locations associated with Cards (TA-A02-LOC). Every Card can be associated with a latitude and longitude. A Card editor allows for the easy insertion of these two values by simply selecting a location on a map (CF-L11-GEO). For every user the Transformation Agent increases the priority of Cards that are associated with similar geographic locations as Cards on the users' Workspace View. The Transformation Agent also increases the priority of Cards that maintain relationships (established by Interpretation Agents) with Cards that are associated with similar geographic locations. Consider the following example: The Workspace View of user A contains a Card associated with Washington (Card 1). The Workspace View of user B contains a Card associated with Washington (Card 2) next to a Card associated with Boston (Card 3). The Interpretation Agents copy the three Cards to the database and create a relationship between Card 2 and 3 due to their close spatial proximity on user B's Workspace View. The Transformation Agent suggests Card 2 to user A because it is associated with the same location as Card 1. The Transformation Agent also suggests Card 3 to user A because it maintains a relationship with a Card (Card 2) that is associated with the same location as Card 1. The Transformation Agent visualizes with red dots on a map all geographic locations that correspond with the geographic locations of Cards in the database (Figure 5, Bottom Right) (IV-C03-LOC). The sizes of the red dots are indicative for the number of Cards associated with particular geographic locations. Dashed lines between red dots reveal the presence of relationships between groups of Cards associated with different geographic locations. The dashed lines can help users detect potential relationships among geographic locations that emerge through the spatial organization and collaborative use of Cards. For example, there may be a dashed line between Washington and London because two users engaged in a heavy exchange of Cards associated with these two geographic locations.

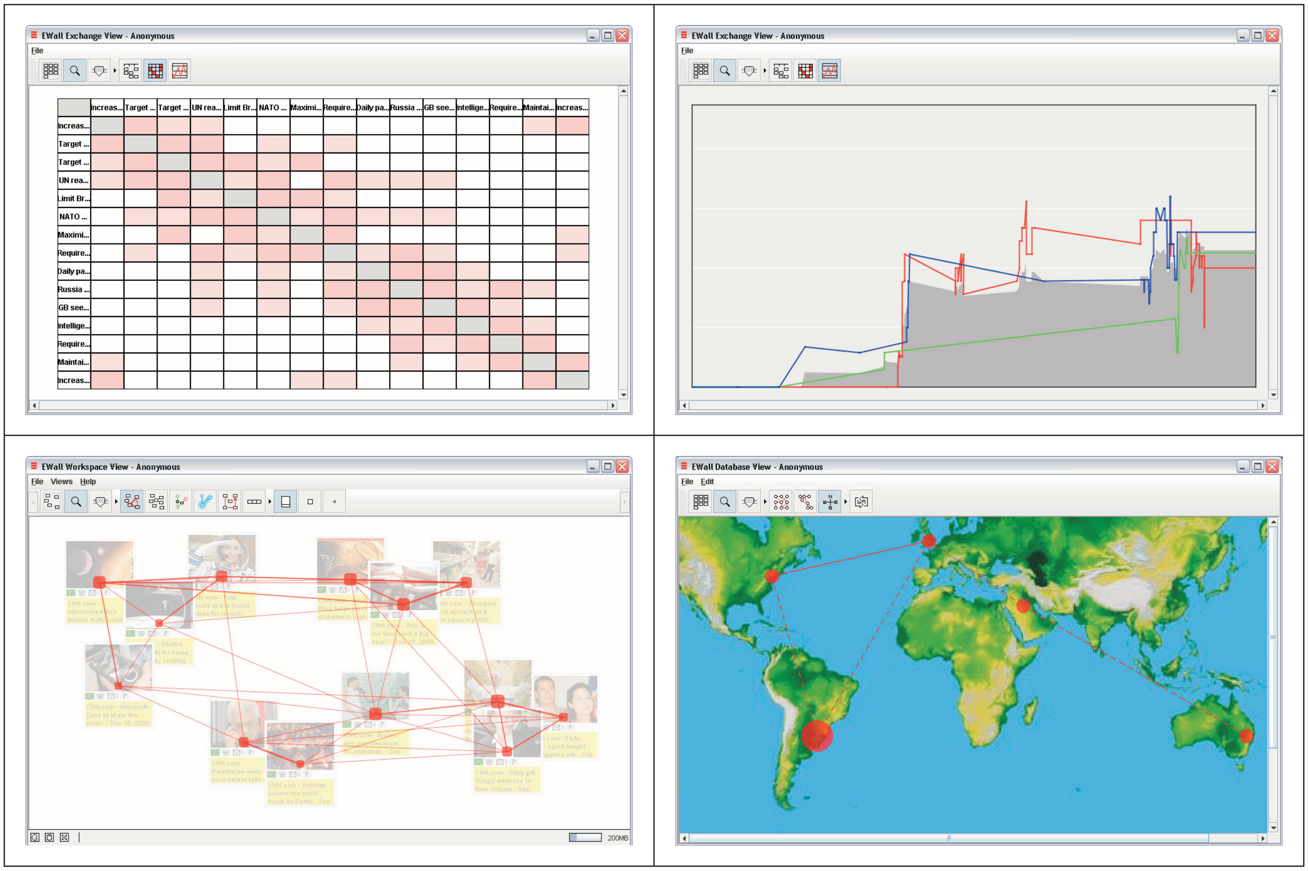


Figure 5: Examples of visualizations that allow for the monitoring and analysis of Transformation Agent operations.

4. BENEFITS

The EWall system is designed for users to conduct sense-making activities, for researchers to monitor and analyze sense-making activities, and for computational systems to support sense-making activities. More specifically:

1. The EWall system provides *users* with a variety of interfaces to easily collect, organize, analyze, discuss and exchange information. A standardized information format referred to as Card is used to represent information in different formats and locations. The EWall interfaces and Cards are aimed at reducing the cognitive burden by enabling the external representation and management of task-relevant knowledge.
2. The inclusive representation of information as Cards allows *researches* to observe and investigate the use, evolution and exchange of knowledge and information during collaborative sense-making activities. The EWall system also provides researchers with opportunities to convert discoveries of cognitive and collaborative processes into computational agents that can be used to investigate and visualize particular sense-making activities.
3. The agents enhance *computational systems* with the ability to monitor and support human sense-making activities. The agents infer from the spatial and temporal organization and collaborative use of information as a basis for helping users locate and exchange task-relevant information as well as to learn about and incrementally adapt to particular user preferences, tasks and circumstances.

Research observations and experiments conducted within the framework of our computational environment inform the direction of additional agent implementations that in turn support sense-making processes and subsequently allow for more advance research experiments. This iterative cycle of operations, experiments and agent implementations incrementally advances the EWall system towards a comprehensive sense-making environment that equally benefits users, researchers and computational systems.

