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INTELLIGENT AGENTS CONCEPTS FOR COMPUTER-SUPPORTED COLLABORATIVE WORK SYSTEMS IN COMPLEX INDUSTRIAL SYSTEMS - RESEARCH DIRECTIONS

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Résumé. Cet article s'intéresse à la contribution de concepts d'agents intelligents pour la mise en œuvre de collecticiels dans les systèmes industriels complexes (nucléaire, espace...) où des agents humains peuvent coopérer avec différents agents logiciels, "intelligents" ou non, dans des situations très différentes. Une caractérisation globale des systèmes hommes-machines industriels complexes est d'abord donnée en insistant sur le contexte coopératif. Puis, plusieurs directions de recherche sont proposées concernant la notion de modélisation d'organisation en vue de la mise en œuvre de CSCW dans les systèmes industriels complexes, sous l'angle de l'Intelligence Artificielle Distribuée.

Abstract. This article deals with the contribution of intelligent agents concepts to design computer-supported collaborative work in complex industrial systems (nuclear power plants, space industry...) where human agents can cooperate with software, "intelligent" or not, agents in very different situations. At first, a global characterization of complex industrial human-machine systems is given, in stressing on the cooperative context. Then, several research directions are proposed about the organization modeling notion in the aim to realize CSCW systems in complex industrial systems from the Distributed Artificial Intelligence point of view.

Keywords. Distributed Artificial Intelligence, Computer Supported Collaborative Work, Interaction, Communication and Information sharing in complex industrial systems

Introduction

In this article, we are interested in developing CSCW systems for control rooms to supervise and control complex industrial systems (chemical, nuclear power, energy nets, transports, ...). This domain offers a large study field in reason of the complexity of the tasks that are entrusted to the humans, the diversity of criteria required to achieve these tasks (linked to the production, economy, quality...), and

the variety of possible computer-supported assistances that can be given to human agents. Few studies have been made until now in this perspective.

In that context, this article is made of three parts. In the first part, we characterize globally the complex industrial systems in stressing on the cooperative context. The second part gives some research directions towards a global model of the human-machine system in control room with the help of multiagent concepts. Finally, the last part gives research lines related to the notion of organisation modelling to realize CSCW systems in complex industrial systems.

I. Complex industrial systems characterization

WOODS (especially in [Woods 88]) has underlined the difficulties of a global definition of a complex industrial system. Indeed, he has shown the difficulty of modeling the capacities of assistance tools, as well as the capacities and resources of human agents. We can consider the development of tools able to plan, and even to adapt themselves, to dynamic functionings, even if numerous research works show that planning is still a crucial and difficult problem. One can notice, however, that the applicability of these tools (which are mostly AI tools) is a new challenge in the study of the human-machine “couple’s behavior”. That challenge, for researchers from different fields (cognitive ergonomists, psychologists, sociologists, computer scientists, automatists...), concerns the study of cooperation among intelligent entities. Such a study leads naturally to determine the cooperation actions that allow to reach optimal performances of the whole system.

In this scope, cooperation implies two essential elements, that are (1) the specific cooperative context of the application, (2) the cooperative structures gathering the participants.

1.1. The cooperative context

Following the technological evolution, the human agents in control room have to achieve more and more complex problem solving tasks, with the means of graphical tools, and this in dynamic and specific demanding situations [Van Daele 92] [De Keyser 92]. They work in a complete physical disconnection from the devices. Especially, they solve, alone or collectively, complex problems including human-computer or computer-computer negotiation and cooperation needs [Reinartz & Reinartz 89] [Brehmer 91] [Schmidt 91] [Heath & Luff 92]. The means put at the teams’ disposal play a basic role in the efficiency and reliability of the human-machine system. Demanding a high knowledge level, the human tasks in complex systems have been classified by ROUSE [Rouse 83] in four main categories:

- *The transition tasks*: they are linked to the system’s rate changes (stop, start, changes of functioning points). The human-machine interface must then allow the members of the team to do pre-established procedures to appreciate their effects on the system and to supervise the evolution of it at every time.

