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# Cooperative Work and its Articulation:

## *Requirements for Computer Support*

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**French abstract**. Le nouveau domaine de recherche interdisciplinaire et de développement appelé Computer-Supported Cooperative Work ou CSCW représente un apport fondamental dans l'approche de la conception de systèmes informatiques.

Dans la conception de systèmes informatiques de base pour un domaine particulier, le problème central a été de développer des modèles de calcul effectifs des structures pertinentes et des processus dans les différents champs du domaine de travail (flux de données, shémas conceptuels, représentation des connaissances) ainsi que les modes de représentation et d'accès adéquats à ces structures et processus représentés dans ces systèmes.

Alors que dans les organisations et sociétés, ces systèmes étaient souvent utilisés par plusieurs utilisateurs, les problèmes de coordination des activités individuelles et les méthodes de travail en commun n'étaient pas considérées directement et systématiquement comme une question de conception elle-même.

La coordination et la distribution du travail ne semblaient pas importantes. Ce n'était évidemment pas un problème pour le concepteur ou l'analyste.

Avec CSCW pourtant, ces problèmes sont devenus primordiaux. Ainsi, pour développer des systèmes informatiques qui fournissent une aide réelle et adéquate pour le “cooperative work”, il est crucial pour progresser, que nous comprenions mieux le concept de “cooperative work” et toutes ses articulations.

Cet article discute de la nature et des caractéristiques du “cooperative work”, et des modifications conceptuelles des systèmes informatiques appropriés que cela implique.

**French keywords**: Articulation du travail, Coordination, CSCW, Mechanismes de l’interaction, Travail cooperatif.

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The last few years have witnessed an almost explosive surge of interest in developing computer systems to support cooperative work. Since 1986, a brand new research area named “Computer-Supported Cooperative Work” — complete with acronym (CSCW), international conferences, numerous workshops, scientific journal, and book series — has emerged, bringing together widely disparate research traditions and perspectives into an arena of interdisciplinary collaboration and contention.

As if swept on by this wave of scientific, managerial, and commercial interest, the very phenomenon of ‘cooperative work’ has become focus of research in itself. This paper will discuss key issues in this research and some of its results. What is cooperative work? How is it articulated? What are the requirements of computer systems supposed to ‘support’ cooperative work?

Before we plunge into these questions, however, let us delve briefly on why the very program — computer support for cooperative work — may have emerged and generated such enthusiastic attention. Why CSCW?

# Why CSCW?

Cooperative work has developed historically. For example, agricultural work and craft work of pre-industrial society was only sporadically cooperative. Due to the low level of division of labor at the point of production, the bulk of human labor was exerted individually or within very loosely coupled arrangements. There were, of course, notable exceptions to this picture such as harvest and large building projects (e.g., pyramids, irrigation systems, roads, cathedrals), but these examples should not be mistaken for the overall picture.

Cooperative work as a systematic arrangement of the bulk of work at the point of production emerges in response to the radical division of labor in manufactories that inaugurated the Industrial Revolution. In fact, systematic cooperation in production can be seen as the ‘base line’ of the capitalist mode of production. However, cooperative work based on the division of labor in manufactories is essentially amputated: the interdependencies between the specialized operators in their work are mediated and coordinated by means of a hierarchical systems of social control (foremen, planners etc.) and by the constraints embodied in the layout and mode of operation of the technical system (conveyer belt etc.).

In view of the fundamental trends in the political economy of contemporary industrial society, this ‘fetishistic’ form of cooperative work is probably merely a transient form in the history of work. Comprehensive changes of the societal environment permeate the realm of work with a whole new regime of demands and constraints. The business environment of modern manufacturing, for instance, is becoming rigorously demanding as enterprises are faced with shorter product life cycles, roaring product diversification, minimal inventories and buffer stocks, extremely short lead times, shrinking batch sizes, concurrent processing of multiple different products and orders, etc. (Gunn, 1987). The turbulent character of modern business environments and the demands of an educated and critical populace, compel industrial enterprises, administrative agencies, health and service organizations, etc. to drastically improve their innovative capability, operational flexibility, and product quality. To meet these demands, work organizations must be able to adapt rapidly and diligently and to coordinate their distributed activities in a comprehensive and integrated way. And this requires horizontal and direct cooperation across functions and professional boundaries within the organization or within a network of organizations.

In other words, modern work organizations require support from advanced information systems that can facilitate the horizontal coordination of distributed decision making. Simultaneously, the proliferation of powerful workstations in cooperative work settings and their interconnection in comprehensive high-capacity networks provide the technological foundation to meet this need. Such developments are illustrated in the area of Computer Integrated Manufacturing (CIM) by the efforts to integrate formerly separated functions such as design and process planning, marketing and production planning, etc., and by the similar efforts in areas such as Office Information Systems (OIS), Computer Aided Design (CAD), Computer Aided Software Engineering (CASE) to facilitate and enhance the exchange of information across organizational and professional boundaries.

CSCW represents a fundamental shift in the approach to the design of computer systems. In the design of conventional computer-based systems for work settings the core issues have been to develop effective computational models of pertinent structures and processes in the field of work (data flows, conceptual schemes, knowledge representations) and adequate modes of presenting and accessing these structures and processes as represented in computer systems (user interface, functionality). Surely, normally computer systems were used in organizational settings and were even often used by multiple users as in the case of systems that are part of the organizational infrastructure (e.g., database systems). Nevertheless, the issue of how multiple users work together and coordinate and mesh their individual activities — 'through' the system or 'around' it — was not addressed directly and systematically, as a design issue in its own right. So far as the underlying model of the structures and processes in the field of work was 'valid', it was assumed that the articulation of the distributed activities was of no import or that it was managed somehow by whoever it might concern. It was certainly not a problem for the designer or the analyst. With CSCW, things have changed. In order to develop computer-based system that *support* the articulation of cooperative work in terms of making articulation work more flexible, efficient, and effective, the very issue of how multiple users work together and coordinate and mesh their individual activities has become the focal issue (Schmidt et al., 1992). CSCW can thus be taken to represent a complete overturn of the conventional paradigm in the design of computer systems (Hughes et al., 1991).

