# Towards the Simulation of Large Environments

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**Abstract.** The development of a smart environment working into large facilities is not a trivial matter. What kind of intelligence is needed and how this intelligence will interact with individuals is a critical issue that cannot be solved just by thinking about the problem. A combination of social and computer science methods is necessary to learn and model the interplay between the environment and the environment inhabitants. This paper contributes with an ongoing case study that exemplifies this kind of combination. The case study considers two faculty buildings and a behavior to be modified. The goal is to design a set of devices that sends signals to passing-by pedestrians in order to make them use more the staircases. Banners, videos, and directed intervention are used. The effect of each one is measured and such measurements are reproduced into computer simulations. This information is necessary in order to determine the duration, the intensity of the stimulus, and the response of the individuals. Opposite to most works, the measurements do not provide full information of what is going on in the large facility. As a consequence, algorithms and software to fill in the gaps consistently are needed. The paper describes the current state of the simulations and the difficulties in modeling with precision the results in a case study.

## 1 Introduction

If a large facility is expected to host an embedded system, as in a Internet of Things or Ambient Intelligence scenario, the definition of such system and its early validation is largely missing in the literature. Given a particular building or large space, a first question is whether the goal to make the visitors of the facility show a new behavior or to alter an existing one. This cannot be done in the traditional way, by consulting a few stakeholders. Interviewing and surveying the occupants of the environment seems more adequate.

How this information is captured and reused later on, it is still an issue. Documenting is out of question. However, the format of the documentation can be subject of discussion. Also, how this documentation is used and accessed in order to ensure the problem is completely understood.

The hypothesis of this work is twofold. First, that social sciences methods can be used in order to capture better the behavior of the humans inhabiting the large facility and what stimulus can trigger this behavioral change. Second, once there is a preliminary solution to the creation of new behaviors or modification of existing ones, the enactment of such behaviors can be something better documented if computer simulations are used.

Besides, documenting something as dynamic as the behavior of big groups of humans through simulations allows too to experiment with the expected effect of different stimulation procedures. This way, responsible of large facilities can have tools that enable them to discover how they want the facility to be altered before the actual smart environment is even built. In order for the simulation to be realistic, the simulation has to reproduce the interplay among users and between users and the environment. The later includes too the devices that are supposed to make the users behave differently. These devices do provide stimulus previously validated by experts as candidates to produce the desired kind of effects.

The paper is structured as follows. First, section 2 analyses if a particular behavior alteration/induction is really possible. The contribution of social sciences to the requirements gathering is made in 3. A guideline is proposed that combines interviews, surveys, but also field studies, as well as analyses of the captured information. Examples of the analysis phase is made in section 4, where a domain example is introduced. The design of simulations that aid to create the smart environment capable of enacting the new behaviors is made in section 5. The related work is introduced in section 6. Conclusions are presented into section 7.

## 2 Stimulus for Behavior Alteration

Literature shows that humans are sensible to external stimulus in subtle ways and that our behavior can be altered. The extent of the alteration may depend on the individual. Some may react notably while others hardly react. Nevertheless, the average person ought to notice this. The nature of the stimulus matters too. In certain conditions, such as evacuations, humans pay more attention to other humans rather than other artificial elements, such as banners.

Humans have sensibility towards the behavior of other humans. If an individual finds a group along the way, depending on its size, will either stop and look what is happening and stay or keep walking [11]. The larger the group, the greater the effect. This is explained as a mirroring behavior effect. If sufficient people stare at an arbitrary point, a passerby individual will unconsciously look at the same place [5]. Gaze copying happens mainly within 2 meters range and the response depends on the physical layout of the environment, the social context, and the sex of the individual.

When the stimulus come from artificial sources, the results are still promising. Sound and images can affect the behavior of pedestrians. Beyer et al. [2] introduce an experiment where an interactive large banner display affects the audience. Through visual stimulus, authors manage to attract approaching pedestrians and distribute them along the display. Miller [12] shows that noise can affect people's performance. A sleepy person may be aroused by noise, but it has also negative effects, like affecting the performance of complicated tasks, affect negatively the mood and disturb relaxation. Negative effects could be used to influence pedestrians. In this paper, it is assumed that, since it can annoy people, this could be used to clear out areas or to reduce the pedestrian traffic around some places where the noise comes from.

