

ARTICULATING COLLABORATIVE ACTIVITY

Design-in-use of Collaborative Publishing Services in the Flora of North America Project

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Abstract

The grand challenge for the 21st century is to harness the rapidly accumulating knowledge of Earth's biodiversity and the ecosystems that support it. Meeting this challenge involves managing two kinds of complexity: the biological complexity of the organisms and the sociological complexity of biological information mobilization. The Flora of North America (FNA) is an authoritative resource to help manage the former source of complexity, while Collaborative Publishing Services (CPServices) is a tool to help manage the latter. The FNA project is an example of a large-scale and complexly distributed scientific database publishing activity that has been tightly coupled with traditional, paperbound publishing practices, which have been able to scale to accommodate and manage the complexities involved in articulating its work. The network-based coordination environment, CPServices, instantiates a role-based view coordinative protocol which inscribes and circumscribes the dependency relations among actors, activities, and resources, thereby both reducing the cognitive load of individual FNA project participants and managing the Project's collaborative load. This paper construes CPServices' role-based view to be a species of a larger class of constructs, normative boundary constructs, which are invented and adopted to manage interdependent work in large, distributed projects of long duration. Finally, normative boundary constructs, in turn, are placed within an activity theoretic framework to better explicate their value and use in such collaborative work arrangements.

Keywords:

Flora of North America, Collaborative Publishing Services, computer-supported cooperative work, activity theory, coordination mechanisms, articulation work, boundary objects

INTRODUCTION

The grand challenge for the 21st century is to harness the rapidly accumulating knowledge of Earth's biodiversity and the ecosystems that support it, if we are to both effectively manage biological resources in a sustainable manner and better understand the often profound effects of human settlement patterns on biological resources (National Research Council, 1993; Schnase et al., 2000). To accomplish this, biological information must be mobilized - assembled, organized, and delivered - with dramatically increased capacity. Problematically, many of the work processes used to create biodiversity databases are derived from traditional publishing methods. However, these approaches were never intended for use in the current distributed, large-scale computing environment that is increasingly a feature of contemporary scholarly activity, and, as a result of their inability to scale to accommodate these large, distributed scientific enterprises, they are increasingly unable to cope with the staggeringly complex problem of managing the articulation of requisite work processes in such projects (Schnase et al., 1997). In fact, many critical, large-scale database activities - such as documenting species diversity and tracking long-term environmental change - are becoming prohibitively expensive, difficult to manage, and are taking longer to complete than expected (French, Jones, & Pfaltz, 1990; Raven & Wilson, 1992; Tranter, 1994).

The Flora of North America (hereinafter FNA) project is an example of a large, distributed scientific database activity that has been tightly coupled with traditional publishing. The goal of bioinformatics researchers is to develop a new generation of network- and web-based tools - i.e., collaborative computing tools - to help the participants in projects such as FNA manage the articulation of their complexly interdependent activities.

Several frameworks and models to study computer-supported cooperative work (hereinafter CSCW) exist: actor-network theory (see, e.g., Callon, 1991; Latour, 1993); articulation work theory (Schmidt & Bannon, 1992); communicative action (Ngwenyama & Lyytinen, 1997); distributed cognition (Hutchins, 1995; Rogers & Ellis, 1994); ethnomethodology (Button, 1993); locales/social worlds (Fitzpatrick, Mansfield, & Kaplan, 1996); situated action (Chaiklin & Lave, 1993; Lave & Wenger, 1991; Suchman, 1987); socio-technical networks (Elzen, Enserink, & Smit Wim, 1996); and speech act theory (Winograd & Flores, 1986), among others. Taken together, they articulate a diverse and heterogeneous problem space and contribute much to our understanding of CSCW. Nevertheless, none of these frameworks has been able to fully comprehend the complexity of the social activity that is constitutive of groupwork since each approach conveys a different perspective and theoretical basis and thus focuses on a narrow area of the problem space.

Thus, as CSCW technologies continue to be designed and implemented at an ever-increasing rate, there is a call for more research to explicate how the complex social interactions of groupwork are articulated *in situ* (Kling, 1991; Grudin, 1993). Moreover, it is vitally important that the design of such systems is thoroughly grounded not only in a deep understanding of actual work practices in their sociocultural matrix (Bannon, 1991; Button, 1993; Suchman, 1987), but in a sufficiently rich conceptual framework to enable the clear and heuristically valuable articulation of this understanding.

In pursuit of such a framework, this research draws heavily on concepts taken from the coordination mechanism perspective (Schmidt, 1994, 1997; Schmidt & Simone, 1995, 1996; Carstensen, 1996; Carstensen & Sørensen, 1996) and from activity theory (e.g., Bannon & Bødker, 1991;

Blackler, 1993, 1995; Cole, 1985, 1996; Engeström 1987, 1990, 1996; Kuutti, 1991a-b; Nardi, 1996a-b). First, this paper reviews the FNA project and its publishing process. Next, the design and development of the web-based collaborative publishing system, Collaborative Publishing Services (hereinafter CPSServices), is outlined. After characterizing the CPSServices environment, the coordination mechanism perspective is introduced and briefly discussed. The characteristics of normative boundary constructs, such as coordinative protocols, are lastly outlined and placed in an activity theoretic framework.

Developmentally, it is necessary to jointly and dialectically embed the design of collaborative computing systems in two design spaces: well-developed conceptual frameworks and detailed understanding of the work practices of user communities. This paper is a contribution to enriching the first design space.

FLORA OF NORTH AMERICA: BACKGROUND

FNA is a project undertaken by the community of systematic botanists to provide a wide range of users - including, scientists, government agencies, private industry, and amateur enthusiasts - with authoritative information on the names, relationships, characteristics, and distributions of all plants that grow outside of cultivation in North America, north of Mexico. The FNA project is gathering and making accessible, in a variety of media, scientifically authoritative and current data on the approximately 20,000 species of vascular plants and bryophytes [1] needed for decision-making, resource management, and innovative research. The geographic scope of the project includes the continental US, including the Florida Keys; the Aleutian Islands; Canada; Greenland; and the St. Pierre and Miquelon Islands – an area of more than 21 million square kilometers. Thus, FNA is intended to serve as a means of identifying plants of the region, as a means of delineating taxa and geographic areas in need of additional study, and as a systematic conspectus of the North American flora. The project first received funding in 1987 and is expected to be complete around 2006 (Morin et al., 1989; Morin, 1991).

