Remarks on the complexity of cooperative work

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ABSTRACT: The research area of Computer-Supported Cooperative Work (CSCW) aims at developing digital technologies that may support cooperating actors in coordinating and integrating their work. In this effort, it is crucial to identify and understand the very coordinative practices through which orderly interaction is achieved. For these reasons, phenomenological sociology plays a central role in CSCW. Based on this approach, the present paper argues that in order to understand what it is like to be a member, to grasp the urgencies and constraints under which members act and interact, the analyst must identify the systemic features of the situation. Arguing that for these purposes the systemic concept of 'complexity' is indispensable, the paper discusses the concept of complexity and its relevance for CSCW and examines the implications of this suggestion.

RÉSUMÉ: L'objectif du champ de recherche portant sur le Travail Coopératif Assisté par Ordinateur (TCAO) est de développer des technologies numériques qui puissent aider des agents coopérants à coordonner et à intégrer leur travail. Dans cette perspective, il est crucial d'identifier et de comprendre la nature des pratique de coordination par lesquelles une interaction ordonnée peut être mise en oeuvre. Pour ces raisons, la contribution de la sociologie phénoménologique est centrale dans le TCAO. Nous inscrivant dans cette approche, nous soutiendrons dans cet article que pour comprendre le contenu expérientiel d'un membre d'un collectif, pour saisir les nécessités et les contraintes auxquelles les acteurs doivent faire face quand ils agissent et interagissent, l'analyste doit identifier les éléments systémiques de la situation considérée. A partir d'une argumentation qui pose que à cette fin le concept systémique de "complexité" est indispensable, l'article discute ce concept et sa pertinence pour le TCAO, et examine les implications de cette proposition.

KEY WORDS: cooperative work; articulation work; complexity; coordinative practices; computer-supported cooperative work (CSCW)

MOTS-CLÉS: travail coopératif ; travail articulatoire ; complexité ; pratiques de coordination ; travail coopératif assisté par ordinateur (TCAO)

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1. The puzzle of 'cooperative work'

1.1. Cooperative work, as an aspect of human ecology, seems to have existed in human societies for hundreds of thousands of years, but until recently only as a marginal phenomenon. Work has, of course, been socially situated and socially organized in all human societies, and 'cooperation' as the sharing of the fruits of our toil is arguably constitutive of human sociality [REY 81]. Cooperative work in a more specific sense, however, i.e., conceived of as constituted by interdependencies among actors in productive activities, is far from universal. In fact, in the modes of production of hunter-gatherers, horticulturalists, ancient and medieval agriculture, craft work, etc. the bulk of work activities such as gathering, hunting, fishing, butchering, skinning, collecting wood, cooking, weaving, sewing, pottery, weeding, harvesting, trashing, etc. were almost always carried out individually; cooperative work only occurs sporadically, for example for the hunting of large game or for clearing land [JOH 87].

Naturally, mobilization of labor on a large scale for political, infrastructural, military, or religious purposes, such as warfare or the building of dams, canals, roads, fortifications, monuments, temples, etc., looms large in the historical record, but is nonetheless economically marginal [MOO 66]. It is not until the establishment of the world market and the concomitant industrial revolution, that is, it is not until the emergence of the capitalist mode of production, that production generally begins to acquire the character of systematic cooperative work in the form of commercial farming, manufactories, industrial factories, etc. [MAR 67].

1.2. Why is that?

First of all, until the emergence of the capitalist mode of production, the scale of the political economy did not necessitate or even warrant systematic production on a large scale [JOH 87]. Furthermore, and irrespective of the scope of the political economy, cooperative work arrangements are only entered into reluctantly, due to the mutual dependencies that define these arrangements. On the one hand, cooperative work relations imply definite social tensions — the precarious reconciliation of divergent motives and interests, the potential conflicts of sharing the burden and the product, the loss of individual and local autonomy — which are all to be addressed and dealt with. On the other hand, coping with the mutual dependence in cooperative work entails an added effort of aligning, meshing, coordinating, and integrating the different individual contributions to the joint endeavor and requires specific organizational skills in terms of punctuality, accountability, planning, logistics, etc.

We can, accordingly, observe that cooperative work arrangements emerge in response to certain requirements — the fact that a necessary or desirable task cannot be performed at all (or as well, as timely, as safely) on an individual basis — only to dissolve again when the situation requiring individuals to join forces no longer exists, or due to technological innovations which enable individuals to achieve the same results without joining forces. This pattern not only emerges strongly from the

ethnographic and historical record but also from studies of cooperative work in contemporary work settings and, indeed, from everyday experience.

That is, a cooperative effort seems to entail such social and coordinative intricacies and troubles that it is not something undertaken lightly. It is apparently only embraced when absolutely unavoidable or at least when working together offers obvious and substantial benefits. In fact, it seems as if the more intricate the interdependencies and the more distributed the control, the more demanding and difficult the alignment, coordination, integration of the cooperative effort and the stronger the reluctance to collaborate. There are, indeed, strong indications that contemporary work organizations typically are faced with coordinative problems which are at the limit of what they can manage — and not rarely beyond that limit, with all kinds of turmoil and breakdowns as a result. If this description is just reasonably correct, the development of computer-based systems that can assist work organizations in coping with the complications, intricacies, and entanglements of the coordinative and integrative aspects of their work can be seen as critically important.

1.3. In the 1990s I was engaged in an extensive research effort in which we were trying to understand a range of coordinative practices which we gave the collective label ‘mechanisms of interaction’ and later ‘coordination mechanisms’ [SCH 94b; SIM 94]. These ‘mechanisms’ are characterized by the fact that interactions among cooperating actors are somehow regulated by means of pre-established coordinative protocols coupled with mediating artifacts. It was of course obvious from the CSCW literature and from our own observations that cooperative work in many settings is coordinated and integrated effectively without such ‘mechanisms’ and, accordingly, that they were only required and adequate under certain conditions of working. We could moreover observe situations where cooperative ensembles invented and adopted ‘coordination mechanisms’ so as to somehow cope with a task of coordinating and integrating their work that had become overwhelming [CAR 96a; CAR 96b]. That is, it was obvious that ‘coordination mechanisms’ were not universally valid practices. Given that, how could we characterize the conditions under which such practices become required and adequate? We also observed that ‘coordination mechanisms’, when they were used in a setting, were merely complementary to other coordinative practices and that they thus were instrumental in handling only certain aspects of the coordinative and integrative task. Again, for which aspects of the work of coordinating and integrating cooperative activities are ‘coordination mechanisms’ required and appropriate?

These questions are of course critical to the design of ‘computational coordination mechanisms’ in particular and of CSCW technologies in general. Thus, in a first attempt to sketch a possible conceptual basis for the design of computational coordination mechanisms, we tried to account for our findings by suggesting the concept of *complexity*. That is, we interpreted what we had observed as so many examples of coordinative tasks that were complex in ways that made it inefficient or impossible for the actors to cope without pre-established and artifactually mediated regulation of their interactions. As to a further analysis of the complexity of cooperative work,

our observations indicated that the complexity of a cooperative effort depended upon the number of actors involved combined with the differentiation of the roles, skills, heuristics, conceptualizations etc. represented in the cooperative work arrangement. Apart from such initial and intuitive ideas, however, our use of the concept of complexity was never systematically worked out or critically discussed.

This then leads to the issues addressed in the following remarks: How can we systematically conceptualize the multifarious coordinative and integrative challenges of cooperative work? Can we methodically identify and compare these challenges? Can the coordinative practices of cooperative work be understood as practices of managing complexity in some sense? Can we analytically identify aspects or areas of cooperative work in which digital technologies might assist cooperative ensembles in managing the complexities of the cooperative effort? Can we in our analyses identify salient or typical sources and dimensions of complexity? How can we understand the complexity or complexities of cooperative work? And, more fundamentally, does it make sense at all to talk about the complexity of cooperative work?

2. Taking serious work seriously

2.1. First of all, of course, we have to clarify the term ‘complexity’ as it seems to be used in confusingly different ways.

In the everyday use of the term it is often being used rather loosely as a synonym of ‘composite’, i.e., to denote that something is made up of many different parts. Normally, however, the term is being used in the sense of *intricacy*, i.e., to denote that something is made up by many *interacting* elements. This is, for instance, the sense in which the term ‘complexity’ has been generally used in organization theory.[1] In this usage, the concept of complexity is a systemic concept. In the words of Condillac, ‘A system is nothing but the disposition of the various parts […] that they mutually sustain one another’ [CON 49, p. 1]. The concept of complexity expresses the *systemic* qualities of a system, i.e., the intensity of interactions among its elements. A system is complex in that and to the extent that its various parts ‘mutually sustain one another’. More precisely, but in exactly the same sense, the term is being used to express features of systems that result from non-linear interactions among the parts. This is for instance the general usage of the term in software engineering. In this conception, the complexity of a system is conceived of as an expression of the number of possible states the system may have [BRO 87].

However, the term ‘complexity’ is also being used in various research programs striving to overcome the perplexities of the reductionist paradigm when tasked with accounting for the evolution of complex and yet stable systems such as biological species and eco-systems. However, because of the particular perspective of these

[1] [BAR 38; SIM 62; THO 67; LAP 75; DEM 87].

research programs, namely their critique of reductionism, 'complexity' is here often used in a derived sense, to denote *emergent order* (as in 'organized complexity', 'self-organization', 'anti-chaos', 'collapse of chaos', 'complex adaptive systems').[2] This particular usage can of course be made out to be in conformance with the above conception of complexity as a feature of non-linear interactions, but the jargon is confusing nonetheless, in that the term 'complexity' is being used both to denote the internal *intricacy* of the system as well as the higher-level *order* in which this intricacy is hidden or collapsed. Anyway, the objective of this paper is not to attempt to conceive of cooperative work as emerging complex order or in other ways apply an evolutionary model to cooperative work, but to investigate the coordinative and integrative problems facing members of cooperative ensembles. More specifically, the task at hand is to investigate if we can usefully conceive of coordinative practices as practices of managing complexity in the sense of a space of (possible) interactions.

2.2. Before we move on to explore how it might make sense to conceive of cooperative work in terms of complexity, we also need to address the fundamental question: Does it make any sense to conceive of work in terms of complexity and thus, by implication, in systemic terms? Is it at all warranted to talk about work in systemic terms? And, if we do that, if we conceive of work in systemic terms, what kind of analyses are we then formulating?

