Elements for a Framework of Analysis for Synchronization Phenomena and Associated Errors in a Work Environment : Anesthesia

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1. Introduction

The emergence of more and more vast work organizations, defined by a high degree of specialization and a segmentation of positions and roles, requires a coordination both in space and time of different individual activities distributed in the field. This coordination, to cite Savoyant (1977), covers two movements: a movement of division and distribution of actions whose role in regards to the reliability of systems has already been demonstrated by several authors (Rogalski 1991, Reason 1988, Van Daele *et al*. 1991, and a movement of temporal integration of actions and synchronization in a work team. Condon *et al*. (1974) talk about synchronization as a basic component of human behavior : at any moment, the individual must temporally organize his behavior and adjust his actions to temporal goals that are more or less constrained. Rare, however, are those works specifically devoted to synchronization phenomena. A special link must be established between synchronization and anticipation. Synchronizing behavior requires becoming aware of the temporal structure of the work environment and an anticipation. The relationships with the works that study the preparation for action (Hoc 1968) and temporal organization (Jones *et al*. 1989) seem apparent. Certain recent studies (Decortis *et al*. 1991, Hollnagel 1991) in Work Psychology present a classification of temporal errors by reference to the cognitive activities of man. Among these, the error of synchronization. These classifications proceed more from description than from psychological analysis of mechanisms underlying this temporal error.

The present article aims at the development of a framework of analysis that allows for the apprehension, in a more systematic manner, of the phenomena of synchronization and the associated errors in a work environment. It relies on the idea that the construction of such a framework requires taking into account the activities of information processing brought into play by the subject. This is why it appeared necessary to us to first clarify what we mean by synchronization and to identify, if possible, the process behind this kind of temporal adjustment, by relying on the literature. With the framework of analysis thus developed, we will see how it allows for the analysis of the phenomenon of synchronization and associated errors in a specific and concrete work situation: the situation of anesthesia.

2. Framework of analysis

2.1. Definition of synchronization

For our analysis, we can take as a starting point a general definition of the notion of synchronization which states that " ***it occurs when an agent (either single or multiple) has to temporally coordinate several actions or facts (states, events, instants) which must maintain relations of temporal interdependence between themselves (simultaneity, sequentiality).*** "

From this definition we will retain two essential points:
On the one hand, the idea of differentiation, as Condon *et al*. (1967) has suggested, between interactional synchronization, when several individuals are involved, and self-synchronization in order to designate the unified nature of an individual's actions.
In the firm, the essence of synchronization is essentially to ensure that action "a" by person "i" occurs in a relation to the time when action "b" is done by person "j" (Mcgrath *et al.* 1986). Synchronization is then a matter of relating events and activities to one another in "time" such that the activities of different people performing their different tasks become coordinated in phase and periodicity. What *time is* is a complex question, indeed there are a multitude of answers. The schedule, for example, determines when some event must occur in relation to an "external" calendar or clock. It involves starting times and deadlines. As

for the task, it first refers to "contextual"time; the operator localizes his activity in time, more often in relation to a variable directly drawn from the task than in relation to the clock. there is then a juxtaposition of different time frames in the firm, clock time being only one of the best known examples. Some of these time frames, as Mcgrath *et al*. (op. cit.) have pointed out, are times with a universal status (official clock calendar), some of these time frames are times to which the operator ascribes important but strictly personal meaning (time to pick up a child from school, etc.) and some of these are times whose meanings derive from the task or specific situation.

“ Synchronization involves the timing of starts and stops of multiple activities with respect to their time frames. “ (Mcgrath et al. op.cit.)

On the other hand, the definition contains the expression “several actions or facts which must maintain relations of temporal interdependence between themselves” which expresses the idea of temporal constraints to be satisfied. These can originate from the physical system of the task or from the organization of work. Depending on their origin, they will not all have the same constraining character for the operator and will express different relations of interdependence. The common-sense, everyday life acceptance of synchronization only conceives the existence of one single temporal interdependence relation, temporal equality, where two activites are synchroneous when they are done simultaneously. Our definition extends the notion of synchronization to other relations of order, thus covering a greater variety of temporal constraints encountered in the field. The “mutual exclusion” is for example a synchronization constraint which does not express a relation to simultaneity. On the contrary, one will speak of mutual exclusion when it is not desirable for two events to occur simultaneously.

For several years now, logicians, philosophers, computer scientists and reserachers in artificial intelligence have been reflecting on the way to represent all of the possible states within one space and the relations that two events or two actions can maintain with one another. They have developed formalisms which have been adapted to the purposes of Applied Psychology (Javaux *et al*. 1991). We believe that these constitute a powerful means of describing and pinpointing the temporal structure of a work environment; that is to say, of identifying the relations of interdependence and the temporal constraints between events, states and actions justifying a behavior of temporal adjustment or of synchronization in the operator(s).

