Simulation of Online Social Networks with Krowdix

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Abstract—Online Social Networks (OSNs) are a key phenomenon of Internet. Simulations are widely used in their study as means to harness their size and complexity, and to overcome the difficulties to set up experiments in real environments. However, these tools are still limited. They are usually focused on the structure of relationships and emulate changes only from statistical data. This approach is unsuitable to study OSN evolution as a result of the personal attributes and behaviours of their members. Our work addresses this issue with an agent-based simulation framework for OSNs called Krowdix. It provides support to specify simulations of discrete time where agents represent members acting according to their profiles and context. This context comprehends the environment, other agents, groups of agents and the whole network. Agent actions are responsible of network changes. Additionally, system actions can be used to represent unexpected events. This agent-based approach facilitates the translation of actual observations to simulation models, and explaining networks in terms of their members. A case study on Facebook illustrates the use of the framework.

Keywords: Krowdix; online social network; simulation; social network models; agent-based modelling.

I. INTRODUCTION

Online Social Networks (OSNs) have reached a great development and popularity on the Internet in the last years [1]. They adapt real world social structures to online channels, both web and mobile [2]. Their members construct personal profiles with the information they want others to know, share interests through recommendations, links or documents, and build lists of people with whom they are connected to. These instruments have produced a variety of new and extended behaviours that go beyond of their real-life counterparts.

Several research fields are paying attention to different aspects of OSNs, from the sociological and psychological analysis of their communities and users [2], to studies on the support tools required for such networks [3]. These works face with relevant challenges due to the heterogeneity of the involved information, the enormous volumes of data, and the difficulties to control actual settings. For these reasons, simulations have become a common tool to study OSNs.

Simulations allow creating OSN models with specific features and watching their evolution with full accessibility to all their components. Nevertheless, they present certain limitations regarding the required analysis. First, most of them [4] focus on the analysis of the structure of the network [5]. This approach is not well-suited to study the role that the information of the different components plays to manage those links. For instance, it does not relate user profiles and linking behaviour, something possible with real data [6]. Second, researchers usually define the simulation model with statistical approaches that transform observed behaviours in manageable sets of evolution models, as in [7]. This misses the necessary flexibility to interact with unexpected real-time events and changes in context variables that could affect the simulation at both the macro and micro levels. Third, these tools frequently offer only a limited and predefined set of features and actions to consider in the generation of the network [4]. This implies certain underlying assumptions about how OSNs are and what can be studied, making them unsuitable for different settings.

Our research addresses these issues with Krowdix, a platform to simulate OSNs based on Agent-Based Modelling (ABM) [8]. Agents focus on the intentional and knowledge features of users, and regard interactions as the core of social modelling. The agent paradigm also highlights the impact of the environment over behaviour. This overall perspective for simulations is thus close to studies on actual OSNs.

Krowdix defines agents by means of user models, which are patterns of information (i.e. attributes) and behaviour (i.e. actions). The effect of the environment appears making these actions dependent on context attributes for their triggering and results.

A Krowdix simulation has a state that comprises the state of all the elements in its model, both the environment and agents. This state changes when actions are executed, producing a new state. Agents carry out common actions, which correspond to member activities. Researchers execute system actions, which introduce arbitrary events, e.g. adding a new trending topic or decreasing members’ interest. System actions stress that real OSNs are affected by circumstances unforeseen by their members.

All actions happen under a discrete time. Common actions have duration, so an agent can perform several actions in a simulation step or an action can span over several steps. On the contrary, events are instantaneous.

As agents and researchers can choose alternative actions for execution, the evolution of a simulation is not linear, but a time tree of states. Krowdix supports its exploration through the forward and backward navigation over different branches of these time trees.

These features of Krowdix are illustrated with a case study on Facebook. It shows how to discover and model the main aspects of this OSN as Krowdix elements.

The rest of the paper is organized as follows. Section II makes an overview of current OSNs and their features. The description of the main principles of Krowdix and how it supports the specification of models for OSNs appears in
section III. Section IV briefly introduces the methodology to develop models. Section V applies the framework to the analysis of Facebook. Section VI compares Krowdix with related work. Finally, section VII discusses some conclusions and future lines of research.

