Behaviour of Fuzzy Agents within a Collaborative Design Platform

Alain-Jérôme Fougères[1,2] and Egon Ostrosi[2]
[1]*ESTA, School of Business and Engineering, Belfort, France*
[2]*Research Laboratory M3M, University of Technology of Belfort-Montbéliard, Belfort, France*

Keywords: Fuzzy Agents, Fuzzy Agent Modelling, Fuzzy Agent Behaviour, Collaborative Design Platform.

Abstract: This paper presents first a fuzzy agent-based approach for assisting collaborative design, and then, an analysis of behaviours of fuzzy agents evolving within a collaborative design platform. In a collaborative design platform, more effective design decisions can be made by fuzzy agents when fuzzy design information is considered in a fuzzy interaction based process and fuzzy evolving systems. The modelling of fuzzy agents, their fuzzy interactions, their fuzzy roles, and their fuzzy organization, are presented. During design process, fuzzy agents grouped in communities interact and play fuzzy roles for converging to solutions of design. A case study of product configuration illustrates the analysis of fuzzy agents' behaviour.

1 INTRODUCTION

Our research focuses on computer support for distributed design activities. These activities are inherently distributed, and then we proposed the multi-agent systems as efficient computing paradigm. Furthermore, many agent-based systems have been proposed in many industrial fields, especially in concurrent engineering and collaborative and intelligent manufacturing (Monostori et al., 2006).

During the collaborative design process, designers deal with some distinct forms of uncertainty such as imprecision, randomness, fuzziness, ambiguity and incompleteness. Imprecision is caused by the non-precise nature of design information. Therefore we assume that more effective design decisions can be made by fuzzy agents when fuzzy design information is considered in a fuzzy interaction based process.

Fuzzy agents are reactive to their environment and they interact between them to adjust their actions with their fuzzy knowledge (Ghasem-Aghaee and Ören, 2007). Their evolution is fuzzy (Lughofer, 2011), when they are designed to interpret fuzzy information and to adopt a fuzzy behaviour (Ostrosi et al., 2012; Fougères and Ostrosi, 2013). Indeed, they interpret the fuzzy information that they either receive or perceive. So they interact in a fuzzy way.

Fuzzy agents are well adapted to respond to heterogeneity and evolving of some organizations (Fougères, 2012). So, we propose to analyse both the evolution of their fuzzy roles and the change of their distribution in different communities of an organization, within a collaborative design platform.

This paper is organized as follows: in following section, a fuzzy agent modelling is proposed; in third section, an agentification of a product configuration model is presented; in fourth section an illustration of a fuzzy agent-based product configuration and an analysis of fuzzy roles of fuzzy agents during this configuration process are proposed; finally, conclusions of this research are presented.

2 FUZZY AGENT MODELING

2.1 Fuzzy Agent Model

An agent-based system is fuzzy if the agents that compose it are fuzzy:

- Knowledge of an agent is fuzzy (defined by fuzzy values).
- Behaviour of an agent (Fig. 1, 2) depends on the fuzzy evaluation of its fuzzy perceptions, its fuzzy decisions, and its fuzzy actions.
- Interactions between agents are fuzzy, since 1) the relationship or affinities between agents are weighted by a fuzzy value, and 2) interactions provide a relative interest (fuzzy evaluation) to agents based on roles that they play at a given

Fougères A. and Ostrosi E..
Behaviour of Fuzzy Agents within a Collaborative Design Platform.
DOI: 10.5220/0004551802410248
In *Proceedings of the 5th International Joint Conference on Computational Intelligence* (FCTA-2013), pages 241-248
ISBN: 978-989-8565-77-8

time.

- Roles of agents are fuzzy, which means that a fuzzy value is associated to all roles a fuzzy agent plays. At a given time, it is possible to determine what roles an agent plays based on fuzzy values of its roles and a threshold value setting the minimum value an agent should invest in these roles.
- Organization of the agent-based system is fuzzy, insofar as the distribution of roles played by fuzzy agents is continually evolving – this defines a self-organizing agents which is the result both of their fuzzy multiple interactions and the continuing evolution of their roles in the general activity of the agent-based system.

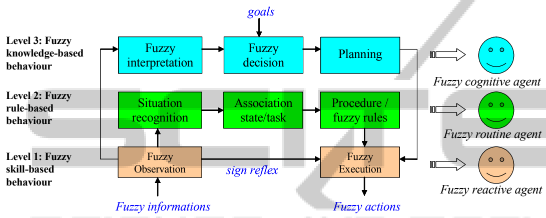

Figure 1: Variable agent behaviour and fuzzy agent behaviour, based on Rasmussen's model.

A fuzzy agent-based system is described by the following tuple (1):

$$\tilde{M}_{\alpha} = < \tilde{A}, \tilde{I}, \tilde{P}, \tilde{O} > \quad (1)$$

where $\tilde{A}$ is a fuzzy set of agents, $\tilde{I}$ is the fuzzy set of interactions between agents fuzzy set of $\tilde{A}$, $\tilde{P}$ is the fuzzy set of roles that fuzzy agents of $\tilde{A}$ can play, and $\tilde{O}$ is the fuzzy set of organizations (or communities) defined for fuzzy agents of $\tilde{A}$. We can then affirm the plasticity of these organizations. However this plasticity is most pronounced in matrix organizations than in hierarchical organizations. If the agents that compose it are fuzzy: agents have the knowledge and behaviour fuzzy, their interactions are fuzzy, their roles are fuzzy, and the resulting organizations are themselves fuzzy.

