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# DEVS-BASED FRAMEWORK FOR MESSAGE DISSEMINATION IN MULTI-LAYER NETWORKS

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## ABSTRACT

Many research efforts focus on the definition of models and techniques to simulate and predict the reaction of individuals face to an information. In this context, great benefits could derive from the exploitation of individuals' personality and cultural values in the diffusion model process. In this paper we describe a new architecture for agent-based model using the DEVS (Discrete Event System Specification) framework and show how this architecture is flexible and can serve to simulate the dissemination process. In more details, we define a set of models of individuals characterized by a set of state variables to represent the behavior of an individual and the mesh between the individuals within a multi-layer social network. Then, we introduce the platform architecture, specifically designed to simulate message propagation in a multi-layer network. In the end, a military scenario of message diffusion during a stabilization phase is used to test our DEVS models on the platform and the relevancy of the simulation results.

Keywords: Social Simulation, DEVS Formalism, Social Network Diffusion Process

## 1. INTRODUCTION

Nowadays, many researchers are interested in developing new and more efficient systems for social simulation. The issues explored include psychology, organizational behavior, sociology, political science, economics, anthropology, geography, engineering, archaeology and linguistics (takahashie et al, 2007; Bouanan et al, 2014). In the field of military defense, modeling the human operators in a system is complex because it has to represent the behaviors in critical situations. So, military simulation systems have to support detailed analysis of individual and organizational performance. The SICOMORES project seeks to create a given ethno-cultural community in an artificial society framework. It aims to formalize and simulate the propagation of the psychological effects in a multi-layer social network.

Social networks play an important role in studying the propagation of information, innovation, ideas, and influence among its members. When information appears - for example, the use of cell phones among

students, the adoption of a new information system within the enterprise, or the rise of a political movement in an unstable society: it can either die out quickly or makes significant inroads into a population. Network diffusion process allows us to understand the dynamics and the propagation of information in social network. These networks can consist of individuals, group of person or organizations. The interactions could be done by physical contact, collaboration, religious meeting or some forms of verbal or written communication depending on the situations. This network diffusion process is used to raise numerous research issues such as contamination minimization problem or influence maximization problem (IMP).

Agent-based modeling approach is used to model complex systems composed of interacting and autonomous 'agents'. Agents have behaviors, often described by simple rules and interactions with other agents, which in turn influence their behaviors. By modeling agents individually, the full effects of the diversity that exists among agents in their attributes and behaviors can be observed as it gives rise to the behavior of the system as a whole.

This paper begins by representing the agent-based model approach, The DEVS formalism and the dissemination process in social networks. Then, it provides model of individuals with DEVS characterized by a set of attributes and it presents our architecture to simulate the diffusion process in a multi-layer network using DEVS. At last, the final part concerns our experiments and the conclusion.

## 2. BACKGROUND AND RELATED WORK

### 2.1. Agent-Based Social Simulation

Agent-based social simulation (ABSS) consists of social simulations that are based on agent-based modeling, and implemented using artificial agent technologies (Davidsson 2002). ABSS is a scientific discipline concerned with simulation of social phenomenon, using computer-based multi-agent models. In these simulations, people or group of people are represented by agents. Different agent-based platforms have been used for implementing agent-based social simulation (Tobias and Hofmann 2004). NetLogo

is the highest-level platform, providing a simple yet powerful programming language, built-in graphical interfaces, and comprehensive documentation. MASON, Repast, and Swarm are "framework and library" platforms, providing a conceptual framework for organizing and designing Agent-Based Models (ABMs) and corresponding software libraries.

Most of the simulation frameworks are oriented towards applications in the field of artificial intelligence and are not sufficiently dedicated for social scientific applications. In our study we develop a new library based on DEVS formalism in which agents can be modeled as 'free' and complex objects that represent such as institutions as social scientific models do.

