# Metadata of the chapter that will be visualized online

| | |
|---|---|
| Chapter Title | Avatars and Behavioral Experiments: Methods for Controlled Quantitative Social Behavioral Research in Virtual Worlds |
| Copyright Year | 2016 |
| Copyright Holder | Springer International Publishing Switzerland |



| | | |
|---|---|---|
| Corresponding Author | Family Name | **Hmeljak** |
| | Particle | |
| | Given Name | **Dimitrij (Mitja)** |
| | Suffix | |
| | Organization | Indiana University |
| | Address | Bloomington, IN, USA |
| | Email | mitja@indiana.edu |
| Author | Family Name | **Goldstone** |
| | Particle | |
| | Given Name | **Robert L.** |
| | Suffix | |
| | Organization | Indiana University |
| | Address | Bloomington, IN, USA |
| | Email | rgoldsto@indiana.edu |





| | |
|---|---|
| Abstract | 3D3C Worlds can support real-time, quantitatively controlled experiments for studying human group behavior. This chapter provides a review of social behavioral research in virtual worlds, their methodologies and goals, such as studies of socio-economical trends, interpersonal communications between virtual world residents, automated survey studies, etc. The chapter contrasts existing research tools in virtual worlds with the goals of studying human group behavior as a complex system—how interacting groups of people create emergent organizations at a higher level than the individuals comprising such groups. Finally, the chapter presents features of virtual world-based group behavior experiments that allow the recreation of controlled quantitative experiments previously conducted in supervised lab sessions or web-based games. |





| | |
|---|---|
| Keywords (separated by '-') | Group behavior - Computational models - Agent-based models - Measuring avatar behavior in virtual world |

# Avatars and Behavioral Experiments: Methods for Controlled Quantitative Social Behavioral Research in Virtual Worlds

AU1

**Dimitrij (Mitja) Hmeljak and Robert L. Goldstone**



## 1 Introduction

The computing infrastructures of 3D3C Worlds can support real-time, quantitatively controlled experiments for studying human group behavior. While there exist effective techniques for designing experiments and analyzing human group behavior in synthetic ad-hoc environments, there is under-exploited scope for controlled group experiments in virtual worlds, to facilitate the study of how groups of individuals behave under well-defined conditions when undertaking a specified task.

The goal of this chapter is to define the criteria and parameters for a software platform for behavioral experiments in 3D3C Worlds. To accomplish this goal, we start by providing a background introduction of social behavior research and related methods of study; we then present a review of relevant previous behavioral research studies in 3D3C Worlds, and we conclude by presenting our own experimental platform.

Virtual worlds "have great potential as sites for research in the social, behavioral, and economic sciences, as well as in human-centered computer science" (Bainbridge, 2007, p. 472). This chapter reviews examples of social behavioral research in virtual worlds, their methodologies and goals, such as studies of socio-economical trends, interpersonal communications between virtual world residents, automated survey studies, etc. The chapter contrasts various existing social behavioral research tools in virtual worlds with the goal of studying human group behavior as a complex system, specifically exploring how interacting groups of people create emergent organizations at a higher level than the individuals comprising such groups (Goldstone, Roberts, & Gureckis, 2008): the research goal is to conduct well controlled experiments on group behavior within an existing 3D3C

D. Hmeljak (✉) • R.L. Goldstone
Indiana University, Bloomington, IN, USA
e-mail: mitja@indiana.edu; rgoldsto@indiana.edu


Y. Sivan (ed.), *Handbook on 3D3C Virtual Worlds*, Progress in IS,
DOI 10.1007/978-3-319-22041-3_7

World. This chapter further provides a synopsis of tested techniques that may be used to implement such experiments, highlighting those computational constraints imposed by 3D3C Worlds' infrastructures that may require a Resource-Limited Computing approach. The presented final design and implementation, our Group Behavior Virtual Platform implemented in the Second Life (SL) virtual world, secures advantages of both laboratory and real world field research. Like typical behavioral laboratory research, these studies are designed to carefully control the participants' environment, randomly assign participants to experimental conditions, and log moment-to-moment behaviors of the participants. Like field research, these studies recruit participants from their existing environment, in this case a virtual world, and the participants choose their own identity and are behaving in an environment with which they are familiar and comfortable.

Throughout the chapter, the term "Reference Studies" will refer to the studies pertaining to the specific research goal of studying human group behavior as a complex system, and the term "Reference Implementation" will refer to the design and implementation of our *Group Behavior Virtual Platform* that has been instrumental to conducting well controlled experiments on group behavior within an existing 3D3C World.

The sections comprising this chapter are shown in Fig. 1. Here is a brief overview of the organization:

Section 1: Group Behavior Studies: Background and Overview of Related Work. AU2
The first section provides the background information necessary to understand the problem and its domain, by illustrating relevant concepts in social behavior research and related methods of study.



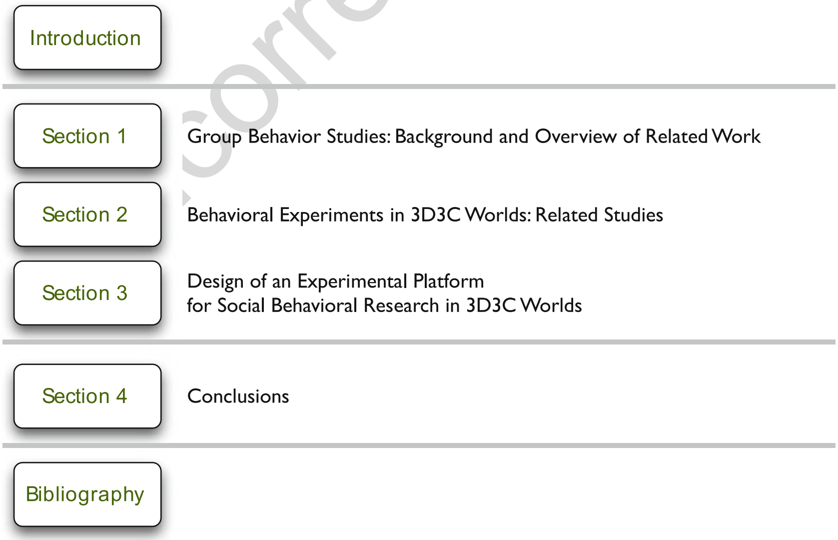





**Fig. 1** Organization of this chapter and layout of its sections

Section 2: Behavioral Experiments in 3D3C Worlds: Related Studies. This section includes a review of relevant previous studies in behavioral research in 3D3C Worlds, as well as the problem of supporting controlled quantitative experiments in 3D3C Worlds.

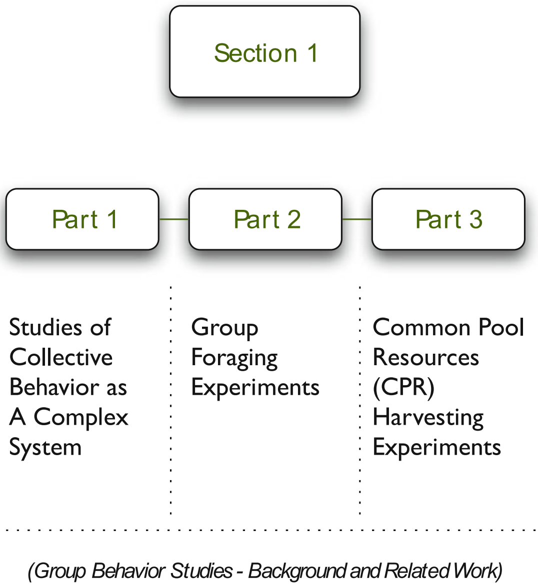
Section 3: Design of an Experimental Platform for Social Behavioral Research in 3D3C Worlds. This section covers techniques for designing an experimental infrastructure in a 3D3C World, detailing the various issues encountered in providing support for running quantitatively controlled real-time group experiments.

Section 4: Conclusions.