Agents developed in our various projects can perform reflex actions (automatic), routine actions, and actions in new situations (creative or cooperative situations). Thus, a fuzzy agent $\tilde{\alpha}_i \in \tilde{A}$ is described by the following tuple (2):

$$\tilde{\alpha}_i = < \Phi_{\tilde{\Pi}(\tilde{\alpha}_i)}, \Phi_{\tilde{\Delta}(\tilde{\alpha}_i)}, \Phi_{\tilde{\Gamma}(\tilde{\alpha}_i)}, \tilde{K}_{\tilde{\alpha}_i} > \quad (2)$$

Global algorithms of $\Phi_{\tilde{\Pi}(\tilde{\alpha}_i)}$, $\Phi_{\tilde{\Delta}(\tilde{\alpha}_i)}$, $\Phi_{\tilde{\Gamma}(\tilde{\alpha}_i)}$ respectively functions of observation, decision and action, are given in figure 2. The set of fuzzy knowledge $\tilde{K}_{\tilde{\alpha}_i}$ includes decision rules, values of the domain, acquaintances (networks of affinities between agents), along with dynamic knowledge (observed events, internal states, etc.).

$\tilde{\varepsilon} \in \tilde{E}$ // a fuzzy event
$t \in T$ // a courant task
$\tilde{\pi} \in \tilde{\Pi}$ // a fuzzy observation
$\tilde{\rho} \in \tilde{P}$ // a fuzzy rule
$\tilde{\delta} \in \tilde{\Delta}$ // a fuzzy decision
$\tilde{\gamma} \in \tilde{\Gamma}$ // a fuzzy act

i) Fuzzy agent observation function ($\Phi_{\tilde{\Pi}(\tilde{\alpha}_i)}$)
if $\Phi_{\tilde{\Pi}}(\tilde{\varepsilon})$ = true then // fuzzy observation
if t = true then
if relation($\tilde{\varepsilon}$, t) = true then
$\tilde{\pi} \leftarrow \tilde{\varepsilon}$; $\Phi_{\tilde{\Delta}}(\tilde{\pi})$
else *insert(* $\tilde{\varepsilon}$ *, Agenda)* endif
else
$t \leftarrow$ true
$\tilde{\pi} \leftarrow \tilde{\varepsilon}$; $\Phi_{\tilde{\Delta}}(\tilde{\pi})$
endif
endif

ii) Fuzzy agent decision function ($\Phi_{\tilde{\Delta}(\tilde{\alpha}_i)}$)
if $\Phi_{\tilde{\Delta}}(\tilde{\pi})$ = true then // fuzzy decision
if *find_rule(* $\tilde{\pi}$, $\tilde{\rho}$ *)* = true then
$\tilde{\delta} \leftarrow \tilde{\rho}$; $\Phi_{\tilde{\Gamma}}(\tilde{\delta})$
else $\Phi_{\tilde{\Gamma}}$ *(null)* endif
endif

iii) Fuzzy agent action function ($\Phi_{\tilde{\Gamma}(\tilde{\alpha}_i)}$)
if $\Phi_{\tilde{\Gamma}}(\tilde{\delta})$ = true then // fuzzy action
$\tilde{\gamma} \leftarrow$ *extract_conclusions(* $\tilde{\delta}$ *)*
process($\tilde{\gamma}$ *)*
else
process(null)
endif

Figure 2: Functional algorithms of a fuzzy agents $\tilde{\alpha}_i$.

2.2 Fuzzy Agents Organization

Problems due to the partial view of agents (local goals, interleaving activities, etc.), require the development of strong coordination mechanisms (Kubera et al., 2011). The organization shall allow an agent-based system to behave as a coherent whole, to solve a problem unequivocally. It controls and coordinates the interaction between agents of the system, thus structuring their activities with the goal of convergence. Ferber et *al.* (2009) distinguish between "organizational structure" and "organization", corresponding to the process of designing the structure. Wooldridge (1997) proposed a more practical definition: "a collection of roles that stand in certain relationships to one another and that take part in systematic institutionalised patterns of interactions with other roles". From these definitions, we extract the following characteristics:

- Organization includes active entities having behaviour and defined functionalities.
- An organization can be partitioned into groups or communities of agents.
- A group (or community) is comprised of agents sharing a goal and characteristics.
- An agent can play one or more roles within the group or groups to which he belongs.
- An agent interacts with agents of its community and/or other communities to carry out its roles.
- A role corresponds to a function to be performed by an agent in a group.

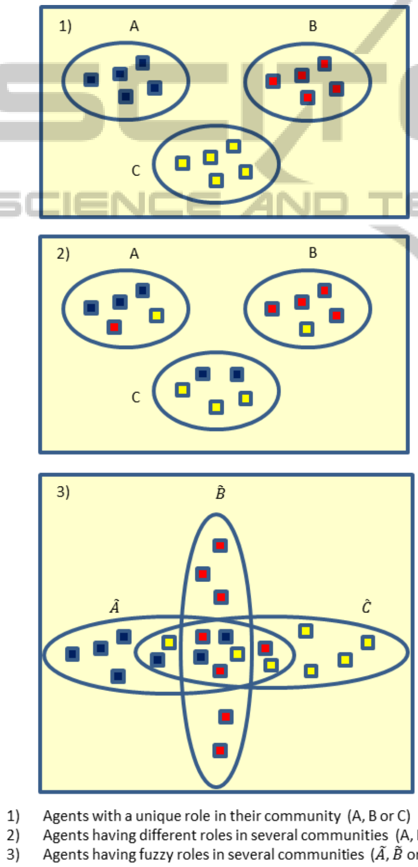

Figure 3: Different distributions of agents in communities based on the roles they play at a given time.