II. ONLINE SOCIAL NETWORKS

The term OSN refers to a variety of communities whose interactions are mainly supported by networked computer systems [9]. Some examples are social network sites (e.g. Facebook1 and MySpace2), blogging and micro blogging sites (e.g. Blogger3 and Twitter4), and content sharing sites (e.g. YouTube5 and Flickr6). The analysis of these OSNs requires considering two levels: their groups and members. The term “member” indicates a participant with a unique representation in the OSN, such as individual users, organizations, or interest groups. A “group” is a community of members with some shared features or information.

The study of groups relies on the links that members establish among them, their types and features [4]. Thus, it has a mainly structural perspective. This explains the organization of the OSN, but it offers limited insights to discover the rationality behind it. This rationality depends on the individual members making decisions on how and when building links, which in turn depends on their goals, information and capabilities.

Researchers gather this information about members by using mainly the supporting infrastructure of computer systems. This infrastructure is quite heterogeneous [2] [6], but in most cases there are some common functionalities. Systems allow creating and maintaining member profiles; linking to other members or contents; and examining and navigating the previous information according to the privacy policies of the community and its members. The actual means to implement these functions change depending on the type of OSN and the available technical facilities.

Regarding the definition of profiles, these usually comprehend both structured information in the form of key-value pairs, and unstructured information, mainly text-free fields or uploaded contents. Structured information provides basic descriptors about members. Some common ones are name, age, gender, location or web page. For instance, Facebook and YouTube profiles include all of these descriptors. Unstructured information offers non-standard and extended information. A typical example is the “About me” section present in most of social network sites or the favourite quotation in Facebook. Members can also provide information about them by sharing contents, for instance uploading pictures or videos or creating fan pages.

Members of OSNs also describe their links with other members, which is the way of making explicit their networks. These links have a variety of features that imply differences in meaning. A first classification is between bidirectional links, which require a mutual confirmation of participants (e.g. Facebook friends), or unidirectional ones, which only require action of one member (e.g. Twitter followers). A second classification is between direct links, where members point to others indicating their relationship (e.g. the already mentioned Facebook friends and Twitter followers), and indirect ones, where members only link to a given common element that is not a member (e.g. Facebook interests on music and books or “like” indications).

The display and navigation of the previous information are key to unite members into communities. Here, the main difference between OSNs is the level to which they allow controlling information visibility and privacy. Members may have the capability to constrain the access to some information to others with certain features, such as being members of the OSN or their friends. For instance, Facebook allows limiting profile visibility to friends, friends of friends, or everyone, while Twitter posts are public or only available to followers.

Finally, OSNs are also characterized by the actions their infrastructure provides to manage information. Members cannot modify their identity, but they are usually allowed to create, modify and delete all the other information they own.

A tool for OSN simulations should provide the possibility of defining its members in terms of the previous information. There must also be means to specify how a simulated member actually behaves (i.e. executes actions) depending on its rationality and knowledge, and establishing a suitable mix of user types similar to that in the real OSN.

III. THE KROWDIX SIMULATION PLATFORM

Krowdix [10] is a tool for managing, executing and displaying discrete-time simulations of OSNs. It has been developed on top of an extensible framework that allows its adaptation to different analysis needs. Its design is based on the principles of ABM [8]. The core concept of Krowdix is the agent, an intentional and social modelling abstraction: it manages information to achieve goals through the execution of actions, which can act on information, the environment, or other agents (in this last case actions are communication interactions).

Krowdix represents the previous components with three main elements: social network models, their members, and the actions these can perform.

A. Social Network Models

A Social Network Model (SNM) is a characterisation of an OSN. It comprehends several elements and relationships.

The Social Network User (SNU) represents a member of an OSN. It performs actions that change the state of the network. SNUs are discussed in detail in section B.

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1 http://www.facebook.com/
2 http://www.myspace.com/
3 http://www.blogger.com/
4 http://twitter.com/
5 http://www.youtube.com/
6 http://www.flickr.com/
Members of OSNs are linked through different relationships, such as friendship or common interests. Krowdix represents these links with relationships, which are unidirectional links between two SNUs.