The context matters too. Foster [4] analyzes different domains in

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order to promote healthy habits. Each context is different. A shopping center and railway station involve different behaviors on behalf the population.

Also, sensibility towards stimulus changes depending on the context. In an airport, passengers pay special attention to information panels. A change in one panel may trigger movements of user groups, such as changing one boarding gate ten minutes before the boarding starts. Fun parks also influence the behavior of their visitors through information panels that tell expected waiting time for each attraction.

## 3 Guidelines for Developing Ambient Intelligence in Large Facilities

The system to be developed aims to interact with several inhabitants of a large space. These inhabitants may be transient ones or permanent inhabitants of the considered space. It is assumed that the people in this physical environment can be either a management staff, in charge of the facilities and aiding to the occupants of the facilities to fulfill the identified system goals; and the visitors, who are the clients of the facility. In general, the staff interacts with the visitors in order for helping them perform certain activities. In the physical space, it is assumed the staff is expected to modify the behavior of the clients in a way that clients perceive an benefit.

To identify what behavior modifications are possible and how to best convince inhabitants of the facility to commit to such behavior, a guideline affecting particular system development is introduced following:

- Analysis phase. The facility to be analyses is assumed to fulfill one or many purposes. The staff is expected to alter the behavior of the inhabitants in order to achieve certain behavior. This behavior is compatible with the purposes of the facility, and it is supposed to be regulated or activated through some environmental devices. There is a review of the meaningful behaviors, according to the literature, on the expected behaviors (domain or non-domain specific) for the chosen facility. A selection of stimulus is made based on the available resources (the budget of the modification, for instance). Also, field studies have to be planned to know more of the visitors and also to evaluate the effect of those stimulus over time. Effect of each stimulus is measured and annotated so that it can be reproduced later on. Each stimulus is expected to have a duration and an intensity.
- Design phase. The different stimulus and the expected reaction is modeled into a simulation that serves as reference. The simulation includes the physical space, the inhabitants of the space, the expected behaviors of those inhabitants according to the field studies, and the simulated devices that are going to provide the stimulus. The measurements made in the field studies are interpolated to guess the overall behavior of the whole population. Accordingly, the expected behavior is studied, taking into account the reaction to the stimulus. As a result, an expected orchestration of the stimulus is obtained.
- Deployment phase. The synchronization of the stimulus is deployed into real devices already working in the facility. The simulation is expected to have identified several critical observation points whose measurements indicate if the stimulus is working or not.

The role of human scientists is important in the development of this kind of systems. In this guideline, it is assumed that human scientists involve themselves mainly into the analysis stages. However, their collaboration is needed too along the design stages. Human sciences scientists, such as psychologists or social scientists, provide insight into the behavior of the users beyond common wisdom. Hence, they are needed in order to properly design the field experiments, to study the results, and to assess the validity of the simulations.

It is assumed that there is a simulation parameterization whose behavior is close to the observed behavior. Such simulation should be possible because the behavior of users into installations is not heterogeneous and tend to fit into standard behavior patterns, that we associate with activities of the daily living typical of the installation. The definition and parameterization of the simulation is considered following.

### 3.1 Specifying the crowd simulation

An important part of the simulation is the description of the physical space inhabitants, which is called here population description. For this goal, it is necessary to identify a set of possible actor behaviors, an enumeration of the number of instances of these behaviors, and a timestamp of when the behavior&actor instantiation happens.

Actor instances are created along the simulation and destructed when the behavior of the character finishes. It is assumed the designer determines a suitable place where this destruction happens. After all,actors cannot vanish from the scenario just anywhere. These actors instantiate a particular set of behaviors with particular parameters. The different parametrization determines individual variations of the behavior.

It is assumed that actors can belong to two distinguished groups: those responsible of operating the facilities and those visiting the facilities. The first are expected to perform different activities oriented towards coordinating the behavior of the second group within the facility. The second group are executing activities of the daily living related to the main purpose of the facility. It is not expected that one actor belonging to one group suddenly becomes an actor belonging to another. Even thought there maybe cases where this role switch makes sense, it is not considered in this paper. Within each group, there can be further decomposition of responsibilities, but it depends on each particular domain.