## 2.2. DEVS Formalism

The DEVS formalism for modeling and simulation (Zeigler et al, 2000) is based on discrete events modeling. It tends to represent more mathematical oriented notations consisting of sets and functions in algebraic representation. The sets in DEVS formalism specify the potential states, inputs, and outputs of the model; the functions describe the transitions either from outside input or from the time expiration of the state. The DEVS formalism provides a framework with mathematical concepts based on the sets theory and systems theory to describe the structure and the behavior of a system. With DEVS, there is an explicit separation between a model and its simulator. Once a model is defined, it is used to build a simulator (i.e. a device able to execute the model instructions). Two kinds of models are proposed: the atomic models, which describe behavior, and the coupled models, which describe a hierarchy.

The DEVS formalism supports an open approach to formalism extension, allowing the researcher to explore new extended or specialized formalism (Zeigler and Vahie 1993). These extensions facilitate the development of models for various applications in many different domains such as biology, engineering, and sociology. For example, Barros proposed the dynamic structure DEVS (DSDEVS) formalism which allows changes in model structure during execution (Barros 1996). Chow and Zeigler proposed the parallel DEVS (P-DEVS) for parallel execution benefits (Show and Zeigler 1996). From a network modelling perspective, Uhrmacher proposed Multi-Level-DEVS (ml-DEVS) which supports an explicit description of macro and micro level (Uhrmacher et al. 2007) and Wainer proposed the cell-DEVS formalism which is a combination of cellular automata and DEVS that allows the implementation of cellular models with timing delays (Wainer et al. 2002).

There are a large number of DEVS based simulators. It is difficult to compare the performance or the implementation of these tools. The DEVS standardization group lists on his web site the most used DEVS tools known by the DEVS community (DEVS 2015). Among these platforms, the proposed DEVS models in this study is implemented in the VLE (Virtual

Laboratory Environment) because it supports multi-modeling simulation and analysis by using recent developments in the theory of modeling and simulation proposed by Zeigler. It is also possible to perform statistical analysis of results thanks to a plug-in that allows communication between VLE and R (Quesnel et al, 2007).

## 2.3. Diffusion process in social network

Social network consists of interconnected individuals linked by informal patterned flows of information and communication that are described as social ties (Tenkasi and Chesmore 2003). Some modern examples of social networks include online social networks, where vertices are user accounts and edges represent a relationship between accounts (e.g., friendship, coworkers), and communications networks, where vertices represent e-mail addresses or phone numbers, and edges represent e-mails sent or phone calls between vertices. Social networks play an important role in studying the propagation of information, innovation, ideas, and influence among its members. An idea will appear - for example, the use of cell phones among students, the adoption of a new information system within the enterprise - and it can either die out quickly or make significant inroads into the population.

The network diffusion processes have a long history in social sciences (Rogers 1962). With the advent of sufficient storage and computational power, this network diffusion process became an emerging research area in computer science (Domingos 2005). Propagation models are designed to reproduce phenomena observed in social networks with applications in viral marketing, spread of disease and diffusion of ideas and innovations. Most models proposed recently are extensions from the independent cascade (IC) (Goldenberg et al, 2001) and the linear threshold models (LT) (Granovetter 1978). The two models characterize two different aspects of social interaction. The IC model focuses on individual (and independent) interaction and influence among friends in a social network. The IC models can also be identified with the so-called Susceptible/Infective/Recovered (SIR) model for the spread of disease in a network (Bailey 1975). The LT model focuses on the threshold behavior in influence propagation, which we can frequently relate to; when enough of our friends bought a new phone, played a new computer game, or used new online social networks, we may be converted to follow the same action.

## 2.4. Human behaviour

Human behaviour modelling as individuals in groups and in societies is the subject of several fields of research: social science, economics, epidemiology and military service because it has such an important role in many aspects of daily life. Scientific literature abounds in heterogeneous and highly specialized, theoretically founded concepts of human cognition, emotion and other behaviour aspects. A few related works have

provided DEVS models of human behaviour that we use with slight modifications: (Seck et al. 2005) present a DEVS based framework for the modelling and simulation of human behaviour with the influence of stress and fatigue; (Faucher et al. 2012) proposed a first approach using G-DEVS formalism for Civil-Military Cooperation actions (CIMIC) and Psychological actions (PSYOPS), which are actions of influence that take precedence over combat.

