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Vianney Sicard, Mathieu Andraud, Sébastien Picault. Organization as a Multi-level Design Pattern for Agent-based Simulation of Complex Systems. 13th International Conference on Agents and Artificial Intelligence, Feb 2021, Online Streaming, France. pp.232-241, 10.5220/0010223202320241 . hal-03342052

HAL Id: hal-03342052

https://hal.inrae.fr/hal-03342052

Submitted on 2 Sep 2022

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Organization as a multi-level design pattern for agent-based simulation of complex systems

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Keywords: multi-level agent-based simulation, design patterns, organizational system, complex systems

Abstract: This paper describes a generic design pattern to introduce organizational mechanisms into multi-level agent-based simulation architectures, to help the modelling of highly structured complex systems. This pattern makes it possible to specify how to couple any three levels of agents in a multi-level simulation architecture, through their relationships to environments, taking into account organizational constraints. As a proof of concept, we applied this pattern to the fine-grained modelling of batch management in pig farms, and illustrate how the pattern can be instantiated and composed at several agent levels to accurately handle a complex organization in time and space. We thus demonstrate the benefits of combining organizational concepts and multi-level patterns to represent and simulate complex dynamic systems.

1 INTRODUCTION

Multi-level agent-based simulation (MLABS) emerged during the last decade as a fruitful approach to model complex systems in a broad range of fields (Morvan, 2012). This approach extends Multi-Agent Systems (MAS) by providing an explicit representation of the macroscopic level and of each intermediary level, as agents endowed with behaviours of their own. Several meta-models or architectures have been proposed for the agentification of agent groups at multiple scales. However, none of these models developed specific methods to take explicitly into account organizational characteristics that can be found in several complex systems (e.g. in anthropized systems). In natural systems indeed, organization is often studied as an emerging phenomenon, which results from interactions of the underlying agents and is not meant to be introduced as such in the model. On the contrary, in human-designed systems, organization is often an explicit frame which impacts the behaviour and interactions of individuals, and thus has to be modelled explicitly.

Conversely, organizational architectures are not designed to cope with multi-level structures. In multi-level approaches, the issue is to represent agent groups corresponding to nested structural elements (e.g. cells in a tissue, in an organ...) whereas in organizations, the issue is to represent agent groups based on functional features or constraints (which results in the concept of role). Besides, organizational approaches often separate physical and social dimensions, whereas modelling complex ecosystems require a strong coupling between those dimensions (Bousquet and Le Page, 2004). Thus, multi-level approaches and organizational architectures are two complementary ways to address complex systems modelling.

The purpose of this work is to propose a generic design pattern to introduce organizational mechanisms into a MLABS architecture. Essentially, an agent group can be considered both a structural aggregation of finer-grained agents as in multi-level approaches, and a predefined structured part of an organization. Agent states can thus either lead to a specific grouping (bottom-up multi-level aggregation), or result from a specific grouping (top-down propagation of organizational constraints). As in MLABS groups are agents encapsulating an environment, introducing organizational features leads to specifying the relationship between organizational and environmental dynamics and constraints, without prior distinction between physical and social environments.

This paper is structured as follows: Section 2

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analyses related works about MAS organization and multi-level agent-based systems. Section 3 describes the rationale for an organizational multi-level pattern and the corresponding architecture. Section 4 presents an application of this pattern to modelling a highly structured farming system (batch management of a pig farm). Finally, we discuss methodological and epidemiological modelling perspectives before concluding.

2 RELATED WORK

2.1 Multi-level agent-based systems

Multi-level agent-based simulation systems differ from holonic systems (Fischer, 1999; Zhang and Norrie, 1999) or recursive architectures such as SWARM (Minar et al., 1996) by their ability to cope with non-hierarchical structures, in order to represent non-arborescent level couplings observed in complex systems. Apart from the huge number of ad-hoc MLABS applications, a few meta-models propose an agentification of agent groups at multiple scales, between atomic individuals and the whole system (Kubera et al., 2011; Morvan et al., 2011; Drogoul et al., 2013; Camus et al., 2015; Hjorth et al., 2020). Recent developments also recommend design principles based on patterns (Mathieu et al., 2018) as in other fields of agent-based simulation (Juziuk, 2012; Klügl and Karlsson, 2009) to enhance the genericity and reusability of conceptual solutions to recurrent issues.