The development of the EWall system is expected to continue with subsequent funding. The goal is to increase the stability and functionality of the EWall system to widen the range of possible applications. The current implementation allows for the demonstration of new and unique concepts for computer-supported collaborative sense-making (Chapter 4.1) and also provides researchers with a test-bed for research observations and experiments (Chapter 4.2). Subsequent efforts to stabilize and expand the EWall system will allow the use of the software by a broader audience for advanced experiments and real-life applications.

4.1. Demonstration of Concepts

The EWall system helps demonstrate novel concepts for thinking about, managing and computationally processing data, information and knowledge. The following paragraphs introduce four essential EWall concepts.

4.1.1. Object Oriented Thinking

The EWall system is designed to help users encapsulate, organize and compare data, information and knowledge through the use of card-like objects (Cards) on a computer canvas (Workspace View) (Figure 2). The Cards are conceived as a potential replacement for desktop icons. The EWall system includes functionality to create, modify, remove and arrange Cards as well as to combine, separate and substitute Card contents. To think of data, information and knowledge in terms of objects offers several benefits: First, the use of Cards allows for the easy comparison of different data, information and knowledge formats such as ideas, thoughts, comments, documents, notes, executables, web sites, emails, instant messages, database items, files, and directories (Figure 6). Second, the creation of Cards encourages users to carefully evaluate and abstract data, information and knowledge. Third, Cards convert data, information and knowledge into something more tangible that can be possessed, sold, exchanged, traded, organized, and collected. Fourth, Cards allow for complementary functionality such as attaching files and executables, adding comments and annotations, or hyper-linking remote contents and Card arrangements.

4.1.2. Emergent Associations

The EWall system allows for the detection of explicit and implicit relations among spatially arranged Cards (Figure 4). Explicit relations are usually more obvious and often interpreted similarly by different people. Examples of explicit relations include relations among spatially arranged Cards grouped with bounding boxes or connected with rubber lines. Implicit relations are usually less obvious and often interpreted differently by different people. Examples of implicit relations include relations among spatially arranged Cards in close proximity or Cards created during similar time frames. Relations reflect not only associations among Cards but also partial Card contents, Card histories, data and information associated with Cards, or human knowledge stimulated by Cards. For example, a relation between two Cards could materialize if the first Card contains information on a subject that the author of the second Card is an expert in. Any collection of Cards can contain a virtually unlimited number of possible relations. Furthermore, different relations emerge and dynamically change depending on the viewers' interpretations and the circumstances.

4.1.3. Circular Information Flow

The EWall system provides individual users with a prioritized selection of information that it considers relevant to their work and that might stimulate future additions and modifications to their Card arrangements. The EWall system acts analogous to and in parallel with human observers that review and respond to a user's Card arrangement. The user and the EWall system communicate indirectly meaning that the user gathers information through the evaluation of suggested additions by the EWall system (on the Kiosk View) and that the EWall system gathers information through the analysis of the user's evolving Card arrangement (on the Workspace View). This so-called "circular information flow" (Figure 7) suggests a process by which the user and the EWall system make each other more "knowledgeable". The "circular information flow" leverages and brings together the human capacity for problem solving and the computer's capability for processing large amounts of information. Furthermore, the "circular information flow" causes minimal interference with human sense-making activities as it does not impose a particular work process, does not depend on direct human-computer interaction, does not confront humans with internal computational analyses, and clearly separates the interfaces controlled by humans and computers.

4.1.4. Dynamic Knowledge Construction

The EWall system collects, combines and structures information from different users and information sources. This information includes Cards, explicit and implicit relations among Cards, as well as information about the history and collaborative use of Cards and Card arrangements. All this information accumulates in a database whose structure evolves and dynamically changes through the continuous addition of Cards and relations. The database bears several similarities with mental processes: A first example is that associations between Cards in the database evolve and dynamically change over time. The human analogy is that any interpretation of knowledge is unique. In other words, humans never produce the precisely same thought twice. This is primarily due to a human’s continuously evolving knowledge structure as well as a human’s changing foci, needs, and objectives. While these inconsistent interpretations of human knowledge may be viewed as a limitation they are essential for the creative conception of new ideas. A second example is that associations between Cards become more resistant to change with the growing number of relations in the database. The human analogy is that children are commonly more flexible in creating and adapting new knowledge since they are less constrained and influenced by previously acquired knowledge. On the other hand, adults a more likely to hold on to their views and develop a tendency to accumulate new knowledge that does not fundamentally contradict previously acquired knowledge. While the decreasing adaptability of the human mind may be viewed as a limitation it is what makes humans unique in terms of style and character.

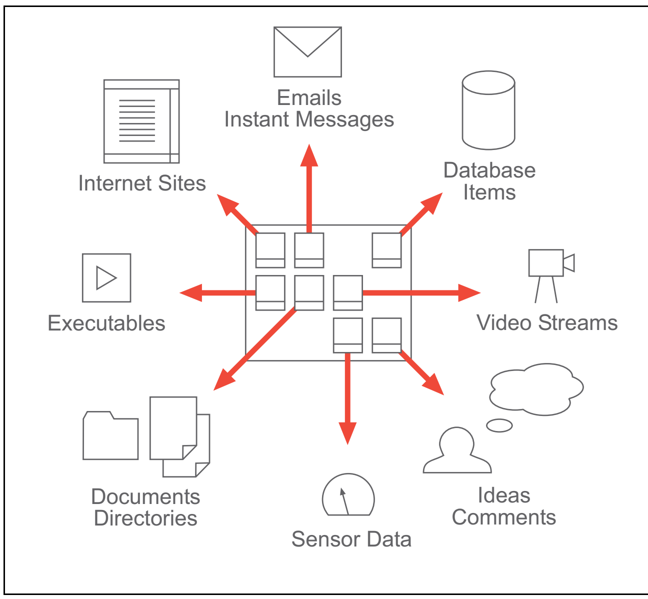


Figure 6: Object Oriented Thinking

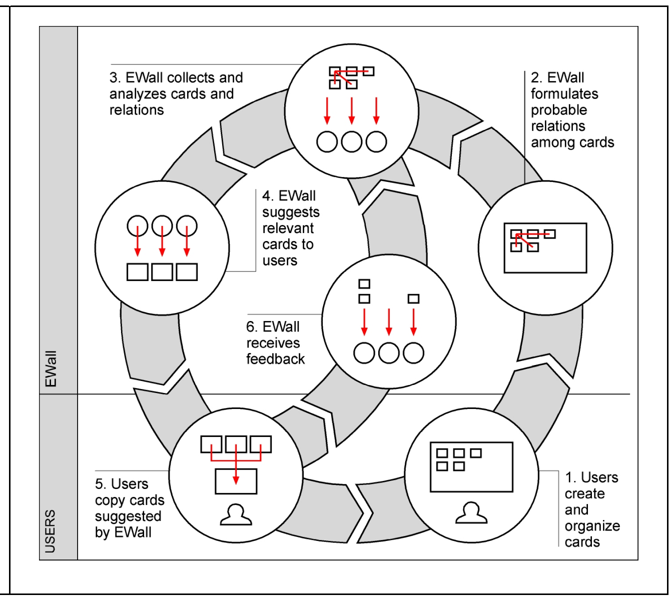


Figure 7: Circular Information Flow

4.2. Research Observations and Experiments

The current implementation of the EWall system primarily benefits researchers that may use this software for conducting research observations and experiments related to collaborative sense-making. The following four examples highlight opportunities and applications for the use of the EWall system in research settings.

