Mind the gap!
Towards a unified view of CSCW

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Abstract. CSCW at large seems to be pursuing two diverging strategies: on one hand a strategy aiming at coordination technologies that reduce the complexity of coordinating cooperative activities by regulating the coordinative interactions, and on the other hand a strategy that aims at radically flexible means of interaction which do not regulate interaction but rather leave it to the users to cope with the complexity of coordinating their activities. As both strategies reflect genuine requirements, we need to address the issue of how the gap can be bridged, that is, how the two strategies can be integrated conceptually. In addressing this problem, the paper discusses two general modalities of articulation work — *ad hoc* alignment and improvisation on the basis of mutual awareness versus coordination in terms of a predefined flow of work — and argues that these modalities are seamlessly meshed and blended in the course of real world cooperative activities. On the basis of this discussion the paper outlines an approach which may help CSCW research to bridge this gap.

1. The gap in CSCW

When considering the many imaginative and inspiring computer-based facilities for supporting cooperative work which have been proposed in recent years, research prototypes as well as commercial products, one can distinguish two diverging strategies with respect to the underlying conceptions of 'computer support': On one hand, a strategy which suggests to support cooperative work by providing normative models of cooperation so as to regulate the routine coordinative activities and thereby enable cooperative ensembles to perform more reliably and efficiently. And on the other hand, a strategy that suggests to support cooperative work by offering a medium such as a 'shared work space' through which actors can interact directly, i.e., by means of generic competencies such as talking, gesturing, pointing, monitoring etc., without other restraints than those of bandwith, latency, etc.

(1) *Regulating interaction*: An attempt to overcome the limitations of 'office automation' that had become obvious in the early 1980s, the former strategy, that of regulating interaction, generated a range of different support systems. While these systems are different

in important ways, it is beyond the scope of this paper to enter into a discussion of these differences. For our purposes it is sufficient to consider how the different modeling approaches deal with the crucial *requirement of flexibility* that arises from the changing needs of the cooperative work setting and which was learned the hard way, in the use of these systems [e.g., 35, ff.].

As far as this issue is concerned, the issue of how to combine prescribed regulation with flexibility, two general approaches can be distinguished:

(a) The first group of approaches attempts to reconcile these two apparently contradictory goals by looking for a language that incorporates an ontology of cooperation. A typical example of this approach is the Language/Action Perspective which led to the development of systems such as Action Workflow [37]. Based on the notion of structured conversation, such systems provide a set of primitives which is claimed to be sufficiently expressive to cover the needs of users in articulating their activities. Flexibility is thus claimed to be achieved by means of a universal language which provides a set of primitives derived from the ontology.

(b) The second group of approaches tries to achieve the same reconciliation of flexibility and prescription by selecting a suitable metaphor for modelling cooperative work. Such metaphors usually privilege a specific type of workflow and takes other types as subordinated and derived: the flow of tasks, as in the case of Regatta [60]; or the flow of documents, as in the case of LinkWorks™[1]; or the flow of communication, as in the case of Strudel [51] or Conversation Builder [9; 33]. Flexibility is here achieved by providing primitives for manipulating the flow, for example by allowing the flow to be defined dynamically and incrementally.

To many CSCW researchers these approaches are problematic. In general, Suchman [59] has raised fundamental doubt as to the conceptual validity of such approaches by pointing to the situated nature of action. More specifically, the approach based on the Language/-Action Perspective is considered conceptually unfounded [4; 11; 57] and — together with other workflow technologies — not grounded in empirical studies [10], whereas the flow metaphor approaches seems too narrow and to be causing a fragmentation of the technological support to cooperation. In fact, each system was focused on only one aspect of coordination and could not be integrated with technologies supporting other aspects.[2] All these problems, together with the actual difficulty of making significant progress in providing flexibility, generated increasing interest in looking for an alternative approach. This trend was also motivated by the emergence of novel forms of cooperation where coordination exhibits the property of an inherently emergent behavior, e.g., in the case of the network comsmunities.

Moreover, a range of empirical investigations [e.g., 27; 28; 58] has highlighted the ‘physical’ nature of cooperation (as opposed to the ‘abstract’ nature implied by the notion of flow) which can be described in terms of artifacts around which people, flexibly, organize their cooperative activities. No approach based on the flow of work is actually able to capture this aspect. In such flow oriented approaches, artifacts are merely seen as complementary to the flow, as part of the context in which the flow takes meaning, as conveyors supporting information delivery, not as means of aggregating activities and organizing work.