In a dynamic organizational structure, the roles of agents can become dynamic, variable and determined by the actions to be done (Fig. 3). We proposed that the roles of agents are considered fuzzy. An agent in this organization can have several fuzzy roles at a given time. Thus a fuzzy set of roles is defined as follows (3):

$$\tilde{\mathrm{P}} = \{\tilde{\rho}_1, \tilde{\rho}_2, \ldots, \tilde{\rho}_q\} \qquad (3)$$

Then, the fuzzy set of roles played by an agent is defined by (4):

$$\tilde{\mathrm{P}}(\tilde{\alpha}_i) = \{\mu_{\tilde{\rho}_1}(\tilde{\alpha}_i), \mu_{\tilde{\rho}_2}(\tilde{\alpha}_i), \ldots, \mu_{\tilde{\rho}_q}(\tilde{\alpha}_i)\} \qquad (4)$$

Fuzzy agent interacts by sending messages within its initial community (in this case, it plays its main role), but it also interacts with fuzzy agents from other communities (in this case it plays other roles). A fuzzy agent $\tilde{\alpha}_i$ by interacting with a fuzzy agent $\tilde{\alpha}_j$ of another community then participates in the same role as $\tilde{\alpha}_j$ (5):

$$\begin{aligned} &\forall \tilde{\alpha}_i \in \tilde{\mathrm{A}} \supset [\exists x : \tilde{\rho}_x \in \tilde{\mathrm{P}} \wedge \alpha_j \in \tilde{\mathrm{A}}_x, \Phi_{\tilde{\mathrm{P}}}(\tilde{\alpha}_j, \tilde{\rho}_x) \\ &\wedge \tilde{\lambda}_{i,j}(\tilde{\alpha}_i, \tilde{\alpha}_j, \tau, \tilde{\eta}) \supset \Phi_{\tilde{\mathrm{P}}}(\tilde{\alpha}_i, \tilde{\rho}_x)] \end{aligned} \qquad (5)$$

2.3 Fuzzy Agents Interactions

In multi-agent systems, as in human organizations, actions, interactions and communications, are closely linked and interdependent (Jennings, 2000). Interaction is an exchange between agents and their environment. This exchange depends on the intrinsic properties of the world in which agents are active. Perception of agents may be passive when receiving messages/signals, or active, when it is the result of voluntary actions. Communication is an exchange between the agents themselves, using a language.

A fuzzy interaction $\tilde{\iota}_i \in \tilde{\mathrm{I}}$ between two fuzzy agents is defined by the following tuple (6):

$$\tilde{\iota}_i = < \tilde{\alpha}_s, \tilde{\alpha}_r, \tilde{\mathrm{P}}_{\tilde{\alpha}_s}, \tilde{\gamma}_i > \qquad (6)$$

where $\tilde{\alpha}_s$ is the fuzzy agent source of the fuzzy interaction, $\tilde{\alpha}_r$ is the fuzzy agent destination, $\tilde{\mathrm{P}}_{\tilde{\alpha}_s}$ is the fuzzy set of roles played by $\tilde{\alpha}_s$, and $\tilde{\gamma}_i$ is a fuzzy act of cooperation, and has a goal. Interactions are fuzzy; also the recipient agent always evaluates an interaction (fuzzy value) to determine the interest this interaction can take for it.

For cooperating, agents can express their intentions using a language derived from the speech acts theory. In most agent platforms we developed, fuzzy agents perform five main speech acts: $\tilde{\Lambda}$ = {*inform*, *diffuse*, *ask*, *reply*, *confirm*}. For interacting, a fuzzy agent chooses its fuzzy destination agent according to its intentions, the context-solving and the state of its acquaintances. A fuzzy communication act $\tilde{\lambda}_{s,r}$ between two fuzzy agents is defined by (7):

$$\widetilde{\lambda}_{s,r} = < \widetilde{\lambda}, \widetilde{\alpha}_s, \widetilde{\alpha}_r, \widetilde{\mathrm{P}}_{\widetilde{\alpha}_s}, \tau, \widetilde{\eta} > \qquad (7)$$

where $\widetilde{\lambda} \in \widetilde{\Lambda}$ is a fuzzy speech act denoted by a performative verb, $\widetilde{\alpha}_s$ is the fuzzy source agent of communication, $\widetilde{\alpha}_r$ is the fuzzy receiver agent, τ is a type of message, $\widetilde{\mathrm{P}}_{\widetilde{\alpha}_s}$ is the fuzzy set of roles played by $\widetilde{\alpha}_s$, and $\widetilde{\eta}$ is the fuzzy message, which can be a question, a response, etc.