An actor behavior specification consists of a sequence of parameterized activities of the daily living plus an initial location. The amount of instances of each actor behavior specification determines the composition of the population.

Actors are not allowed to alter their behavior and they constantly perform the same sequence. The sequence terminates with the destruction of the character. This enforces designers to define precisely what actors are expected to do since their creation until completing their part in the simulation.

## 4 The case study

The crowd simulation has been applied to a scenario situated in two faculties. The goal is to alter the behavior of the inhabitants in order to make them choose an activity that requires additional effort over another activity that does not. The behavior to be altered is using the elevator, which ought to be replaced by using the staircases. The experiment is run into two different faculties, the Computer Science Faculty and the Political and sociological Sciences faculty.

The application of the methodology starts with a field study structured as follows. First, the managers of both faculties are interviewed to know more of the daily problems they have to face. This provides an insight on the students and other staff using the facility. It also helps to identify possible incompatibilities between the planned stimulus and the current activities. The chosen stimulus are:

- Human-to-human interaction. A person playing the role *facility operator* interacts with another playing the role *visitor* and tries to suggest the use of staircases is better.
- Banners. Banners are proposed containing information of interest to the visitor and that may aid in suggesting an alternative behavior. It is important to notice that there ought to be an evident profit for the visitor, otherwise the behavior modification will not occur. In this case, the banner is presented at figure 1. It suggests the visitor will gain health improvements, will arrive faster to the destination, and will save electricity. These facts, specially the savings in time during travels, has been proven to be true.
- Multimedia. A video shows a dramatization of a person that uses the elevator for everything even though can perfectly walk. The video is shown through a short distance beamer sufficiently visible and the equivalent of a 55' screen. The short distance beamer is projecting vertically and permits a less disturbing installation. The projection is made close enough to the elevator. Due to safety concerns, it was not allocated right next to the elevator.


**Figure 1.** Banner for motivating users to use the staircase. It written in spanish. The main title says *stair climbing and avoiding elevators* at the top. The alleged reason are *1. improving your health*, *2. You will get faster to your destination*, and *3. you will save energy*

A plan for measuring the effects of these stimulus was made. The plan consisted on a five week schedule. The first week (week A) there was no stimulus and it was used to collect a base line of staircase/elevator traffic stats; during the second week (week B) the banner stimulus was introduced; along the third week (week C1) the videos were added; and in the fourth week (week C2), the human-to-human interaction. Then, there were some days of no stimulus to let users decide whether they want to keep the new behavior or get back to the old one. Therefore, the fifth week (week D) is dedicated to measure the resilience of the stimulus.

Collected data was a set of pedestrian traffic into strategic checkpoints of the faculties. Measurements indicate whether visitors come or go, and whether they are using the elevator or the staircases. An account of persons per minute is provided. The resulting influence of the stimulus along the field experiment stages is included in table 1. The number of people arriving through the elevator remains mostly the same along stages. However, the number of people choosing not to use the elevator is reduced up to 4 points in phase C2. This is a variation of 13,65% over the original use of the elevator. The results are not shocking, but it should be taken into account that each stimulus lasted for one week, and not months.

**Table 1.** Variation of the traffic in elevators into two faculties

| % use elevators | A | B | C1 | C2 | D |
|---|---|---|---|---|---|
| Total | 23,1 | 21,9 | 21,4 | 20,3 | 22,2 |
| Departures | 29,3 | 28,2 | 26,2 | 25,3 | 26,4 |
| Arrivals | 14,4 | 14,4 | 15,2 | 14,0 | 16,2 |
| #total= | 9730 | 9797 | 9459 | 9165 | 9088 |
| #departures= | 5688 | 5371 | 5335 | 5109 | 5345 |
| #arrivals= | 4042 | 4426 | 4124 | 4056 | 3743 |

With the obtained traffic data, a simulation is arranged so as to reproduce the observed behaviors.

## 5 Reproducing the experiments

The result of the experiments is being transferred to computer simulations, to identify complexities and capture individual behavior as precisely as possible.

In the simulation, all actors are belonging to the visitor role. Their actions consists in entering the building, visiting a previously unknown number of rooms, and exiting the building. Hence, a parameterization of the problem includes an account of the rooms each actor visits and how long they stay there.

