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COORDINATION OF ACTIVITIES: APPLICATION OF SOME CONCEPTS AND FORMALIZATIONS TO AGRICULTURAL SYSTEMS SIMULATION

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ABSTRACT
Coordination is defined as the management of dependencies between activities in order to reach an objective. These dependencies generally concern resource sharing and the compliance with temporal (simultaneity, precedence) and spatial constraints. This management is made according to two principal modes: explicit and implicit. The explicit mode is based on using 'protocols' (e.g. procedures, plans) explicitly describing how the agents must perform their actions to guarantee the good functioning of the system they are committed to. The implicit mode, characterized by the absence of protocol, is mainly based on using artefacts, implicitly fostering the behaviour of the agents through their interaction with their physical environment (concepts of 'stigmergy' and 'affordance'). In this paper we try to synthesize theories and relevant concepts necessary to represent coordination. Our goal is to propose, at last, a modelling framework to simulate the coordination of human activities in complex agricultural production systems.

Keywords: activity coordination, planned action, situated action, action representation, resource allocation, agricultural system modelling.

1. INTRODUCTION

Agricultural production systems (APS) are made of interacting components among which human agents performing interdependent activities. These activities need resources of material, financial or human natures to be accomplished. They may be characterized by their temporal dimension (i.e. start and end dates, duration) along with their spatial dimension (i.e. they occur at determined locations). The agents interact through the activities they perform and their effects on the environment, altogether contributing to the attainment of some desirable system's goal, as defined by the system's designer or manager. One of the questions posed is how to manage these interactions? This is crucial to be able to propose which is our aim: a modelling framework enabling one to represent and simulate interacting farming activities at operations level (Guerrin, 2009). Many authors (Malone and Crowston, 1994; Schmidt and Simone, 1996; Whang, 1995) have dealt with the issue of 'coordination' in various domains, namely, computer-supported cooperative work systems and supply chain management. This article is a tentative synthesis of some existing theories and concepts about coordination. Before all, we need make more precise two terms which meanings are too often confused using the definitions given by Clancey (2002):

- Task: "a specification of work … to be performed";
- Activity: "how people actually work within the constraints of their environment".

Hence, to denote farming practices, i.e. what is actually done by the farmers, we use 'activity', conceived as a complex set of coordinated elementary actions.

This article is organized as follows. In Section 1 we define the concept of coordination with various types of dependence between them. Sections 2 and 3 are devoted to two coordination modes: explicit and implicit. In Section 4, we introduce two formal tools enabling activity coordination in APS's to be represented, i.e. Allen's temporal logic (Allen, 1984) and the modelling framework of action by Guerrin (2009).

2. WHAT IS COORDINATION?

Malone and Crowston (1994) have defined coordination as the management of interdependencies between activities performed by one or more agents, necessary to attain a goal that can be common or not. When several agents share the same objective these authors speak of coordinating cooperative activities. They distinguish between two main types of dependences: (i) resource sharing and (ii) temporal dependences (simultaneity and precedence). To these two we propose to add (iii) spatial dependence.

2.1. Resource sharing

Because resources in all kinds of production systems are limited they may be required by several actions at the same time or exhausted by previous ones. Consequently, resource allocation is necessary to avoid conflicting situations or to foster some preferred actions against others.

2.2. Temporal dependencies

Some actions must be performed simultaneously as driving a tractor while spreading manure (simultaneity). Others, conversely, should not: for a same crop in a same field, ploughing must take place before sowing, and sowing before harvest (precedence). These temporal dependencies among actions can be represented and simulated using the formal tools described in Section 5: Allen's temporal relations (Allen, 1984) and Guerrin's framework (2009).

2.3. Spatial dependencies

To our knowledge, this aspect is scarcely dealt with in the literature whereas an action should also be characterized by the place it is executed. A production system is, very generally, composed of productive units located at different places; e.g. a farm or a set of farms with several fields and livestock enterprises scattered over a territory. Obviously, necessary resources for action must be disposed at the right place at the right time. Thus, an agent likely two perform two actions at two different places should schedule one before the other. A precedence constraint must hence be added as well as a third intermediary action, that of agent transportation (with possibly other necessary resources) from the first location to the second. Assume a farmer must deliver a product to two buyers at a given place and due date. It is hence necessary, not only to coordinate those three people in time (i.e. synchronize them) but also in space in order they meet at the right place and date. The relative locations of the productive units are also important to be accounted for as they can strongly determine the agents' actions. For example, a farmer having made something on a field can perform in the sequel another action on a neighbouring field to spare time and transport.