A fuzzy agent plays roles evolving in function of its knowledge, its fuzzy competences and its fuzzy interactions. Thus, fuzzy decision rules $\widetilde{\Delta}_{\widetilde{\alpha}_i}$ of fuzzy agent $\widetilde{\alpha}_i$ are defined by (8):

$$\widetilde{\Delta}_{\widetilde{\alpha}_i} = < \widetilde{\mathrm{E}}_{\widetilde{\alpha}_i}, \widetilde{\mathrm{X}}_{\widetilde{\alpha}_i}, \widetilde{\Gamma}_{\widetilde{\alpha}_i} > \qquad (8)$$

where $\widetilde{\mathrm{E}}_{\widetilde{\alpha}_i}$, $\widetilde{\mathrm{X}}_{\widetilde{\alpha}_i}$, $\widetilde{\Gamma}_{\widetilde{\alpha}_i}$,are respectively the set of fuzzy events that $\widetilde{\alpha}_i$ can observe, the set of fuzzy conditions associated to the internal states of $\widetilde{\alpha}_i$, and the set of fuzzy actions that $\widetilde{\alpha}_i$ can perform.

3 A DESIGN PLATFORM

3.1 Product Configuration Model

Configuration tasks consist of selection, arrangement of components, and evaluation test: the configuration is a design problem (Deciu et al., 2005). Product configuration must consider explicitly different domain actors and their perspectives influencing simultaneously the design of configurable products. Moreover, during the design for configuration process each product is customized according to customer's preferences. Therefore, product configuration must be able to deal with various, instable and imprecise requirements coming from fuzziness of design problems (Agard and Barajas, 2012). In order to capture the uncertainty aspects that characterize design for configuration, the fuzzy sets (Zadeh, 1965) approach can be used.

Configurable product design is a mapping process between product requirement view, functional view, physical solution view, process view and fuzziness of collaborative design process. Thus a fuzzy approach for searching configuration structures, performing into three phases, is proposed (Ostrosi et al., 2012) (Fig. 4):

- Phase 1. *Fuzzy relationships in engineering design*: the engineering design models, from requirements to solutions, necessary for the configuration of a product, are built.
- Phase 2. *Searching the fuzzy set of consensual solutions*: a designer customizes the product based on particular customer's requirements and specific domains' constraints involved in its production. Result is a fuzzy set of consensual solutions.
- Phase 3. *Fuzzy optimal solution agents based product configuration*: the result is a fuzzy set of consensus solutions.

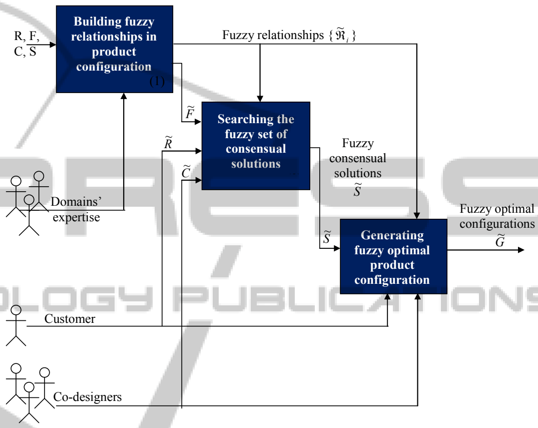

Figure 4: Product configuration approach.

3.2 Fuzzy Agent-based Configuration

Requirements, functions, solutions and constraints are fuzzy agents, with a degree of membership in each community defined for the configuration: specification community, function community, solution community and constraint community. Cooperative interactions can occur between fuzzy agents in the communities of functions and solutions (*intra-communities interactions*), or between fuzzy agents of different communities (*inter-communities interaction*).

A fuzzy agent-based platform called *FAPIC* (Fuzzy Agents for Product Integrated Configuration) was developed for product configuration (Fig. 5). In *FAPIC*, fuzzy agents are organized in four communities (9):

$$\widetilde{\mathrm{A}}_r \subseteq \widetilde{\mathrm{A}}, \widetilde{\mathrm{A}}_f \subseteq \widetilde{\mathrm{A}}, \widetilde{\mathrm{A}}_c \subseteq \widetilde{\mathrm{A}}, \widetilde{\mathrm{A}}_s \subseteq \widetilde{\mathrm{A}} \qquad (9)$$

Each community has a clear objective, which determines the main role that fuzzy agents play in this community (Fougères and Ostrosi, 2013). This means that each fuzzy agent belongs to a community of reference in which it plays its main role (10):

$$\forall \widetilde{\alpha} \in \widetilde{\mathrm{A}} \supset [\exists x \in \{r, f, c, s\}, \widetilde{\alpha} \in \widetilde{\mathrm{A}}_x \wedge \Phi_{\widetilde{\mathrm{P}}}(\widetilde{\alpha}, \widetilde{\rho}_x)] \qquad (10)$$

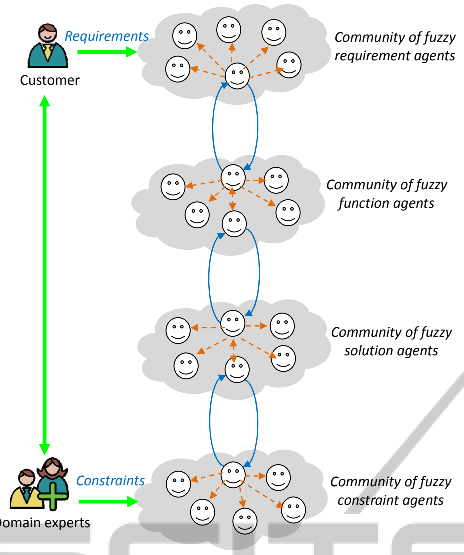

Figure 5: Agent-based architecture of *FAPIC* platform.

4 CASE STUDY

To illustrate the fuzzy agent configuration approach, a "chair configurable product" is chosen because of both the simplicity and accessibility of this illustration. Though a chair is composed of a few elements, it can be configured in multiple ways satisfying both customer's requirements and different experts' process views (*Production*, *Recycling*, *Maintenance*, *Assembly*, and *Design*).

