A CyberOrganism Model for Awareness in Collaborative Communities on the Internet

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The Internet/World Wide Web has grown very rapidly to become a major resource supporting collaborative activities in a wide range of groups, disciplines, and communities. However, the growth of the net/web creates problems of information overload and of maintaining awareness of activities at other sites relevant to one's own tasks. This article discusses awareness issues in collaborative group; develops a conceptual framework for studying and supporting awareness on the web; describes CHRONO, a tool for supporting awareness of changes at another site. Finally a preliminary sketch of an overall conceptual framework for the Internet is presented and explored. This CyberOrganism framework is used to analyze and classify chronological awareness support systems and general communication systems that support awareness maintenance on the Internet. © 1997 John Wiley & Sons, Inc.

I. INTRODUCTION

The recent phenomenal growth of the Internet information resource such as the World Wide Web (the web or WWW) and the growing availability of collaborative tools and services on the Internet have provided a tremendous opportunity to expedite the diffusion of various knowledge creation/dissemination infrastructures, such as: digital journals, electronic libraries,[1] resource discovery environments,[2] distributed co-authoring systems,[3] and virtual scientific communities.[4] Collectively, these Internet infrastructures have become integral parts of an emerging information system for a systematic acceleration of scientific research through the use of computer networking technology to support collaboration in distributed research communities.

One of the problems of supporting scientific collaboration on the Internet is that of maintaining awareness between remote research partners that activities had occurred in one location that affected those in another. Such *mutual awareness* is an important issue for supporting task-oriented collaborative projects of research groups or organizations. On the other end of the spectrum, the issue of *resource awareness* becomes important for supporting the research communities at large.

As one of the fastest growing services on the Internet, the World Wide Web was originally conceived and developed at CERN for the purpose of assisting

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and facilitating collaborative interactions among high energy physicists, working at various institutions in different countries, to conduct joint research projects.[5] Since 1993, it has diffused in a phenomenal rate from its origin and gradually has subsumed various popular Internet communication services such as: USENET Newsgroup, Electronic Mail, etc. The original charter of the web can be summarized in the following quote:

The World Wide Web (W3) was developed to be a pool of human knowledge, which would allow collaborators in remote sites to share their ideas and all aspects of a common project.[5]

The phenomenal growth of the web can be attributed to its emergent growth property: the ability for a new state of being to emerge naturally from a synergy among existing systems. The web is structured such that if it was used independently for two projects, and later relationships are found between the projects, then no major or centralized changes have to be made, but the information can be linked to represent the new state of knowledge. This property of emergent growth has allowed the web to expand rapidly from its origins at CERN across the Internet irrespective of national or disciplinary boundaries.

The dynamics of the web are based on three fundamental notions: (i) computer-supported cooperative work; (ii) hypermedia; and (iii) transboundary, emergent growth. The implications of combining these three basic notions to support the web's raison d'etre (that is, to be a pool of human knowledge) will be explored in the following sections. A common thread through the subsequent discussion is the concept of awareness. Group awareness is essential to provide smooth coordination among members in a collaborative project team. Through community awareness, the web, as a global hypermedia system on the Internet, supports an emergent CyberSociety[6] that transcends the traditional boundaries of both physical and social communities.

This article is concerned with providing an overall conceptual framework for the psycho-socio dynamics of scientific/scholarly communities on the Internet. In the following sections, awareness issues in collaborative groups are discussed, a preliminary conceptual framework is developed, and an experimental system for facilitating chronological awareness on the Internet is described. Later, a preliminary sketch of a CyberOrganic conceptual framework for the Internet is presented and explored. This conceptual framework is used to analyze and classify specific chronological awareness support systems and general communication systems that support *mutual awareness* on the Internet in terms of Miller's *living systems theory,*[7] Smith's *collective intelligence* model,[8] and Blume's *information exchange* social system of science.[9]

II. AWARENESS ISSUES IN COLLABORATIVE WORK

This section presents a brief survey of research in collaborative works in respect to awareness issues, and describes a taxonomy of different types of awareness involved in group collaboration.

A. Awareness Issues in Supporting Collaborative Work

Many workflow processes in teamwork environments share a common goal of trying to assist people to work collaboratively as a cohesive team and to provide them with a sense of common purposes (e.g., completion of the group task). A critical requirement in shared tasks is maintaining *situational awareness*[10] by keeping everyone adequately informed. In an environment where each member has a well-defined role, the need to have face-to-face communication in order to perform a cooperative task becomes less necessary if mechanisms for situational awareness have been well established between members. For example, in Hutchins' study[11] the navigation of a large ship requires effective coordination of various people with differing roles. Many key members of the navigation team (conning officer, plotter, bearing takers, deck log keeper, bearing-timer recorder, and fathometer operator) are geographically separated (pilot house, chart house, and port and starboard wings) and communicate with each other by a common telephone circuit. The common audio channel and the physical layout of the pilot house provide opportunities for the navigation crews to observe and be aware of each other's work, contributing to partial redundancy in their joint knowledge. They also support maintenance of the group over time to provide fault-tolerance if some group members fail to perform their roles.

Thus, one of the important criteria for achieving group cohesiveness is the situational awareness of what other group members are doing. It can be achieved through either face-to-face (as on the pilot house) or telephone communication (as between the port and starboard wings). Together the functional specificity of the team members (e.g., the navigational crews) and the cognitive artifacts that facilitate situational awareness (e.g., the single telephone circuit, the pilot house with high visibility among navigational team members) can create an effective collaborative system.

The emphasis on the importance of social interaction and cognitive artifacts (such as the telephone circuit described previously or the Internet) as the means to enhance human abilities has also been echoed by Norman.[12] A cognitive artifact is defined as ''an artificial device designed to maintain, display, or operate upon information in order to serve a representational function.'' The power of a cognitive artifact comes from its function as a representational device. However, artifacts do not actually change an individual's capabilities. Rather, they change the nature of the task performed by the person. When the informational and processing structure of the artifact is combined with the task and the informational and processing structure of the human, the result is to expand and enhance cognitive capabilities of the total system of human, artifact, and task.

Hence, when designing a computer-supported collaborative system, system designers need to keep the representational aspect of the whole system in mind (i.e., people, machines, situations, information, and tasks). A system designed with this holistic perspective in mind can provide tools that enhance communication, coordination, and social interaction capabilities. Therefore, the collaborator's intentions can be easily transferred to each other and common goals can

be achieved with mutual satisfaction. In various studies on the subject of team work, situational awareness has acted as an important coordination mechanism among collaborative groups.

B. Collective Awareness

Recently, Smith has proposed a *collective intelligence* theoretical model[8] that provides a holistic perspective on the nature of computer-supported intellectual collaboration. It focuses primarily on project groups and/or relatively small, close-knit teams within larger groups in designing/creating artifacts (e.g., committee reports, computer software). He calls such a group-artifact-task arrangement, artifact-based collaboration (or ABC). His comprehensive model takes into account cognitive processes within individuals, artifacts to-be-built, and situated actions.