## 2 Group Behavior Studies: Background and Overview

Designing and running controlled and quantitative group behavior experiments in virtual worlds involves concepts and methods from disparate domains including social psychology, virtual reality, and resource-constrained computing. To familiarize the reader with the topics, this section introduces concepts relevant to the study of human group behavior in general, and experiments for studying emerging social patterns in particular. The parts comprising this section are shown in Fig. 2. Here is a brief overview of the organization: this section begins with an introduction to established methods in emergent group behavior studies—traditional controlled lab experiments, with in-person group participants, where patterns in group behavior are observed and measured for subsequent analysis. The section then presents

**Fig. 2** Organization of Sect. 1



two fundamental experiments from this category: the Group Foraging and the Common Pool Resources Harvesting experiments.

## 2.1 Studies of Collective Behavior as a Complex System

Complex adaptive systems theory studies how a large number of interacting elements may lead to higher level properties emerging from lower level interactions acting as a form of decentralized, distributed processing. Examples range in nature from non-organic formations, to plant structures, to complex social structures in the animal world. Applications of mathematical and computational models become relevant to apparently dissimilar systems.

While cognitive science often focuses on studying the behavior of single individuals, the study of human group behavior as a complex system seeks understanding of how interacting groups of people may create emergent organizations at a higher level than the individuals comprising such groups.

Collective yet not intentionally coordinated actions of a large number of participating individuals can produce structures, architectures and group-level behaviors that are distinct from any individual's goals; as from Goldstone et al. (2008, p. 10): "Just as neurons interconnect in networks that create structured thoughts beyond the ken of any individual neuron, so people spontaneously organize themselves into groups to create emergent organizations that no individual may intend, comprehend, or even perceive."

Participants in group behavior studies are placed in dynamic and interactive simulations of real life situations, interacting in real-time while asked to solve a specific task. The goal is to scientifically observe and model how groups of people behave when their behavior depends on the behaviors of others around them. For example, in some of these experiments, individuals are asked to manage the growth of a resource available to the entire group, while simultaneously trying to maximize their own harvesting of the same resource. A problem faced by all mobile organisms is how to search their environment for resources. Animals forage their environment for food, web-users surf the internet for desired data, and businesses mine the land for valuable minerals (Goldstone & Ashpole, 2004). When groups of animals in natural settings forage for resources, each animal may be free to move between sources of food, yet food resources available to each individual are affected by other animals' foraging behavior as well as its own. Each individual's best strategy for gathering resources becomes more complex than the mere discovery of resource locations, because it is affected by other individuals' foraging strategies as well.

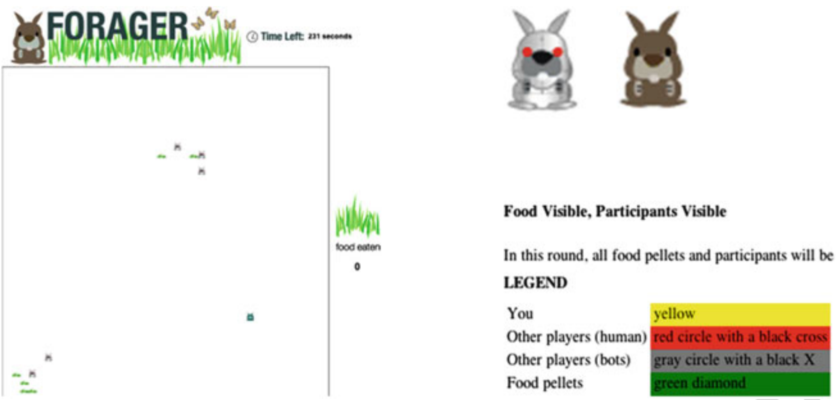



**Fig. 3** The Forager Game implemented as a Java applet

## *2.2 Group Foraging Experiments*

Experiments designed to study group foraging for resources are typically set in an environment where desirable virtual resources are provided for participants to collect. An experimental technique for studying human foraging behavior utilizes a stylized 2D computer game platform that allows many human participants to interact in real time within a common environment (Goldstone & Ashpole, 2004). The Forager Applet, an online game version of the same experimental platform, establishes the settings for a foraging group behavior experiment, where the goal of the game for each participant is to gather food pieces from a grid of squares, as in Fig. 3.

Resource pools can be created within this environment, and the experimental platform must track and record moment-by-moment exploitations of these resources by each human participant. The game can be run under a number of independently controlled conditions, such as resource distribution, user visibility, and food visibility.



## *2.3 Common Pool Resources (CPR) Harvesting Experiments*

In another example, as part of a larger project described in Janssen, Goldstone, Menczer, and Ostrom (2005) aimed at studying what causes individuals to invest in rule development, and which cognitive processes explain the ability of humans to craft new rules, experiments have been designed to study how a group of human subjects share a renewable resource, by implementing Common Pool Resource (CPR) Harvesting games. Here too, resources are created within a synthetic environment, and the experimental platform must track and record moment-by-moment

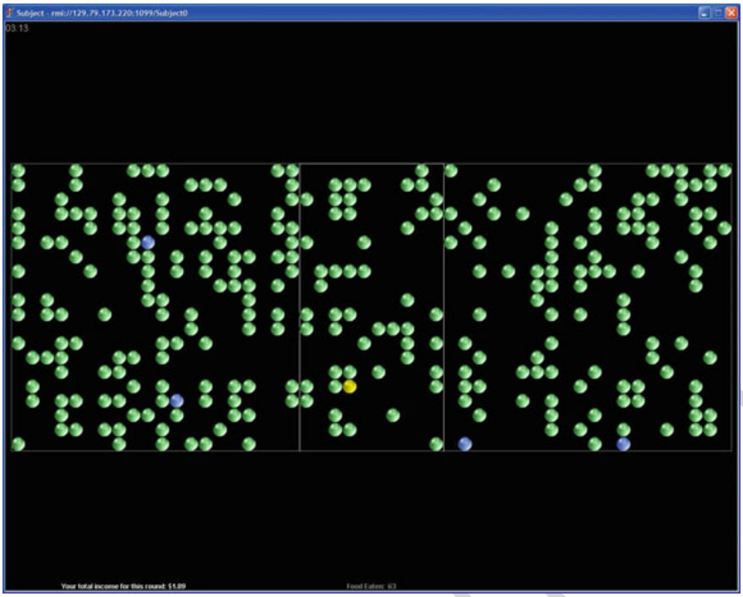



**Fig. 4** A screenshot from a 2D CPR Harvesting game experimental environment. Participants see themselves as represented by a *yellow dot*, other participants as *blue dots*, and food resources as *green dots*, while the *white lines* show property boundaries for the *yellow dot* (Credit: Janssen et al., 2005)

harvesting of these resources by each human participant. A screenshot from this 2D CPR Harvesting game experimental environment is shown in Fig. 4.

When studying the emergent behavior of groups of individuals, there are further advantages in following well-defined controlled quantitative experiments: these methodologies also allow for comparisons between experimental results in group behavior studies with agent-based computational models.