4.1 Product Configuration

This section gives a detailed illustration for the three phases of the proposed approach (Fig. 4).

In the first phase (*fuzzy agents based systems building*) communities of fuzzy agents are built. In this case study, 11 fuzzy requirement agents, 4 fuzzy function agents, 20 fuzzy solution agents, and 44 fuzzy constraint agents, are built. Then, interactions between fuzzy agents of all communities are built.

The second phase (*searching fuzzy set of consensual solution*, see Fig. 8) comprised six steps:

- Step 1: Definition of fuzzy set of requirements. The fuzzy set of requirements $\tilde{R} = \{\tilde{r}_i\}$ for a particular customer is defined. The fuzzy requirement agents observe what the requirements of a particular customer are, and take the corresponding fuzzy values.
- Step 2: Emergence of fuzzy product functions. It spells out functions that configuration product will support. Given the fuzzy set of customer requirements, the fuzzy set of product function agents are computed using the fuzzy relationship between requirement agents and product function agents. These agents are called active functions.
- Step 3: Emergence of fuzzy set of solutions. Solutions agents will be activating as soon as the set of active function agents emerge. Agents interact to compute the fuzzy set of solutions, called active solutions. Active solutions are computed from interaction between the set of active function agents and solution agents.
- Steps 4 and 5: Definition and integration of fuzzy set of constraints. Constraints of different process views are defined. The constraints agents observe what the requirements of a particular process view are and they decide to take the corresponding fuzzy values.
- Step 6: Emergence of consensual fuzzy set of solutions. Constraint agents interact with active solution agents to converge towards a consensual fuzzy set of solutions (respecting both of requirements through functions and constraints).

In the third phase (*fuzzy optimal solution for configuration*), the consensual solution agents through their interactions, using their affinities from the fuzzy solution agents' structure, are structured into modules. The fuzzy optimal solution agents represent a network of fuzzy solution agents which maximise the objective function. Results of this phase are given in Fig. 6. For instance, considering the solution agent *s1* as solution for the class Cl_1, its optimal network is formed by the solution agents [*s1, s6, ∅, s16*], with value of objective equal to 1.8.

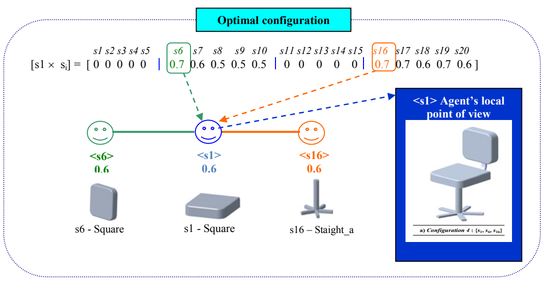

Figure 6: Configuration: local point of view of agent <s1>.

4.2 Fuzzy Roles

Considering the set $\tilde{P} = \{\tilde{\rho}_r, \tilde{\rho}_f, \tilde{\rho}_c, \tilde{\rho}_s\}$ of four roles defined in *FAPIC*: roles of *specification, function, constraint,* and *solution*. Then, the fuzzy set of roles an agent $\tilde{\alpha}_i$ plays is defined by (11):

$$\tilde{P}(\tilde{\alpha}_i) = \{\mu_{\tilde{\rho}_r}(\tilde{\alpha}_i), \mu_{\tilde{\rho}_f}(\tilde{\alpha}_i), \mu_{\tilde{\rho}_c}(\tilde{\alpha}_i), \mu_{\tilde{\rho}_s}(\tilde{\alpha}_i)\} \quad (11)$$

Figure 7 shows one of the typical partitioning proposed for the six fuzzy roles of product configuration: the repartition for the role "solution".

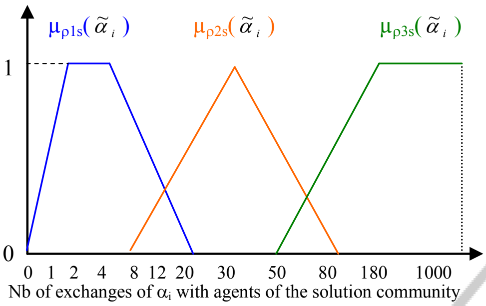

Figure 7: Membership function of $\tilde{\alpha}_i$ to the role "solution".

In this diagram, the universe *Us* is defined by the number of exchanges of $\tilde{\alpha}_i$ with agents of the solution community. 3 fuzzy subsets $\rho 1_s$, $\rho 2_s$ and $\rho 3_s$ are defined, meaning respectively "fuzzy agent plays little role", "fuzzy agent plays moderate role" and "fuzzy agent plays important role" (12-14):

$$\rho 1_s = \begin{Bmatrix} 0/0, 0.8/1, 1/2, 1/4, 0.6/8, 0.3/12, 0.1/20, \\ 0/30, 0/50, 0/80, 0/180, 0/1000 \end{Bmatrix} \quad (12)$$

$$\rho 2_s = \begin{Bmatrix} 0/0, 0/1, 0/2, 0/4, 0.1/8, 0.3/12, 0.5/20, \\ 1/30, 0.5/50, 0.1/80, 0/180, 0/1000 \end{Bmatrix} \quad (13)$$

$$\rho 3_s = \begin{Bmatrix} 0/0, 0/1, 0/2, 0/4, 0/8, 0/12, 0/20, 0/30, \\ 0.1/50, 0.4/80, 0.8/180, 0/1000 \end{Bmatrix} \quad (14)$$

with $\mu_{\rho 1s}(\alpha_i)$, the membership function of $\tilde{\alpha}_i$ in the fuzzy subsets "little role"; $\mu_{\rho 2s}(\tilde{\alpha}_i)$, the membership function of $\tilde{\alpha}_i$ in the fuzzy subsets "moderate role" and $\mu_{\rho 3s}(\tilde{\alpha}_i)$, the membership function of $\tilde{\alpha}_i$ in the fuzzy subsets "strong role".