2.2. The notion of Temporal Frameworks

From a temporal point of view, a state of the world, in artificial intelligence is presently represented in the form of a particular point within a space describing the set of all possible states. An event or an action are themselves generally described as an ordered couple of points (the state of the world before the event, the state of the world after the event) or as an interval. These points and intervals, fundamental temporal objects, can maintain between themselves complex relations of order. In this theoretical frame, ***a Temporal Framework (Bestougeff et al. 1989) is then defined as the specification of a type of fundamental temporal object (points, intervals) and of the particular order relations they may entertain.***

insert figure 1

Point-based frameworks have points as basic temporal objects. The relations between temporal-points are usually simple and express ideas about equality (simultaneity) and precedence (anteriority).

insert figure 2

Interval-based frameworks have intervals as basic temporal objects. The relations between temporal intervals are more complex than with point-based frameworks. Allen's framework (Allen 1981), for example, uses six basic relations :

insert figure 3

We should note that the notion of duration can, moreover, be integrated into temporal frameworks either as a distance between two temporal instances (points or intervals) or as a property of intervals themselves.

Within the framework of the present work, Temporal Frameworks will allow us to express the temporal relations that exist or must exist between certain elements making up a work environment. Classically, a work situation can be broken down into three elements:

a) a process to control, characterized by some states and events. It might be some complex continuous casting installations, a plane to pilot, a patient to manage in an anesthesia situation,...

b) a set of agents acting on the process. Each agents is also characterized by his knowledge, his competence, his goals, which are sometimes antagonist.
c) some environmental conditions describing states and events that are external to the process to control but nevertheless influence the agents and the process to control.

From the operator's point of view, we can conceive three main axes of synchronization:

- synchronization with the controlled process
- synchronization with the other agents
- synchronization with the environment

The same agent can consequently be simultaneously involved in several processes of synchronization, with agents and varied references. Each one of these axes covers, in addition to events, actions that justify a synchronization. It can be defined in a much more precise manner from a temporal point of view, by abstracting it into a Temporal Framework expressing the nature of fundamental temporal objects (points or intervals) and of their relations. The controlled process, for example, will most of the time be expressed in a Interval Based Framework : The interval units corresponding to the natural segmentation of the operator's performance, based on regular markers such as stop times, absence and taking up the activity again. These units are clearly present in the performance because very characteristic action patterns and temporal constraints correspond to them. The set of the units is nevertheless organized into a type of flow which is called the process, in reference to the characteristics of continuous process (De Keyser 1991).

If Temporal Frameworks provide a powerful language for describing the temporal aspects of a work environment, they do not allow however to study in detail the strategies used by the subjects to deal with problems of synchronization. What are the units of information processed by the subject? How does he break down the flow of information which is for him the process, to temporally organize his behavior? These questions raise the primordial problem from the cognitive point of view, of the informations and of the activities of information processing brought into play by the subject in order to identify the temporal relations of interdependence between several actions or facts, and to repond to the requirements of synchronization.

2.3. Strategies of synchronization - Concept of Temporal Reference Systems

The principles on which are founded the tracking down and storage of temporal information are still poorly known. There are reasons to suppose that events can be somehow predicted from a time label that is contextual in nature (Anderson *et al*. 1972-1974, Hinzman *et al*. 1975). *"Time - related information about events and relationships among events is encoded as part of memory of an event." (Block 1990).*

In this case, the operator can make use of these labels to reconstruct the temporal relations. As for relations of sequentiality, Jackson (1990) recognizes the existence of an automatic encoding of temporal relations of a simple nature of the type beginning-end or center-adjacent. But aside from this restrained number of positions, the temporal judgements require, according to him, a deliberate process. *"Temporal information is not encoded unless noticed and not noticed unless meaningful" (Michon et al. 1984).*

This model gives to the problems of duration (duration and action delay) a status of controlled reasoning - and thus costly from a mental point of view. This is to postulate, following Michon (1990) that in long-term memory there is no encoding of the duration of an event, this relation being deduced from the relations of simultaneity or of succession with other events.

The analysis of operators' activity in the field shows us more experiences of "natural" synchrony without efforts than a conscious processing of information concerning the duration that synchronization would involve.

In a study done on the oven systems feeding a lamination line in a steel-making firm, Savoyant (1977) studied the mode of cooperative synchronization. The temporal integration of actions is assured by the verbal communication as an "initiating" or "start-up" action for the distributed actions in the field. By transforming the nature of the temporal problems posed by the requirements of synchronization, the operator localizes his behavior in time in an automatic and rapid manner. He relates a problem of estimation of duration of an action delay to a problem of succession, following the hypothesis of Michon (1979), by serving as an external reference point which directly precedes his action and which warns of the moment of action, thus decreasing his mental load.

The analysis of the modes of synchronization shows furthermore that they evolve in relation to local conditions. To the extent that the situation is repetitive, Savoyant observes a reduction of information exchanges of a verbal nature. In order to explain this reduction, he takes the hypothesis of Cuny (1972) according to which the informations taken directly from the work field replace the verbal exchanges. Any action, any parameter value or any alarm take on the "initiator" character of verbal communication. This communication, according to him, involves an internalization on the part of the operators of a strategy defining the temporal coordination of certain individual action sequences distributed in the field. Condon (op. cit.) uses the term "training". Indeed, there exists in the world work, processes which have the feature of being regular : certain states or events succeed each other by respecting certain specific relations of order (in the form of cycles for example, De Keyser, op.cit.). With experience, the operator learns their sequentiality and their operational duration, which allows him to a certain extent to predict their occurrence.