“Treatments” provide data for the FNA database, electronic publications, and the printed multi-volume Flora. They typically focus on species within a single genus, and include identification keys, summaries of habitats and geographic ranges, pertinent synonymies, descriptions, chromosome numbers, phenological information, and discussions of other significant biological observations, distribution maps, and illustrations. Each treatment is prepared and reviewed by specialists, who study plants in the field, examine herbarium specimens, and review the scholarly literature. Despite their synoptic format, many of the treatments present, for the first time, knowledge from a systematist’s lifetime of study (Schnase et al., 1997).

In terms of the number of participants and their geographic distribution, FNA is one of country’s largest scientific collaborations; its workforce currently numbers over 800 personnel, including professional plant taxonomists throughout the world and biologists in such government agencies as the U.S. Forest Service, Bureau of Land Management, U.S. Fish and Wildlife Service, and myriad provincial, state, and county biological survey offices. More than 30 institutions have committed significant resources to the FNA project.

FNA PUBLISHING PROCESS

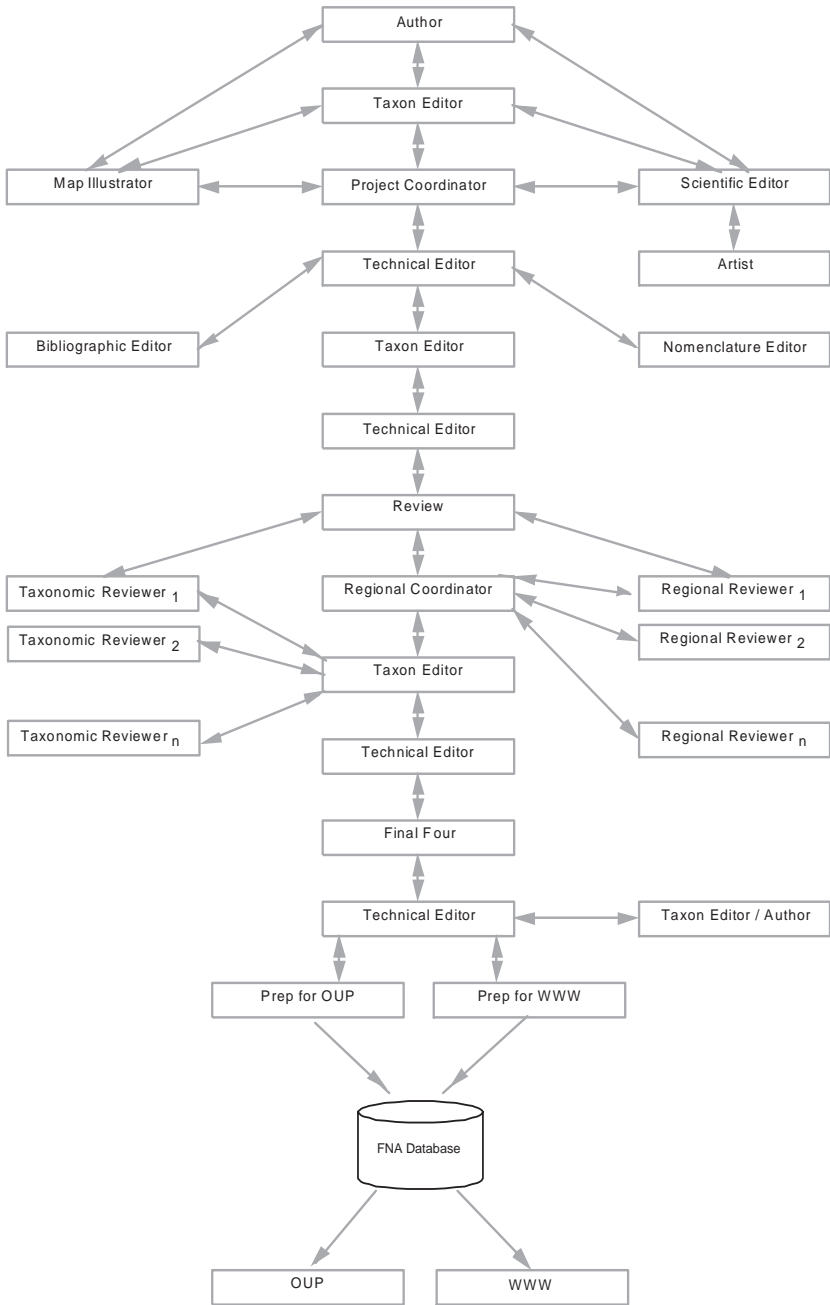
Authors are invited by the FNA Editorial Committee to prepare treatments describing various taxa; and collections of taxonomic treatments, including distribution maps and illustrations, are then reviewed, databased, and assembled into published volumes. The FNA Editorial Committee is responsible for identifying experts, soliciting their participation, and managing the various review processes.

The project's daily activities are coordinated at the Missouri Botanical Garden in the FNA Organizational Center. A mix of mostly paper and some electronic documents are used throughout. A total of five distinct review processes – taxonomic, regional, nomenclatural, bibliographic, and technical – ranging from review of scientific content and of style to evaluation of a taxon's conversation status, are performed (sometimes repeatedly) on each treatment once it is submitted. In fact, as depicted in Figure 1 below, there are approximately 100 discrete events associated with the publication of a single manuscript, and each event must be tracked and coordinated with other events, occurring serially and concurrently. Moreover, as many as 300 manuscripts can go into a single volume, and it is necessary to coordinate progress across several volumes simultaneously. This means that participants in the FNA project must effectively articulate a vast number of intra-document, inter-document/intra-volume, and inter-volume interdependent relationships among activities and participants.

In sum, the FNA project represents an attempt to adapt traditional methods of small-scale print publishing to a large-scale databasing and electronic publishing effort.

While the project is moving forward (the first three volumes have been published, and intensive work is well under way on volumes 22-24 and volume 4), with its 800+ participants scattered across North America involved in a decades-long effort and with hundreds of manuscripts in various stages of review by different sets of participants at any one time, traditional publishing methods are proving inadequate, inefficient, and simply unable to scale.