Thus, in order to develop computer systems that provide adequate and effective support for cooperative work in the emerging flexible work organizations, it is crucial to advance our understanding of cooperative work and its articulation.

# Cooperative work

The term 'cooperation' has a wide variety of connotations in everyday usage, ranging from notions of joining alliances (as in the 'cooperative' movement) and being amicable and altruistic ('You should be more cooperative') to actually working together in producing a product or service irrespective of whether those working together are allies or friends. On the other hand, the term 'cooperative work', chosen by Greif and Cashman to designate the object domain of the new R&D area of CSCW, happens to be a term with a long history in the social sciences and one which is quite appropriate to the current context of CSCW (Schmidt et al., 1992). It was used as early as the first half of the 19th century by economists such as Ure (1835) and Wakefield (1849) as the general and neutral designation of work involving multiple actors and was further developed by Marx (1867) who defined it as "multiple individuals working together in a conscious way [planmässig] in the same production process or in different but connected production processes." In this century, the term has been used extensively with the same general meaning by various authors, especially in the German tradition of the sociology of work (Popitz et al., 1957; Bahrdt, 1958; Dahrendorf, 1959; Kern et al., 1970; Mickler et al., 1976, for example).

Work is, of course, always social, deeply and complexly social (Marx, 1857). What is gained, then, by referring to 'cooperative work'? While work is always socially organized, the very work process does not always involve multiple people that are mutually dependent. People engage in *cooperative work* when they are *mutually dependent* in their work and therefore are required to cooperate in order to get the work done (Schmidt, 1991). We are social animals, but we are not *all* of us *always* and in *every* respect mutually dependent in our work. Thus, in spite of its intrinsically social nature, work is not intrinsically cooperative in the sense that actors are mutually dependent in their work.

The notion of mutual dependence *in work* does not refer to the interdependence that arises from simply having to share the same resource. Actors using the same resource certainly have to coordinate their activities but to each of them the existence of the others is a mere nuisance and the less their own work is affected by others the better. The time-sharing facilities of mainframe computers cater for just that by making the presence of other users imperceptible.

A cooperative work relationship is constituted by the fact that multiple actors are transforming and controlling a complex of *mutually interacting* objects and processes. They are thus, so to speak, working on the same 'field of work'. Thus, being mutually dependent *in work* means that A relies positively on the quality and timeliness of B's work and vice versa. B may be 'down stream' in relation to A but in that case A nonetheless will depend on B for feedback on requirements, possibilities, quality problems, schedules etc. In short, mutual dependence in work should primarily be conceived of as a positive, though by no means necessarily harmonious, interdependence.

Because of the underlying and constitutive interdependence, cooperating actors must articulate (divide, allocate, coordinate, schedule, mesh, interrelate, etc.) their respective activities. Thus, by entering into cooperative work relations, the participants must engage in activities that are, in a sense, extraneous to the activities that contribute directly to fashioning the product or service and meeting the need. The obvious justification of incurring this overhead cost and thus the reason for the emergence of cooperative work formations is, of course, that actors could not accomplish the task in question if they were to do it individually, at least not as well, as fast, as timely, as safely, as reliably, as efficiently, etc. (Schmidt, 1990).

For example, in a study of the impact of technology on cooperative work among the Orokaiva in New Guinea, Newton (1985) observes that technological innovations for hunting and fishing such as shotguns, iron, torches, rubber-propelled spears, and goggles have made individual hunting and fishing more successful compared to cooperative arrangements. As a result, large-scale cooperative hunting and fishing ventures are no longer more economical or more efficient and they are therefore vanishing. Likewise, the traditional cooperative work arrangements in horticulture for purposes such as land clearing and establishment of gardens have been reduced in scope or obliterated by the influence of the steel ax. A similar shift from cooperative to individual work can be observed wherever and whenever new technologies augment the capabilities of individual actors to accomplish the given task individually: harvesters, bulldozers, pocket calculators, word processors, etc.

Generally speaking, cooperative work relations are formed because of the limited capabilities of single human individuals, that is, because the work could not be accomplished otherwise, or at least could not be accomplished as quickly, as efficiently, as well, etc., if it was to be done on an individual basis. More specifically, a cooperative work arrangement may emerge in response to different requirements and may thus serve different generic functions (Schmidt, 1990):

*Augmentation of capacity*: A cooperative work arrangement may simply augment the mechanical and information processing capacities of human individuals and thus enable a cooperating ensemble to accomplish a task that would have been infeasible for the actors individually. As an ensemble they may, for instance, be able to remove a stone that one individual could not move one iota. In the words of John Bellers: “As one man cannot, and 10 men must strain, to lift a tun of weight, yet one hundred men can do it only by the strength of a finger of each of them.” (Bellers, 1696, p. 21). This is cooperative work in its most simple form. By cooperating, they simply augment their capacity: “With simple cooperation it is only the mass of human power that has an effect. A monster with multiple eyes, multiple arms etc. replaces one with two eyes etc.” (Marx, 1861-63, p. 233).