1. The EWall system can help investigate the way people abstract information to more easily compare information and to deal with large amounts of information. Furthermore, the EWall system can provide insight into how people spatially arrange information for the purpose of organizing, categorizing, understanding and analyzing information. The EWall system can also help researchers understand the creation of new information, the collection of existing information, the abstraction of information as well as the spatial arrangement of information.

2. The EWall system can provide insight into how people deal with information overload and how people determine the relevance of new information. This is especially important because information that may not be of immediate relevance may inspire solutions to problems of relevance. The EWall system can also be used to provide mechanisms that allow for the filtering of relevant information without eliminating potentially important and inspiring yet presently less relevant information.
3. The EWall system can help examine how people promote ideas, exchange information, reach consensus during collaborative efforts and form teams for the resolution of sub-tasks. The EWall system can support the exchange of information allowing more people to collaborate simultaneously. The EWall system can also provide the technology to dynamically group people into teams for the resolution of sub-tasks.
4. The EWall system can allow for discoveries into how people relate and visualize information. Relating information refers to the mental process that allows people to relate new information with existing knowledge while visualizing information refers to how people layout information for the purpose of comprehending and presenting relations between information. The EWall system may also be used to realize mechanisms for the automatic creation and visualization of relations among information items.

The EWall system is composed of multiple independent software components that may be used and combined in ways other than initially intended. Some of our research collaborators have conceived additions, alternative combinations, and different applications for many of our software components. We expect that the flexibility of our software components and the standardized data formats will significantly ease efforts to interface our computational environment with other software applications. The following few paragraphs inform about cases where we customized our computational environment for the needs of particular research groups.

4.2.1. Decision-Making Constructs in Distributed Environments

The Decision-Making Constructs in Distributed Environments (DCODE) project conducted at SPAWAR offers solutions for human analysts to quickly and easily categorize information based on a predefined set of criteria such as credibility, timeliness, confidence, effect and importance (Cowen & Fleming 2002, Fleming & Kaiwi 2002). The objective of the project is to "improve the quality of group decision making by enhancing the ability of each participant to assess/evaluate their pool of disparate information findings, simplifying the process by which participants share uniquely held information, improving the process for integrating this shared information into the on-going decision process, and developing information "drill down" capabilities so that participants can quickly focus on the differing subjective assessments that are causing lack of decision consensus".

We have integrated the DCODE functionality including some supplemental features into the EWall system to allow analysts to quickly categorize and qualify information. Users can complement individual Cards with DCODE criteria, filter for Cards based on DCODE criteria, organize Cards by DCODE criteria, and render statistical information about DCODE criteria associated with Cards. The integration of the DCODE functionality offers several benefits: First, the DCODE functionality will provide users with the means to easily categorize Cards with criteria that help other users to quickly notice relevant information. This is particularly useful if the people that collect information are not the same people as the people that later use the information. Second, the EWall Software provides an alternate testbed and a more sophisticated computational environment for DCODE operations. Third, the DCODE research complements the EWall Software with functionality that has previously been tested and proven effective. Forth, the integration of the DCODE research demonstrates the flexibility of the EWall Software to accommodate additional functionality.

4.2.2. Collaborative Knowledge in Asynchronous Collaboration

NAVAIR laid out design specifications for additions to the EWall Software that make it conform to the Collaborative Knowledge in Asynchronous Collaboration (CASC) research project (Warner & Letsky & Cowen 2006, Warner & Letsky & Wroblewski 2008). The objective of the CASC project is to "understand the unique cognitive mechanisms that should be employed to optimize collaborative decision-making activity in a geographically distributed and time-delayed situation. The focus is on the cognitive mechanisms and processes of building knowledge in an asynchronous, distributed collaboration environment." One of the earlier CASC research products includes the "Structural Model of Team Collaboration", a chart that displays collaboration stages and cognitive processes involved in collaborative sense-making activities.

We complemented the EWall system with functionality based on CASC specifications without conflicting with the philosophy of the EWall project. For example, Cards can have different colors and be used as a subject-based instant messaging system. Furthermore, Cards can be copied between Workspace Views allowing users to separate private from public information.

4.2.3. Relief Operation Coordination Center

The Relief Operation Coordination Center (ROCC) Viewer developed at NPS helps users to relate events, people and geographical locations (Bordetsky & Hutchins, 2008). More specifically, users are presented with a map that graphically indicates the location of events and people. The geographic locations are established manually based on user input or automatically based on GPS input. To associate events and people with geographical locations is contextually important for many types of information. For example, newspaper articles are often associated with geographic locations. Similarly, the coordination of people often requires knowledge about their current geographic locations.

We complemented the EWall system with the ability for users and computational systems to associate Cards with geographic locations as a basis for interfacing with the ROCC Viewer. Consequently, the ROCC Viewer will eventually be able to place EWall icons on a geographic map indicating the availability of Cards associated with particular locations. A mouse click on one of these icons will open a EWall View and display the Cards associated with this particular location. Individual users will be able to copy Cards to their Workspace Views and combine and organize these Cards with previously created or copied Cards. The ROCC Viewer could potentially query the EWall database for the availability of new Cards. If new Cards are detected, the ROCC Viewer would then create new icons on the geographic map.

5. POTENTIAL IMPACT

We believe that the EWall system can impact future research and development of enabling technologies in various domains related to collaboration and knowledge management by:

1. supporting the asynchronous and intermittent participation of remotely dispersed collaborators that have varying levels of involvement, may not know each other, may not work on a common task, may operate under different circumstances, or may have different foci, interests and objectives.
2. enabling team members to work independently without diverting from common objectives, increase shared awareness and understanding, and encourage anonymous contributions that are less influenced by social factors such as reputation, prestige and organizational status.
3. providing computer assisted team management by connecting together users with similar or complementary responsibilities, interests and backgrounds, by dynamically regrouping users based on their availability and expertise, and by enabling simultaneous contributions to multiple tasks and work groups.
4. accelerating information sharing by helping users navigate large amounts of information, determine information relevant to their work, investigate the certainty associated with information, and minimize the necessary amount of verbal communication during the acquisition and exchange of information.

The EWall system was initially designed for supporting command and control collaboration. The scope of the EWall system has since broadened to allow for a wider variety of possible applications. The following sub-chapters provide a few examples that demonstrate the diverse use of individual EWall components.