Figure 1. (Right) Pre-CPServices manuscript workflow diagram for the FNA Project showing steps involved in the publication process for each treatment (Schnase et al., 1997, p. 91). Single-arrow lines indicate directed flow; double-arrow lines represent bi-directional flow; rectangles to each side of the main vertical axial flow suggest parallel performance and processing of activities.



COLLABORATIVE PUBLISHING SERVICES (CPSERVICES)

Because of the huge scope of the project and the staggering number of inter-task and interpersonal dependencies that must be articulated in publishing thousands of manuscripts contributed by several hundred geographically dispersed scientists, traditional methods of small-scale print publishing have not scaled. Consequently, it was decided that new tools to enable new work processes must be developed, if FNA was not to fall even further behind its planned publication schedule.

In much of daily working life, the required articulation of individual activities is managed effectively and efficiently by a rich variety of intuitive interactional modalities, so much so in fact that the distributed nature of collaborative work is made neither manifest nor explicit. However, in the complex work environments of modern organizations, such as FNA, problems inevitably emerge because the scale of collaborative work is dramatically increased along the following dimensions (all of which characterize the FNA project):

- the collaborative work arrangement includes many geographically distributed actors;
- there are an enormous number of intertwined activities, actors, and resources;
- different areas of competence and different conceptualizations and goals are involved;
- different goals and objects are represented; and/or
- the collaborative effort is undertaken over a long time-span (e.g., FNA will take, at a minimum, from 1987 to 2006 to complete) (Carstensen & Sørensen, 1996).

The difficulty of coordinating work activities in large projects such as FNA conducted in elaborate settings can be clarified by making two fundamental distinctions. First, the social nature of all work must be distinguished from interdependence in work. All work is immediately social in that the relations between the subject and object, the means and the end(s), the motives and the needs, and the artifacts and actors' competencies are socioculturally mediated (Schmidt, 1994). However, mutual dependence in work does not refer to the interdependence that arises from simply having to share the same resource. Being mutually dependent in work means that actor A relies positively, but not necessarily harmoniously, on the quality and timeliness of actor B's work and vice versa.

Having asserted that participants in the FNA project are interdependent in their work, and thus that their inter-relations will inevitably be constrained by limited resources, practical exigencies, and social accountability, it is necessary to make a second distinction between *collaborative work* – interdependent multiple actors who interact through changing the state of a common field of work – and, on the other hand, *articulation work* – the work, in terms of meshing, aligning, integrating, scheduling, coordinating, etc., required for the orderly accomplishment of cooperative work. Conceptualizing the difficulties experienced by participants in the FNA project jointly in terms of their interdependence in work and of the difficulty of articulating this work helps explain the adaptation and adoption by the FNA project of coordination mechanisms, or artifactually inscribed protocols (described in detail below). In terms of CPServices, it is the role-based view protocol.

The goal has been to design a system that enables participants to better manage the complexity of articulating FNA's work processes, thereby improving the cost effectiveness and operational

efficiency of FNA database publishing. CPServices is being developed by researchers and scientists at the Missouri Botanical Garden's Center for Botanical Informatics (CBI) to help project participants better manage, if not reduce, the collaborative load involved in publishing multiple (in some cases, hundreds of) manuscripts simultaneously (see Figure 1 above). During the past year, the system has been incrementally implemented for use by two groups within the FNA project: bryologists and agrostologists [2].

Following the typologies presented in Grudin & Poltrock (1997) (see also Ellis, Gibbs, & Rein, 1991 for a similar treatment of both spatio-temporal and functional groupware options) we can characterize CPServices in terms of the space-time categorization matrix popularized by DeSanctis & Gallupe (1987) and subsequently refined by Johansen (1989). In terms of the location of intended users and the temporal nature of their interactions, CPServices is being primarily designed to support distributed, asynchronous work (the bold and italicized options in Figure 2 below), whether the collaborative nature of their work is predictable or unpredictable.

Figure 2. 3x3 typology of groupware options (Grudin & Poltrock, 1997, p. 283). Bolded and italicized options represent CPServices functionality. Work shifts is simply italicized because, while not a primary design consideration, CPServices can support the work of co-located users (e.g., FNA staff co-located in the Organizational Center).

		TIME		
		Same	Different but predictable	Different and unpredictable
SPACE E C A L P	Same	Meeting facilitation	<i>Work shifts</i>	Team Rooms
	Different but predictable	Teleconferencing Video conferencing Desktop conferencing	<i>Electronic Mail</i>	<i>Collaborative writing</i>
	Different and unpredictable	Interactive Multicast Seminars	<i>Computer boards</i>	<i>Workflow</i>

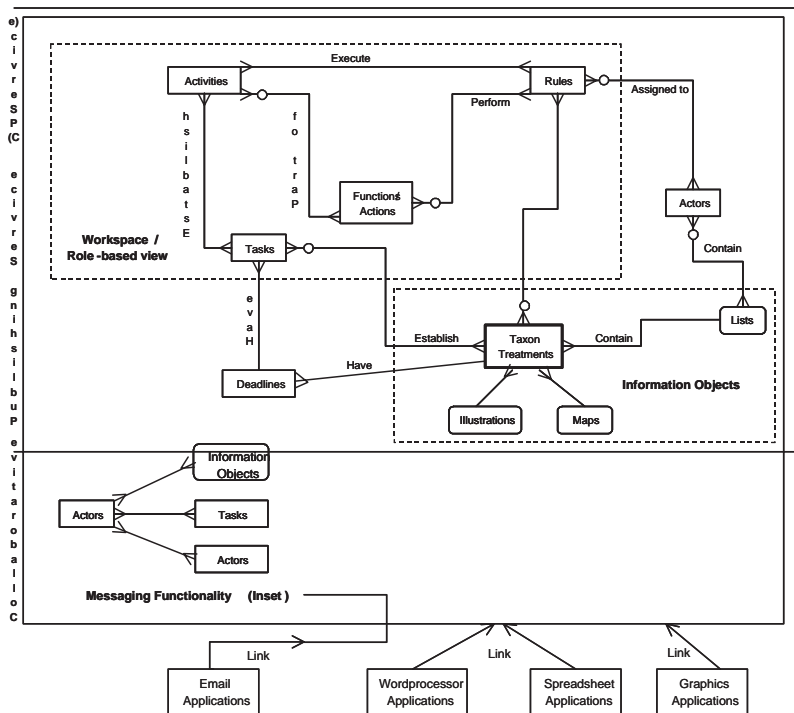
A second kind of typology functionally distinguishes the collaborative tasks supported by the information technology. Grudin & Poltrock (1997) identify three broad, yet serviceable, classes of groupware features: communication (direct person-to-person) between participants, collaboration in a common information space (indirect through shared artifacts), and coordination of work processes. While most groupware applications emphasize one type of feature and can be classified accordingly, CPServices attempts to effectively support all three aspects of collaborative work.