## *2.4 Data Analysis Methods*

To collect data for subject behavior analysis of the studies presented above, a complete data snapshot of the synthetic environment needs to be sampled every few seconds. Recorded data has to include all participants' locations as (x, y) coordinates on the game grid, the number of resource units collected by each participant at that instant, and uncollected food pieces' (x, y) cell coordinates on the game grid. For each experiment run, groups are assigned to different experimental conditions related to the proportions in the food distribution between two resource pools, and visibility or invisibility of other participants and resources. Figure 5 shows how by computing the proportions of participants in the two pools

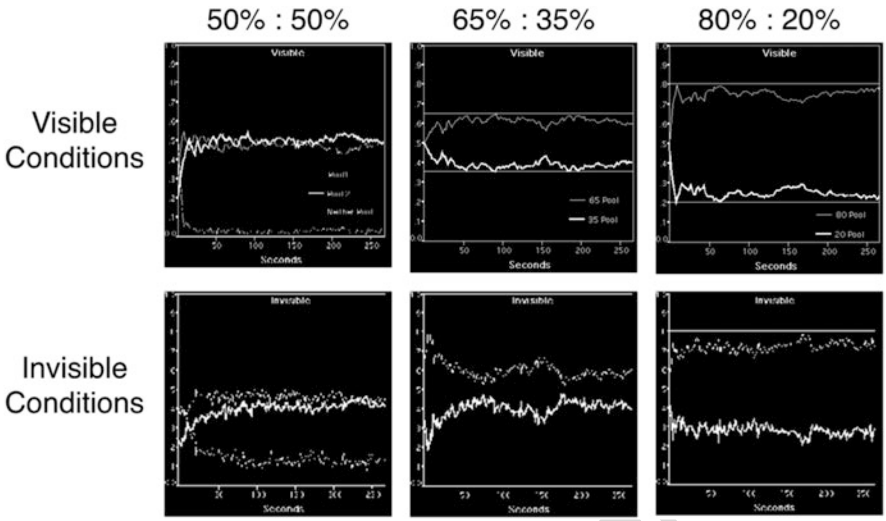



**Fig. 5** Dynamics of the distribution of foragers to resources: proportions of participants in two resource pools, broken down by the six conditions. (Credit: Goldstone & Ashpole, 2004). This figure shows the dynamics of the distribution of participants to resources in the Forager study, broken down by the six controlled conditions as from the experiment design. In this figure, the proportion of participants in two pools is plotted over time within a session. *Horizontal lines* indicate the proportions of participants that would match the distribution of food. Although the figure shows that the distribution of participants adjusted quickly, including the earliest time samples in the probability distribution estimate would lead to estimates that were inappropriately regressed toward the mean of 50 %. The figure also shows that the distribution of participants systematically undermatched the optimal probabilities. For example, in the 65/35 distribution of resources, the 65 % pool attracted an average of 60.6 % of the participants in the 50- to 270-s interval of the experiment





over time within a session, one can obtain the dynamics of the distribution of participants to resources during the session.

Analyzing the distribution of participants to that of food resources, one result was that groups approximate the distribution of resources, but systematically undermatch them, as shown in Goldstone, Roberts, and Roberts (2005): for example, if resources are distributed in a 20/80 fashion, the actual distribution of people to these resources is 27/73, indicating that there are fewer people at the more prolific resource than would be ideal, and in fact, the resources earned by the average person at the more prolific resource are greater than those earned by the average person at the sparser resource.

The group behavior studies presented above, their standard settings, their well-controlled conditions, represent the type of studies we want to conduct in 3D3C Worlds experiment. Similarly, the type of data collected in the above studies, e.g., timestamps, participant locations, and the gathering of resources, which allow for such analysis as shown in Fig. 5, is the kind of data we expect to obtain from successful well-controlled experiments in group behavior conducted in 3D3C Worlds.

## 3 Behavioral Experiments in 3D3C Worlds: Relevant Issues

Custom and vertical-market Virtual Reality platforms have been used in interdisciplinary research projects for over 20 years. The Research Directions in Virtual Environments report (Bishop & Fuchs, 1992, p. 156) stated as follows: "Though we still have far to go to achieve 'The Ultimate Display', we have sufficiently advanced towards the goal that is timely to consider real systems for useful applications."

In this Section, we present a review of social studies that have been conducted in 3D3C worlds, and compare their methodologies and implementations with the goals of studying human group behavior as a complex system by means of quantitative controlled experiments.

The parts comprising this section are shown in Fig. 6. We begin this section with a brief introduction to the problem of conducting social studies in 3D3C worlds. 

A virtual world platform for group behavior experiments could have been designed and implemented in controlled laboratory settings by linking a number of high-end virtual reality devices installations: albeit extremely costly, the technical aspects would not have been insurmountable with technology such as the CAVE hardware (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992) and one of the shared-environment software frameworks implemented on that platform.



**Fig. 6** Organization of Sect. 2

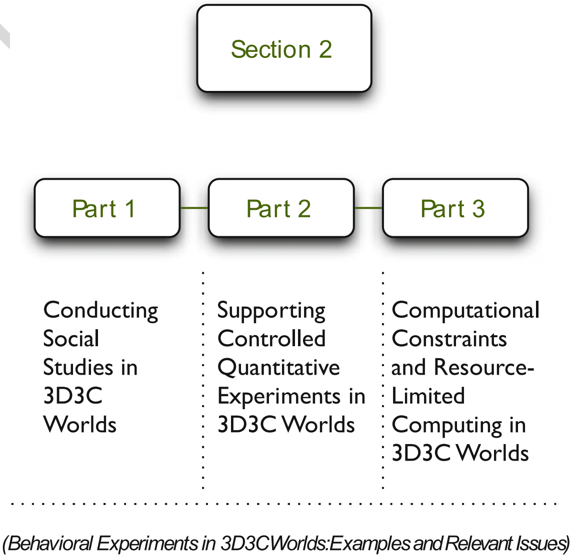


**Table 1** Sutherland's ultimate display characteristics as presented in Sutherland (1965)

| | Characteristic |
|---|---|
| 1. | Display as a window into a virtual world |
| 2. | Improve image generation until the picture looks real |
| 3. | Computer maintaining world model in real time |
| 4. | User directly manipulates virtual objects |
| 5. | Manipulated objects move realistically |
| 6. | Immersion in virtual world via head-mounted display |
| 7. | Virtual world also sounds real, feels real |

What has changed in the last 10 years is the availability of popular, well designed massively shared networked virtual worlds. In these, several requisites originally considered essential by "hard" Virtual Reality definitions (Brooks, 1998, 1999) remain unfulfilled, such as points (2.), partially (6.), and (7.) in Table 1, while the other aspects are well established in 3D3C Worlds and reachable to the point of becoming nearly "commodity."

A report summarizing an extensive feasibility study aimed at elevating 3D3C Worlds to a higher status than games (Yee, 2006, p. 310) motivated the expansion of social studies into networked virtual worlds: "[3D3C Worlds] provide a naturalistic setting where millions of users voluntarily immerse themselves in a graphical virtual environment and interact with each other through avatars (visual representations of users in a digital environment) on a daily basis." 3D3C Worlds have thus become an interesting platform for controlled behavioral experiments. The question about 3D3C Worlds including sufficient computing resources and interactive features for implementing such studies is examined in the next section in this chapter. It is important to understand where lay benefits in conducting controlled quantitative studies within 3D3C Worlds, and whether the methodological model used by the kind of experiments described in the previous section may be implemented in 3D3C Worlds.



## 3.1 Conducting Social Studies in 3D3C Worlds

A review of scientific research conducted in virtual worlds presented in Bainbridge (2007) includes several reasons supporting the creation of virtual laboratory experiments in 3D3C Worlds, as shown in Table 2.

Since virtual worlds provide a 3D simulation of real world-like environments, and user avatars are designed to provide a realistic rendering of bodily features and movements, their actions and positioning can be studied to analyze their mutual placement, orientations and gestures. An observational study (Yee, Bailenson, Urbanek, Chang, & Merget, 2007, p. 115) aimed at analyzing whether "social

**Table 2** Advantages in conducting experiments in Virtual Worlds, as from Bainbridge (2007)

| | Relevant and potential advantages |
|---|---|
| 1. | The potential for recruitment of thousands of research subjects over an extended period |
| 2. | The capability of providing incentives to motivate participation, such as virtual currency or in-world perks for experiment participants |
| 3. | Software tools and virtual world modeling that allow the (re)creation of virtual laboratory settings |
| 4. | There is potential for new experimental designs, for conducting studies that were previously not possible |
| 5. | Classic experiments can be recreated within 3D3C Worlds to provide confidence in older results as well as to improve virtual world design skills |

behavior and norms in virtual worlds are comparable to those in the physical world," showed that established interpersonal distance and eye gaze social norms tend to transfer into virtual worlds, with results from male–male and female–female interaction analysis in Second Life—even though movements in virtual worlds are controlled by mouse and keyboard input devices. In "Coming of Age in Second Life: An Anthropologist Explores the Virtually Human" (Boellstorff, 2008) the virtual world of Second Life (SL) is showcased for its potential for residents engaging in extensive activities and interactions, from land exploration to forming relationships and building communities.