Table 1 illustrates the behaviour of fuzzy agents. For instance, let us consider the decision rule $\tilde{\delta}_i$:

(i) $\tilde{\varepsilon}_1$:= <*inform*, $\tilde{\alpha}_{f_i}$, $\tilde{\alpha}_{r_k}$, *t = 2, V*> ;

(ii) $\tilde{\chi}_1$:= <*V = sup(0.4)*> ;

(iii) $\tilde{\gamma}_1$:= <*diffuse*, $\tilde{\alpha}_{f_i}$, $\tilde{F}$, *t=2, V*>.

This rule means that: (i) depending on fuzzy event $\tilde{\varepsilon}_1$: the fuzzy agent $\tilde{\alpha}_{f_i}$ ($\tilde{\alpha}_{f_i} \in \tilde{F}, \tilde{F} \subseteq \tilde{A}$, is a function agent) receives a message of type *t* whose value is equal to 2 by which a fuzzy agent $\tilde{\alpha}_{r_k}$ ($\tilde{\alpha}_{r_k} \in \tilde{R}, \tilde{R} \subseteq \tilde{A}$, is a requirement agent) informs $\tilde{\alpha}_{f_i}$ of its value *V*; (ii) under condition $\tilde{\chi}_1$ "*V* must be greater than the threshold value 0.4"; (iii) then action $\tilde{\gamma}_1$ is triggered: agent $\tilde{\alpha}_{f_i}$ communicates this information to all function agents of the set $\tilde{F}$.

Let us consider the Phase 2 of the configuration

Table 1: Behaviour of fuzzy agents and evolution of fuzzy roles during the step 2 of phase 2.

Behaviour of a fuzzy agent	Illustration with the fuzzy function agent $\tilde{\alpha}_{f_l}$
1) Receiving a message OR observing its environment	1) Event $\tilde{\varepsilon}_1$: receiving "*inform* $(\tilde{\alpha}_{r_l}, \tilde{\alpha}_{f_l}, V_{\tilde{\alpha}_{r_l}}, 0.7, \mu_\lambda(\tilde{\alpha}_{r_l}) = 0.8)$"
2) Computing interest (fuzzy degree) of the message or the observation	2) Knowledge of $\tilde{\alpha}_{f_l}$: $\mu(\tilde{\alpha}_{f_l}) = 0.9$; $\mu(\tilde{\alpha}_{r_l}, \tilde{\alpha}_{f_l}) = 0.7$; $\tilde{P}(\tilde{\alpha}_{f_l}) = \{\mu_{\tilde{\rho}_r}(\tilde{\alpha}_{f_l}) = 0.5, \mu_{\tilde{\rho}_f}(\tilde{\alpha}_{f_l}) = 1, \mu_{\tilde{\rho}_s}(\tilde{\alpha}_{f_l}) = 0.5, \mu_{\tilde{\rho}_c}(\tilde{\alpha}_{f_l}) = 0\}$ **Interest** $= min(\mu(\tilde{\alpha}_{f_l}), \mu(\tilde{\alpha}_{r_l}, \tilde{\alpha}_{f_l}), \mu_{\tilde{\rho}_r}(\tilde{\alpha}_{f_l}), \mu_\lambda(\tilde{\alpha}_{r_l})) = 0.5$
3) Updating fuzzy values of roles from the cooperative activity of the message sender, or in connection with observation	3) Message interest > 0.4 then changing fuzzy value of **role "*Requirement*"**: $\mu_{\tilde{\rho}_r}(\tilde{\alpha}_{f_l}) = moy(\mu_{\tilde{\rho}_r}(\tilde{\alpha}_{f_l}), \mu(\tilde{\alpha}_{r_l}, \tilde{\alpha}_{f_l})) = 0.6$
4) Consulting fuzzy rule-base and selecting fuzzy rules to be triggered (see scenario below)	4) Two kinds of rules can be triggered after the event $\tilde{\varepsilon}_1$: 4.1) related to the communication protocol: *inform/confirm* ; 4.2) related to the conditions : message interest (> 0.4), roles $(\mu_{\tilde{\rho}_r}(\tilde{\alpha}_{f_l}) \geq 0.4 \wedge \mu_{\tilde{\rho}_f}(\tilde{\alpha}_{f_l}) \geq 0.4)$, transmitted value $(V_{\tilde{\alpha}_{r_l}} \geq 0.4 \wedge \mu_\lambda(\tilde{\alpha}_{r_l}) \geq 0.4)$
5) Triggering fuzzy rules: construction and implementation of actions associated with the selected fuzzy rules	5) 2 communication acts are performed : 5.1) *confirm* $(\tilde{\alpha}_{f_l}, \tilde{\alpha}_{r_l}, V_{\tilde{\alpha}_{r_l}}, 0.7, \mu_\lambda(\tilde{\alpha}_{f_l}) = 1)$ 5.2) *diffuse* $(\tilde{\alpha}_{f_l}, \tilde{F}, V_{\tilde{\alpha}_{r_l}}, 0.7, \mu_\lambda(\tilde{\alpha}_{f_l}) = 0.6)$

process and the fuzzy agents *r1*, *f1*, *c1* and *s1* (traced agents) (Fig. 8). The fuzzy values of roles played by an agent $\tilde{\alpha}_i$ are calculated by the formula (15):

$$(n_e/n_a)/((n_e/n_a)+1) \qquad (15)$$

where n_e is the number of exchanges between $\tilde{\alpha}_i$ and agents of the community corresponding to the target role and n_a is the number of agents in the community corresponding to the target role.