Finally, the pursuit of an alternative — ‘lightweight’ — approach was further assisted by the evolution of technological infrastructures that support application development by providing integration of different communication media (e.g., audio and video), manipulation and aggregation of objects and their presentation, easier interface design, possibilities of

1 LinkWorks™ is a groupware product by Digital.

2 Recent work to further develop these proposals attempt to overcome this limitation [cf., e.g., 36].

distributing applications across heterogeneous machines, and open infrastructures across the World Wide Web. All this have made it incomparably easier to build flexible applications which are, however, simplistic from the point of view of their support of coordination.

(2) *Mediating interaction*: The alternative strategy, that of mediating interaction without undue restrictions, denies not only the possibility but even the usefulness and, in some cases, the legitimacy of regulating cooperation in terms of a flow of action: rather, it proposes a fully unstructured approach where the keywords become: *ad hoc* improvisation, uniqueness of events and situations, and so forth. In this framework, the articulation of activities is mainly performed through an extensive reliance on mutual awareness.

Accordingly, the technological proposals are focused on and characterized by the support of mutual awareness. In this vein we can find the work on ‘media spaces’ where the ‘space’ is a combination of a virtual space and a physical environment equipped with continuously open audio/video channels to promote mutual awareness: the goal is to amplify the physical capabilities of actors, irrespective of their location and movement capabilities in physical space [20; 22; 23; 31]. Similarly, the ‘shared object space’ metaphor has gained great popularity and has produced a set of different technological components that can be combined to provide services for supporting cooperation. In this case the virtual space is populated by objects enriched with cooperation capabilities [cf., e.g., 61] and supported by a suitable architecture managing the lower level services [cf., e.g., 39; 62]. In addition, the explosive growth of the World Wide Web and the improved capabilities that are foreseen will make it possible for the virtual space to transcend any local barriers and become the support environment for geographically and organizationally distributed cooperation [8].

Unlike the regulation strategy, CSCW *applications*[3] seem to be relegated to the background. Instead, researchers and developers concentrate their efforts on providing infrastructures that — by meeting requirements such as openness, flexibility, integration of different basic functions, and so forth — provide a basis upon which applications can be developed. The message seems to be: I give you a powerful toolkit, and then you build whatever you desire. Obviously, the provision of powerful infrastructures is highly desirable, and the related efforts have led to significant progress in CSCW. However, this trend can be also interpreted as a decision to resign from taking an explicit position about how coordination technologies can solve specific (classes of) problems in cooperative work settings. In this way, the gap between the empirical studies which have highlighted the need for sophisticated applications and the provided technology is not reduced but, paradoxically, increased. In fact, the necessity of providing general purpose functionalities makes these infrastructures ‘light’ in terms of semantic content: for example, the focus on *artifacts* and their role in cooperation can only be expressed in terms of *objects*, which clearly is a more generic and semantically weaker concept.

One could, of course, remonstrate that the appropriate semantic level can be achieved by a appropriate programming activities on top of the rich infrastructure. But this objection is not convincing if the issue of flexibility has to be taken seriously. In fact, users have to be in control of the requested flexibility and they do not want to become programmers nor do they want, in the general case, to have flexibility limited to the adjustment of selected parameters through the user interface (as in the case of, e.g., T-Views [65]). For flexibility to make sense it must be controlled by users and for this to be feasible, the control must be expressed in terms which make sense to users, i.e., expressed at the semantic level of articulation work. If that is not the case, users are in effect not supported in handling the complexity of their cooperative activities. They are left with sophisticated facilities for *ad hoc* adaptation and improvisation.

3 The term ‘application’ is here used to denote a specific configuration of functionalities and data structures for a specific purpose.

This, then, is the gap in CSCW: On one hand a strategy which aims at the provision of systems that prescribe interaction but which, in doing so, restricts coordinative interaction to *a priori* models of interaction or to a set of narrow and incongruent metaphors of interaction, and on the other hand a position which aims at radically flexible systems that do not prescribe interaction but rather provide an infrastructure which can provide the basis for any application but which, in doing so, leaves it to the users to cope with the complexity of coordinating their cooperative activities.