2.2.1. When we conceive of human affairs in terms of 'systems', the perspective adopted is one in which social relations and social processes are not accounted for in terms of the intentions and experiences of individuals but in term of interactions beyond the scope of the concerns of individual actors — that is, systemic interactions. This does not imply, however, that it is not a sensible thing to do. One can obviously obtain valid and significant insights by conceiving of national and international economies, technological revolutions, human populations and demographic transitions, and large-scale socio-technical systems such as the development of cities, traffic patterns, the Internet, etc. in systemic terms, that is, as formations whose emergence, dynamics, and characteristics cannot be understood (entirely or primarily) on the basis of an understanding of the dispositions and notions of the individual actors.

This perspective was succinctly expressed by Marx in his famous proposition that 'society does not consist of individuals, but expresses the sum of reciprocal relations between these individuals' [MAR 57-58, p. 188] and was given a striking manifestation in his analysis of the circulation of commodities and money: 'Although this movement [i.e. the circulation of commodities and money] as a whole appears as a social process, and although the individual moments of this movement appear to arise from the conscious will and particular purposes of individuals — the totality of the process appears as an objective connection that arises spontaneously; it arises, it is true, from the reciprocal actions of conscious individuals, but it is neither located in their consciousness, nor is it as a whole subsumed under them. Their

[2] [BER 68; PRI 79; NIC 89; COH 94; HOL 95; KAU 95].

own mutual collisions with one another produce an *alien* societal power standing above them; their reciprocal action as a process and power independent of them.' [MAR 57-58, p. 126].

2.2.2. By adopting a systemic perspective, however, one does not obtain an insight into the actions of members as these themselves conceive of and account for them, that is, into their concepts and routines, their concerns, aspirations, motives, etc., and thus into how actors make sense of what they and others do, have to do, could have done, etc. — in short, into what it means to be a practitioner. Without such insights, it is very difficult if not impossible to design computer-based systems that facilitate or enhance the coordinative practices of cooperating actors.

What we need to understand is, what does it mean to be a practitioner? To answer that question, in the words of Bourdieu, 'one has to situate oneself *within* "real activity as such," that is, in the practical relation to the world, the preoccupied, active presence in the world through which the world imposes its presence, with its urgencies, its things to be done and said, things made to be said […]' [BOU 90, p. 52]. What are the concerns of the practitioners? What do they strive to achieve and to avoid? Which pressures and impediments do they have to deal with?

More than that, we are not trying to understand what it is to be practitioner of human activity in all generality: hiking, reading poetry, praying, besieging a beloved, daydreaming, finding a proper spouse, etc. We are after something far more specific, namely what it is to be involved in *cooperative work*.

Working, in turn, can be conceived of in infinite ways and from innumerable perspectives: as the source of income and identity and new jokes; as the location of the exercise of skill and as the site of the acquisition of skill; as scenes where the passions of human life play out, ambition and disenchantment, power and submission, mutual aid and deceit, friendship and competition, hate and love, and so on and so forth. None of these threads of working life can be dismissed in advance and in general as irrelevant to understanding coordinative practices, but they do not constitute what working is about.

2.2.3. Work is activity that is highly constrained technically. As argued by Marx, work is 'always a realm of necessity' [MAR 63-67, p. 838]. By contrast to Fourier who envisaged that working in a future ideal organization of social life becomes 'mere fun, mere amusement', Marx insisted that even 'really free working, e.g., composing, is at the same time the most damned seriousness, the most intense exertion' [MAR 57-58, p. 499]. In general terms work facilitates humanity's 'metabolism' with (external) nature, directly or indirectly. Human kind must work in order to survive, as a species and as formations of social division of labor. As a constituent part of this wider system, a given cooperative ensemble must see to it that the product of its labor is of some utility to its members or, as a functional part of a system of social division of labor, to its customers or clients or other stakeholders. The wider social, political, and organizational environment may also pose severe demands as to how the work processes are to be conducted, e.g., in terms of efficiency,

safety, and security. And finally, work is conducted under more or less severe limitations in terms of resources: financial, personnel, space, time, etc. That is, work is conducted under severe demands in terms of the functionality, quality, and cost of the product, as well as in terms of the safety, reliability, and timeliness required of the process. The sum total of all this is that the activities of work are characterized by (typically unremitting) technical constraints in terms of cause/effect, dynamics, means/ends, spatial order (e.g., part/whole, separation/containment, relative location, relative volume), temporal order (e.g., sequentiality, concurrency, synchronicity, reversibility), and so forth.

If such constraints and interrelationships are not considered systematically in a study of the phenomenon of work, the study will make the 'phenomenon disappear', as Sharrock and Anderson put it. Thus, in a critique of sociologists who generally 'assumed that sociological inquiry must avoid the technical issues involved in them, and that the purpose of sociological inquiry is to show that considerations of a social, rather than a technical, kind enter into practice', Sharrock and Anderson argue that the opposite obtains: in the study of domains of work '*the technical aspects of activity*, far from being an irrelevance, *must be central to all consideration*, for it is in their technicalities that [different kinds of work] consist'. Thus, for the purpose of understanding work practices, our inquiries must be *directed at* finding out what the specific activities consist in 'as course of action': 'what does someone *really have to do*' to do that particular kind of work [SHA 86, pp. 86-89].[3]

A serious investigation of cooperative work must take the technical aspects of activity seriously and make them a central concern of the study, because work is fundamentally about mastering technicalities: 'Surely we are free to chose what we are interested in, but this interest, once established, determines the system of relevances intrinsic to the chosen interest. We have to put up with the relevances thus set, to accept the situation determined by their internal structure, to comply with their requirements. […] We are, however, not only centers of spontaneity, gearing into the world and creating changes within it, but also the mere passive recipients of events beyond our control which occur without our interference. Imposed upon us as relevant are situations and events which are not connected with interests chosen by us, which do not originate in acts of our discretion, and which we have to take just as they are […]' [SCH 46, p. 126 f.]

In their work activities, actors have to accept the situation determined by 'the internal structure' of the 'system of relevances' and 'comply with their requirements'; more than that, actors have to deal effectively with the 'imposed relevances' of 'events beyond [their] control' which 'occur without [their] interference' and of which they are 'the mere passive recipients'. *In doing that, actors are conceiving of and dealing with the world in systemic terms*, i.e., in terms of causality, temporal and spatial order, means and ends relations, etc.. And to the extent that actors are conceiving of and dealing with the world in a systemic terms, we as analysts

[3] Emphasis added.

(whether ethnomethodologists or not) are not only perfectly entitled to conceive of their work in the same terms: *to the same extent any serious study of cooperative work must adopt a systemic perspective to be able to understand what it is like to be a member*.

3. The problematic concept of complexity

3.1. In addition to the use of the concept of complexity in parts of organization theory, the concept of complexity has been object of particular attention in research areas devoted to the study of work. It was here adopted along with concepts such as 'system', 'control', and 'feedback' as part of the 'systems approach' that had become required in the design and management of large-scale 'man-machine systems' or 'socio-technical' complexes such as ballistic missile systems and nuclear power plants.[4] It was hoped that conceiving of work in terms of complexity would enable analysts to identify and formulate 'objective' characteristics of 'human-machine systems' in different work domains [ROU 79; WOO 87]. These hopes were soon abandoned, however, as researchers realized that it was exceedingly difficult if not simply nonsensical to compare the complexities facing workers in different domains. After all, which is most complex, a psychiatric ward or a nuclear power plant?

3.1.1. Thus, in a critical discussion of the concept of complexity, Rasmussen and Lind argued that 'complexity' is a fundamentally problematic concept: "The complexity observed depends upon the resolution applied during information search. A simple object becomes complex if observed through a microscope. Objective complexity can only be defined for a given representation of a system, not for the system itself" [RAS 81, p. 8].

The point is well taken. A cow can for instance be described as just another cow in the herd; as an average unit with standard component parts (shank, round, rump, loins, flank, rib, tail, etc.); as an individual unit with certain characteristics (milk yield per week, etc.); as a physiological system with interacting subsystems (blood circulation system, digestive system, neural system, hormonal system, reproductive system, etc.); as a system of interacting cells, hormones, proteins, etc.; as a self-reproducing system of nucleic acids; as a system of molecules and atoms; as a quantum mechanical wave function, etc. The cow that, from the farmer's point of view, is just another brown cow, will be conceived of by a biologist as a complex of systems, from tissues and organs, over the various control systems such as the hormone and immune systems, to the elemental processes of cellular respiration, excretion, and reproduction.

However, while Rasmussen and Lind put the finger on a very problematic issue in the common-sense and often naïve use of the concept of complexity, the solution

[4] [LAP 75; ROU 79; PER 83; PER 84; PER 86; VON 90]-

proposed by them is not satisfactory. Firstly, they do not address the obvious issue that a system may be more or less complex 'for a given representation' of the system. More fundamentally, however, their argument hinges on a common-sense notion of 'object' or 'system'. They argue as if what constitutes an 'object' or a 'system' is self-evident, or more to the point: as if it is the same 'object' or 'system' we see with our eyes and under the microscope, as if the difference is only one of 'resolution'. What we look at when we use a microscope is not necessarily the same system at a different resolution but may be a different system with properties that cannot be directly applied to the macroscopic system. It is surely not possible and does not make sense to conceive of the brown cow in terms of its quantum mechanical wave function. The 'underlying' system cannot be conceived of in the same terms as the target system and the difference is not necessarily one of data compression. *A system is always defined under a certain perspective and hence in terms of certain principles of abstraction, distinction, aggregation, and representation.* Hence it leads to confusion to conceive of the relationship between the 'representation of a system' and 'the system itself' as an *external* relationship. Different principles of abstraction, distinction, aggregation, and representation refer to different 'systems' and *vice versa*. By implying certain principles of abstraction, distinction, aggregation, and representation, the definition of a particular system implies a certain *metric of complexity*. This has important implications. A given system (as defined in terms of certain principles of abstraction etc.) *may be more or less complex* according to the implied metric of complexity.

