Simulating information diffusion in a multidimensional social network using the DEVS formalism (WIP)

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ABSTRACT
The impact of information on individuals within a social network is, mostly, statically modeled and the dynamic is not frequently tackled. In addition, the work of modeling and simulation of the population's reactions to the information do not use explicit specification languages to describe their models. These models are specified in the shape of graph or math formulas and then directly implemented and coded using classical programming languages. We propose to model the actions of influence in a multidimensional social network (MSN). Each graph layer corresponds to a predetermined social network based on one relationship. In this work, the use of the DEVS formalism has permitted to explicit M&S of human behavior and the interaction between individuals as a network. In more detail, we define a set of models of individuals characterized by a set of state variables (e.g., using Maslow's theory [15] to construct the behavior of an individual) and the mesh between the individuals within a social network. Then, we introduce the platform architecture, sharing resources, specifically designed to simulate MSN. In the end, a scenario is used to validate our models using the platform based on DEVS Specification.

Author Keywords
Multidimensional social network; DEVS Formalism; Information Propagation; Human behavior; Modeling and simulation.

ACM Classification Keywords
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INTRODUCTION AND MOTIVATION

Human behavior can be difficult to understand and predict, thus it can be qualified as a complex system. DEVS is a well-defined formalism, which has numerous advantages over other formalisms in the modeling of complex dynamic systems. The purpose of this work is to provide a simple but efficient and accurate framework to model the behavior of an individual, but also to simulate the propagation of information among a group of individuals and its influence on their behavior.

General definitions define human behavior as the collection of behaviors demonstrated by humans [14]. Behaviors are influenced by numerous aspects (e.g., culture, attitudes, emotions, values, ethics, authority, rapport, persuasion, coercion, etc.). Also, humans have many ways to communicate (e.g. word of mouth, phone, SMS, emails, and the mass diffusion as radio or TV). The communication takes place in the social networks where the individuals are involved. We propose a greatly simplified model of human behavior and the message dissemination in the social networks using a defined media. Then these models are validated by simulation. The communication will be established thanks to the individual connection with other individuals within the different social networks. The results will consist of measuring the diffusion of the information and the ability to reach the targeted people.

In literature most multidimensional social networks (MSN) are flattened at the implementation of the solution. Today some approaches formalize MSN but they are little used in computer practice. No complete implementation is done that integrates the social networks and the dynamic message propagation.

Most current MSN-based simulations flatten the different networks into one, which serves to manage all the network-specific rules into one place. This approach makes it hard to develop, validate and, ultimately, reuse the model. A shared component as proposed in [5], offers a good opportunity to have one human behavior model shared in several networks.

DEVS is a timed, highly modular, hierarchical formalism for the description of reactive systems. It can be appropriated to implement networks, propagation and human behavior. A few related works have provided DEVS models of human behavior that we will use with slight modifications; Seck et al. present a DEVS based framework for the modelling and simulation of human behavior with the influence of stress and fatigue [20]. Faucher et al. 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 [7].

In more detail, this paper will participate in the definition of a set of models that addresses the entities and the structure of a population working in firms. It will begin by

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representing the MSN, The DEVS formalism and VLE toolkit. In addition, it will provide model of individual with DEVS characterized by a set of attributes and it will present our architecture to simulate a Multi-layer Graph using DEVS. At last, the final part concerns the case study and the conclusion.

BACKGROUND

We present in this section the general background of our work. This background has three dimensions: the multidimensional social network, the DEVS formalism and the VLE toolkit.

Multidimensional social network

A social network is a modeling of a set of nodes (individuals, groups or organizations) and a set of relationships between them. It is structured as a graph G=(V,E) where V is a set of nodes and E a set of edges.

Since a few decades ago research in sociology has described multidimensional social network (MSN) as in [12]. Note that you can find in the literature a multiplicity of terms such as it is summarized in [11]. In this paper, we use the term multidimensional social network [3]: the term dimension is frequently used to talk about human relationships in the social sciences literature [1].