The problem is that cooperative work in the real world is not conducted according to the division of labor of CSCW research. In cooperative work, *ad hoc* alignment and improvisation on the basis of mutual awareness is inexorably interlaced with the execution of predefined procedures and similar formal constructs, and vice versa.

How do we move beyond this schism? This is the problem addressed in this paper. We will first, briefly, discuss the two general modalities of articulation work — *ad hoc* alignment and improvisation on the basis of mutual awareness versus coordination in terms of predefined flow of work — and how they are seamlessly meshed and blended in the course of cooperative activities. On the basis of this discussion we will outline an approach which, we submit, will help CSCW research to bridge this gap.

2. The seamlessness of articulation work

Cooperative work is constituted by interdependence of activities. The cooperating actors in a given cooperative work arrangement are interdependent in their work in the sense that one actor's actions will change the state of a set of objects and processes and, in turn, this change of state has implications, directly or indirectly, for the work of the other members of the ensemble, and vice versa [46]. Let us call the set of objects and processes the members of the ensemble act upon *the common field of work* of this cooperative work arrangement.

By involving multiple actors, cooperative work is inherently and inexorably distributed, not only in terms of time and space but also, and more importantly, in terms of control, i.e., in terms of local contingencies, individual heuristics and biases, incongruent specialisms and incompatible perspectives, divergent or conflicting motives and interests, etc. That is, no actor is all-knowing and all-powerful; actors must thus act and interact on the basis of partial knowledge and they are, accordingly, partially autonomous in their work [45; 54].

However, a system that consists of interdependent activities which are carried out in a distributed manner will become 'as densely tangled as a plate of spaghetti', so that every action is contingent on multiple other actions and vice versa, and it is thus on the verge of 'trashing around chaotically', to use Waldrop's apt expressions [64, p. 109]. To prevent interdependent and yet distributed activities from degenerating into chaos, the cooperative effort must be coordinated, aligned, integrated, meshed — in short, articulated [24; 55; 56].

Moreover, articulation work is a recursive phenomenon [49]. Activities undertaken to ensure the fluent articulation of activities within the arrangement (somebody observing another, somebody directing another's attention to something, somebody asking somebody else about something, somebody requesting or ordering some action, or somebody negotiating actions to be taken) may themselves be observed, etc. as well, and so forth.

Now, the obvious and fundamental way to articulate distributed activities is of course to facilitate the generation of mutual awareness among actors so as to enable them to align their individual contributions to those of their colleagues in a fluent and seamless manner.

2.1.1. Mutual awareness

While the term ‘awareness’ has become widely used in CSCW research, it is often used without any definition, as if its meaning is intuitively clear and agreed upon in the community. In fact, it is being used to denote quite different phenomena, from peripheral awareness to focused attention, and from consciousness-in-flux to general background knowledge. Like others [43] we therefore believe that a proper definition of mutual awareness is required.

Consider a given cooperative work arrangement:

(a) When an actor changes the state of the common field of work, the field of work will, so to speak, emit signals of this change which the other actors may perceive. They may be able to perceive these signals ‘directly’ (i.e., with their senses) or perhaps only indications of them (i.e., by means of sensors and other intermediate equipment). Such changes to the state of the common field of work will propagate within this field of work in different ways and as they propagate they become perceivable by members in different ways. If the field of work, for instance, is a tightly coupled system (e.g., a power plant or an aircraft), changes will typically affect the work of others instantly and ineluctably; in a loosely coupled system, by contrast (e.g., a building under construction or a design under development), changes will typically propagate over time and contingently. Furthermore, the cooperative work arrangement may be deployed in such a way with respect to the field of work that actors are able to perceive the state of the field of work in its entirety or in such a way that they can perceive only a section thereof [40].

(b) From perceiving the state of the field of work and the changes to it, that is, without necessarily being able to perceive each other and each other’s bodily conduct, competent members can develop a rudimentary awareness of the activities undertaken by colleagues which enables them to align their own activities with the unseen activities of their colleagues so as to accomplish the joint work in an orderly fashion [41]. In addition, also from perceiving the state of the field of work and the changes to it, and again without necessarily being able to perceive each other and each other’s bodily conduct, competent members can, to some extent, infer the plans and intentions of colleagues, detect if colleagues are facing disturbances, etc. [41].