From this comes the postulated existence of different temporal systems of reference in a representational modes, and of external synchronizers linked to these systems. The clock can constitute a temporal system of reference, but also for example the evolution of a variable which determines the operator's activity, or still the observable activity of an operator that is sufficiently regular and predictable.
As soon as **an observable and regular physical process (e.g. the clock) is used as a temporal reference by the individual (projection mechanism) in relation to states, events or external actions, and described within a Temporal Framework (mechanism of abstraction), it is defined as a *Temporal Reference System*.** (Javaux *et al*. op. cit.)

From the point of view of the study of synchronization, the concept of ***Temporal Reference System*** presents an essential interest.

Primo, it supports the idea that time is a construction (Gibson 1975). Temporal information is borrowed from events themselves or constructed on the basis of these events. In this it is consistent with our way of approaching synchronization in the firm in relation to multiple time frames. The use of T.R.S. allows operators to synchronize their activities in a more independent way; the synchronization being no longer based or guided by the interaction between operators, but by some external reference. In this sense we can distinguish two forms of synchronization: in symmetric synchronization both agents modify their behavior to synchronize their actions, in asymmetric synchronization only one agent modifies its behavior to get synchronized with the other. Analysis of activity can identify temporal reference systems which are actually used by the operator. Their choice is based on a series of factors: expressiveness and the mental load associated with their visibility, their accessibility, their relevance to the task and their degree of social support.

Secondly, the concept of Temporal Reference System imposes few constraints on the temporal structure of referents used by the operator, which have to do with whether the temporal reference system is to be regarded as "continuous" or "discontinuous", as pure "duration" or as "succession", as "homogeneous" or as "epochal". Clock time, for example, to which the schedule refers, is an objective time in the mathematical sense. It is considered to be singular, measurable as a distinct dimension separate from other dimensions of existence (such as space and motion). The evolution of a determining variable for the activity of the operator itself refers to a time which is not necessarily a clearly differentiated dimension but rather is confounded with other physical dimensions of the process. It is relational rather than absolute and it also concrete - considered to have real effects on the process, hence experiential.

The operator must somehow deal with all of those time conceptions in respect to the time referents of every event and problem. If those time referents are based on sharply contrasting time conceptions, one can imagine the difficulty for the operator to harmonize the requirements of synchronization of the process. Since everything does not have the same constraining value, we will see with the help of an example in the second part of this article how the operator chooses to synchronize his activities in relation to one referent rather than in relation to another, and selects one system of reference over another according to the circumstances and the nature of the problem.

The success of the use of the T.R.S. as a strategy of synchronization obviously depends on the weak variety of durations and temporal relations that link events and actions in the work environment. A disruption of the regular flow of operations, an absent TRS, can bring about the faultiness of this acquired strategy and be the source of the synchronization error. Moreover, there can be situations for which the operator does not dispose of a T.R.S. that will allow him to respond to the requirements of synchronization automatically, rapidly and simultaneously. Faced with temporal events not learned and unpredictable, he must resort to a temporal information processing mode that is more laborious and serial and which requires conscious attention, either by calling on causal knowledge to calculate, like in an arithmetic problem, the duration or the delay of an action, either by resorting again, as Savoyant observed, to informative exchanges of a verbal nature that warn him of the moment of action.

These theoretical references, although they are rather general, constitute an essential point of departure for us: our procedure aims at the elaboration of a framework of analysis of phenomena of synchronization taking into account the activities of information processing brought into play by the subject. At this stage of the present work, it seems necessary to us to see how the framework of analysis thus developed allows us to analyze in a more precise manner a concrete work situation and brings a new view of synchronization error.

3. The work situation and observations

We are dealing here with conducting general anesthesia, which is inserted in a collective and dynamic work situation, where the requirements of single and multi-agent synchronization and its precision are crucial to the very life of the patient.
Diverse methodologies have been applied to gather data: behavioral observation in a work situation (or 200 observation hour in the operating room), subjects' verbalizations, and interviews with different members of the team to gain access to diverse representations of anesthetists of the activity rules and their knowledge of them.

After a general presentation of the work situation, we will try to identify the relations of temporal interdependence justifying a synchronization in the work environment, by asking questions on process segmentation and on temporal reference systems used by the operator(s). We will end with an analysis of two cases of errors associated with the requirements of synchronization.

3.1. General presentation of the work situation

The anesthesia process does not consist, as one could naïvely imagine it, putting a patient into a state of sleep by the means of an injection - but in managing the human body's tolerance to the surgical act. This basic statement implies :

- that, three persons will be of major importance : *the surgeon,* with his goals, plans, actions and reactions; *the patient,* with his physiological limits, his specific pathology, his expected and unexpected reactions; *the anesthetist,* with his goals, plans, actions and reactions.