A brief sketch of the model is presented in subsection V-B. But first, the following subsections describe a taxonomy of group awareness (what Smith calls collective awareness) based on the *collective intelligence* model. Using human self-awareness model and cognitive Information Processing System (IPS) architecture[13,14] as references, two analogous forms of awareness can be identified for collective groups: awareness of the group's collective long-term memory (LTM) and awareness among and of each other.

1. Awareness of the Group's Collective Long-Term Memory

The collective LTM has two parts: the artifact (the objective of the group task) and the body of shared intangible knowledge (that is, the information carried out in the heads of group members originally). Since awareness of the artifact exists only in the minds of the human beings who comprise the group, awareness of the artifact can also be seen as part of the group's intangible knowledge. Awareness in groups exists at several levels of detail:

Global Awareness—The most general level is the body of intangible knowledge that is shared by all member of the groups. It includes the overall goals of the project, its ways of operating, the strategies it uses to develop the artifact, its current status and problems, the relation of the project to the external environment, etc. This awareness is not deep, if the project is large, but it provides each member with a sense of the whole.

Deep Awareness—At the other extreme is the deep, detailed, often technical, knowledge held by individual members. Depending on the project, a single individual is often responsible for a particular part. Thus, the level of awareness and expertise required to generate a segment of the overall artifact (project) is significantly greater than that required for another person to understand it.

Peripheral Awareness—Between the extreme of general, shared knowledge and deep, individually specialized and generative knowledge, is an intermediate level: the thick knowledge of adjacent or near specialty areas. It takes the form of understanding, rather than generation. Thus, it is shared with individuals or the team responsible for developing other parts of the artifact, but it is not as

deep as their knowledge nor is it shared with the entire project. This critical peripheral awareness is ultimately responsible for the integrity of the group's work. It provides a context for the interfaces between areas. Thick shared knowledge can be developed through informal interactions, such as conversations, but it can also be developed through more formal mechanisms, such as institutional reviews (e.g., structural walk through process in a software project). Thus, the model identifies three forms of awareness with respect to a group's LTM:

(1) close, detailed, *deep awareness* of particular segment of the artifact;
(2) less detailed, but still substantial, *peripheral awareness* of the artifact's adjacent parts;
(3) the much thinner, *global awareness* of the artifact as a whole that is shared by the entire group.

2. *Awareness Members Have of One Another*

A different kind of awareness is the awareness members have of one another. This category of awareness is closer to the notion of *situational awareness* described earlier.

Resource Awareness—One of the primary reasons for assembling a group is to assemble the expertise required to carry out a project. Therefore, the issue becomes one of providing the group (as a whole) with a collective awareness of its members' respective specialized knowledge and expertise. Thus an extremely valuable resource for a group is shared knowledge of who is an expert on what.

Task-Socio Awareness—Another form of awareness involves the interaction between social and intellectual processes operating within in the group. It would be simple if groups were purely intellectual organisms, but they are not: tensions exist and factions develop. These developments are inevitable. For example, one member may oppose an idea voiced by another not because the idea is objectionable but because of who said it. The opposite condition—support an idea because of friendship or attraction—is equally bad. These so very human situations are unlikely to go away, but a group should be aware of itself as a dynamic, functioning organism as well as be aware of the artifact it is developing to insure that the integrity of its work is not compromised by them.

Chronological Awareness—A third form of awareness is the instantaneous awareness that an individual has regarding the activities of other individuals. This is what constitutes chronological awareness. For example, one member of the group may be aware (or wish to know) what another member of the group is working on in a nearby part of the artifact. This behavior is monitored at a very low level by the collaboration support system in its concurrency control mechanisms to insure that two members do not attempt to change the same part of the artifact at the same time. These mechanisms, however, do not prevent one member's access from blocking that of another, or prevent one member's subsequent work from affecting earlier work done by another. Groups may need help in monitoring domains of activity. For example, members may want to see where colleagues are working; they may even wish to see a display over time of the ''tracks'' left by colleagues.

Thus, the model identifies three forms of awareness among members of one another:

(1) cognitive-guide-map like, *resource awareness* for locating specific knowledge and expertise among the group members;
(2) emotional, but rationalized, *task-socio awareness* concerning social and political dynamics within the group in relation to the artifact/task;
(3) and more situational, *chronological awareness* about when and what and by whom something in the collective system is changing.

The above *collective awareness* taxonomy provides a useful starting point for an overall conceptual framework for the awareness mechanisms for the Internet scientific/scholarly communities. In the next section a preliminary conceptual framework based on the *living systems theory*[8] is presented. Following that, the *collective intelligence* model is sketched as a cognitive substructural level for a higher system level in the *living systems theory*.

III. CONCEPTUAL FRAMEWORK FOR THE INTERNET

In order to analyze the full range of awareness issues relating to how to provide and to access information resource on the Internet effectively for scientific/scholarly communities, an overall conceptual framework based on the *living systems theory* can be used for describing various requirements from small collaborative projects to the research communities at large. In addition, such overall framework allows a smooth integration of the *collective intelligence* cognitive model with an *information exchange* sociological model of science.

A. Living Systems Theory

Communities (or groups, organizations) are open systems. That is, a community maintains a relatively stable structure and boundary while receiving inputs from the environment, processing them, and extruding outputs. The human components of organizations—individuals and groups—are also open systems. Furthermore, these open systems are composed primarily of living entities—cells, organs, and organisms.[15]

Living systems theory is the life's work of James Grier Miller.[7,16] The basic systems theory was built upon a search for the common properties of all living systems. Miller's theory of living systems goes beyond general and open systems theories in describing the vital systems and processes inherent in cells, organs, organisms, groups, organizations, communities, societies, and supranationals (Fig. 1).

Viewed from this open systems perspective, the Internet and the virtual scientific communities on it can be considered as the integral parts of a cybernetic living system at the meta-community level. It is natural, therefore that living systems theory should be applied to the understanding of this emergent CyberOrganism and its psycho-social behaviors. Such an ensemble from the human–machine–environment triad can be conceptualized as a cross-over between Cyber-

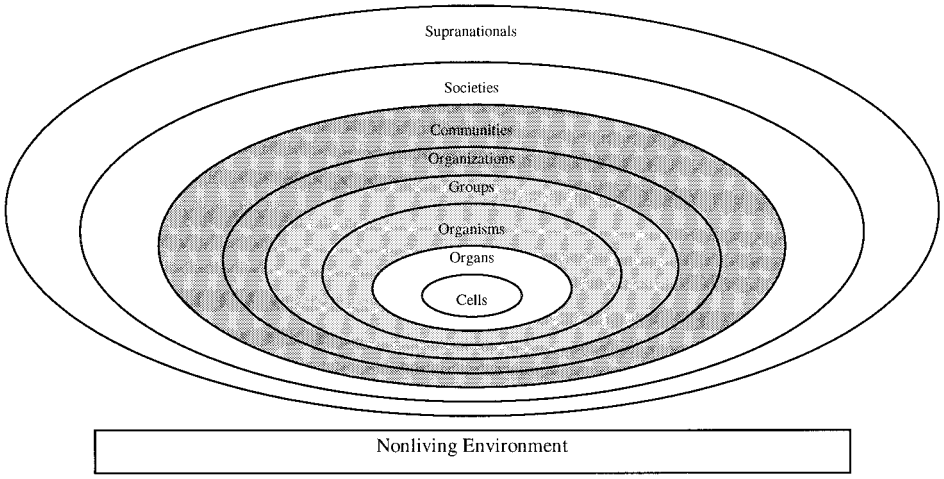

Figure 1. Levels of living systems and nonliving environment.