### 3. CONTRIBUTION

In this section, we propose an agent-based model for the information diffusion in a Multi-layer network.

#### 3.1. Problem statement

Several research studies attempted to model and simulate the influence diffusion in a social network. However, the focus is on one layer network (one link or relationship between persons) e.g., the message disseminates only within friends. In addition, they did not consider the individual and cultural factors on diffusion process; the message disseminates in the same way between two friends or two coworkers. Actually, the way how people communicate is highly dependent of the person who people are talking to. In the frame of SICOMORES project, we aim to provide solutions to artificially generate multi-layer social network of realistic population and simulate the effects of information on population with a propagation algorithm of the effects across networks. The challenge is to improve the realism of socially intelligent agents and take into account the impact of individual's personality and cultural values in the diffusion model process. The SICOMORES system can be useful in the domain of military simulation for training and education.

#### 3.2. DEVS-based Social Agent Model Framework

There are several methods to study the information propagation in social network, such as complex network analysis (Ma et al, 2013), cellular automata

(Goldenberg 2001) and agent based modeling (Smith 2007). Based on our needs, we use agent-based models and simulations for this study. Computational models and simulations, especially agent based ones, have been widely used to study a variety of social, organizational and natural phenomena. Agent-based models are capable of simulating macro-level structures resulting from micro-level interactions of heterogeneous agents within complex systems.

We use a low-level language (DEVS) to define a set of models of individuals characterized by a set of state variables to construct their behaviors and the mesh between the individuals within an MSN. Then, we develop an architecture and a methodology that promotes modularity and reusability of these models as a package. We implement these models in a virtual laboratory based on DEVS formalism (VLE). This simulator has been tested and validated with several scenarios (Quesnel et al. 2009).

In the context of this study, we need modularity and reusability. We have to perform the simulations by varying the inputs but also the algorithms of the agents. For example, diffusion algorithms may change depending on the targeted population, the type of message or network on which the message travels. In order not to have to fully develop a model for each combination of algorithms we want to set in the agent, we decided to opt for a modular approach. This approach needs some methodology to be carrying through. Section 3.2.1 presents the architecture of simulation and methodology used. Section 3.2.2 describes the proposed solution in terms of modular and reusable model design.

#### 3.2.1. Architecture and methodology

Figure 1 presents the simulation architecture we have developed.