*Differentiation and combination of specialties*: A cooperative work arrangement may combine multiple *technique-based specialties*. In augmentative cooperation the allocation of different tasks to different actors is incidental and temporary; the participants may change the differential allocation at will. By contrast, technique-based specialization requires an “exclusive devotion” to a set of techniques (de Tracy, 1815, p. 79). That is, as opposed to the contingent and reversible differentiation of tasks that may accompany augmentative cooperation, the *technique-based specialization is based on an exclusive devotion to a repertoire of techniques*. In the words of the eulogist of technique-based specialization, Adam Smith: "the division of labour, by reducing every man's business to some one simple operation, and by making this operation the sole employment of his life, necessarily increases very much the dexterity of the workman" (Smith, 1776, p. 7.). The different techniques must be combined, however, and the higher the degree of technique-based specialization, the larger the network of cooperative relations required to combine the specialties (Babbage, 1832, §§ 263-268, pp. 211-216). That is, *technique-based specialization requires combinative cooperation*. This combinative cooperation is defined by Marx as "cooperation in the division of labor that no longer appears as an aggregation or a temporary distribution of the same functions, but as a decomposition of a totality of functions in its component parts and unification of these different components" (Marx, 1861-63, p. 253). Hence, the combination of multiple technique-based specialties assumes the character of a mechanical totality in which the human actors are assigned the role of a component. In the words of Ferguson's classic denunciation of this kind of division of labor: "Manufactures […] proper most, where the mind is least consulted, and where the workshop may, without any great effort of imagination, be considered as an engine, the parts of which are men." (Ferguson, 1767, p. 183)

*Mutual critical assessment*: A cooperative work arrangement may facilitate the application of multiple problem-solving *strategies and heuristics* to a given problem and may thus ensure relatively balanced and objective decisions in complex environments. Under conditions of uncertainty decision making will require the exercise of discretion. In discretionary decision making, however, different individual decision makers will typically have preferences for different heuristics (approaches, strategies, stop rules, etc.). Phrased negatively, they will exhibit different characteristic 'biases'. By involving different individuals, cooperative work arrangements in complex environments become arenas for different decision making strategies and propensities where different decision makers subject the reliability and trustworthiness of the contributions of their colleagues to critical evaluation. (Schmidt, 1990). As an ensemble they are thus able to arrive at more robust and balanced decisions. For example, take the case of an "experienced and skeptical oncologist," cited by Strauss and associates (1985):

> "I think you just learn to know who you can trust. Who overreads, who underreads. I have got X rays all over town, so I've the chance to do it. I know that when Schmidt at Palm Hospital says, 'There's a suspicion of a tumor in this chest,' it doesn't mean much because she, like I, sees tumors everywhere. She looks under her bed at night to make sure there's not some cancer there. When Jones at the same institution reads it and says, 'There's a suspicion of a tumor there,' I take it damn seriously because if he thinks it's there, by God it probably is. And you do this all over town. Who do you have confidence in and who none."

The point is, as observed by Cicourel (1990, p. 222), that "the source of a medical opinion remains a powerful determinant of its influence." That is, "physicians typically assess the adequacy of medical information on the basis of the perceived credibility of the source, whether the source is the patient or another physician." Thus "advice from physicians who are perceived as 'good doctors' is highly valued, whereas advice from sources perceived as less credible may be discounted." This process of mutual critical evaluation was described by Cyert and March (1963) who aptly dubbed it 'bias discount.' Even though dubious assessments and erroneous decisions due to characteristic individual biases are transmitted to other decision makers, this does not necessarily entail a diffusion or accumulation of mistakes, misrepresentations, and misconceptions within the decision-making ensemble. The cooperating ensemble establishes a negotiated order.

*Confrontation and combination of perspectives*: A cooperative work arrangement may finally facilitate the application of multiple *perspectives* on a given problem so as to match the multifarious nature of the field of work. A perspective, in this context, is a particular — local and temporary — conceptualization of the field of work, that is, a conceptual reproduction of a limited set of salient structural and functional properties of the field of work, such as, for instance, generative mechanisms, causal laws, and taxonomies, and a concomitant body of representations (models, notations, etc.).

To grasp of the diverse and contradictory aspects of the field of work as a whole, the multifarious nature of the field of work must be matched by a concomitant multiplicity of perspectives on the part of the cooperating ensemble (Schmidt, 1990). The application of multiple perspectives will typically require the joint effort of multiple agents, each attending to one particular perspective and therefore engulfed in a particular and parochial small world.

The cooperative ensemble must articulate (interrelate and compile) the partial and parochial perspectives by transforming and translating information from one level of conceptualization to another and from one object domain to another (Schmidt, 1990).

An interesting issue, raised by Charles Savage in a 'round table discussion' on Computer Integrated Manufacturing (Savage, 1987), illustrates this issue quite well:

> "In the traditional manual manufacturing approach, human translation takes place at each step of the way. As information is passed from one function to the next, it is often changed and adapted. For example, Manufacturing Engineering takes engineering drawings and red-pencils them, knowing they can never be produced as drawn. The experience and collective wisdom of each functional group, usually undocumented, is an invisible yet extremely valuable company resource."

This fact is ignored by the prevailing approach to CIM, however:

> "Part of the problem is that each functional department has its own set of meanings for key terms. It is not uncommon to find companies with four different parts lists and nine bills of material. Key terms such as *part*, *project*, *subassembly*, *tolerance* are understood differently in different parts of the company."

The problem is not merely terminological. It is the problem of multiple incommensurate perspectives. The issue raised by Savage is rooted in the multiplicity of the domain and the contradictory functional requirements. In Savage’s words: “Most business challenges require the insights and experience of a multitude of resources which need to work together in both temporary and permanent teams to get the job done”.

In sum, a cooperative work arrangement arises simply because there is no omniscient and omnipotent agent.

Since cooperative work relations emerge in response to the requirements and constraints of the transformation process and the social environment on one hand and the limitations of the technical and human resources available on the other, cooperative work arrangements adapt dynamically to the requirements of the work domain and the characteristics and capabilities of the technical and human resources at hand. Different requirements and constraints and different technical and human resources engenders different cooperative work arrangements.