There are, in fact, two agents (the anesthetist and the surgeon) who intervene on a complex physiological "process", the patient, with his own developments and characteristics (states and events). The medical team plays a secondary, but still important role, namely in the data gathering and the information circulation. It is made up of nurses, or secondary agent, and of functional and laboratory services, which can be assimilated, according to our formulation, to the environmental conditions; They are external to the process to control but nevertheless influence the agents.

- that the actions launched, either by the surgeon, or by the anesthetist, will not only take into account technical constraints (the constraints of the surgery, the constraints of the patient, etc.), but also temporal constraints. These constraints derive from the dynamicity of the situation, and from the synchronization to be maintained between the patient state, the surgical act, and the anesthetist interventions.

From the point of view of the anesthetist, the synchronization is expressed following the three main axes we have brought out :

- between the anesthetist and the process to control (patient)
- between the anesthetist and the agents (surgeons)
- between the anesthetist and the environmental conditions.

The notion of synchronization implies furthermore the relations of temporal interdependence between events and actions. It supposes, as we have seen, the elicitation of the temporal structure of the task which is highly task-dependent. Citing Elman (1990):
" *There is no temporal representation....Temporal representation intermix the demands of the task with the demands imposed by carrying out that task over time*." . This suggests that classical cognitive task analysis as developed by Amalberti *et al*. (1991), Rasmussen *et al*. (1990), Roth *et al*. (1988) can be used to discover the temporal structure of the task . They will, nevertheless, have to be more centered on the temporal conditions, and describe the activity by a sequence of behavior or of units of actions defined in relation to states of the process to control, on which they are applied and to the states they produce.

3.2. Elicitation of temporal relations of interdependence

3.2.1. Segmentation of the activity of the anesthetist's behavior

From the awake to the waking up patient states, there is a series of states induced and controlled by the anesthetist that are organized in a sequence. These are the *functional units* of the activity, classically characterized by their goal and their physiological constraints, but also by some temporal conditions. Some of these units are critical : so are the intubation and the extubation of the patient, that must take place at very precise moments, according to the surgery evolution, and the respiratory state of the patient. We can distinguish :

* *The pre-anaesthesia unit* : its main objective is the patient preparation, allowing him to survive to the surgery act. It implies the choice and the planning of an anaesthesia strategy, taking into account the patient state, his pathology, his medical past; a cocktail of appropriate drugs will be selected. It implies also the patient's installation in the operating room, the setting and the checking of the monitoring tools and of the anaesthesia equipments.

* *The induction unit* : its main objective is the achievement of the anaesthesia itself, with the consciousness removal, the upholding of the vital functions, the pain anesthetization, and the muscular relaxation. This is obtained by the means of drugs induction, patient intubation, control of the air passages, and regulation of the anaesthesia equipments; during this induction unit, the physiological parameters of the patient are tightly monitored. As already mentioned, encapsulated in the induction, is *the intubation*, a critical unit.

* *The anaesthesia regulation unit* : its main objective is to maintain the anaesthesia depth, according to the patient reactions towards the surgery act, and the drugs administration. This entails : the detection - if not the anticipation - of any change in the patient's state, the identification and the diagnosis of any incident, the assessment and the choice of the actions to undertake, and the checking of their effects. In parallel to the on-line unfolded activity, the anesthetist tries to predict, in a quite accurate way, the end of the surgery act; this prediction allows him to progressively reduce the drugs administration. During the anaesthesia regulation unit, the dynamicity of the patient state is maintained as slow as possible - but it can evolve abruptly.

* *The post surgical unit* : its goal is the waking up of the patient, obtained by stopping drugs administration at the right moment. Once the patient has recovered his vital functions, the *extubation* can be performed; it is a critical unit. The patient's parameters have to be monitored and checked during a certain period in order to avoid any further complications.

insert figure 4

At this simplified level of description, an Interval-Based Temporal Framework provides sufficient expressiveness to suit our descriptive needs: there are four intervals, corresponding to the four functional units and one type of order relation: before. The sequential order of the anesthesia functional units are not to be changed - they are stable and predictable. Indeed, the detail of the different phases is not predictable *a priori*, and the anesthetist must adjust his behavior during the execution of the plan while following the state of the patient, his reactivity, the surgical act and other parameters that are undeterminable ahead of time. The *a priori* sequential representation gives rise to internal representation which is hierarchical in nature. It is thanks to this hierarchical and partial structure of the plan, according to the terminology of Sacerdoti (1973), that the anesthetist can adapt himself to its indeterminacy. A more descriptive framework could be elaborated be calling on temporal reference systems that activity analysis allows to extract.

3.2.2. Temporal Reference Systems in anesthesia

Synchronization seem to be organized in function of three temporal reference systems :

- **the surgical act** : it is comprised of at least two important synchronizers, the beginning and the end of the operation. It is in relation to these two reference points that intubation and extubation of the patient are situated : just before and just after these two points.

- t**he patient's respiratory function :** this function reflects the influence of the action of drugs, and its equally conditions the intubation and extubation. One would never extube a patient while he is still a bit asleep! It is by referring to a series of observable parameters which describe the patient's respiratory function that the anesthetist decide when to extube.