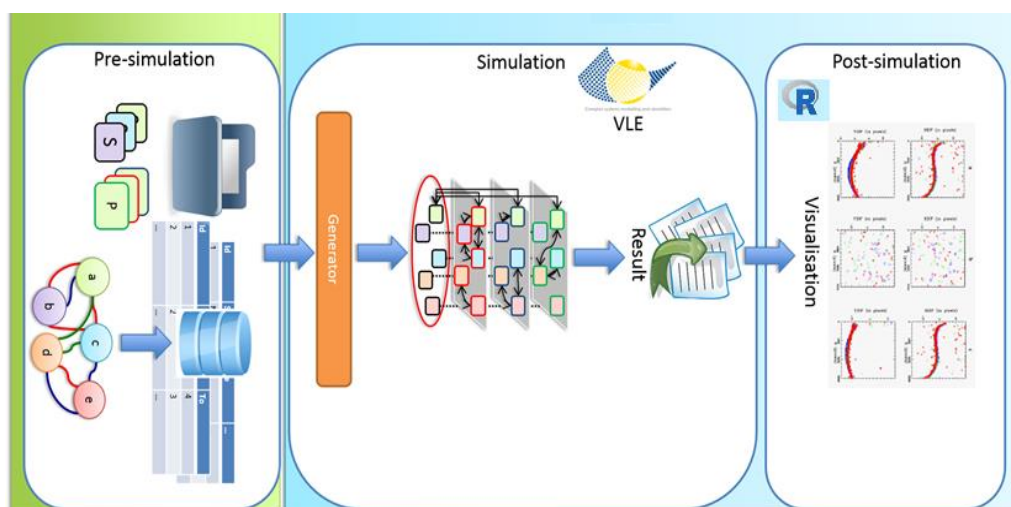


Figure 1: Agent simulation architecture

**Pre-simulation:** Before making a simulation, we build a new experiment and develop the simulation models we need if they do not already exist in the repository. An experiment includes one or several groups. A group includes many individuals. A graph represents all relations between individuals. We opted for the storage of information in a database so that each experiment is easily accessible and re-playable. The repository contains all the models available to execute the simulations, i.e., all the servers and proxies that will be used by the generator to produce the simulation model.

**Simulation:** The simulation starts with the experiment to simulate, as well as servers and proxies to use. In this

way, for the same experiment, we can test different behavior algorithms. The generator connects to the database to retrieve all the information from the experience to execute. The generator instantiates agents and related links. The DEVS simulation is executed using VLE and produces a result set in the form of a file.

**Post-simulation:** The R script post-processes the simulation result. The result file is used to visualize the course of the simulation and to develop an analysis and conclusion. The analysis can lead to a new simulation, i.e., makes a new pre-simulation, simulation and post-simulation.

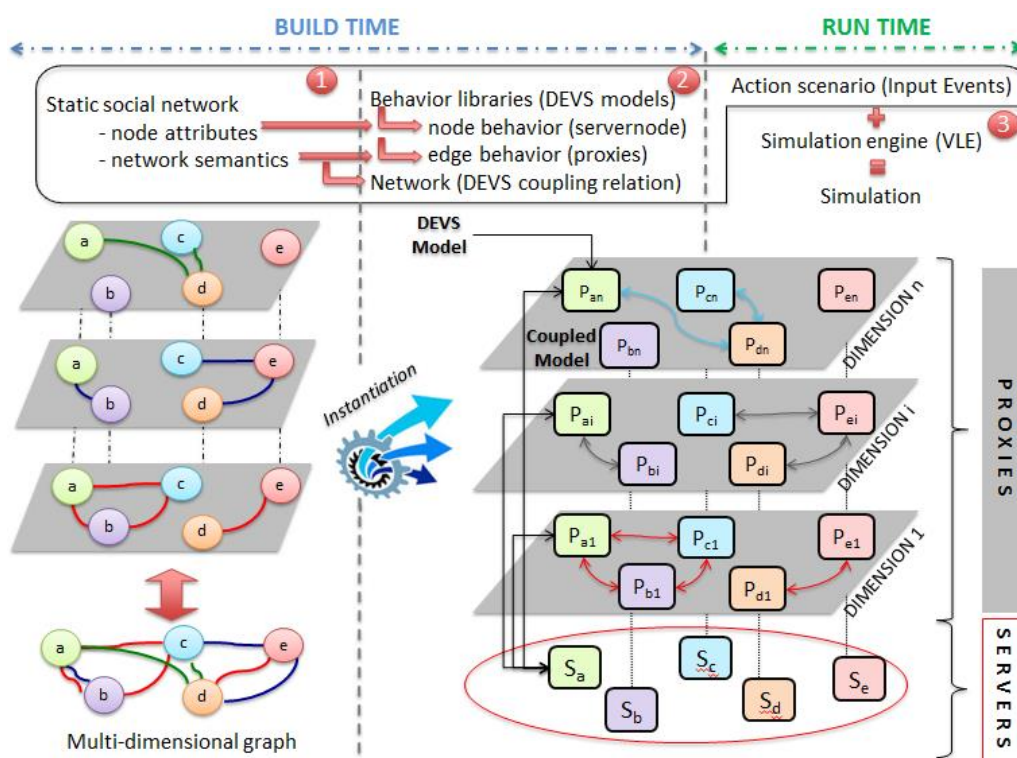


Figure 2: Conceptual overview

### 3.2.2. DEVS model

Figure 2 presents the solution we have developed to take advantage of a low-level framework allowing the development of algorithms that take into account the specificity of each individual. This solution also considers our needs for modularity and reusability.