Linked members frequently share features. For instance, participants in forums or blogs may share their location, age or interests, and some of them probably present similar behaviours. The explicit modelling of these shared features facilitates the incremental specification of models and highlighting the key features of populations. Krowdix considers this level of abstraction with groups, which are sets of SNUs with common values for some attributes.

SNUs operate on content. The content represents any kind of information present in an OSN that their members can create, modify, further comment on and delete, and that it is not an attribute of an entity. For instance, contents in Facebook are the members’ pictures and their wall entries. Content is always associated to its creator SNU, but can be attached to different types of elements: SNUs, groups or other content. For instance, a content of type message (e.g. an e-mail or message in a social network site) is associated to its sender SNU, but also attached to its receiver SNUs and the contents it attaches.

Finally, attributes represent semantic information of the previous elements. They are key-value pairs of a given type. Besides characterizing elements, its use is the calculation of semantic distances between elements. This kind of distances appears, for instance, when finding people with similar preferences or searching groups related to some topic. Their actual calculation depends on the modelled situation.

With the exception of attributes, all the previous elements can be extended using programming interfaces. This allows providing new elements intended for specific needs. Table I lists some of the extensions for groups.

### Social Network Users

As it is said in the previous section, SNUs represent members of OSNs. A type of SNU is described by its profile, which is the set of actions it performs over time. Actions characterize the changes that can happen in an OSN (see some examples in Table II). They are defined by their triggering conditions, action points representing their duration, and effects on the simulation state (more on state evolution in section C). Both the triggering conditions and effects are described in terms of the values of attributes of the environment, including the SNUs involved in their execution, their relationships and the related contents.

Krowdix considers two types of actions:

- **Common actions.** SNUs execute this type of actions to perform changes in the simulation state. They are extensible so that new actions can be created in Krowdix. A particular action of this type is the no action, which reflects time passing without executing any change in the simulation state.

- **System actions.** Researchers execute these actions out from the usual simulation flow. They are intended to generate arbitrary effects on the simulation state, which are not directly derived from the current state.

The liaison between SNUs and actions is achieved by means of profiles. A profile describes the kind of behaviour that a SNU will develop during the simulation. It is a weighted subset of common actions, with some of them tagged as initial actions. The weight indicates the frequency of execution of actions. For example, some typical profiles could be blogger, whose main actions are to write blogs and comment on others’ blogs, or friend finder, whose target is to achieve the maximum number of friends and send messages to them. Both profiles assign high weights to the mentioned actions, as they represent those tasks where actual members of OSNs with those profiles invest more time. Initialization actions are executed prior to the first simulation step for every SNU.

### Table I. Krowdix Extension for Groups.

<table>
<thead>
<tr>
<th>Extension element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blog</td>
<td>A group where only the owner SNU can post information and all its friends can comment on posted information.</td>
</tr>
<tr>
<td>Themed group</td>
<td>A group where the owner SNU sends invitations to other SNUs that decide either to participate or not.</td>
</tr>
<tr>
<td>Forum</td>
<td>A group where candidate SNUs ask the owner SNU to participate. All the members can add information, which is shared within the group.</td>
</tr>
</tbody>
</table>

### Table II. Sample Krowdix Actions.

<table>
<thead>
<tr>
<th>Type of actions</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common actions</td>
<td>Create a friendship request</td>
</tr>
<tr>
<td></td>
<td>Accept friendship request</td>
</tr>
<tr>
<td></td>
<td>Create content</td>
</tr>
<tr>
<td></td>
<td>Comment on content</td>
</tr>
<tr>
<td></td>
<td>Send message to a friend</td>
</tr>
<tr>
<td></td>
<td>Create a themed group</td>
</tr>
<tr>
<td></td>
<td>Request participation in themed group</td>
</tr>
<tr>
<td></td>
<td>Accept participation in themed group</td>
</tr>
<tr>
<td></td>
<td>Send content to themed group</td>
</tr>
<tr>
<td></td>
<td>Create a forum</td>
</tr>
<tr>
<td></td>
<td>Request participation in forum</td>
</tr>
<tr>
<td></td>
<td>Send content to forum</td>
</tr>
<tr>
<td>System actions</td>
<td>Create a blog</td>
</tr>
<tr>
<td></td>
<td>Send content to blog</td>
</tr>
</tbody>
</table>

---

**Figure 1.** Action execution order and rearrangement based on quotas.
A SNM specifies the initial distribution of SNUs as a set of weighted profiles. The weights indicate the percentage of SNUs for each profile at the beginning of the simulation.