Communication

While communication technologies can support both real-time (synchronous) and/or asynchronous communication, CPServices – given that it is being designed to support distributed, asynchronous work – provides extensive electronic messaging functionality. Such communication func-

tionality is thoroughly integrated with, and suffused throughout, CPSServices [shown as Messaging Functionality (Inset) in Figure 3 below]. According to Strauss (1993), because actions are embedded in, and contextualized by, interactions, the former always carry meanings and must be located within systems of meanings. In CPSServices, this is instantiated by embedding action processes within interaction processes so that both formal and informal communication are supported.

Figure 3. Structural representation of the CPSServices prototype. The messaging inset represents CPSServices's instantiation of Strauss' dictum that all "actions are embedded in interactions" (Strauss, 1993, p. 24). Moreover, in a distributed environment, such as FNA, collaboration must be accomplished by both indirect (through actions on objects) and direct (person-to-person) communication. Single-forked lines indicate one-to-many relationships, whereas double-forked lines represent many-to-many relationships.



Common Information Space (Information Sharing)

Artifacts are created as the product, and are used to mediate and support most work processes; in fact, artifacts are the medium and outcome of the recursive social praxises they organize. Workgroups, such as FNA, create these artifacts collectively, and common information spaces (Bannon & Bødker, 1997) more or less permeably frame such collaborative activities. In a distributed, asynchronous work environment, such as FNA, collaboration will necessarily be accomplished by both indirect (through actions on, and transformations of, objects; feedthrough) and direct (person-to-person; feedback) communication (Dix, 1997; Marmolin, Sundblad, & Pehrson,

1991), and thus CPServices must necessarily support both modalities of information sharing. In fact, project-wide collaborative load will be reduced to the degree that users communicate via their interaction with shared artifacts.

Information technologies such as CPServices that enable activities to occur at levels lower than person-to-person communication (e.g., person-to-resource and resource-to-resource) have two principle benefits (Frontczak & Miner, 1991):

- Increased efficiency of the activity (e.g., continuously available tools that capture expertise for later use and that locate, select, and transfer resources as needed).
- Increased time for people to engage in more meaningful, higher quality communication [e.g., the meta-level thinking that characterizes knowledge work (Davis et al., 1991)].

It is universally accepted that even with the best of computer-based tools, people will still benefit from and always need direct interpersonal contact to perform their work. However, by supporting and substituting communication at an interpersonal level with communication at either the person-artifact or artifact-artifact level, where appropriate, such tools will allow users to focus on working together, rather than on the mechanics and processes of articulating their work.

In addition, messaging in CPServices allows users to thread discussions according to relevant interest areas and *ad hoc* topics. Enabling users to sort and segregate messages on the basis of subject or topic facilitates the meaningful organization of communication about the shared objects of their work, and, by extension, of the common information space. Finally, in terms of its support for collaborative writing, CPServices provides the three basic types of control:

- Access control: determines who can create, read, or modify documents.
- Concurrency control: prevents users from accessing the same document at the same time, by forcing users to download a document to modify it (constituting a form of opportunistic concurrency control).
- Version control: modified documents do not replace original or previous versions of documents; CPServices is an accrete-only, no-delete environment.

Coordination

All collaborative activities require some degree of coordination and actor-activity-resource dependency management; however coordination is essential when work groups are distributed and interacting asynchronously in common information spaces.

CPServices is based on the idea of managing information interaction by means of dynamically constructed activity-and-information spaces, such as *role-based views*. This coordinative protocol inscribes and circumscribes the actor, object, and resource interdependencies that must be managed to accomplish the project's work. Actions permissible to users and views of the FNA database are functionally partitioned, and allocated to project participants, on the basis of their assigned (or perhaps negotiated) roles. These views thus instantiate perspectives on the field of work in terms of the conglomerate of mutually interacting information artifacts, activities/actions, and roles required to accurately characterize work within the FNA project. Because roles are derived directly from those extant in the FNA project, CPServices, like FNA, is a negotiated order (Strauss, 1993).

The various role-based views are instantiated by dynamically constructed and tailored home

pages that can be accessed using any unmodified Web browser. Personalized pages are tailored in response to a user's login, which is functionally (from the backend) a combination of the user's personal identification number and role. Views are tailored so that authors can track the status of the taxa treatments for which they are responsible; taxon editors can track manuscripts for which they are responsible by author or taxon; and, finally, the lead editor can both track the status of treatments by taxa, author, or editor, and perform various database management functions, such as re-assigning authors to editors, and authors and editors to taxa.

Roles are related hierarchically and enact a many-to-many relationship in CPSServices (although other arrangements are possible and, depending on a user community's objective, may be desirable), so that a taxon editor can also be an author and the project editor can also be an editor and/or an author. Several bryologists, for example, have multiple roles in the FNA project, and accordingly can change roles and access respectively different views of the FNA digital library. Icons are used to signal appropriate actions, and the location and state of each treatment component: text (morphological description), illustration, and distribution map. For example, by clicking on the dumptruck (i.e., upload) icon, authors can upload documents or treatment-parts in many different formats from remote sites. Moreover, the status of each treatment-part is tracked via a series of publication statuses (Submitted, Checked, Format checked, Reviewed/Taxonomic & Regional, Reviewed/Nomenclatural & Bibliographic, Accepted), depending on its stage in the edit, review, and publication cycle.

Figure 4. 2x2 categorization of selected CSCW technologies, including CPSServices (adapted from Carstensen & Schmidt, 1999).