Our simulation is based on a static multi-layer graph (1). Specifically, we generate a Multi-layer Social Network (MSN). Our MSN models individuals with attributes (such as gender, age and opinion) and several relations linking them (such as family relation or friendship relation). The idea behind the use of an MSN is to assume that people do not communicate in the same way according to people with whom they are talking, e.g., families or friends. In the second phase of the build run (2), we set the architecture based on a proxy/server framework to model the several layers of relations based on DEVS specifications. Each node of

the MSN is modeled by a server-node and has as much proxies that there are layers.

The node  $a$  in the multi-layer graph becomes the server-node  $S_a$  in phase (2) and detains  $P_{a0}$  to  $P_{an}$  proxies. The sever-node contains the individual behavior, i.e., how an individual receives an information and how this information can change his state. The proxies associated to a sever-node contain the rules of message dissemination for each layer. Finally, the phase (3) corresponds to the runtime: using an action scenario of simulation, and a simulation engine we simulate the propagation of information in the multi-layer social network.

Each agent is created at run-time by a generator that has access to the experiment data. This generator initializes each individual, i.e., each server and proxy, and binds the server with all of its proxies. Then, each proxy is

bounded to several proxies depending on the graph between individuals.

### 3.3. Formalization of human behaviour

In the agent-based model, individuals or group of individuals are represented as agents. Each agent is described by a set of attributes:

- Static attributes: gender, social status, religion, age class, ethnicity, leadership and language.
- Dynamic attributes (variables): opinion, interest, un/satisfied-needs.

Static attributes are intrinsic or unchanged parameters, i.e., time has no effect on them. Dynamic attributes evolve with time or events. For example, individuals can be reached or not by the information depending on its opinion and the social network configuration.

We use DEVS specifications to describe the human behavior. As we presented in section 1.1, DEVS is a well-defined formalism which has numerous advantages over other formalism in the modeling of complex dynamic system. The following notations describe the server model. We do not describe detailed operations of this model; we just explain the role and interface of the server model (Server-Node).

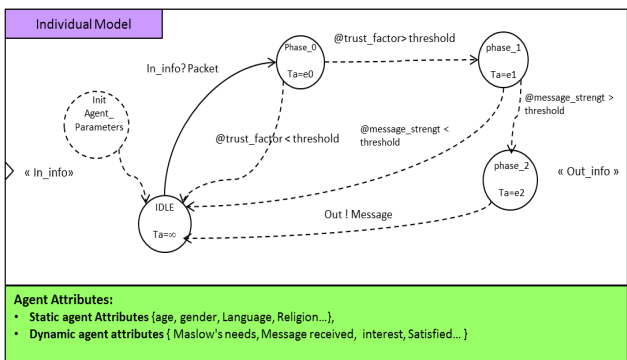


Figure 3: DEVS specification of individual model

Figure 3 describes the message influence on the individual behavior and potentially its dissemination using the DEVS specifications. The first phase is used to configure and initialize the agent's attributes. Then, when the agent is in the  $\delta IDLE\delta$  phase and if it receives an external event from another agent on port  $\delta In\_info\delta$  (In\_info? Packet), it goes into phase  $\delta phase\_0\delta$ . Here, the agent calculates the trust factor ( $i,j$ ) between him and the sender depending on the sender's religion, language and age class. If the trust factor is higher than a predefined threshold, the receiver goes into phase  $\delta phase\_1\delta$  else it returns to  $\delta IDLE\delta$ . Then, if the message strength is still strong enough, the receiver goes into phase  $\delta phase\_2\delta$  else it returns to  $\delta IDLE\delta$ . This message creates an impact on the individual, and eventually its behavior depending on the agent's opinion and the relationship between him and the sender. After a period, *processing-time*, the receiver transmits the message on its ego-network. After the contact between receiver and sender, the receiver's

variables (opinion, interest, satisfaction) change according to the message content, the sender and cultural factors.