- **the clock, which here is the manifestation of the hospital planning** : each operation involves a planned duration which cannot be exceeded without a serious reason, or the entire hospital planning may be disrupted. This additional requirement of adjustment of the operation to a clock duration places heavy pressure on the set of actors.

insert figure 5

They are Reference Systems because they characterize the patient's state, the agents and the environmental conditions. They are Temporal Reference System because they have a regular structure with a directed order. The surgical act and the patient's respiratory function seem to combine points and intervals - they are continuous, whereas hospital scheduling should be seen preferentially as a point-based discrete system. These three systems of temporal reference are to some extent imposed by the task. They are constraints for the anesthetist and their integration into running the anesthesia can lead the anesthetist to take certain risks.

3.3. Two synchronization error cases :

3.3.1. Single-agent synchronization based on external reference : Temporal Reference Systems

> The anesthetist on duty is scheduled to be on call that night. It is the beginning of the afternoon. The intervention is carried out on a two-year old child. The anesthesia was administered without any problem and the surgical act is finished. Hurried by the hospital planning, the anesthetist extubes a bit too fast at the first sign of awakening (cough in the tube). The child goes into a laryngal spasm (reflex closing of vocal chords causing a complete or partial glottal obstruction). The anesthetist succeeds in quickly reintubing the patient and recovers the incident.
>
> Remarks : extubation must be carried out either when the patient is relatively sound asleep or after complete awakening, otherwise this increases the risk of a laryngospasm. Small children are particularly vulnerable to these complications, they have been known to fall back to sleep after the first signs of awakening, the anesthetist must then wait for this phase to pass before extubing the child.

One single agent intervenes in the process of synchronization. Three events must be synchronizes : extubation of the patient, the end of the surgical act and the recovery by the patient of his vital functions.

The constraint of synchronization is expressed here as follows :
" *The extubation is carried out as soon as the surgical act is finished, at the moment when autonomous respiratory function starts up again.*"

This synchronization constraint is part of the task, is essential for the very survival of the patient and can be expressed in an Interval-based Temporal Framework. In order to assure this constraint of synchronization, the anesthetist uses a mode of synchronization based on two Temporal Reference Systems : the surgical act and the respiratory function of the patient. The error here consists of a poor evaluation of the patient characterized in the reference system constituted by the respiratory function to which the action of the anesthetist must be synchronized. It is however favored by two factors :

1/ The fact that the operation is on a child, a case in which the relation between the observable parameters on the TRS constituted by the respiratory function of the patient and the real state of awakening can lead to a misinterpretation.

2/ The multiplicity of synchronization constraints. The same agent can, as we pointed out above, be simultaneously involved in several processes of synchronization. The hospital schedule associated with the temporal reference system constituted by the clock introduces, up to a certain point, clock time as a constraint of synchronization; sometimes leading the anesthetist to take certain risks. Thus the experienced anesthetist no longer waits until the end of the surgical act to decrease the drugs before extubing the patient, but anticipates it. He has learned with experience to know the operational durations of his own actions. He has also improved his knowledge about the T.R.S. constituted by the surgical act. *Taking into account the drugs administered and his estimation of the probable duration of the operation, he decreases then stops the injection of the drugs, starting from the moment when he esteems their duration of effect to be identical to the time necessary for the end of the operation.* In this way, he reduces the awakening time and assures the synchronization constraint linked to the hospital schedule.

insert fig. 6

This widened view of the case shows that indeed there is competitive interaction between the constraints of synchronization linked to extubation and those linked to the schedule. This has two effects :

a) in order to attempt to satisfy the scheduling constraints while at the same time satisfying the extubation constraint, the anesthetist anticipates the action of restoration of vital functions.

b) because of this competition, the anesthetist lowers the priority assigned to the extubation constraints, and hence the quality of the related synchronization process : he evolves toward a degraded solution for which, while remaining in the same mode of synchronization, he does not attribute the observation of one of the crucial T.R.S. the attention it deserves given the specificity of the case.

3.3.2. Multi-agents synchronization based on verbal communication.

A cardiac surgery operation, the second "heart" of the day. It is the end of the afternoon. Everyone is tired but the atmosphere is relaxed. The anesthesia presented no problems. The anesthetist on duty is in his fifth year of training and is assisted by an intern to whom he explains the procedure.
During open-heart surgery, the blood circulation is turned away from the heart towards an external pump in order to allow the surgeon to operate. At this moment the controlled ventilation is interrupted, the respirator no longer functions and oxygenation of blood is carried out thanks to a device integrated into the pump. The extra-corporal circulation is controlled by nurse, technicians and by the anesthetists.
Coming off the pump, the anesthetist and the surgeon must synchronize their actions in such a way that the patient is ventilated again (reconnection to the respirator by the anesthetist) before the surgeon can authorize the technician to stop the extra-corporal circulation. Usually, the synchronization is sustained by an interaction between the anesthetist and the surgeon: verbal exchange and observation.