C. Dynamic behaviour

SNM instances (also referred as simulations) are created by means of executing a simulation. A simulation is the process of evolving a SNM through time. Since Krowdix uses discrete time, this evolution is parcelled in steps.

At each step, the state of the simulation is characterized by an instance state. The instance state includes the values of all the attributes in its SNM at the moment. The initial state is the result of creating the SNUs indicated by the distribution of profiles of the SNM and executing their initialization actions. After that, the simulation evolves in simulation steps where the effects of the execution of actions change the state generating a new one.

At every simulation step, all the SNUs existing in the current instance state perform some actions. Fig.2 illustrates this process. It starts randomly arranging the SNU turns. When the turn of a SNU comes, it selects for execution the first suitable non-executed action in its profile, which depends on the action characteristics and parameters, and the conditions satisfied in the instance state. SNUs have assigned an execution quota, which is the same for all of them in a step. Action execution consumes this quota. A SNU can execute the action if there is remaining quota. Let \( P \) be the action points of the action and \( Q \) the execution quota. Two situations can happen:

- \( P \leq Q \). The action is completed and \( Q \) is set to \( Q - P \).
- \( P > Q \). \( Q \) is set to \( 0 \), and \( P - Q \) action points remain pending for the next step.

Note that execution quotas and action points control the speed of evolution of the instance. The higher the execution quota is for a step, more actions are to be executed by SNUs, so the instance state evolves more quickly.

After all the SNUs have depleted their quotas, a new simulation step can start. Execution quotas are renewed for the new step. If a SNU has already executed all the actions in its profile, these are rearranged keeping the weights specified by the profile. Fig.1 shows an example of this rearrangement. Researchers can also execute system actions and modify simulation parameters, e.g. the execution quota, the available types of SNUs, or the size of the population.

When the simulation step finishes, several potential alternative instance states could be available. For instance, SNUs that completed the execution of their profiles can have their actions rearranged in different ways, and system actions and parameter changes can be performed. Krowdix supports a “what-if” approach that allows exploring these alternatives. If the instance state resulting from a simulation step is modified in one of those ways, a new alternative state is added to the simulation. Each of these states starts its own branch. Krowdix keeps all these branches, generating a simulation tree. Researchers can navigate them and even open new alternatives during simulation.

IV. SPECIFICATION GUIDELINES

The study of an OSN using Krowdix is a process with three main stages: the definition of the SNM, its initialization and the simulation.

The definition of the SNM starts with the OSN static or structural analysis, which maps the elements of the OSN to those available in Krowdix. Common OSN elements analysed here include, for instance, groups, relationships, messages and comments. Krowdix includes a set of basic SNM elements to cover the most common elements (see section III.A). However, new types of OSNs or the functional evolution of their support systems can make necessary extending existing elements to cover new needs. The Krowdix platform provides interfaces for this extension, though they are not discussed in this paper for the sake of brevity. Extensions will be incorporated to the tool distribution in new releases.

The OSN Dynamic Analysis specifies the profiles that correspond to the OSN users’ behaviours and the events that could appear in the evolution of the OSN. As it happens in the previous stage, Krowdix provides a basic set of actions (see section III.B) that can be extended to support new requirements. Researchers need to identify the types of users in the actual OSN and the actions these perform. These types identify profiles. Then, researchers map the actual actions to Krowdix common actions and define their parameters if required. Parameterization is currently limited to success rates and attribute values to filter potential targets (e.g. for a friendship request or to write in a blog). The definition of profiles ends assigning the weights of actions for each profile. At this stage, researchers also identify those events that do not depend on the population of members but could alter the evolution of the OSN. These events are mapped to system actions, that must also be parameterized.

The setting of the initial conditions defines the initial population. It identifies the profiles appearing in that population and their percentage of the total.