3.1.2. Suchman makes a point rather similar to Rasmussen and Lind's, by stating that 'the complexity or simplicity of situations is a distinction that inheres not in situations but in our characterization of them. All situations are complex under some views, simple under others' [SUC 93]. We *can* certainly describe *any* situation, or any action, in such a way that it, from a certain point of view, can been seen as highly or even infinitely complex. Consider, for example, an encounter between two persons in a room. From the point of view of the actors themselves or of an unsuspecting observer it may be quite ordinary and unremarkable. From the point of view of other observers, however, the same situation may appear rather complex. Where the neutral observer may only see a couple talking about a job, a jealous lover to one of the persons, for example, may see lingering glances, stolen touches, shining eyes. Likewise, where the participants will only see each other, the carpet, the chair, the table, etc., a forensic investigator will look for and see foreign fibers on the carpet, human hairs on the back of one of the chairs, fingerprints on the table top, and so forth. Which of the many potential points of view is *relevant* depends, of course, upon the interests of the observer [SCH 47-51]. If no crime has been committed, for example, the forensic perspective is hardly relevant.

One can only talk about complexity with reference to a specific system, that is, from a certain perspective and thereby in terms of certain principles of conceptualization (categorization, distinction, abstraction, aggregation, representation, etc.). Which perspective is relevant depends on the purpose of the analysis.

3.1.3. In this context Alfred Schutz' concept of the 'natural attitude' of the actor is of crucial importance. In 'the natural attitude' characteristic of everyday practice, the practitioner will not take the infinite number of possible perspectives, points of view, or principles of conceptualization into consideration, before acting. According to Schutz 'this world is to our natural attitude in the first place not an object of our thought but a field of domination. We have an eminently practical interest in it, caused by the necessity of complying with the basic requirements of our life. But we are not equally interested in all the strata of the world of working. The selective function of our interest organizes the world in both respects — as to space and time — in strata of major or minor relevance' [SCH 45, p. 227]. Unless an actor has practical reasons for considering the situation from a different perspective, he or she will stick to those perspectives that are presumed *relevant* to his or her project. Thus the observer's perspective should not be taken for members' perspective. While members are faced with things to be done, with constraints to observe, and with urgencies to be dealt with, the observer is in the privileged position of considering the different points of view of different actors and of contemplating any number of alternative perspectives that might also be applied.

Egon Bittner argues this point forcefully.[5] 'The paramount fact about the reality bounded by an ethnographic held work project is that it is not the field worker's own, actual life situation.' The urgencies with which members have to deal are not urgencies to the observer who has deliberately undertaken to view the world 'as the world of others': 'Since the field worker, as field worker of course, always sees things from a freely chosen vantage point […] he tends to experience reality as being of subjective origin to a far greater extent than is typical in the natural attitude. Slipping in and out of points of view, he cannot avoid appreciating meanings of objects as more or less freely conjured. […] Hence, without it ever becoming entirely clear, the accent of the field worker's interest shifts from the object to the subject. […] Moreover, since he finds the perceived features of social reality to be perceived as they are because of certain psychological dispositions people acquire as members of their cultures, he renders them in ways that far from being realistic are actually heavily intellectualized constructions that partake more of the character of theoretical formulation than of realistic description.' [BIT 73, pp. 121 ff.].

3.1.4. For the purposes of designing usable and useful computer systems for cooperative work settings we do not need to know how cooperative work *could* be construed as complex by a disinterested observer but what makes it complex to competent members and how computer systems may be of assistance in reducing or otherwise coping with this complexity. The relevant perspective from which to analyze the complexity of cooperative work is not something which can only be determined arbitrarily or subjectively, as Rasmussen and Lind as well as Suchman seem to imply. It is a *researchable* issue: what is the relevant perspective, the relevant

[5] Bittner's analysis of the observer's perspective is a development of Schutz' analysis of 'common-sense' and scientific perspectives [SCH 53].

level of abstraction, etc. to a competent actor ‘in the natural attitude’ of a given line of action has to be determined empirically.

Modern architects, for example, are faced with and have to deal with issues and interdependencies which previous generations of architects did not have to handle. In the course of the industrial revolution, the needs of industry led to the introduction of facilities for heating, ventilation and sanitation, which began to be applied to domestic architecture as well. Central heating in the form of steam-heating systems appeared in the early nineteenth century; cold- and hot-water systems and sanitary plumbing developed rapidly in the second half of the century. Gas lighting came to London in 1809 and by the 1880s electric light was ‘available to those who could afford it and were prepared to take the risk of using it.’ Elevators, telephones and mechanical ventilation were introduced in the last decades of the century. ‘However much people may have regretted or been frightened by the scale and rapidity of the changes, what had been produced in a hundred years was a whole new range of possibilities, and therefore a new aesthetic and a new challenge to the designer. How was he to cope with change and express architectural qualities in such a revolutionary milieu?’ [NUT 97, 245]. The challenge to architects is not only an aesthetic one, but an immensely practical one, as the vastly increased ‘range of possibilities’ implies a vastly increased number of structural and functional elements of the building to be integrated in the design and in the construction plans. In the course of the last century, the range of possibilities and thus structural and functional elements to be integrated has been further extended by the introduction of air-conditioning systems, facilities for tele-communications, security, safety, firefighting, etc. [SAB 89]. As a result the work of modern architects is intensely collaborative. In a typical large building project various people work on different sections of the building and they may be responsible for particular design tasks. Thousands of documents are created in this process. Moreover, a contemporary building project engages many external actors, in addition to the client and perhaps prospective users: technical consultants (for structure, insulation, heating and ventilation, electricity, the lighting concept, the facade, etc.), various authorities, the general contractor, specialized building companies, and craftspeople. The architects may have to coordinate the effort and consent of between 30 and 50 different people from different institutions and companies, each with their own professional competences and perspectives [SCH 02b].

Although fundamentally different in important ways, the medical domain exhibits the same increase in ‘range of possibilities’. Witness, for instance, this description of developments in contemporary medical work by ‘a veteran of emergency rooms, post-operative wards, and intensive-care units’: ‘The remarkable advances of ultramodern biotechnology have brought with them complexities of such magnitude that medicine sometimes seems in danger of being overwhelmed by forces of increasing intricacy and incomprehension. In certain situations, only the small number of superspecialists who deal in a particular aspect of diagnosis or therapy are equipped to interpret a finding or observation. What conclusions are to be drawn from a hard-to-interpret test of liver function? In what situation is it better to rec-

ommend angioplasty rather than coronary bypass? Which of three possible antibiotics is best for a particular resistant bacterium? The opinions of the highly specialized consultants called to address such problems sometimes conflict. The responsible attending physician who must actually make the major decisions may not fully comprehend every assumption and each piece of medical evidence that should enter into them. And once having chosen a course of action, he must then trust to an unknown number of others that it will be properly carried out. These range from the surgeon doing an operation to the maintenance man servicing a piece of equipment or the orderly cleaning it. We are caught in a spiral of uncertainty that is only magnified by the increasing range of our capacity.' [NUL 02, pp. 10-11].[6]

The same goes for manufacturing [SCH 91b; CAR 99], software engineering [CAR 96a; CAR 96b; GRI 96a; GRI 96b], etc. Practitioners are faced with complexities in the form of issues and constraints that interact and intersect. An observer may think of them as subjectively constructed. There is, of course, no 'objective' reason why the farmer should not look at a brown cow with foot-and-mouth infection as a quantum-mechanical wave function, just as there is no 'objective' reason why an architect should take for granted that buildings need plumbing, heating, electrical wiring, air-conditioning, etc. To practitioners, however, these issues are given, imposed, taken for granted, — not construed. Architects have to deal with the specific technical and organizational complexities stemming from the requirements that buildings must have plumbing, heating, electrical wiring, air-conditioning, and so on. Medical workers have to deal with the specific technical and organizational complexities stemming from the vast array of technologies and techniques of modern medicine. Software engineers have to deal with the specific technical and organizational complexities stemming from the astronomical number of possible interactions in large software systems.

Deprived of the concept of complexity as an objective feature of a system we would be unable to take seriously the specific challenges and urgencies contemporary workers are face with and thus understand their specific work practices.

3.2. The concept of complexity as used here implies a notion of limited resources on the part of the actor in question.

3.2.1. The notion of resource limitations is even more problematic than the concept of complexity, however; it is ripe with confusion. The source of this confusion is the cognitivist postulate that human action and cognition can and should be conceived of in terms 'information processing'. In the words of one of the key proponents of the 'information processing' paradigm, Herbert Simon, 'The point of departure is the observation that human thinking powers are very modest when compared with the complexities of the environments in which human beings live. If computational powers were unlimited, a person would simply consult his or her preferences (utility functions) and choose the course of action that would yield maximum utility under the given circumstances. That is, of course, just what the

[6] For identical observations about the complexity of hospital work, cf. [STR 85b].

"rational man" of classical economic theory does. But real human beings, of bounded rationality, cannot follow this procedure. Faced with complexity and uncertainity, lacking the wits to optimize, they must be content to satisfice—to find "good enough" solutions to their problems and "good enough" courses of action.' [SIM 79, p. 3].

Simon's way of reasoning is quite bizarre. For the proposition of 'bounded rationality' to make sense, the obverse notion of 'unbounded rationality' would have to make sense too, but theological discourse aside, the notion of 'unbounded rationality' is nonsensical. The 'boundedness' of rationality is not a function of some fixed limit on human cognitive capacity (whatever that might mean and however it might be measured) but of a trivial epistemological condition: the world cannot be exhaustively described; there is always another possible perspective, another level of abstraction or granularity, etc. under which things can be seen and described differently. But instead of realizing that the premises of neo-classical economics are epistemologically false, Simon presumes that the problem is psychological.

This 'psychologism' — false epistemology dressed up as an empirical proposition — goes a long way towards explaining the utter futility of the endeavors to investigate the putative mechanisms underlying the fixed limits of human cognitive capacity. It is of course evident that there are limitations to our individual and collective cognitive capabilities at any point in time. We make mistakes, we oversee important things, we forget. But to explain those facts of life by reference to a specific determined capacity limitation is unwarranted. In fact, when such claims are thoroughly investigated they are just as thoroughly dissolved.