5.1. Command and control collaboration

The EWall system may be leveraged as a decision-support software for remotely dispersed groups with particular attention to command and control collaboration. The objective of the EWall system is to support decision-makers to make faster and better decisions, to keep decision-makers better informed, to improve the exchange of information between decision-makers as well as to support multiple styles of working and collaborating. The EWall system can provide the means to make command and control environments more alike without imposing a standardized work process. Furthermore, the EWall system suggests a decentralized environment that allows for the collaboration of decision-makers and commanders across organizational domains and hierarchies.

5.2. News acquisition and distribution

The EWall system introduces the mechanics and visualization techniques to quickly and easily keep track of changes in information sources such as newspapers, databases or web pages. This capability is valuable to any kind of organization that has to keep track of new information or changes to existing information. The EWall system has the capability of spatially visualize news items in a subject-time matrix allowing users to more easily recognize the chronology of news additions and gain a contextual understanding between news messages in different subject rows. Furthermore, the EWall system allows the author as well as the reader to easily add and comment on news items making it a valuable tool for the news exchange among members of virtual communities.

5.3. Meeting support

The EWall system utilizes computation as a means to both expand upon the advantages and resolve the limitations of traditional brainstorming and problem-solving processes. The EWall system focuses on supporting the collaboration between people working on explorative and creative tasks. The EWall system provides solutions for synchronous and asynchronous meetings in large groups of people of differing backgrounds. The EWall system will allow a large number of people and computational agents to collaborate on a decision-making task. The intent is to greatly reduce the necessary amount of verbal communication so as to improve efficiency and to allow for more people to participate in brainstorming and problem-solving process.

5.4. Organizational knowledge management

The EWall system introduces solutions for limiting data redundancy, tracking authorship, dealing with data expiration and retrieving near-matches in database searches. The motivation lies in creating a data space without current knowledge about its future use. With the EWall system both the structure and the use of the data space emerges through the collaborative effort of individual content providers actively adding, deleting, modifying and assembling data. The EWall system can become a valuable tool for companies to maintain an organizational knowledge base that not only captures but also meaningfully structures information from multiple sources. Thus, the EWall system can allow for more responsive organizations as well as more effective cross-organizational collaboration.

5.5. Peer-to-peer learning and problem solving

The EWall system may become a tool for education in a world of increasing complexity, specialization and decentralization. We expect increasing autonomy and responsibility for students in a rapidly changing and exceedingly competitive educational environment. The EWall system can provide virtual environments for the emergence of learning communities. The EWall components under development propose new models to allow for the independent construction and maintenance of distributed knowledge. The EWall system will provide the technology to connect people that "need to know" with people that "know" and also direct users to appropriate knowledge sources that may provide solutions to problems or explanations to questions.

5.6. Web book marking and web shopping

In addition to carefully tracking user activities, the EWall system can also visualize, distribute, prioritize and organize large amounts of information such as records of brainstorming sessions, Internet based news sources, questions and queries as well as database modifications. These mechanisms can easily be transformed into smaller tools for the bookmaking and the categorization of web-based resources. Furthermore, the EWall system's analysis of user activities will be able to guide web shoppers more effectively towards what they are most likely interested in. While there are similar tools available, the EWall system's competitive advantage is the retrieval, organization and visualization of relevant information.

6. DELIVERABELS

Our efforts have translated into a variety of documentations in various formats as well as several software prototypes that demonstrate various concepts and functions.

6.1. Publications, Theses, Reports, Presentations, and Handouts

Our efforts resulted in three publications. The first publication is titled "Collaborative Visual Analytics: Inferring from the Spatial Organization and Collaborative Use of Information" and was presented at the IEEE Symposium on Visual Analytics Science and Technology in Baltimore, MD. The second publication is titled "EWall: A Visual Analytics Environment for Collaborative Sense-Making" and was published in the Palgrave journal "Information Visualization". The third publication is titled "EWall: Computational Support for Collaborative Sense-Making Activities" and will appear as a book chapter in "Macrocognition in Teams: Understanding the Mental Processes that Underlie Collaborative Team Activity". Our work was also referenced in "Proceedings" (Walsh E. Knowledge Collaboration Promises Payoffs for ForceNet. Proceedings, Naval Systems, April 2005. 89) and in "Signal" (Lawlor M. Researchers Investigate Cognitive Collaboration. Signal, May 2005. 30-34). We believe that the current set of publications sufficiently reviews and exposes the work conducted within the context of this grant and will provide an effective basis for subsequent work in this research area.

Five of our students concluded their theses on project related issues. Paul Keel's thesis (Knowledge Trading: Computational Support for Individual and Collaborative Sense-Making Activities, 2004) elaborates on the general concept of EWall. Mike Kahan's thesis (Computer Analysis, Learning and Creation of Arrangements of Information, 2004) investigates computational mechanisms for converting spatial arrangements of information into networked arrangements of information. Yao Li's thesis (Discovering Structure of Data to Create Multiple Perspective Visualization, 2004) focuses on the visualization of data and information. John Bevilacqua's thesis (Decision Making by Agent Committee, 2004) looks into the use of computational agents that autonomously adjust the influence of the various EWall Algorithms. Matthew Sither's thesis (Adaptive Consolidation of Computational Perspectives, 2006) includes and investigation into various options for EWall's learning mechanism.

Our work and progress is also documented in several quarterly reports, three progress and one final report as well as in the proceedings of three ONR sponsored workshops and the presentation handouts of three ONR site visits. The progress reports and handouts provide a detailed record of our activities and highlight achievements and discoveries during the funding period.

Finally, we documented some of the key the concepts underlying our research efforts and the development of the software prototype in the form of several one-page handouts (see example handouts attached to this report).

6.2. Software Prototypes and Manuals

We spent a significant amount of time and effort for the development of several software prototypes. The software prototypes constitute the most tangible deliverables of our work. The current collection and implementation status of our software prototypes is stable enough to demonstrate and explain EWall concepts and functions. We provided software and source code components to various research organizations (including NAVAIR, SPAWAR, NPS, Saab Aerospace, and Colorado State University) for research and evaluation purposes. Appendix B includes detailed information about the implementation status of individual functions and agents.

We also developed individual software manuals for the EWall Views (Workspace, News, Database, and Exchange Views) and EWall Servers (News, Database, and Exchange Server). The manuals are complemented by animated introductions allowing the viewer to quickly and easily learn about the most essential concepts and functions. The primary purpose of the software manuals is to provide a detailed account of our implementation efforts. We also started to develop short movies that demonstrate some of the mechanics of the EWall system such as agent operations. Our efforts to document our work in movie format are supposed to continue with subsequent funding.