In what follows, to exemplify the design pattern we propose, we use the PADAWAN meta-model (Picault and Mathieu, 2011), which relies on a simple formalism and little specific assumptions, so that the pattern can be transposed to other MLABS meta-models. In this interaction-oriented model for multi-scale simulation, the multi-level aspect is represented by the ability for agents to encapsulate an environment. An agent is also located in one or more environments (without any prior distinction between physical or social environments), and this agent may itself encapsulate another environment, and so on (Fig. 1). The different levels between the whole system and the finest-grained individuals are then represented by the agents that, through the environment they encapsulate, host other agents.

Also, an interaction matrix is associated to each environment to define possible interactions between a source and a target agent family in this environment, as in the interaction-oriented simulation approach (Kubera et al., 2011). The key underlying as-

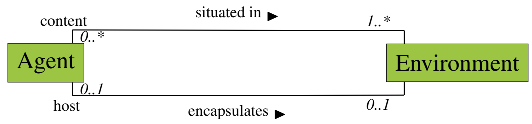

Figure 1: Typical multi-level architecture. Class diagram showing the relationships between agents and environments to manage multiple levels which can represent non-hierarchical structures.

sumption here is that behaviours that agents can exhibit can be specific to each level.

The main limitation of MLABS architectures in general, as regards organizational features, is that they focus on structural specifications for groups (as agents hosting other agents through an environment) rather than functional ones, thus ignoring notions such as role. They provide powerful coupling mechanisms between agents, environments and interactions, but not much on e.g. constraints that could control which agents and behaviours are allowed in each group. Hence, MLABS architectures are well suited to model highly structured systems where macroscopic agents are built on top of microscopic agents, as an aggregation, e.g. to simulate organisms or traffic simulations. The opposite design process, starting with macro agents and trying to propagate constraints towards the microscopic level, is still a challenge.

2.2 Organization in MAS

The common definition of organization is based on three principles (Ferber et al., 2004): (1) The organizational level describes the "what" and not the "how"; (2) No agent description and therefore no mental issues are provided at the organizational level; (3) An organization provides a way for partitioning a system, each partition (or group) constitutes a context of interaction for agents. Organization can be understood from two perspectives (Dignum et al., 2008): as a process (i.e. a set of individuals with constraints — structure, rules, models), or as an entity (with its own requirements and objectives). An organization provides a framework for structuring and managing interactions between agents, and adjusting the level of autonomy of the agents (Hübner et al., 2009).

The AGR ("Agent-Group-Role") meta-model (Ferber and Gutknecht, 1998) defines organizations as an additional abstraction level in the system, composed of groups of agents having common goals or tasks. It can be seen as a kind of dynamic framework where agents are components. The environment (assumed social) represents the context of communication between agents. Within a group, agents play roles. A role describes the constraints (obligations, requirements, skills) that an agent must satisfy, the benefits (abilities, authorization, profits) that an agent receives when performing a role, and the associated responsibilities. An agent can play several roles and therefore be situated in several groups of the same organization at the same time. But a group can belong only to one organization. AGRE (Ferber et al., 2005) extends AGR by introducing a physical environment in addition to social environments. The notion of "Space" provides a generalization for physical and social groups, both remaining strongly separated (there can be only one physical environment but many social ones). This approach provides a high level of abstraction, and establishes the basis for the minimum structure of an organization. However, the strict association between groups and organization and the distinction between the physical and social environments are a limitation for representing systems with complex structuring, because a same group cannot participate in several organizations. Moreover, AGRE does not propose a structured environment, restricting spaces to a context for a pattern of activities, and is used for partitioning the system. This limitation implies that the impact of the structure of the environment, and the dynamic of these structured environments are not taken into account.

In MOISE (Hannoun et al., 2000), the organization is considered to be a system of rules compelling the agent behaviour. These constraints correspond to the role, i.e. the specifications of authorized behaviours of an agent in the organization through the set of activities that the agent can perform. A group is defined by a set of roles and a sub-set of objectives of these roles that can be achieved in the group. The roles are quite similar of the notion in AGRE, but constraints are not directly linked to the consistency of the organizational system. Agents have a set of constraints, called missions, they must take into account for executing specific activities. Groups are a composition of agent with their roles and missions, and are not explicitly linked to the notion of environment. However, a group is a context of interaction between agents, and can be understood as an environment (at least social). Organization concept is formally divided into organizational structure (OS) and organizational entity (OE). OS is a graph defined by a set of roles which are nodes and links (acquaintance, communication, authority) which are edges, and OE is the implementation of the corresponding OS. MOISE provides a definition of an organizational system and a division of this system, but the notion of environment, structured and dynamic, is not taken into account.