(c) Moreover, if the members of the ensemble share the same (physical or media) space, they may also be able to perceive each others bodily conduct: a nuclear power plant operator may notice the other operator moving to the other end of the control room, to a particular set of control panels, and may infer that the colleague is going to initiate certain changes which in turn will affect himself in his work [34], or an air traffic controller overhears a radio conversation between his colleague and a pilot and takes appropriate steps etc.

(d) Finally, since articulation work is a recursive phenomenon, the activities through which actors align their activities with respect to those of their colleagues can be perceived in exactly the same way and become an additional source of awareness.

In all of this actors, so to speak, exploit what is there for the picking. They utilize the ubiquitous signals, signs, and cues which somehow indicate the state of the field of work and the state of the cooperative work arrangement and that are continually emitted and disseminated as a by-product of the cooperative effort or as a by-product of *articulating* the cooperative effort, so as to be aware of what their colleagues are doing, that is, to develop *mutual awareness*.

The exploitation of what is already there for the taking distinguishes mutual awareness from other modalities of articulation work, such as directing attention to something, asking about something, requesting or ordering some action, and negotiating actions to be taken, which are all characterized by being intrusive in that they, under conditions of social accountability, ‘enforce’ a response or some other interruption of ongoing action.

As an aspect of articulation work, mutual awareness is 'the elementary or undifferentiated consciousness of or sentience'[4] to the state of the cooperative effort. The provision of information pertaining to mutual awareness is achieved in the course of doing the work, through the emission and dissemination of requisite signals, signs, and cues, by contrast to more intrusive modes of articulation work. Likewise, the acquisition of information pertaining to mutual awareness is non-intrusive in the sense that it does not intervene in the flow of work by enforcing a response: it merely enables the actor to adjust his or her activities to the perceived or projected state of affairs so as make his or her activities mesh seamlessly into the collective effort.

However, while mutual awareness is based on the exploitation of cues and signals that are emitted and disseminated in the course of the work, a series of workplace studies [e.g., 27; 29; 30], investigating how mutual awareness is produced and maintained by members of the cooperative ensemble, have demonstrated that mutual awareness does not occur through osmosis or some other automatic process. It does not simply happen by 'being there'. Mutual awareness is produced through very delicate practices. While much research is required for these practices to be well understood, the following summarizes what has been established so far:

In doing their individual parts of the joint effort, actors will typically modulate their own activities so as to provide their colleagues with cues and other kinds of information pertinent to their being aware of these activities; that is, they conduct their own activities in such a way that colleagues can perceive *that* they are being done, *how* they are being carried out, *that* they will meet constraints of time and quality, *that* the apparent contingencies will not affect the work of colleagues (as if to say, 'don't worry, I can handle that'), or *that* they will affect the work of colleagues and *when* and *how* and *to which extent*, so that they can adjust their part of the effort accordingly. In doing that, actors do not make their own work conspicuously and comprehensively visible — doing that would add to the complexity of the work of colleagues — but make it visible in a form and at a level of granularity which is relevant to the situation facing the colleagues. In short, the message is tailored to the particular audience. Conversely, actors continually 'monitor' or 'scan' the activities of their colleagues — by watching or listening, by observing the state of the field of work as it changes due to the work of colleagues etc. — so as to ascertain the state of these activities, that is, to ascertain whether they are being done and progressing as expected, to determine exactly how one's own activities need to be adjusted to mesh with the unfolding work of the colleagues, and so forth. Again, this monitoring of the work of colleagues typically is not done conspicuously because doing so would make the colleagues being watched aware of being watched — unless, of course, *that* is desirable, e.g., for safety purposes, as if to say 'Don't worry, I see what you're doing' [48].

That is, any attempt to reduce the provision and acquisition of mutual awareness to a 'mechanical' reaction to some ongoing phenomenon is not appropriate.

2.1.2. Coordinative artifacts and protocols

While cooperative work is constituted by interdependence of activities, this interdependence is of varying complexity[5] and task interdependencies are often of an order of complexity where the articulation of cooperative work in terms of *ad hoc* interaction and improvisation based on mutual awareness is quite insufficient. To make task interdependen-

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4 *Webster's Revised Unabridged Dictionary* (1913).

5 The complexity of a system is a function of the number of possible states the system may have, in part as a result of interactions among its elements. As in the case of software systems, 'the elements [~activities] interact with each other in some non-linear fashion, and the complexity of the whole increases much more than linearly' [13].

cies tractable other modalities of articulation work are required which rely on the use of artifacts for coordination purposes and often also implicit or explicit protocols which regulate how the artifacts are to be used [47; 49].