- *The control and supervising tasks*: the human-machine interface must make the system state supervision easier to the team, in the aim to detect and anticipate abnormal event outbreaks and to optimize the production by sharp adjustments.
- *The default detection and diagnosis tasks*: by alarms settings and/or the possibility to observe some variable of the system's abnormal evolution, the members of the team must be able to detect the defaults and to make his diagnosis accordingly. Then, the human-machine interface must necessarily enable an easy underline of the causes/effects relations among the system variables.
- *Compensation or correction tasks*: to restore the system normal functioning state, the interface must help the members of the team to decide the actions to achieve and to display their effects on the system.

To achieve these complex tasks, some including thousands of variables, the human agents have at their disposal mostly common human-machine interfaces, that display an information set in a graphic way. Such interfaces can be linked to assistance modules, whose reasoning is sometimes called “intelligent” when based on artificial intelligence techniques. These assistance modules can be specialized in diagnosis, prediction of defaults, alarms filters, etc [Kolski 93]. The human-machine interfaces have to synthesize the process state and assist the members of the teams during their activities. Thus, the human agents do not have a direct view on the system and on the actions results, they must build their own mental representation of the remote system functioning state and of the variables that compose it. Then, they work through the mental representation they have of the system, the representation they get especially by the human-machine interface [Norman 86] [Rasmussen 86] [Tanni et al. 94].

1.2. Cooperative structures in an industrial context

Despite many works about the human-machine cooperation notion (Cf. for example [Mandiau et al. 91], [Vanderhaegen et al. 94], [Karsenty & Brezillon 95], [Mandiau & Le Strugeon 95], [Millot & Mandiau 95]), it is still difficult to characterize sharply the notion of “cooperation” between a single operator and an “intelligent” tool (called AI tool in the following paragraphs). Of course, the difficulty is bigger when studying the cooperation aspects among several operators and AI tools. We propose to develop the cooperation notion seen from the Distributed Artificial Intelligence angle, starting with the works of SCHMIDT [Schmidt 89], who distinguishes the notions of (1) cooperation form and (2) cooperation mode.

The cooperation form puts in light the reasons why the different entities of the system cooperate. These reasons are linked to the fact that each (human or AI) entity has bounded cognitive capacities. Moreover, some applications require cooperation because the tasks can not be individually achieved (in reason of time, security or efficiency constraints). That is why SCHMIDT has proposed three cooperation forms, summed up in the table 1.

These cooperation forms correspond to different ways to use each entity's capacities in different aims. The integrating cooperation enables to obtain a global result from entities that have distinct and specialised tasks. It is above all a coordination problem. The debate cooperation allows to use different points of view, knowledge or strategies on a given problem. In the argument cooperation, the aim is to pool every entities' abilities to perform a task more efficiently than what could be done by each of them.

Table 1: cooperation forms (synthesized from [Schmidt 89])

integrating cooperation	Performing tasks that integrate the abilities of each and every entity
debate cooperation	Need for a multi-representation of the points of view to perform the task
argument cooperation	Increase of the group's capacities

Similarly, SCHMIDT proposes a classification for the cooperation modes (table 2) that shows the way to achieve cooperation among different entities.

Table 2: cooperation modes (synthesized from [Schmidt 89])

Location dimension	Proximate cooperation : the cooperating entities are at the same location Remote cooperation : the cooperating entities are in different places, implying bounds in their interactions
Time dimension	Synchronous cooperation : the tasks are simultaneously performed Asynchronous cooperation : the inter-dependent tasks must be coordinated
Organization dimension	Collective cooperation : the entities cooperate overtly and consciously to a common goal Distributed cooperation : the entities can modify their behavior and are not necessarily informed of the others' activities
Communication dimension	Direct cooperation : the entities interact by the means of verbal (speech acts) or non-verbal (moves, visual) exchanges Mediated cooperation : the entities cooperate via a shared information space (wall screens, calculators)

More recently, RODDEN and BLAIR [Rodden & Blair 91] have proposed a classification of CSCW systems along two dimensions: the cooperation form (synchronous, asynchronous, mixed) and the geographical nature of it (co-located, virtually co-located, locally remote, remote). In the case of an industrial system supervision, the cooperation form which is used is mainly of the "asynchronous" type since the actions are made in real-time on the supervised process; the cooperation acts among the members of the team are made in real-time either. Regarding to the geographical nature of the system, the supervision team may be either grouped together in a single room, or be dispatched among several rooms. Thus, it is the case of the "virtually co-located" system defined by [Rodden & Blair 91].