APPENDIX A: REFERENCES

- Bordetsky A, Hutchins S. *Plug-and-Play Testbed for Collaboration in Global Information Grid*. In: Letsky M, Norman W, Fiore S, Smith C (Eds). Macrocognition in Teams: Understanding the Mental Processes that Underlie Collaborative Team Activity. Ashgate; 2008.
- Byrne, M.D. (1993). *Using icons to find documents: Simplicity is critical*. SIGCHI Conference on Human factors in computing systems (Amsterdam, The Netherlands).
- Cowen MB, Fleming RA. *Quantification of Subjective Information Assessments in C2 Decision Option Selection*. Command and Control Research and Technology Symposium (San Diego, California, USA, 2006).
- Fleming R, Kaiwi J. *The Problem of Unshared Information in Group Decision-Making: A Summary of Research and a Discussion of Implications for Command and Control*. SPAWAR Systems Center-San Diego, Technical Document 3149. 2002.
- Foltz PW. Latent Semantic Analysis for text-based research. *Behavior Research Methods, Instruments and Computers* 1996; 28. 197-202.
- Haramundanis, K. (1996). Why icons cannot stand alone. *ACM SIGDOC Asterisk Journal of Computer Documentation* 20.
- Johnson M. Functional Brain Development in Humans. *Nature Reviews / Neuroscience* 2001; 2. 475-483.
- Keel P. *Collaborative Visual Analytics: Inferring from the Spatial Organization and Collaborative Use of Information*. IEEE Symposium on Visual Analytics Science and Technology (Baltimore, Washington DC, USA, 2006).
- Keel P. EWall: A Visual Analytics Environment for Collaborative Sense-Making. *Information Visualization* 2007; 6. 48-63.
- Keel P. *EWall: Computational Support for Collaborative Sense-Making Activities*. In: Letsky M, Norman W, Fiore S, Smith C (Eds). Macrocognition in Teams: Understanding the Mental Processes that Underlie Collaborative Team Activity. Ashgate; 2008.
- Kirsh, D. (1995). *Complementary strategies: Why we use our hands when we think*. Conference of the Cognitive Science Society. (Hillsdale, New Jersey: Lawrence Erlbaum).
- Lewis, J.P. Rosenholtz, R. Fong, N. Neumann, U. (2004). Identifying & sketching the future: VisualIDs: Automatic distinctive icons for desktop interfaces. *ACM Transactions on Graphics* 23.
- Li W, Eades P, Nikolov N. *Using Spring Algorithms to Remove Node Overlapping*. Asia-Pacific Symposium on Information Visualization 2005 (Sydney, Australia, 2005). Conferences in Research and Practice in Information Technology 2005; 45. 131-140.
- Pena, W. Parshall, S. (2001). *Problem Seeking: An Architectural Programming Primer*. (John Wiley & Sons).
- Robertson, G. Czerwinski, M. Larson, K. Robbins, D.C. Thiel, D. van Dantzich, M. (1998). *Data Mountain: Using Spatial Memory for Document Management*. UIST Symposium on User Interface Software and Technology (San Francisco, CA, USA).
- Prante T, Magerkurth C, Streitz N. *Developing CSCW tools for idea finding: Empirical results and implications for design*. ACM conference on Computer supported cooperative work (New Orleans, Louisiana, USA, 2002).
- Sack W. *Design for Very Large-Scale Conversations*. Ph.D. Dissertation. MIT Media Laboratory: Cambridge, MA; 2000.
- Sarukkai R. *Link prediction and path analysis using Markov chains*. International World Wide Web Conference 2000. 377-386.
- Ullman S. Visual Cognition and Visual Routines. In: *High Level Vision*. MIT Press: Cambridge; 1966. 263-315.
- Varghese G, Allen T. Relational Data in Organizational Settings: An Introductory Note for Using AGNI and Netgraphs to Analyze Nodes, Relationships, Partitions and Boundaries. *Connections* 1993; 16.
- Warner N, Letsky M, Cowen M. *Structural model of team collaboration*. http://www.au.af.mil/au/awc/awcgate/navy/model_of_team_collab.pdf (accessed 30 September 2006).
- Wertheimer M. Laws of organization in perceptual forms. In: Yantis S (Ed): *Visual Perception: Essential Readings (Key Readings in Cognition)*, Psychology Press; 2000. 216–224.
- Warner N, Letsky M, Wroblewski B. *Empirical Model of Team Collaboration: Focus on Macro-Cognition*. In: Letsky M, Norman W, Fiore S, Smith C (Eds). Macrocognition in Teams: Understanding the Mental Processes that Underlie Collaborative Team Activity. Ashgate; 2008.
- Winnicott, D.W. (1982). *Playing and Reality*. (London: Routledge).
- Zobrist A, Thompson W. Building a distance function for Gestalt grouping. *IEEE Transactions on Computers* 1975; C-24. 718-728.

APPENDIX B: EWALL COMPONENTS AND IMPLEMENTATION STATUS

The tables below provide a comprehensive list of EWall system components as well as information about past, planned and optional implementations efforts. The goal was not to realize all items on this list but to focus on a selection of implementations that help demonstrate essential EWall concepts.

Level = Implementation complexity on a 1 - 10 scale (Relative to other items in the same category).
xx-xx = Level of completion at past and future key dates (Non-linear. Effort increases towards 100%).
(1) = Core implementation (Does not include Card Features, Agents and Visualizations).
(2) = Instances of the Kiosk View.
* = Agents and functions referenced in the report.

User Interfaces	Level	09-04	09-06	09-07	03-08
Workspace View V2.0 [(1)]	10	30%	70%	80%	
News View V3.0 [(1)(2)]	9	20%	70%	80%	
Exchange View V1.0 [(1)(2)]	4	50%	70%	80%	
Database View V1.0 [(1)(2)]	4	50%	70%	80%	
Custom Implementation DCODE (SPAWAR)	6	50%	100%	100%	
Custom Implementation CASC (NAVAIR)	4	0%	40%	40%	
Custom Implementation ROCC (NPS)	6	0%	40%	40%	

System Mechanics	Level	09-04	09-06	09-07	03-08
Agent System Infrastructure [(1)]	6	20%	70%	80%	
Database [(1)]	8	30%	70%	70%	
Interpretation Agent Mechanics V2.0 [(1)]	7	20%	80%	90%	
Transformation Agent Mechanics V2.0 [(1)]	7	20%	80%	90%	
Agent Learning Mechanism Option 1 (Democratic)	5	60%	70%	80%	
Agent Learning Mechanism Option 2 (Genetic Algorithm)	8	0%	20%	20%	
Agent Learning Mechanism Option 3 (Neural Network)	8	0%	0%	0%	
Agent Learning Mechanism Option 4 (Agent Negotiation)	10	0%	20%	20%	