In recent years, network research has given a more precise formalization to these MSN [3, 11]. Actually, relationships between people are often too complex to be modeled by one link, e.g., in real life, people can be friends, kin, neighbors, and so on. Berlingerio et al. defined a structural framework for MSN: the graph is seen as an Edge-labeled undirected multi-graph G=(V,E,L) where V is the set of nodes; L is a set of labels; E is a set of labeled edges, i.e., a set of triples (u,v,d) where $u,v \in$ V are nodes $d \in$ L is a label [3]. Note that we can also use the term dimension instead of label.

Although social networks have long existed, multidimensional formalization and modeling is fairly recent. We find a very few works about this subject as in [2, 8, 17]. In their paper, Pappalardo et al. propose an MSN where relations between people come from three websites of social networking: Foursquare, Twitter and Facebook. Then, they try to measure the strength of these links. As for Berlingerio et al., they analyze hubs in a multidimensional network. Actually, measurements from social network analysis have to be adjusted to MSN. Finally, Forestier et al. propose a MSN from online discussions where relations are from discussion structure and text content. These relations help to find celebrities in the discussions.

DEVS Formalism

The DEVS formalism for modeling and simulation is based on discrete events, and provides a framework with mathematical concepts based on the set theory and the systems theoretical concept to describe the structure and the behaviour of a system [25]. 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's instructions. DEVS uses two kinds of models: the atomic model, which describes behaviour, and the coupled model, which describes hierarchy. The smallest element in DEVS formalism is the atomic model.

Recently, several researchers proposed extensions to the DEVS formalism. These extensions facilitate the development of models for different application in many different domains such as biology, engineering, and sociology. Multi-Level-DEVS (or ml-DEVS) support an explicit description of macro and micro level [23]. Information at macro level can be accessed from micro level and vice versa. Micro models can be simultaneously activated by the macro model, and the micro models can trigger the dynamics at macro level. In [24], Wainer and Giambiasi presented an N-dimensional version of the Cell-DEVS Models.

VLE toolkit

VLE (Virtual Laboratory Environment) is an open source software and API under GPL which supports multi-modeling and simulation by implementing the DEVS abstract simulator [18]. It is able to integrate specific models developed in most popular programming languages into one single multi-model. VLE proposes several simulators for particular formalisms; for example, cellular automata, ordinary differential equations (ODE), difference equations, various finite state automata (Moore, Mealy, Petri-nets, etc.) and so on.

This framework can be used to model, simulate, analyze and visualize dynamics of complex systems. Its main features are: multi modeling abilities (coupling heterogeneous models), a general formal basis for modeling dynamic systems and an associated operational semantic, a modular and hierarchical representation of the structure of coupled models with associated coupling and coordination algorithms, distributed simulations, a component based development for the acceptance of new visualization tools, storage formats and experimental frame design tools.

CONTRIBUTION

To address the recent problems of the MSN use, we firstly propose to design complex and independent networks between agents. Then, we simulate the agent's behavior depending on the input transiting on those networks. Finally, a software architecture is proposed to respond to the MSN simulation problematic.

Multi-dimensional network modeling

From our perspective, an agent is an individual and the MSN models all the relationships between these agents. As stated in the background, MSN are usually built upon data collected from websites. In the absence of available data, we generate a MSN based on a firm structure.

Firstly, we generate nodes which represent individuals with attributes (e.g., age, sex, esteem [15]). Then, we generate the three relationships constituting the three levels of the

MSN. Note that the number of levels is not fixed, it depends on the case study.

Relations inside a department represent the first level: people belong to one department. Each individual in this department is connected to each other forming cliques (fully connected subgraph).

The second level represents the relations between people inside a firm. This second level allows to transmit the information in a second time as for example when people meet at lunch. We can associate this relation as friendship so we use probabilities of homophily to create friendship links [15]. Homophily can be resume by the expression “birds of feather”: people tend to link with similar people.

Finally, the third level corresponds to relation between people from several firms.