Studies comparing different levels of behavioral and form realism in person-to-person interactions (Bailenson, Yee, Merget, & Schroeder, 2006) examine the question of "how much avatar realism" in terms of form and behavior is critical to establish co-presence and self-disclosure in virtual world participants. In findings from these experiments, subjects disclosed more information (both verbally and nonverbally) to avatars that were low in realism, "emoting" more freely when their avatar did not express those emotions.

Other studies examine virtual worlds as a context for communication, focusing on the opportunities for conducting multiple conversations simultaneously (not unlike other online social venues) as well as possibly multiple virtual simulated places with their own separate visual and auditory contexts. This multiplicity of interaction contexts may induce users to keep a more careful tailoring of their presence and availability to communicate with others, for example by limiting or blocking voice channels altogether even when these become easily available (Wadley, Gibbs, & Ducheneaut, 2009). Of specific interest in this category are studies that can not be easily conducted by controlling aspects of the real world, or that would require the comparison of social and economic consequences of possibly mutually exclusive government policies, etc. A prominent example in this category are the studies described in Castronova (2001, 2005). These examine social and economic coordination in 3D3C Worlds, both by comparing results from different virtual worlds, as well as by implementing entire experimental virtual worlds of their own, independently designed and constructed: "There are major methodological advantages to addressing macro-scale social science questions using virtual world petri dishes." (Castronova, 2008, p. 15).

Further long-term examinations of 3D3C Worlds describe these platforms as being "unlike any other social science research technology" due both to the high numbers of participants and the opportunity of studying their populations with careful control of experimental conditions (Castronova, 2005, p. 1), suggesting that: "large games should be thought of as, in effect, social science research tools on the scale of the supercolliders used by physicists: expensive, but extremely fruitful."

A major incentive in using virtual worlds to explore social-scientific issues is the amount of time and resources spent in 3D3C Worlds by an ever-increasing portion of the non-specialized population, as well as the vastness of social interactions conducted within them. It thus becomes both meaningful and useful to compare results from studies researching different but comparable virtual worlds. World of Warcraft can be used to conduct extensive observational quantitative studies, because it already provides the capability of adding character behavior macros, or even longer scripts written in the Lua language—these range from auction system analysis tools, to census summaries, etc. A separate example of a software tool developed within the context of these studies is the Virtual Data Collection Interface, designed for use within Second Life to allow survey research using immersive Heads-Up Display (HUD)-based virtual instruments for "Virtual Assisted Self Interviewing" (Bell, Castronova, & Wagner, 2008).

### *3.2 Supporting Controlled Quantitative Experiments in 3D3C Worlds*

The study of collective behavior as a complex system, while in agreement with the motivations quoted above, requires research tools within 3D3C Worlds that are capable of supporting real-time controlled, and multi-condition experiments with limited subject pools per run, specifying the relevant environmental parameters and rules of interaction between participants on a run-by-run basis. The number of distinct factors needs to be carefully chosen and limited: real world situations, people creating new identities, etc., could easily become noise factors, hard to overcome or filter out. The Reference Studies method for group behavior studies in Second Life, as presented in this chapter, relies on its API's openly available and described capabilities to program experiments according to specific conditions, with interaction rules chosen in advance, rather than following a user space with potentially limitless variables.

The experimental model for target experiments in Second Life may be considered as a middle ground between social studies in the real world and the schematized, idealized group behavior experiments of a behavioral studies laboratory (the latter may also be referred as "clean-room approach"). The aim is to recreate in Second Life similarly controlled conditions to those employed in self-contained research games as presented in the above section. However, SL social rules, its users' habits, and ways of interacting are not be ignored. By integrating the architecture and design of group games within the established SL canon, experiment participants are allowed to continue their SL experience, bringing their own characters and in-world expectancies to the games, ultimately approaching experiment games within Second Life more seriously than they might in isolated laboratory settings. At the same time, to run controlled experiments without disruptions in the relatively unconstrained SL world environment, there will be necessary limits to those SL avatar behaviors that might otherwise permit participants' behavior within the group to compromise designed control conditions. Moreover, given Second Life's notorious griefer activities (Bakioğlu, 2007), it would be naively permissive not to block private script-running capabilities for subjects within the experimental environment boundaries.

### 3.2.1 Interactivity and 3D3C World Platform Capabilities

In any real-time group behavior study involving real-time visual output to subjects, tracking of their movements and decision-making inputs, one of the main required functionalities for designing an experimental environment is the capability to track and log all the relevant events, in order to record a timeline with known and specified precision. For time-stamped event logging in Second Life, the Linden Scripting Language (LSL) Virtual Machine (VM) provides access to the virtual world's time units, within the limits imposed by the Second Life Grid (SL Grid, i.e., the computing engine behind the Second Life 3D3C World) through its API functions.

Given the interactivity and time-logging requirements necessary to recreate in Second Life the kind of group behavior experiments described above, the platform capabilities listed in Table 3 need to be evaluated. The design of an interactive environment for these experiments is necessarily constrained by time response limits, memory/data limits, virtual geometry limits, etc.



**Table 3** Required SL Grid capabilities for designing controlled group experiments in Second Life

| | Required capability |
|---|---|
| 1. | Human Participant Tracking |
| 2. | Response Time to Avatar Input |
| 3. | (Quasi) Real-Time Computing Data Logging |
| 4. | Pseudo-physics (collisions, geometry interactions, avatars' degrees of freedoms) |

**Table 4** Obtaining unobtrusive observational data: methods and related issues as in Novak (2007)

| Precision | Methods |
|---|---|
| Higher precision | Positional (*XYZ* coordinates) with time stamp |
| ↑ | Presence in pre-defined spherical scanner regions |
| • | Object interaction (touch, buy, etc.) |
| • | Video (machinima)—video capture built into Second Life |
| • | Snapshots |
| ↓ | Chat logs |
| Lower precision | Avatar name, birthday |

| Related issues |
|---|
| XYZ coordinates require considerable effort to decode into meaningful units of analysis |
| Sensors can be used to pre-code XYZ coordinate areas, but sensors can only scan activity in spherical regions |
| Increasing the number of avatars tracked, and the frequency with which snapshots are taken, increases server load and compromises the performance of the sim |
| How can one best deploy (position, scan frequency, number) both long and short range sensors to capture the needed data, but minimize lag and drain on resources? |
| Capturing “touch” and purchase data requires buy-in of merchants, scripts will need to be added to their product displays |

## *3.3 Computational Constraints and Resource-Limited Computing in 3D3C Worlds*

As illustrated above, one of the main functional requirements for a software framework supporting human group behavior studies in a virtual world is the capability to gather real-time data about its residents. Such a software framework needs to be implemented within the computational constraints imposed by a 3D3C World’s API, which can be characterized as resource-limited computing environment. This section examines the constraints imposed by the Second Life API that are relevant to a Reference Implementation, contrasting it to related methods employed by existing research tools in virtual worlds.

All interactivity and simulations in Second Life need to be scripted as LSL code embedded in object prims, including any program designed to obtain unobtrusive observational data. A summary of possible methods and issues related to obtaining this kind of information in Second Life is shown in Table 4, as from Novak (2007, pp. 39–43):

### 3.3.1 Human Participant Tracking

A record of experiment participants’ positions is a common requirement for the kind of experiments described above. This type of data is indispensable for the correct functioning of the VM when simulating the virtual world, for avatar-object interactions, etc.; furthermore, all connected SL clients need real-time data for the correct graphical rendering of the "window into the virtual world", as outlined above.