In this case, communication did not take place. The extra-corporal circulation was interrupted on the surgeon's orders but the ventilator was not reconnected by the anesthetist. Since the respirator was not plugged in, the alarms did not work. The patient's heart beat dropped from 110 to 70 in ten seconds. The anesthetist noticed this, saw that the lungs were not moving, surveyed the respirator, detected the problem and fortunately recovered the incident in time.

Two principal agents (anesthetist and surgeon) and a secondary agent (technician) intervene in the process, thus defining multi-agent synchronization constraint in which two actions, the stopping of extra-corporal circulation and the restarting of the ventilator, must be synchronized. This synchronization can be expressed in an interval-based temporal framework.

insert fig. 7

The mode of synchronization usually put in place by agents to assure this constraint is based on a symmetric cooperative interaction (verbal exchange) and asymmetric interaction (observation of the surgeon by anesthetist).

The synchronization error is here favored by three factors :

- On the one hand, the surgeon breaks the cooperative strategy of synchronization by not making sure with the anesthetist that the ventilator was reconnected before ordering the stoppage of extra-corporal circulation.

- On the other hand, the anesthetist, distracted by the presence of the intern, does not use the TRS constituted by the surgical act. The observation of this would have allowed him to assure by himself the synchronization constraint, according to an asymmetric, multi-agents, interactional mode.

- Finally, faced with the incident, when the anesthetist observes a drop in the heartbeat, the synchronization constraint takes, on the cognitive level, second place. The main goal of the anesthesia being the patient's survival of the surgical act, the setting up of the recovery strategy now occupies the cognitive field. In an emergency, there is a redistribution of priorities. We should note that the satisfaction of this goal guarantees the satisfaction of the synchronization constraint.

This case illustrates very well the dynamic evolution of the modes of synchronization during a work session. The change of local conditions and some unexpected events lead the agents to restructure their processes of synchronization. Here the quality of the temporal adjustment is deteriorated by a progressive decline of the modes of synchronization used by the anesthetist, which lead to a late and then poor quality synchronization.

4. Conclusions

These initial reflections on synchronization had as their main goal to attract attention to the essential aspect of work situations that are more and more collective: the temporal integration of individual actions distributed in the field and their temporal ordering. They quickly led us to distinguish several forms of synchronization. Certain situations involve a single agent, others several. Certain operators, in order to synchronize their actions, resort to verbal communication, others call on regular external referents. From this comes the necessity of developing an analytical framework allowing for a more systematic apprehension of the phenomenon of synchronization within the whole set of these work situations. The concept of temporal framework, borrowed from artificial intelligence, and the notion of T.R.S. constitute two essential elements for the construction of this framework. While Temporal Frameworks provide a language for describing the temporal aspects of a situation and for better pinpointing the temporal relations of interdependence and the temporal constraints between events and actions justifying a behavior of temporal adjustment or of synchronization in operators, the Temporal Reference Systems have as an ambition to represent their regular temporal structures, used by the operator in a representational mode in order to synchronize his actions. With the help of an example, we saw how the framework of analysis thus developed allows to analyze in a more precise manner the phenomena of synchronization in a concrete and specific work situation, contributing a new view of synchronization error. It appears, however, absolutely necessary, to test the hypothesis of the T.R.S. in an empirical manner and to multiply the study of concrete situations in order to improve the framework of analysis that we have tried to define in this work.

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ABSTRACT

The phenomena of synchronization and associated human errors are studied through the development of a frame of analysis taking into account the activities of information processing brought into play by the subject. The concept of temporal framework, borrowed from artificial intelligence, and the notion of Temporal Reference System constitute two essential elements for the construction of this framework. With the help of an example, we saw how the framework of analysis thus developed allows to analyze in a more precise manner the phenomena of synchronization in a concrete and specific work situation - Anesthesia - contributing a new view of synchronization error.

KEYWORDS

Synchronization phenomena - Synchronization human error - Temporal Framework - Temporal Reference Systems - Analysis of work situation : Anesthesia.

