Believable Decision for Virtual Actors

Marc Parenthoën* Jacques Tisseau* Thierry Morineau**

* Laboratoire d'Informatique Industrielle, ENIB
EA 2215/Université de Bretagne Occidentale
BP 30815, F-29608 Brest Cedex, FRANCE
{parenthoen,tisseau}@enib.fr

** Laboratoire GRESICO
Cognition Group/Université de Bretagne Sud
BP 573, F-56017 Vannes Cedex, FRANCE
morineau@univ-ubs.fr

Abstract— **This study lies in the context of cognitive ergonomy and virtual engineering. We propose to model and implement the behaviour of autonomous virtual agents, using ideas from psychology (fuzzy cognitive maps, affordances) and neurophysiology (active perception). We describe the basis for a behavioral model imitating human beings' perceptive operation. The psychological notion of "affordance" will help us in the construction of cognitive maps for virtual actor's behaviour specification.** *Sensus* **Alain Berthoz, neurophysiologist, perception is not only an interpretation of sensorial messages: it is also an internal simulation of the action and an anticipation of the consequences of this simulated action. Following neurophysiological experiments on hippocampus in which were observed oscillations permitting prediction of trajectories, our virtual actor simulates its own behaviour in an imaginary space. This simulation in the simulation allows him to predict the consequences of actions. The expected benefit from our model consists in elaborating a believable virtual helmsman within the framework of a virtual sailing ship. We have implemented such a virtual actor in the multi-agent environment** ***oRis*****.**

Keywords— **Active Perception, Affordance, Autonomy, Believable Virtual Actors, Fuzzy Cognitive Map (FCM)**

I. Introduction

This study lies in the context of virtual engineering and human information systems. We propose to model and implement the behaviour of virtual believable agents [Bates 92], [Magnenat 91], [Perlin 95], using ideas from some psychologists [Tolman 48], [Gibson 58] and neurophysiologists [Berthoz 97], [Buzsaki 92]. Virtual worlds are peopled with autonomous entities improvising in free interaction [Hayes-Roth 96]. Autonomous entities is one of the keys for believable virtual human creation [Thalmann 00]. Autonomy rests on sensorimotor autonomy: each entity is equipped with sensors and effectors enabling it to be informed and to act on its environment; an autonomy of execution: the execution controller of each entity is independent of the controllers of the other entities; an autonomy of decision: each entity decides according to its own personality (its history, its intentions, its state and its perceptions). Autonomization of a model consists in giving to it a sensorimotor interface and also a decision module so that it could adapt its reactions to inner and extern stimuli. At the opposite from an avatar which control is provided by a human operator, an animat must compute it-self this control for coordonating its perceptions and its actions [Meyer 91]. One could distinguish three main types of computational models: descriptive, causal and behavioral [Arnaldi 94]. We propose in this article the basis for a behavioral model imitating human beings' perceptive operation.

We use Fuzzy Cognitive Maps (FCMs [Kosko 86]) for specifying agent's behaviour (graph structure) and for controlling its movement (FCM dynamic) in the multi-agents environment *oRis* [Harrouet 00]. Thus, an FCM owns perceptive concepts activated by the fuzzyfication of agent's sensors. It owns motor concepts which activations are defuzzyfied to be sent to agent's effectors. Intermediate concepts translating agent's inner state and are used by FCM dynamic calculus. We distinguish sensation from perception: sensation is resulting from sensors only, but perception is sensation influenced by inner state. An FCM allows the modelling of perception thanks to link between innner concepts and sensitive concepts. A self-perceptive agent can also use an FCM in an imaginary space and simulate a behaviour [Maffre 01]. We argued that FCMs are a great tool for autonomous agents' behaviour specification, control and prediction [Parenthoen 01].