Other approaches address more explicitly organization from the software engineering point of view, such as ORA4MAS (Hübner et al., 2009) and MACODO (Weyns et al., 2010). MACODO, which extends ORA4MAS, is a middleware for context-driven dynamic agent organization and proposes an abstraction of organization separating coordination and structuring aspect from the local behaviour of agents. Environments represent the software context of communications, perceptions and actions between agents. This approach provides several answers to the issue of the dynamic relationship between agents, organization level and environments, but no explicit concepts to describe the dynamics of organizations.

Current organizational approaches do not take into account multi-level aspects, such as the dynamics of environments, the dynamic structuring of groups, and the couplings between these different elements. Modelling a highly structured system requires an explicit representation of interactions between atomic elements and their environments, but also between agents from each level. In these different approaches, it is not possible to represent in a simple way the dynamics of the environments and the transversal coupling between groups and organizations, particularly in a multi-level context.

Therefore, we propose in this article a design pattern to enable the flexible introduction of organizational features into multi-level agent-based simulations. The goal of this approach is to make it possible to represent and consider the specific coupling between agents considered atomic, their environment with its associated dynamics and the organizational level, allowing that a group (agent that hosts several agents from a sub-level) can have multiple purposes, and can thus be located in several environments.

3 The multi-level organization pattern

The purpose of a design pattern is to provide a generic, reusable and modular solution to solve a specific problem (Gamma et al., 1994), namely here introducing organizational concepts into MLABS, allowing organizations to have an explicit representation. This solution addresses a specific issue concerning a subpart of a MLABS architecture and is designed to be adaptable to other MLABS meta-models.

To allow an organization to have an explicit representation in a MLABS, it has to meet three criteria: 1) express and formalize the structural relationship between agents ; 2) constrain the behaviours and interactions between agents with a notion of roles (at least implicitly) ; 3) take part in the control of the environment both structurally and functionally.

The pattern must also be compatible with classical MLABS design, in particular as regards the grouping of agents in the multi-level acceptance (Mathieu et al., 2018). Thus, belonging to a group does not necessarily imply being member of a specific organization, but membership in an organization involves belonging to a group.

As MLABS meta-models do not assume anything specific on what the different levels represent, organizational features may thus concern potentially any subset of agents in the multi-level system, depending on the application domain. Hence, transposing organizational concepts into MLABS through a pattern approach is highly relevant, since it only requires to identify which agents are concerned by each organization, and specify the appropriate relationships between levels, i.e. how agents and environments relate, with which constraints and dynamics.

3.1 Structure of the multi-level organizational pattern

The Organization Pattern describes the structural and dynamical relations between three levels within the MLABS: Organization, Groups and Atom (Fig. 2).

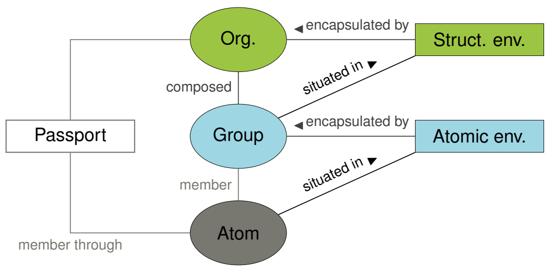

Figure 2: Structure of the multi-level organization pattern. Agent Organization encapsulates a structured environment which is composed of atomic environments, themselves encapsulated by Group agents. Agents involved as Atoms belong to an organization by their location in an atomic environment, according to the constraints applied by the Organization. The Passport is a mediator between an atom and its organization.

Organization is the agentification of a structured environment, i.e. an environment that can be partitioned into specific sub-environments that are called "atomic environments". The Atom is any agent which is member of the organization. More precisely, organization membership comes from the localization of the Atom in an atomic environment of this organization, according to the associated constraints. The atomic environment contains information and has its own dynamics through the encapsulation by a Group agent. Groups are located in the structured environment encapsulated by the Organization agent, which manages the dynamics of the environments and its own consistency through its constraints. As in (Ferber et al., 2005), the organization is a frame within which the agents behave. Information regarding Atom membership in an Organization are stored in a Passport: e.g., location of the Atom, status regarding the constraints of the organization, etc.