3.2.2. For example, when summarizing an expert conference on 'Mental Workload' [MOR 79a], Neville Moray observes in a quite disillusioned manner 'that perhaps there is no value which can be assigned to the [mental] load imposed on a man. The extent to which a man is loaded is a function not merely of the man, but of the task-specific situation in which he finds himself. The implications would be that there are as many measures as there are types of task, and the hope for a unified theory of load is a false hope' [MOR 79b, p. 13]. Moreover, referring to a series of experiments 'in which apparently infinite transmission rates were obtained', Moray comments dryly: 'Since no system can have an unlimited channel capacity, the theory's performance is not as good as that of man' [MOR 79b, p. 14]. And finally, in a report from a working group on 'mental workload', Johannsen notes that 'It is at least certain that man is not a "single channel" system, and when sufficiently well practiced may not even be of "limited capacity". But on occasions and in certain tasks he may behave like either […]. [W]ith practice performance improves and effort declines. This seems to be linked to the fact that prolonged practice in highly motivated human subjects makes the single channel limited capacity model of the human operator less and less appropriate.'' [JOH 79, pp. 103, 108].

In a quite similar vein, Ulric Neisser and his colleagues undertook a series of experiments in which the claim that human attention capacity is limited was put to test

and failed miserably [NEI 76, pp. 79 ff.]. Neisser concludes that 'there is no physiologically or mathematically established limit on how much information we can pick up' [p. 99]. It is all a matter of acquired skills: 'Practiced subjects can do what seems impossible to the novice as well as to the theorist […]. The more skilled the perceiver, the more he can perceive.' [pp. 92 f.].[7] More fundamentally, Neisser points out that the very notion of a single object of attention is confused: 'The very notion of "a single thing" is far from clear: how many things am I aware of when I listen to an orchestra, watch a ballet, drive a car, make love?' [NEI 76, p. 104].

3.2.3. The notion of bounded rationality is evidently[8] based upon the concept of 'information' in the 'mathematical theory of communication' proposed by Shannon for the purpose of being able to measure the transportation capacities of communication channels, from which the notion of the *meaning* of 'information' was explicitly and deliberately eradicated: 'The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. *These semantic aspects of communication are irrelevant to the engineering problem.* The significant aspect is that the actual message is one selected from a set of possible messages' [SHA 48, p. 379].[9] In his summary of Shannon's theory, Warren Weaver was even more clear and adamant in distinguishing this telecommunications usage of 'information' from its everyday usage: 'The word *information*, in this theory, is used in a special sense that must not be confused with its ordinary usage. In particular, *information* must not be confused with meaning' [SHA 49, p. 8]. Realizing, however, that a theory of human cognition from which the notion of *meaning* has been erased fails immediately and utterly when given the task of accounting for skillful everyday human activity, the 'information processing theory' was surreptitiously tampered with, by the introduction of the obscure idea of 'chunking' [MIL 53; MIL 56; SIM 74]. Miller, for example, describes 'chunking' as 'a process of organizing or grouping the input into familiar units or chunks, and a great deal of learning has gone into the formation of these familiar units. […] Since the memory span is a fixed number of chunks, we can increase the number of bits of information that it contains simply by building larger and larger chunks, each chunk containing more information than before.'[10] Miller and Simon and other fathers of this idea never bothered to notice that they thereby had abandoned their claim of having a

[7] One may object that the phenomenon of selective attention has been subjected to extensive research since 1976. However, in an extensive review of the literature on this issue from 1986 Johnston and Dark wonder whether 'understanding the nature of selective attention is ultimately futile' [JOH 86, p. 70]. Again, in a sweeping review of the literature from 1993 Allport questions whether attention is a coherent field of study and whether any theoretical progress has been made in 25 years of research [ALL 93].
[8] George Miller is quite explicit about this [MIL 53; MIL 56].
[9] Emphasis added.
[10] Notice how dilligently Miller makes 'the number of bits of information' the measure of 'familiarity' and 'learning'.

computational model of human cognition. They just swapped paradigm whenever convenient.

In fact, this confusion runs deep. The 'information processing' paradigm is based on using the concept 'information' in the sense of an arrangement of *signs* (a spoken utterance, a written text) and at the same time in the sense of the *meaning* of these signs. The equivocation has been carefully and deftly crafted and maintained. The term 'information' is being used to denote the arrangement of a set of physical objects (a sequence of sounds, a graphical configuration of ink marks) *as well as* the meaning that the particular arrangement of signs has in a particular community in a certain situation. When cognitivists speak of the processing of 'physical symbols' it is thus never quite clear whether they mean, say, sheets of paper with ink marks or the conventional usage of those objects by members of a community. It is by means of this equivocation that they seem to be able to reduce human understanding, reasoning, doubting, etc. to the manipulation of physical objects by agencies to whom these objects do not have any meaning as signs. The fact that 'physical symbols' only are 'symbols' if they have meaning to some community has been officially eradicated, only to be invoked again surreptitiously.

This goes a long way towards explaining why the notion of 'limited processing capacity' in its many guises ('bounded rationality', 'mental workload', 'cognitive overflow', and sometimes 'selective attention') has been so persistent in spite of overwhelming evidence to the contrary. The point is that the handling of 'physical symbols' (speaking and listening, writing and reading, as well as the arranging, indexing, sorting, storing etc. of objects that serve as signs) are *genuine activities*; they take time and effort. An actor's capacity for handling 'information' in this sense (as *encoded)* is of course bounded, constrained by his or her skills in handling different coding schemes and in organizing the code, as well as by the technologies at hand. But as Wittgenstein points out, 'don't think of understanding as a "mental process" at all' [WIT 45-48, § 446]. Seeing a house, understanding a gesture, intending some action, having an insight, etc., by contrast, are not activities in this sense; they are not limited by some fixed 'processing capacity' but by the conceptual constructs of the community and by the competences of the actor.

3.2.4. Complexity is a systemic category and it makes *no sense* to say that *p* is too complex to be meaningful. The concept of complexity does not apply to the experience of meaning. The experience of meaning does not involve work. The confusion created by such a conflation of categorically different concepts is truly boundless.

The trivially evident limitations on our individual and collective cognitive capabilities are not the expression of the limited capacity of some innate mechanism. Nor can the various limitations be conceived of as expressions of the *same* underlying phenomenon. In the world of situated real-world action, the actor is not a disinterested subject trying to perform absurd tasks such as remembering meaningless syllables. In their everyday activities, actors are not *struggling to cope* with, say, a bar-

rage of ‘sense data’ or an infinite array of possible interpretations and avenues of action. They are not fighting to make sense; their everyday world is overwhelmingly meaningful. The infinite range of possibilities facing the actor is delimited, not by some inherent ‘processing capacity,’ but by the fact that the actor has needs and desires, interests and motives, ambitions and intentions, fears and concerns. The actor is faced with a ‘system of relevances’. There are things to do and things to avoid, immensely practical issues.

However, as pointed out by Charles Babbage [BAB 32, §217], *learning* takes time and effort. Thus, at any point in time, the skills and competences of a particular individual are finite. There are things, many things, that are difficult or even impossible for a particular actor to do at a particular point in time. The experimentalist will for instance easily find that a given subject cannot read a text while simultaneously counting backwards from one hundred. But as demonstrated by Neisser and his colleagues, with time and effort even such perverse tasks can be learned and mastered. More than that, we also acquire techniques that enable us to acquire other competences more efficiently and effectively: actors learn to speak and to read and write, to calculate and to use mathematical notations, to use dictionaries and libraries, and so forth.

In fact, it is absurd to abstract from historically developed and culturally mediated practices. In the words of Geertz, ‘Men without culture […] would be unworkable monstrocities with very few useful instincts, fewer recognizable sentiments, and no intellect: mental basket cases’ [GEE 73, p. 49]. The cognitivist theory of delimited cognitive capacity is a theory of such monstrocities, not a theory of culturally situated, competent actors engaged in perpetual development and refinement of their practices.

That is, in addition to the issue of the ‘system of relevances’, the trivially evident limitations of our collective and individual cognitive capabilities are expressions of the frailty and fallibility of the vast array of techniques, procedures, representations, notations, etc. we routinely rely on, collectively and individually.

3.2.5. What must be investigated is the ‘system of relevances’ and the practices that competent practitioners have developed and employ in their daily work. What the concept of complexity helps us to do in this context is to handle important systemic aspects of cooperative work, namely causal relationships, means/ends relationships, part/whole relationships, temporal order, etc., in short, what Schutz call ‘imposed relevances’.

Identifying the urgencies and constraints under which actors act and coordinate and integrate their activities only provides the groundworks of the analysis. What is then required is to investigate, in detail, the strategies and techniques, the procedures and routines, the categories and classifications, the criteria and indicators, the artifacts and notations actors use in their actual routine coordinative practices.

4. A systemic conception of cooperative work

Now, how do we define 'the system' when analyzing cooperative work?

4.1. Cooperative work is often defined by actors' having a 'shared goal'. Although widely popular, especially with social psychologists, the definition is confused. We can certainly talk about 'shared goals', but a 'shared goal' is not a state, mental or otherwise (and even less so is it, in Garfinkel's words, 'a common intersection of overlapping sets' of mental states [GAR 67]); it is a practice, the very practice we need to understand. Why this is so is not difficult to see. What is the *criterion* for determining that A and B have a 'shared goal'? Well, that is their obviously concerted effort. Defining cooperative work in terms of a 'shared goal' thus presumes what it purports to define.

Cooperative work arrangements arise because individual actors cannot do the work individually, or cannot on their own do it as well, as timely, as safely, etc. In this sense, cooperative work can be said to be constituted by interdependence of activities. That is, the cooperating actors in a given cooperative work arrangement are interdependent in their work in that one actor's actions will change the state of affairs in some part of the world upon which other actors depend and this change of state, in turn, has implications, directly or indirectly, for the work of the other members of the ensemble, and so forth [SCH 91c; SCH 94a]. To simplify language, let us call that part of the world the state of which actors affect through their actions, and through which they thereby interact, *the common field of work* of this cooperative work arrangement.

This should not be taken to mean that the field of work is something simple. In the same way as other cases of reciprocal concepts (such as 'figure and ground', 'means and ends', 'text and context', etc.), the concepts 'cooperative work arrangement' and 'field of work' reciprocally define each other: a cooperative work arrangement is defined in terms of the particular part of the world in virtue of which their actions are interdependent, whereas the field of work hand is defined with respect to a particular cooperative work arrangement.