Cooperative work and individual work should not be conceived of as different work domains. In daily work practice, cooperative and individual activities are inextricably interwoven. Cooperative work is always conducted by individuals (albeit interdependently and hence concertedly), and yet, in cooperative work settings individual activities are always penetrated and saturated by cooperative work as by a social ‘ether’ (Hughes et al., 1991). More than that, the boundary between individual and cooperative work is dynamic in the sense that people enter into cooperative work relations and leave them according to the requirements of the current situation and the technical and human resources at hand. That is, cooperative work arrangements emerge contingently, to dissolve again into individual work. Cooperative work is punctuated by individual work and vice versa. Over time, people shift between individual and cooperative activities and, while engaged in cooperative work activities, they may be simultaneously involved in parallel streams of activity conducted individually.

## The distributed nature of cooperative work

The very fact that multiple actors are involved in doing the work introduces an element of distributed decision making. The contingencies encountered in any human action may defeat the very best plans and designs. As pointed out by Suchman (1987), “the relation of the intent to accomplish some goal to the actual course of situated action is enormously contingent.” Plans may of course be conceived by actors prior to action but they are not simply executed in the actions. Action is infinitely rich compared to the plan and cannot be exhausted by a plan. Thus, each individual encounters contingencies that may not have been anticipated by his or her colleagues and that, perhaps, will remain unknown to them. Each participant in the cooperative effort is faced with a — to some extent — unique local situation that is, in principle, ‘opaque’ to the others and have to deal with this local situation individually. For example: misplaced documents, shortage of materials, delays, faulty parts, erroneous data, variations in component properties, design ambiguities and inconsistencies, design changes, changes in orders, cancellation of orders, rush orders, defective tools, software incompatibility and bugs, machinery breakdown, changes in personnel, illness, etc. That is, due to the fundamentally 'situated' nature of human action, cooperative work arrangements take on an indelible distributed character.

Furthermore, the fact that the cooperative arrangement involves - and has emerged to allow - a combination of different specialties, incongruent heuristics, and incommensurate perspectives introduces a systematic element of distributed decision making in cooperative work.

And finally, work is an individual phenomenon in so far as labor power happens to be tied to individuals and cannot be separated from the individuals. That is, a cooperative work process, is performed by individuals with individual interests and motives. Because of that, cooperative ensembles are coalitions of diverging and even conflicting interests rather than perfectly collaborative systems. Thus, in the words of Ciborra (1985), the use of information for “misrepresentation purposes” is a daily occurrence in organizational settings. The Russian proverb saying that 'Man was given the ability of speech so that he could conceal his thoughts' applies perfectly to the use of information in organizations.

In sum, then, cooperative work is, in principle, distributed in the sense that decision making agents are semi-autonomous in their work in terms of contingencies, criteria, methods, specialties, perspectives, heuristics, interests, motives and so forth.

# Articulation of cooperative work

Due to the very interdependence in work that gave rise to the cooperative work arrangement in the first place, the distributed nature of the arrangement must be kept in check, managed. The distributed activities must be articulated: Who is doing what, where, when, how, by means of which, under which requirements? Articulation work arises as a integral part of cooperative work as a set of activities required to manage the distributed nature of cooperative work. In the words of Strauss (1985), articulation work is “a kind of supra-type of work in any division of labor, done by the various actors”: “Articulation work amounts to the following: First, the meshing of the often numerous tasks, clusters of tasks, and segments of the total arc. Second, the meshing of efforts of various unit-workers (individuals, departments, etc.). Third, the meshing of actors with their various types of work and implicated tasks.”

In a CSCW perspective, that is, when analyzing cooperative work with a view to designing computer-based systems to support the articulation of cooperative work, it is useful to distinguish different modes and mechanisms of articulation work.

## Cooperative work mediated by the field of work

Since a cooperative work relationship is constituted by the fact that multiple actors are interdependent in their work in the sense that they are working on the same 'field of work', all cooperative work involves a basic indirect interaction through changing the state of a common field of work. What one actor - A - is doing is of import to the B and C and they can to some extent infer what A is doing from the changing state of the field of work.

The classic study by Popitz and others (1957) of cooperative work in the German steel industry provides an eloquent example of "structurally mediated co-operation" or cooperative work mediated by the field of work, in this case cooperative manual control of a rolling mill that shapes hot steel ingots into strips of different forms and dimensions. The members of crew running the mill are - for all practical purposes - unable to articulate their individual activities by talking to each other. The noise level prevents them from talking during work, and some of them cannot even see each other. It thus often happens that operators do not talk to each other during a eight-hour day. Furthermore, the operators are so intensely preoccupied with controlling a process that has its own intrinsic temporal order, that they do not have the time to talk or to watch the hand movements of each other. (p. 185). Each operator is on his own in doing his work - but in such a way that his activity at any time fits closely into and continues the technical transformation process and every variation in the work of another of import for this process must immediately be countered by him by a variation in his own work. The crew nevertheless manages to act in a concerted may without verbal communication and without watching the operations of each other. Each of them knows what the other is doing by apperceiving the behavior of the mill: the movement of the rolling-way and the tip cart as well as the setting and direction of rotation of the rolls. In a normal rolling process they can coordinate their distributed activities by apperceiving the behavior of only one object: the glowing strip (p. 187).

While the indirect articulation of cooperative work via the field of work is basic to all cooperative work, it is rarely adequate. Changing the state of the field of work is a perilous channel of articulation work because state changes in the field of work may have undesirable consequences. In the case of the hot rolling mill, the transformation process allowed operators no degrees of freedom for conveying information to the other operators. Even if the nature of the transformation process allows degrees of freedom for modulating the way in which the field of work can be changed and thus a means of interaction, such state changes are rudimentary as a means of communication: The bandwith is quite restricted; the turn-around time of the interaction is determined by the frequency of state changes in the field of work, and - most importantly - the message is completely embodied in the state of the field of work.