Coordinative artifacts are used in different ways and for different purposes in cooperative work:

- *Templates*, i.e., artifacts that to competent members *specify the properties of the result* of individual contributions, e.g., product standards, drawings, 'style sheets' [cf., e.g. 63].
- *Maps*, i.e., artifacts that to competent members *specify interdependencies* of tasks or objects in a cooperative work setting, e.g., organizational charts, classification schemes, taxonomies, 'group technology' [cf., e.g. 12; 14, p. 114; 59, p. 188 f.].
- *Scripts*, i.e., artifacts that to competent members *specify a protocol of interaction* in view of task interdependencies in a cooperative work setting, e.g., production schedules, kanban systems, office procedures, bug report forms [cf., e.g. 15; 16; 47; 49].

Coordinative artifacts stand proxy for the affordances and constraints of the physical and social environment. They circumscribe, for all practical purposes, action in the same way as the physical and social circumstances [59, p. 179]. More specifically, as far as coordinative protocols are concerned, a protocol conveys a 'precomputation' [38] of task interdependencies, i.e., it offers a limited, predetermined selection of actions which are considered safe, secure, legal, valid, advisable, efficient or otherwise prescribed with respect to the field of work in general and to the current state of the field of work in particular while excluding actions that generally would be considered unsafe, etc. It thereby assists actors in reducing the complexity of coordinating their activities. Under conditions of limited resources, practical exigencies, and social accountability actors rely on such prescriptions in order to get the job done, unless they have good reasons not to do so.

However, a protocol only conveys stipulations within a certain social context, within a certain community, in which it has a satisfactorily certain and agreed-to meaning and it only does so under conditions of social accountability.

Protocols and other formal constructs cannot exhaustively describe action. As pointed out by Suchman, 'the vagueness of plans' is 'ideally suited to the fact that the detail of intent and action must be contingent on the circumstantial and interactional particulars of actual situations' [59, pp. 185 f.]. Thus, not only is a protocol, as a linguistic construction, inherently vague compared to the infinitely rich details of actually unfolding activities, and not only is it inherently decontextualized, but it is deliberately 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. The protocol must be defined at 'an appropriate level of ambiguity' [12, p. 77].

And finally, as pointed out by Gerson and Star, 'no representation of the world is either complete or permanent' [24, pp. 257-258]. That is, a coordinative artifact will, inevitably, encounter situations where it is beyond its bounds, its inherent vagueness and appropriate ambiguity notwithstanding.

2.1.3. Articulation work is seamless

As already indicated, the general modalities of articulation work which we for the sake of clarity discussed separately — *ad hoc* alignment and improvisation on the basis of mutual awareness versus action constrained by coordinative artifacts and protocols — are not 'natural kinds' in the Aristotelian sense: they do not exist as distinct domains of action, they are analytical distinctions.

On one hand, actors cooperating in some 'shared space' of artifacts are fundamentally engaged in articulating inescapably distributed activities. However, the actors will routinely rely on the common-sense meaning these artifacts and the actions taken in this space have for them as competent members; they will routinely develop and agree upon conventional ways of doing things ('this thing should be called that', 'that is to be put there', 'when that happens, do this and then that') which they, as competent actors, will take for granted and also expect others to adhere to, unless there are reasons not to. In the words of Alfred Schutz:

> "As we normally have to act and not to reflect in order to satisfy the demands of the moment, which it is our task to master, we are not interested in the "quest for certainty". We are satisfied if we have a fair chance of realizing our purposes, and this chance, so we like to think, we have if we set in motion the same mechanism of habits, rules and principles which formerly stood the test and which still stand the test.' [50, p. 65]

Sometimes, when faced with highly complex interdependencies, actors will not only rely on implicit conventions but will devise more or less well designed coordinative artifacts and protocols which they, again, will take for granted and rely on for all practical purposes. Articulation work is thus characterized by a continuum of interactional modalities from improvised *ad hoc* interaction and the adoption of learned common-sense constructs which are taken to be 'shared' 'for all practical purposes' and 'until demonstrated otherwise', over the tacit adoption and use of conventions, to the design, introduction, and application of coordinative artifacts and protocols.