The reciprocity or circularity of the definition does not mean that the concept is arbitrary. The concept of field of work is an analytical construct that denotes certain systemic aspects of working together. It is legitimate as an analytical construct in so far as cooperating actors in their practices *take and have to take* their *interdependencies* as objectively given and *take for granted and have to take for granted* that their colleagues do so and must do so as well. Take, for example, the work of architects [SCH 02b]. The not yet existing building for which architects are developing and specifying the plans may be a notional construct in that the building can not be seen in the street and entered, but architects have every reason to treat the notional building as an objective construction; it is, if you will, a 'social fact'. If somebody removes the representation of a load-bearing wall from the CAD drawing, the work of the other architects is immediately and substantially affected, and they will ob-

servably act accordingly. Although not yet materially realized, the objectivity of the planned building is taken for granted as a fact and has to be taken for granted as such by the practitioners.

Conceiving of the interdependencies as a field of work does not imply that it exists as a clearly delimited and tangible object or set of objects. It may not, for example, be possible for the cooperating actors themselves, or by an observer, in advance to delimit and define the set of objects and processes the state of which is being affected by the actors, or it may be more or less difficult or costly to do so. If that is the case, as it obviously is in domains of criminal or scientific investigation for instance, the notion of a field of work is not useless, however, but rather allows us to characterize such settings as settings in which actors, as an integrated and crucial aspect of their cooperative effort, cannot take 'the system of relevances' for granted. To manage the quite particular circumstances for orderly interaction posed by such settings, members develop and establish rigorous procedures for assessing and accepting the relevance and validity of whatever is submitted as belonging to the field of work. In other domains of work, crucial aspects of the field of work may be ephemeral, invisible, and intangible, as in the cases of the energy transformations of a nuclear power plant, the economic transactions of the clients of a bank, or the behavior of a software system, or the field of work simply does not exist yet, as in the case of design work. Again, such a description is an illuminative and useful characterization of the conditions of cooperative work in these domains; and in order to establish conditions for orderly interaction in such settings, members develop and use a vast variety of representational artifacts, such as the mass-flow and energy-flow representations provided by the control room, the records of the bank clerks, the drawings of the engineers, the class diagrams and flow charts of the programmers, etc., by means of which the state of the otherwise invisible and intangible crucial aspects of the field of work are made visible and tangible. In short, in order to be able to cooperate in an orderly fashion under such conditions, members so to speak compensate for the indeterminacy, ephemerality, or virtuality of the field of work by objectifying it in the form of representations that are visible at a glance, persistent, and tangible.

Finally, however, what to members is *something to be done*, is an inferred construction to the observer. Constructivism is the observer's privileged stance. To competent members, the field of work is objectively given for all practical purposes. For the analyst, however, it is less straightforward. The interdependencies that constitute the field of work of a given cooperative work arrangement only have hypothetical status until the analyst empirically and systematically has uncovered the interdependencies in members practices and accounts, until the interdependencies have been identified and characterized, etc.

4.2. 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 contingencies, individual heuristics and biases, incongruent specialisms and incompatible perspectives, divergent or conflicting

motives and interests, etc. This usage of the term ‘distributed’ accords with the definition of distributedness suggested by Gasser and Bond: ‘Elements of an intelligent system are distributed if there is some *distance* between them,’ i.e., ‘a *conceptual distance*, with respect to some conceptual frame, such as time, space, semantics, etc.’, ‘and if some significant cost and/or some intermediary process is entailed in connecting them.’ [GAS 88, p. 8]. In other words, as long as we do not master telepathy and clairvoyance, there is a cost to any coordinative act: a cost of effort, a cost of time, etc. Shared goals, shared knowledge, shared understanding, etc. are not defining features or preconditions of cooperative work but rather local and temporary closures, obtained and maintained at a cost. Thus, no actor is all-knowing and all-powerful; actors must act and interact on the basis of partial knowledge and they are, accordingly, partially autonomous in their work [SCH 91a; SIM 98].

4.3. However, from the point of view of systems analysis, a system of processes that are *interdependent* but which are nonetheless controlled 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 metaphor [WALDROP '92, p. 109]. I hasten to add, however, that this kind of reasoning is not, strictly speaking, theoretical, as it has no explanatory force. It is simply an elaboration of the concept of system. Anyway, to prevent interdependent and yet distributed activities of a cooperative effort from degenerating into chaos requires, in sociological terms, the additional or secondary activities of alignment, coordination, integration, — in short, what Anselm Strauss and his colleagues have called ‘articulation work’ [STR 85a; GER 86].

4.4. The distinction between cooperative work and articulation work is a deviously slippery one. Articulation work is not another *kind* of action. One cannot create a taxonomy in which actions are neatly categorized as either cooperative work or articulation work. Cooperative work and articulation work are of the same category. The activities involved in articulating a cooperative effort can themselves be the object of articulation work. Activities undertaken to ensure the 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, negotiated, and so forth. In other words, cooperative work is reflexive. Articulation work is work to make work work. Or to be exact, articulation work is cooperative work to make cooperative work work. The articulation of cooperative work is itself a cooperative effort; its field of work the given cooperative work arrangement.

What is taken to be cooperative work and articulation work respectively is determined by the given perspective; what from one perspective is considered articulation work can be considered cooperative work from another perspective. The distinction is crucial, however, as articulation work poses specific complexities in its own right.

The distinction between cooperative work and articulation work is reflexive. This reflexivity is a fundamental and ubiquitous aspect of human action in general. As pointed out by Talbot Taylor, it is found in everyday metadiscursive forms of expression such as ‘I told you so!’, ‘That’s what she said’, ‘What did he mean by that, anyway?’, ‘Sorry, could you say that again?’, ‘Did she understand what you said?’, ‘That’s not true!’, ‘He said he was sorry’, ‘She ordered me to leave’, ‘Yes, that’s right’, ‘Will you explain that?’, ‘What’s that called?’, ‘I believe you’, ‘Would you ask him to shut up?’ And so on [TAY 97; TAY 00]. Reflexive practices are not confined to linguistic reflexivity or to the practices of sign systems in general (mathematical notations, sheet music, written dance lessons). They are aspects of showing somebody how to strip paint from an old commode, of forming a line at a bus stop, and so on.

Finally, the distinction between cooperative work and articulation work is not merely an analytic distinction; it is a distinction members make, for instance when actors interrupt a meeting to discuss the agenda or interrupt the discussion of the agenda to discuss the protocol of the discussion, or when members of a design project interrupt their design work to have a meeting about, say, the project schedule. In fact, members will typically institutionalize the distinction, for example when the responsibility of certain aspects of articulation work (e.g., chairing meetings, taking minutes, planning and scheduling tasks, allocating resources, monitoring progress) is assigned to or assumed by certain actors (e.g., chair persons, secretaries, coordinators, foremen, project leaders). More than that, actors performing such specific coordinative activities may have acquired specialized competences for such coordinative responsibilities (conductors of symphony orchestras, logistics specialists, production planners).

4.5. In order to understand the complexity of cooperative work we must thus systematically distinguish different ‘systems’:

(1) The *common field of work:* the constellation of interlaced processes and interlinked objects, actual or anticipated, physical or social, which constitute the part of the world upon which the given cooperative work arrangement is operating as well as the interfaces to these processes and objects, such as sensors, effectors, tools, and representations, e.g., the power plant with its fuels and energy transformation processes, its vast array of cables and steam pipes, as well as the sensors, effectors, and representations of its control system; the steel plant with the scrap and melted steel being processed, the alloying elements and the control system; the ship, its cargo, and its immediate environment; the economic transactions of the bank’s clients and the vast repositories of representations of these transactions; the emerging design as represented in drawings, specifications, models, prototypes, test results, minutes, etc. — Also, since the characteristics of the field of work only make sense in view of the operational constraints that are and have to be observed by workers (e.g., safety, quality, timeliness), the identification of these constraints is a necessary aspect of the definition and characterization of the field of work.

(2) The *cooperative work arrangement*, the ensemble of interdependent actors as constituted by a system of interdependent activities: the operators of a power plant or a steel plant; the crew of a ship; the controllers of a train line; the clerks of a bank branch; the engineers involved in the design of an artifact, etc. — as well as the formation of the cooperative work arrangement, that is, the 'first order' articulation work through which the cooperative work arrangement is actually constituted and organized: the mobilization and deployment of actors with respect to activities and resources, the differentiation and configuration of skills, etc.

(3) *Articulation work*: the reflexive system of 'second-order' activities (or aspects of activities) through which the interdependent and yet distributed activities of the cooperative work arrangement, as deployed and configured, are continually coordinated and integrated.

The different 'systems' pose different complexities, and the complexity of one system does not necessarily express itself in another.

5. The complexities of the common field of work

5.1. In his seminal comparative study of high-risk and high-tech work settings, Charles Perrow [PER 84] suggests a two-dimensional distinction: on one hand 'complex' *versus* 'linear interactions' and on the other hand 'tight' *versus* 'loose coupling'. This distinction allows him to compare (the systemic risk-potentials of) different 'systems'. Perrow's distinctions are demonstrably quite suitable for identifying systemic risk potentials — he argues convincingly that a 'system' that is both 'complex' and 'tightly coupled' is a catastrophe waiting to occur — and they have been highly influential in the area of human factors research. The same orientation also makes Perrow's distinctions somewhat problematic for our purposes, however.

Firstly, the concept of 'the system' is ambiguous. This becomes evident when, for example, characteristics of the work organization are treated as characteristics of 'the system'. From the point of view of the issue of safety one can definitely justify to consider the socio-technical system in its totality, without discrimination, as the potentially problematic 'system'. But from the point of view of designing computational artifacts for cooperative work, exactly that kind of distinction is critical.

Secondly, the concept 'tightly coupled' is ambiguous as well, in so far as it collapses (a) *causal coupling*, in which sub-processes have no (or few) degrees of freedom and changes propagate without intervention and without modifications, and (b) *intense interdependence*, in which different processes are (largely) causally separate and hence (relatively) decoupled but in which their coupling has to be *ensured*. The various processes of steel production, for example, (*viz*. melting, refining, and casting) are not coupled in any physical sense but they are intensely interdependent nonetheless; it is for the actors to ensure the coupling. By contrast, a mechanically coupled system is characterized by predictable and non-ambiguous interdependen-

cies. A causally coupled system may thus pose interdependencies that are easily managed by a cooperating ensemble. For example, in their classical study of the cooperative operations of a hot rolling mill Popitz *et al.* noted that the four operators were able to cope with their task — not in spite of but *because of* the rigorous temporal regime its operation imposed on the actors [POP 57].

