Agent-based interaction analysis of consumer behavior

Lamjed Ben Said
FTR&D / LIP6
2, avenue Pierre Marzin - 22307 Lannion Cedex – FRANCE
lamjed.bensaid@rd.france-telecom.com

Thierry Bouron
FTR&D
38-40 rue du Général Leclerc 92794 Issy les Moulineaux cedex 9 PARIS FRANCE
thierry.bouron@france-telecom.com

Alexis Drogoul
LIP6
Case 169 - Université Paris 6, 8 rue du Capitaine Scott 75015 PARIS FRANCE
alexis.drogoul@lip6.fr

ABSTRACT

Our goal is to create a virtual consumer population that can be used for simulating the effects of marketing strategies in a competing market context. That requires having a consumers' behavioral model allowing the representation of observed individual behaviors and the simulation of a large population of consumers. That also requires finding the parameters' values characterizing the virtual population that reproduces real market evolutions. This paper proposes a consumer behavioral model based on a set of behavioral primitives such as imitation, conditioning and innovativeness, which are founded on the new concept of behavioral attitude. It shows that this model provides an interpretation of the main concepts and cognitive features, issued from marketing research and psycho-sociology works on consumption. The paper presents also the CUstomer BEhavior Simulator (CUBES), which has been realized for implementing the customer model and leading multi-agents simulations. It shows how genetic algorithms (GA), in addition to multi-agent systems, are used to fit the characteristics of the virtual consumers' population into a global realistic market behavior.

Categories and Subject Descriptors

I.2.11 [**Computing Methodologies**]: Artificial Intelligence – Distributed Artificial Intelligence – *Multiagent systems.*

General Terms

Algorithms, Economics.

Keywords

Multi-agent simulation, consumer behavior.

1. INTRODUCTION

There is a growing concern in the socio-economic science community for the use of agent-based simulation (ABS) to give new insights into several phenomena, which are often difficult to analyze with standard methods [5]. In fact, ABS offers to specialists a set of powerful prospective tools for analyzing, observing and explaining the evolution of social norms and institutions, and the emergence of collective behavior within specific contexts. Our research investigates the contribution of such analysis methodology to build a new marketing approach for studying consumer behaviors in competing markets [8].

More precisely, the objectives of the CUBES project (CUstomer BEhavior Simulator) are to develop a software for simulating consumer behaviors in a competing market including several brands and to build a virtual population of consumers including several thousands of individuals, that reproduce real market properties (segmentation, evolution) independently of a given product. CUBES provides the simulation of (1) *behavioral attitudes* (BA) of consumers, (2) impacts of consumption acts resulting from these attitudes, (3) retroactive effects of these acts on the consumers themselves, (4) brand reactions to the market evolutions and their retroactive effects on the individual behavioral attitudes. We have defined an integrating theoretical framework that has been used to specify the main concepts related to the study of consumer behaviors. One of the key properties that distinguish CUBES model from prior consumer models is that CUBES takes into account, not only individual cognitive features, but also interactions between consumers or specific segments that occur in real consumers' populations.

This paper presents a multi-agent based simulation of consumer behaviors. It introduces an original behavioral model used to perform a series of simulation experiments. We show through the experiments' results that macro emergent market phenomena could be explained in terms of basic behavioral attitudes such as imitation, innovativeness and mistrust. The paper addresses also the issue of calibrating the consumer agent population using a GA method.

The paper is organized as follows. The second section explains the need for a new analysis and modeling approach to simulate large consumer populations in order to observe the behavior evolution within different consumer segments facing divers marketing strategies. It presents also an integrating theoretical framework for studying consumer behaviors. The third section presents the CUBES model and shows how interaction aspects are taken into account and how it covers the basic concepts issued from marketing, psychology and sociology research fields. The forth section presents experimentations where GA have been used to calibrate the initial consumer agent population. In the fifth section, conclusions are drawn and perspectives of further research are outlined.