The psychological notion of "affordance" will help us in the construction of FCMs for believable virtual human behaviour specification. Researches in ecological psychology show that individuals base their behaviours on certain critical pieces of information provided by their immediate environment and relating perception and action. These pieces of information called "affordances" are directly perceived without cognitive effort and drive the modalities of action [Gibson 58]. In cognitive ergonomics, the notion of affordance is a scope for user interface development [Vicente 90], wich is named "ecological interface" [Flach 96] for information system design [Jordan 98] or work analysis [Lahlou 00]. Concerning human-VR interaction, researchers have underlined the necessity to display affordances in order to immerse the subject for helping interaction [Cronin 97]. In the field of experimental psychology, some recent works propose to model affordances through equations [Stoffregen 99]. Nevertheless, these models elaborated in laboratory are based on a relation between an individual and a single affordance. Approaching affordances in a real or virtual environment requires a model showing how individuals select an affordance among the others. We argue that FCMs can be a good modelling for affordances selecting, using the attractor of an FCM constructed by affordances. Furthemore, in a virtual world it is essential that artificial entities act with believable behaviour [Mateas 97]. The appraise of a sensorimotor activity driven by intentions (like sailing) allows the extraction of affordances and their relations, as the expert explains his activity. Then, from the appraise we can extract affordances-based FCMs that could drive a virtual agent. Such an agent behaves according with expert description, then increases its believability. We argue that affordances-based FCM is a very usefull tool for believable agent prototyping in virtual worlds.

As an affordances-based FCM drives the modalities of actions, we need a model of the action for increasing believability and autonomy. Neurophysiology assiociates perception of movement with permanent and coordinated fusion of various sensors: proprioceptive, vestibular and cutaneous receptors [Lestienne 95]. But this multisensorial informations are combined with signal coming from brain which controls the motor command of muscles. Perception is not only an interpretation of sensorial messages: it is also an internal simulation of the action and an anticipation of the consequences of this simulated action [Berthoz 97]. For understanding the brain's role in active perception, we need to begin with what goal the organism want to reach and we need to study how the brain will ask its sensors, by specifying estimated values in function of the internal simulation of the predicted consequences of this action. Each affordance is associated with a predicted sequence of sensorimotor configurations. Following neurophysiological experiments on hippocampus in which were observed oscillations permitting prediction of trajectories [Buzsaki 92], [Lisman 95], our virtual actor can also use an FCM in an imaginary space and simulate a behaviour. This simulation in the simulation allows him to predict the consequences of an action. On one hand, it can sporadically verify state of its sensors while performing an action and then control the coherence of the prediction, on the other hand it has the ability to choose an action among possible ones, not by logical reasonning about an abstract representation of the world, but by simulating its behavior model. We call these abilities for virtual agent the proactive perception.

The expected benefit from our affordance-based and proactive model consists in elaborating a "human-like" virtual helmsman, with a believable behaviour for sailors, facilitating man-machine cooperation and within the framework of a virtual sailing ship intended for sporting drive. We have implemented such a virtual actor in the multi-agent environment *oRis* [Harrouet 00]. As we dispose of data-recording of a racing sailing ship, we compare the virtual skipper thus prototyped with the human helmsman.

In the following section we describe the psychological affordance-based model and the FCM modelling for affordance selection. Next section presents neurophysiologic notion of active perception and what we call proactive perception for virtual actors. In Section 4, a believable proactive virtual helmsman is specified, then implemented in the multi-agent environment *oRis* and compared with a real helmsman.

II. Affordance-Based FCM

Precedent work shows that FCMs can specify, control and predict perceptive actors' behaviours [Parenthoen 01]. This section is a guide for construction of believable actors' FCMs using psychological notion of affordance. Furthemore, such a work proposes the basis for a model showing how individuals select affordance among others.

A. Psychological Model of Activity

From researches in ecological psychology, *Sensu* Gibson, Affordances are critical pieces of information provided by immediate environment, relating perception and action, directly perceived without cognitive effort, driving the modalities of action. Landmarks, gateways, pathway, obstacles are the most common ones, but not any exhautive list seems to exist. To study affordances during activity, we must consider three elements defining environment-human interaction: environment, agent & tool. The environment is a set of objects (or other agents) and physical laws having properties that constitute potential affordances for agent and its tool. The agent has got physical and sensorimotor features defining perceptual and motor fields for affordance capturing (field of view, maximal reaching distance, *etc.*). Agents are also located in spacio-temporal dimension. Tools possess a function determining the field of action. It is also a medium between environment and agent for affordance collecting. The interaction between environment-tool-agent generates affordances processed by the agent.