Space[17] and Virtual Communities.[6] The CyberOrganic context is mainly focused on the four levels: organism (i.e., individual), group, organization, community of living systems theory (the shaded areas in Fig. 1).

B. Critical Subsystems in Living Systems Theory

This subsection briefly describes the basic concepts in living systems theory (LST) as a foundation of a basic overall conceptual framework for the Internet. The basic living systems theory was built upon a search for the common properties of all living systems. It should be noted at this point that the basic theory is in flux, and may continue to be. LST demonstrates that living systems exist at eight levels of increasing complexity from cells, organisms, to groups, communities, and supranationals.[18]

Originally, the book *Living Systems*[7] presented 19 basic subsystems at seven levels, and since then, James Grier Miller and his long time collaborator and co-author Jessie L. Miller, have added a 20th subsystem, the *timer*, and an eighth level, the *community*. The community level was added between the organization and the society. The timer subsystem was added to the original list of nine information-processing subsystems, making a total of 10 (not counting the boundary and reproducer, which process both information and matter–energy).[16] The 20 subsystems (shown in Table I) are responsible for the ongoing day-to-day operation of the living system; it is these subsystems which keep the system alive.[18]

1. Critical Subsystems

The survival and health of individuals, groups, organizations, communities, and societies depend on performance and coordination of a set of essential processes. In all, LST identifies 20 critical subsystems carrying out these

Table I. The twenty critical subsystems of a living system.

Subsystems Which Process Both Matter–Energy and Information	
1. Reproducer	
2. Boundary	
Subsystem Which Process Matter–Energy	Subsystems Which Process Information
3. Ingestor	11. Input transducer
	12. Internal transducer
4. Distributor	13. Channel and net
	14. Timer
5. Converter	15. Decoder
6. Producer	16. Associator
7. Matter–energy storage	17. Memory
	18. Decider
	19. Encoder
8. Extruder	20. Output transducer
9. Motor	
10. Supporter	

Source: Adapted from Refs. 7, 15, and 16.

processes at every level. For example, a channel and net subsystem to convey information from one part of the system to another was found to be necessary in cells as well as societies. The nature of that subsystem might vary but the function remained the same. Some critical subsystems process matter–energy, some process information, and some process both.[15] From this holistic perspective, the chronological awareness for community can be viewed to be one of the fundamental components (in the intersection of the timer critical subsystem and the community level) in the living systems theory. A comprehensive presentation of the critical subsystems in the LST, is given by Miller[7] and Tracy.[15] For the purpose of this article the timer subsystem is most relevant to chronological awareness. The following subsections provide brief descriptions and examples of the 20 critical subsystems in the LST.

a. Subsystems processing matter–energy and information.

Reproducer. The subsystem which carries out the instruction in the genetic information (*template*) or character of a system and mobilizes matter, energy, and information to produce one or more similar systems. For examples: in the group level, parents who create a new family; in the organization level, any individual, group, or department that produces a new organization with an implicit or explicit charter similar to that of the original organization; and at the community level, national legislature that grants state status to territory.

Boundary. The boundary is the subsystem at the perimeter of a system that holds together the components which make up the system, protects them from environmental stress, and excludes or permits entry to various sorts of matter–energy and information.[7] At the group level, matter–energy: inspect soldiers of a platoon; information: TV-viewing rules in a family. At the organization level,

matter–energy: security guards at entrance to a firm; information: librarian. At the community level, matter–energy: agricultural inspection officers; information: movie censors in a town.

b. Matter–energy processing subsystems.

Ingestor. The Ingestor is the subsystem that brings matter–energy into the system across its boundary. At the group level: refreshment chairperson of a social club. At the organization level: receptionists and personnel department process inputs of people. And at the community level: airport authority of a city.

Distributor. The distributor subsystems carries matter–energy throughout the system wherever it is needed. The matter–energy may come from the environment through the Ingestor, from another internal process, or from storage. At the group level: father who serves dinner. At the organization level: assembly line. And at the community level: county school bus drivers.

Converter. The subsystem which changes certain inputs to the system into forms more useful for the special processes of that particular system. At the group level: work group members who cuts cloth. At the organization level: operators of an oil refinery. And at the community level: city stockyard organization.

Producer. The producer subsystem takes matter–energy inputs directly or from the converter and synthesizes them into new materials. These new materials may be used by the system to provide energy, repair damage, or grow. They may also be extruded as trade goods or waste. At the group level: family member who cooks. At the organization level: machinery artifacts in manufactures. And at the community level: bakery and restaurant.

Matter–Energy Storage. The subsystem which places matter or energy at some location in the system, retains it over time, and retrieves it. At the group level: family members who put away groceries. At the organization level: stockroom personnel. And at the community level: county jail officials.

Extruder. The extruder subsystem transmits products and wastes across the boundary and out of the system. At the group level: kids who put out trash. At the organization level: employees in packaging, shipping, and mail room. And at the community level: city sanitation department.

Motor. The motor subsystem moves the system itself or parts of it, as well as components or the environment. At the group level: drivers of family cars. At the organization level: earth movers or cranes and their drivers of a manufacture. And at the community level: subway system and city transit authority.

Supporter. The support subsystem separates the various components of the system and maintains the proper spatial relationship between them so that they do not crowd each other. At the group level: housing construction crew. At the organization level: land and artifacts such as buildings and platforms. And at the community level: maintenance crew at capital building.

c. Information processing subsystems.

Input Transducer. The input transducer subsystem serves the same function with respect to information that the ingestor serves for matter energy. The input transducer brings information-bearing markers across the boundary and into the system. (A marker is a physical representation in form of a structure, pattern, or interaction of matter–energy.) At the group level: lookout of a gang of thieves. At the organization level: people in such departments as marketing research, sales, purchasing, legal, accounts, and receivable, and product research. These people obtain information from the environment. And at the community level: representatives who report from a state capital to local voters.

Internal Transducer. The internal transducer subsystem receives information-bearing markers from other subsystems or components of the system and converts the markers to nerve impulses. It is the sensory subsystem that receives markers changing them to other matter–energy forms of a sort which can be transmitted within it. At the group level: group member who reports members' opinions to group decider. At the organization level: employees who makes internal reports on the status of, or changes in, variables of the system's components or subsystems, such as a factory quality control unit. And at the community level: neighborhood watch groups.