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2. BREAK WITH PREVIOUS APPROACHES AND THEORETICAL FRAMEWORK

2.1 Why do we need an agent-based analysis of consumer behaviors?

Consumers interact, through processes such as imitation and conditioning, with individuals and groups of individuals (friends, family, etc.). In addition to these interactions, the brands' advertising campaigns influence the consumers' choices. Brands refer here to service suppliers or product distributors. The consumers' purchasing or adoption decisions influence reciprocally the brands' marketing policy. Interactions between the different actors (consumers and brands) of a given market can be analysed to study consumers' behaviors.

2.1.1 From Traditional Marketing Analysis …

Several behavioral models have been proposed during the last three decades. These models have generally intended to provide a global vision of the purchase decisional process. Fundamental studies were led mainly in the sixties [2][14]. These works describe individual behavioral components. More recently, models resulting from marketing works, such as [9], tend to reduce the complexity of the preceding models in order to obtain operational marketing decision tools. These models provide a general outline of the consumer behavior but give few operational descriptions of the considered cognitive processes. Consequently they are not well suited for designing operational behavior models to be used for simulating several thousands of consumers. In addition to this, these models do not consider the social dynamics expressed by the different types of interactions within the real market. This limitation restricts the efficiency of such models and encouraged us to propose a novel modeling approach based on the interaction analysis to study consumer behaviors.

2.1.2 To Agent-Based Interaction Analysis …

The CUBES modeling approach of consumer behaviors is in break with aforementioned consumer behavior models in the sense that, contrary to these ones, the CUBES approach is not based exclusively on the cognitive representation of the consumer. A central issue in our agent-based simulation model is the interplay among individual behavioral and socio-economic profiles and the interaction rules (including interaction rules between different groups or consumer segments) [6].

Moreover our approach is not targeted on a given population segment and a given type of product. A strong assumption of our approach is that it is possible to provide interpretations of behavior in general, and of consumption in particular, in terms of elementary attitudes related to behavioral primitives such as imitation, opportunism and mistrust that are not specific to the purchase behavior. The combination of these attitudes gives a behavioral profile description that determines the consumer purchase decisions in a market. These attitudes are intended to be fundamental and operational (Cf. section 3).

In order to represent interactions occurring in real consumer populations, CUBES introduces stimuli based on promotional offers, brand loyalty, innovation diffusion and recommendations.

2.2 Theoretical framework

Consumption has been considered according to several points of view that we have merged into an integrating consumer theoretical framework. For a more detailed presentation see [8].

From a sociological point of view, consumption is considered as an activity related to the sociability relationships between individuals belonging to different social *groups*. Groups (family, friends, social class) refer to sets of individuals sharing common values. They constitute a privileged network for interacting and exchanging information. Groups, according to their cohesion degree, influence more or less the consumer purchase decisions. Two main concepts are introduced in this context which are *innovation diffusion* and *opinion leaders* [14][15].

From a psychological point of view, studies relative to the consumer behavior are interested by the cognitive information processing leading to brand comparison and purchase decisions. Purchase is analyzed through *perception*, *learning* and information-treatment processes. These processes are re-used in marketing to describe and qualify consumer behaviors [18]. Principles resulting from learning theories and based on reward stimuli are exploited to analyze the brand loyalty phenomenon and to predict the effects of promotional advertising campaigns. Theoretical concepts relative to perception are declined in the scope of attitude theories for analyzing the nature of links between the consumer and the product or the advertisement. They are considered to increase the favorable opinion towards a product or a brand and to maintain a positive reinforcement of this opinion [10].

From the economy point of view, the individual consumption behavior is described as being a process leading to a rational choice based on variables such as the price and the cost of information search. An attempt to integrate principles resulting from micro-economy and psychological theories regarding consumer behavior such as psychological attitude and the economic utility concepts has been made in [3].

The marketing point of view is mainly based on the derivation of concepts defined in other research domains as it is illustrated through the concept definitions within the following framework.