## Modes of interaction

In fact, articulation of cooperative work involves and, indeed, requires a vast variety of direct articulation by means of different *modes of interaction* that are combined and meshed dynamically in accord with the specific requirements of the unfolding work situation and the means of communication available. The following modes of interaction are ubiquitous:

*Formation of reciprocal awareness*: A reciprocal awareness among the members of the cooperating ensemble of the work activities, concerns, and intentions of the other members of the ensemble is normally a prerequisite to the fluent articulation of the distributed activities in a cooperative setting. The formation and maintenance of reciprocal awareness may be quite unpremeditated and inconspicuous. By perceiving the activities of A (where is he in the room, what is he doing with his hands, what is he gazing at, what is he saying to third parties etc.), B and C may be able to infer tacitly what A is doing or even anticipate what A intends to do in relation to the field of work.

A recent study by Kasbi and Montmollin (1991) exploring the impact practice of computerization of the control room design for a new generation of French nuclear power plants on cooperative work provides striking insight in the formation of reciprocal awareness. In traditional control rooms plants, information on the state of the plant is displayed on a panel that is several meters long; it is located in a room in which the two operators both work. By contrast, in the new control room design each operator has a computer workstation. While these workstations provide access to all relevant control data, the new design has some disruptive effects on articulation work. In a conventional control room, each operator is continuously informed of the part of the process monitored by the other operator from the position of the other in relation to the instrument panel. From the changing positions of his colleague in the room, he or she can effortlessly infer what the other is up to. Furthermore, he only has to take a few steps to get a clearer idea of what is happening and in doing so he does not need to disturb the activities being carried out. That is, the specific characteristics of the conventional interface to the control system of the plant provide cues for operators that enable them to develop and maintain the required mutual awareness without forcing them to resort to verbal communication. In the new design, however, the formation of this mutual awareness is not supported by the design of the control room. As a result, articulation work requires precise verbalization and conscious and perhaps disruptive workstation management activities.

As illustrated by the study by Kasbi and Montmollin as well as by the study of the control rooms in the London Underground by Heath and Luff (1992) the development and maintenance of reciprocal awareness of the work of the other members of the ensemble involves an ongoing process of inconspicuous and unobtrusive monitoring of the activities of the others.

*Directing attention*: In articulating their joint effort, each of the members of the cooperative ensemble may deliberately - but not necessarily consciously - direct the attention of the other members to certain features of the state of the field of work, a possible problem, disturbance or danger, a task to be carried out etc. In doing this, actors may invoke a multitude of means of interaction: they may tacitly highlight particular items in the common environment, for instance by positioning them in certain locations and ways; they may more overtly point or stare at certain items, or they may simply address their colleagues explicitly by talking or shouting.

A comprehensive study on cooperative work in air traffic control conducted over several years by researchers at the Department of Sociology at the University of Lancaster (Hughes et al., 1988; Harper et al., 1991; Hughes et al., 1992; Hughes et al., 1993; Harper et al., 1994) has provided interesting insights into the delicate and multifaceted handling of an artifact - the flight strip - to facilitate fluent and dynamic articulation work, *inter alia* by directing attention by means of cues embedded in the position artifacts.

Air traffic controllers have three main artifacts to aid them direct flights safely and efficiently to their destinations. First, secondary radar displays show a trail of 'blips' representing a particular flight, with a data block alongside showing the flight number and flight level. Second, telephone and radiotelephone communications enable controllers to talk to pilots, to controllers on other suites in the center, and to control centers of neighboring airspaces. And third, flight progress "strips" each of which contain information for each flight. The strips are made of card, approximately 200 by 25 mm and divided into fields. The information in the fields comes from a database holding the flight plan filed by the pilot prior to departure, sometimes modified by inputs keyed in by controllers or assistants. In includes the aircraft's callsign, its flight level, its heading, its planned flight path, the navigation points on its route and its estimated time of arrival, the departure and destination airports, and the aircraft's type. Strips are arranged in racks immediately above the radar screens, and the racks are in turn divided into bays divided by fixed markers representing particular navigation points in the sector. The strips enable a controller to gauge how many aircraft are due in the sector, where they are bound and when, and the strip can be used to record any instructions given to the aircraft. When a controller gives an instruction to a pilot, for example to ascend to flight level 220, he or she marks this on the strip. In this case, the mark is an upwards arrow and the number 220. When the pilot acknowledges the instruction, the controller crosses through the old flight level on the strip. When the new flight level is attained, the controller marks a check beside it. Changes in heading, estimated time of arrival, route, call sign etc. are dealt with in similar ways.

Strips are organized and annotated according to a standardized format: The categories of information on the strip and its general typographical layout follow a standard format; the color of the strip holder is used to effect a two-fold categorization into east and west bound traffic; the color of the strip paper is used to effect a two-fold categorization into 'standard' and 'crossing' or military traffic; the color of hand notations on the strip is used to effect a two-fold categorization distinguishing annotations made by the controller from annotations made by the sector chief; and, in general, annotations follow an elaborate set of conventions specified in the *Manual of Air Traffic Services* (e.g., upward or downward arrows, check marks, crosses through numbers). Because of their "formatted character", "strips provide a *template* for noting and recording what is happening and will happen in the sector." (Harper et al., 1989, pp. 15 f.).