3.2 Atoms and their states

An atom is any kind of agent that needs to be hosted by an organization and is subject to the constraints of that organization. The term "atom" means that, in the pattern, we do not consider its underlying structure (it can, or not, encapsulate an environment where other agents can be located, etc.) because it is not relevant as regards organizational features.

Atoms can interact with other agents according to their location in environments. This location in an environment implies the belonging to a group corresponding to the agent that encapsulates the corresponding environment. The agent can act on the environment, i.e. take or deposit information (§3.5).

As any agent, the atom is endowed with states, which change according to the atom's behaviour, called "actual states" in the pattern. These actual states may come to violate constraints of the organization which the atom belongs. The organization can decide either that this violation is prohibitive (and exclude the atom), or that the atom can nevertheless be seen as temporarily complying with the organization's constraints (and let the atom stay in the organization). In the latter case, the organization overrides this perceptive discrepancy and assigns a "nominal state" to the atom. In order to preserve the atom's autonomy, this nominal state cannot be imposed directly on the atom, thus it is rather stored in a special data structure called a "Passport" (§3.3).

For example, a boxer (atom) has a weight which is an actual state (e.g. 187 pounds). According to the division where he plays (professional or amateur), seen as an organization, he will receive a different nominal state (respectively cruiserweight or heavyweight). This nominal state is obviously an interpretation of the weight by either a professional or an amateur organization, not an intrinsic state of the boxer.

3.3 Organization, constraints, passport

The organization agent is the concretization of the organization abstract level, endowed with its own behavior and states. An organization encapsulates a structured environment which is partitioned into sub-environments encapsulated by agents that are groups, and where atoms are actually situated (Fig. 2). The organization is in charge of its own integrity and consistency control through constraints. Especially, the organization has to check that its members (atoms) comply with the constraints, and if not, decide whether to exclude the intruders or reconsider how it perceives them by updating their passport.

The constraints allow the organization to admit atoms and locate them, or to reject atoms if necessary. They are a set of rules (r) regarding either actual or nonimal states of atoms, that an atom must fulfil to enter or remain in an organization, and corresponding actions (a) that have to be performed when atoms fulfil or violate the rules.

The passport is a mediator pattern between an organization and an atom. It stores information on the location and nominal states, to represent the point of view of the organization on the atom, at a given time. The passport is owned by an atom but is only handled by the organizational system (organization agent, Fig. 2). The passport is composed of two items: the history of successive locations of the atom over time, and a visa which is the current status of the atom regarding an organization and its constraints, including how actual states are interpreted into nominal states.

3.4 Roles

Roles are considered abstract behaviours that agents can exhibit within a group (Ferber and Gutknecht, 1998). As in PADAWAN (Kubera et al., 2011), we assume that behaviours that agents can perform in a level are specified through an interaction matrix, which is a function that assigns possible interactions to a source family and a target family. Source/target families, depending on the application context, can be either a specific agent (e.g. “George Foreman”), or an arbitrary name such as an agent class (“Boxer”) or an actual or nominal state (“Heavyweight”). As a consequence, roles in the organizational pattern are defined by the matching between behaviours specified in interaction matrices and the combination of information stored in atoms and passports.

3.5 Environment, structured environment, group

Environments are considered in accordance to (Mathieu et al., 2015), i.e. a space endowed with two functions: placing agents and providing information, and which can be physical or social indifferently. Furthermore, environments have their own dynamics linked to their topology (neighbourhood, information transmission, etc.).

A structured environment is composed of smaller parts (atomic environments), with a specific topological arrangement and a dynamic of its own. Its topological representation is a graph composed of vertices that represent atomic environments carrying information, and weighted edges that represent information flows, which constitutes the dynamics of the environment (Fig. 3).