While LSL API calls exist to provide information about agents present within a certain region, as in the sensor-level tracking method included in Table 4, these functions do not return exact locations for each detected avatar within a region of space. Other indirect methods exist for more precise user tracking: a commonly used technique is the implementation of avatar-worn code, as tested in initial code prototypes for our Group Behavior Virtual Platform presented in this chapter. Adaptive expertise studies (Weusijana, Svihla, Gawel, & Bransford, 2007) utilize this method to investigate residents' learning experiences in Second Life, for example, to track avatar motions through emergency situation dry-run simulations.

Literally embedding LSL code for avatars to "wear" is not permitted by SL design. It is however allowed for avatars to wear simple objects containing running LSL scripts. Direct positional data transmission from worn objects to other receiving LSL code would be too restricted by the SL architecture's imposed penalties for real time processing, so caching methods would have to be employed for complete experiment data logging, were this method otherwise acceptable.

### 3.3.2 Real-Time Visual Feedback for Subjects

The worn-script method just described has one crucial flaw in that it cannot provide any low-latency visual responses to avatars in a group behavior tracking situation, and visual feedback to participants is essential to recreate the experimental conditions described above.

Participants in the Forager and CPR Harvesting experiments, as presented in the previous section, search for resources—this goal needs to remain the same in the Second Life versions of these experiments. When a participant's avatar reaches a resource unit, their position must be detected, and two subsequent events need to take place: the participant needs to be notified of having found a resource (and subsequently rewarded for it), and the transaction has to be recorded. To support both these actions, the typical SL data-gathering solutions just described are not fast enough when implemented in LSL. To provide these functionalities, our Group Behavior Virtual Platform's architecture includes layered data processing, distributed caching, asynchronous communications and a designed graceful degradation. Together, these techniques successfully solve communication bandwidth restrictions and code penalties imposed by the platform.

### 3.3.3 (Quasi) Real-Time Computing

In CPR experiments such as the harvesting situation recreated in the Reference Implementation environment, as subsequently described, in-place processing is used to update resource availability, to provide a very simplified model of resource growth in nature. Participants have to manage a resource system consisting of a core resource part and resource fringe units. The type of computation involved in the model is not entirely dissimilar from mechanisms implementing arrays of Cellular Automata (CA), where each cell updates its status as a function of its neighboring cells' states. There exist interesting Cellular Automata implementations and other abstract machine simulations in Second Life, for example using synchronized agents to model individual cells (Crooks et al., 2009), but they do not provide usable speed for real-time support of 10–20 individuals interacting with the system simultaneously with the necessary scale for large surface data collection such as the Reference Implementation's 27 × 27 tile floor.



While the processing needs of such models (especially on the scale required by the supported experiments) may be trivial to satisfy on almost every available computing platform today, implementing this kind of functionality within Second Life is one of the most noticeably constrained tasks, due to limits imposed to LSL scripts in terms of operations per second, constrained data space, networking/communication penalties and unsupported data types. This is one case where originally planned functionalities had to be redesigned and partially altered to be achievable within the limits of the SL Grid, in order to maintain all the essential features of the experimental environment's resource growth mechanism in CPR experiments.

### 3.3.4 Data Logging

In addition to the functionalities described so far, an indispensable part of any quantitative behavioral experiment is the recording of all obtained data into a trail file, for data post-processing and analysis. Such "trail file" contains a chronological record of controlled activities, which may be subsequently used to re-play and examine the relevant aspects of each experiment run. Both to satisfy data security requirements for IRB approval, as well as to have complete control over the information obtained from experiment runs, all gathered data is transmitted to Common Gateway Interface (CGI) (i.e., web-based) servers that are external to the SL Grid, where the data can be safely stored and subsequently accessed without needing to rely on third-party systems. This task is again impacted by the limits imposed by the SL Grid to LSL scripts, specifically by the restricted data space constraining caching mechanisms, and by networking penalties associated with the various communication channels when transmitting data between SL Grid servers and any internet hosts outside its domain. In solving data logging-related issues, our Group Behavior Virtual Platform design has been—in a rare and unexpected instance—aided by Second Life's evolving platform capabilities, when the allowed networking limits were raised to a more usable level, during the timeframe of this work's first design and platform trial stages. Previously existing extreme penalties imposed by the SL Grid to out-of-grid communications were relaxed by orders of magnitude, easing potentially insurmountable limits in the framework's design.

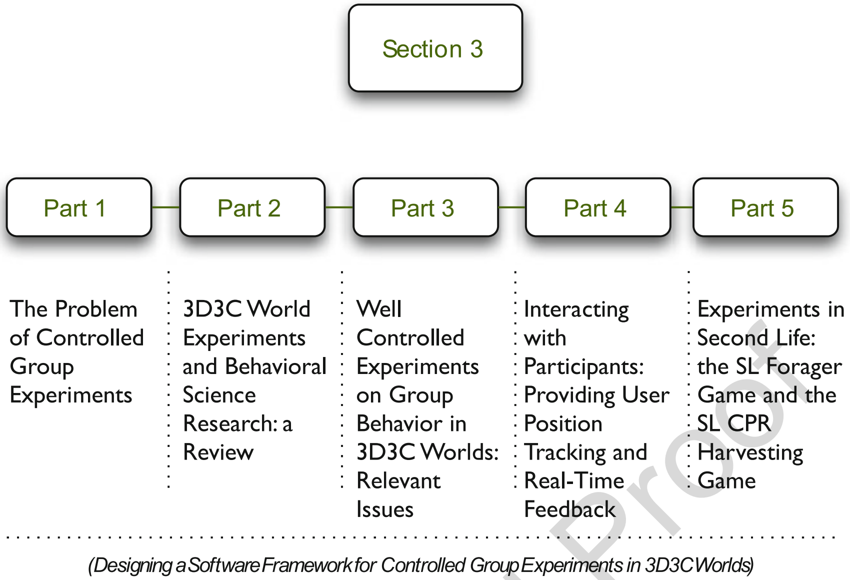





**Fig. 7** Organization of Sect. 3

## 4 Designing a Software Framework for Controlled Group Experiments in 3D3C Worlds

Functional requirements for the desired Group Behavior Virtual Platform are dictated by desired operational conditions for group behavior experiments. Non-functional requirements demand appropriate resource-limited computing methods within the highly multithreaded platform provided by the SL Grid.

The parts comprising this section are shown in Fig. 7. This section reviews the design aspects of various existing social behavioral research tools in virtual worlds, with particular focus on the goal of satisfying both functional and non-functional requirements that are relevant to studying human group behavior as a complex system, and conducting well controlled quantitative experiments in virtual worlds. We present a review of social studies that have been conducted in 3D3C Worlds, and compare their methodologies and implementations with the goals of studying human group behavior as a complex system by means of quantitative controlled experiments. Finally, we propose a design for an experimental platform in 3D3C worlds: our Group Behavior Virtual Platform, which has been successfully deployed to run series of experiments in Second Life.

## *4.1 The Problem of Controlled Group Experiments*

The goal of the experiments supported by the described Reference Implementation is to research how groups of human subjects act when each individual faces the task of gathering valuable resources for personal benefit, where the outcome depends on the entire collective's behavior. The real-life situations that this system is designed to simulate are part of studying how human subjects allocate themselves to available resources in specified environments (group foraging), and to analyze how collective groups manage Common Pool Resources (CPR), i.e., group harvesting. All experiments are therefore set in environments where desirable virtual resources are provided for participants to collect. The blueprint for the foraging experiments is derived from an experimental technique developed for studying human foraging behavior utilizing a 2D computer game-like platform, the Forager Applet presented in Sect. 1, Fig. 3.

## *4.2 3D3C World Experiments and Behavioral Science Research: A Review*

### 4.2.1 Manipulation Rules and Experimental Constraints in Group Behavior Studies

Computational models of agents are oftentimes used in social simulations, where agent-based modeling describes large-scale system behaviors by modeling the individuals that compose the system. In designing controlled group behavior experiments, the Reference Studies presented in this chapter aim for relatively pure, idealized experiments that fit well with similarly pure and simple agent-based models. Most studies where data are collected about online group behavior e.g., in web-based communities, are too complicated to be easily compared to agent-based models without adding many situation-specific details to the models. By creating a Reference Implementation for a social behavioral research platform, a simple self-contained world can be designed so as to be in agreement with agent-based model assumptions. By imposing fairly simple rules and well-defined constraints, there is less to worry about participants manipulating their identities, about cheaters and other intentional or unintentional disruptive behaviors in participants.