Computer-supported collaborative work systems have been mainly studied in office automation contexts. For this type of applications, KARSENTY [Karsenty 94] has classified the groupware systems by the functions they propose: (1) electronic mail, (2) shared editor, (3) computer-supported conferencing and meeting, (4) decision making assistance system and (5) coordinator aiming at facilitating the work in the group. These two last categories can be seen as really potentially including the main functions that are useful in an industrial process supervision context. Indeed, these systems' complexity comes, for the most part, from management of more than one action at the same moment on the same dynamic piece of data (or the same set of dynamic data) problems and from consistency management among the distributed handled data.

We think it is necessary to tend to a more global approach, in which the human and AI agents are situated in an organization, with strong interconnections through human-computer, computer-computer and human-human interfaces. This aspect is developed in the following part.

II. Global modeling of a work organization in a control room - research directions from the DAI point of view

Using a multiagent view in the context of a control room, we could see the team made of human operators and artificial intelligent assistants as a system of agents working jointly with a shared goal. An agent is defined here as either a human or an artificial tool with intelligent capacities that allow it to act on its environment so as to achieve its goals.

II.1. Environment of a human agent in complex industrial systems

A human agent in a control room is the most often interacting with other human agents, and also with software agents. The figure 1 illustrates, for example, a human agent X cooperating through a human-machine interface (in which an assistance tool is embedded) with others human agents (in/out the control room), and with a responsible human agent (for example, a foreman) coordinating their actions. This example which may be a priori simple, underlines the lack of studies about interactions between the human agent and his interface. In fact, considering a single human agent faced to his human-machine interface is not appropriate in this context. In such environment, we have to consider the set of interactions between human(s) and machine(s).

In a complex industrial system (nuclear, space...), the recent interfaces may include one or several aid tools. These systems may be based on concepts and techniques issued from Artificial Intelligence. They may take decisions and act, in some cases, directly on the process. According to BOY [Boy 88] [Boy 95], they may be considered as intelligent "assistant agents" collaborating with the human agent to perform the task. They are more and more studied and considered as software autonomous and personal assistants. For example, [Maes 94] proposes a "metaphor of the personal assistant": the agent learns how he could assist the user and how, in some cases, it could take the place of the human agent in his interaction with the application, and this by observing the human agent and imitating him.

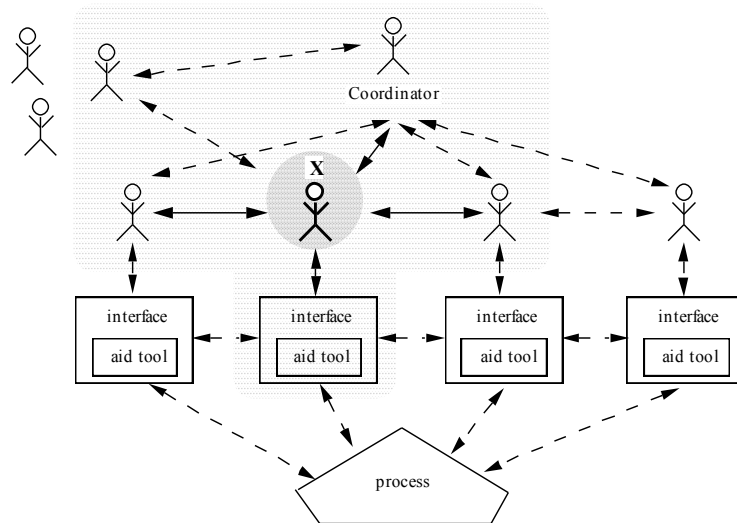


Fig.1: Simplified example of human agent environment in control room.