Opinion leader designs an expert consumer who is familiar with innovations in a particular field. His competences are recognized and his opinion is sought-after by less informed consumers

Attitude is used to determine the consumer predisposition to act in a favorable or unfavorable way towards a product or a brand.

Involvement characterizes the state of motivation or interest caused by a product or a specific purchase situation [12]. It influences simultaneously the perception, the aptitude to differentiate between alternatives and the brand loyalty.

Diffusion of an *innovation* is defined as the large-scale process of penetration of a new type of product on the market [4] It is characterized by the shape of its diffusion curve in function of time. It follows always an S-shaped curve that indicates the cumulated percentage of individuals who adopted an innovation to a given moment.

In marketing, *learning* is an essential factor of the progressive consumer behavior transformation. It can be considered as a cumulative process that produces a modification followed by a reinforcement of the individual attitude [1].

Perception is defined as the selection, organization and interpretation of the marketing and environmental stimuli by a consumer [1].

3. CUBES DESCRIPTION

CUBES is a software that simulates a population of consumer agents interacting concurrently. The CUBES simulator software includes a simulation engine, tools to parameterize and control the simulation and tools to observe the simulation output. It re-uses the Swarm simulation engine (http://www.swarm.org). The different CUBES tools have been presented in [6]. It offers the possibility to follow the evolution of the simulation and to observe the emergence of collective phenomena. Simulations are based on the creation of a virtual population composed of several thousands of consumers and a fixed number of agents representing competing brands on the virtual market. Figure 1 shows an overall view of the considered components in CUBES.

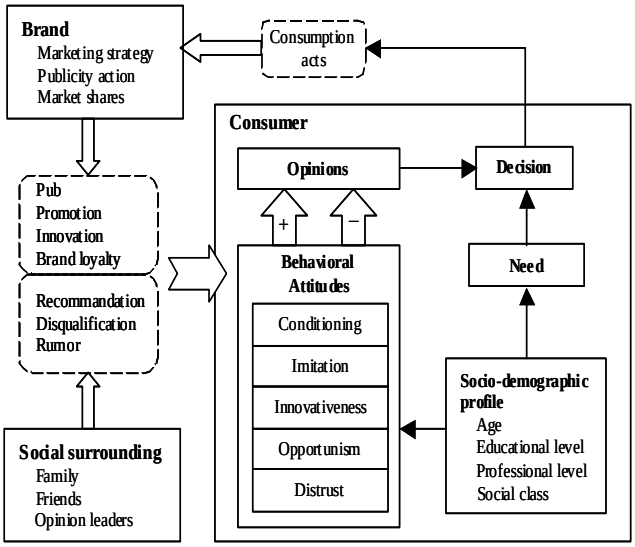

Figure 1. Overview of CUBES model.

3.1 Behavioral Attitudes

Our consumer behavioral model is based essentially on a set of *behavioral attitudes (BA)* issued from *social processes* and *personality traits* (Figure 2). We considered two social processes to model interactions between the individuals of a virtual consumer population: *Imitation_Process* and *Conditioning_Process*. In our simulation the role of the BAs issued from these processes is to ensure the diffusion of external stimuli concerning: (1) recommendation and disqualification through the members of the consumer population and (2) loyalty and brand image marketing actions.

We defined three behavioural attitudes issued from personality traits: *Mistrust_BA*, *Opportunism_BA* and *Innovativety_BA*. These BA play the role of reactive modulators that filter and weight the effect of external stimuli.

BA are formalized uniformly by generic *behavioral primitives* (BP). BP are activated by different types of external stimuli such as promotions, rumors, innovations and recommendations. These stimuli affect positively or negatively the consumer agent opinions. Their effects are weighted according to the consumer agent behavioral profile.