The computer simulation has to capture emergent behaviors. Rather than organizing dynamically the behavior of a whole population and letting a central node orchestrating everything, the approach is multi-agent based one, where individual behaviors of characters is coded. The individual behaviors is explained along the next paragraphs, but the goal is to attain the same, or close, traffic data to those obtained from the different experiments. Since the data from each phase is available, the simulation ought to capture the effect of the stimulus over the visitors. Henceforth, if the stimulus is a banner and the measured effect is a 25% variation, then the simulated traffic ought to show such change as well.

The total aggregation of the traffic ought to provide with numbers similar to those of table 1. Achieving this traffic data while coding individual behaviors is a hard task because of two reasons. First, there are several elements whose interplay affects the outcome of the simulation. Actors interact among themselves and with the environment, specially elevators and the physical layout of the environment, a building with several floors. Second, the gathered information is partial, since only a few pedestrian traffic check points were established in the field study from section 4. This means there were not cameras recording the full activity. As a consequence, there may be many populations of simulated actors whose movement along the facility matches the obtained measurements in the field experiment of section 4

The problem has been studied in [13] and the provisional solution is a greedy algorithm that produces a population of actors whose behavior matches to some extent the expected behavior of the whole population. A first attempt is presented in figures 2 and 3.

The behavior of each individual can be summarized as follows. Each character has a navigation path from the starting point to a particular location determined by the greedy algorithm [13] and going through some intermediate points that are part of the parameterization. Intermediate points may correspond to specific rooms the characters may or may not visit. Along the navigation, the character may find obstacles. Fixed obstacles are already avoided by the navigation algorithm. Mobile obstacles are avoided through maneuvers around the expected collision points. Afterwards, the navigation path is rechecked and resumed.

Figure 2 shows a part of the 3D simulation created with the greedy algorithm. In the simulation, to compare the simulated vs the real scenario, the simulation assumes there is a device in the area capable of counting people as they cross the section corresponding to the checkpoint. The counting is compared against the real measured traffic in the bottom part of the figure.

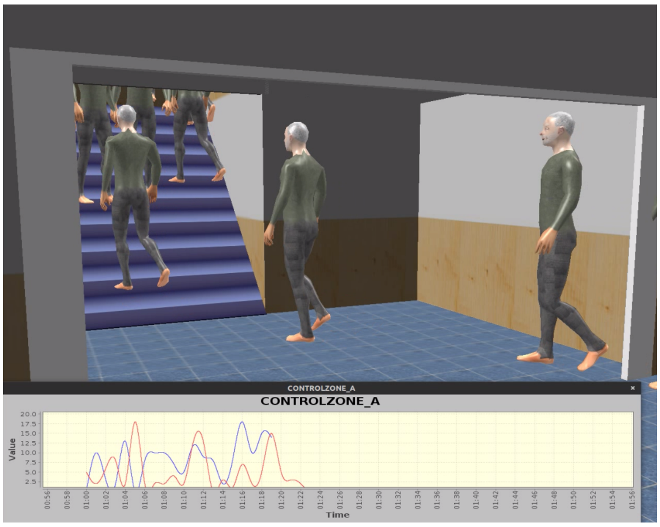


**Figure 2.** Simulation of pedestrian traffic along checkpoints and simulated traffic data gathering

There are many possible populations of actors whose movements have the same effect in terms of traffic through the checkpoints, at least, in theory. The greedy algorithm from [13] achieves the performance shown in figure 4. This figure focuses on the traffic data and compares the simulated to the real measured traffic along the experiment. The considered time window is different from 2. In figure in 3, there is a small variation in the obtained simulated traffic measurements. The main reason for such variations is the interplay of actors along their paths, which is not taken into account. Collisions and bottlenecks happen too, and they cause a different transit time. This is a positive sign the simulation is more complex than the simplified model the greedy algorithm uses.

Another source of complexity is the modeling of elevators, as shown in figure 3. The characters that occupy the interior of the elevator must coordinate to exit into each floor. Problems happen when one character situated at the back of the elevator wants to get out, but no one of those situated at the front wants to move. Again, this alters the traffic. To prevent this, the simulated actors have to be aware of what is the right use of an elevator.