5.2. In an approach that continues Perrow's work for the design of decision support systems for safety-critical work domains, David Woods [WOO 88] distinguishes different complexity factors for problem solving with respect to three basic elements ('the agent', 'the representation', and 'the world'). As far as the complexities posed by 'the world' are concerned, Woods divides the two dimensions suggested by Perrow into four, namely 'dynamism', 'many highly interacting parts', 'uncertainty', and 'risk'.[11] In suggesting these distinctions, Woods gives an important contribution to our ability to understand and analyze work. Again, however, the preoccupation with safety-critical systems makes the categories problematic for the purposes of focusing on the cooperative aspects of work. Firstly, it is not evident why the issue of 'risk' in the relation to the environment should be given a unique status, as other socio-economic issues might be equally relevant, such as, for instance, cost, reliability, flexibility, product quality, quality of working life. Furthermore, and more critically for our purposes, the categories proposed by Woods are not orthogonal: If the complexity of the system as a result of 'many highly interacting parts' is intractable (a non-computable problem space, for instance), actors are faced with massive 'uncertainty'. Conversely, 'uncertainty' concerning the current state of the field of work, e.g., due to distortions in the available representations of the state of the system, arguably increases the number of *possible* system states to be taken into account at any point in time; that is, it adds to the complexity of the task.

Be that as it may, the distinctions suggested by Perrow and by Woods provide a fertile ground for developing a conceptualization of the 'system of relevances' of the common field of work.

5.3. Building on the dimensions developed by Perrow and Woods, I submit that we can, as a starting point, assume that the complexity of the common field of work of a given cooperative ensemble will depend on, e.g.:

(i) Structural sources of complexity, such as the number of interacting elements; the heterogeneity of the elements (different kinds of properties, behavior); the number and intensity of interdependencies among elements, the heterogeneity of interdependencies among elements; the degree of freedom of elements (i.e., the number of possible states of each element); the stability, operability, and consistency of constraints, etc.

(ii) Intensity of interdependencies (cf. 'tight versus loose coupling'), such as the rate of spontaneous changes in field of work (i.e., changes not induced by actors); the rate of propagation of state changes among elements of the system; the irreversi-

[11] Wood's distinctions harks back to Thompson's [THO 67].

bility of changes; the system's reactivity to induced changes; the frequency of interactions among elements, etc.[12]

(iii) Apperceptive sources of complexity (cf. 'uncertainty'), such as inadequacy of indicators or sensors (and their representations) with respect to the state of (parts of) the field of work (latency, invisibility, distortions, granularity); inadequacy of effectors with respect to the state of (parts of) the system (sluggishness, distortions, granularity); inadequacy of available information (in terms of e.g., level of abstraction, granularity, organization), ambiguity, missing information, dubious information, misinformation, etc.

6. The complexities of the cooperative work arrangement

6.1. Conceived of as constituted by a set of interdependent activities, the cooperative work arrangement is (in principle, conceptually) a transient formation of interdependent actors, emerging contingently to meet specific requirements, only to dissolve again if and when the need for multiple actors and their concerted effort is no longer present. However, the interdependencies of the actors do not in any simple and straightforward way reflect the structural and behavioral characteristics of the field of work; they reflect the field of work *as mediated* by a *particular configuration* of the cooperative work arrangement.

The cooperative work arrangement is ongoingly produced in processes of reciprocal 'mapping' of interdependent activities onto interdependent actors, and *vice versa*, and involves processes of mobilization (who?) and of deployment (what, where, when?).[13] The specific complexity of the cooperative work arrangement consists in the fact that these processes of deployment and mobilization involve multidimensional tradeoffs.

6.2. There is a sense in which actors must be *mobilized*, that is, be identified and at hand as potential actors, before they can deploy.

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[12] The more intense the interdependencies of activities are, the larger the space of possible states the actor will need to take into account before taking action, especially with respect to the state of the field of work of colleagues, etc.

[13] The terms 'mobilization' and 'deployment' are here used as the neutral terms to denote the processes of (a) identifying potential actors and (b) specifying the relationship between actors and activities, irrespective of the particular social form of these processes. Mobilization may thus involve *conscription* as well as *volunteering*. Likewise, 'deployment' may mean somebody's *assigning* somebody else to a particular task as well as somebody's *assuming* a particular task. The point is that the styles and forms of mobilization and deployment vary immensely. When deploying, actors may be commanded to do something, they may be specifically paid to do it, they may be expected to do it, they may believe they might be expected to do it, they may do it because they believe it may be in their interest to do it, they may offer to do it as a helpful gesture, they may do it because it's fun, and so on. Very often all of these styles and forms of governance coexist and complement each other in an infinitely variegated pattern.

The formation of a cooperative work arrangement entails an initial cost in terms of (a) the need for identifying likely and appropriately skilled partners and negotiating the allocation of tasks and responsibilities and (b) the need for new partners to acquire particular skills and become acquainted with local settings and practices.

This is complicated by the fact that the constellation of available or potentially available actors with requisite skills and competences is open-ended in that it is contextually determined (i.e., facilitated and constrained) by the socio-economic environment: the historically, culturally, and geographically given levels of education and training; the typical configurations of skills and competences in individuals, the geographical and industrial distribution of actors with different skills and competences, the institutional provisioning of skilled actors (guilds, trade unions, professional associations, etc.), and so on.

However, in order to deal with these issues under the conditions of continual emergence and dissipation of cooperative work arrangements, that is, in order to deal with the costs of mobilization, the formation of such arrangements is typically facilitated by relatively stable configurations of human resources, aimed at a certain range of tasks and situations, which in organizational theory and sociology of work is often termed *the work organization*. The work organization is a contingency plan; more than that, it is, so to speak, an *embodied* contingency plan: it is a plan in the form of a cohort of potential actors.

The work organization should be distinguished from the *system of appropriation* through which resources are committed and pooled and results are distributed, e.g., household and band; farm and manor, village and commune, firm and corporation, department and institution, consortium and alliance. A crucial aspect of the system of appropriation is what in organizational theory is often called the *'formal organization'*, i.e., the institutional practices of contractual governance through which stakeholders (workers, customers, investors, trade unions, professional organizations, authorities, etc.) regulate their diverse, partially incongruent, sometimes conflicting interests and concerns, such as informal conventions for the allocation of responsibility and resources or formalized schemas such as tariff agreements; certifications; budgeting, accounting and auditing procedures; safety regulations; etc.

These distinctions are required and warranted for several reasons. Firstly, they enable us to avoid the gross simplifications of much of sociology of work and organization theory where the organization of cooperative work is typically thought of in terms of reified notions such as 'team work' or 'taylorism' or 'bureaucracy'. These are rather to be taken as prototypical regimes, specific configurations of specific institutionalized forms of work organization and systems of appropriation. Secondly, and more importantly for our purposes, the distinctions between cooperative work arrangement, work organization and system of appropriation are essential so as to avoid confusing cooperative work with for instance collocation (working at the same location) or mere employment (working for the same company).

That is, the distinctions help us not to be blind to the dynamics and complexity of the formation of the cooperative work arrangement. The point is, on one hand, that a particular work organization at a certain point in time may encompass multiple, operationally autonomous cooperative work arrangements The night shift of the emergency ward at a hospital, for instance, may at one point in time exhibit multiple cooperative work arrangements working in parallel in caring for different patients, whereas at some other time all staff members may be involved in one and the same cooperative effort, or some may be working while others are on stand-by. On the other hand, a cooperative work arrangement may intersect multiple work organizations, as in the case of emergency management when actors from fire departments, hospitals, police forces, toxic waste disposal agencies, and so on converge on the site and cooperate to deal with the situation. Similarly, a given unit of appropriation such as a firm or a department may incorporate multiple work organizations (shifts, projects, etc.), whereas a given work organization may involve actors from separate companies.

The conventional and institutional practices of the work organization and the system of appropriation are instrumental in reducing the complexity of mobilization, in that they provide an ensemble of potential cooperating actors, as a cohort, with requisite skills and competences, at the appropriate time and location, with the issues of interests and motives contractually regulated. The infinite space of possible constellations of actors is drastically reduced; closure is provided.

6.3. As far as *deployment* is concerned, it is first of all crucial to keep in mind that the cooperative work arrangement and the field of work reciprocally constitute each other; not only in the sense that they define each other, but in a very practical sense. On one hand, the characteristics and changing state of the field of work pose requirements to the cooperative ensemble; but on the other hand it is the ‘project’ of the cooperative ensemble, the ‘things to be done’, the ‘system of relevances’, which identify the field of work. Alternative paths of action may exist that imply interdependencies of perhaps radically different intensity and scope. When exploring and considering alternative paths of action, cooperating actors may opt for strategies that will pose less complex interdependencies. They may acquire technologies that augment the capacity of individuals with respect to certain tasks (chain saws, bulldozers, combine harvesters, calculators) and thus reduce or eliminate the need for multiple actors to be involved in the effort in the first place. Alternatively, they may even abandon the effort as being overly demanding or unacceptably uncertain or unsafe. In the context of working, however, to actors in the ‘natural attitude’, under the typical conditions of ‘imposed relevances’ and massive constraints, the field of work is given. It poses practical requirements.

Actors deploy according to vastly different criteria. Actors may, for example, deploy to take charge of particular time periods, or of a particular position, station, desk, machine, room, etc.; or they deploy to take responsibility for specific types or groups of task, product or product family, case, client, customer, etc.

Just as activities that are intensely interdependent may be distributed over multiple actor, activities that otherwise are completely unrelated may be assigned to a particular actor, for the simple reason that he or she happens to be at the relevant location at the pertinent time to do them, but as a consequence of this particular deployment the activities become interdependent, like two universes connected by a wormhole.

Actors may deploy on the basis of incidental individual preferences or propensities; or they may deploy systematically, by virtue of having — by experience, training, or education — acquired specialized skills and competences. Working with a range of different materials or processes, for example, may involve radically different procedures and strategies and hence a range of differentiated skills and competences. Systematically differentiated deployment may also arise to meet requirements in terms of temporal orientation (maintenance versus operation, design versus production), professional ethos (production versus quality control public relations versus research) or similar. But differentiation of skills and competences will increase the scope and density of interdependencies among actors.

Actors may conversely deploy so as to minimize interdependencies between them, for instance, if bounded clusters of activities that are intensely interdependent can be identified and each handled by single actors (or small groups of collocated actors). Similarly, interdependence in action may of course be off-set if individual actors, typically through meticulous and systematic training, acquire the skills and competences required to perform the given cluster of activities. This way, the cooperative effort may be reduced to a set of relatively decoupled jobs that only interface occasionally or marginally or that are interdependent in relatively simple ways. But of course, reducing the differentiation of skills so as to reduce interdependencies among actors implies relatively higher costs of learning and training.