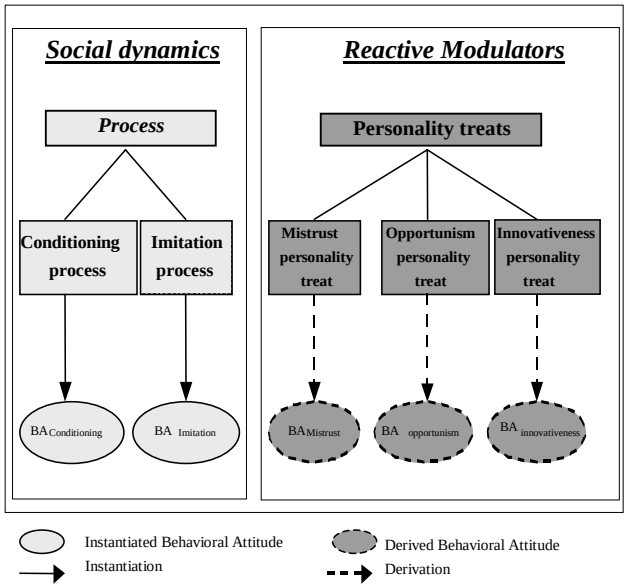

Figure 2. Behavioral attitudes.

BP are activated after the perception of external stimuli. Each stimulus is characterized by its type (rumor, pub, promotion..), its color and its intensity. The color indicates the brand to which the stimulus is related. This value is null if the stimulus designs a rumor relative to the whole virtual market. The external stimulus intensity has a numeric value which indicates its force.

Each consumer agent has an opinion on each brand of the virtual market. These opinions change according to the frequency and the filtered characteristics of the stimuli. When a consumer agent perceives a stimulus, the BP mechanism, described in Figure 3, checks if the stimulus belongs to the set of stimuli types that are susceptible to activate this particular BP. In this case, the behavioral primitive intensity (V_{BP}) is compared to a lower inhibiting threshold (Inh_Thr_{inf}) in the case of a positive stimulus and respectively to a higher inhibiting threshold (Inh_Thr_{sup}) in the case of a negative stimulus. V_{BP} expresses the BA intensity formalized by this BP. The lower and higher inhibiting threshold indicate respectively the limit below and above which external stimuli (Ex_St_{+}) and (Ex_St_{-}) do not cause any positive or negative reinforcement of the BA intensity. Once the V_{BP} is updated by the addition or the subtraction of a computed value, which is a function of the Ex_St characteristics and the current V_{BP}, the new value of the BP is compared to a third triggering threshold (Trig_Thr) that indicates the BP level above which the external stimulus has an impact on the consumer agent opinions.

The triggering and the two inhibiting thresholds are expressed as a function of the consumer agents' socio-demographic profile and the initial specified simulation parameters. Indeed, the population is initially divided into several segments according to attributes such as age, family and professional status.

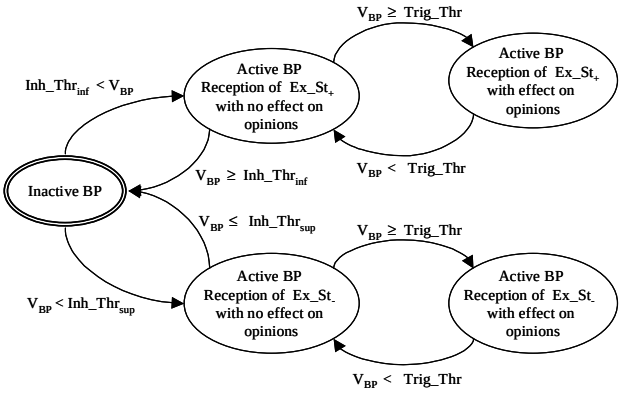

Figure 3. Behavioral primitive state diagram.

3.2 CUBES Representation of Theoretical Concepts

CUBES redefines respectively the attitude and the learning concepts in terms of the presented behavioral attitudes and classical reinforcement conditioning. In our model, attitude is resulting from five distinct BA while the attitude is generally viewed as a single non-differentiable psychological state. BA are not *situated* as far as they are not related to a given brand. This assumption means that the set of individual psychological criteria forms a single attitude whose characteristics evolve globally and independently of the number of competing brands.