Channel and Net. The subsystem composed of a single route in physical space, or multiple interconnected routes over which markers bearing information are transmitted to all parts of the system. At the group level: person-to-person communication channels among group members. At the organization level: people at nodes of organizational networks, such as switchboard operators, secretaries, managers at all levels. And at the community level: telephone linesmen in a city.

A *timer* subsystem transmits information to a decider subsystem about time-related environmental states or about of components of the system. This information signals the deciders of subsystems to start, stop, alter the rate, or advance or delay the phase of one or more of the system's processes, to coordinate them in time. The timer consists of one or more oscillators known as clocks or pacemakers, the phase of which can be reset. They measure duration or order in time or underlying rhythms of various sorts. The timer synchronizes internal processes of the system and coordinates the system with its environment.[16] For example, at the group level, a mother wakens other family members on time; at the organization level, workers take regular monthly inventory; and at the community level, artifacts such as clocks mark the opening and closing of schools and buildings, as well as regulating traffic lights and parking meters. The same can also be applied to a larger time scale, in terms of annual community celebrations of local and national holidays.

Decoder. Each living system has its private code for information. Data obtain through the input and internal transducers must be decoded and recorded into this private code by the decoder subsystem. At the group level: member who explains rules to a project team. At the organization level: manager who decodes the angry countenance of an employee into thoughts about the employee's atti-

tude. And at the community level: attorney general of a state who interprets law.

Associator. The Associator subsystem carries out all the learning processes of forming links or associations among various items of information. The associator is analogous to the producer in the sense that an association between two or more bits of information is a new bit of information. That is, putting bits of data together is like combining elements such as carbon and oxygen; the result is more than the sum of its parts. At the group level: parents who teach good behaviors to their children. At the organization level: people who train new employees. And at the community level: city school teachers, religious leaders in a neighborhood.

Memory. The memory subsystem completes the learning processes. It stores original bits of information and associations so that the total information in the system can grow over time. Memory processes involve input (recording or memorizing), maintenance (retention and recording as well as forgetting), and output (retrieval or remembering). Humans use artifacts like books, memos, diaries, files, and recordings to aid the memory subsystems. At the group level: father who keeps family records and history. At the organization level: accounting department keeps financial records or filing department of a firm. And at the community level: operators of computer data bank at a central police department.

Decider. The decider subsystem is the most essential of all, according to Miller. It is the executive center that receives data from various sources throughout the channel and the net and sends control information (orders) to all parts of its system.[7] Decision involves four stages: (i) establishing purposes and goals; (ii) analyzing discrepancies between the current state and variables and their desired state; (iii) synthesizing and choosing a plan of action to attain the desired state; (iv) implementing the plan by issuing appropriate commands. Human artifacts of this subsystem include handbooks, algorithms, and computers.[15] At the group level: parents, family council. At the organization level: the top echelon of the decider may be the board of directors as a group or an individual such as the chief executive officer. And at the community level: governor, legislators, judges of a state.

Encoder. The subsystem which alters the code of information input to if from other information processing subsystems, from a ''private'' code which can be interpreted by other subsystems in its environment or by other living systems. It reverses the processes of the decoder. At the group level: writers of a group communication. At the organization level: billing, advertising, public relations, and legal departments that handle bills, advertising copy, and other messages that must be encoded for transmission to other systems. And at the community level: writers of city ordinances.

Output Transducer. The output transducer transfers information from internal markers to external markers that are suitable for carrying information in the system's environment. It changes the internal markers into other matter–energy forms which can be transmitted over the channels in the system's environment. At the group level: jury foreman who speaks for the jury as a whole. At the organization level: employees who deal with the public, such as salespeople,

secretaries, spokespersons, and labor negotiators. And the community level: representatives from a state to a regional legislature.

IV. CHRONOLOGICAL AWARENESS

This section examines various issues relating to awareness of changes in a working environment. The focus here is on chronological awareness, that is, the awareness of when something (an event or an artifact) has changed. Members of a group may be interested to know someone has modified an artifact, or when a new (and potentially relevant) artifact has been created. The information systems that support such awareness correspond closely to the timer critical subsystems in a living system.

A. The Need To Be Aware of Changes

In a dynamic environment where large amounts of information are created and updated frequently, the need to keep up with the most up-to-date and relevant information has become more important as the Internet communities expand. In terms of group collaboration, to be aware of changes is one of the fundamental requirements for coordination and for providing a sense of connectedness.

Some of the characteristics of human intellectual work that are valued most highly are: coherence, consistency, correctness, and elegance. It is difficult to imagine how work with these attributes could be produced without that structure of ideas having been held in its entirety by a single mind—if not actually produced by that mind.[8] As stated previously, however, by considering awareness from a functional point of view, one may be able to construct mechanisms that enable groups to achieve comparable results. Web pages, FTP archieves, Listservers, and other common infrastructures are becoming the primary means for information dissemination on the Internet, and these information infrastructures are being constantly updated to reflect members' current states of knowledge on their portions of collective memory.

As a part of the collective awareness taxonomy, a chronological awareness support system for the Net provides each individual an instantaneous awareness of other individuals' activities. Hence it allows team members to synchronize their activities in a more coherent way by keeping them informed and aware of any changes made ot each other's web pages or other information resource that might be relevant to their current tasks.

In addition, a chronological awareness support system saves time and effort in several ways. For examples: first, there is no need for group members to sit in front of their web browsers (e.g., Mosaic, Netscape) clicking and checking each other's documents separately; and, second, web users do not need to check every URL they monitor just to learn that nothing has changed. The system indicates for the users the Internet documents that have changed and need their personal attention.