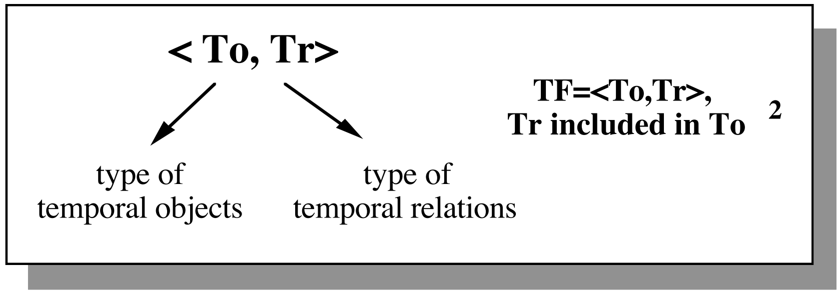

Fig. 1 : Temporal Framework

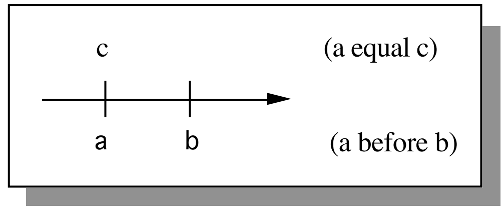

Fig. 2 : Relations between temporal points

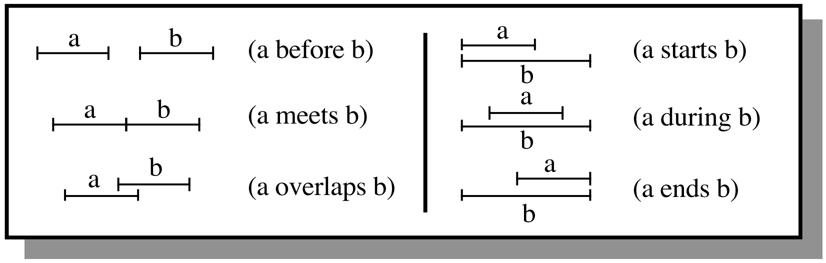

Fig. 3 : Relations between temporal intervals (Allen 1981)

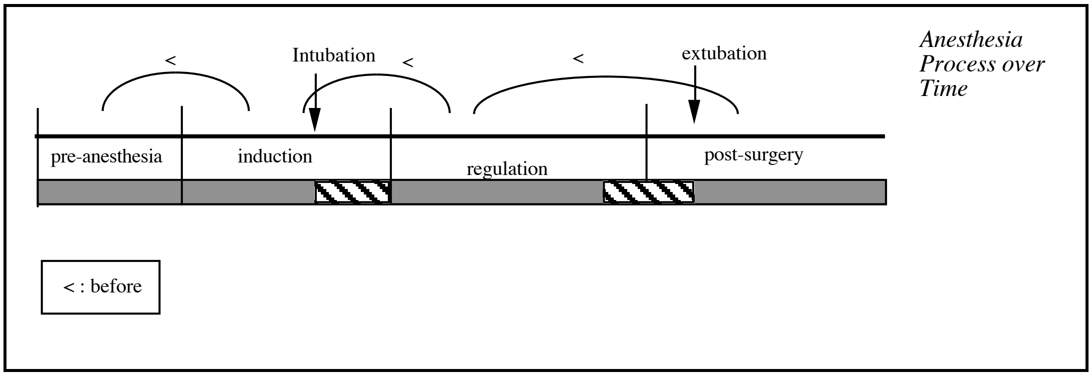

Fig. 4 : Interval based temporal framework in anesthesia

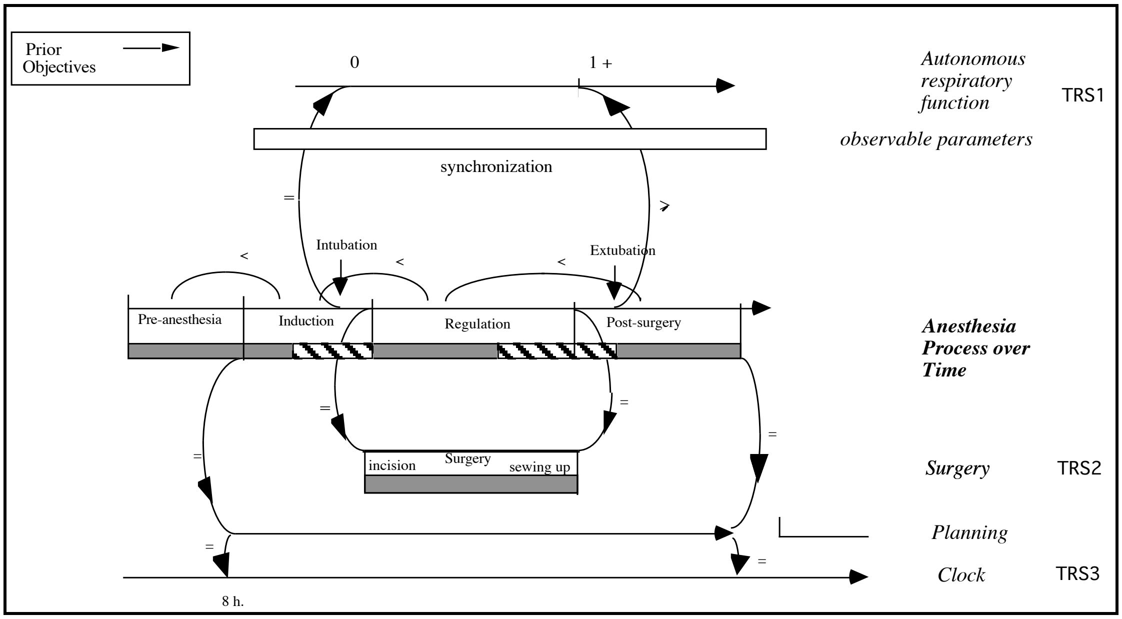

Fig. 5 : Temporal reference systems in the anesthesia process : the surgical act, the patient's respiratory function and the clock, which is the manifestation of the hospital planning.