Once the temporal and spatial dependencies among activities are determined, the manager has to find a way to coordinate them in both dimensions. This can be made according to two modes, explicit and implicit.

3. EXPLICIT COORDINATION

In explicit coordination, technical facilities are implemented to clarify how the agents should execute their activities. These are 'artefacts' (e.g. document, blackboard) jointly used with 'protocols' (e.g. rules, procedures, plans) prescribing the ways of acting (Schmidt and Simone, 1996). Although also a means of coordination in day-to-day life, conventions (arbitrary habits) are not considered here as they seem less relevant for APS. Artefacts are used to share information among agents as material supports to coordination protocols. This mode of coordination can take two modalities: centralized and distributed. The latter can take two perspectives: the team, which members pursue a common objective, and the market, in which, by letting each agent pursue his own objective, Adam Smith's 'invisible hand' makes the system converge to equilibrium (Whang, 1995).

3.1. Coordination protocols

3.1.1. Rule

A rule is a statement prescribing a determined behaviour as an injunction, a prohibition, or even a simple recommendation (Batifoulier, 2001). It is generally accompanied by an explicit threat of sanction and, so, must be justified to enabling the application of a penalty in the case of non-compliance. Observing a rule is accomplished through a judgment made contextually by the agents. Hence it needs a common representation of the situations at hand.

3.1.2. Procedure

Two issues inherently linked to interpretation appear to execute a rule (Kechidi, 2005):

- How assess the situation to decide if it matches with the rule premises?
- How select the rule to be triggered when several are candidates in a given situation?

Triggering a rule needs in fact to reduce its subjective interpretability giving it a stronger prescriptive feature, that is specifying precisely which behaviour is required, preferred or prohibited in determined contexts. When such a rule exists it is a 'procedure' (Kechidi, 2005).

3.1.3. Plan

Planning is an emblematic sub-domain of Artificial Intelligence which aims, as one of the theories of action, at answering the question "What should be done?" That are: Which actions are to be performed? In which order? In its more classical sense, a plan is a sequence of actions capable to drive a system from its current state to a final desired state called a goal. In executing the plan, an action is triggered as soon as its conditions are met. A plan can encompass alternative conditional paths to cope with external events.

3.2. Modalities of explicit coordination

3.2.1. Centralized coordination

The production system is here managed by a unique coordinator endowed with roles of observation, information collection and decision-making (Li and Wang, 2007). The information relevant to it is about the dependencies among activities, the system states and external observed processes (e.g. market or climate evolutions).

In this case, the protocol is often an action plan specifying the sequence of actions to be performed over time and the resources needed. To design this plan, the first step is to identify the precedence and simultaneity constraints among activities and those sharing the same resources (Malone et Crowstone, 1994). The second step consists in determining resource allocation rules. For example, as some activities are critical and must be performed within specified time-windows, they may be assigned higher priorities to get the resources they need in time; other activities, owing to be executed in parallel should be given their resources at the same time to avoid delays. The coordinator may be obliged to revise the plan in cases unexpected situations appear.

3.2.2. Distributed coordination

This modality of explicit coordination is characterized by the absence of a central coordinator: management is thus shared by all agents. Two perspectives may be distinguished: the team and market perspectives.

3.2.2.1. Team perspective

Each agent has limited information on the system and must coordinates its own activities by communicating with other agents to achieve their common goal. This can be made through plan exchanges, according to the "Partial Global Planning" approach (PGP) described by Ferber (1995) and involving three types of plans:

- Local plans for managing each agent's own activities.
- 'Node-plans', synthesizing the sole relevant information in local plans to be exchanged with others.
- PGP's, gathering all the information relevant for each agent about its own and others' activities.

Consubstantial to this perspective is the notion of 'cooperation', which "usually implies shared goals among different actors" (Malone and Crowstone, 1994).

3.2.2.2. Market perspective

Contrary to the team perspective, which members share a common goal, each market agent pursues its own goal, the coordination with other agents emerging naturally from the functioning of the whole. In some cases, coordination may be based on contracts among stakeholders (Whang, 1995). This system prevails in supply/demand APS such as a set of farms collectively managing their wastes on a territory scale (see application to livestock waste management in Courdier et al., 2002). This perspective generally coexists with others: a production system can be coordinated internally according to a centralized mode and externally by the market with many other firms.