More than that, also because of their "formatted character", strips serve as a resource for articulating the activities of the different members of the sector team. In maintaining a constantly up-dated representation of the 'state of the sector' in terms of the standard categories of information on the strip itself and in the standard format and notation, the controller is not just providing information relevant to his or her own work but is also providing what Harper and associates calls "team relevant information". Thus, anyone who notices a problem with a strip or pair of strips - perhaps two flights due at the same navigation point at a similar time and at the same height - can "cock out" the strips, i.e., move them noticeably out of alignment in the racks. This makes it immediately obvious that, when it becomes time to deal with those flights, a problem will need to be considered, and to the practiced eye it will be obvious from a glance at the strips what the problem is. The vocabulary and syntax of annotation and ordering the strips are a language through which the members of the team communicate with each other and create a 'common statement' about the state of the flight and of the sector. (Hughes et al., 1992)

When necessary, overt coordination can be achieved by pointing to particular strips where there may be a problem, perhaps two flights due at the same navigation point at a similar time and at the same height. If the controller cannot attend to the request at that time, anyone who notices the problem can "cock out" the strips, i.e., move them noticeably out of alignment in the racks. In a very inconspicuous and non-intrusive way, this makes it immediately obvious that, when it is time to deal with those flights, a problem will need to be considered, and to the practiced eye it will be obvious from a glance at the strips what the problem is (Hughes et al., 1992). "Drawing the strip slightly out of position, pointing to it, making a notation, are 'sufficient' to draw attention to *that* strip, and its aircraft, and any problem it may represent and, as such, are actions manifesting the interdependence of one controller's activities with those of others." (Harper et al., 1989, p. 24).

Embedding cues in objects belonging to or representing certain objects in the field of work, e.g. by highlighting certain flight strips is an non-intrusive and tacit way of directing attention. On the other hand, the expressive power of materially embedded cues is limited. In the case of the flight strips, the 'categorical distinction' supported by highlighting strips is "effectively limited to two categories", namely relatively routine versus relatively problematic (Harper et al., 1989, p. 30).

*Negotiation*: Cooperative work will typically require - at least intermittently - consultation and negotiation among the members of the ensemble. For example, situations characterized by uncertainty (by incomplete, ambiguous, erroneous, and contradictory information; by incomplete, equivocal, contradictory, or ephemeral criteria; or by a conceptual world of a rich and varied semantics) will involve discretionary decision making; in these situations, articulation work will require various negotiation processes. For such purposes, ‘face-to-face’ conversation provide a rich variety of interactional modes (speech coupled with proto-verbal utterances, intonations, facial expressions, gesticulations) with powerful and flexible social connotations.

The different modes of interaction can be realized in numerous ways, by means of multitude ‘means of interaction’. They may, for example, be realized tacitly (monitoring) or overtly (highlighting, gazing, pointing, talking), they may be realized by embedding cues in objects (highlighting, leaving traces) or by explicitly expressed interventions, or they may be realized by expressed orally of in writing.

The different modes and means of interaction have different characteristics and pose different requirements to the means of communication available. What is appropriate naturally depends on the specific characteristics of the field of work of the cooperative work arrangement. Following Woods (1988), the following characteristics of the field of work can be highlighted:

- The *degree and nature of interdependence* between members of the cooperating ensemble as determined by the field of work, e.g. the rigorous and causal coupling of different functions of a power plant *versus* a loose and indeterministic interdependence of the distributed activities within a research area.
- The *time critical nature* of the work, i.e., the extent to which the field of work requires instantaneous reactions to events and, hence, rapid articulation of activities, e.g., the time critical demand on air traffic control *versus* the more pedestrian pace allowed for processing tax cases.
- The extent to which the field of work is characterized by *uncertainty* and, accordingly, the extent to which tasks require *discretionary decision making* and concomitant negotiations, e.g., the relatively unambiguous character of ticket reservation *versus* the decidedly discretionary character of legal proceedings, medical diagnosis, policy making, etc.
- The extent to which *risk* is involved and possible outcomes of choices are irreversible and can have large costs, e.g., the security demands posed on nuclear power production or air traffic control *versus* the relative serenity of administrative work. The presence of risk means that one must be concerned with rare but catastrophic situations as well as with more frequent but less costly situations, e.g.,

These dimensions of cooperative work can be translated into requirements for the techniques of communication in terms of bandwith (bits per second) and turnaround time (the delay from dispatch to reply as determined by the medium).

For example, a low degree of interdependence of distributed activities and time pressure on their execution and articulation allows for more sporadic interaction by means of channels of communication with a high turnaround time, say, surface mail. On the other hand, a high degree of interdependence and time pressure (as in the case of air traffic control) requires a permanently open channel of communication with minimal turnaround time so as to convey the multitude of inconspicuous cues that are required for cooperators to acquire and maintain peripheral or general awareness of the changing state of affairs within and beyond the cooperating ensemble.

Likewise, articulation of distributed activities that involve discretionary decision making will typically require, at least intermittently, various negotiation processes. For this purpose, conventional co-located 'face-to-face' interactions provide the required large bandwith, not only in terms of gigabits per second but also, and more importantly, in terms of a rich variety of interactional modes with powerful and flexible social connotations.

The requirements of articulation work for the means of communication are neither stable nor consistent. Different tasks within the same cooperative work setting may require support by different media, and any one person within the ensemble may be involved in multiple tasks, over time or concurrently. The time pressures under which a given task or class of tasks is carried out may change over time. Consequently, cooperating actors will typically be changing medium quite frequently, and for a given task may be applying an arsenal of means of communication and modes of interaction, 'synchronous' as well as 'asynchronous' (Bignoli et al., 1991). In a meeting, for example, participants will use the agendas that may have been distributed in advance; they may bring files from archives as well as prepared notes and overhead transparencies; in the course of the negotiations they may use whiteboards, flipovers, etc. to convey suggestions, organize the debate, and retain results achieved; they will take notes and minutes for future use; and in all this they will mobilize the powerful repertoire of human speech and body language. All more or less concurrently and meshed in a very fluent way.

That is, the different modes and means of interaction are meshed and interwoven fluently and dynamically in accordance with the requirements of the situation and constrained by the capacity of the means of communication available.

## Mechanisms of interaction

In team-like cooperative work characterized by a small and relatively stable and homogeneous ensemble, articulation work can be mediated by the rich variety of intuitive interactional modalities of everyday social life. However, 'real world' work settings are characterized by dispersed, distributed, and dynamic cooperative work arrangements and involve a large, varying, or indeterminate number of participants.

In such 'real world' settings, the intuitive modes of interaction of everyday social life are insufficient for articulating the distributed activities. Hence, articulation work becomes extremely complex and demanding.

