Populations with Purpose

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Abstract. There are currently a number of animation researchers that focus on simulating virtual crowds, but few are attempting to simulate virtual populations. Virtual crowd simulations tend to depict a large number of agents walking from one location to another as realistically as possible. The virtual humans in these crowds lack higher purpose. They have a virtual existence, but not a virtual life and as such do not reasonably depict a human population. In this paper, we present an agent-based simulation framework for creating virtual populations endowed with social roles. These roles help establish reasons for the existence of each of the virtual humans. They can be used to create a virtual population embodied with purpose.

Keywords: Crowd Simulation, Social Roles

1 Introduction

Military training and other applications desire simulations that establish normal human behavior for an area. Once normalcy is established, observers can be trained to recognize abnormal and possibly dangerous behaviors. This requires the simulation of longer periods of time including different times of day. The problem is how to select reasonable, purposeful behaviors for a population for such periods of time. Roles are, in part, expected patterns of behavior and therefore seem like an intuitive feature for authoring these scenarios. Furthermore, role switching would enable plausible variations in behaviors throughout a day, but requires mechanisms to initiate the switching. While admittedly not comprehensive, role switching based on schedules, reactions, and needs, seems like a good starting point.

This paper describes an agent-based simulation framework for creating virtual populations endowed with various social-psychological factors including social roles. These roles help establish reasons for the existence of the virtual humans and can be used to create a virtual population embodied with purpose. Human decisions and the behaviors that result, stem from a complex interplay of many factors. The aim of this work is not to try to replicate all of these factors. We have focused on social roles because they are so heavily linked to meaningful behaviors. From this starting point we have included other factors that are linked to role and that can add reasonable variability to behaviors while still maintaining a framework where scenarios can be feasibly authored, modified, and controlled.

In addition, our framework focuses on higher level control mechanisms as opposed to lower level animation implementations. It also links roles and role switching to different action types such as reactions, scheduled actions, and need-based actions. As such the authoring of roles is largely just associating a set of these actions with a role. The techniques and methodologies used are adopted from a number of research disciplines including multi-agent systems, social psychology, ontologies, and knowledge representations, as well as computer animation.

2 Related Work

Crowd simulation research has been approached from several different perspectives. Some research groups are addressing how to simulate large crowds mainly through focusing on global path planning and local collision avoidance [18, 17, 19]. The behaviors in these simulations are for the most part limited to locomotion maneuvers.

Work has also been done on adding contextual behavioral variations through spatial patches [26, 11, 23]. The common theme in these works is defining regions in the virtual world and associating these regions with certain behaviors and interactions. The computer game, *The Sims*, might also be considered to incorporate spatially dependent behavior [25]. For example, if an agent is hungry and near a refrigerator, even if not being explicitly directed by the player, he would eat. While these certainly add richness to the virtual world, they still fall short of embodying consistent reasonable behaviors with purpose.

Most of the works described so far included few or no social psychology factors. There have, however, been some that do. The work of Pelechano et al. included the concept of role and other psychological factors, but the roles were limited to leaders and followers which along with the other factors influence only the navigation behavior of agents [20]. In [16], Musse and Thalmann describe a crowd simulation framework that includes sociological factors such as relationships, groups, and emotion, but again the behaviors are centered around locomotion actions.

In [21] Shao and Terzopoulos describe a virtual train station. Here they classified their autonomous pedestrians into a few categories, including commuters, tourists, performers, and officers. Each type of character is then linked to hand coded action selection mechanisms. Similarly in [27] the authors introduce a decision network which addresses agent social interaction based on probabilities and graph theory, however action selection is still manually coded.

Some research groups have worked directly on incorporating roles into virtual humans. Hayes-Roth and her collaborators were one of the first research groups to develop virtual roles [8]. Their interactive intelligent agent was instilled with the role of bartender and a set of actions were defined such that the user's expectations would be met. There was, however, no switching of roles for this character and the behaviors were only related to communication acts.