CUBES considers opinion leader and innovation concepts simultaneously at the micro and the macro levels. They are both viewed as individual properties as well as emergent collective phenomena. The opinion leader concept refers to individual properties of a given consumer agent profile and corresponds to the observation of individuals located at the center of emergent groups of consumers choosing a given brand. Opinion leader agents diffuse positive recommendation stimuli corresponding to their more estimated brand and negative disqualification stimuli corresponding to their least estimated brand. These stimuli are characterized by a strong intensity, which remains constant independently of the distance to the receiving consumer agents. This reproduces the fact that these recommendation and disqualification stimuli answer to a consumer queries confirming or invalidating opinions preceding a purchase decision. In CUBES purchase acts are intrinsically related to innovation through the definition of the innovativeness behavioral attitude. The diffusion of the innovation within the consumer agent population is modeled by a "mouth-to-ear" propagation mechanism of the information. Each consumer agent propagates information concerning the innovation following a gradient. It has a perception field to limit its communication wideness with its vicinity. This communication field is a function of the behavioral profile, in particular the innovativeness BA and the socio-demographic profile (membership of groups).

CUBES models perception and involvement, which are two fundamental intrinsic consumer properties, in terms of variations of behavioral attitudes thresholds. The motivation state related to the consumer involvement is determined by the behavioral attitude thresholds mechanism previously described. Consumer involvement is controlled by an adjustment of the behavioral attitude rejection margins relative to positive and negative stimuli, which respectively have a positive and a negative influence on consumer agent opinions. The enlargement of these margins increases the number of necessary stimuli to reinforce *positively* the opinions relative to the virtual market brands.

4. MODEL CALIBRATION USING GA AND EXPERIMENTAL RESULTS

Experiments led in cellular phone market context using CUBES and including several thousands of artificial consumer agents, have validated several advanced postulates. Classical consuming curves were restituted and the emergence of collective phenomena was observed and interpreted in terms of individual characteristics. We have used GA to adjust in an iterative way the simulation parameters in order to build a first virtual consumer agent population, which is compliant with a real market. We report in the following section a set of experimental results using the obtained population.

4.1 Determining realistic population with GA

GA [11] have been used for evolving systems such as neural network [16] and cellular automata [17]. In this paper we propose to use GA in order to calibrate parameters of the simulated consumer agent population in CUBES.

Figure 4 describes the simulation process integrating GA to obtain an artificial consumer agent population that exhibits a realistic behavior.

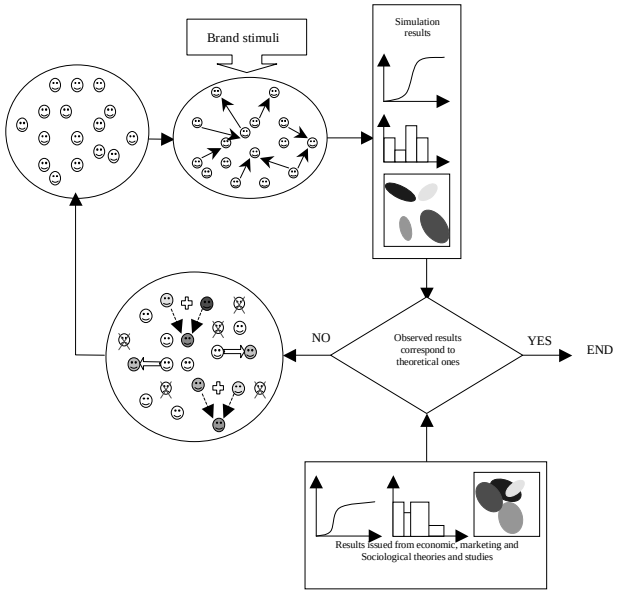

Figure 4. Multi-agent simulation including GA for calibrating consumer agents' characteristics.