Consider, for example, the cooperative activity of a team of designers: their shared space is populated by drawings, test results, process specifications, planning documents, user requirements documents, manuals, technical papers and reports, and so forth. In order for this shared repository not to degenerate chaotically they will adopt implicit naming conventions and other conventions specifying in which place to put and how to label artifacts of a certain kind. In typical design environments, they will not rely entirely on negotiations and conventions; the repository will be organized according to a written classification scheme. The latter governs how actors locate, access, manipulate these artifacts in such a way that the other actors can use the repository in orderly fashion. Other forms of coordinative constructs — 'scripts' — may be adopted as well to handle other aspects of dealing with this shared space, for instance for regulating the process of changing the contents of the repository as well as the classification scheme (e.g., by means of 'change notes') and for maintaining consistency [cf., e.g., 2; 16; 25; 26].

On the other hand, the execution of protocols presumes and involves situated action. Situated action is not something that is 'essentially outside the plan's scope' [59, pp. 188 f.]. To the contrary, coordinative protocols are predicated on competent members to fill in the blanks unavoidably left unspecified by the protocol [66]. Since coordinative protocols are inexorably underspecified, the complete and exhaustive definition of a protocol is achieved only in the course of their execution, i.e., when the unfolding context of action allows the actor to incrementally solve all non-determinism by taking specific decisions or alternatives and, possibly, by enforcing some local and temporary modification.

The situated activity inherent in protocol execution thus requires actors' mutual awareness with respect to the state of the field of work, of the cooperating ensemble, of the protocol itself (as proposed in [1]), and of intersecting protocols. Hence, information pertaining to the provision and acquisition of mutual awareness is a primary resource for an effective and adaptable use of protocols to support distributed activities. In other words, the combined use of coordinative protocols and mutual awareness allows for the reduction of 'computational' cost through 'precomputation' without imposing undue rigidity to the flow of activities, and to take the 'best at hand' decision due to adequate knowledge of the current state of affairs.

These considerations have three main consequences: First of all, as the general ubiquitous foundation for articulation work mutual awareness is crucial in all types of situations: by providing a basis for *ad hoc* improvisation as a specific articulation strategy in shared work spaces and by providing the rich texture which enables actors to specify and situate the protocols which would otherwise remain vague linguistic constructs. Secondly, a technology supposed to support cooperative work cannot avoid to *address protocols and mutual awareness in an integrated way* so as to make it is possible, at any time, to use the most appropriate means of coordination. Otherwise, the means which has been left out will be not only be un-supported but will create an impediment to the other one since it is managed in a completely disconnected way. Finally, for both protocols and awareness functionality adaptability by the users to their current situation is a mandatory requirement.

3. Towards integrated support of articulation work

The concepts of coordinative protocols and mutual awareness as outlined above have been taken as working concepts in the development of an integrated support environment to support articulation work. This has been achieved through the design and implementation of a series of prototypes:

- *Coordinative protocols and artifacts*: A language (Ariadne) has been developed for defining, specifying, and executing 'coordination mechanisms'[6] [17]; this language is implemented in an agent-based architecture (ABACO) that offers a specialized Interoperability Language to support flexibility at various levels of depth [18]: its categories and composition laws have been identified empirically [49].
- *Mutual awareness*: A set of linguistic features for the definition of mutual awareness both between actors and artificial entities have been identified. These features, which have been implemented in a software component called AW-Manager [52], allow for the specification of triggers, as well as the provision and acquisition of and reaction to awareness information.
- *Interoperability*: A software component (called Reconciler [53]) supports the interoperability of different 'coordination mechanisms' in terms of the mutual alignment of their boundary objects and events.

In the following we will briefly sketch the design principles that govern the integration of coordinative protocols and mutual awareness in the development of the three prototypes by focusing on some major problems.

3.1 The problem of semantic level

In order to achieve the integration of coordinative protocols and mutual awareness it is mandatory to adopt a uniform approach to the definition of the capabilities supporting any of them. Here the issue of flexibility plays a central role. In fact, for users to be capable of adapting the mutual awareness and protocol functionalities in a way that is adequate to their needs, appropriate linguistic features by means of which to define these functionalities must be identified and made visible [49] to them.