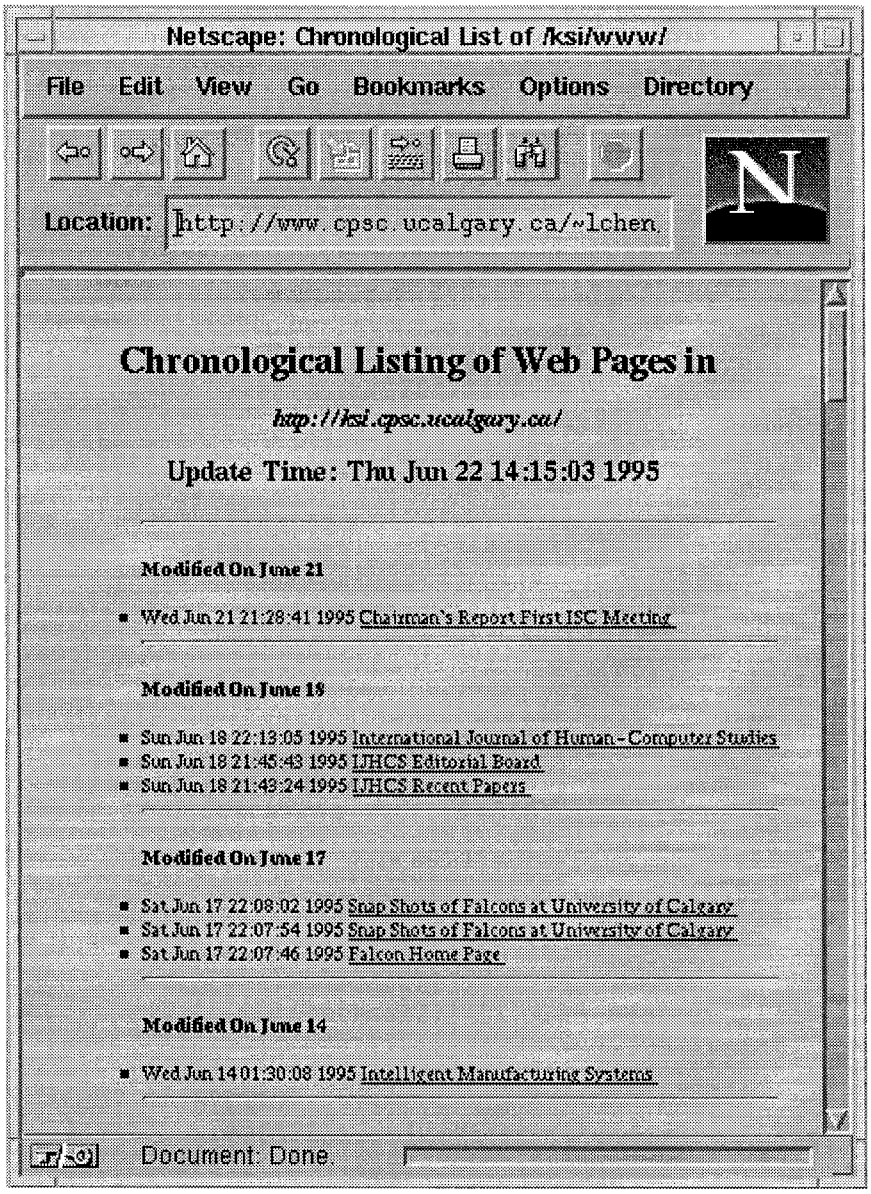

Figure 2. Screen snapshot of CHRONO.

The following subsections describe a group of experimental awareness–support systems related to the *timer* subsystem and explore how the chronological awareness support systems together with various existing information systems on the Internet can fit into an overall conceptual framework based on a collective intelligence model and living systems theory.

B. The CHRONO Chronological Awareness System

CHRONO† is an HTTPD server-side system which generates chronological listings of web pages that have been changed recently at specific sites. It provides a basic awareness-support that lets visitors to a web site (e.g., members of a group, an organization or other net-surfers) see which web pages have been modified since their last visit. Currently, the CHRONO system is implemented on a UNIX platform (see Fig. 2). CHRONO presents to the visitors an HTML document that lists the titles of web pages at the site in reverse chronological order. This chronological listing of web pages also functions as a collection of hyperlinks to the listed pages.

1. CHRONO User Interface and Its Functionality

The user interface of the CHRONO system is fairly straightforward and intuitive for web users. It looks like an automated *what's new* page to the users. From the list, the visitors will be able to tell at a glance what documents have been modified or created recently. They can also scroll down the list to check those older documents at the site. Because the titles of the listed pages also act as hyperlinks to the actual web pages, the visitors can simply click on them and jump to the relevant pages of interests.

Therefore in addition to typical hyperlinks in HTML documents which provide linkage to related information, chronological hyperlinks presented in the CHRONO listings provide the visitors the means to access the newly modified or created pages. This *time-line* (or history) dimensionality of a chronological listing complements the functionality of the associative memory characteristic found in typical hyperlinks that join related information.

This *time-line* dimension allows frequent visitors of a web site an immediate awareness on what have been changed since their latest visit. The changes may reflect some web pages in which they have been previously interested or they may show some pages that the visitors have never seen before but now appeal to them. Hence this chronological browsing characteristic is analog to spatial (subject-category) browsing characteristic that library patrons have often experienced when looking for books on open bookshelves [i.e., accidentally finding (more) relevant books near the books that they were looking for originally].

The difference is that instead of finding relevant information via browsing the near by subject-categories, the users may now find relevant information via browsing the concurrently modified/created web pages. Sometimes, conceptually related documents are created (or modified) around the same time, however their author(s) may not remember to update the HTML links to them. Unlike a manually updated what's new page in which the users have to rely on the timely updates made by a webmaster (or by the document authors), CHRONO

†CHRONO and related systems can be accessed via: http://ksi.cpsc.ucalgary.ca:8008/cgi-bin/release?cois1.

provides the time-line dimension to the users automatically, in a reliable and periodic fashion.

2. CHRONO Current System Usage

The CHRONO system has been set up for the Department of Computer Science at the University of Calgary since March, 1995. Because this is still an experimental service, its services have been limited to five web locations: two research units and three individuals. People associated with the two research units: Knowledge Science Institute and GroupLab periodically have utilized the system to check on new developments of each other (both within group and between groups).

From a preliminary examination of the HTTPD access_log of the CHRONO system site and from talking with individual group members, we have found that the system indeed has provided chronological awareness for group members at both the group and the organization levels. Most people have found such chronological awareness–support service helpful to them in keeping themselves informed about works of others. Occasionally, there have been visitors from other institutions browsing the chronological listings, but such accesses have been infrequent; the service has only recently been made generally known.

The chronological listings of the three personal sites have offered other group members more focused chronological awareness about these three individuals' working patterns. Occasionally, some people had discovered new projects the targeted individuals were working on that they were not previously aware. This positive usage experience of personal chronological listings suggests to us that there is a need to further examine the effectiveness of providing different subgroupings of chronological listings to group members. For example, chronological listings for particular subdirectories of a web site, for particular projects of a group, or for chronological access pattern of particular documents may prove to be useful for different occasions and user needs. The last example (i.e., the chronological access pattern) can be categorized as an instance for supporting mutual awareness.

In summary, the current experience of the CHRONO system has indeed demonstrated its usefulness for frequent visitors of a particular web site in formulating chronological awareness of changes at the site. It has been used by group members of two research units keeping tracks of new developments between the groups and within a group. Finally, there are different ways of subgrouping chronological listings at any given site. They may prove to be useful for different purposes and under different circumstances. Therefore they require further investigation to determine how they function as cognitive artifacts in supporting chronological awareness.

C. Related Chronological Awareness Systems

There are three other systems that provide support for chronological awareness based on different designs and implementations. These systems are briefly examined in this subsection, followed by a comparative evaluation of current chronological awareness systems.

1. WebWatch

WebWatch is a client-side chronological awareness system for keeping track of changes in selected web documents. Given an HTML document referencing URLs on the web, it produces a filtered list, containing only those URLs that have been modified since a given time.