### 3.4. Diffusion process in multi-layer social network

The multi-layer social network is defined as a graph  $G=(V,E,L)$  where  $V$  is a set of nodes (DEVS model),  $L$  is a set of labels (also called layers),  $E$  is a set of labeled edges (DEVS coupling relation), i.e., the set of triples  $(u,v,d)$  where  $u,v \in V$  are nodes and  $d \in L$  is a label.

Each node represents an individual with characteristics who can share information on one of its networks  $L$ . Each individual who receives a message and does not have enough interest in it becomes "passive" and the message do no spread longer.

In this regard, the state of the nodes can belong to one of these three categories: (type A) informed node: the node has received a message and spread it to its neighbors; (type B) uninformed node: the node has not received any message, (type C) passive node: the node has received a message but does not spread it.

Four conditions can cause the end of the simulation: (1) The individual who receives the information is a type B; (2) The strength of the message to be propagated falls below a given threshold; (3) All nodes are a type C; (4) It has been a long time (higher than a given threshold) since the scenario occurred.

## 4. EXPERIMENT

### 4.1. Overview

We illustrate the concepts presented in the paper by modeling and simulating the spread of information in a multi-layer social network. The context of the experiments is motivated by confidential training scenarios provided by the French military. The goal of this scenario is to predict the reactions of people facing events. In more details, the military missions aim to reduce local support for the insurgents by convincing people that it is not in their interest to support or join an insurgency. Using the data described in the scenario, we generate a population of 100 individuals connected on three layers: family, friends and neighbors. These three layers represent the primary groups defined by (Litwak and Szelenyi 1969). The following are types of characteristics that may describe an individual: ethnicity, religion, gender, social status, etc.

Related to the concepts of opinion change described by (Friedkin 1999) and at the contact of a receiver with an emitter, the receiver calculates the trust factor ( $i,j$ ). This mechanism for opinion change has been validated using an approach based on three issues (Friedkin 1999). The  $(i,j)$  represents the trust between agents based on their attributes. The trust factor has value

$(i,j)=1$  if the two agents  $i$  and  $j$  are similar (they have same religion, same ethnicity and same class of age) and  $(i,j)=0$ , otherwise. In the first case, agents receive the message and their variables (opinion, interest and satisfaction) change over time depending on some rules;

for simplicity, the receiver agent adopts the emitter's opinion. Then, it is able to propagate the message to its neighboring agents. In the other case ( $(i,j)=0$ ), the receiver will enter the informed state and propagate the message, if the emitter is a lead agent. In the all other cases, the message is ignored and the receiver will not propagate anything.

#### 4.2. Settings

To test our architecture, we drive three experiments with the same population but with different algorithms of message propagation (Table 1). In the first experiment, we do not consider the type of the message or the type of the relationship between the emitter and the receiver to implement rules in the proxies (one graph with different connections). In this case, the uninformed agents receive the message from their neighbors without calculating the trust factor. The trust factor between all the agents is equal to one.

In the second experiment, we take into account the trust factor between agents. In this experiment, the receiver calculates the trust factor between him and the emitter before accepting the packet. The diffusion process depends on the strength of the message and on the trust factor.

**Tableau 1: Description of simulated experiments**

Experiments	Description
Experiment 1	Trust factor between all agents is equal to one
Experiment 2	The diffusion process depends on the trust factor but not on the type of connections
Experiment 3	Each proxy has some specific rules to filter the information

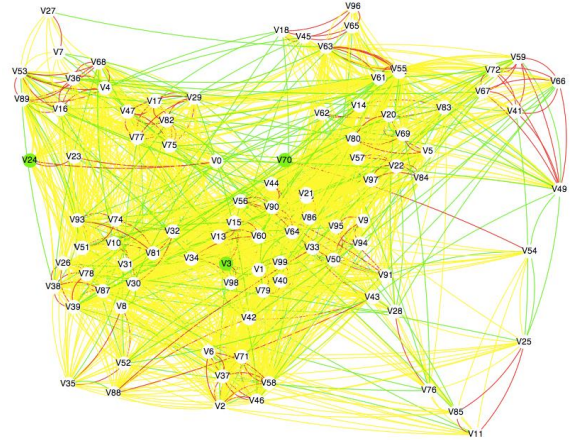
In the third experiment, we use our multi-layer architecture by implementing specific rules to the type of message and to the relationship between different agents. We block the diffusion process in the friends and neighbors layer. We assume that at night and in the absence of communication channels the message will be spread only by face to face between family members.