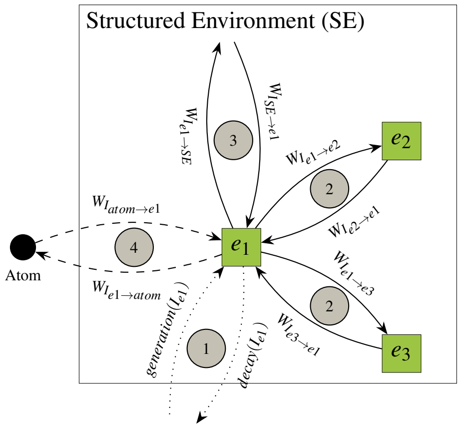

Figure 3: Representation of the dynamics of an information I in an atomic environment e_1, resulting from in/out flows due 1) to intrinsic dynamics (sources/sinks), 2) to exchanges with other atomic environments (e_2, e_3) or 3) with the structured environment SE, and 4) to actions performed by atoms located in e_1. E.g., if I is a pheromone level, it changes through deposition by atoms, diffusion to and from neighbours respective to distance, and evaporation.

An environment is considered atomic according to a given point of view of the pattern, i.e. depending on the part of the system relevant as regards organizational concerns. Hence, the environment considered atomic at a level used in the pattern (group or atom level) can itself be actually structured to implement the pattern recursively. Similarly, an agent considered atomic in an instance of the pattern for a given triplet of levels, can be considered an organization in another pattern instance, applied to another triplet of agent levels (Fig. 4 & 5).

4 Application to the modelling of complex farming systems

Mechanistic models make it possible to understand and predict the spread of pathogens at several scales (from individuals to territories) under various scenarios (control measures, climate...) (Keeling and Rohani, 2008; Ezanno et al., 2020). Accounting for the complexity of agricultural systems, with their strong environmental and population structuring,

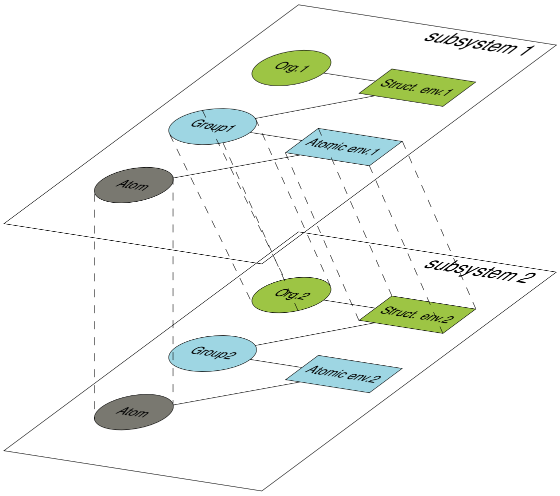

Figure 4: Example of a group-focused pattern composition. In this case, a Group level of the sub-system involved in the first pattern is itself structured as an Organization implementing the pattern with other levels of the system. The Atom level is the same in both patterns.

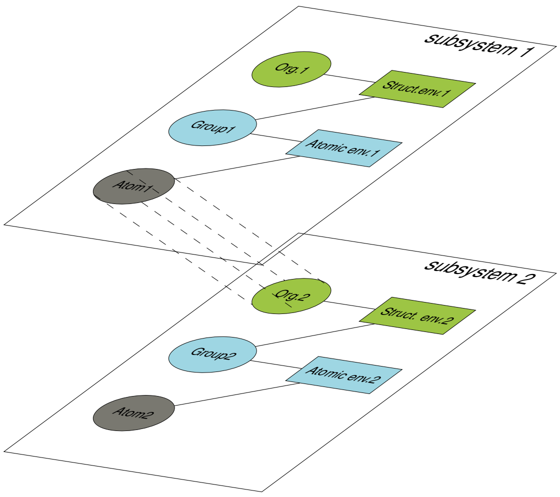

Figure 5: Example of an atom-focused pattern composition. In this case, the Atom level of the first pattern is itself handled as an organization in the second pattern.

dynamics and constraints, and the coupling between these concepts, is a real challenge to make models more realistic and identify the mechanisms involved and possible control levers.

MLABS appears a suitable solution for addressing such complex pathosystems, as evidenced by EMULSION[1] (Picault et al., 2019), an open source framework dedicated to mechanic stochastic modelling in epidemiology, already based on MLABS (Mathieu et al., 2018). Thus, it was quite natural to implement the multi-level organizational pattern on top of this platform to address our own concerns in the field of complex farming systems.