The problem becomes more complex when the activities of the daily living is added to the considerations. The protocol of lectures in a classroom is simple: students come to the classroom; they sit down; a teacher comes and starts the lecture; more students may come during the lecture; the lecture finishes and then all, or a few, students leave the room. The uncertainty in the process, such as teachers finishing sooner or later, makes the evacuation of students from classrooms more smoother than it should be if all teachers coordinated

**Figure 3.** Elevator carrying people from one floor to the other

precisely the lectures to finish exactly at the same time. Such individual behaviors are relevant to be modeled too.

Also, the simulations may lead to inconsistent results. For instance, most of the resulting populations according to the algorithm [13] have in common that upper floors are mostly empty. Upper floors only have offices and not classrooms, what would explain this result. Then, it may be subject of discussion if a better occupation of the building was possible. If the space allocated in upper floors is the same as lower floors while the traffic is much lower, perhaps a higher number of offices could be arranged without compromising an eventual evacuation of the building.

Capturing complexity at the simulation allows to realize the software-in-the-loop approach. It is a goal of the project to include sensor/actuator devices in the simulation so that a designer can explore the effect of the stimulus of those devices on the population. The simulated devices would be operated using control software that was close to the simulated one. This approach has been essayed in [6] for gesture recognition devices design using 3D simulated environments generated with the AIDE environment [3].

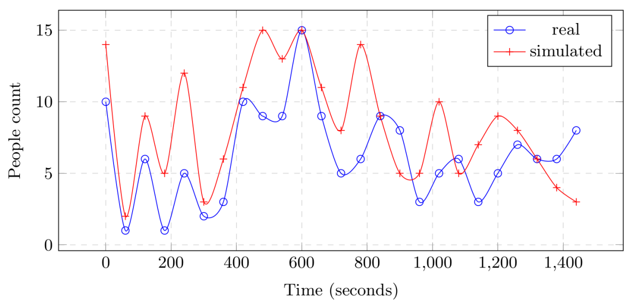


**Figure 4.** Measured traffic in the simulation compared to observed real traffic using a different time window from figure 2

## 6 Related work

There are works dealing with the design of smart systems, but they do not frequently consider human sciences and stimulus to plan the kind of system which is needed and what performance it will have. Harrison [7] claims the analysis of mutual and incidental user interaction has not been accounted and proceeds to apply fluid flow analysis to understand it. This kind of analysis is necessary, but, it does not replace a more conventional study and cannot assume a 100% response of the individuals every time. Other works focus on the devices expected to provide the stimulus at small scale, such as [14]. Thought authors stress the involvement of human scientists too, the behavior of people in small spaces cannot be compared to that of large spaces.

There are precedents too in reproducing observed data as simulations. In [8], video recordings were used to reproduced later on a crowd simulation of simulated actors. Behavior of the individuals were obtained from a multiple checkpoint observation that allowed. The project introduced in this paper, however,assumes incomplete information about activities and traffic. The less information is used, the less expensive a real installation would be. Following the same paradigm, Lerner et.al [9] propose the creation of an example database for evaluating simulated crowds based on videos of real crowds. Bera. et.al [1] also developed a behavior-learning algorithm for data-driven crowd simulation, capable of learn from mixed videos. Zong et.al [15] developed a framework for generating crowds for matching the patterns observed on video data,taking into consideration the behavior both at the microscopic level as at the macroscopic level. Finally, Yi Li et.al [10] developed a technique for populating large environments with virtual characters, cloning the trajectories of extracted crowd motion of real data sets to a large number of entities.

## 7 Conclusions

The paper has introduced a guideline with recommendations inspired into human sciences and the realization of field experiments. Such experiments are necessary to fine tune devices that aim to influence the behavior of the facility inhabitants. With this information, computer simulations have been created. These simulations reproduce the observed behavior and can be used to experiment with different setups and stimulus until a suitable combination is found. The next step is to devise the control software capable of synchronizing the stimulus over the population and then deploying such software to real devices having that capability.

Simulations can be used also to reason about what is happening inside the facility. In particular, the produced simulations show there are concerns in how the building is actually used. The identified traffic, and assuming most of the people that goes through a staircase/elevator do it only once, permits to infer that the upper floors of the building are less occupied than expected.

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