Most recently work by Stocker et al. introduced the concept of priming for a virtual agent [22]. Here agents are primed for certain actions based on the other agents and events around them. While they do not address roles specifically, this concept of priming is somewhat similar to the role switching behaviors we will describe in this paper.

3 Approach Overview

In this section, we provide an overview of our approach and describe the social psychological models on which it is founded, including a definition of roles, factors affecting role switching, and action types.

3.1 Definition of Role

A role is *the rights, obligations, and expected behavior patterns associated with a particular social status* [1]. Ellenson's work [6] notes that each person plays a number of roles. Taking into consideration these descriptions as well as discussions from other social psychologists [13, 4], we conclude that roles are patterns of behaviors for given situations or circumstances. Roles can demand certain physical, intellectual, or knowledge prerequisites, and many roles are associated with social relationships.

3.2 Role Switching

People's priorities are set by a number of interplaying factors, including emotions, mood, personality, culture, roles, status, needs, perceptions, goals, relationships, gender, intelligence, and history, just to name a few. In this work, we have chosen a few factors that are related to roles and role switching that we believe will help endow virtual humans with meaningful, purposeful behaviors.

Switching from one role to another can be linked to time, location, relationships, mental status, and needs (See Figure 1). For example, one can imagine someone switching to a *businessman* role as the start of the work day approaches or as he enters his office or when he encounters his boss. Also, someone may need to shop for groceries to provide for his family. The *shopping* behavior would stem from a need and cause a switch in role to *shopper*. Elements of mental status, such as personality traits, can impact the selection and performance of these roles. For example, a non-conscientious person might not shop for groceries even if the need exists.

Action and role selection is further affected by a filtration of proposed actions according to an agent's *Conventional Practice* and *World Knowledge* [10, 4, 3]. *Conventional Practice* is a set of regulations and norms that each individual in the society should obey. *World Knowledge* indicates that certain physical, intellectual, and knowledge elements are required for specific roles.

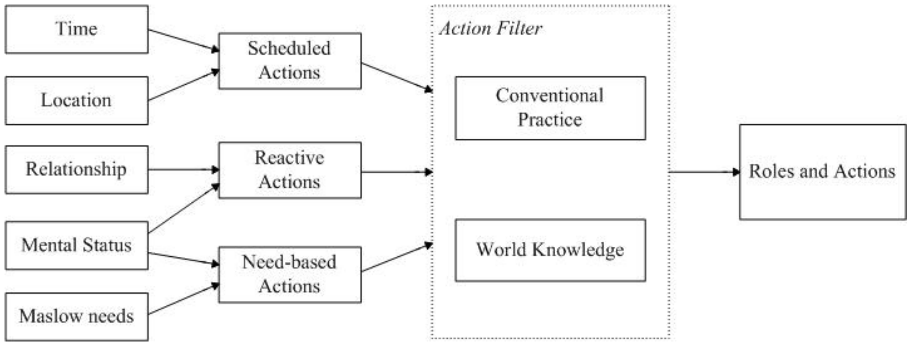


Fig. 1. System Diagram

Another perspective from which to consider selection is to examine what triggers various behaviors. Some actions are planned for such as going to work or attending a meeting. These actions, called *Scheduled* actions, tend to establish a person's daily routine and are often heavily coupled with their roles. Other actions are not so predetermined. Some actions arise to fulfill needs. Among these needs might be those depicted in *Maslow's Hierarchy of Needs*, including, food, water, excretion, friendship, family, employment, and creativity [12]. These type of actions, called *Need-based* actions, can also be linked to roles. For example, in order to maintain employment safety, a businessman might need to contact his clients are on regular basis. Still other actions, *Reactive actions*, are responses to agents, objects, or events in the world. Who and what we react to is at least partially determined by our roles. If we see a friend or co-worker as we are walking to work, we are likely to stop and greet them.