[1] https://sourcesup.renater.fr/www/emulsion-public/

4.1 Application to batch management

In what follows, we demonstrate how the multi-level organizational pattern can be applied to model the batch management in a French pig farm, and its added value. Pigs are bred in batches, to guarantee a homogeneous evolution of the physiological states (i.e. different steps in the animal like such as gestating for sows or fattening for piglets). This involves that batches must be consistent, i.e. that all animals are in the same physiological state at the same time. The animals, according to their type (sow or piglet), their physiological state (depending on their age or reproductive stage) and therefore their belonging to a batch, are located in specific spaces (room, sector) corresponding to environments. These environments have a physical structuring, which directly impacts the environment dynamics and the relationship between the environments and animals hosted (sharing information like faeces, shedding of pathogens, airflow, etc.). This type of management corresponds to a challenging realization for our issues:

- the physical environment is highly structured (housing, litters, pens)
- the physical environment has its own dynamics (pathogen spread, release, accumulation and decrease)
- the batches (social environments) must maintain their consistency (homogeneity criteria)
- agents can have different statuses (actual: the real value, and nominal: as considered for batch management) for a same state regarding the context (e.g. depending on their belonging to a batch, their physiological stage, their housing, etc.)
- environments and agents are closely coupled (sharing information, etc.)

We consider a “typical” farm structure (Salines et al., 2020) composed of five sectors corresponding to different physiological stages: 1) a mating sector where sows are inseminated, 2) a gestating sector, 3) a maternity where sows and piglets are together for suckling, 4) a post-weaning sector where piglets are separated from their mothers and 5) a fattening sector where pigs are fattened before being sent to the slaughterhouse (Chambre d’Agriculture de Bretagne, 2010). The number of batches determines the management (housing and timing). As an example, we consider here a management in 7 batches with an interval of 21 days. The evolution of a batch over time depends on the duration spent in a sector, corresponding to physiological stages (Table 1).

Table 1: Typical pig herd batch management for 7 batches with a 21-day interval (Chambre d'Agriculture de Bretagne, 2010). The duration in a sector for each batch is calculated to optimize room occupation, yet accounting for a time of cleaning and disinfection.

	Mating sector	Gestating sector	Maternity sector	Post-weaning sector	Fattening sector
Physiological stage	Insemination	Gestating	Suckling	Post-weaning	Fattening
Number of batches to be housed	2	4	2	3	6
Entrance to the sectors every ... (days)	35 or 42	77 or 84	35 or 42	56 or 63	119 or 126
Sector occupancy (days)	35	77	28	4×61 or 3×54	6×114 or 1×121
Duration of cleaning and disinfection (days)	5×4 or 2×1	7 and 1	14 and 7	2	5

Before addressing pathogen spread and control, our first objective was to simulate this management and to observe both the overall behavior of the system, and the evolution of animals constituting batches, for social (batches) and physical (housing) aspects. To do so, we adapted the EMULSION framework to provide the multi-level organizational pattern, and instantiated the pattern with the appropriate levels of agents.

An animal corresponds to an atom, and we consider two main organizations: one for batches (social) and one for housing (physical). The "batch" organization is decomposed into several litters with one sow per litter. Each litter is a (social) atomic environment encapsulated by a group, and linked to the organization by a structured environment which reflects the relationships between atomic environments. The "housing" organization is decomposed into several sectors, which are atomic spaces and also, recursively, organizations representing the decomposition of a sector into rooms (Fig 6).

The evolution of the physiological state is time dependent, specific duration for each step is directly controlled by the atom and is, of course, dependent of its type (sow or piglet). During the transition between gestating and suckling, sows produce offspring (piglets).

The housing of atoms depends on their states (physiological stage, type, batches) and on constraints which define the coupling between the "batch" and "housing" organizations:

- the location in a sector depends on the physiological step of the animal
- all animals of a same batch are located in a same room
- all animals of a same litter are located at the same location

For example, to be located in the maternity sector, animals can be either a sow or a piglet, and they have to be in the suckling physiological step. Some animals from different batches can potentially satisfy these constraints and be in the same sector at the same time, possibly with a different duration. This is why the different batches are distributed in the different rooms (one batch per room). The batch management is optimized according to the occupation of the rooms, accounting for a time for cleaning and disinfection (Chambre d'Agriculture de Bretagne, 2010).