Finally, researchers execute the SNM and explore the simulation tree. Tools support different visualizations to highlight those aspects considered more relevant.

V. CASE STUDY: MODELLING FACEBOOK

Facebook is today the most popular OSN [1]. Its success story, the growing size of its community and the richness of its environment has made of it a common object of study. This section specifies how Krowdix has been used for creating a SNM for Facebook using the steps previously outlined and some achieved milestones.

The modelling starts with the static analysis. A typical user account contains the following elements: users, pages, events, news feeds, groups, applications, status messages, photos, photo albums, profile pictures, videos, notes and check-ins (i.e. localization registers). This set is not complete, but it is relevant for the case study purposes.
The mapping of these elements identifies if they can be represented with available elements (see section III.A) or require defining new ones. Users are SNUs, news feeds are blogs, events are themed groups, and applications are forums, and messages, pages, photos, and so on are new content-derived entities. For instance, feeds are modelled as blogs because only the owner can add new posts, but all the friends (depending on the privacy policy) can comment on posts. Events are themed groups because the owner sends invitations to potential participants, and these decide whether to participate or not. Groups are forums created by the owner where all their participants can add information.

The dynamic analysis identifies the profiles present in the SNM. Although there are not comprehensive analyses of the use of functionality in Facebook, some examples of its evolution can be found, such as [11], and used here.

The specification of profiles starts identifying the actions that support the users’ behaviour and mapping them to Krowdix actions. Table III summarizes this information.

Actions are combined in profiles depending on the types of behaviours that exhibit the actual users of the OSN. This case study adopts the qualitative classification in [6], which is based on the empirically observed usage. The designed profiles include with higher weights those actions highlighted in the study, and complement them with other actions less used. Table IV shows a sample profile.

The last stage establishes the initial conditions of the simulation. Researchers define the percentage of the different profiles in the initial population. Table V shows simple values for illustrative purposes. In this example, many SNUs of the deep end diver profile (see Table IV), which are the main responsible for relationship evolution, are included.

The simulation explores several alternatives in the evolution of the SNM with the following system actions:

- **Profile deletion.** Profiles responsible for increasing the number of SNUs are replaced with moderate users to slow down the pace of user creation.
- **Reducing execution quota.** Less actions (or parts of them) will be performed in every simulation step, reducing the simulation change pace.

Visualization should be selected to highlight the key aspects of this simulation. The growth of the population, the type of users, and their links are particularly relevant here.

The preliminary simulation results of the outlined model showed several behaviours present in Facebook. The model reproduces phenomena such as a growing heterogeneity of the population, the increasing linkage in the community, and the generation of highly coupled groups. The use of system actions made possible a certain representation of user’s evolution. In particular, the model considers how many users start very active but become tired of the network. This change was reproduced by replacing SNU profiles, though this does not preserve changes in SNU attributes happened during the simulation.

### TABLE III. Krowdix Actions for Facebook.

<table>
<thead>
<tr>
<th>Facebook functionality</th>
<th>Krowdix action mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facebook Finding / Meeting people</td>
<td>Create a friendship request</td>
</tr>
<tr>
<td></td>
<td>Accept friendship request</td>
</tr>
<tr>
<td>Facebook Post content</td>
<td>Create content</td>
</tr>
<tr>
<td></td>
<td>Comment on content</td>
</tr>
<tr>
<td>Facebook Keeping in touch</td>
<td>Send message to a friend</td>
</tr>
<tr>
<td>Facebook Events management</td>
<td>Create a “themed” group</td>
</tr>
<tr>
<td></td>
<td>Request participation in “themed” group</td>
</tr>
<tr>
<td>Facebook Groups</td>
<td>Accept participation in “themed” group</td>
</tr>
<tr>
<td>Facebook News Feed</td>
<td>Send content to forum</td>
</tr>
</tbody>
</table>

### TABLE IV. Sample Profile for Facebook.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Actions Mix</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV. The Deep End Diver (Creating Friends)</td>
<td>Create a blog</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Send content to blog</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Create a friendship request</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>Accept friendship request</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>No action</td>
<td>29%</td>
</tr>
</tbody>
</table>

### TABLE V. Initial Population for Facebook Simulation.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. The Moderate User (Typical User)</td>
<td>30%</td>
</tr>
<tr>
<td>II. The Town Crier (Continuous status update)</td>
<td>15%</td>
</tr>
<tr>
<td>III. The Power User (Uses all functionality very often)</td>
<td>5%</td>
</tr>
<tr>
<td>IV. The Deep End Diver (Creating Friends)</td>
<td>50%</td>
</tr>
</tbody>
</table>

### VI. State of the Art

Krowdix is related with three main fields of research: the analysis of OSNs and tools for their analysis and simulation.