In order to reduce the complexity and, hence, the overhead cost of articulation work in large-scale, real world settings, cooperative ensembles apply various *mechanisms of interaction*, e.g.:

- Plans, schedules, time tables.
- Standard operating procedures, statutes, routing schemes, forms, check lists.
- Classification schemes, thesauruses, and taxonomies for indexation of objects so as to organize distributed inclusion and retrieval of objects in 'public' repositories, archives, libraries, databases etc.

A study by Kaavé (Kaavé, 1990; Kaavé, 1992) provides a clear example of a mechanism of interaction in cooperative work, namely the *kanban* system. *Kanban* is a Japanese word meaning 'card' and is now used to denote a production control system where a set of cards serve as the coordination mechanism, both as carrier of information about the state of affairs *and* as a production order conveying an instruction to initiate certain activities.

The basic idea of the *kanban* system is that loosely coupled but interdependent production processes can be coordinated by means of exchanging cards between processes. A particular card is attached to a container used for the transportation of a lot of parts or sub-assemblies between work stations. When the operator has processed a given lot of parts and thus has emptied the container, the card is sent back to the operator who produces these parts. Having received the card he has now been issued a production order.

The basic set of rules of a *kanban* system is simple: (1) No part may be made unless there is a *kanban* authorizing it; (2) there is precisely one card for each container; (3) the number of containers per part number in the system is carefully calculated; (4) only standard containers may be used; (5) containers are always filled with the prescribed quantity - no more, no less (Schonberger, 1982, p. 224). The *kanban* system can be considered as a mechanism of interaction in the sense that it is a symbolic artifact that it used to reduce the complexity of articulating a large number of different cooperative work activities.

However, the *kanban* system is not adequate for coordinating manufacturing operations faced with severe demands on flexibility of volume. The *kanban* system can only handle small deviations in the demand for the end product (Schonberger, 1982, p. 227; Monden, 1983). Furthermore, in a *kanban* system, information only propagates 'up-stream' as parts are used down the line. The speed and pattern of propagation of information is severely restricted and the information ultimately conveyed has been filtered and distorted by the successive translations along the line up-stream. The *kanban* system does not provide facilities allowing decision makers to anticipate disturbances and to obtain an overview of the situation. They are enveloped by an overwhelming and inscrutable automatic coordination mechanism.

Accordingly, since the company studied by Kaavé is faced with extreme fluctuations in demand, operators constantly experience that the configuration of the *kanban* system (the number of containers per part number and the quantity per container) is inadequate. They therefore regularly change the configuration in various ways, for example by pocketing a card for time, by leaving card on the fork-lift truck, by ordering new lots before a container has been emptied, by handing cards over directly, by changing lot sizes, etc.

The *kanban* system only serves as a mechanism of interaction because it incorporates pertinent features of the operation (in the form of the configuration of the system). Thus, in spite of the fact that the *kanban* system is often used in situations where it is “beyond its bounds” (Roth et al., 1989), it is not discarded but merely adapted to the requirements of the situation. When an operator pockets a *kanban*, he is *changing* the configuration of the system, not switching the system off.

In order to be usable in a setting like the one discussed here, the *kanban* system must to be managed (monitored, adapted, modified) continuously. This is done by an informal network of clerks, planners, operators, fork-lift drivers, and foremen in various functions such as purchasing, sales, production, shipping etc. A member of this network will for example explore the state of affairs ‘up-stream’ so as to be able to anticipate contingencies and, in case of disturbances that might have repercussions ‘downstream,’ issue warnings. That is, the indirect, dumb, and formal *kanban* mechanism is subsumed under a direct, intelligent, and informal cooperative coordination. The cooperative ensemble has ‘appropriated’ the *kanban* system in order to increase its flexibility. They have taken control of the system, and having done so they are controlling the production far more closely and flexibly than warranted by the *kanban* system.

The particular design of the *kanban* system as a mechanism of interaction allows operators to manage the system in so far as the control of the execution of the mechanism is in the hands of the operators as opposed to an automated control mechanism (for example, with sensors in the containers).

In general, plans, procedures, and schemes can be conceived of as *mechanisms* in the sense that they (1) are objectified in some way (in the form of an artifact), and (2) give reasonably predictable results if applied properly. And they are *mechanisms of interaction* in the sense that they reduce the complexity of articulating cooperative work. In other words, a mechanism of interaction can be defined as a symbolic artifact that serves to reduce the complexity and cost of articulating the distributed activities of a cooperative work arrangement by regulating and mediating the articulation of the distributed activities: who is to do what, where, when, how etc.

Because of the dynamic and distributed character of cooperative work arrangements, mechanisms of interaction are local and temporary closures with a limited area of validity and they are by necessity underspecified. Thus, mechanisms of interaction are not executable code but rather heuristic and vague statements to be interpreted and instantiated, maybe even by means of intelligent improvisation. Mechanisms of interaction are not automata but “resources” in the sense that “plans are resources for situated action” (Suchman, 1987, p. 52). Following Gerson and Star (1986, p. 266), we posit that such mechanisms themselves need to be managed, i.e., constructed, maintained, developed, interpreted, applied, adapted, circumvented, modified, executed, represented, and negotiated. This secondary level of articulation work is, of course, also performed cooperatively (Schmidt, 1991).

# Implications for CSCW systems design

Computer technology is penetrating ever deeper into the realm of work. Increasingly, work involves and requires manipulation of representations incorporated in computer systems. By the same token, if computer technology is not to have disruptive effects on cooperative work, the articulation of cooperative work therefore now requires that those involved in the cooperative activities can apperceive the state of the common field of work (as represented, in part, in the computer system), monitor the activities of colleagues in relation to the field of work, highlight features in the field of work, and so forth.