#### 4.3. Result and discussion

The results show that both the network structure and the node attributes (individual and cultural factors) have an impact on the proportion of informed agents and their opinion.

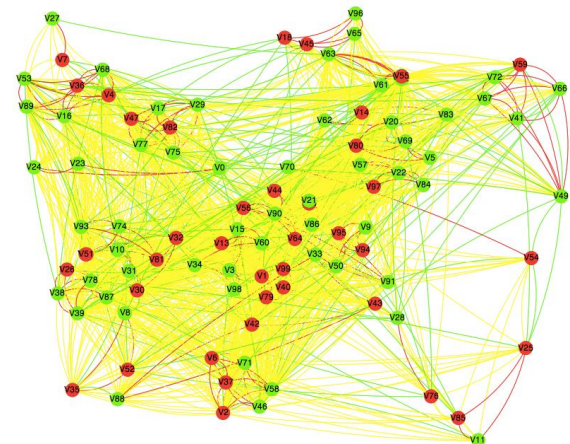
Figure 4 presents the initialization phase of the simulation using the generator as explained in Figure 2 in Section 3.2.2. Each node in the network represents an agent with different attributes. These entities may be uninformed individuals or information sources. Source nodes initiate the original message. The info-sources are chosen randomly. Each node is colored according to its status: green for informed nodes, red for passive nodes and white for uninformed nodes. At  $t_0$ , all nodes are uninformed except for the three info-sources: nodes V3, V24 and V70. As we are working with an MSN, we

have three kinds of link: family relationships (red links), friendship relationships (green links) and neighborhood relationships (yellow links).

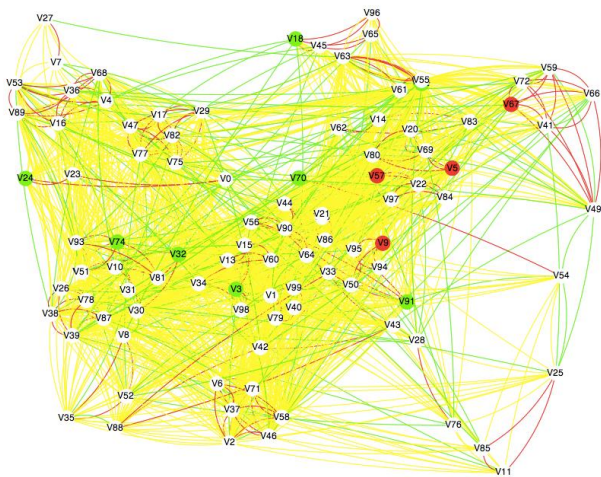


**Figure 4: Initializaton of the simulation**

Figure 5 shows the simulation results of the first experiment. The green nodes represent the agent who received the message and is interested by it. Red nodes represent the agent who received the message and not interested by it. White nodes represent the agent who did not receive the message. In this case, the diffusion process depends only on the strength of the message. The process is ended when the strength of the message becomes less than zero. The notion of interest used here does not refer to the receiver's emotion causes by the message. At this stage, we use a function that determinates if the agent is interested in the message or not by comparing closeness of the emitter's and receiver's characteristics (e.g., religion, ethnicity, age, language, social status).