Designation	Card Features	Level	09-04	09-06	09-07	03-08
CF-L01-HYP*	Hyperlinks	5	70%	80%	80%	
CF-L02-ATT*	Attachments	9	0%	20%	20%	
CF-L03-DYN*	Dynamic Updates (RSS)	10	0%	50%	60%	
CF-L04-HIS*	History Log (Authors, Cards)	6	0%	50%	60%	
CF-L05-INS*	Instant Messages	8	50%	70%	80%	
CF-L06-CAT	Categories	5	0%	0%	0%	
CF-L07-VOT	Votes	3	0%	0%	0%	
CF-L08-PRI	Priorities	3	0%	0%	0%	
CF-L09-DIS	Custom Distribution	7	0%	0%	0%	
CF-L10-ACC	Access Restrictions	9	0%	0%	0%	
CF-L11-GEO*	Geographic Locations	7	40%	70%	70%	
CF-L12-TRA	Trade (Currency)	10	0%	0%	0%	
CF-G01-SKI*	Custom Skin	7	40%	60%	60%	
CF-G02-EXC*	Exchange (Transfer, Export, Email)	10	20%	50%	60%	
CF-G03-IMP*	Import (Auto-Create)	8	0%	70%	80%	
CF-G04-GRO*	Group	9	0%	60%	70%	80%
CF-G05-MAG*	Magnetize (Snap, Stack)	9	0%	0%	60%	70%
CF-G06-SHA*	Share: Card	6	40%	60%	60%	70%
	Share: Workspace	10	20%	50%	50%	

Designation	Interpretation Agents	Level	09-04	09-06	09-07	03-08
IA-I01-PRO*	Proximity	6	50%	90%	90%	
IA-I02-DIR*	Direction: Horizontal	4	80%	90%	90%	
	Direction: Vertical	4	80%	90%	90%	
IA-I03-OBJ*	Objective Set (History)	4	40%	70%	80%	
IA-I04-CLO*	Closure (Grouping)	8	0%	40%	60%	70%
IA-I05-SIM*	Similarity	10	0%	0%	0%	
IA-I06-COM*	Common Fate (Conflict)	-	-	-	-	
IA-I07-GOO*	Good Curve (Ambiguities)	10	0%	0%	0%	
IA-I08-PAS*	Past Experience	10	0%	0%	0%	
IA-E01-BOU*	Group (Bounding Box)	8	0%	70%	70%	80%
IA-E02-MAG*	Magnet	8	0%	0%	40%	60%
IA-E03-SEQ*	Sequence, Stack	8	0%	0%	0%	
IA-E04-LIN*	Link: Rubber Line	6	0%	0%	0%	
	Link: Hyperlink	9	0%	0%	0%	
IA-P01-DIS*	Discovery	7	0%	0%	0%	
IA-P02-SHO*	Shortcut	8	0%	0%	0%	20%
IA-P03-FOO*	Footprint	6	0%	0%	0%	
IA-P04-HIG*	Highway	8	0%	0%	0%	20%

Designation	Transformation Agents	Level	09-04	09-06	09-07	03-08
TA-C01-INT*	Interaction: Cards Copied	4	0%	70%	80%	
	Interaction: Ownership Taken	4	0%	70%	80%	
	Interaction: Comments Posted	4	0%	70%	80%	
	Interaction: Card Relationships Created	6	0%	30%	50%	70%
TA-C02-BAL*	Balance: Organization	6	0%	60%	80%	
	Balance: Frequency	5	0%	0%	0%	30%
TA-C03-REL*	Relevance	4	30%	60%	70%	
TA-C04-POP	Popularity: Author	7	0%	0%	0%	
	Popularity: Card (Users)	4	30%	80%	80%	
	Popularity: Card Weight (Relations)	4	30%	80%	80%	
TA-C05-FOC	Focus: Collaborative	5	0%	0%	0%	20%
	Focus: Individual	3	0%	0%	0%	20%
TA-C06-PAT	Pattern (Similar Groupings)	10	0%	0%	0%	
TA-C07-CXT	Context (Wide Proximity)	8	0%	0%	0%	
TA-C08-INT	Interpretation (Close Proximity)	8	0%	0%	0%	
TA-H01-REP	Replica: Sibling (Self-Created)	2	80%	100%	100%	
	Replica: Parent (Previously Copied)	2	80%	100%	100%	
	Replica: Offspring (Copy of Self-Created	2	80%	100%	100%	
	Replica: Relative (Same Origins)	2	0%	0%	0%	
TA-A01-AGE	Age (Date/Time)	2	50%	80%	100%	
TA-A02-LOC*	Location (Geographic Relationships)	7	40%	50%	70%	80%
TA-A03-IMP	Importance: Vote	3	0%	0%	0%	
	Importance: Priority	3	0%	0%	0%	
TA-A04-APP	Appearance: Size	4	0%	100%	100%	
	Appearance: Color	2	0%	0%	0%	
TA-A05-CNT	Content	10	0%	0%	0%	

Designation	Information Visualizations	Level	09-04	09-06	09-07	03-08
IV-A01-REL*	Relevance	4	70%	80%	90%	
IV-A02-CHR	Chronology	6	70%	80%	90%	
IV-A03-PRO	Proximity	6	0%	50%	50%	
IV-A04-MAG	Magnets	9	0%	50%	50%	
IV-B01-TRA	Transparency	6	0%	70%	70%	
IV-B02-SIZ	Size	6	0%	60%	60%	
IV-B03-HIS	History	6	0%	60%	80%	
IV-B04-LIN	Link Sum	6	60%	70%	80%	
IV-B05-HIG	Highway	9	0%	30%	30%	
IV-B06-AIR	Airway	9	0%	20%	20%	
IV-B07-CLO	Closure (Grouping)	5	0%	0%	50%	
IV-C01-INT*	Interactions (Teams)	8	20%	60%	70%	80%
IV-C02-BAL*	Balance	7	20%	60%	70%	80%
IV-C03-LOC*	Location	8	0%	60%	70%	80%
IV-C04-LOG*	Log	3	0%	50%	50%	
IV-C05-DAT	Database: Interpretation Agent Relations	5	30%	60%	60%	
	Database: Discovery Relations	2	0%	0%	0%	
	Database: Highway Relations	2	0%	0%	0%	
	Database: Foci (Individual, Collaborative	3	0%	0%	0%	

Office of Naval Research
Science and Technology, Human Systems, Collaboration and Knowledge Management Program

EWALL
ELECTRONIC CARD WALL

Massachusetts Institute of Technology	
Patrick Winston, PI	William Porter, CPI
Paul Keel, PM	Mathew Sither
Edith Ackermann	Jeffrey Huang

The EWall Application is divided into five Modules. The Modules are aimed at making, collecting, organizing, understanding, discussing, searching, exchanging, and visualizing information more intuitive. The Modules also introduce a "circular information flow" in which humans and computers gradually develop a shared understanding of a particular task and continuously adapt to changing processes and circumstances.

Circular Information Flow:

The EWall Application provides individual users with a prioritized selection of information that it considers relevant to their work and that might stimulate future additions and modifications to their information arrangements.

1. The Workspace View provides users with a canvas for the creation, collection, organization, analysis, and discussion of Cards.

2. The Cards on the Workspace Views of all users are retrieved, combined, and stored on Servers.

3. The Servers automatically establish relationships between Cards based on the organization, history, and collaborative use of Cards, thus creating a meaningful network of information that reflects the activities of all users.

4. The News, Database, and Exchange Views present users with a prioritized list of Cards relevant to the contents on their Workspace Views.