### 4.2.2 Repeatable Controlled Experiments

A review presenting the scientific research capabilities of virtual worlds (Bainbridge, 2007, p. 473) compares the potential for human behavior studies in Second Life (SL) and World of Warcraft (WoW): "In terms of scientific research methodologies, one can do interviews and ethnographic research in both environments, but other methods would work better in one than the other. SL is especially well designed to mount formal experiments in social psychology or cognitive science, because the researcher can construct a facility comparable to a real-world laboratory and recruit research subjects. WoW may be better for nonintrusive statistical methodologies examining social networks and economic systems, because it naturally generates a vast trove of diverse but standardized data about social and economic interactions. Both allow users to create new software modules to extract data."

A virtual experiment room in Second Life has to allow the experimenter to set different conditions and to schedule well-defined experiment runs where selected variables are manipulated and controlled. In general, experiment reliability is achieved by supporting repeatability of experiments having exactly the same conditions and a sufficient number of groups of participants. The Reference Implementation therefore also directly provides for arbitrarily repeatable and fully programmed controlled experiments, in contrast to naturalistic investigations of 3D3C Worlds such as World of Warcraft, studies of social norms in Second Life (Yee et al., 2007), studies of web communities, etc.

A visual comparison of the Second Life virtual room in the Reference Implementation (configured for the Forager experiments) and the Forager Applet online game is shown in Fig. 8.

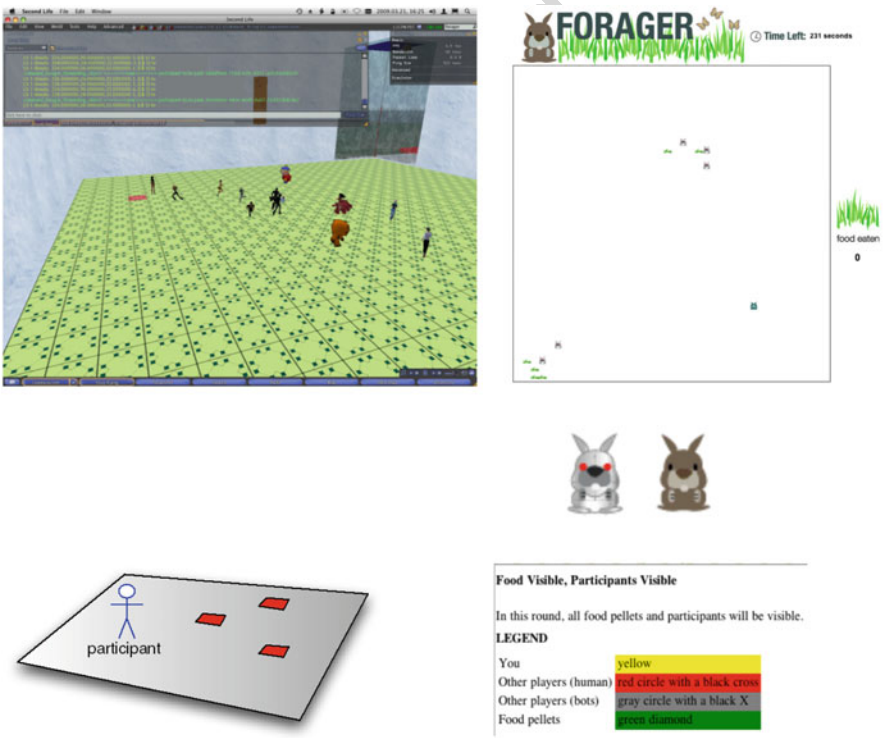



**Fig. 8** The Second Life Forager experiment compared to the Forager Applet online game environment

### 4.2.3 Automated Survey Tools

Among the multitude of programmable tools for conducting survey studies entirely within Second Life, a significant example is the Virtual Data Collection Interface (VDCI) (Bell et al., 2008). Their work has produced a tool in the form of an in-world immersive Heads-Up Display (HUD)-based virtual instrument for "Virtual Assisted Self Interviewing" (VASI), which has then been made available to the SL research community, as advertised on the Second Life Researcher's List (SLRL) (Bell & Robbins, 2008). The VASI methodology is quantitative in its data gathering capabilities, and these studies aim at researching optimal sampling frames and sampling procedures within 3D3C Worlds like Second Life. While not targeting controlled experimental environments, the VDCI tool's development shows how the computing infrastructure available to Second Life's end-users and LSL developers offers valuable resources to allow the automation of survey research in 3D3C Worlds.

### 4.2.4 Adaptive Expertise Studies

Another line of behavior-related research in Second Life, albeit with quite distinct goals from the experiments supported by the described Group Behavior Virtual Platform, includes some computational aspects related to the functional requirements that became one of the main resource-limited computing problems that had to be solved for a fully functional Reference Implementation. The goal of Weusijana et al. (2007, p. 34) is described thus: "Adaptive expertise, briefly, is the idea that expertise is dissociable into innovative and efficient dimensions, and that not all experts or learning experiences equally incorporate both. [...] Second Life (SL) makes it possible for students to experience events first-hand rather than simply learn about them secondarily. [...] This chapter's specific study addresses a more important goal [...], to help people learn about adaptive expertise by enabling them to experience differences between 'efficiency' and 'innovation' modes [...]" This Adaptive Expertise study in Second Life aims at investigating SL residents' learning experiences, for example in emergency dry-run simulations. Analyzing subjects' responses requires avatar motions to be tracked through such situations. This solution requires participating avatars to wear SL objects containing running LSL scripts, which can in turn transmit positional data tracking the worn object's location to other receiving LSL code. For a study that does not involve groups of interacting participants, nor does it require complex real-time visual feedback based on the processing of multiple avatar inputs and cellular automata-like rules, the avatar tracking method implemented by avatar-worn code is sufficient for the considered situations.

### 4.2.5 Longitudinal Behavioral Data Collection

Another approach, similar to the one just described, has been presented in Yee and Bailenson (2008, p. 594) with the goal of providing a foundational framework within Second Life for measuring interesting behavioral variables, both for individuals as well as at the group level, to be transmitted off-world for further analysis. Their solution also utilizes avatar-worn objects containing LSL scripts for positional tracking: "The solution we describe allows researchers to capture avatar-related data from Second Life (SL) at a resolution of one minute or less over a period of weeks."

Equivalent methods for subject position tracking have been tested in initial experimental trials to evaluate their performance within SL for the purposes of the Reference Studies described in this chapter, but were found inadequate in supporting low-latency tracking of multiple avatars in group situations with real-time visual feedback based on their locations, due to bandwidth limitations within the SL platform.

## *4.3 Well Controlled Experiments on Group Behavior in 3D3C Worlds: Relevant Issues*

Two representative examples of well controlled experiments on group behavior, presented in the above section "Group Behavior Studies: Background and Overview", are the Group Foraging applet and the CPR Harvesting experiment. An effective implementation capable of supporting equivalent experiments in 3D3C Worlds necessarily differs from the quantitative studies tools and methodological approaches just described (e.g., Automated Survey Tools, Adaptive Expertise Studies, Longitudinal Behavioral Data Collection). A well controlled study on group behavior aims at conducting controlled experiments with groups typically comprising 10–30 human subjects, where specific parameters and rules of interaction between participants and the environment can be set on a run-by-run basis. The approach presented here is a compromise between two extremes: experiments or analyses of group behavior in the real world, and idealized experiments of a clean-room approach. This approach led to the design and implementation of two set of experiments that are part of the Reference Studies in Second Life considered throughout this chapter: the SL Forager game and the SL CPR Harvesting game.