The chronological criteria used for filtering can be given as a global setting that applies to all URLs, or can be derived automatically, using the time of user's last visit to the document, as recorded by the web browser in the user's local HTLM (bookmark) file. The system generates a local HTML document that contains links to only those documents which were updated after the given date. Later on, the user can load this document into any web browser and use it to navigate to the updated documents. WebWatch retrieves only the ''header'' of a document, to check its ''Last Modified'' date. The size of this header is usually quite small compared to that of the entire document. Hence, the user connect time, and ultimately the load on the network, is significantly reduced.

In contrast with the simple line listing strategy used in CHRONO, it stores its arguments in a parameter file. Once the users have customized the program to their needs, using its graphical front-end, they can have it run periodically in unattended mode.

2. Katipo

Katipo is another client-side chronological awareness system built for Macintosh that shares many similar concepts as WebWatch. It reads through the Global History file maintained by some web browsers checking for documents that have changed since the last time a user viewed them. It writes a report file (in HTML format) listing all such documents in a format that allows you to easily visit the updated documents. Currently, Katipo only checks for HTTP URLs, not Gopher, FTP, etc. The basic differences between it and WebWatch is that it uses the Global History file as its reference for checking URLs, whereas WebWatch uses the Bookmark file.

3. URL-Minder

URL-minder is a centralized system that keeps track of resources on the Net and sends registered users e-mail whenever their personally registered resources change. Users can have the URL-minder keep track of any web resource accessible via HTTP. It can be anything—not just web pages users personally maintain.

The chronological awareness system keeps track of one web page, image file, or other Internet resource at a time. It will not keep track of all the web pages linked to the page that a user submits. A separate URL must be submitted for every distinct page users want the URL-minder to track for them. The URL-minder tracks the actual HTML markup, binary contents, or ASCII contents of the URL they have submitted. If an HTML page includes a GIF or JPEG graphic, the URL-minder will inform them when the reference to the graphic changes.

If the users want to know when the actual content of a binary graphic file changes, they must submit the URL to the binary graphic itself. The URL-minder currently checks on users' registered URL's at least once per week, and will inform them if it fails to retrieve their registered URL after trying twice.

D. Evaluation of the Chronological Awareness Systems

This subsection presents a comparative evaluation of the four chronological awareness support systems discussed previously: CHRONO, WebWatch, Katipo, and URL-minder. Each system has its unique approaches for achieving chronological awareness support for web users and complement each other along three main dimensions:

(1) Locus of Responsibility: Server-Side, Client-Side, or Centralized Dispatcher
(2) Method of Locating Changes: Browsing versus Targeting
(3) Complexity of User Interaction: Simplicity versus Customization

The first dimension, the *locus of responsibility*, differentiates who is responsible for maintaining the record-keeping mechanisms for chronological awareness. For example, CHRONO is a server-side system in which chronological listings are being updated and kept at the web server-side. This strategy ensures that only the users who are current visiting the web site would need to know what information has been changed. Hence, it reduces network traffics by avoiding needless broadcasting of chronological information to some users who might not be concerned with it. Thus, CHRONO can be thought of as offering ''chronological awareness on demand.'' The main disadvantage of this strategy is that in order to know whether or not any particular page has been changed, a user would need to check out the specific web site periodically. WebWatch and Katipo, however, put the responsibility of maintaining chronological awareness on the client-side. Both client-side systems periodically monitor specific pages at various web sites and report whether or not they have been changed recently. Hence, both ensure the user would be aware of any changes. The main disadvantage is that the users need to remember to run such a system, or it must be set up to run periodically, in turn causing it to consume higher network bandwidth. Finally, URL-minder requires its users to register at a centralized site, so that it can automatically monitor the registered pages for the users. Its main disadvantage is the high network traffic involved in such a centralized broadcasting scheme.

The second dimension, the *method of locating changes*, involves two different ways of locating documents that have been changed: browsing and targeting. CHRONO uses the browsing approach in order to facilitate the chronological browsing characteristic: visitors of a site may find relevant information via browsing the concurrently created/modified web pages, because closely related documents are sometimes created (or modified) around the same time. This browsing approach allows the *at glance* attribute for accidental discovery of relevant information without prior awareness of their existence. Conversely, WebWatch, Katipo, and URL-minder employ a targeting approach in which they are targeted

on specific pages or information that users have previously specified. Therefore this method of locating changes is more direct and efficient. However the main disadvantage of such an approach is that the users cannot be made aware of any new information which have been created recently. They are limited only to change made to prior knowledge.

Finally, the third dimension, the *complexity of user interaction*, denotes system usability in terms of simplicity versus customization. CHRONO and URL-minder are in the simplicity category in the sense that their user interfaces are simple and familiar to web users (i.e., scrolling list of hyperlinks and fill-in form of URLs and e-mail address). They are geared toward ease of use and a shallow learning curve. Both systems, however, have no capability for individual customization. In contrast WebWatch and Katipo allow elaborate customization of features, but they also demand more efforts by the users to learn and utilize their functionality.

Therefore, each chronological awareness support system examined so far have various degrees of advantages and disadvantages along the three dimensions. CHRONO has the advantages of: (i) simplicity of user interface; (ii) supporting accidental discovery via its browsing characteristic; and (iii) server-side chronological awareness information on demand. It is nicely complimented by WebWatch and Katipo for their strength in the efficiency of targeting approach and customization capabilities. And finally URL-minder offers another unique service: it uses e-mail as its notification channel. This approach is useful for users who use their e-mail systems more frequently than web browsers. Therefore together as a whole, these chronological awareness support systems have covered a wide range of approaches in respect to three major dimensions of chronological awareness support.

V. TOWARD A CYBERORGANIC FRAMEWORK

When the *collective intelligence* model is viewed with in the context of the living systems theory (LST), its basic concepts of human–computer symbiosis, collective awareness, and collective control can be extended to formulate a broader conceptual framework for the Internet. This LST-oriented conceptual framework characterizes the Net as an emergent living system that is called CyberOrganism. Such an overall conceptual framework also takes into account the *information exchange* process in the social system of science.

Using the living systems theory as a fundamental blueprint, a preliminary framework for conceptualizing the psycho-social dynamics of the scientific/scholarly communities on the Internet can be sketched. The Internet and the virtual scientific communities will be considered as the integral parts of a cybernetic living system at the meta-community level in the living systems theory.

The following subsection tentatively sketches out a preliminary, structural–functional description of the emerging CyberOrganism (i.e., the Net as an emergent phenomenon/artifact from organizational, group, individual sublevels). Global computer networks (like the Internet), workstations, etc. become its

matter–energy infrastructures and WWW, Mosaic, CSCW, etc. become its information processing infrastructures.

A. Critical Subsystems at the CyberOrganism Level

Reproducer. Matter–Energy: Corporations (usually multinationals) and governmental agencies (e.g., NSF, ARPA) that build computer networks and communication infrastructures which use the Internet as their blueprint/foundation. Information: Communication system engineers who design communication protocols, networking software, and operating systems for the Internet and the World Wide Web.