As a proof of concept of the organizational pattern, we represent the occupancy of sectors and rooms within 452 days for a 7-batch management. Due to the 21-day time gap, we start with the first batch in suckling step, and initialize each batch considering this state: the second batch is in gestating since 21 days, the third batch is in gestating since 42 days, etc. The herd is composed of 15 sows per batch (i.e. 105 sows in total) with a fertility rate of 10, which can increase the total population to over 1,000 animals.

Simulation outcomes (Fig. 7) show exactly the main housing described in the literature (Chambre d'Agriculture de Bretagne, 2010) and observed on the field. The multi-level organization pattern proved convenient to represent, model and simulate the specificities of the batch management farm system. The organizational pattern makes it possible both to observe the spatial behavior (allocation) and to follow the "social" organization aspect at different levels, from batches to animals. Consequently, this fine-grained modelling capability allows precise aspects of communication and interaction between agents to be taken into account, whether they are atoms, organizations or encapsulated environments.

4.2 Perspectives

We have demonstrated that is possible to accurately represent and consider the complex organizations such as highly structured farming systems in an existing MLABS architecture, based on a design pattern approach. Our next objective will be to study the

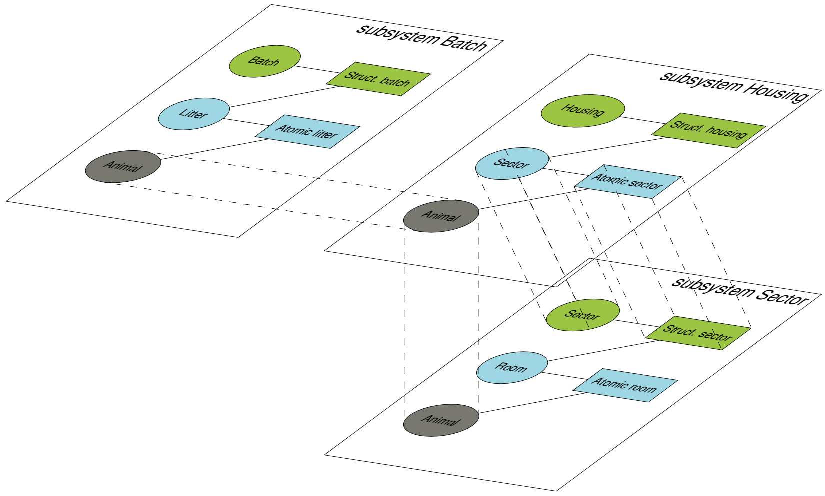

Figure 6: Composition of three instances of the multi-level organization pattern for the modelling of the batch management of a French pig farm. Two main organizations are defined: Housing corresponding to a physical organization, and Batch corresponding to a social organization. The organization of sectors within housing provides a finer grain to control this level.