	Computer as <i>medium</i> of interaction (Common information space)	Computer as <i>regulator</i> of interaction (Interdependence in work/Articulation Work)
Tight coupling	Mutual Awareness Media space (RAVE) ClearBoard Collaborative VR systems	Adjustment Floor control Shared object services CPSServices
Loose coupling	Conceptual Structures GIBIS EGRET CPSServices	Coordination The Coordinator DOMINO ConversationBuilder OVAL Regatta Ariadne CPSServices

Figure 4 provides another, interesting way to construe coordination. This 2x2 matrix categorizes systems and platforms according to whether interaction among collaborating actors is tightly or loosely coupled and to whether the collaborative information system functions primarily as a medium or a regulator of interaction. Acknowledging that those are two essential characteristics of cooperative work (Carstensen & Schmidt, 1999), CPSServices can be seen to both mediate and regulate loosely coupled interaction among FNA collaborators. CPSServices users are primarily loosely coupled in that their computer-based interaction is predominantly asynchronous and can

be transacted over extended periods of time.

CPServices mediates loosely coupled interaction by instantiating a vetted publishing cycle as a conceptual structure that contextualizes interactions pertaining to, and surrounding, all manuscripts. Moreover, to the extent that the publishing cycle prescribes a sequence of steps through which all treatments must pass, interaction is tightly coupled in a logical manner (CPServices is greyed out in the upper right cell). Finally, CPServices' primary function is to regulate the loosely coupled, yet highly interdependent, activities of FNA conceived of as a distributed publishing enterprise. The system regulates interaction, logically and in some cases temporally [see the Freeflow Project (Dourish et al., 1996) in which sequential logical and sequential temporal work flows are explicitly distinguished and differentiated in system design], by requiring a semi-rigid sequence of stages that comprises the vetting process for all published manuscripts.

CPServices Context/Contexture [3]

The CPServices shared workspace consists both of information objects (or artifacts) such as treatment descriptions, map images, illustrations, messages and, threaded discussions, and other resources; and of services (i.e., actions or processes) over those artifacts such as document upload, document management, group administration, messaging, project management, and more – all accessible from different computing platforms, using unmodified browsers. Information resources included in the CPServices common information space are, among other artifacts/objects, lists of authors, editors, and taxa; data structures that map the assignments of authors to taxa, editors to taxa, etc.; taxonomic treatments, which include textual descriptions, keys, maps, and illustrations of the plants being described; and other material such as informal notes, annotations, bibliographies, pointers to relevant resources, etc.

CPServices is designed to be a relatively lightweight, modular, extensible, and scalable shared environment that integrates communication, collaboration, and coordination services, which can be accessed across heterogeneous, autonomous, and distributed hardware, operating systems, and application software. Because integration and interoperability among systems, applications, and data formats already entrenched in work domains have been primary concerns in the development of the web infrastructure, unlike most other collaboration technologies, the web – as a robust, evolving, platform-independent, and groupwork-enabling infrastructure – can be extended from an essentially passive and expansive information repository to a more active coordination environment (Bentley, Horstmann, & Trevor, 1997). The web, thus, provides an increasing familiar and accessible collaboration-enabling infrastructure.

In sum, CPServices accomplishes the following:

- CPServices lessens individual *cognitive load* by computationally allocating relevant information objects and permissible actions over those objects to project participants on the basis of their roles (i.e., by access to a well-defined process, to information about the status of their tasks, and to the tools and resources they need when they need them) (Tomlinson, Spasser, & Schnase, 1997; Tomlinson et al., 1998).
- CPServices functionally partitions the workspace (e.g., the common FNA information space) and inscribes a powerful role-based view coordinative protocol, thereby reducing project-wide *collaborative load* (Marmolin, Sundblad, & Pehrson, 1991) insofar as project participants can

better manage the complexity of coordinating their logically and geographically distributed activities (i.e., by flexible adherence to coordinative procedures and protocols, and more efficient project-wide resource allocation and utilization) (Spasser, 1998).

Evolution-in-use of CPServices

CPServices is evolving into a common information space (Bannon & Bødker, 1997) which comprises a flexible and extensible set of communication, collaboration, and coordination tools, as well as a dynamic, shared information repository. Specifically, CPServices enables users to:

- define sequence of events (or states) that constitute a process or workflow (e.g., an editorial process such as submit, format, review, publish);
- identify and invite potential participants;
- assign one or more roles to these participants;
- define, instantiate, and allocate (or functionally partition) the actions that occur during a process.

CPServices is being participatively prototyped and, as a result, is rapidly evolving-in-use. In terms of enabling community computing in general, important challenges and opportunities include:

- processing – entering, digitizing, cleansing, normalizing, organizing, indexing, displaying, delivering, etc. – information independent of its format or content;
- maintaining and sustaining dynamic information repositories and coordinating complex information flows; and, perhaps most importantly,
- increasing the stewardship of information by its creators and communities of use.

COORDINATION MECHANISM PERSPECTIVE

CPServices is a computer-based tool being designed to manage the articulation of complexly interdependent activities, by supporting communication, information sharing (e.g., instantiation of common or shared fields of work), and dependency management and coordination. As such, the underlying philosophy and functionality of CPServices is consonant with, and understandable in terms of, aspects of Schmidt et al.'s coordination mechanisms perspective. It is useful to consider CPServices as a computer-based artifact in which *aspects of a coordinative protocol* are inscribed such that changes to the state of the protocol effected by one actor are conveyed, in accordance with the protocol, by the computational artifact to other actors. Because they model – internally and symbolically – crucial dependencies among work practices, computational mechanisms are better able than conventional (e.g., paper-based) coordination mechanisms to articulate work without impeding actors in the conduct of their work.

For example, CPServices:

- contains an inscribed coordinative protocol, the role-based view, that mediates (by conveying changes to actors via notifications, for example) and stipulates (by prescribing how objects and resources should be allocated to actors) aspects of the articulation of FNA work practices;
- incorporates such symbolic artifacts as the CPS server, the code and scripts underwriting the protocol, and each instance of the Flora database, all of which are persistent to changes to the actual field of work accessed, i.e., they can be accessed independently from a particular moment in the workflow and independently from individual actors.