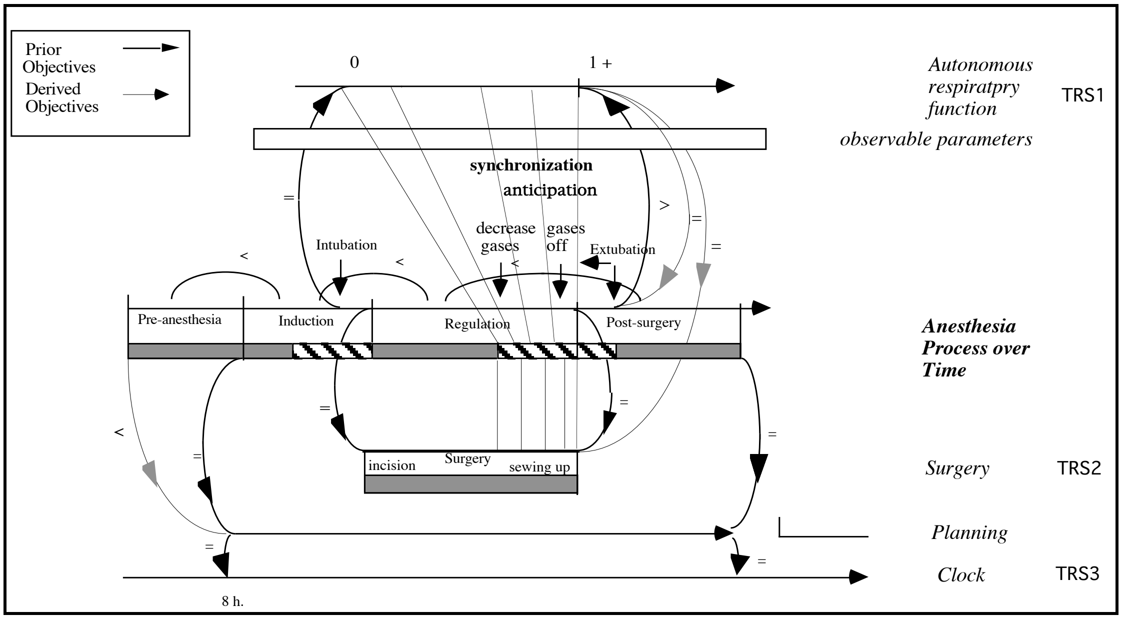

Fig. 6 : T.R.S. in the anesthesia process : the operatory schedule introduces a temporal adjustment requirement. In order to decrease awakening time and the total time of the operation, the anesthetist anticipates the end of the surgical act, decreases the anesthetic gases and / or intravenous anesthetic agents, then stops them.

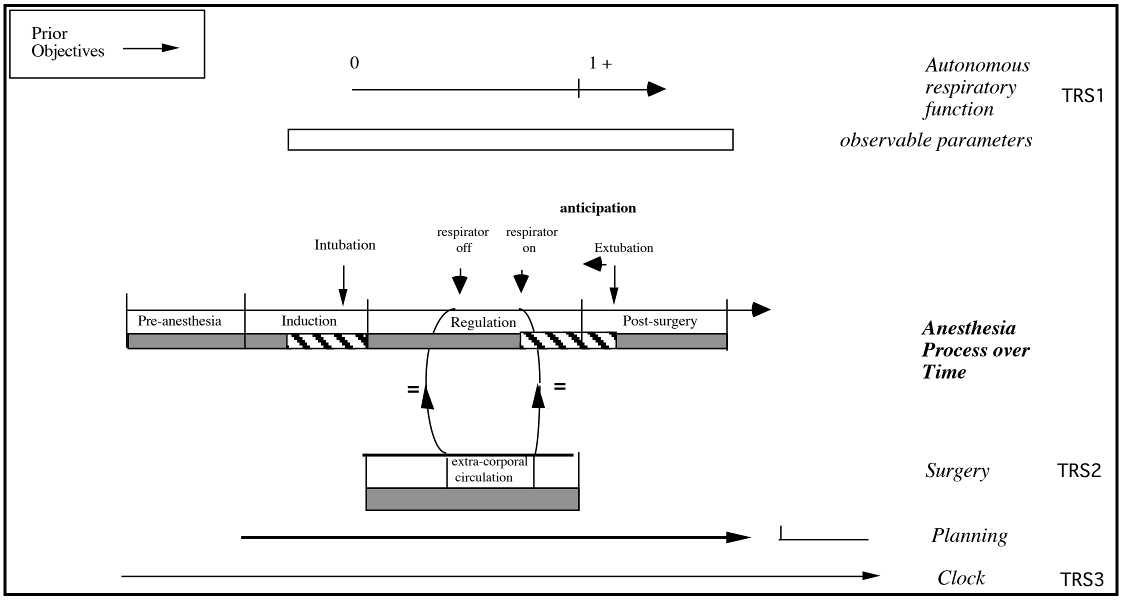

Fig. 7. Multi - agent synchronization : the stopping of extra corporal circulation (surgeon and technicien) and the restarting of the ventilator (anesthetist) must be synchronized.