There is thus an obvious trade-off between the cost of learning and training and the cost of having to handle intense interdependencies.

The complexity of deployment arises from the infinite array of possible mappings and it is, again, handled by practices that drastically reduce the space of possibilities. Specific patterns of deployment become routine and taken for granted; a certain division of labor and responsibility among actors is institutionalized.

6.4. Irrespective of the particular deployment and mobilization practices, *a cooperative work arrangement invariably exhibits a characteristic 'topology' of 'local practices'*, i.e., of particular concerns, priorities, criteria, principles of aggregation and abstraction, technically specific routines, principles of ordering, concepts, etc. that are 'localized' to certain members in certain physical or organizational locations, to members dealing with certain tasks, to members having particular professional responsibilities, etc. Cutting sheet metal, for example, involves radically different technical skills and practical orientations than machining, drilling, and grinding, even though they all are operations of changing the geometry of a work piece through mass reduction, and such processes of mass reduction are in turn radically

different from operations of deformation such as bending, forging, and rolling, or operations of joining pieces such as welding, gluing, and mechanical assembly. Radically different principles of temporal and spatial ordering are involved.

The point is not that these skills (or any other combination of skills) cannot be mastered by a single individual, or that radically different principles of ordering in general cannot be integrated in the competence of one person, which they obviously can, but that the acquisition of skills and the integration of radically different skills takes time and effort. More generally, the integration of skills, strategies, conceptualizations, etc. is *work*, and as all work foremost the practical issue is one of weighing costs and benefits.

All this is, of course, just another way of saying that cooperative work is *distributed*, but the point of expressing it this way is to emphasize that not only are issues, concerns, priorities, criteria, concepts, strategies not globally and permanently shared, but they are typically unevenly distributed. Firstly, cooperative work arrangements are, so to speak, often 'lumpy', in that there typically are virtual or actual localities of work where actors have comparable skills and competences or where differently skilled actors have the same or compatible tasks and responsibilities: trades, lines, specialties, professions, communities of practice, sections, departments, institutes, offices, groups, teams, task forces, projects, etc. Secondly, cooperative work arrangements should be seen as superimposed and intersecting networks of *differently* interdependent activities. What can be conceived of as a cooperative work arrangement from one perspective may from another perspective be seen as a subset of a wider arrangement or may conversely be seen as comprising multiple constituent arrangements. Thirdly, cooperative work arrangements intersect in different ways. For instance, as noted in passing above, if a particular actor is contributing to different and otherwise independent cooperative efforts, these efforts are then coincidentally linked, and this linkage then gives rise to particular local coordinative issues and concerns. Cooperative work arrangements may similarly intersect by 'sharing' resources such as archives, buildings, rooms, machinery, equipment, etc.[14] In sum, cooperative work is characterized by a fundamental and inevitable interplay of local and global contingencies and issues.

7. The complexities of articulation work

7.1. As indicated above, the activities of mobilization and deployment — the very constitution and reconstitution of the cooperative work arrangement — can be seen as articulation work 'of the first order,' so to speak, as opposed to articulation work 'of the second order' as the activities through which the activities of the cooperative work arrangement, as already constituted, are coordinated and integrated. The distinction is not categorical but pragmatic. It is not relevant in so far as the

[14] Cf. Leigh Star's concept of 'boundary objects' [STA 89a; STA 89b].

cooperative work arrangement is transient. In typical cooperative work settings, however, cooperative work arrangements are enduring, or they recur regularly, and the specific articulation activities involved in the initial constitution of the cooperative work thus do not have to be reiterated, or reiterated completely. It is the 'second-order' articulation work involved in the enduring or recurring cooperative effort that concern us here, and in order to avoid confusion the term 'articulation work' will be used in the remainder of this paper in the latter sense.[15]

Since the different distributed actors, while facing local contingencies and concerns, are *interdependent,* and since the cooperative work arrangement spans an array of local practices, the cooperative work arrangement, in its totality, involves activities performed under different, perhaps incongruent criteria, concerns, procedures, strategies, etc., which have to be aligned, coordinated, integrated, in short, articulated.

From this perspective, then, articulation work ('of the second order') is to be conceived of as the system of activities by means of which the members of the cooperative work arrangement, as deployed and configured with respect to a particular field of work, align and integrate the (differentiated and intersecting) local issues, concerns, priorities, criteria, and so forth, not only 'locally', as in 'just here and now', but also with respect to the remote but related or intersecting local issues etc. of other localities of the cooperative work arrangement and of the wider network of cooperative work arrangements.

As already mentioned, cooperative work is reflexive in that working involves secondary work to make cooperative work work. The point is that articulation work is cooperative work from another perspective; its field of work being the given cooperative work arrangement. The complexity of cooperative work is thus reflexively also the complexity of articulation work.

7.2. The claim that articulation work *is work* and thus requires effort is not self-evident, however. Are the practices of articulation work indeed distinct from work practices? An immensely complicating issue here is that cooperating actors in typical work settings continually align their activities with those of their colleagues and that they do so in a fluent and seemingly effortless manner. It thus may seem meaningless to talk about complexity of articulation work in the first place.

7.2.1. The practices of mutual alignment appear to be effortless for two quite distinct reasons.

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[15] It is worth noticing that the two usages of the term 'articulation work' are reflected in the literature. On one hand, Anselm Strauss consistently uses the term 'articulation work' in the sense of 'first order' articulation work. To him the 'granularity' of the concept is defined by the concept of 'tasks' and articulation work is simply same same the 'articulation of tasks' as he also puts it [STR 85a]. By contrast, Gerson and Star do not treat 'task' as a black box; they open up the box and generalize the concept of articulation work to denote the ongoing adjustment of action in view of inexorable contingencies: the concretization, instantiation, adaptation, modification, etc. of routines, plans, and representations [GER 86]. — In my usage of the term 'articulation work' I am following Gerson and Star.

Firstly, competent actors make sense of and understand what colleagues are doing on the basis of their knowledge of and familiarity with the structural and behavioral characteristics of the field of work. Changes to the state of the common field of work will, so to speak, emit signals that can be observed, not only by the actor directly effecting the changes but also by colleagues, perhaps in the same location, perhaps in a different location, perhaps 'directly' (i.e., with their senses through 'natural' media), perhaps technically mediated (i.e., by means of sensors and representations and other intermediate technologies). From observing the state of the field of work and the changes to it, that is, without necessarily being able to directly perceive each other and each other's bodily conduct, competent members normally understand the situations faced by their colleagues and what their colleagues are doing, are not doing and will be doing, which enables them to align their own activities with the conduct of their colleagues and thus to accomplish the joint work in an orderly fashion. This appears effortless, because, to a competent member — in the flux of doing the work and thus attuned to the changing state of the field of work — what the colleagues next to him are doing is immediately meaningful; it does not require interpretation, reflection, contemplation to know why they are doing what they are doing or why they are not doing something else. Competent actors do not *infer*, they *see* the problems and intentions of their colleagues. In that sense, the mutual awareness among cooperating actors that can be observed in many cooperative work settings is practically effortless.

Secondly, the practices of mutual alignment play out without obviously interrupting the flow of work, in contrast to other coordinative practices, such as directing attention to something, searching for information, asking about something, requesting or ordering some action, negotiating actions to be taken, etc., which are all characterized by being intrusive in that they as 'speech acts' (under conditions of social accountability) 'enforce' a response or some other interruption of ongoing action. The practices of mutual alignment thus do not, normally, appear distinct from primary work practices and thus do not appear as specific coordinative practices. However, in spite of this virtually seamless integration, the practices of mutual alignment are not strictly speaking *effortless*. Actors' mutual alignment is predicated on selective and active monitoring and displaying. A range of workplace studies (e.g., [HEA 92; HAR 93; SHA 94; HEA 96]) have demonstrated that the apparently effortless mutual alignment and integration of activities do not occur through osmosis or some other 'automatic' process. In doing their individual parts of the joint effort, actors will typically *modulate* their own activities in such a way that they provide their colleagues with cues and other coordinative resources pertinent to what concerns they may have. In doing that, however, competent actors do not display their own local agendas and issues conspicuously and comprehensively, since doing that would add to the complexity of the work of colleagues; actors rather make their own activities publicly available in a form and at a level of granularity which is appropriate to the situation facing the colleagues. In short, the way activities are modulated is tailored to the particular situation at hand. Conversely, competent actors continually 'monitor' what colleagues are doing so as to ascertain how these

activities are being performed and whether they are progressing as expected, to determine exactly how their own activities should be adjusted to be integrated 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 might make the colleague being watched *aware* of being watched — unless, of course, *that* is desirable, for instance for safety purposes [SCH 00].

The coordinative practices of mutual awareness and alignment are highly efficient and effective for the simple reason (a) that they utilize signals incidentally emitted by the field of work and thus exploit what is there for the picking, so to speak, and (b) that the subtle practices of directing attention by modulating activities are integrated with the 'first-order' work practices of simply doing the work. In short, these practices appear effortless because the indicators of states or state changes in the field of work and of colleagues' intentions are ready-at-hand or are easily made ready-at-hand.

7.2.2. The virtually effortless character of mutual alignment of cooperative activities is bounded, however, as it is rooted in practices of limited scope.

Actors may have differential access to assessing the state of the field of work of each other. To understand this, it is helpful to consider a cooperative work setting where the cooperating actors are unable to directly perceive each other and each other's bodily conduct [POP 57]. That is, the actors are restricted to interacting by changing the state of the common field of work and to assess the state of affairs through observing the state of the field of work. The actors may be deployed in such a way with respect to the field of work that they are all practically able to directly perceive the state of the field of work in its entirety or they may be deployed in such a way that they can directly perceive only a particular region of it. Likewise, changes to the state of the common field of work will unfold and propagate within the field of work in different ways, through different routes and at different velocities, state changes will cross boundaries between regions and will be distorted accordingly by various mechanisms of selection, abstraction, aggregation, concatenation, etc., and as they unfold and propagate they will be observable by members in different ways due to different representations. If the field of work is 'tightly coupled' (e.g., a power plant or an aircraft), changes may affect the work of others instantly and without exception; in a 'loosely coupled' system, by contrast (e.g., a building under construction or a software design under development), changes may propagate sporadically and contingently.