While we cannot claim that these three types of actions make a complete categorization of all behaviors, we believe that they can encompass a wide range of behaviors and provide strong ties to roles and purposeful behaviors. Another key factor is the ability to easily author or initiate these behaviors. Each requires a finite, straightforward amount of data:

Scheduled actions: $Sch = \langle P, A, L, T \rangle$, where P is the performer (an individual or group), A is the action to be performed (simple or complex), L is the location where the action is to be performed (based on an object or a location), and T is an indication of the time (i.e. start time and duration).

Reactive actions: $Rea = \langle P, S, A \rangle$, where P is the performer (an individual or group), S is the stimulus (an object, type of object, person, location, event, etc) and A is the action to be performed (simple or complex)

Need-based actions: $Nee = \langle P, N, D, C \rangle$, where P is the performer (an individual or group), N is the name of the need, D is the decay rate, and C is a set of tuples $\langle A, O, F \rangle$, where A is the action to be performed (simple or complex), O is a set of object types, and F is the fulfillment rate.

4 Implementation

The work presented here extends work previously reported [2]. Previous work included an implementation of different action types and very rudimentary roles, but was limited to a single role per character which is not realistic for day scale simulations.

To continue to ensure scenario authoring is feasible, we have extended our data-driven approach where all of the vital scenario data is stored in a database. This includes information about each agent such as conventional practices, mental status, world knowledge, and role sets. We also store a mapping of the relationships between agents. Information about the world, objects in the world, and actions are also stored in the database. This includes the specification of schedules, needs, and reactions. As such, scenarios can be authored entirely through the database and without any coding. In addition, our framework is built on an existing crowd simulator that provides navigation and collision avoidance for the agents [19].

We have extend the previous implementation including now a much richer definition of role. The most important component of a role is a set of actions [13]. This action set corresponds to the conventional practices associated with the role. These actions may be scheduled, need-based, or reactive actions as mentioned in the previous section. Furthermore, these actions may also be linked to parameters such as location, object participants, start-times, and durations. Interpersonal roles are also associated with relationships, which are a simple named linking of agents. Among agent parameters is a set of capabilities corresponding to actions that they can perform. These capabilities form the foundation of an agent's world knowledge.

As described in the previous section, factors influencing role selection include, time, location, relationships, mental status, and needs. In this section, we will describe the implementation of each of these factors and how they have been incorporated into the three action types. We will also discuss how actions and roles are further filtered by conventional practice and an agent's world knowledge (See Figure 1).

4.1 Action Types

A large part of the definition of a role includes a pattern of behaviors. Our framework associates each role with a set of actions. These actions can be of any of the three types of actions described earlier, namely *Scheduled*, *Reactive*, or *Need-based*.

Scheduled Actions Scheduled actions include time and location parameters [2] and can be used to establish an agenda for a day. Some roles are directly associated with scheduled actions. For example, a businessman may be scheduled to work in his office from 9am to 5pm. As 9am approaches, the framework will initiate processing of the scheduled work in office action and send the character to his office and the businessman role.

However, if an agent does not have a scheduled action to perform, they will perform a default action that is associated with their current role. Generally default actions are the actions most often performed by that role. For example, a businessman or administrator might work in an office. A shopkeeper might attend to the cash register. Just as in real life, scheduled actions can be suspended by higher priority need-based and reactive actions.

Need-based Actions Need-based actions are merely database entries associating a decay rate, actions, objects, and a fulfillment quotient. The examples described in this paper are based on *Maslow's Hierarchy of Needs* [12]. Conceptually, there is a reservoir that corresponds to each need for each agent. Currently the initial level of each reservoir is set randomly at the beginning of the simulation. At regular intervals, the reservoirs are decreased by the specified decay rates. When the level of a reservoir hits a predetermined threshold, the fulfilling action is added to the agent's queue of actions. Its priority will increase as the reservoir continue decreases eventually its priority will greater than all actions on the queue. Then the agent will perform the action, raising the level of the reservoir.