The GA begins with a population of N randomly generated chromosomes encoding the consumer agent behavioral and socio-economic characteristics. In particular we encode: (1) the BA characteristics (2) the consumer agent's age (3) the number of the agent's acquaintances (4) the social class to which the consumer agent belongs (5) the professional level and educational levels of the consumer agent and (6) the product necessity.

As most of these parameters are real numbers, we used value-encoding technique to represent the consumer agents. In each generation including one simulation run, the GA goes through the following steps:

Step1: A fitness value f_i is calculated for each consumer agent C_i , $i \in [1,N]$. Fitness evaluation is done by a *Result-Analysis Module* (RAM). The role of this process is to associate a fitness value to each individual in the population after one simulation run. The RAM works as follows: simulation results describing the population's global observed behavior are collected and processed in order to associate the micro level represented by the consumer agent socio-behavioral profile to the macro level observed results.

Mainly two categories of results are considered. The first category includes diffusion and market shares evolution curves whereas the second category includes curves and statistical series probing the consumer agent behavior along each simulation run. In addition to this, formatted theoretical results are the second input for the RAM. A comparison is made between these two sets of data and a fitness value is associated to each consumer agent chromosome. This fitness value measures how far is each C_i "located" from its ideal position on a diffusion graph[1] and how realistic is the observed behavior generated by the encoded profile.

Step2: A portion of n consumer agents chromosomes having the highest fitness (elite) are copied without modification into the next generation. We fixed an elite rate of the order of 10% of the population size.

Step3: *Selection*, *crossover* and *mutation* GA operators are applied to the remaining individuals. Selection of individuals for reproduction is fitness-proportionate. In our case study we used the Roulette Wheel selection method. We apply an arithmetic crossover where a simple arithmetic operation is performed to make a new offspring. Consider for instance these two parents represented by the following chromosomes (a_i, b_i, c_i, d_i) and (a_j, b_j, c_j, d_j). Consider the real number p that belongs to [0,1].So the two children are calculated as follows:

$(pa_i + (1-p)\, a_j\, ,\ pb_i + (1-p)\, b_j,\ pc_i + (1-p)\, c_j,\ pd_i + (1-p)\, d_j)$,

$(pa_j + (1-p)\, a_i\, ,\ pb_j + (1-p)\, b_i,\ pc_j + (1-p)\, c_i,\ pd_j + (1-p)\, d_i)$

We fixed crossover rate to 85%.

The mutation technique we used consists to pick randomly a value belonging to the definition range of the chosen gene to mutate. Mutation rate is fixed to 1%.

Step4: To verify the termination criteria of the GA. We considered a combination of two termination criteria. The first is that the individuals' proportion whose fitness exceeds a fixed value, reaches a certain percentage. The second one is that the global fitness of the population does not vary during a fixed number of GA iterations.

[1] In the diffusion process, groups of consumers are identified according to the speed of adopting an innovation. The distribution of these groups is assumed to be normal. Five groups are taken into account: Innovators, early adopters, early majority, late majority and laggards. Each group has a specific set of behavioral and socio-economic characteristics.

The graph illustrated in figure 5 shows the evolution of the average population fitness over 45 generation of a population including initially 5000 consumer agents.

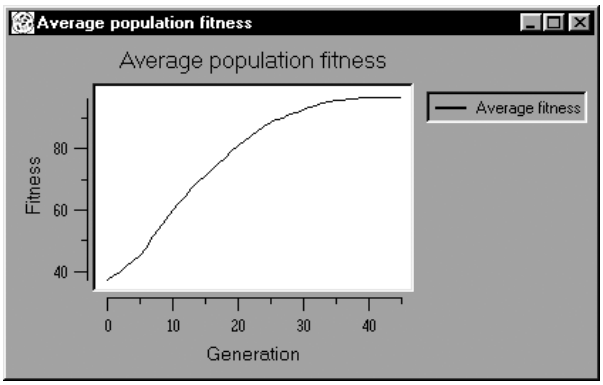

Figure 5. Evolution of the average population fitness over 45 generations.