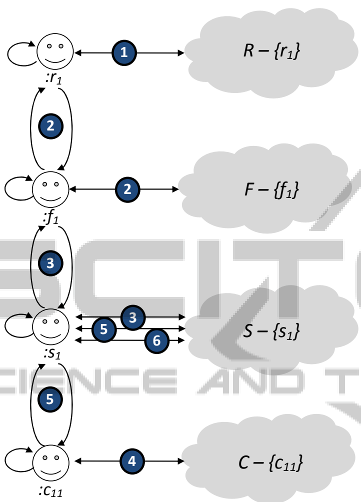

Figure 8: Illustration of Phase 2: Searching the fuzzy set of consensual solution agents.

The following tables (Table 2-7) show the change step by step of the fuzzy values of agents' roles during the Phase 2. These tables indicate for each step of the Phase 2 and each of the four tracks agents $(\tilde{r}_1, \tilde{f}_1, \tilde{c}_{11} and \tilde{s}_1)$: 1) the number of exchanges between these fuzzy agents and other fuzzy agents of *FAPIC* (inter or intra-community interactions) $\tilde{R}/\tilde{R}, \tilde{R}/\tilde{F}, \tilde{F}/\tilde{F}, \tilde{F}/\tilde{S}, \tilde{C}/\tilde{C}, \tilde{C}/\tilde{S}, \tilde{S}/\tilde{S}$), and 2) the fuzzy values of the different fuzzy roles played by the fuzzy agents (a vector of fuzzy roles corresponding to $\tilde{P} = \{\tilde{\rho}_r, \tilde{\rho}_f, \tilde{\rho}_c, \tilde{\rho}_s\}$).

Table 2: Fuzzy values of agents' roles during the step 1.

Agent	R/R	R/F	F/F	F/S	C/C	C/S	S/S	Roles
$\tilde{r}_1$	10	-	-	-	-	-	-	[0.5,0,0,0]
$\tilde{f}_1$	-	-	-	-	-	-	-	[0,0,0,0]
$\tilde{c}_{11}$	-	-	-	-	-	-	-	[0,0,0,0]
$\tilde{s}_1$	-	-	-	-	-	-	-	[0,0,0,0]

Table 3: Fuzzy values of agents' roles during the step 2.

Agent	R/R	R/F	F/F	F/S	C/C	C/S	S/S	Roles
$\tilde{r}_1$	10	1	-	-	-	-	-	[0.5,0.2,0,0]
$\tilde{f}_1$	-	1	3	-	-	-	-	[0.1,0.5,0,0]
$\tilde{c}_{11}$	-	-	-	-	-	-	-	[0,0,0,0]
$\tilde{s}_1$	-	-	-	-	-	-	-	[0,0,0,0]

Table 4: Fuzzy values of agents' roles during the step 3.

Agent	R/R	R/F	F/F	F/S	C/C	C/S	S/S	Roles
$\tilde{r}_1$	10	1	-	-	-	-	-	[0.5,0.2,0,0]
$\tilde{f}_1$	-	1	3	1	-	-	-	[0.1,0.6,0,0.1]
$\tilde{c}_{11}$	-	-	-	-	-	-	-	[0,0,0,0]
$\tilde{s}_1$	-	-	-	1	-	-	19	[0,0.2,0,0.5]

Table 5: Fuzzy values of agents' roles during the step 4.

Agent	R/R	R/F	F/F	F/S	C/C	C/S	S/S	Roles
$\tilde{r}_1$	10	1	-	-	-	-	-	[0.5,0.2,0,0]
$\tilde{f}_1$	-	1	3	1	-	-	-	[0.1,0.6,0,0.1]
$\tilde{c}_{11}$	-	-	-	-	27	-	-	[0,0,0.5,0]
$\tilde{s}_1$	-	-	-	1	-	-	19	[0,0.2,0,0.5]

Table 6: Fuzzy values of agents' roles during the step 5.

Agent	R/R	R/F	F/F	F/S	C/C	C/S	S/S	Roles
$\tilde{r}_1$	10	1	-	-	-	-	-	[0.5,0.2,0,0]
$\tilde{f}_1$	-	1	3	1	-	-	-	[0.1,0.6,0,0.1]
$\tilde{c}_{11}$	-	-	-	-	27	1	-	[0,0,0.5,0.1]
$\tilde{s}_1$	-	-	-	1	-	1	38	[0,0.2,0.1,0.7]

Table 7: Fuzzy values of agents' roles during the step 6.