First of all, Ariadne as well as AW-Manager incorporate functionalities based on a limited number of elemental categories that can be composed flexibly to obtain more complex behaviors. Their meaning has been not only univocally defined to support flexibility in terms of compositionality but it has been defined also to make sense to the users themselves: that is, the elemental categories and the rules of their composition are expressed at

6 Cordination mechanisms, in our terminology, are dyads of coordinative protocols and artifacts.

the semantic level of articulation work, as it emerged by a rich set of empirical studies documented in the literature. We can illustrate the point by considering the case of text processing: categories such as word, sentence, paragraph, list, chapter, heading, footnote, etc. are taken as basic categories and text processing is achieved through a combination of commands manipulating them, as e.g. in SGML. What was needed, then, and what has been identified, are languages that *in precisely the same way* allows users to express salient categories of articulation work and the rules for combining them for purposes of managing coordinative protocols and mutual awareness facilities.

As for protocols, the elemental categories and composition laws capture how actors identify the basic units of work and information for articulating their activities and the relations between these units. For this to be feasible requires a degree of expressiveness such that no specific modelling approach is imposed: that is, any type of flow of work up to the light-most shared working space should be representable. Moreover, since classification schemes and coordinative artifacts play an important role in articulation work, the basic categories and relations must allow for their definition as well. Finally, all entities must be able to communicate in such a way as to ensure the different *intrusive modes of articulation work.*

As for mutual awareness, the elemental categories capture how actors identify which basic units of information have to be associated to which basic types of triggers of information pertinent to the formation of mutual awareness. Here the composition rules refer to how *triggers* are combined, how information is *provided* and *acquired,* and how recipients can *adjust their activities accordingly*. The metaphor underlying the related language is based on the chemico-physical phenomena of reaction, diffusion, and transportation, which seems to aptly represent the dissemination of and reaction to awareness information in the physical and logical space determined by the target cooperative setting. Again, all entities must be able to communicate in such a way as to ensure different levels of intrusiveness (based on message strength and sensitivity thresholds) with respect to the recipient's course of action.

Secondly, in both prototypes the categories and the composition rules have been made visible to the users in such a way that they can freely decide the appropriate level of adaptation, from 'shallow' to 'deep customization' [18] without being involved in any programming activity. This implies that the language clearly states what can be described and what cannot, what can be modified and what cannot. This leads to the next issue, namely the validation of the selected features and rules on the basis of empirical evidence. That is, the identified linguistic features are not and should not be conceived of as an ontology, but rather as the outcome of an empirically based inductive abstraction process. As such, they are open to revision at any time and still well defined at any moment.

3.2. The problem of integration

The semantics of the linguistic features necessary to construct, on the one hand, the functionality of coordinative protocols and, on the other hand, the functionality of mutual awareness facilities, are quite different; the elemental categories and the composition rules therefore should reflect this distinction while preserving the integrability of the two resulting sets of features. The problem is, however, how to integrate the two sets of primitives characterizing the above-mentioned languages. This is basically achieved by providing each category (and each aggregation of categories) within the ARIADNE language with 'mutual awareness capabilities'. In this way, mutual awareness can be 'expressed' (triggered, provided, acquired, used) at any level of depth in the definition of protocols. A similar solution has been adopted in [61] to give objects 'awareness' capabilities; the point we want to make is that the solution has to be raised, again, to the semantic level of articulation work, by qualifying the appropriate object types and their aggregations.

In our approach the basic idea is that the (aggregations of) categories constituting the protocol notify the AW-Manager of the awareness triggers by using their communication capabilities. The AW-Manager then handles the awareness space and the execution of the scripts which are associated to those triggers and which are defined as combinations of awareness primitives. Finally, the AW-Manager returns the awareness information to the appropriate (aggregation of) categories, again by virtue of their capability of receiving awareness information. The way in which this integration is achieved may sound somewhat strange since it gives artificial entities mutual awareness capabilities typical of human beings. However, this possibility is partially contemplated in the Spatial Models of awareness as well. For example, in [43] 'The set of users U is a heterogeneous collection of objects that may represent users, group of users, and any object capable of exerting an active presence.' The main difference is that the proposed approach to integration also gives endow entities with the capability of *adjusting their activities.* Of course, since these entities are artificial, they do not posses any intentionality and they can then only be defined to react to their state changes such as changes produced by the acquisition of mutual awareness information.