Although the researches attempt to study the intelligent agent notion in a static discrete context (office automation, personal assistant), in this paper, we investigate it for a continuous dynamic process. In this context, the human-machine and machine-machine interfaces are used as acting on the process and as interacting with the assistant agents (figure 2) [Le Strugeon et al. 95]:

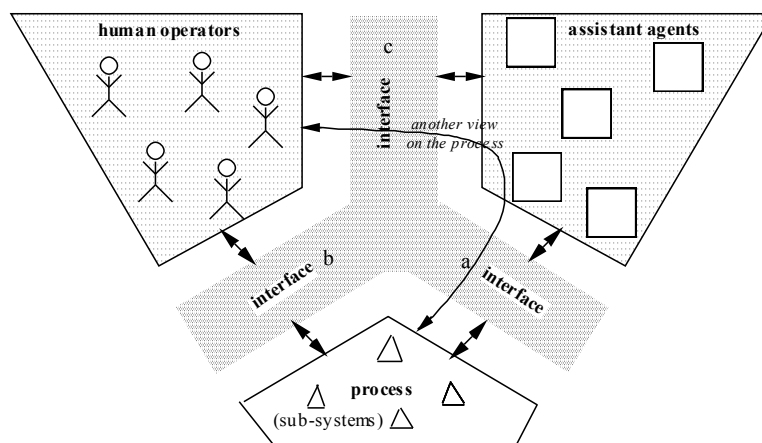


Fig. 2: Human and artificial agents acting on the process¹.

- (a) A machine-machine interface is required between the software agents (or assistant agents) and the process. It is essentially a filter allowing to translate raw data from the process (data from sensors for instance) towards information at a higher level (using a communication protocol) for the assistants, or conversely.
- (b) The human agents act on the process using a classical human-machine interface.
- (c) The human agents interact with software agents by a human-machine interface of another type. Through this interface, the human agents have another view on the process, the raw data have been filtered compared with those perceived with the interface (a). With this interface, the software agents must either be able to give explanations about their solutions, and also about the

¹See also [Woods et al. 91] for a discussion about the representation of the human-machine interactions.

actions which can be—in some cases— directly performed on the process. It is very important for the human operators to have a feedback on the artificial agents' activities.

Control and supervision team may be considered as composed of interacting human and artificial agents. They work together to solve problems and to intervene on the process. This vision —of the domain— allows to underline different interaction types with associated research field(s).

II.2. The different interaction types and their associated research fields

According to the previous paragraph, the study of the interaction between heterogeneous entities is the object of different research fields, figure 3.

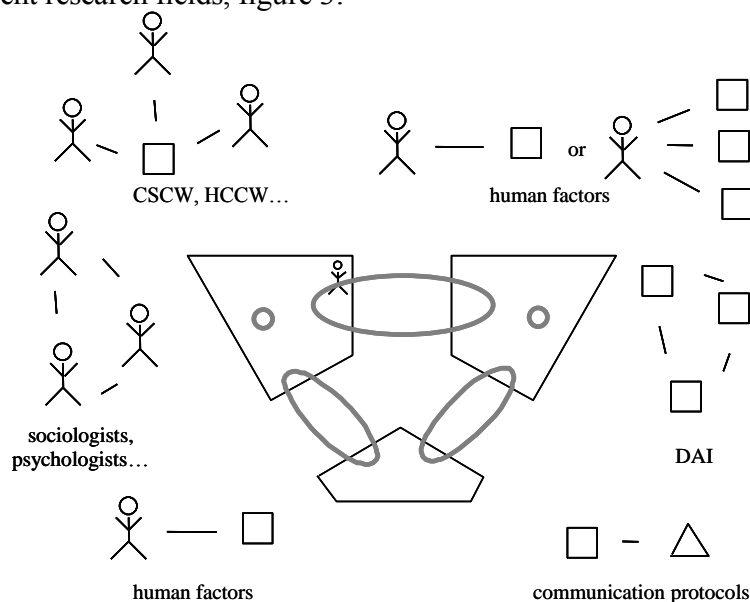


Fig. 3: Research fields concerned by the different types of interaction between human and software agents

Several types of interactions can be distinguished, and particularly the interactions among the human agents. This type of interaction is studied by sociologists and psychologists (see for example [CACM 94]) ; note the promising studies issued from sociologists focusing on organization notion [Mintzberg 86].