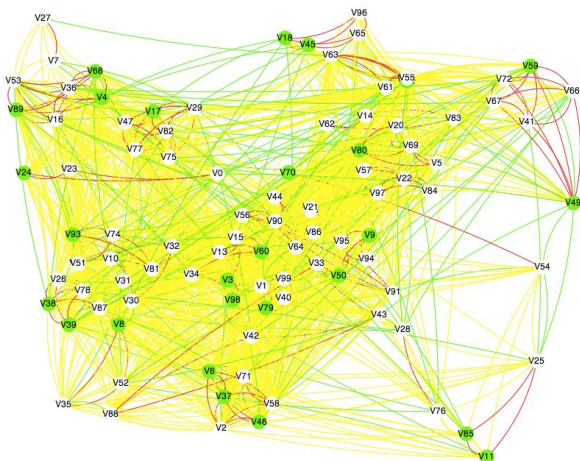


**Figure 5: Result of the first experiment**



**Figure 6: Result of the experiment 2**

In the Figure 7 we observe that only the nodes connected by the family relationship are the informed nodes because we add some rules in the other layers to block and filter the diffusion process. We can explain this result by sending an urgent message at night and in the restriction of the use of communication channels (phone and internet).



**Figure 7: Result of the experiment 3**

The different experiments show the flexibility of our Server/proxy architecture based on DEVS. We easily manage the diffusion process according to numerous parameters. We can simulate more realistic phenomena based on cultural and human factors. In addition, we can exploit our architecture to study the information diffusion in a dynamic network.

Our architecture separates the individual behavior modeling from the networks structure modeling. It allows tuning easily the rules of diffusion or the structure of the network as soon as we have to change the context of the study or to test different human's behavior models. Finally, the human behavior algorithms implemented in the models presented in this paper are quite simple but however innovatively used by mixing social sciences studies and multi-layer social networks. The behavior algorithms used in the models were validated in social science studies but in a

different context (Friedkin 1999). The network topology is coming from (Mitchell 1969; Lazega 1998). The VLE simulation platform was also validated (Quesnel et al. 2009; Ramat et al. 2003). Nevertheless, because we merged human behavior and networks structure in a DEVS M&S environment for the first time, the complete framework hasn't been validated yet. We have started to confront the first scenarios models and simulation results to military experts. We have received a positive feedback but we agree that this feedback lies on simple and limited number of models; so it does not permit to validate the genericity of these models of networks and individual behavior. We find only two ways to validate our models. The first, already started, will consist in facing military expert with several sets of input scenarios and results obtained by simulation. The second issue is to set historical situations in models, run them, observe and compare output to historical facts. We are at the moment working on both aspects.

## CONCLUSION AND PERSPECTIVES

We presented in this paper a new simulation framework feature for MSN based on the DEVS formalism. This low-level framework allows a full control of the agents' models; it promotes also modularity and reusability. This new architecture is fully dedicated to simulate, as transparently as possible, the propagation of information within a population network. In details, the mechanisms implemented in the models are, at the moment, simple but they are easily upgradeable by modelers. In addition, we assumed that relationships between people are too complex to be modeled by a unique network. Furthermore, information diffusion is dependent of the category of relationship between the people who communicate. So, the DEVS-based agent framework with the Server/Proxy architecture has been proposed to separate individual behavior in Server and perception of the environment in Proxy. It is flexible and sensitive to changes in the environment. In the last section, we managed two experiments showing (1) the importance of managing each relationship separately in the information diffusion process and (2) the simplicity to modify the diffusion rules for each relationship using our Sever/Proxy architecture. We are aware that, even if the different technics employed were previously validated in their respective domain, the models and simulation results proposed in the paper have not been validated. Nevertheless, we already confronted the first results to expert in the domain and will continue in that way. Beyond this, the perspective of our work seems promising to facilitate the setup and run of network structured DEVS models. This framework can be used to solve the problem of influence maximization (IM); find a set of initially activated nodes (info-sources) with the maximum number of activated nodes after the time step  $t$  by launching several simulations with different nodes. Then, we will compare the final results to select the nodes that maximum influence or spread the information. As perspective, we are integrating



progressively more variables to describe more accurately human behavior including social and psychological feelings and health. The inner idea is to obtain, using simulation, a better understanding of how information can affect behavior of people and population. We are also looking to adapt our model to other domains such as marketing, logistics and manufacturing.

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