### 4.3.1 Considerations About Second Life's Social Environment

While aiming at the idealized conditions of self-contained research games, the described Reference Implementation is nevertheless bound by Second Life rules and its users' habits, ways of interacting and expectancies.

This also means that the design of our Group Behavior Virtual Platform has to adapt the original Group Behavior Studies experiments to SL users, e.g., allowing for specific avatar appearances, as well as control of those aspects of SL avatar behavior that would allow for undesired degrees of freedom in participants' actions within the group, such as movement capabilities within the world—typical instances would be avatars flying, or running their own scripts, within the boundaries of the experiment room space. These capabilities are both blocked at the level of virtual ground property permissions, so that for example participants who may enter the briefing/debriefing area while their avatar is in flying mode, will not be able to resume flying once their avatar lands on the briefing area, and especially not after having been teleported into the Reference Implementation experiment room.

Supporting the use of Second Life's virtual world for human social interaction research, an extensive study presented in Yee et al. (2007, p. 119) aims at comparing social behavior and norms in virtual worlds to those in the real world: "Overall, our findings support our hypothesis that our social interactions in online virtual worlds, such as Second Life, are governed by the same social norms as social interactions in the physical world. This finding has significant implications for using virtual worlds to study human social interaction. If people behave according to the same social rules in both physical and virtual worlds even though the mode of movement and navigation is entirely different (i.e., using keyboard and mouse as opposed to bodies and legs), then this means it is possible to study social interaction in virtual worlds and generalize them to social interaction in the real world."

As a further corollary of these studies' conclusion, and supporting the relevance of controlled group behavior experiments within 3D3C Worlds, one can infer that SL residents may treat games taking place entirely within Second Life (such as the forager and harvesting scenarios implemented within the described Group Behavior Virtual Platform) more seriously, as some kind of real life extension. By participating in these games, 3D3C World residents simply continue their SL experience, bringing their own characters and in-world existence to the games.

### 4.3.2 Tracking Individual Actions and Supporting Experimental Control Conditions

Participants in the SL Forager and SL CPR Harvesting experiments/games have the implicit task of gathering resources, and are rewarded with Linden Dollars for collecting them. This process has several complicated data transmission and communication constraints. For example, when a participant's avatar steps on a floor tile in the experimental virtual room, their position is detected by the tile's activity monitor script handling collision detections. If the tile contains one of the resources being sought, two things need to happen: the participant needs to be notified, and the transaction has to be recorded for monetary reward. In the SL CPR Harvesting experiment, further processing is required for computing the next growth of resources.

All these actions must happen within a reasonable time, in order to maintain responsiveness for all participants in the game—it is essential, for the design conditions to be valid, that every subject experiences seamless experimental conditions. This translates to a non-functional requirement for our Group Behavior Virtual Platform: the necessity of near-real-time visual feedback to all user interactions with the active objects in the virtual world, with an allowed time for all processing between user input and the feedback response from the virtual interface to be contained within the order of magnitude of 1 s.

By comparison, one of the most extensive studies of group behavior in Second Life (as illustrated above) had quite different data collection and processing time constraints. Their study, presented in Yee et al. (2007, p. 117), also made use of LSL scripts to collect positional information from present avatars. However, that method employed a massive force approach, with research assistants working for an extended period of time, and manually triggering scripts where groups of SL avatars were interacting: "A triggered script was used to collect information from avatars in the world. When triggered by a designated key press, the script would collect the name, Cartesian coordinates (x, y), and yaw of the 16 avatars closest to the user within a 200 virtual meter radius. The script would also track whether the avatars were talking at that given moment. The script would then store the information as a text file. Six research assistants, paid at an hourly rate for 10 h a week, collected data within Second Life over a period of 7 weeks. There were 688 zones (discrete locations) in Second Life, and undergraduates were each assigned to 115 zones. These research assistants were instructed to systematically explore the zones and trigger the script near locations where a group of at least two people were interacting."

Specifically, in that study there was no need for immediate feedback to subjects. A closely related work provides a solution for behavioral research in Second Life with automated scripts allowing the tracking of subject data at a resolution of "one minute or less over a period of weeks" (Yee & Bailenson, 2008, p. 594).

Given that such approaches could not satisfy the application goal for an experimental software framework with near-real-time user feedback and well-defined processing time constraints, different options needed to be explored for tracking each individual avatar's data in groups of subjects interacting within a dynamic virtual world.

## *4.4 Interacting with Participants: Providing User Position Tracking and Real-Time Feedback*

### 4.4.1 Avatar Locations

Keeping an accurate record of every participant's position is a common requirement for all of the experiments supported by our Group Behavior Virtual Platform. This would initially appear to be trivially satisfiable: the Reference Implementation has been located within a Second Life region maintained by Indiana University research support personnel, therefore complete administrative access is available over simulator status. Also, all participants access the experiment room with their Second Life avatars, and the virtual world server-side engine necessarily keeps track of each avatar's position with maximum possible accuracy, so that all connected clients may receive real-time data about the region in which they are connected, to make correct rendering possible. This continuous data stream contains updates on every object primitive and avatar's locations within a region.

### 4.4.2 Restrictions Imposed by the LSL Function Library

One fundamental limitation faced by every program running on the Second Life grid is defined by the set of functions available in the LSL API. These function calls are the only way provided to LSL programmers to access data from the Second Life grid. For the purpose of programmable access, each Second Life participant's avatar is referred to as an agent, and it has both a uniquely defined name (Second Life user's first and last names) as well as a unique key—a string of alphanumerical characters that is assigned to a user when their account is initially created.

Once an avatar's first and last name are known, it is trivial to obtain their unique key string by querying the Second Life server-side database using LSL API functions. The knowledge of this key's value is necessary to programs detecting avatar actions, because it is the only way API function calls use to identify detected agents.



### 4.4.3 Tracking with Sensor Sweeps

The accepted way to track any user in a 3D3C World is to have available a function call returning a list of the avatars and their locations present in the virtual space. This is especially true for applications in which the rendering of the environment depends on the virtual location of the end user.

There are available methods in the LSL library that provide an apparently usable way to inquire about agents present within a certain region: such functionality is considered necessary, for example, in order for a virtual land owner to be able to measure usage and average occupancy within a region. Unfortunately, these functions do not return a precise location for each detected avatar within a region of space. The most that can be achieved by using these methods is a rough approximation of positional tracking: sensor code built using them can provide a maximum accuracy of detection within a 10 m radius, where the available precision goes down to 1 mm. For example, each end user has a constantly updated display of their virtual location within the occupied region, expressed in (x, y, z) coordinates with the precision of 1 mm. However, direct tracking of agent positions is completely missing from the library functions available to LSL scripts, and the 10 m radius is the best that can be achieved in terms of direct queries.

### 4.4.4 Tracking with Avatar-Worn Scripts

Since unmediated direct determination of avatar positions is impossible in Second Life, the necessary functionality needs to be achieved in some other way. An attempt at a working method was devised through the use of avatar-worn objects containing scripts. This method provides tracking data by avoiding two additional limits in the Second Life design, which intentionally prevents any avatar from containing LSL code, even though avatars and independent objects are both built using Second Life primitives. Secondly, even code-containing primitives cannot be directly queried for their position. This widely used method works by having avatars wear simple objects (such as a hat), which in turn contain LSL scripts internally tracking their own position. This is possible by LSL API queries. Because an object worn by an avatar becomes at that point the avatar's property, any external code that is part of the Reference Implementation game room can only attempt to communicate with its LSL code through standard, textual-chat channels. This would seemingly provide a usable method of tracking avatar positions in real time:

- Avatar-worn code. Each participant wearing a provided tracking hat would have their position tracked by the script in the hat. Although that script could continuously broadcast its position, that would create chat channel bandwidth saturation if the experiment were to run with the expected number of participants (10–20). Instead, each worn code can simply keep track of its position in a time-stamped local variable, which can be then queried when necessary by the experiment tracking object. With this mechanism, the avatar-kept code can cache thousands of time-stamped positions. Test run actions typically required them to store up to a couple dozen events before being queried, and therefore this was not a source of resource constraints.
- Experiment controller object. As part of the tracking context, the main task of the experiment tracking object is to be the listener that periodically queries avatar-worn code for their positions, and subsequently receives all their updates.
- Chat-based communication channels. The exchange of query/response pairs between avatar-worn code and the controller object has to happen using the only available communication mechanism for unlinked objects, namely the chat channels. The limitations of chat channels include low bandwidth and the absence of guarantees that flow latency would not cause unacceptable delays. These problems ultimately caused us to discard this approach entirely.