Agent	R/R	R/F	F/F	F/S	C/C	C/S	S/S	Roles
$\tilde{r}_1$	10	1	-	-	-	-	-	[0.5,0.2,0,0]
$\tilde{f}_1$	-	1	3	1	-	-	-	[0.1,0.6,0,0.1]
$\tilde{c}_{11}$	-	-	-	-	27	1	-	[0,0,0.5,0.1]
$\tilde{s}_1$	-	-	-	1	-	1	57	[0,0.2,0.1,0.8]

Finally, after a full configuration, we get for fuzzy agents r_1, f_1, c_{11} and s_1 (our reference agents), the number of inter/intra-communities exchanges and the fuzzy values of roles given in Table 8.

Table 8: Fuzzy values of roles at the end of process.

Agent	R/R	R/F	F/F	F/S	C/C	C/S	S/S	Roles
$\tilde{r}_1$	220	44	-	-	-	-	-	[1,0.9,0,0]
$\tilde{f}_1$	-	11	66	220	-	-	-	[0.5,1,0,0.9]
$\tilde{c}_{11}$	-	-	-	-	1512	560	-	[0,0,1,0.9]
$\tilde{s}_1$	-	-	-	80	-	560	12800	[0,0.9,0.9,1]

This analysis shows that organizations in the proposed agent-based system *FAPIC* are fuzzy evolving systems. Indeed, dynamic adaptive organizations emerge from the fuzzy interaction of heterogeneous fuzzy agents and their fuzzy roles. The analysis of the behaviour of fuzzy agents during design collaborations has shown that the distribution of roles played by fuzzy agents is continually changing. Fuzzy agents are characterised by fuzzy organizations. The last one is the result of agents' fuzzy roles and their fuzzy interactions.

5 CONCLUSIONS

In previous work we have already shown that collaborative design is characterized by fuzzy interactions, heterogeneous, and evolving organizations (Fougères and Ostrosi, 2011). In this paper, the modelling of fuzzy agents, their fuzzy interactions, their fuzzy roles, and their fuzzy organization, are presented. During the collaborative design process, fuzzy agents grouped in communities interact and play fuzzy roles for converging to solutions of design.

A simple case study of "chair configuration" illustrates clearly our fuzzy agent-based approach. The analysis of fuzzy agents' roles during the collaborative configuration process shows that organizations within *FAPIC* platform are fuzzy evolving systems. Indeed, dynamic adaptive organizations emerge from the fuzzy interactions of heterogeneous fuzzy agents and their fuzzy roles. Furthermore, the analysis of fuzzy agents' behaviour during this collaborative design shows that the distribution of roles played by fuzzy agents is continually changing. Fuzzy agents are characterised by fuzzy organization which is the result of fuzzy roles of fuzzy agents and their fuzzy interactions.

We continue to work on a better understanding of self-organization of fuzzy agents and on the level changes of their behaviour during collaborative design activities. The current extension of *FAPIC* platform to other design tasks offers an experimental context to test the evolution of our model.

REFERENCES

Agard, B., Barajas, M., 2012. The use of fuzzy logic in product family development: literature review and opportunities, *Journal of Intelligent Manufacturing*, 23(5), pp. 1445-1462.

Deciu, E. R., Ostrosi, E., Ferney, M., and Gheorghe, M., 2005. Configurable product design using multiple fuzzy models, *Journal of Engineering Design*, 16(2-3), pp. 209-235.

Ferber, J., Stratulat, T., and Tranier, J., 2009. Towards an integral approach of organizations in multi-agent systems: the MASQ approach, in Multi-agent Systems: Semantics and Dynamics of Organizational Models, Virginia Dignum (Ed), IGI.

Fougères, A.-J., 2011. Modelling and simulation of complex systems: an approach based on multi-level agents, *International Journal of Computer Science Issues*, 8(6), pp. 8-17.

Fougères, A.-J., 2012. A Modelling Approach Based on Fuzzy Agents, *International Journal of Computer Science Issues*, 9(6), pp. 19-28.

Fougères, A.-J., Ostrosi, E., 2011. Fuzzy Agents Communities for Product Integrated Configuration, *11th Int. Conf. on Intelligent Systems Design and Applications*, November 22-24, Cordoba, Spain.

Fougères, A.-J., Ostrosi, E., 2013. Fuzzy Agent-based Approach for Consensual Design Synthesis in Product Integrated Configuration, *Integrated Computer-Aided Engineering*, 20(3): 259-274.

Ghasem-Aghaee, N., Ören, T.I., 2007. Cognitive complexity and dynamic personality in agent simulation, *Computers in Human Behavior*, 23, pp. 2983-2997.

Jennings, N. R., 2000. On agent-based software engineering," *Artificial Intelligence*, 117, pp. 277-296.

Kubera, Y., Mathieu, P., and Picault, S., 2011. IODA: an interaction-oriented approach for multi-agent based simulations, *Autonomous Agents and Multi-Agent Systems*, 23(3), 303-343.

Lughofer, E., 2011. Evolving Fuzzy Systems - Methodologies, Advanced Concepts and Applications, Springer, Berlin Heidelberg.

Monostori, L., Vancza, J., Kumara, S.R.T., 2006. Agent-Based Systems for Manufacturing, *Annals of the CIRP*, 55(2), pp. 697-720.

Ostrosi, E., Fougères, A.-J., Ferney, M., 2012. Fuzzy Agents for Product Configuration in Collaborative and Distributed Design Process, *Applied Soft Computing*, 8(12), pp. 2091-2105.

Wooldridge, M., 1997. Agent-based Software Engineering, *IEE Proceedings on Software Engineering*, 144(1), pp. 26-37.

Zadeh, L. A., 1965. Fuzzy Sets, *Information and Control*, 8, pp. 338-353.