We have chosen to use *Mental Status* as an influence on needs (and reactions), because social scientists have linked it to roles and we feel it adds plausible variability. It includes several factors, but we focus on personality as it addresses an individual's long-term behavior. There are several psychological models of personality. One of the most popular is the Five-Factor or OCEAN model [24]. The five factors are: *Openness* (i.e. curious, alert, informed, perceptive), *Conscientiousness* (i.e. persistent, orderly, predictable, dependable, prompt), *Extroversion* (i.e. social adventurous, active, assertive, dominant, energetic), *Agreeableness* (i.e. cooperative, tolerant, patient, kind), and *Neuroticism* (i.e. oversensitive, fearful, unadventurous, dependent, submissive, unconfident).

We have based our implementation of personality on the work of Durupinar et al. [5]. An agent's personality π is a five-dimension vector, where each is represented by a personalty factor Ψ_i. The distribution of the personality factors in a populations of individuals is modeled by a Gaussian distribution function with mean μ_i and standard deviation σ_i:

$$\begin{aligned}&\pi = \langle \Psi^O, \Psi^C, \Psi^E, \Psi^A, \Psi^N \rangle\\ &\Psi^i = N(\mu_i, \sigma_i^2), for\, i \in O, C, E, A, N\\ &\text{where} \quad \mu \in [-10, 10],\, \sigma \in [-2, 2]\end{aligned}$$

Since each factor is bipolar, Ψ can take both positive and negative values. For instance, a positive for *Extroversion*, E+, means that the individual has extroverted character; whereas a negative value means that the individual is introverted. In Section 4.1, we will describe how personality dimensions affect the decay rates of need reservoirs, creating reasonable variations in behaviors from person to person.

Needs and priorities differ from person to person. We represent this variation by linking the personality traits just described with needs. This is, of course, a massive oversimplification, but one that leads to plausible variations. Table 1 shows our mapping from Maslow needs to OCEAN personality dimensions. It should be noted that just the personality dimension is represented, not the valence of the dimension. For example, neuroticism is negatively correlated with needs for security of employment and family. This mapping was formulated by examining the adjectives associated with the personality dimensions and the descriptions of the Maslow needs.

Reservoir Descriptions	**Personality Traits**
problem solving, creativity, lack of prejudice	O, A
achievement, respect for others	O, A
friendship, family	E
security of employment, security of family	C, N
water, food, excretion	

Table 1. Mapping between Maslow need reservoirs and personality dimensions.

In this work, we represent the decay rate as β. For example, $\beta^{friendship}$ indicates the decay rate of the *friendship* reservoir. For Maslow based needs, we also apply a correlation coefficient r which ranges from (0,1] to represent the relationship between decay rate and personality traits. More precisely, $r_{E,friendship}$ represents how strongly the *Extroversion* trait and *friendship*'s decay rate correlated. The closer r gets to 1 the faster reservoir empties (i.e. the decay rate is high indicating the agents strong need for friendship). Since a need can be affected by more than one personality trait, for those needs marked with multiple personality traits we assign weights to each one: $\omega_{E,friendship}$ meaning the impact of *Extroversion* on *friendship.* If a need has more than one trait's influence, its summation of ω should be equal to one and for simplicity in this work we assume each personality trait contributes the same weight.

Consequently, for ith agent the decay rates and their relationship with personality traits are shown below (here we list two examples):

***security of employment (se)*:**
$\beta_i^{se} = (\omega_{C,se}|r_{C,se} \times \Psi_i^C| + \omega_{N,se}|r_{N,se} \times \Psi_i^N|) \times 0.1$
where $\omega_{C,se} + \omega_{N,se} = 1$, $\beta_i^{se} \propto C, N$ and $\beta_i^{se} \in [0, 10]$

***friendship (fr)*:**
$\beta_i^{fr} = (\omega_{E,fr}|r_{E,fr} \times \Psi_i^E|) \times 0.1$
where $\omega_{E,fr} = 1$, $\beta_i^{fr} \propto E$ and $\beta_i^{fr} \in [0, 10]$

Reactive Actions As a simulation progresses, agents make their way through the virtual world, attempting to adhere to their schedules and meet their needs. In doing so, agents encounter many stimuli to which a reaction might be warranted. Reactions play an important part in our implementation of roles. In [7], Merton states that a person might switch roles as a response to those around him. Relationships are a major impetus for reactive role switching. For example, if two agents encounter each other and are linked by a relationship such as friendship, they will switch to the friend role.