CHARACTERISTICS OF FORMAL CONSTRUCTS

The role-based view coordinative protocol inscribed in CPServices can be considered a normative construct in that it "... offers a limited selection of safe, secure, legal, valid, advisable, efficient, or otherwise prescribed 'moves' while excluding 'moves' that generally would be considered unsafe, etc." (Schmidt, 1997, p. 144). Such constructs represent, model, and accumulate social knowledge and collective experience. As a protocol that is to be followed, unless CPServices users have good reasons not to do so, the role-based view helps regulate the articulation of FNA work processes.

According to Schmidt (1997), normative constructs can function, and be used, quite differently both in routine conditions and in breakdown situations, and in small ensembles and in large-scale collaborative settings. They can play either the "weak" role of a map, offering a codified representation of salient features of pertinent activities to which actors orient as a referent, the "strong" role of a script, embodying the social knowledge of, collective experience with, and material representation of interdependencies that must be successfully negotiated, or any point in-between. Thus, a construct is more or less normative, depending on the nature of the work activity, social roles and relationships, as well as on the organizational context.

Notwithstanding these distinctions, normative constructs, such as coordinative protocols, have the following characteristics:

- They stand proxy for the affordances and constraints of the material and social environments in which they are designed and used. Coordinative protocols, such as the role-based view, inscribe crucial actor-activity-resource interdependencies that assist users in managing the complexity of articulating their activities.
- They are situated in that they only convey stipulations within a specific social setting and within a particular community of practice, in which it has a more or less consensual meaning and under conditions of social accountability.
- They will serve more as a map or as a script depending upon the extent to which it is possible (or desirable) to identify, model, and inscribe interdependencies among activities. This feasibility or desirability will, in turn, depend on the situation, in terms of the extent, for example, to which a protocol applies, or to which situational parameters are within the operational conditions for which the protocol is presumably designed.
- They cannot exhaustively describe situated action or specify its enormous contingency. Schmidt (1997) reminds us that normative constructs as linguistic constructions, are "... inherently vague compared to the infinitely rich details of actually unfolding activities, and not only ... [are they] inherently decontextualized, but ... [they are] under-specified with respect to (a) factors that are immaterial for the purpose of the given protocol or (b) factors that can more efficiently and effectively be left unspecified typically until a later stage" (p. 144).
- Finally, they are no more than local and temporary closures and will inevitably encounter situations beyond their bounds of jurisdiction: "no representation of the world is complete or permanent" (Star & Gerson, 1986, pp. 257-258).

COORDINATION MECHANISMS AS BOUNDARY OBJECTS

Not only are coordination mechanisms normative constructs that mediate and stipulate work activities, but they are boundary objects as well that necessarily mediate (i.e., coordinate) the relations between actors (both individuals and collectives) who are, by definition, interdependent in work. Very briefly, boundary objects have the following characteristics; they:

- can be abstract (ideal) or concrete (material);
- can inhabit several intersecting worlds and satisfy the informational requirements of each (Boland & Tenkasi, 1995 characterize such (inter)communal artifacts as being symbolically adequate);
- are *plastic* enough to adapt to local needs and the constraints of the several parties employing them, yet are *robust* enough to maintain a common identity across sites and among communities; and
- are *weakly structured* in common use, but become *strongly structured* in local (i.e., individual site) use (Star, 1989; Star & Griesemer, 1989).

The coordination mechanism perspective suggests that as organizational endeavors, such as the FNA project, scale along the dimensions of complexity, size, and duration, project participants will increasingly require artifactually inscribed protocols to help them manage the complexity of articulating their work. In addition, because project participants are highly interdependent in their work, the artifacts constructed to mediate and effectively manage this work will also be relatively robust, strongly structured, and stipulative (i.e., script-like) boundary objects: inter-personal or –communal artifacts that facilitate collaboration without consensus (Star, 1993). Because these heteropraxial artifacts are robust and structured, but are always used in the context of a community of practice (or intersecting communities of practice), they can provide effective tools for distributed, heterogeneous actors to articulate their interdependent, yet contingent, activities.

NORMATIVE (BOUNDARY) CONSTRUCTS IN ACTIVITY THEORY

We can invoke key principles from activity theory to help explicate the multifarious nature and use of normative boundary constructs *in situ*. Kuutti (1991), among many others, has proposed that the fundamental unit of analysis for CSCW is artifact-mediated, object-oriented activity, a unit of socioculturally situated behavior that carries with it a sufficiently rich representation of context, conceptualized at an analytically helpful level of granularity.

The activity approach emphasizes the study of artifacts-in-use, not in isolation, and the study of specific material and sociohistorical contexts of use, in which specific practices are situated (Bannon & Bødker, 1991). Obviously, artifacts play a central role mediated activity. According to Bannon & Bødker (1991):

"They are objects in the world around us, which we can reflect on, and they mediate our interaction with the world, in which case they are themselves the object of our activity in use ... Artifacts are there for us when we are introduced into a certain activity, but they are also a product of our activity, and as such they are constantly changed through our activity" (pp. 241-242).

Thus, artifacts in activity theory are considered crystallized cultural knowledge, "... historical devices that reflect the state of praxis up until the time that they are developed" (p. 243) and that incorporate previous use practices into the technological artifact itself.

Blackler (1995) has nicely summarized key precepts of activity theory by considering activity to be at once:

- Mediated: all human (work) activity is performed by appropriating and using artifacts and tools, such as artifactually inscribed normative constructs.
- Pragmatic: all activity is object oriented, is driven by the conceptions that people have of the object of their activities. Activities can be distinguished on the basis of these motivating objects (see also, Kozulin, 1986).
- Situated: all activity is located in specific conjunctures of time and space and in particular communities of practice, and will reflect the rules (implicit and explicit) and role structures of those communities. Activity theorists share Suchman's (1987) view of activity as depending "... in essential ways upon its material and social circumstances" (p. 50).
- Provisional: all work activity is a continually transformational process; as artifacts are appropriated-in-use, they, the actors involved, and the objects of the activity(ies) develop or evolve – essentially, they are continually reproduced, without replication.
- Contested: all human activity is mediated by artifacts that differentially inscribe the interests of more or less powerful actors and, consequently, can be appropriated in contradictory [or ironic (DeSanctis & Poole, 1994)] ways by those involved.