Boundary. Matter–Energy: network routers, networked personal workstations. Information: computer networks administrators; referees of electronic scientific journals.

Ingestor. Purchasing departments that are responsible for acquisition of computers and networking gears; local telephone companies that act as common networks carriers; local power utilities which bring in electrical power source for the computer networks.

Distributor. Long-distance telephone companies that provide the networking backbone infrastructures for the Internet.

Converter. Packet switching network servers that converts raw data into data packets for transmission, e.g., ATM networks.

Producer. Telecommunication and computer companies that produce workstations, networking hardware, etc.

Matter–Energy Storage. Computing centers at university campuses that store computer equipments, spare parts, etc.

Extruder. Data processing departments that produce billing letters, advertising mails, etc.

Motor. Telephone linesmen, computer networks installation crews.

Supporter. Chief information system officers in corporations who maintain overall integrity of company computing resources.

Input Transducer. Data processing operators who input information; software programmers who input computer codes into computers; anyone who operates computers that are tied to the Net directly or indirectly.

Internal Transducer. Client-side networking programs (like Mosaic and Netscape browsers) that receive markers from the input transducers or other subsystems and convert them into HTTP network protocols for transmission in the web.

Channel and Net. Various LAN's; the Internet information technology; World Wide Web.

Timer. Chronological awareness support subsystems like *CHRONO* (or *WebWatch*) that periodically update the information about the time-related states of the environment (or of components of the system) to other subsystems.

Decoder. Operating systems that handle data packets and low-level protocols like TCP/IP.

Associator. Hyperlinks in Web pages; subject hierarchy systems like *Yahoo*; editorial departments that keep *what's cool* site information; educational institu-

tions that teaching computer skills; USENET Newsgroups, MOO, IRC, and Web conferencing systems (such as *HyperNews*) for collaborative learning between individual users or project groups that are often instigated by individual inquiry, followed by collective idea-generation process.

Memory. Long-term: ftp archives, list servers, gopher or Web documents, etc. short-term (working memory): USENET, e-mails (could become long-term if necessary; however, such STM to LTM transformation are often selective).

Decider. Technology policy departments in national government; industrial consortia; individual research groups.

Encoder. HTTPD CGI (common gateway interface) servers that encode relevant information into HTML (hypertext markup language) documents for the web.

Output Transducer. Computer users who get information from the Internet and act upon it, such as customer service, accounting, and credit-checking departments, field technicians, private detectives who counsel the Internet information services for data retrieval.

B. Collective Intelligence Model

Smith's Collective Intelligence Model[8] can be characterized as a cognitive model within the living systems theory. It focuses on two system levels: the individual (organism) and the group levels (the lightly shaded inner areas in Fig. 1). The model regards collaborative groups as a form of information processing system, analogous to Newell's and Simon's IPS model of individual cognition.[14,15]

Within the model, a collective memory system includes subsystems that provide a collective long-term memory (LTM) for tangible knowledge, built and maintained in a computer system, and for intangible knowledge, carried in the heads of the human beings that comprise the group. The memory system also includes working memory (the currently attenuated awareness) for both types of information.

A collective processor includes the fine-grain operations used by groups to develop, access, and maintain the information stored in the memory system. The collective processor as a whole can be viewed as a loosely coupled distributed system that includes multiple independent processors, joined by communications and social networks.[8]

Collective strategy enables coherence in collaborative work. Individual processes occur not in isolation but in purposeful sequences. These strings of operations are analogous to statements in a language intended to accomplish a goal or to communicate a message. The system responsible for generating sequences of operations is analogous to the grammar individuals used to generate a string of words. Therefore a collection of collective strategies become a work-flow model for the collaborative group.

Finally, the model considers two meta-cognitive issues: collective awareness and collective control. Many collaborative projects are too large and too complex to be understood by any one person. However, people often expect groups to

produce work with the same integrity and consistency sometimes found in work produced by a single good mind working alone. By developing thick, overlapping areas of shared knowledge, groups may be able to piece together a form of collective, but distributed peripheral awareness that is sufficiently coherent to achieved this goal. Control must also be distributed over a group. Otherwise, information will not flow across boundaries, and the group and its work will be brittle. However, although many decisions can, and probably made by consensus, authority must ultimately be centralized in order to resolve disagreements and to preserve the integrity of the group's work.[8] Here chronological awareness provides essential information for groups to exercise distributed, collective controls that maintain smooth coordination.

C. Social System of Science

In his book, *Toward a Political Sociology of Science*, Blume describes the social system of science.[9] Sociologists use the term, *social system*, to stress *pattern* of interaction between individuals characteristics of the system in question, recognizable, and not subject to unanticipated change. Maintenance of these characteristic patterns of actions is inductive of their mutually rewarding nature for participants.

The permanence of social systems and of economic, religious and other subsystems indicated that the rewards received by participants in response to prescribed behavior are unchangingly desirable and obtainable. Some sociologists have emphasized the ''*exchange*'' element in the operation of social systems. Thus the question becomes: what is the precise nature of the commodity of science: what do scientists contribute to the scientific community, for which they expect reward?

Some sociologists view the contribution of information as crucial, although such information must be original for the higher rewards. Merton emphasized the importance of originality and the significance of establishing one's own priority in making a discovery.[19] Because originality alone is rewarded, priority disputes are necessary for maintenance of the scientific system. They also produce neurotic anxiety in scientists, and deviant patterns of secretive behavior.[20,21] Therefore chronological awareness systems on the Internet become essential for establishing records of *priority* keeping.

Also, the *information exchange* process can also be viewed in terms of ''communication.'' Hence the issue of responsibility for maintaining communication becomes important. For example, a researcher needing some information has to determine if the effort required to find out if that information is on the Internet is greater than or less than the effort required to find it in other sources or to regenerate it. Similarly, a provider of information resource has to determine how much effort should be put into making it accessible to others for the dissemination process. Both sides have their own responsibility and reward criteria at different system levels in the CyberOrganism framework.

D. CyberOrganism and Awareness Maintenance

The *collective intelligence* model is viewed within the context of the living systems theory (LST), its basic concepts of human–computer symbiosis, *collective*

awareness, and *collective* control can be extended to formulate a broader Cyber-Organism conceptual framework for the Internet.

Within this CyberOrganism perspective, individuals, groups, organizations, and communities together create a collective intelligence that becomes a pool of human knowledge for individual collaborators in remote sites to share their ideas and all aspects of collaboration. In order for the CyberOrganism to function in a cohesive and integrative manner, coordination at various system levels must be maintained. However the means for maintaining the Net cohesion and integrity are still in a gradual process of emerging and evolving.

One of the main issues involved in achieving system coordination is the notion of awareness maintenance. Awareness maintenance is concerned about how subsystems in various levels of the CyberOrganism (namely, group, organization, and community) be aware of each other, both within specific levels and between them. Such maintenance of mutual awareness is essential whenever individuals, groups or organizations are involved collaborative tasks.