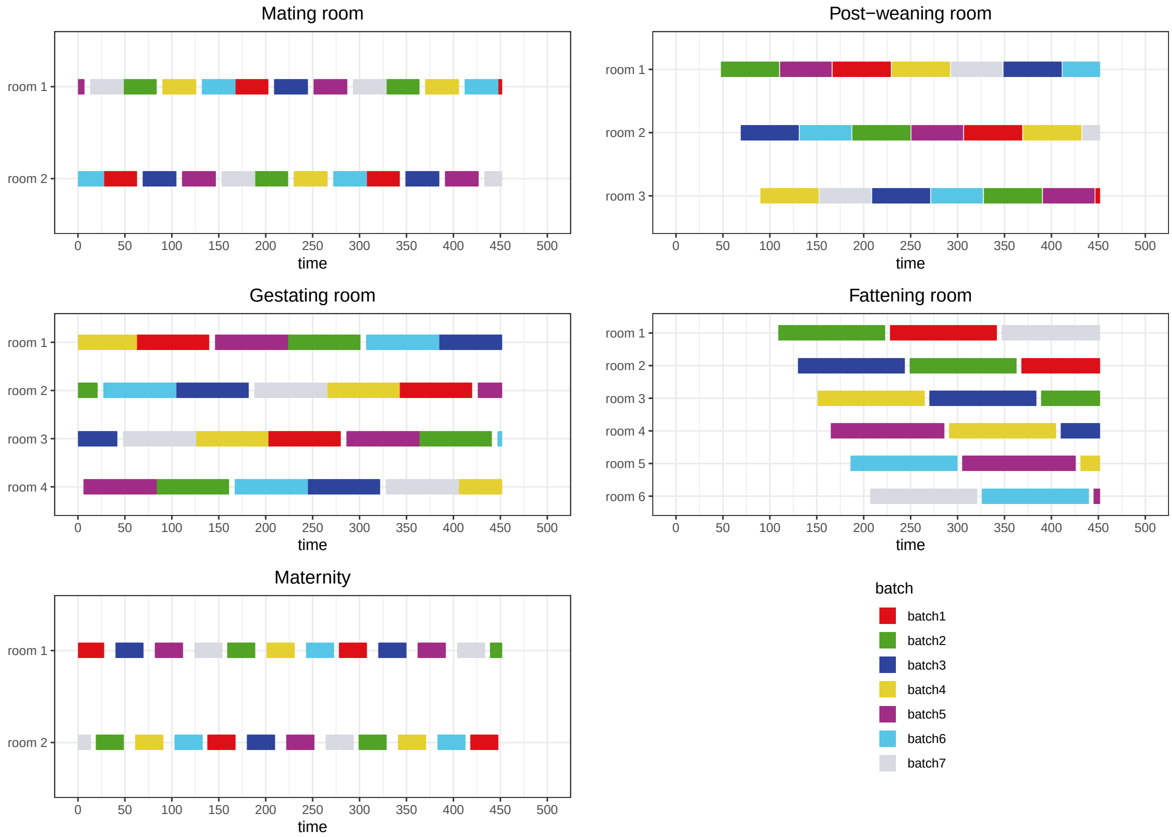

Figure 7: Results of housing coming from the simulation of the batch management farm system. Animals are located in the different sectors and rooms according to their states with regard to the organizations (Chambre d'Agriculture de Bretagne, 2010). It is thus possible to accurately track the system at different levels (batch, litter, animal, etc.)

spread of pathogens within the system, taking into account interactions between individuals, environments and organization levels. This new opportunity to address assumptions that could not be easily taken into account until now, should help to better understand pathogen transmission in these complex systems, especially to evaluate various control scenarios in a realistic and efficient way.

Reducing health risk at the animal, farm and territorial levels is essential to the viability of livestock farms and production sector. The Porcine Reproductive and Respiratory Syndrome (PRRS) is a viral contagious disease and extremely widespread in areas with a dense pig population (Rose et al., 2015). To understand and predict pathogen transmission and to compare the effectiveness over time of realistic control strategies, mechanistic epidemiological modelling is essential to complement the expertise of health managers, quantifying epidemiological and economic impacts. The possibility of considering the complex structuring of herds and the farming system provides new opportunities for controlling the spread of the pathogen.

5 CONCLUSIONS

We have analysed the difficulties encountered in explicitly taking into account the organizational characteristics that can be found in several kinds of complex systems.

To overcome existing limitations, we propose an organizational system for multi-level agent-based simulation that take into account the representation and implementation of the dynamic relationships between agents, organization levels and environments. This proposal comes as a design pattern so that it can be reused and adapted in other multi-level architectures, and can be composed to cope with highly complex structures (sub-organizations or concurrent organization). Besides, it fully relies on the fact that all entities of a MLABS are represented by agents, thus supporting the structural homogeneity of the system. This pattern was easily implemented in an existing simulation platform based on existing multi-level patterns (EMULSION framework), demonstrating the flexibility and consistency of our proposal with existing MLABS approaches.

The proof of concept implemented in EMULSION also contributes to the multi-scale epidemiological modelling of complex ecosystems. The representation of the interaction between agents, environments and levels of organization is an important step to represent highly structured populations and environments to enhance classical modelling paradigms. That will provide a deeper understanding of the dynamics of anthropized environments and help to assess realistic control scenarios.

Finally, introducing organizational features in MLABS contributes to reduce the gap between a structural and a functional approach to complex systems. Using a design pattern approach to do so makes it possible to extend the concept of organization as a specific relationship between several levels reified by agents, rather than a dedicated component added to a MAS, hence leading to a more homogeneous and flexible architecture.

ACKNOWLEDGEMENTS

This work is supported by a grant from the Animal Health division of INRAE (French national research institute for agriculture, food and environment) and the French region Pays de la Loire.

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