Moreover, different fields of work may offer different affordances (degrees of freedom, means of expression) for actors to 'modulate' their activities so as to display pertinent aspects of their work or direct attention to certain aspects of the field of work to others or, conversely, for actors to monitor the activities of others. In some work domains, objects that are part of the field of work may be used for conveying cues to colleagues. In office settings, for example, workers can be seen placing a file on the corner of the desk to indicate that they have finished using it or

leaving a file on the chair of a colleague to indicate that this is somehow urgent. Similarly, but in a quite different domain, fighter pilots will tip the wings of their aircraft to signal some intention to other pilots. On the other hand, the operators of a hot rolling mill do not have such degrees of freedom [POP 57]. They are restricted to the un-modulated changing state of the of the field of work as a source of knowledge of the state of the work of their colleagues, their plans and intentions, the disturbances they are facing, etc.

Collocated cooperating actors are of course typically not confined to the changing state of the field of work and the action modulations afforded by the field of work as a means of mutual awareness and alignment. They will for example often be able to observe each other's bodily conduct, overhear each other's conversations with other actors, direct attention, engage in conversations, etc. For example, a nuclear power plant operator notices his colleague moving to the other end of the control room, to a particular set of control panels, and may assume that the colleague is going to initiate certain changes which in turn will affect himself in his own work [KAS 91], or an air traffic controller overhears radio conversations between his colleague and a pilot and takes appropriate steps [HAR 93].[16] But what was said above about actors' ability to modulate their activities, applies to bodily conduct as well, in so far as the modulation of activities in order to convey coordinative cues to colleagues in some settings may disturb or even perturb work. It may, for instance, be deemed unacceptable if a violinist in a chamber ensemble jumps up and down for coordinative purposes, whereas the very same form of conduct may be perfectly acceptable in a rock band.

7.2.3. Anyway, the costs of learning the subtle coordinative practices of picking up signals and cues and of modulating action may be significant due to the inevitable heterogeneity of the cooperative work arrangement. Since the skills of a given individual or ensemble are limited at any point in time, members knowledge of 'remote' regions of the field of work may be limited and patchy and their ability to make sense of what actors engaging these remote regions of the field of work are doing may be equally limited and patchy. That is, the scope of effortless mutual alignment is limited by the parochial character of actors' domain knowledge. The specific topology of the cooperative work arrangement is thus reproduced in the practices of articulation work. In this sense, the complexity of cooperative work is directly reflected in the complexities of articulation work. Articulation work ac-

[16] It should be emphasized, however, that actors observe and understand the bodily conduct of colleagues, not simply on the basis of some putatively generic and innate semantic scheme of postures and gestures, but *with respect to* and *in terms of* the actor's knowledge of the state of the field of work. I am stressing this because the role of bodily conduct in cooperative work is often idealized and overstated. An actor's observation of the bodily conduct of a co-worker may or may not be critical in a particular setting or situation but it is always grounded in the observer's understanding of the structural and behavioral characteristics of the common field of work, its current state, as well as the operational constraints and procedures and is thus an integrated aspect of their domain-specific professional competences.

cordingly involves the coordination and integration of local practices with practices 'beyond the pale', at remote regions of the field of work.

7.2.4. In sum, then, the practices of mutual awareness and alignment enable practitioners to coordinate and integrate their individual activities in practically effortless ways, but only within the scope of local practices. That is, articulation work inevitably requires effort.

7.3. The specific complexity of articulation work arises and becomes intractable as interdependencies transcend local practices.

(i) Cooperating practitioners are typically faced with remote and perhaps incongruent local routines, agendas, criteria, perspectives, principles of interrelation, aggregation, and abstraction, principles of temporal ordering (urgency, reversibility), etc., with which they nonetheless have to coordinate and integrate their own local activities. As already pointed out, we need not and should not presume that the required translations and re-conceptualizations are impossible. The important point is that such translations and re-conceptualizations *are work*; it takes time and effort. But since the requirement of general or global consistency is only one among multiple issues and constraints, consistency can only be achieved, under normal practical conditions of expediency and urgency, at the expense of local issues and constraints.

(ii) To local actors, the ramifications and repercussions of their local activities to other regions of the cooperative effort are not immediately and straightforwardly evident; the same applies, *vice versa*, to the local implications of remote activities, of course. There are several reasons for this, in addition to the costs of translation and conceptualization. On one hand, remote state changes to the field of work are subjected to various deformations (delay, abstraction, transformation, distortion, etc.) as they propagate through the field of work. On the other hand, for actors to compensate for these deformations through communication takes time and effort and may interrupt the flow of action.

For example, take Peter Carstensen's study of a software development project [CAR 96a; CAR 96b]. In previous projects the systems they had been constructing had been small (as measured, for example, by the number of lines of code) and the programming work had been done by single programmer or perhaps a couple of programmers. In these projects they had been able to manage their interdependencies practically effortlessly. They had been working next to each other and had had practically unconstrained access to consulting each other and to monitoring each other's work. At the time of the study, however, a new project had been undertaken in which the engineers were building a significantly larger system comprising many hundred thousands lines of code. Their traditional coordinative practices were now quite inadequate. The interdependencies of their cooperative effort now transcended the local practices, and they were faced with interdependencies that had ramifications and potential repercussions that were unknown and unknowable to them with the resources. To deal with the ensuing crisis, the ensemble developed a new work

organization with new roles and with a set of coordinative practices based on constructs such as coordinative protocols and artifacts.

7.4. In order to handle the complexities of articulation work that arise as interdependencies transcend local practices, practitioners routinely and pragmatically develop a variety of practices that serve to regulate (curtail, contain, suppress, harmonize, standardize, interrelate, synchronize, etc.) local practices.

The articulation of cooperative work is first of all typically a *practice* in the sense of a distinct established practice involving a repertoire of specialized techniques and procedures that are developed and refined as well as taught and learned by members. Articulation work involves cooperative work practices by means of which *local* cooperative work practices are integrated; *practices that integrate practices*: *coordinative practices*.

Such coordinative practices are characterized by the crucial role played by *coordinative artifacts*: calendars; memos, agendas, and minutes; records and archives; catalogues and taxonomies; maps and charts; standard operating procedures; forms and templates; schedules and production plans, and so on and so forth. Contemporary workplaces are littered with coordinative artifacts of different kinds that serve different coordinative functions:

(i) Product standards, blueprints, drawings, 'style sheets' may serve as 'templates', that is, artifacts that specify the properties of the result of individual contributions [cf., e.g. TUR 93]. By defining interfaces between local practices, such artifacts may provide means for a relative decoupling of interdependent activities and hence for reducing the complexity of articulation work.

(ii) Bulletin boards, archives, taxonomies, maps, charts, procedures, schedules, etc. may reduce the cost of taking remote or global concerns into account by making remote or global concerns 'visible, e.g., by providing representations of interdependencies, by providing representations of the state of affairs, by highlighting crucial issues, by affording the calculation of possible or probable remote effects of local actions, etc.

(iii) Calendars, clocks, agendas, time tables, flight plans, project schedules, production plans, production control systems (MRP systems, kanban systems), etc. may be instrumental in synchronizing local activities that are otherwise decoupled and performed concurrently or intermittently. Alerts, calls, and reminders can be seen as similar but more intrusive means of synchronization.

(iv) Flight deck checklists, safety procedures, flight databases, workflow systems, production control systems, etc. may be instrumental in prescribing certain aspects of local activities (steps to be taken or not taken, the sequence of steps, alternative steps, criteria, etc.). By stipulating the course of action in certain ways and thus curtailing parochial aspects of those practices, such coordinative artifacts are introduced and used as means of increasing operational safety, reliability, efficiency, etc.

(v) Complex artifact-based coordinative practices such as notations, nomenclatures, and classification schemes may serve to promote consistency of certain aspects across boundaries between local practices. By offering standard schemes of description, naming, classification, identification, etc. such coordinative artifacts are instrumental in reducing the cost of translation and re-conceptualization across regions of practice. At the same time, of course, due to the implicit bias in favor of global concerns such artifacts may also be instrumental in increasing the complexity of local practices.

What seems to obtain as a general characteristic is this. A given coordinative artifact offers competent members a limited selection of options that are considered necessary, mandatory, relevant, 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 options that generally would be considered irrelevant, superfluous, unsafe, etc. By reducing the space of possible options, coordinative artifacts assist competent actors in reducing the complexity of coordinating their activities. Under conditions of limited resources, practical exigencies, and social accountability actors rely on such prescriptions to get the job done, unless they have good reasons not to do so [SCH 97].

7.5. Coordinative artifacts are specialized constructs, devised to deal with certain aspects of interdependencies. The reason for this is not only practical. It is not just that such artifacts are constructed in a distributed fashion, although this is obviously an issue. Nor is it that their construction requires effort and time and that resources finite, although this is most certainly also an issue. The reason is, *au fond*, that 'No representation of the world is either complete or permanent [GER 86, p. 257].

On closer inspection, one finds that these specialized constructs form complexes of interrelated coordinative practices and artifacts. Ina Wagner and I have suggested to call such complexes *ordering systems* [SCH 02a]. For example, in most if not all contemporary work settings one will find a complex of artifacts and practices that in their totality are devised and used for organizing meetings: not only agendas and minutes, but also clocks, calendars, room numbers on floor plans and doors, and so on. Other ordering systems can be distinguished in the composite practices of, e.g., handling large-scale collections of items or complex work flows. What we observe in any event are ordering systems consisting of interrelated artifacts, notations, nomenclatures, standard formats, validation procedures, schemes of temporal, spatial, conceptual, etc. ordering, and so on.

To members these complex practices are instrumental in managing interdependencies that transcend local interactions. They are deliberately and carefully devised in a cooperative process to regulate and align local practices and are being used that way, that is, to enforce requisite coherence, keep track of potential repercussions, ensure accountability, etc. Moreover, to handle the inevitable contingencies of work, ordering systems are open ended. Classification schemes, for instance, are amended

or extended to deal with specific features of particular projects; new notations are invented and introduced as required, and so forth.

In forming of ordering systems, coordinative artifacts and practices form intricately recursive relationships where one distinct coordinative practice may regulate, constrain, define, modify, etc. another.

The reflexivity of cooperative work has no end.

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