Each View has a distinct function: The News View displays only recently modified Cards, the Database View displays Cards available in shared databases, and the Exchange View displays Cards currently used by members of the same community.

The News View may be compared with a newsstand for the acquisition of recent information, the Database View with a library for the exploration of older information, and the Exchange View with a meeting space for the discussion of task specific information.

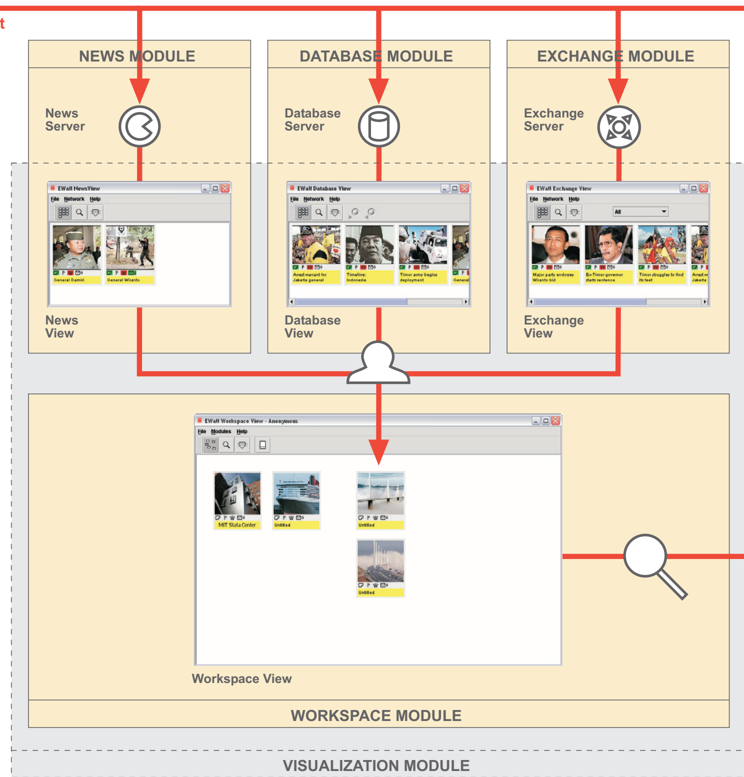
The News, Database, and Exchange Views are analogous to, and act in parallel with, human observers that review and respond to a user's Card arrangement.

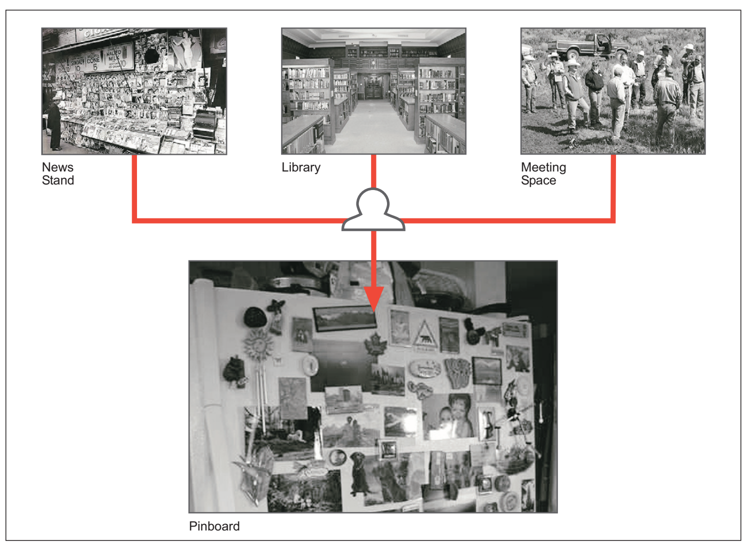
5. Each user can copy Cards from the News, Database, and Exchange Views onto the Workspace View.

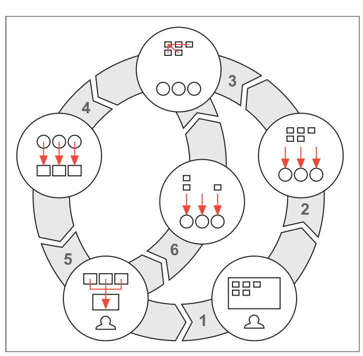
6. Every Card-copy operation indicates a successful suggestion, thus fostering additional suggestions based on similar considerations. This learning mechanism allows the prioritization mechanisms in the individual Views to improve the accuracy of their suggestions by incrementally adjusting to particular users, tasks, and circumstances.

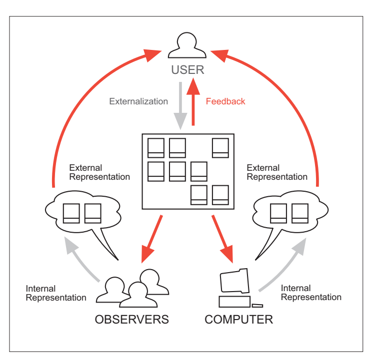
This "Circular Information Flow" causes minimal interference with human sense-making activities as it does not impose a particular work process, does not depend on direct human-computer interaction, does not confront humans with internal computational analyses, and clearly separates the interfaces controlled by users (Workspace Views) and the EWall Application (News, Database, and Exchange Views).

External Input









Workspace Module:

The Workspace Module provides users with an environment to create and spatially arrange EWall Cards. The Workspace Module also introduces technology for the detection of both explicit and implicit relations among spatially arranged Cards. The Workspace Module may be used by itself yet is required for the operation of the remaining four Modules.

News Module:

The News Module keeps users informed about recent additions and modifications to information sources such as web sites, shared computer directories and databases. The News Module consists of a News Server that monitors, collects and abstracts information as well as a News View that displays the information with EWall Cards. Users can copy EWall Cards from their News Views to their Workspace Views. Users can also send EWall Cards from their Workspace Views to the News Server.

Database Module:

The Database Module introduces a database whose structure evolves and dynamically adapts via the collaborative effort of individual users creating, collecting, organizing, exchanging, and exploring EWall Cards. The Database Module consists of a Database Server that automatically copies, analyzes and organizes EWall Cards from the Workspace Views of multiple users as well as a Database View that provides individual users with EWall Cards relevant to what they are currently working on. Users can copy EWall Cards from their Database Views to their Workspace Views.

Exchange Module:

The Exchange Module allows users to copy EWall Cards from the Workspace Views of other users and enables the collaborative functionality built into EWall Cards (e.g. instant messaging). The Exchange Module consists of an Exchange Server that interconnects the Workspace Views of multiple users and an Exchange View that displays the Card arrangement from the Workspace View of one participant or the combined contents from the Workspace Views of all participants. The combined contents are organized in the order of relevance for every individual user. Users can copy EWall Cards from their Exchange Views to their Workspace Views.

Visualization Module:

The Visualization Module visualizes the contents presented by the Workspace, News, Database and Exchange View in a variety of different ways. Users can easily combine and quickly switch between visualizations.