Literature presents taxonomies of actual OSNs and their features from different perspectives. Typical ones are based on their structural and content characteristics.

The structural approach analyses OSNs as graphs [5]. According to the centric element of the network, there can be ego-centric networks (focused on the individual), socio-centric (organized around the group, e.g. a class-room or a company) and open-system (with no clear limits). Krowdix supports all these types introducing profiles with actions to send and accept friendship requests, and assigning different weights to these profiles.

The content classification focuses on the predominant type of information that members manipulate in the OSN. Some types of OSNs in this classification are the already mentioned social network sites, blogging and microblogging sites and content sharing sites, but also OSNs based on e-mail or chat. Krowdix abstract these networks by focusing on the types of available actions (e.g. adding a link, creating content or accepting a friendship request) and to whom they are allowed (e.g. the types of groups in section III.A).

Moreover, researchers can specify new types of contents if they need that SNUs work on particular attributes of the information.
Regarding analysis and simulation tools, most of them adopt a structural vision of OSNs [5]. For instance, this is the case of analysis tools such as Pajek [12] and UCINET [13] and simulation tools such as [14] and [15]. Regarding analysis tools, they can be used with Krowdix simulations as they only require the data of the graph being exported to a suitable format. Krowdix already supports exports to different formats and it also includes interfaces to build new ones if required. Regarding simulation tools, Krowdix simulations build graphs where nodes are SNUs and contents, and links are relationships. Different distributions of these can be achieved with profiles and the parameterization of actions. Thus, mechanisms used in other tools to build graphs [16] can be embedded in SNMs. However, these approaches based on analytical abstractions of users’ behaviours are frequently difficult to correlate with the observed behaviours of real users. In this sense, an ABM approach, as that of Krowdix, offers a more direct mapping of observations and interpretation of results, at least at the microscopic level [8].

VII. CONCLUSIONS

This paper has presented Krowdix, a platform for the modelling and simulation of OSNs. It adopts an ABM approach with discrete time for simulation. The framework has been designed to be extensible, so researchers can adapt the basic primitives to address new needs.

Krowdix simulations cover several aspects of OSNs: its macroscopic level (focused on the network structure), its microscopic level (focused on its members and features), and the dynamics that guide their evolution. SNMs specify their structure with SNUs (i.e. agents) that establish relationships with others, making up sometimes groups. Both SNUs and groups generate different types of content, granting different rights on them to other SNUs. Attributes represent the features of the previous elements, either individual or shared. Dynamics of SNM simulations are defined through profiles. They allow representing different mixes of actions and their parameterizations, and tuning the speed of simulation evolution.

The paper has also introduced a brief guideline to map actual OSNs to Krowdix components. It covers the static and dynamic analyses, and the initialization.

The previous elements allow modelling several relevant features of OSN phenomena, as the case study on Facebook illustrates. When compared with other simulation tools, Krowdix presents several differences. It replaces common mathematical models for users with action-profiled agents using ABM. This modelling is closer to the actual observations, so it facilitates alignment between SNMs and OSNs. It also offers a fine-grained control of the simulation and the possibility to explore its execution tree. Some simulation examples can be found at [11].

Krowdix is ongoing research with several open lines of work. First, additional experiments are bringing new needs about modelling elements. These are being incorporated to make possible a more precise simulation of different OSNs. Another aspect is representing the evolution over time of individual SNUs. Now, researchers can remove and add profiles, but this also replaces the related SNUs. The inclusion of dynamic profiles will allow changing the SNU behaviours depending on attributes or time conditions. Finally, the generation of alternatives in the simulation tree could be improved defining macros that abstract sequences of systems actions with suitable parameterizations.

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