An environmental property or affordance called $\mathcal{P}$ would provide an attractive or a repulsive effect on agent or tool in regards with the agent's activity. During a locomotion activity, obstacles would be considered as providing a repulsive effect. Then $\mathcal{P}$ is repulsive. while pathway, gateway, landmark correspond to objects having attractive effect. Then $\mathcal{P}$ is attractive.

In the frame of tool utilisation, we suppose that the **absolute value** of affordance for any environmental property $\mathcal{P}$ would be equal to the sum of dependency relationship between the feature of tool and $\mathcal{P}$. A dependency relation is observed when $\mathcal{P}$ is concerned with tool feature during a mutual contact. For instance, the width of a door $\mathcal{P}$ will be in dependency with the volume of the crossing tool.

A property $\mathcal{P}$ will be more or less accessible to agent & tool. $\mathcal{P}$ **accessibility level** can be divided in two components. Fist component is **perceptual** accessibility, wich depends on the perceptual agents' field and on the feature of the tool as a medium to transmit affordances. An affordance would be more or less available in perceptual field and thus it would have a different level of effect on agent. Second component is a **motor** accessibility, which depends on the field of action available for agent and tool. In the same way, the position of affordance in the field of action would bring it a different weight. For instance, if we consider tool or agent's speed as constant, then we can define accessibility as a perceptual or motor distance between $\mathcal{P}$ and the agent with the tool.

At moment t, a property will hold a **relative value** in terms of affordance, which is its absolute affordance value weighted by its perceptual and motor accessibilities.

The selection of one affordance among others is not restricted to the choise of the affordance with highest relative value. All the agent's unconcious knowledge is required for this operation. We propose in the next subsection to use FCM for modelling this selection, in the case of a specialised activity. We argue that it's possible to construct a FCM for the creation of believable virtual agent, when this activity can be appraised in terms of affordances.

B. Perception of Affordances via FCMs

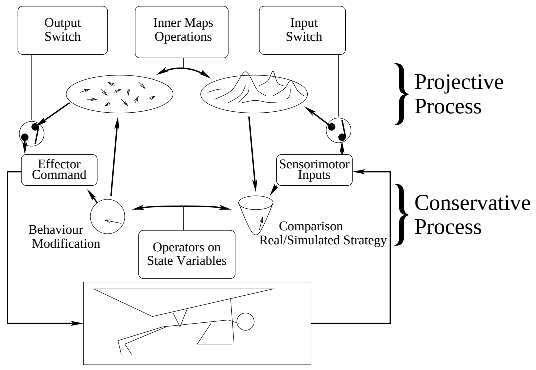
The goal of this subsection is to describe how to construct a believable virtual autonomous agent for the realisation of a given activity. The use of psychological affordance-based model is a scope for believability or efficiency. This study is possible if an expert can list (in interaction with psychologist) a set of required affordances for this activity.

- **Concepts**: affordances proposed by expert are the concepts of an FCM $\mathcal{F}$.
- **Sensation of affordances**: an expert of this activity gives a formula of the **absolute affordance values**. This formula could be in function of virtual agent sensors and fuzzy rules. This gives us a new extern activation value of the concept related to this affordance for $\mathcal{F}$ at each time ending formula evaluation. Between two evaluations, extern activation value could be null or equal to the last calculated one.
- **Perception of affordances**: In the framework of **affordance accessibility level** and FCM, the formalisation of expert knowledge could help to choose boxes for arc weights between concepts. A part of expert knowledge can be translated into inhibition/excitation relations between affordances, then into a link matrix for $\mathcal{F}$. For instance, obstacles could inhibit pathway, gateway & landmarks, gateway could inhibit themselves.

The FCM thus obtained can be connected to the virtual agent as explained in [Parenthoen 01]. This affordance-based FCM should drive a behaviour corresponding to the given activity according to expert. This cognitive activity is the first browsing of the environment to work out a network of affordances. Once an affordance is selected, it triggers off the associated strategy of trajectory. These affordances are given with the assistance of an expert, but the browsing activity being strongly nonconscious [Spence 99], it is necessary to validate in experiments the relevance of the affordance network.