We used the calibrated consumer agent population to lead several simulations, in particular two experimental contexts were tested concerning the BA and market shares evolutions. The following section reports these simulations and interpretations of the obtained results.

4.2 Experimental results

4.2.1 Behavioral Attitude Evolution

The first series of simulation experiments reported in this paper concern the evolution of the five behavioral attitudes considered in our model. We start by creating a consumer agent population whose individuals have initially randomly distributed behavioral attitudes intensities. Two experimentation contexts were tested. We simulate in both experiments a population of 5000 consumer agents within a virtual market including 3 competing brands. In the first experiment we consider a "young" population including 15-25 years old individuals

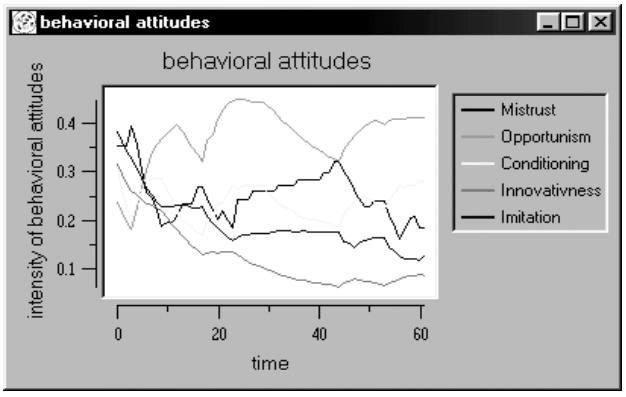

Figure 6. Average intensity evolution of behavioral attitudes for a 15-25 years old consumer agents.

Figure 6 illustrates a graph describing results relative to this experiment. It indicates the average intensity evolution of the five behavioral attitudes. We can notice an unstable oscillation over the 60 simulation steps for the five behavioral attitudes. This phenomenon is explained by the high interaction level (frequency

and intensity) between consumer agents belonging to this particular population segment. In fact, brands in CUBES use reactive marketing based on the communication of a number of publicity stimuli (promotions, innovative products, brand loyalty actions..) whose effects on individuals are amplified through their diffusion in the population. Thus the high communication rate between the consumer agents tends to destabilize the behavioral attitude intensities.

In the second one, we consider an "old" population including 45-65 years old individuals. Simulation results shown in figure 7 indicate that the average intensities of the five behavioral attitudes converge and are kept stable after about 15 simulation steps.

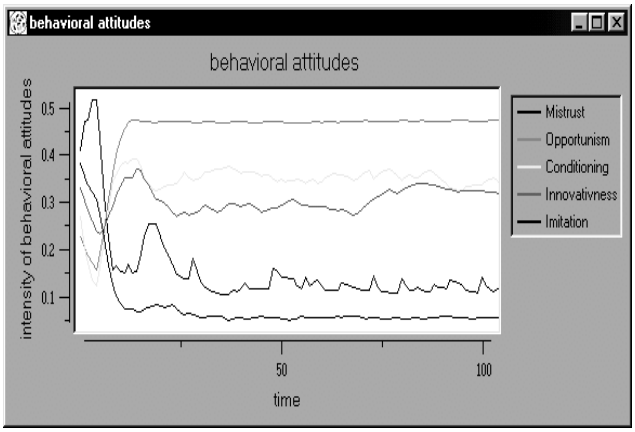

Figure 7. Average intensity evolution of behavioral attitudes for a 45-65 years old consumer agent population.