4. IMPLICIT COORDINATION

Another coordination mode, called implicit or reactive, also exists based on concepts of 'stigmergy' and 'affordance' allowing actions to be coordinated without specifying protocols.

4.1. Stigmergy

This way of coordination stems from the research by Pierre-Paul Grassé on ants colonies (Susi and Ziemke, 2001). The general principle of stigmergy is as follows: every ant wanders randomly in its environment searching for food. As soon as a food source is found it goes back directly to its nest, dropping on its way back pheromone traces so that other ants may found them and follow the path until the food heap. These new ants, doing the same, reinforce the path gradually. Ants thus use their environment to communicate by the means of pheromone droppings let on their way. Using modifications of the environment to influence other agents behaviour is stigmergy (Susi and Ziemke, 2001).

We can try to generalize this concept to human activity when the result of an agent's action influences the behaviour of other agents. For example, consider two neighbouring farmers that use to help each other. One has crop fields and the other livestock. The fact the first one has completed the harvest of some crops may be a signal for the second bring manure on these fields. Observing the heaps left on their edges, the first farmer may be fostered to spread this manure within the next few days. Stigmergy is obviously an implicit means of coordination as it allows an indirect communication between agents based on the persistence of effects of past activities in the environment to determine activities in the future.

4.2. Affordances

Another concept, called affordance, can be used as coordination means. It originally emerged from the works made by Gibson (1979) on human vision in the field of Ecological Psychology, whose goal is to explain how an individual adapts to its environment. An 'affordance' is the perception of possibilities of action that are "offered" by objects in the agent's environment. It allows an immediate adaptation of the individual perceiving it in the form of a response action. In a sense, the artefacts used in the theory of stigmergy could be considered as affordances fostering agents to commit to some specific action. With affordances and stigmergy, the activities of agents are not determined by protocols but by an evolving space of possibilities in which they navigate and choose, at any time, the action to commit to. Being confronted permanently to concurrent solicitations from the environment poses, nevertheless, the issue of how individuals select the one which will make them act. This has been a criticism addressed to Gibson's by authors like Reed (1996). In the case of APS this dilemma is solved by the farmer's experience, knowledge and memory that will make him/her focus on some signs rather than others: although many affordances can be generated by a tractor (that can allow various works: ploughing, sowing, transporting,…) he/she will select the one corresponding to its current priority (e.g. if he has already prepared the soil, he may sow).

5. FORMAL TOOLS OF REPRESENTATION

5.1. Allen's temporal logic

Allen's formalism (1984) is based on 7 binary relations (and their inverses, omitted here for simplicity) between any pair of temporal intervals (T_i,T_j):

- DURING(T_i,T_j): T_i is fully contained within T_j;
- STARTS(T_i,T_j): T_i shares the same start date as T_j, but ends before T_j;
- FINISHES(T_i,T_j): T_i shares the same end date as T_j, but begins after T_j;
- BEFORE(T_i,T_j): T_i lies before T_j with no overlap;
- OVERLAPS(T_i,T_j): T_i starting before T_j overlaps it;
- MEETS(T_i,T_j): T_i ends exactly when T_j starts;
- EQUAL(T_i,T_j): T_i and T_j are superimposed.

These relations are mutually disjoints (if one holds for two intervals, no other holds) and complete (given any two intervals always one relation holds). This formalism is useful to represent and manage the essential temporal dependencies among actions: simultaneity (DURING, STARTS, FINISHES, EQUAL) and precedence (BEFORE, MEETS). It is used in the modelling framework of action proposed by Guerrin (2009) to simulate human activities in APS.

5.2. Dynamic simulation of action at operations level

In Guerrin's (2009) framework activities are considered as complex coordinated set of actions. Every action is represented as a dynamic process determined by conditions stemming from observed processes of various kinds (including other actions). It is characterized by a start date and an end date or duration. Hence, actions are actually represented in the same way as temporal intervals, making the use of Allen's primitives natural. In the sequel we present some aspects of the mathematical formalization that will be used to deal with coordination representation.

5.2.1. Representation of action

Every action A is represented by a binary function of time:

$$S_A(t) = \begin{cases} 1 & \text{if } \ C_A(t) \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

Where $C_A(t)$ is a logical proposition evaluated true or false whether its value is respectively 1 or 0. Therefore, an action A defines a sequence of temporal intervals during which its value is 1 or 0.