Office of Naval Research	EWALL ELECTRONIC CARD WALL	Massachusetts Institute of Technology	
Science and Technology, Human Systems, Collaboration and Knowledge Management Program		Patrick Winston, PI	William Porter, CPI
		Paul Keel, PM	Mathew Sither
		Edith Ackermann	Jeffrey Huang

The EWall Server administers the transfer of information between users, databases, and external information sources. The EWall Server also contains the mechanics to establish relations between cards and to determine the relevance of cards for individual users by analyzing the spatial arrangements, the collaborative uses, the histories, and the database organization of cards.

The News, Database, and Exchange Views present users with a prioritized list of cards (information) with potential relevance to the contents on their Workspace Views.

Users monitor their News, Database, and Exchange Views and copy cards of interest to their Workspace Views.

Users use their Workspace Views to individually or collaboratively create, collect, organize, evaluate, and discuss information.

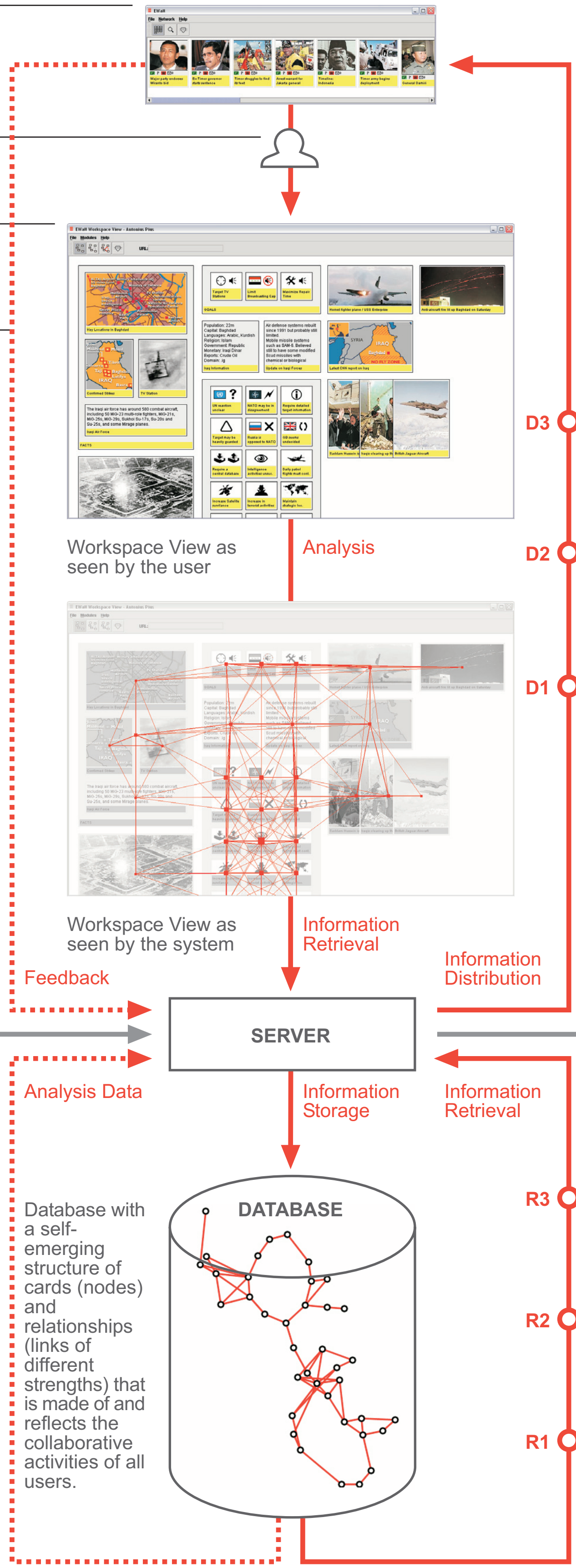
Every card copy indicates a successful suggestion and is reported back to the server thus fostering additional suggestions based on similar considerations. This feedback mechanism allows the server to improve the accuracy of its suggestions by incrementally adjusting to particular users, tasks, and circumstances.

Server Operations

The server collects cards from the Workspace Views of users, retrieves cards stored in databases, receives feedback from the News, Database, and Exchange Views, views the structural constellation of the database, and also collects information from external sources.

The server analyzes available information to establish relations among cards based on the spatial arrangement of cards on the individual Workspaces (Level I and II Algorithms), the collaborative use and history of cards (Level III Algorithms), as well as the current structural constellation of the database (Level IV Algorithms).

The server outputs cards and relations to the database, to the News, Database, and Exchange Views of individual users, as well as to external information sources.



Input from other Workspace Views and external information sources

Export to other Views and external information sources

D3. Visualization

By default, cards on the News, Database, and Exchange Views are arranged from left to right in the order of relevance. Optional arrangements, visualizations, and statistical illustrations are available to help users recognize, comprehend, and leverage associations among cards. Users can apply and combine multiple arrangement and visualization options to compare different types of associations.

D2. Prioritization

Cards are prioritized for every individual user. The card with the highest priority is the card that is most likely of relevance for the work of a particular user. The prioritization process is based on a comparison between the contents and the organization of a particular user's Workspace View and the relations associated with the cards to be prioritized.

Typical examples of evaluation criteria for determining the relevance of individual cards include if the cards were created by people with similar foci, interests or backgrounds, if the cards are currently being used by several members of the same team, or if the cards have existing relations with cards currently used by the user. The evaluation criteria dynamically change based on user activities.

D1. Separation

The server separates information into three primary categories and displays this information on different Views:

New information received from external information sources is sent to the News View.

Information retrieved from databases is sent to the Database View.

Information currently on display on Workspace Views of collaborating users is sent to the Exchange View.

Level I and II Algorithms

The system discovers explicit and implicit relations in user created spatial information arrangements. Every system algorithm focuses on one particular criterion such as the proximity between cards, the grouping of cards, or the horizontal and vertical alignment of cards.

Level III Algorithms

The system creates relations between cards based on the analysis of the direct exchange of cards between users as well as based on the indirect exchange of cards through the use of shared databases.

Level IV Algorithms

The system constructs relations based on the analysis of previously established relations and in complete isolation of any input source. The addition of such relations is supposed to ensure a flexible and dynamic data structure that prevents the long-term domination of strong network segments and allows for more explorative and inspiring data discoveries.

R3. End Point

The End Point of a database exploration is determined based on an analysis of the node contents and properties, the total number of nodes examined, or the distance between the nodes and the Start Point of a database examination.

R2. Exploration Path

The Exploration Path determines in what order the nodes in the database are being explored. Any exploration initiates at a Start Point and proceeds with the evaluation of connected nodes. The system offers various options for the examination of nodes that are located in remote and weakly connected network segments.

R1. Start Point

The Start Point references a node in a database from where directly and indirectly connected nodes are explored and whose content is related or relevant to the content on the Workspace View of a particular user.