Concerning the human(s)-machine(s) interactions: the interactions between (1) a human and a machine (2) a human and an artificial agent are studied for a long time by the human factors specialists. The interaction between an artificial agent and several human agents seems more complex. In fact, this type of interaction is a support for cooperative work, as it is studied by many researchers in CSCW (Computer Supported Cooperative Work) or HCCW (Human Computer Cooperative Work) (see for example [Jones et al. 94] [Li et al. 94]) fields.

Concerning the interactions between artificial agents: the Distributed Artificial Intelligence (DAI) is the domain in which the interactions between agents are studied. An artificial agent may be composed of two facets, figure 4: an internal aspect (how it is implemented) and an external aspect (its behavior). In an industrial complex system, it is possible to study an agent as a cooperative entity

[Mandiau 93]. The study of these two aspects facing this problematic open a lot of research perspectives.

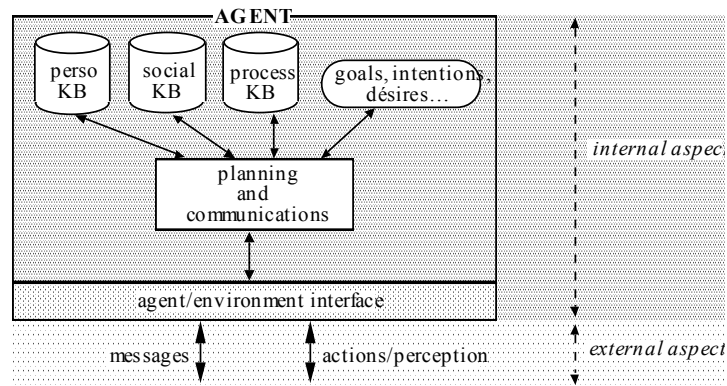


Fig. 4: Representation of intelligent agent's principal elements.

II.3. Internal aspect of an artificial agent - needs for complex industrial systems.

According to an internal aspect, artificial agents -able to assist human agents and to communicate with one another- must have at least the following abilities [Mandiau et al. 91, Mandiau 93]:

- **Reasoning.** An intelligent agent must have Knowledge Bases (KB) about itself (current states, goals, capacities...), the other agents (current states, goals, capacities, knowledge, beliefs...) and the process (current states, expertise). It must be able to reason on symbolic (and/or numerical) knowledge. It must also integrate planning capacities (for the generation of plans based on beliefs and intentions) and decision capacities (for the choice of actions sequence that must be elaborated).

If the environment of an artificial agent includes human agents, it must have a specific representation for these specific colleagues. An artificial agent cooperate with its acquaintances in reasoning from the knowledge it posses about them. It is the same when it cooperates with a human agent: the artificial agent must have a representaton of each human with whom it collaborates. In the case of other artificial agents, it can deduce the reason of their acts using what it knows of them, because they reason in the same as it does. It is obviously far more complex when it interacts with human agents. To introduce pertinent knowledge about human agents in the bases of the artificial ones is one of the problems that must be solve to obtain efficient cooperation in such teams.

- **Communication.** The agents must be able to exchange (to send and to receive) information, and particularly by messages. The communication must also (1) allow the agents to include new knowledge about their environment, and (2) support the coordination of actions between the agents. Note that the tendency consists in basing the communication on the Speech Acts [Cohen & Levesque 90] [Blanford 93] which are defined as physical actions (i.e. pre-conditions and effects of action in a given situation).

II.4. External aspect of an artificial agent - needs for complex industrial systems.