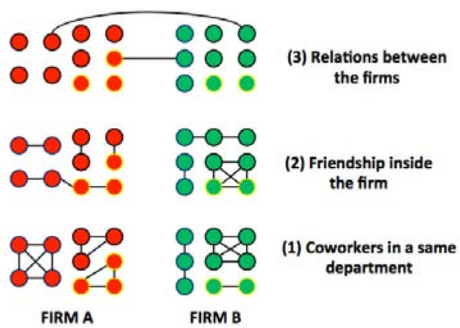

Figure 1. Example of a multidimensional social network.

Figure 1 shows an MSN consisting of 19 people and three dimensions: (1) relations inside a department, (2) friendship inside the firm and (3) the relations between the firms. These 19 people work in two firms (A and B) composed of three departments each (yellow, blue, and black traits). In the first level all people in the same department are linked together. Then people are mixed according to their friendship. Finally, people in the top level are connected to people in the other firm.

Note that an ego-network represents all the connected nodes to an individual whatever the MSN dimension.

Human Behavior Modeling

Each node in the MSN represents an individual who is described by a set of attributes:

- Static attributes: age, sex, social status, and so on.

Variables: attitude, satisfied-needs, unsatisfied-needs (according to Maslow’s classification of human needs [15]).

Static attributes are intrinsic or unchanged parameters, i.e., time has no effect on them. Variables (dynamic attributes) evolve with time or other reasons. For example, individuals can be reached or not by the information depending on its opinion and the social network configuration. The state of an agent can be one of these dynamic attributes.

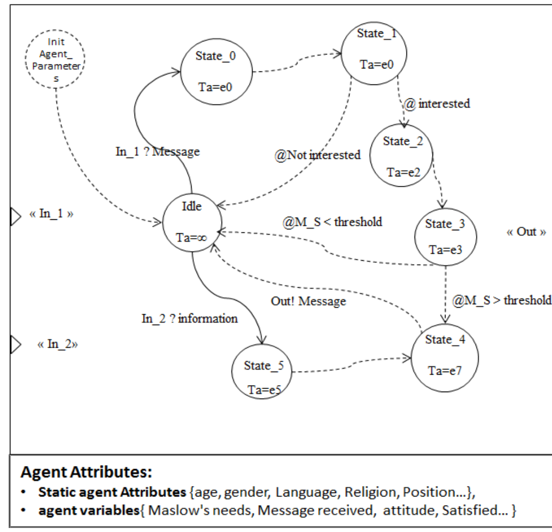

Figure 2. Specification of the node model.

The model presented by Figure 2 describes the message influence on the individual behavior and potentially its dissemination using the graphical representation of [21]. The first state is used to configure and initialize the agent’s attributes. Then, when the agent is in the “idle” phase and if it receives a message from another agent on port “In_1”, it will enter in phase ‘state_1’. This message creates an impact on the individual, and eventually its behavior depending on the agent’s opinion. Besides, if the message strength is still strong enough the receiver will transmit the message on its ego-network. In the other case, when the agent is in ‘idle’ phase and he receives an order from the generator on port ‘In_2’, it will transmit the message on its ego-network.

Diffusion Model

The study of information spread, propagation of ideas and influence in a social network has a long history in social sciences [19]. With the advent of sufficient storage and computational power this network diffusion process has become an emerging research area in the computer sciences [6]. Propagation models are designed to reproduce the phenomena that can be 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 [9] and linear threshold models [10]. In these models, the diffusion process is based on the interaction between network users (social pressure). The message contains the category of information and tracking data, e.g. current emitter and final target.

There are clear relations between epidemic diseases and the information diffusion through social networks. Epidemic models were used originally to study the spread of diseases among biological populations. Various epidemic models have been proposed and studied over many years. Recently, researchers have also applied epidemic models to the diffusion of information and influence in social networks.

Both diseases and information can spread from person to person, across similar kinds of networks that connect people, and in this respect, they exhibit very similar structural mechanisms. Sotoodeh et al. presented a general model of information diffusion, which is based on epidemic diseases [22]. It is a result of developing a SIRS deterministic model and including compartmental assumption. Bouanan et al. presented an analogy between the dissemination of information among a group of individuals and the transmission of infectious disease between individuals [4].