Since reactive actions must be performed soon after the stimulus is encountered, they are given a higher priority and generally result in the suspension of whatever other action might be being performed, though this is not always the case. For example, if an agent is fulfilling a high priority need, then they might not react to the people and things around him.

The duration of responses can vary according to the activity and characteristics of the agents. For example, an agent that is hurrying off to work or who is introverted, may not linger as long on the street to greet a friend, as someone strolling home from work or an extrovert would.

4.2 Action Filter

Once a set of actions and roles have been purposed, some may be eliminated due to conventional practice constraints or an agent's lack of necessary world knowledge.

Conventional Practice Social science researchers believe that when an agent plays a role in a given organizational (or social) setting, he must obey *Conventional Practices*, meaning *behavioral constraints* and *social conventions* (e.g. the businessman must obey the regulations that his company stipulates) [15, 14]. To be more specific, behavioral constraints are associated with the following factors: responsibilities, rights, duties, prohibitions and possibilities [15]. Role hierarchies include conventional roles (e.g. *citizen, businessman, mailman*) and interpersonal roles (e.g. *friends, lovers, enemies*). Figure 2 shows part of the conventional role hierarchy that we designed according to the taxonomy presented in [9]. We have linked each conventional practice norm with an impact factor (range [0, 1]) which reflects how strongly these norms are imposed on certain roles. Having 1 as an impact factor would indicate that it is the most powerful norm. For convenience, we have set all impact factors in our current simulations to be high enough to indicate that every agent would obey not only the conventional practice of current professions but also those inherited from upper levels of the hierarchy. However, users could choose whatever impact factors they would like according to the behaviors that they desire.

World Knowledge Some roles have physical or intellectual requirements and these requirements may be difficult to obtain. Also some people are just naturally more physically or intellectually gifted or have more talent in an area than

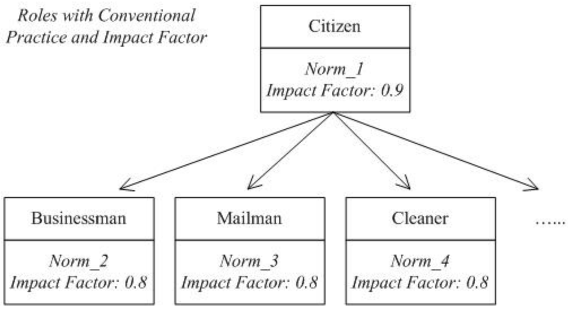


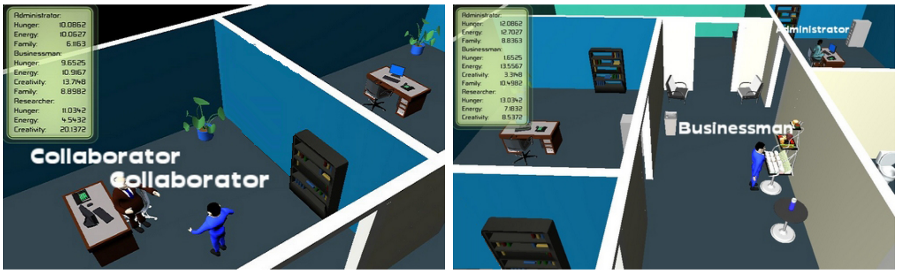
Fig. 2. Role Hierarchy with Conventional Practice and Impact Factor

others. These factors can put limitations on what roles a person can take on [4]. We represent world knowledge as capabilities. Agent capabilities are the set of actions that the agent can perform. Actions are categorized and placed in a hierarchy to lessen the work of assigning capabilities to agents and also checking to ensure that agents meet the capability conditions before performing an action.