NORMATIVE BOUNDARY CONSTRUCTS IN LARGE-SCALE COLLABORATIVE SETTINGS

Activity theory, thus, provides us with a conceptual armamentarium to explicate the role of normative boundary constructs such as coordination mechanisms in large, complex projects of long duration, such as the FNA project. As projects characterized by interdependence in work scale in terms of complexity, size, and duration, the object of work increasingly becomes its management, or the articulation of complexly interdependent work. In terms of individual work, normative constructs such as coordinative protocols help reduce the individual's cognitive load (Tomlinson, Spasser, & Schnase, 1997); whereas, in terms of the entire organizational enterprise, they help manage the collective collaboration load (Marmolin, Sundblad, & Pehrson, 1991).

Moreover, when individuals are interdependent in work (as they are in the FNA project), such protocols will necessarily provide the actual basis for articulation within a project: individual workers need to mesh or coordinate their work activities in a fairly structured way to get the actual work done. Robinson (1997), advocating the reconstitution of procedures as boundary objects, sees such normative boundary constructs as grounding inter-communal dialog: "[e]ntrance into ... the practices of other communities ... happens within the space provided by the 'boundary objects' of procedures" (p. 272).

Specifically, in terms of the FNA project, participants have invented and adopted a variety of coordination mechanisms to help manage the complexity of their work. FNA Organizational Center personnel have created a detailed guide for contributors that has gone through several revisions (instantiating the provisional, and essentially incomplete nature of normative constructs), as well

as adopted the spreadsheet (specifically, its tabular format), as a powerful and familiar visual formalism (see Nardi, 1993 for a detailed discussion of visual formalisms) to ensure the parallelism and consistency of the contributors' treatments.

Unfortunately, these artifacts and the protocols and standard operating procedures inscribed therein have failed to effectively reduce the complexity of articulating project work processes. For example, the use of the spreadsheet became localized in the Organizational Center as a means of coordinating its work, but was never successfully deployed project-wide because of its different and contradictory objects of use: while Organizational Center personnel saw the spreadsheet as an efficient and effective means to ensure consistency and parallelism, the authors perceived the use of spreadsheets to be unnatural and to contradict their current work practices of writing descriptions in prose. Thus, the use of the spreadsheet (and its tabular protocol) has been limited to the Organizational Center through which work is forced to repetitively and recursively flow (Spasser, 1998).

The use of the contributors' guides have become increasingly problematic as the format they inscribe has become increasingly complex. As the complexity of the tool has increased, it has become increasingly difficult for authors to adapt it to meet local needs — in the case of FNA, the unique characteristics of plants and plant groups. As a result of the difficulty in using the guides in a situationally appropriate way, FNA contributors have frequently abandoned them, thereby increasing the coordination work of the FNA Organizational Center (e.g., by increasing the work that must be done to normalize manuscripts) and disarticulating individual work.

Accordingly, computer-based protocols, such as CPSServices' role-based view, have attracted an increasing amount of attention and have become increasingly important, and relied upon, mediating tools for projects, such as FNA, to manage the complexity of articulating their work in situationally sensitive ways (see, for example, Carstensen & Sørensen, 1994, 1995, 1996; Carstensen, Sørensen, & Borstrøm, 1995; Carstensen, Tuikka, & Sørensen, 1994). Interestingly, the role-based view protocol has been a widely praised and accepted feature of CPSServices within the FNA project; whereas the socially determined nature of determining file format has proven extremely problematic and contentious.

This should not be surprising given the need for a project-wide mechanism for coordinating the interdependent work activities of a such a widely distributed work group as exists in the FNA project. Moreover, the role-based view coordinative protocol exemplifies essential features of both boundary objects and normative constructs: it is relatively weakly structured, plastic, and orienting in global, or common, use (e.g., as a generic tool or construct, the protocol only requires that roles be specified, and actors and resources be allocated on the basis of role definitions once they have been delineated); whereas it is strongly structured, robust, and prescriptive in local, or individual site, use (e.g., for a particular FNA group such as the bryophytes, the coordinative protocol specifies a bounded, concrete set of roles, allocates specific actors to those roles (and resources to those committed actors), and prescribes a particular sequence of stages through which manuscripts must pass).

Nevertheless, activity theory reminds us that when artifacts are used in human activity, they are actively and artfully appropriated, that is, they are transformed and modified in activity. Artifacts are thus constructed as they are brought into the sphere of human activity. By collapsing the

Cartesian distinction between a subjective goal and an object “out there,” object-oriented, artifact-mediated activity becomes a process in which a subject, an object, the means of appropriation and construction, and social relations are simultaneously established and transformed (Miettinen, in submission). For example, as the CPServices prototype has been implemented-in-use, it has been continually modified on the basis of user needs and user-developer interactions.

However, as exemplified in Schmidt’s (1997) description of the use of the *kanban* protocol in complex manufacturing environment, users have not advocated the abandonment of the system, but instead have encouraged and helped developers modify its configuration *in situ* as it is appropriated by an increasing number of users. Consequently, in situations when the protocol has been experienced as being ‘beyond its bounds’ (e.g., when it inaccurately, or incompletely, models the publication sequence or is insufficiently flexible in allocating privileges to roles), it has not been discarded, but has been modified locally (i.e., for use by an individual group), on the basis of user input. The role-based view protocol inscribed in CPServices has not been abandoned because as FNA participants become competent in its use, they can increasingly rely on it to accurately model their work domain and helpfully articulate their interdependent work activities.

An activity theoretic reading of the use of normative constructs allows us to see them, not as prescriptions to be taken literally, but as indispensable resources that presume observed practices of competent actors engaged in situated activity (Schmidt, 1997). Artifacts, and the normative constructs they perspicuously inscribe, can, and will, be appropriated in many different ways, depending on the object of activity and the affordances and constraints of the socio-material context. And despite their structured, robust, and prescriptive nature, coordination mechanisms are boundary objects, mediating interdependence in work among multiple actors. Thus, it is imperative that designers of CPServices remain mindful of both the polymotivated nature of tool appropriation and the heteropraxial character of tools that mediate intersecting work practices, and design it to accommodate as many different objects of activity as possible (Bardram, 1997). A process-oriented activity perspective on the design of artifacts for use, including those like CPServices that inscribe normative boundary constructs, entails:

“a process in which we [not only] determine and create the conditions that turn an object into an artifact of use ... [but also] design new conditions for collective activity ... and new ways of coordination, control, and communication” (Bannon & Bødker, 1991, p. 245, 247).