To drive the dissemination of information and test its impact on individuals within a social network, we developed some rules based on epidemiological models. We split the population into two compartments: info-targets and info-source(s). The first category contains individuals who do not have the information at time t=0; the other group represents people who have the information and who will diffuse it to their ego-network. Once the simulation is started, the opportunities for information to spread are given by the MSN.

Three conditions can stop the propagation process:

- The individual who receives the message does not have enough interest to transmit it (the interest falls below a certain threshold).
- The strength of the message to be propagated falls below a given threshold.
- The time since the action occurred is higher than a threshold.

Architecture

The use of MSN in simulation is pretty new and raises architectural problems. Figure 3 represents a MSN composed by three networks (*Network1*, *Network2*, and *Network3*). Each network is independent from the others and all networks contain the same nodes. We can see that *f*, *f'*, and *f''* are the same individual. In *Network3*, this individual is connected with *b*, and in *Network1* it is connected with *a''* and *e''*.

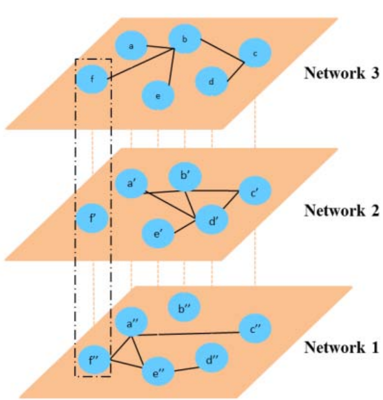

Figure 3. Example of a Multidimensional Network.

The usual solution when we have to face the simulation of several graphs is to flatten them into a single one as represented by Figure 4. In this flattened network, individuals are connected to other individuals directly. Benefits are the simplicity of representation and the strict minimum number of components and bindings.

In fact, we only have 6 nodes corresponding to the 6 individuals and 16 connections (5 for *Network1*, 6 for *Network2*, and 5 for *Network3*). Drawbacks are the non-separation of concerns. Each individual must contain concern (as an atomic or as a coupled model) about the network rules (to transmit or not the information on this specific network for example) as well as individual rules (affected or not by the message for example). This non-separation of concern prevents us to reuse the model with other networks or in other study. It also makes harder the validation, verification and accreditation process (VV&A).

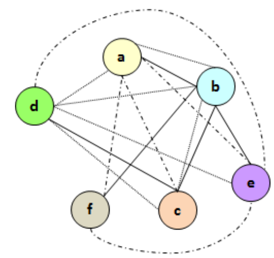

Figure 4. Flattened Multidimensional Network.

Figure 5 represents the proposed architecture. We want to keep the separation of concerns at the network level, each network remains independant from the others. Node *a*, *a'*, and *a''* are called Proxy Node and contains the specific network rules for each individual. Each Proxy Node are connected to a Server Node representing the individual state and containing the individual rules. The sequence when an information arrive to *a''* on *Network1* is the following :

- Proxynode *a''* sends an event to Servernode *A*
- Servernode A reads the event and depending on its state and rules, can propagate the information to its networks. Thus, an event is sent to Proxynode *a*, *a'*, and *a''*.
- Proxynode *a*, *a'*, and *a''* read the event and depending on their state and rules, can diffuse the information to their neighbors. In this case *a''* already has the information and does nothing; *a'* sends an event to *b'* and d'; *a* sends an event to *b*.
- Proxynode *b*, *b'* and *d'* send an event to respectively Proxynode *B* and *D* and so on.

This approach aims to enhance the reusability, the VV&A process, the model representation, and thus eases the development. It's easy to add a new network: we just have to build the specific rules (if any) in a new Proxynode component. We can change individuals without changing the networks. Drawbacks are the increased number of nodes and bindings.