5 Examples

To explore the effects of roles and more precisely role switching on virtual human behaviors, we have authored a typical day in a neighborhood. As with real humans, each virtual human is assigned a set of roles. Figure 3 demonstrates one agent taking on the role of *businessman* as he enters his office building (i.e. location-based role switching). Two other agents react to seeing each other by switching to *friend* roles (i.e. relationship-based role switching). Another agent reacts to trash in the street by starting her *cleaner* role (i.e. behavior selection-based role switching). These first examples of agents going to work demonstrate how time, location, and behavior selection impact role switching. They focus on role transitions caused by scheduled and reactive actions. The following office examples concentrate more on need-based actions. The top image of Figure

Fig. 3. Locations, relationships and behavior selection affect role switching.

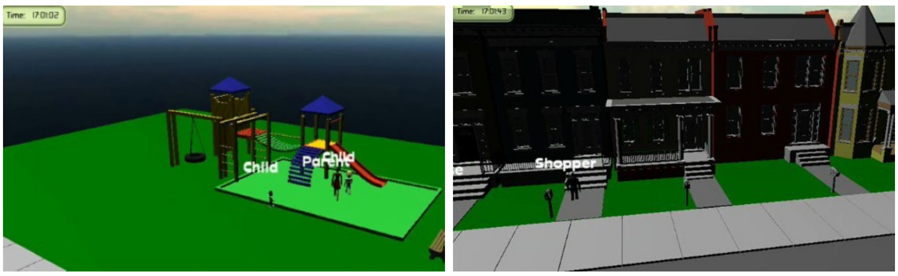


(a) (b)

Fig. 4. (a) The businessman's *creativity* need prompts him to speak to a co-worker, causing both to switch to *collaborator* roles and replenish their creativity reservoirs. (b) The businessman's role remains while eating to refill his hunger reservoir..

4a shows that the businessman's *creativity* reservoir is approaching the critical threshold (i.e. 2). When it reaches the threshold, he suspends his current action and starts a conversation with his co-worker. This exchange of ideas causes the *creativity* reservoirs of both men to refill.

Figure 4b shows that not all need-based actions cause role switching. The hunger need is associated with the role of being human, because *businessman* is a descendant of this role in the role hierarchy there is no need to switch. The final scene depicts a late afternoon in our neighborhood. Figure 5a shows a *businesswoman* becoming a *parent* when playing with her children. In Figure 5b, a man was headed home from work, but before he could reach his door, the *security of family* need prompted him to switch his role and instead he go to the grocery store.



(a) (b)

Fig. 5. (a) A businesswoman switches her role to parent when she spends time with her children. (b) A businessman is heading home after work, when his *security of family* need preempts this action and switches his role to *shopper*.

6 Discussion

In this paper, we have presented a framework for instilling virtual humans with roles and role switching to produce more typical virtual worlds where people's behaviors are purposeful. The methods presented are based on social psychology models and focus on approaches that facilitate authoring and modifications. As people's complicated lives rarely allow them to embody just a single role during the course of a day, role switching is important to creating reasonable virtual human behaviors. The framework presented can also be used to include abnormal behaviors. For example, one could author a subversive role for a character that includes reacting to pedestrians by robbing them or includes a strong need for drugs and alcohol.

There are numerous possible extensions to this work. First, we could illustrate the dynamics that stem from status hierarchies by experimenting with the concepts of power scale and social distance. We might also address situations where multiple roles could be adopted. For example, a man being approached by both his boss and his child. Here, social power scales and social distance might result in different social threats which would cause one role to be favored over the other. Finally, we could focus on agents that learn role definitions by observing the behaviors of others, enabling each agent to have customized definitions based on their own experiences.

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