III. Virtual Active Perception

Brain can be considered as a biological simulator which predicts using its memory and making hypothesis about internal modelling of the phenomenon. Let's take a sportman as an example: he will mentally and predictivly go though the evens of the performance in the same time he will performe it, and sporadically verify his sensors' states. The inner simulation of movement is made easier by a neuronal mecanism of inhibition. Brain possesses a biological modelling of the action to be performed. It does not only compare sensorial with memorised informations, it also uses anticipatory mecanisms (Figure 1 [Droulez 88]).



During an action, the brain uses two modalities in parallel. A predictive or projective one for selecting sporadicaly the state of some sensorimotor sensors. And a reactive or concervative one for holding some variables in boxes defined by action intentions. The brain would lost too much time in controlling every time all the sensors.

Fig. 1. The two Modalities of Movement Control by Brain

Let's take an agent which behaviour is specified by an affordance-based FCM. Each affordance belonging to this FCM is associated with a specific strategy of trajectory, described by a sequence of sensorimotor configurations. An expert gives these caracteristic sensorimotor configurations associated to each affordance. If the affordance selection is correct, then the prototypic sequence of sensorimotor configurations should be observed. The simulation of behaviour in imaginary space is synchronized with the real time behaviour of the virtual actor. This synchronization follows neurophysiological experiments on hippocampus in wich were observed oscillations permitting prediction of trajectories [Buzsaki 92], [Lisman 95]. A low frequency oscillation ask the context of the action to the FCM. During one of this cycle, a high frequency oscillation synchronizes the prototypic sensorimotor configurations with the real time observations by pattern matching. This pattern matching between configurations and observations is only done on the prototypes associated with the affordance selected by the FCM. The frequency ratio of these oscillations is equal or greater than the number of configurations in this prototypic sequence. The virtual agent then go through the sequence of configurations discribing the contextual strategy, always anticipating to reach the next configuration. If the pattern matching fails on every configurations, then a new context is asked to the FCM, inhibitting the current selected affordance and memorizing sensorimotor features of the last low frequency cycle. The agent will virtualy run (with low calculus priority) in its imaginary space these stored sensorimotor features for various affordances. Then the agent chooses the one which best fits this low frequence cycle sensorimotor features according to the predicted prototypic sequence. This choise permits an hebbian modification of the FCM weigths, exciting the chosed affordance and inhibiting the others.

IV. Virtual Believable Helmsman

Within the framework of the realization of a virtual sailing ship intended for sporting drive, it is significant to give believable behaviour to virtual sailors. Such virtual sailors have to be able to act, within a virtual marine universe, as a helmsman could pilot, as a reglor could play on the veils and as a tactician could choose strategies of navigation. The behaviour of the sailing ship must be qualitatively compatible with anticipations of a real sailor. For that, it is necessary to understand the affordances which a sailor uses to locate himselve on the waves and to choose a trajectory. Indeed, the more the extraction of affordances is pertinent, the more believable will be the virtual sailing ship thus prototyped. This section describes the begining of the construction of a virtual believable helmsman using affordance-based FCMs and active perception.

A. Affordance-Based FCM Construction

The marine environment is extremely complex. The parameters involve the state of sea (waves), the weather evolution (wind), the trim, the power and the tiredness of the sailing ship, and of course the sailor. However, there are prototypic behaviours of sailing ships with systematical reactions according to most sailors. Sailing expert knowledge permits the construction of an affordance-based FCM. This FCM selects one affordance among others and drives the behaviour of a virtual helmsman. After a light appraise about open sea sailing (one of us being a sailor), we established some affordances guiding trajectories' choice when sailing back winds and sea. There are **Landmarks** (*Course*: constant gyroscope, compass; *Trim*: constant wind-vane), **Gateways** (*Restart*: to explore front wind road for increasing speed; *Back wind VMG*: to explore back wind road compensating restarts), **Obstacles** (*Luff*: converge towards a dangerous blocking with windward side; *Jibe-luff*: converge towards a very dangerous blocking jibe), **Specific & Physic** (*Surfing or Not*: surfing is the state of a sailing ship which speed passes a critical threshold, a sailing ship then can go temporarily more quickly than a wave; *Moments' equilibrium and control*: the formula (*Eq.*1) results from physical study. It is based on the piloting description as a compensation by the rudder blade effect of the various couples unbalancing a sailing ship around the vertical axis).