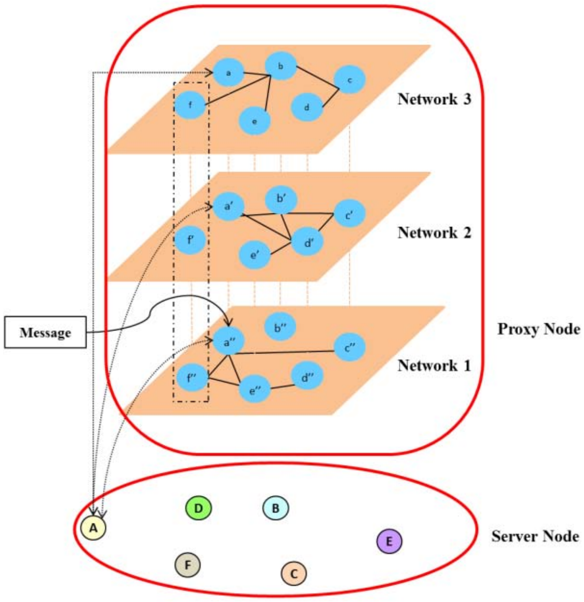

Figure 5. Proposed MSN implementation architecture.

CASE STUDY

In this section we present a simple model of the social influence using the DEVS formalism. We aim to simulate the effects of some actions of influence on the population structured in an MSN. For each action, there are info-targets that are reached through a mechanism of propagation.

Figure 6 represents the MSN we generate. It is composed of ten firms between 30 and 50 people each and divided in four departments. The color of the nodes represents the firm that people belong to. People are linked with three dimensions: people working in a same department (black links), people who share friendship in a same firm (blue links), and relations between people across firms (cyan links).

VLE API is used to implement the DEVS propagation rules. One of the main problems is the instantiation of a single node shared among several networks. Either we choose to flatten graphs into a single one or we choose to keep the different networks separate, which implies the implementation of the notion of a main agent (unique) and a proxy agent (one for each network). We chose the second solution for modularity concern. In fact, the addition of a graph becomes transparent from the main agent model. Moreover, each network can have its own acceptation/transmission rules set in the proxy agent. Then, the main agent decides to be affected or not by messages received from a proxy belonging to a trusted network or not.

This study simulates the message propagation from info-sources to info-targets. The main goal is to test and verify the architecture proposed in this paper. This architecture allows the implementation of MSN in a software based on DEVS formalism.

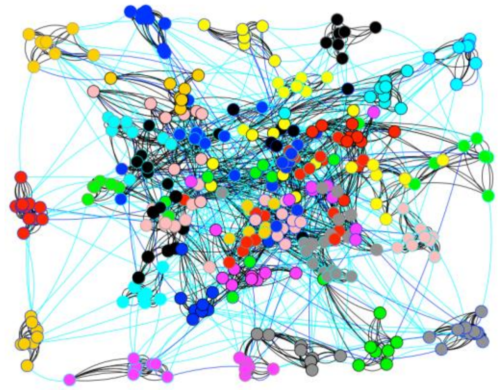

Figure 6. Representation of the ten firms.

The simulation takes in input from 3 files representing the adjacency matrix (one file for each network) of the MSN. The simulation also takes in input from an xml file containing all the attributes related to each individual. We use this file to initialize our model by assigning each agent the values of its attributes. At the time of writing, human behavior is simple but it will be extended with social sciences studies realized by our partners.

The simulation lasts 10 hours (600 time units in simulated time). A generator designates one of the agents to be the sender (info-source) and others as the receivers (info-targets) of the message. At the end of the simulation a text file of data is generated. This file contains the ID of the agents who received the message and at which time they received it. This data allows us to analyze the relationship between two individuals who are not directly connected according to rules that drive the spread of the message.

CONCLUSION AND FUTURE WORK

This work is still at an ongoing stage. The idea is to integrate more state variables to describe more accurately the human behavior and the reaction to the received information. Nevertheless, the models of individual, the multidimensional social network, and the architecture sharing resources have been validated. The next steps will consist in defining population with a higher number of individuals and proposing a more complex human behavior model based on social science studies realized by the social science specialists.

Our approach consisting on the simulation of information diffusion in a multidimensional social network using the DEVS formalism has been envisaged with other application domains including marketing, teaching and organization study.

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