5.2.2. Temporal bounds of action

The start and end date (t^-, t^+) and the duration ($\tau_A(t)$) of an action are also functions of time, determined according to a condition $P_A^-(t)$ (resp. $P_A^+(t)$):

$$t_A^{\pm}(t) = \begin{cases} t & \text{if } \ P_A^{\pm}(t) \\ t_A^{\pm}(max(0, t-\tau_S)) & \text{otherwise} \end{cases} \qquad (2)$$

Where τ_S is the simulation time-step, $P_A^-(t)$ (resp. $P_A^+(t)$) is a logical proposition function of time specified according to any process $X(t)$ on which events relevant to trigger or stop an action are possibly detected. It may be a clock, a schedule, a biophysical process, or even another action.

Note that, as a minimal condition $C_A(t) \equiv (t_A^- > t_A^+)$: A holds as long as $P_A^-(t)$ is true and stops as soon as an event occurs to stop it, i.e. when $P_A^+(t)$ becomes true and an end date is set.

5.2.3. Coordination of actions

5.2.3.1. Specification of complex activities

As an illustration, consider two cultural schedules of two market garden crops, carrot and potato, each being cultivated by two farmers on two different plots. Tables 1 and 2 show these schedules for each crop, the work time and the equipment necessary to each operation.

Table 1: Cultural schedule of carrot

Operations	Period	W time	Equipment
Soil disinfection (DC)	Oct.-Apr.	5 days	Sprayer
Tillage (TC)	Mar.-Jun.	9 days	Plough
Sowing (SC)	Apr.-Jul.	18 days	Seeder
Hoeing (HC)	Jun.-Sept.	5 days	Hoe
Harvest (AC)	Jul.-Nov.	19 days	Carrot harvester

Tableau 2: Cultural schedule of potato

Operations	Period	W time	Equipment
Tillage (TP)	Apr.-May	10 days	Plough
Planting (PP)	Apr.-May	6 days	Potato planter
Hoeing-Ridging (HP)	May-Aug.	3 days	Hoe-Ridger
Harvest (AP)	Aug.-Nov.	5 days	Potato harvester

Here we consider only the constraints linked to material resources. Often farmers rent together with neighbours heavy expansive equipments to save costs and, so, must set a common schedule of utilization. Here we assume two farmers having each a tractor and equipments specific to their own crop are sharing the same plough.

The holding condition for each cultural operation (= action), according to Eq. 1, is true for a crop whenever the current time is within its feasibility period and necessary resources (equipment, labour) are available. Hence in this example the start date $t_A^-(t)$ of each action must verify the following condition:

$$t_P^- \le t_A^-(t) < t_P^+ - \tau_A \qquad (3)$$

Where, with values given in Tables 1 and 2, τ_A is the duration of action A and t_P^- (resp. t_P^+) is the opening (resp. closing) date of each feasibility period, that is the earliest start date (resp. the latest end date) of A.

In each schedule are found precedence constraints among operations. E.g., for carrot, soil disinfection must precede tillage which, in turn, must precede sowing. Hoeing must be done while plants are growing, i.e. between sowing and harvest. Delays between two consecutive operations should be adapted (e.g. it is preferable not to let a bare soil too long). Operations may also different priority: here we take potato with greater priority than carrot. Figure 1 displays a solution for combining these two cultural as a Gantt diagram.

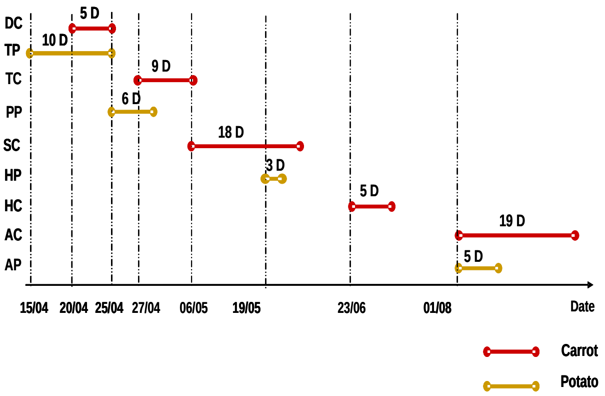

Figure 1: Combination of cultural schedules for carrot and potato for 2 neighbouring farmers sharing a plough.

The resulting schedule can be represented with Allen's relations (cf. notations in Tables 1 and 2) starting from operation DC (soil disinfection in carrot):

- DC
- TP: FINISHES(DC,TP)
- TC: BEFORE(TP,TC),
- PP: MEETS(TP,PP) & OVERLAPS(PP,TC)
- SC: BEFORE(PP,SC) & MEETS(TC,SC)
- HP: DURING(HP,SC)
- HC: BEFORE(HP,HC)
- AC: BEFORE(HC,AC)
- AP: STARTS (AP, AC).