Furthermore, given the immense flexibility and processing power offered by advanced information technology, one is probably not mistaken in assuming that computer-based systems can enhance the ability of cooperative ensembles to articulate their activities more efficiently, more flexibly, more effectively.

The analysis sketched in this paper raises some important issues for CSCW to address.

First, cooperative and individual activities are inextricably interwoven in daily work practice. Cooperative work is always conducted by individuals and in cooperative work settings individual activities are always penetrated and saturated by cooperative work. A CSCW system should thus support the fluent meshing of individual work and cooperative work. For example, when composing an electronic mail message the user should not be required to shift to a special editor, that is, for example, required to leave the word processor normally used for composing letters, writing reports etc. The same applies to CSCW facilities supporting cooperative authoring, drawing, conferencing, etc. The commercial groupware product ASPECTS, for example, allows multiple users to cooperate on writing a document. However, they are required to leave their preferred single-user word processor and shift to the word processing facility of ASPECTS in order to cooperate. The effect of this that the system creates an impedance between cooperative and individual activities.

Further, a vast - presumably open-ended - array of modes and mechanisms of interaction is involved in the articulation of cooperative work. These different modes and mechanisms are combined and meshed dynamically, according to the requirements of the specific situation at hand, and they are meshed fluently and, more often that not, effortlessly. Again, a CSCW system should support the fluent interweaving and combination of modes and mechanisms of interaction.

In order to meet these very general requirements - support the fluent meshing of individual and cooperative activities as well as the multitude of modes and mechanisms of interaction - the allocation of function between general platform facilities and specific applications should be planned and designed carefully.

So far, CSCW systems have generally failed to meet the requirements of users in actual cooperative work settings, primarily due to constraints imposed by current platform designs. To a large extent, this deficiency can be attributed to fundamental conceptual problems in the ‘architecture’ of current computer platforms.

Since the modes and means of interaction are semantically neutral in the sense that they may be invoked (with different scope) in articulation work in all work domains, these modes and means of interaction should be conceived of as functions to be supported by a CSCW platform. As opposed to such CSCW facilities that merely or primarily provide a channel of interaction, CSCW facilities that incorporate a *mechanism of interaction* should be seen as a distinct category of applications in the sense that they are semantically biased. These are genuine *CSCW applications*.

CSCW facilities that support various modes and means of interaction by increasing the bandwith of the communication channel or by reducing the turnaround time should not be conceived of as applications but as *platform functions* accessible to the appropriate applications (and, in the case of, say, desk top video conferences, to users directly). If they are not conceived of *and implemented* as general system functions that can be accessed from and combined with applications, the delicate and dynamic relationship between cooperative and individual work breaks down. This applies to traditional single-user applications as well as genuine CSCW applications.

As far as mechanisms of interactions are concerned, major research efforts in CSCW have been directed at incorporating mechanisms of interaction in CSCW applications, e.g. AMIGO and COSMOS (Danielsen et al., 1986; Benford, 1988; Bowers et al., 1988; COSMOS, 1989), THE COORDINATOR (FLORES ET AL., 1988), DOMINO (Kreifelts et al., 1991), and the Community Handbook proposed by Engelbart and Lehtman (Engelbart et al., 1988). However, in these CSCW research activities, a set of related issues are encountered recurrently, namely the problem of how to support the ongoing dynamic articulation of distributedactivities and the cooperative management of the mechanisms of interaction themselves. This issue is the key issue in CSCW (Schmidt et al., 1992).

It was argued previously that mechanisms of interaction require persistent cooperative management in order to be useful as means of reducing the complexity and the cost of articulating distributed activities and that this management activities is itself a cooperative activity. We can thus state the following requirements for a CSCW application incorporating a mechanism of interaction:

(1) It should make the incorporated mechanism accessible to users and, indeed, support users in interpreting the mechanism and evaluating its rationale and implications.

(2) It should support users in applying and adapting the mechanism to the situation at hand; i.e., it should allow users to tamper with the way it is instantiated in the current situation, execute it or circumvent it, etc.

(3) The system should support users in modifying the underlying mechanism and in creating new mechanisms in accordance with the changing organizational realities and needs.

(4) Since the management of mechanisms of interaction is itself a cooperative activity, the system should support the documentation and communication of decisions to apply, adapt, modify, circumvent, execute, etc. the underlying mechanism.

(5) And in all of this the CSCW system as a whole, i.e., the CSCW platform, should support the process of negotiating the interpretation, application, adaptation, modification, circumvention, execution etc. of the mechanisms of interaction incorporated in various applications by providing general facilities for enacting and meshing an array of modes and means of interaction.

Providing support for distributed cooperative management of mechanisms of interaction is, probably, the toughest challenge in designing computer systems for cooperative work. Is it possible to formulate general principles for the functional allocation between humans actors and a CSCW application so that the cooperating ensemble can maintain control of the situation when the underlying mechanism is beyond its bounds? What are the specific requirements and limitations of different kinds of mechanisms? How should the underlying mechanism of the system be made visible to users? How should different users perceive the mechanism? How and to which extent can it be made malleable? Should a temporary adaptation affect other users? How, when? How should a violation of the mechanism be logged, reported, and presented to other users? And so forth. Questions such as these are still open issues in research and development of computer systems for cooperative work.

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# English abstract

The new interdisciplinary research and devlopment area named Computer-Supported Cooperative Work or CSCW represents a fundamental shift in the approach to the design of computer systems. With the emergence of CSCW the very issue of how multiple users work together and coordinate and mesh their individual activities has become the focal issue in the development of computer systems. In order to develop computer systems that provide adequate and effective support for cooperative work in the flexible work organizations, it is crucial to advance our understanding of cooperative work and its articulation. The paper discusses the nature and characteristics of cooperative work and the design implications for computer systems supposed to support the articulation needs of cooperative work arrangements.

**Keywords**: Articulation work, Coordination, Cooperative work, Mechanisms of interaction, CSCW.

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