$$v_{\text{boat}}^2\theta_{\text{helm}} = \left| \begin{array}{c} \mu_{\text{c}}\Delta_{\text{compass}} + \mu_{\text{t}}\Delta_{\text{trim}} + \\ \mu_{\text{r}}\theta_{\text{roll}} + \mu_{\delta\text{r}}\delta\theta_{\text{roll}} + \mu_{\delta\text{c}}\delta\theta_{\text{compass}} \end{array} \right. \qquad \text{(Eq.1)}$$

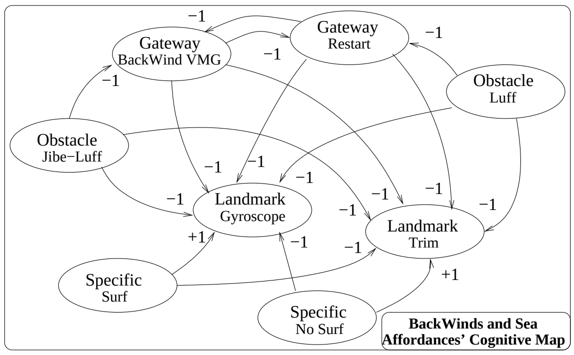
It should be known that a sailor can steer his ship by foggy night. The visual aspect of the sea is thus replaceable by feelings of gyroscopic balance with crisp compass attention to consider the average navigation direction. The direction and the force of the wind is felt jointly by hearing and touching. Surfing is characterized by special noise appearing above critical speed. It should be thus possible to activate these affordances starting from sensors indicating, on the one hand sailing ship pitching, rolling, direction and speed, on the other hand the direction and the force the wind blows.

In this paper, we cannot describe all the affordance values of the environmental properties during sailing. It is too comlex and it is not the place to list them all. However, as an example, we detail absolute affordance value for the luff property in table I. This example can be translated in terms of fuzzy rules on virtual helmsman sensors. Then this gives a formula for absolute luff affordance value or for the extern activation of the luff concept in the FCM.

TABLE I
Luff Sensorimotor Properties

Wave			**Trim**	
before crest or after trough			Back winds to Side winds	
Speed	Pitching	Lodging	Compass	Wind vane
stable, weak or average	front or forwards	unstable backwards wind	stable or unstable towards wind	back winds, stable or unstable towards luff

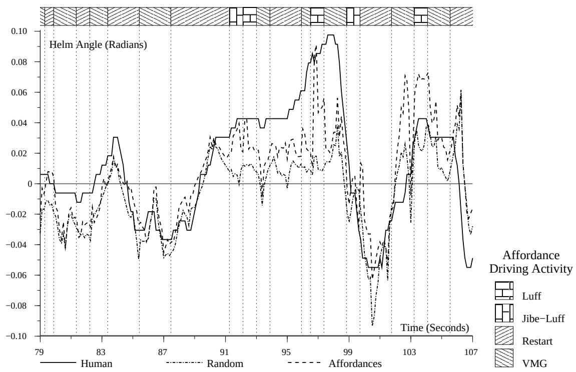
In this first study, only landmarks, gateways, obstacles and surfing or not surfing are selected for FCM extraction. Figure 2 illustrates the resulting FCM from expert knowledge on perception of affordances. Then, we may have a model determining the role of a helmsman on board of a sailing ship with back winds and sea. He can talk about what he feels as a real helmsman could do to cooperate with the reglor and the navigator.



The not specific affordances are organized so that the gateways and the obstacles inhibit the landmarks, the obstacles inhibit the gateways and the gateways inhibit them-selves. Surfing excites gyroscopic affordance and inhibits trim affordance, while the surf absence makes the opposite. Extern activations result from sensorimotor fuzzyfications and FCM dynamic selects an affordances according to sailor's knowledge.