We have seen above some basic needs concerning organizations modeling in complex systems. These organizations may give the possibility to define the behavior of a global system, and thus, to lead to identify -for each (normal and abnormal) situation- the optimal behavior for the group. This modeling may be investigated by the external structure of the agent. In fact, this behavior can be perceived by the realization of (1) physical actions and (2) communicative acts. Moreover, this intelligent agent must have a “social behavior” since it is involved in a group. More exactly, its reactions have to depend on different internal parameters: its intentional states (beliefs, desires, intentions and commitments), its knowledge concerning the others agents and the tasks they have to perform, and its own social position in this group. By the social position, the agents may be able to organize themselves in a way to cooperate.

Several organization models among artificial agents has been defined according to human organization models. The characteristics of these different organizations are studied by DAI’s researchers, sociologists and economists (a synthesis of these works is given in [Le Strugeon 95]): we can define in a simple manner the organizations as hierarchical, market and communities organizations. These organizations lead to attractive researches for the problematic of complex industrial systems. More explanations about them are given in the following part.

III. Organization models - research directions

III.1 Multiagent organization models

According to [Gasser 92] and [Le Strugeon 95], an appropriate classification of multiagent organizations is based on the type of control used. [Gasser 92] distinguishes four organizations categories:

- The centralized organization is an usual structure in human groups. It is a hierarchic configuration, the links between the agents are of the master-slave type. At each level of the hierarchy, masters centralize the decision and control powers.
- The market-like organizations are based on the principle of contract, like the bidding mode of cooperation. The reference example in DAI is the Contract-Net of Smith [Smith 80].
- The pluralistic communities are made of independent agents. They prepare solutions and communicate them to the other members of the community. Each of them verifies, validates or improves the propositions of the others [Kornfeld 81] [Lesser & Corkill 83].
- The community with behavior rules is a community of specialists. They interact according to defined and known protocols. Multi-expert and multi-knowledge bases systems [Geizes et al. 90] belong to this category. Control and communication among the specialists is often done by blackboard techniques.

As a matter of fact, the “community with behavior rules” (or “society”) form is the more realistic one to design or describe complex organizations. It includes the three other categories, which

conversely appear as basic organization forms. Thus, it seems more interesting to consider the organization classification including the three categories: hierarchy, market and community.

An organization can be described as being made of functional components and relations among these components:

- A **component** is described by a type, that allows to distinguish a single component from a group component, and a role, that allows to represent the component's position in the organization. Three roles are defined: coordination, performance and expertise. The coordinator's responsibility consists in managing the coordination among the components, that means to organize the actions to perform in a chronological order. The underling makes no decision, it performs actions. The expert provides information to the others.
- There are two types of **relations** between components: authority and communication relations. The authority links state the relations existing between a component that has a role i with a component with a role j . The communication links state the communication direction that can occur between two specific components. Thus, relations among components are determined by their respective roles in the organization.

This description can be used at the different levels of a complex organization structure. If the component is a group, the same method can be used to describe its own organization: its internal components and the links among them. Thus, an organization including many sub-organizations can be described in a recursive way. The three organization types of our classification are modeled on this pattern:

- The **hierarchy** model is composed of two components types: coordinators and underlings. The coordinator is superior to the underling in the hierarchy. Coordinator gives orders to underling components, that perform the tasks and send back results to coordinators.
- Initially, in the **market** organization, all the components are peers. Then, contracts create several couples among them. The invitation to tender is made by a coordinator. When the contract exists, some components that had no role become underling ones.
- The **community** model includes only one component role. The organization relies mainly on negotiation and partial plans exchanges. Each component takes alternately expert, coordinator or underling roles.

After the explanation of the different organization models, we propose to include them in tools for multi-user cooperation.

III.2 Intelligent agents in multi-user cooperation

It seems that the cooperation between the participants of the supervision team can be improved by the use of intelligent agents. Indeed, some organization models exist in the multiagent systems field, that enable an efficient cooperation in the group. By implementing an intelligent agent in each distributed interface, the communication problem among these sites can be seen as a multiagent cooperation problem.