4.2.2 Emergent Market Shares Equilibrium

In the following we report two results relative to the evolution of market shares in the virtual market. In the first experiment we consider an initial market situation dominated by one brand. Initially, BRAND0 in the figure 8 has 70% of customers in a virtual market including 7000 consumer agents. The rest of customers are equally distributed between the two other competing brands. After more than 90 simulation time steps we can observe a lock-in effect where BRAND0 conserves its dominance on the market despite several attempts of BRAND1 and BRAND2 to pick up BRAND0 customers. Thus the two dominated brands remain with a marginal market shares during all the simulation.

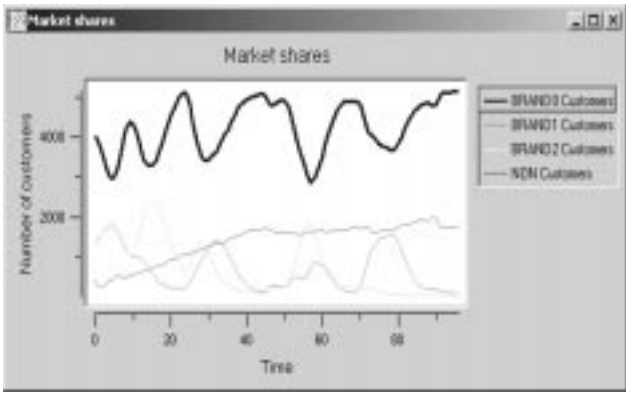

Figure 8. Evolution of market shares in a lock-in situation.

In the second experiment, we start the simulation an equally distributed market shares between the 3 competing brands. The population includes 7000 consumer agents as in the first experiment. The graph in figure 9 indicates that competition among the brands is cyclic over the 120 time steps of the simulation. This phenomenon is observed in the evolution of real market shares where few brands are sharing the customers. What we are emphasizing here is that it is possible to reproduce realistic market evolutions using the CUBES behavioral model using elementary and basic behavioral attitudes.

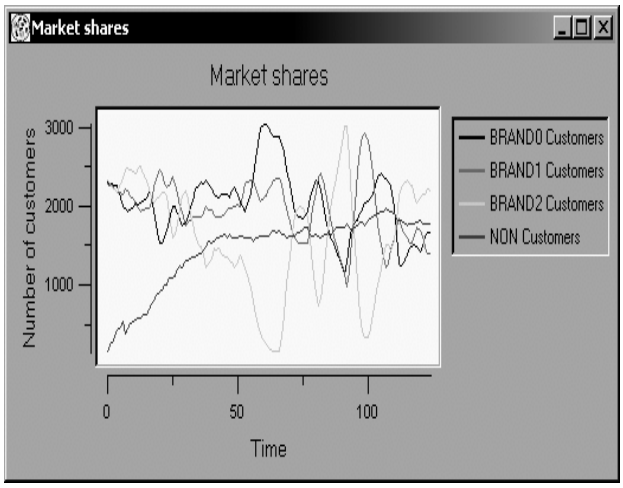

Figure 9. Market shares evolution in an initially equilibrated market.

5. CONCLUSION

This paper has introduced some basic behavioral primitives in order to model the consumer attitude in a given competitive market context. The developed approach is based on the definition of a theoretical framework integrating concepts modeled by various fields of study.

The paper has shown that the CUBES model offered an operational and a conceptual richness that covers a large part of consumer behavior aspects. Two originalities have been underlined: (1) the concepts are simultaneously considered at individual and collective levels, whereas most of the former studies are centered on only one given analysis level (2) the consumer cognitive functions are derived from generic behavioral components intrinsically related to the interaction aspect whereas until now they were mainly defined as reasoning and data processing processes.

A simulator was implemented on the basis of developed model and experiments including several thousands of consumer agents have validated several advanced postulates. The use of GA have improved the overall simulation results allowing us to observe realistic evolutions of the market.

Current and future work in this study concerns essentially the model experimentation including complex and realistic marketing strategies adopted by competing brands in a specific market. More precisely, we are dealing with the diffusion of innovations among consumer population in the telecommunication field.

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