Guerrin (2009) has shown how to simulate such specification of activities.

5.2.3.2. Resource allocation

The issue of resource allocation is posed whenever several actions require the same resources at the same time or when they are exhausted due to a previous action. This may be solved by allocating priorities to actions according to their critical nature in the system. This may lead to cancel or delay some non-priority actions or to execute concurrently actions with same priorities. The priority degrees are given as constants according to an arbitrary numerical scale or as relevant dynamic variables taken in the system (see Guerrin, 2009 for details).

6. DISCUSSION AND CONCLUSIONS

In this article we tackled the issue of coordination based on existing theories namely by identifying two modes: explicit and implicit.

The first mode is based on defining ex-ante the actions to be performed as protocols to be used together with communication artefacts. Be they a rule, procedure or plan, protocols are a way of specifying actions coordination, namely by enabling all agents to anticipate the behaviour of the others. However, protocols (and particularly plans), as necessary means for action, have been strongly criticized by many authors (Selznick, 1948; Suchman, 1987; Clancey, 2002) considering they cannot completely define action in the real practice. For this, it is necessary to take into account the inherent 'situated' dimension of action (Suchman, 1987). According to this theory, every action stems mainly from the dynamical interaction of agents with their environment. Hence, the notion of 'protocol' is theoretically inconsistent with the necessary improvisation an agent must implement to adapt to its changing context. If protocols do not allow one to determine completely and coordinate actions, what are their role? Could there be other means of coordination? According to Schmidt and Simone (1996), all kinds of protocols can play two different roles:

- "Weak": a guide as a "codified set of functional requirements which provides a general heuristic framework".
- "Strong": a script offering "a pre-computation of interdependencies among activities (options, sequential constraints, temporal constraints, etc.) which, for each step, provides instructions to actors of possible or required next steps".

The protocol role, be it weak or strong, depends on agents capacity in determining in advance the dependencies among actions. To determine these dependencies one must anticipate the actions to be performed, which is only partially the case in APS's.

Therefore, another coordination mode, implicit or reactive, must be considered, based on the concepts of 'stigmergy' or 'affordance', both enabling a "protocol-free" coordination of agents. In that respect, this mode seems also appropriate to APS. Stigmergy and affordances allow agents to coordinate implicitly, in both temporal and spatial dimensions by adapting dynamically to their environment. Coordination is in that case made in a distributed way: each agent, endowed with its own perceptive and interpretative abilities, reacts individually and the global coherence emerges, eventually, of the whole. However, the question is posed whether these concepts can also be useful to solve conflicts on resource sharing which are generally dealt with by establishing protocols.

Fundamentally, we came to the conclusion that dealing with the issue of coordination needs to take into account both the temporal and the spatial dimensions of activities. If 'synchronization' can be taken as a synonymous for 'coordination in the temporal dimension', we did not find yet any equivalent concerning the spatial dimension. There exist indeed formalizations that can be used to take into account the temporal dimension of action. This is the case for Allen's work (1984) that cannot be ignored, and most of formalizations quoted in the excellent state-of-the-art on temporal reasoning made by Chittaro et Montanari (2000). However, it must be emphasized that all of these formalizations deal with time in an essentially static mode: they rather allow one to reason about courses of action already made or planned than about action while it is being made. For this, beyond our own works in simulation modelling of APS where human activities are explicitly represented (Guerrin, 2009; Martin-Clouaire and Rellier, 2009) little formalizations exist. In fact activity is often ignored in production system simulation. However, the spatial dimension is lacking in our approaches and we found very little literature on this topic, except about Schelling's focal point (Morel, 2004). This concept, stemming from Schelling's own practical experience tries to tackle the following issue: how two individuals knowing each other lost in a foreign city may found them without communicating? The answer is based on the common knowledge of the participants that can allow, both anticipating the other's solution, eventually, make them converge to a common place. This notion seems to be interesting to explore, however it does not correspond well to the problematic we defined in §2.3 where locations are generally known and agents must navigate among them to act according to various global and local constraints altogether with the time course...

These aspects will be dealt with in our future works, our ambition being, eventually, to propose a modelling framework of human activities applicable to APS. We think to explore, particularly, implicit coordination through the use of artefacts following the stigmergy and affordance theories, as steps to approximate the nice idea of "situated action" promoted by Suchman (1987).

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