Fig. 2. Back Winds Affordance-Based Cognitive Map

Each affordance of this FCM drives the modality of the action. For reactive behaviour, according to (*Eq.*1), a 5^{uplet}, $(\mu_{\text{c}}, \mu_{\text{t}}, \mu_{\text{r}}, \mu_{\delta\text{r}}, \mu_{\delta\text{c}}) \in I\!R^5$ is associated with each no specific affordance. Experimental validation of this affordance-based model uses real records of a sailing ship. This sailing ship was named "ARéVi/oRis" during the Mini-Transat race of 1997. Piching, lodging, compass, speed of boat, wind-vane and helm angle were recorded at 8 Hz during all the crossing of atlantic ocean. As the Mini-Transat'97 is a solo-race, helmsman was the skipper or an automatic pilot. We choose from data some domain $\mathcal{D}$ recorded on human performance during 5 minutes. Then $\mathcal{D}$ is partitionned in 6 subsets $\mathcal{D} = \cup \mathcal{D}_i$ using two different methods: randomized partitions and partition using affordances selected by virtual helmsman FCM dynamic. The 6 subsets thus obtained correspond to obstacles, gateways & landmarks. On each subset $\mathcal{D}_i$ we calculate by Mean Last Square (MLS) the identification of the formula ($Eq.1$). These identifications give six 5^{uplet}, $(\mu_c, \mu_t, \mu_r, \mu_{\delta r}, \mu_{\delta c})_i \in I\!R^5$ optimum for MLS on $\mathcal{D}_i$. Results are the following: in the space $I\!R^5$ of coefficients, distances between optima are twice higher with affordances than without. This means a better differentiation between behaviours associated with affordances. Quadratic error on the whole domaine $\mathcal{D}$ remains similar using affordances or not, but quadratic error is not necessary pertinent for beliviability.



The FCM controls contextual driving. The human helmsman behavior is compared with reactive comportements of virtual helmsmen following equation ($Eq.1$) indentified by MLS on the whole recording set or on a partition given by the affordance-based FCM. 6 waves went under the boat during these 28 seconds and context changed 20 times for almost 40 allowed ones by a low frequency oscillation value $\frac{4}{3}$Hz.

Fig. 3. Human and Virtual Helmsmans

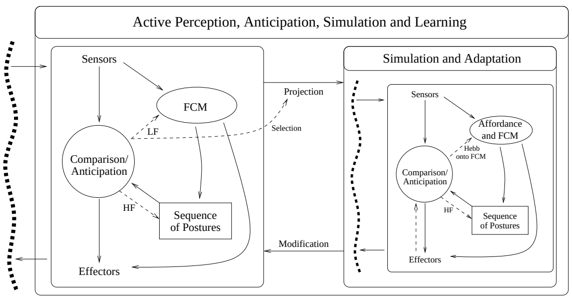
The figure 3 illustrates the mime of the real helmsman by our formula and some differences of behaviour belonging to affordance-based system. Differences appear sporadically, but during the Boc-Challenge'98, the great french sailor Isabelle Autissier was the victime of such a short time mistake due to her automatic pilot system. Such small differences always appear at critical moments and affordance-based system always goes to the good side. For these reasons, we argue that affordance-based FCM realises a more believable helmsman. The contextual formula ($Eq.1$) gives pure reactive behaviour. Because of the lack of prediction, virtual helsman's movement presents ocsilations which are not observable in the real helmsman behaviour.

B. *Active Perception Implemented*

The activation of FCM by fuzzyfication of sensors determines affordance choise *via* FCM dynamic following a low frequency oscillation. The virtual helmsman then uses this selected affordance to adopt a suitable strategy. Such a strategy is chosed when the oscillation begins. If the frequency is too low, the context could change before the end of the oscillation. If this is not detected, the behaviour could be dramatic. If the frequency is too high, calculus load increases and adaptations to each new context will provoque a lack of believability: too much energy consuming from a human point of view. Even if frequency is low, the virtual helmsman should be able to synchronize its low frequency oscillation with pertinent perception of the environment. Each affordance is also associated with a specific strategy of trajectory, described by a sequence of sensorimotor configurations. An expert gives these caracteristic sensorimotor configurations. As an example, we detail such a sequence of configurations (here 3 postures) associated with the restart affordance:

1. Posture $(\theta 1_{\text{helm}}, \Delta 1_{\text{compass}}, \Delta 1_{\text{trim}})$. Calculate only once $\theta 1_{\text{helm}}$ using the reactive process ($Eq.1$) with restart coefficients and $(\Delta 1_{\text{compass}} = \Delta_{\text{compass}} - 5^o, \Delta 1_{\text{trim}} = \Delta_{\text{trim}} + 10^o)$. Inibit the reactive processus and observe compass trim and lodging variations: when $\theta_{\text{helm}} = \theta 1_{\text{helm}}$, should be observed $dh < 0,\ dc > 0$ (else should have been selected jibe-luff affordance) and dr under mean + standard deviation (else should have been selected luff affordance).
2. Posture $(\Delta 2_{\text{compass,trim}} = \Delta 1_{\text{compass,trim}}, v2_{\text{boat}})$. Use unhibited reactive process ($Eq.1$) with $\Delta 2_{\text{compass,trim}}$ for calculating θ_{helm} dynamically. Observe only the speed v_{boat}. It should increase greater or equal to $v2_{\text{boat}}$. If not increasing ask a new low frequence oscillation affordance selection.
3. Final Posture $(v_{\text{boat}} \geq v2_{\text{boat}})$: use then the usual unhibited reactive process ($Eq.1$) with the restart coefficients and ask a new low frequence oscillation affordance selection.

If the first configuration leads to mistake, then the last low cycle of sensorimotor features is memorized and the agent virtualy runs in its imaginary space this cycle for various affordances and chooses the one with lowest mistake. This choise permits the modification of links between concepts following hebbian principle [Kosko 88], [Dickerson 94] and respecting the prototypic FCM (figure 4).



Picture of the active perception model structure for virtual actors. The FCM selects an affordance. Then a strategy is starting, consisting in a sequence of postures characterized by sensorimotor configurations. The expected configurations are compared to sensors then synchronyze the HF sequence when recognition occurs, if fails, that puts in phase the LF oscillation of the FCM and projets onto simulation mode the last LF cycle having led to anticipation mistake. This recorded cycle is played in a imaginary space, forcing affordances to choose the most adapted one, then modifies by hebbian learning FCM links.

Fig. 4. Simulation in the Simulation

V. Conclusion & Perspectives

FCM tool permits specification, control, prediction & learning behaviour for autonomous emotional and perceptive agents. It is a usefull model for defining autonomous actors in virtual worlds.

The concept of affordance comes out from research in ecological psychology. This notion allows making a conceptual bridge between environmental properties and skills commonly engaged by human to perform his adaptation. In order to go beyong the simple metafor, we are trying to explicit the principles on which the affordance processing is based. This attempt drives us to define a framework to assit the formalisation of autonomous believable virtual actors. Moreover, affordance-based FCMs can help in experimental psychology for the formalism of affordance selection among others.

Sensu neurophysiologists, perception is not only reactive, it is also internal simulation and anticipation. Implemented for virtual actors by a simulation in the simulation following oscillating cycles observed in hippocampus, the active perception or proaction increases their autonomy and believability. We are conviced that it is one of the key for autonomous virtual human, especially for learning a specific behaviour starting from a prototypic expert's description.

The sailor's affordances determination seems relevant for believable virtual marine environment realization. However, the principal FCMs difficulty lies in their construction: it is necessary to extract the relevant concepts and to determine links between these concepts. The theoretical framework of the affordances brought by the psychologists facilitates their creation with the assistance of an expert. The adjustment of the weights between the concepts remains difficult, even if active perception could show a pathway to hebb type adaptation.

References

[Arnaldi 94] Arnaldi B., *Modèles physiques pour l'animation*, Habilitation à Diriger les Recherches (HDR), Rennes-1 University, France, 1994.

[Bates 92] Bates J., Virtual Reality, Art, and Entertainment, *Presence*, 1(1):133-138, MIT Press, 1992.

[Berthoz 97] Berthoz A., *Le sens du mouvement*, Odile Jacob (eds), Paris, France, 1997.

[Buzsaki 92] Buzsaki G., Horvath Z., Urioste R. Hetke J. and Wise K., High frequency network oscillations in the hippocampus, *science*, 256:1025-1027, 1992.

[Cronin 97] Cronin P., *Report on the application of virtual reality to education*, Report, HCRC, University of Edinburgh, 1997.