The artificial entity may, to take a simple example, act as the assistant of an actor. In this case, the actor delegates some simple and algorithmic part of mutual awareness management to the system. For example, the assistant may monitor different sources of signals and cues, perhaps even from a dynamically determined subset of sources, depending on the current context, then provide the user with information concerning the state of affairs, packaged according to the user's preferences, i.e., at an appropriate level of granularity, etc. The assistant may thus reduce the user's overhead in staying aware.

A by far more interesting case is when the artificial entity represents a coordination mechanism, i.e., a coordinative artifact (a production schedule, a fault report form, etc.) which stands proxy for a coordinative protocol. The 'active' role of coordinative artifacts in articulation work has been demonstrated by several field studies [5; 16; 49]. This role mainly consists in the capability of conveying awareness information of the current state of affairs to actors, typically in terms of the state of the coordinative protocol for which the artifact stands proxy. The ability of a computational coordinative artifact to acquire awareness information and to adjust its activities accordingly will allow it to take a 'truly active' role; in fact, computational artifacts show much greater flexibility over the paper-based ones when it comes to combining and elaborating different awareness triggers and in propagating different kinds of information to actors as well as other entities.

3.3. The problem of distributedness

Last but not least, the distributed nature of cooperative work requires that coordinative protocols and mutual awareness functionalities are integrated with respect to not just a single cooperation application, but also composite applications which evolve in an autonomous way. The problem of managing mutual alignment of such applications becomes a crucial part of coordination and can be formulated in terms of 'interoperability raised at the semantic level of articulation work' [51], in contrast to current research efforts that aim at the interoperability of applications at the system level (cf., e.g., Corba [3] and the construction of compliant platforms). Although fundamental, interoperability at this level is not sufficient to solve the problem of the mutual alignment of cooperative applications, since that to be effective requires rich contextual information concerning, at least, the modifications and current states of the involved protocols as well as the conventions governing the definition and use of boundary objects with the related events. This is the one of most challenging aspects of the integration we are discussing in this paper.

In order to supply such contextual information we have identified two software components. A 'Contextual Information Service' which is presented in [19] and the Reconciler already mentioned. The latter provides a means for managing the tension between the requisite local perspective and the shared meaning required to interpret the boundary objects and intersecting events that characterize inter-group cooperation. This is achieved by recording the conventions users establish to maintain the correspondence between the different definitions and views of the boundary objects and crossing events. The recorded conventions are then used to improve inter-group cooperation in terms of 'translation' when possible or, when not, to support the related learning process by highlighting discrepancies and increase mutual awareness of how people comply with or violate conventions.

Our definition of mutual awareness employs the notion of 'dissemination' which, in turn, refers to the notion of an 'awareness space'. This idea was aptly captured by the Spatial Models of awareness from the very beginning [6; 43; 44]. In order to support the formation of mutual awareness in distributed cooperative settings we have to take into account that this space can be neither monolithic nor static and, more importantly, how the involved actors explicitly or implicitly, through their actions, define the space of mutual awareness which is pertinent to them and in which they are interested. To this aim, the AW-Manager can manage a set of interacting awareness spaces populated by the entities associated with the interacting coordination mechanisms which Ariadne allows actors to define and activate and the Reconciler tries to keep mutually interpretable. In this way it is possible to combine different awareness spaces in a flexible way, according to the interests of the various actors in marking and exploring them for sake of mutual awareness.

4. Conclusion

To summarize, the design of a technology that meets the requirement of integrating different modalities of articulation work, while taking into account the distributedness of cooperative work as well as the semantic level of articulation work, not only requires suggestive metaphors and adequate models but also languages with the appropriate expressiveness and compositionality. Only then are users provided with a practically open-ended set of possibilities for tailoring the technology according to their dynamic needs. As a direct consequence of this, the still unsolved problem of presentation of contextual information in the articulation of activities in complex work settings, especially in the case of awareness information [36], becomes extremely crucial in view of the paucity of the current user interfaces with respect to such demanding presentation problems. In our opinion, user interfaces can become a real bottleneck to any reasonable evolution of coordination technologies: current screen dimensions as well as graphical metaphors such as windows, buttons, and the like are far from adequate. New metaphors are required to get the appropriate technology [in the line indicated in, e.g., 1; 7; 21; 32; 36; 42].

Moreover, although the designed prototypes have been conceived of in the light of the desired integration, the achievements are presently more at the architectural level [51] than at the level of a set of functionalities that can be effectively and flexibly used. The construction of such a comprehensive and coherent technological framework is part of our future work.

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