Finally, placing coordination mechanisms as normative boundary constructs in an activity theoretic framework may help us determine, in general, how they stipulate the articulation of collaborative work; how they are appropriated and used; and how they are invented, adapted, and/or adopted by competent actors. Specifically, insights drawn from activity theory may help us answer the following two questions posed, somewhat facetiously, by Schmidt (1997):

1. “What is it about normative constructs such as standard operating procedures, schedules, protocols that makes them useful in the first place? What makes them resources?”
- Activity theory stresses the importance of the mediating mechanisms – artifacts – in the enactment of activities. According to Cole (1996), an artifact is “... an aspect of the world that has been modified over the history of its incorporation into goal-directed human action” (p. 117). Once inscribed

upon artifacts, such constructs carry the accumulated knowledge involved in the specific social practices. By crystallizing human experience and the structural properties of social praxis, artifacts as mediators of activity allow users to not only control their own behavior, but also to remotely share useful and usable knowledge across space and time. Because coordination mechanisms can be strongly or weakly structured, robust or malleable, and prescriptive or permissive depending on the circumstances and the contingencies of their use, they are well adapted (and frequently adopted) to articulate interdependent work.

2. "What makes one normative construct more useful than another for a certain purpose in a specific setting?"

The usefulness of an artifact (i.e., its role as a tool) is strongly determined by the object of activity, which in turn is influenced by the nature of the artifact, the activity, and the context of use. Using Christiansen's (1996) mnemonic, objectified motive enables us to see that becoming an object signifies a relationship between an actor and her socio-material environment. As such, artifacts not only transmit cultural knowledge, but as they are appropriated-in-use, they transform the goals of the people who use them. Thus, the degree to which an artifact will be useful in a given social praxis will depend on the trajectory of the developmental processes of subject-object co-transformation and of technology-activity co-adaptation. In the case of FNA's use of CPServices, not only is the system being transformed-in-appropriation, but the community itself is altering its publication practices as it increasingly adopts the system.

Perhaps, even more importantly, activity theory encourages us to discover the institutional anatomy, interactive dynamics, and inherent contradictions of activities (Engeström, 1996). In particular, objects and mediating artifacts/tools must be carefully and dialectically distinguished. As Engeström (1996) correctly notes, "[t]he two play dramatically different, yet constantly switching roles in the unfolding activity" (p. 262).

On the one hand, for example, participants in the FNA project adopted and created, unsuccessfully, the mediating tools of the spreadsheet and various guides for contributors respectively. It is hoped that the adoption of CPServices – yet another tool – will help project participants better articulate their work – the same object(ified motive). On the other hand, CPServices is the object of the activities of developers who employ such tools as the Java programming language and the CPServices server. More subtly, CPServices can (and does) become the object of users' activity when they reflect upon its usefulness. This focus shift reflects the reality that "[a]n artifact works well in our activity if it allows us to focus attention on the *real object* and badly if it does not" [emphasis added] (Bødker, 1996, p. 149). This switch can occur unintentionally as a result of breakdowns or as the intended outcome of planned user evaluation, depending on the object of yet another intersecting activity.

Thus, maintaining the analytic distinction between object and mediating artifact foregrounds the "... difference between the *use situation* where the computer-based artifact is operated while focusing on some other object of subject ... and the *design situation* where the computer-based artifact is one of the objects and outcomes" [emphasis added] (Bannon & Bødker, 1991, p. 245). While the object may remain the reduction, or better management, of the complexity of articulating interdependence in work, the mediating tools will vary, depending on the heterogeneity of the intersecting user and design communities, the conditions and contingencies of the environment(s)

in which their work is situated, and on the characteristics of the tools themselves, such as structure, plasticity, and 'prescriptiveness.'

CONCLUSION

A crucial challenge for next century is the collection, organization, and management of the accumulating knowledge about the Earth's biodiversity and the ecosystems that support it to protect and expand ecosystem diversity, to prevent the continued loss of habitats and species, and to derive new economic wealth from the better management of biological resources and information about them. Once complete, the FNA project will completely and authoritatively catalog the flora of the continental U.S., and thus will constitute a major contribution to achieving these formidable tasks. CPSServices designers hope that by using this system to author, edit, review, and ultimately publish treatment manuscripts, the articulation of the large, distributed FNA work group will be better managed and the publication of the Flora will thereby be facilitated.

Moreover, by employing activity theory as a framework to conceptualize the design, use, and evaluation of CPSServices as a computer-based tool that inscribes normative boundary protocols, we will be in a better position to account for the full range of user needs and for the socially constructed, object oriented, and artifactually mediated nature of all work activity, including floristics publishing. As Nardi (1996b) has observed:

"Without a shared analytic frame of reference we fail to move beyond narrow interests and perspective, to advance a practical science of HCI ... [activity theory] has a well-articulated conceptual apparatus and a core set of concepts that are useful for empirical analyses of HCI problems [including the nature and use of artifactually inscribed protocols to help articulate interdependence in work in large, complex collaborative projects of long duration]" (pp. 244-245).

CPSServices is designed to increase the speed at which manuscripts are processed, while maintaining their uniformly high quality. To accomplish this, CPSServices inscribes and persistently objectifies a coordinative boundary protocol that flexibly structures and stipulates the articulation of the complexly interdependent activities among authors, editors, and reviewers as they collaboratively publish FNA manuscripts. By allowing participants to better articulate their interdependence in work, the software developers expect that the publication process, as represented by/in CPSServices, will be better aligned with, and more closely match, the "true" conception of FNA as an electronic database and digital library, that FNA participants will be better able to articulate their complexly interdependent work processes, and that by fully supporting and perhaps enhancing FNA work practices, CPSServices will become an indispensable resource for the floristics community as they are co-transformed in situated use.

ACKNOWLEDGEMENTS

This research has conducted when the author was at the Center for Botanical Informatics, LLC, Missouri Botanical Garden, St. Louis, MO 63110.

Notes

- [1] Bryophytes (or, bryoflora) are hornworts, liverworts, and mosses. Bryologists are botanists who study bryophytes.
- [2] Agrostologists study the grasses.
- [3] If, after Cole (1996), context is both that which surrounds and that which weaves together, then contexture is that which is surrounded and interwoven.

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