Section IV has presented chronological awareness support systems as a type of systems designed mainly to support awareness maintenance for individuals at the group level (and to some degree at the organization level). Currently there are other types of awareness maintenance systems on the Internet that address different system levels. The following section examines and categorizes them along two dimensions: *level of awareness* and *locus of responsibility*.

VI. CLASSIFICATION OF EXISTING INTERNET TOOLS

The previous section has discussed the concept of system levels in the living systems theory, and described a CyberOrganism framework for the Internet that focuses on the dynamic interactions between individuals, groups, organizations and communities. Within this framework, individuals constitute the fundamental level of analysis in the overall system. Self-awareness provides a sense of identity, purpose, and consciousness to each individual. When perceiving all levels collectively, the notion of self-awareness can be extended to different hierarchical partitions in the system for the purpose of analyzing the interrelationship between the overall system and its parts in the collective stance.[22]

A. Locus of Responsibility for Awareness Maintenance

Hence, collective awareness occurs at every level above the individual level in the system hierarchy. In order to function as a coherent whole, mechanisms for maintaining awareness in the group, organization, and community levels will need to exist first. Currently there are various tools and systems on the Internet that have emerged to fill the roles of providing awareness maintenance for various levels.

Various information systems, such as the web, use the client-server model to partition the computational division of labor. Similarly the locus of responsibility of awareness maintenance at every level can be divided into originators (i.e., providers) of information and retrievers of information. An originator is a source/

Table II. Taxonomy of mechanisms supporting awareness maintenance.

Locus of Responsibility	Level of Awareness		
	Group	Organization	Community
Originator	Work flow model **CHRONO** E-mail to notify	Broadcast to listserver Register in **What's New** Announce in MOO Establish HTML links	Register in **Yahoo** Initialize **Web Crawler**
Retriever	**WebWatch/Katipo** **URL-minder** E-mail to inquire	Participate in **HyperNews** Participate in MOO Follow HTML links	Browse **Yahoo** **LYCOS** search Read/Post to USENET **Web Crawler** search

server of information dissemination and a retriever is an user/client of information resource. Within the living systems theory, originators and retrievers of information are situated at the opposite ends of the channel and net information subsystems.[7] The various awareness maintenance mechanisms (such as the chronological awareness support systems for groups) serve as (or provide the functionalities of) the timer, associator, and memory subsystems in the CyberOrganism. Therefore using the two dimensions: level of awareness and locus of responsibility, a taxonomy of web tools and systems for awareness maintenance can be outlined.

B. Internet Tools Classification

Using the locus of responsibility dimension at the group, organization, and community level, one can categorize various tools and systems for maintaining situational awareness of the current information resource on the Internet (Table II).

At the group level, originators of the information resource can organize and implement work flow models of the group activities, use server-side chronological awareness support systems such as CHRONO, or/and send e-mail notification to users of information. Retrievers of the group level information resource can use client-side chronological awareness tools such as WebWatch and Katipo or register in a centralized dispatcher service like URL-minder. Alternatively, they can send e-mail to information originators to inquire if any new things have come up.

At the organization level, originators of the organizational resource can broadcast to concerned individuals, groups, or organizations via specific Listservers, register in NCSA's What's New service, or announce in organization-maintained MOO or MUD. They can also establish what's new HTML links in organization news while retrievers can participate in HyperNews or MOO, and follow the new HTML links in organizational web pages.

At the community level, originators can register the information resource in hierarchical subject services like Yahoo, or initialize their pages in searching and navigational services like Web Crawler while retrievers can browse Yahoo, search LYCOS or Web Crawler, or read and post to the USENET groups.

One interesting observation can be made about the level of awareness in relation to the level of coordination. As the level of awareness moves from the group level to the community level, the need for closely coupled coordination decreases among members. What happens in practice is the awareness maintenance becomes asymmetrical, rather than mutual, at the higher system level. However major awareness requirement continues. Resource providers may not need to be aware of who their users are, but the users' activities may be critically dependent on the status of the resources.

VII. CONCLUSIONS AND FUTURE WORK

The article first introduced the issues involved with various aspects of awareness in collaborative work on the Internet. This collective awareness taxonomy provides a useful starting point toward an overall conceptual framework for the Net. In this article, one of the major topics has been on chronological awareness, and a group of experimental awareness–supports system has been described. Finally, the last section explored how the chronological awareness system together with various existing systems on the Internet can fit into the CyberOrganism framework via two dimensions of awareness maintenance: level of awareness and locus of responsibility. The framework provides a taxonomy for classifying Internet tools and systems for awareness maintenance. Together, the taxonomy and the evaluative dimensions (discussed in Subsection IV-B) become useful investigative tools[23,24] for studying and supporting collaborative communities on the Internet.

Therefore, the previous sections have developed an overall conceptual framework based on living systems theory and the collective intelligence model. Such a collective stance toward modeling the Internet as a living system presents a basic framework for structural–functional descriptions of the emerging CyberOrganism; that is, the perspective of the Net as a constantly evolving phenomenon/artifact that emerged from the dynamic interactions between the community, organization, group, individual partitions in an open-system.

The conceptual framework provides research directions to further investigate the psycho-socio nature of the Internet communities. For an example, in terms of chronological awareness, there is a need to further examine the effectiveness of providing different subgroupings of chronological listings to group members, such as chronological listings for particular subdirectories of a web site, for particular projects of a group, or for chronological access patterns of particular documents which may prove to be useful on different occasions and for varying user needs. In addition, the issues of how to establish mutual awareness between individuals, groups, organizations need to be explored further.

The difficult issue of what constitutes the decider subsystem in the CyberOrganism will need to be explored. One possibility, viewing from the *collective stance* perspective,[22] the *collective intelligence* might emerge as its executive subprocess-system. If so, a careful consideration of what constitute its senses of purposes will need to be explored, since a living organism is a purposeful system.

One furture research direction is to conduct focused studies on specific communities (e.g., various specialized fields in scientific/scholarly disciplines) that utilize the Internet as a major part of their integrative working environment. Using the conceptual framework stated so far as a guide and observational methodologies for group dynamics (e.g., Bales and Cohen's SYMLOG;[25] Losada, Sanchez and Noble's Group Interaction and Time-Series analysis[26]), it will be possible to investigate further the psycho-socio dynamics of those collaborative communities on the Internet. Presently there is also a preliminary attempt to incorporate individual and group motivational processes[27] into the CyberOrganism framework.

One practical issue inspired from the locus of responsibility for awareness maintenance at the community level is that of awareness of individual researcher profile of specialties as a research resource. One common question among many scientists/scholars is: who and how should one contact when specific research questions, needs, or opportunities have arisen? The challenge is how can we create an environment inductive for informal social networking among scientists on the Internet? What is proper balance between the originators and retrievers of such information resource? And an interesting question then becomes: will the social structures of science such as the Mullins and Crane's *invisible college*[28,29] be changed by the emerging patterns of scientific/scholarly collaboration through the Internet?

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