This cooperation problem is the central point of the research works in the multiagent systems field. Several methods exist, including agents with more or less capacities of reaction to events, mutual knowledge, etc. Generally, an efficient cooperation can be established only when an organization structure, where everyone has a definite role, is created in the group. This way, the actions performed by each one contribute to the common goal and generate as less conflicts as possible, mostly caused by resources sharing. For an application of complex industrial system supervision, the common goal is the well-functioning of the process.

In a context like this, the cooperation in the system composed of human and artificial agents can be described according to the four dimensions exposed in the first part of the article (cf. table 3):

- location dimension: both cooperation types, proximate or remote, can be found. The distinction has no effect if an artificial agent plays a part in the relation, since all the exchanges are made through computing elements (screen, keyboard, etc.).
- time dimension: both cooperation types, synchronous and asynchronous, are conceivable.
- organization dimension: the cooperation is mainly a collective cooperation, in which every entity is conscious of playing a part in the common goal performing. But, it is conceivable that some of the artificial agents do not have all the knowledge required to be “conscious” to take part of the group, so the “distributed” aspect (as SCHMIDT calls it) is present either.
- communication dimension: the cooperation among the human operators can be direct or mediated. But, every cooperation including an exchange between an artificial agent and a human agent is necessarily mediated, because of the distinct nature of them. Among artificial agents, the communication type depends on the way they have been designed: the communication is direct if the agents exchange messages, it is mediated if they use a blackboard.

Table 3: The cooperation dimensions seen from the nature of the cooperating entities

entities / cooperation dimensions	<i>human agents</i>	<i>human agents and artificial agents</i>	<i>artificial agents</i>
<i>location</i>	proximate or remote	with no effect	with no effect
<i>time</i>	synchronous or asynchronous	synchronous or asynchronous	mostly synchronous, but can be asynchronous either
<i>organization</i>	collective	collective with some distributed component	collective and/or distributed
<i>communication</i>	direct or mediated	mediated	depends on the implemented communication type: BB => mediated messages => direct

Otherwise, the table 4 exposes a first description, that must be confirmed by further research works, of the organizations according to the cooperation form previously explained by [Schmidt 89].

The table shows that the organizational structures to establish depend on the relations among the agents:

- integrating cooperation: This cooperation form introduces the problem of the tasks allocation, linked to the negotiation and possible conflicts solving. In a master-slave relation, this cooperation requires a strong coordination between the agents to integrate every agent's abilities into the global task performing. This coordination is efficiently used in a hierarchical structure. In a peer relation between agents, performing tasks that require different abilities, generates organizations of the society type.
- debate cooperation: This cooperation allows to deal with tasks from different points of view. The cooperation enables the results synthesis. That leads naturally to results sharing. In a master-slave relation, this type of cooperation can not really exist, since the slave has the master's point of view. On the opposite and by definition, community organizations, where the agents have egalitarian relations, make the most of it. Results sharing, in these organization types, deals with problems linked to the multi-expertise or to knowledge consistency.
- argument cooperation: In a master-slave relation, this cooperation form fits with a market-like organization, whereas in a peer relation, the organization can be a community or a society.

Table 4: Organization models corresponding to the use of a social links between agents and a cooperation form.

type of social links / cooperation form	<i>master-slave</i>	<i>peers</i>
<i>integrating</i>	hierarchy	society
<i>debate</i>	X	community (multi-expertise)
<i>argument</i>	market	community society

Conclusion

In this article, we have proposed a set of research directions to design CSCW systems in complex industrial systems, with the help of concepts from the multiagent systems studies.

According to the first trends concerning multi-users architectures (like [Hill 92], [Dewan 92], [Croisy 94], [Ben Atallah et al. 95]), it seems more and more necessary to study the organizations to develop. These organizations require to analyze several problems, such as, for example: the coordination among the agents for a given task, conflicts solving by negotiation, communications using speech acts enabling to explain or to cooperate in a natural manner for the (human or not) agents. This research field is really in a growing period, the complex industrial systems offer an extremely rich context of study.

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