[Dickerson 94] Dickerson J.A., Kosko B., Virtual Worlds as Fuzzy Cognitive Maps, *Presence*, 3(2):173-189, MIT Press, 1994.

[Droulez 88] Droulez J. and Berthoz A., *Servo-controlled (concervative) versus topological (projective) modes of sensory motor control*, Disorders of Posture and Gait, Bles and Brandt T. eds, Elsevier, 83-97, Amsterdam, 1988.

[Flach 96] Flach J.M., Bennet K.B., A theoretical framework for representational design, *Automation and Human Performance: Theory and Application*, 65-87, 1996.

[Gibson 58] Gibson J.J., Visually controlled locomotion and visual arientation in animals, *British Journal of Psychology*, 49:182-194, 1958.

[Harrouet 00] Harrouet F., *oRis: s'immerger par le langage pour le prototypage d'univers virtuels à base d'entités autonomes*, Thèse de Doctorat, Brest, France, 2000.

[Hayes-Roth 96] Hayes-Roth B., Van Gent R., Story-making with improvisational puppets and actors *Technical Report KSL-96-05*, Stanford University, 1996.

[Jordan 98] Jordan T., Raubal M., Gartrell B., Egenhofer M.J., An affordance-based model of place in GIS, *Eighth International Symposium on Spatial Data Handling*, 98-109, Vancouver, Canada, 1998.

[Kosko 86] Kosko B., Fuzzy Cognitive Maps, *International Journal Man-Machine Studies*, 24:65-75, 1986.

[Kosko 88] Kosko B., Hidden patterns in combined and adaptative knowledge networks, *International Journal of Approximate Reasoning*, 2:337-393, 1988.

[Lahlou 00] Lahlou S., Attracteurs cognitifs et travail de bureau, *Intellectica*, 30, 2000.

[Lestienne 95] Lestienne F., Equilibration, *Encyclopædia Universalis*, 8:597-601, Paris, France, 1995.

[Lisman 95] Lisman J.E., Idiart M.A.P., Storage of short term memories in oscillatory subcycles, *Science*, 267:1512-1515, 1995.

[Maffre 01] Maffre E., Tisseau J., Parenthoën M., Virtual Agents Self-Perception in Virtual Story Telling, *ICVS'01 proceedings*, 155-158, Springer LNCS 2197, 2001.

[Magnenat 91] Magnenat N., Thalmann D., Complex Models for Animating Synthetic Actors, *IEEE Computer Graphics and Applications*, 11(5):32-44, 1991.

[Mateas 97] Mateas M., An Oz-Centric Review of Interactive Drama and Believable Agents, *Technical Report CMU-CS-97-156*, Carnegie Mellon University, 1997.

[Meyer 91] Meyer J.A., Guillot A., Simulation of adaptative behavior in animats: review and prospect, *from Animals to Animats'91 Proceedings*, 1:2-14, 1991.

[Parenthoen 01] Parenthoën M., Reignier P., Tisseau J., Put Fuzzy Cognitive Maps to Work in Virtual Worlds, *Fuzz-IEEE'01 proceedings*, 1:P038, 2001.

[Perlin 95] Perlin K., Goldberg A., Improv: a system for scripting interactive actors in virtual worlds, *Computer Graphics*, 29(3):1-11, 1995.

[Spence 99] Spence R., A framework for navigation, *International Journal of Human-Computer Studies*, 51:919-945, 1999.

[Stoffregen 99] Stoffregen T.A., Gorday K.M., Sheng Y-Y., Flynn S.B., Perceiving affordances for another person's actions, *Journal of Experimental Psychology: Human Perception and Performance*, 25:120-136, 1999.

[Thalmann 00] Thalmann D., Challenges for the Research in Virtual Humans, *Workshop Achieving Human-like behavior in interactive animated agent*, Barcelona, Spain, 2000.

[Tolman 48] Tolman E.C., Cognitive Maps in Rats and Men, *Psychological Review*, 42, 55, 189-208, 1948.

[Vicente 90] Vicente K.J., Rasmussen J., The ecology of human-machine systems II: mediating "direct perception" in complex work domains, *Ecological Psychology*, 2:207-249, 1990.