An avatar-worn object containing LSL tracking code is depicted in Fig. 9. In the testing environment illustrated there, sample feedback was provided by a detached object replicating the avatar's movements on the floor in a wall-mounted display fashion. Even with a single avatar being tracked with this mechanism, the delay in the replicating object's movements compared to the avatar's was on the order of a couple of seconds on average. Given that each LSL script employing a chat channel listener callback function introduces a delay in the overall responsiveness (lag) of


**Fig. 9** Experiment participant tracking: avatar-worn scripts





the Second Life simulation, the negative effects of this methods when applied to several SL users would be cumulative.

To sum up, the avatar-worn code could adequately record and store the time-stamped locations, and that data could be transmitted to the experiment controller object correctly via the chat channel, preserving all necessary information for subsequent analysis. However, the requirements of providing timely feedback to participants could not be met by this method. For example, participants would experience several seconds of delay in being notified of the successful collection of resources.

The data-collection objectives of the supported experiments could easily have been met by the above method, since time-stamped location data would have been adequately collected. The primary issue that prompted us to abandon this approach, and look for another one, was exclusively in this method being unable to provide all participants with feedback within a tolerable time delay. Since it is necessary to enable subjects to notice the effects of their actions in the game in real time, another method entirely had to be developed to support the interactive virtual experience of the experiment's dynamics. The first two tested approaches to avatar tracking—area sensor sweeps and avatar-worn scripts—are illustrated in Fig. 10, together with properties, constraints, and platform-imposed penalties for each of these two methods.

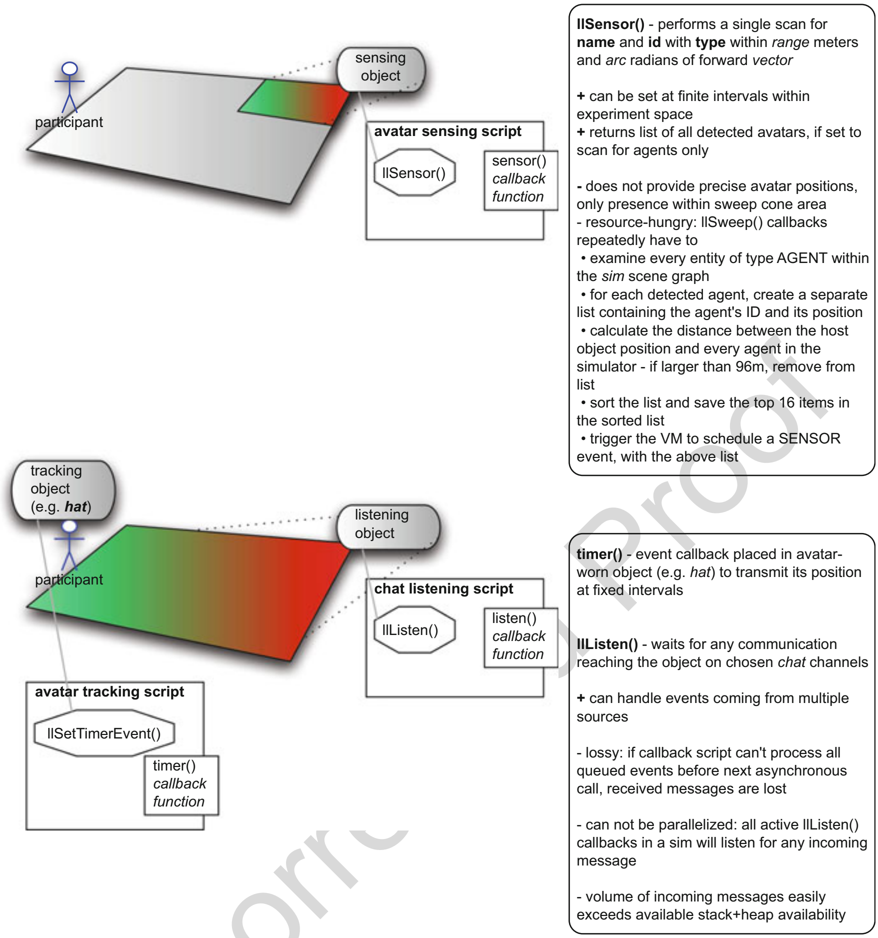



**Fig. 10** Avatar tracking—first two approaches: area sensor sweeps and avatar-worn scripts

### 4.4.5 Collision-Detection Scripts

In order to work around constraints imposed on us by chat channels, a new approach had to be developed to identify avatar locations, track and log their movements, and notify them of resource collections. Initially, individual LSL scripts in each one of the $27 \times 27$ floor tiles reported back two main detected events (money generation and avatar collision detection) through chat channel communications to a centralized controller script running in a separate object. This communication method is not unlike the tracking hat transmitting positional data to an external object, as presented in the previous Section. One main difference in using collision detection scripts is the employed event-based mechanism, which only executes when avatars actually interact with the environment, thus avoiding idle-time processing.

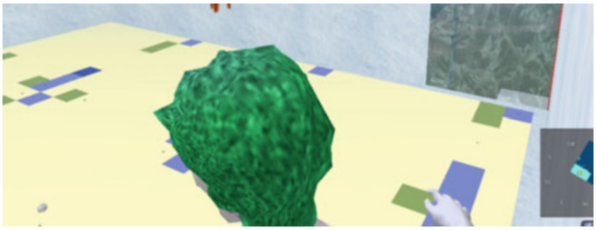


**Fig. 11** LSL scripts using chat-channel communications

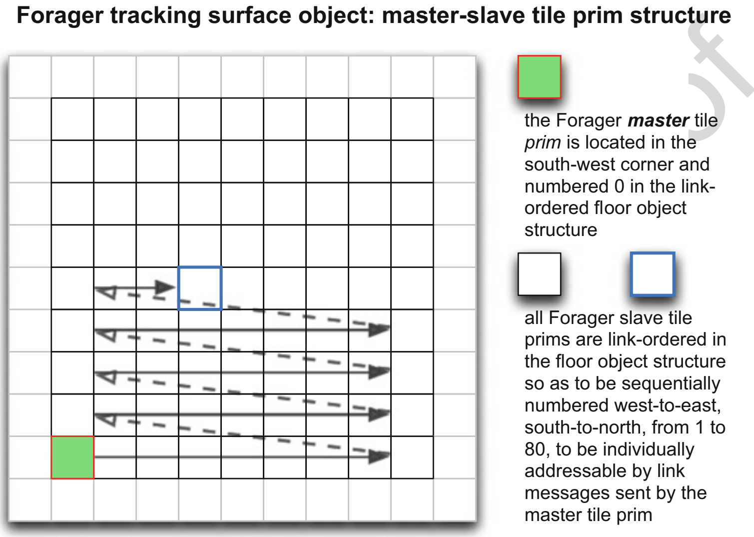





**Fig. 12** Avatar tracking surface $9 \times 9$ subset (final version)

Figure 11 shows an early test of this message passing structure. Here, collisions were simulated with automated randomly generated events at the rate expected during a fully populated game. This method still proved to be unfeasible, due to chat channel bandwidth limitations: having all $27 \times 27$ floor tile scripts reporting to a single controller object saturated the chat channels. To overcome the bandwidth limitations, a multi-level communication strategy was developed for the experimental room's interactive floor to track avatar locations in real time, while still allowing enough processing time to provide real-time user feedback. Figure 12 illustrates the final structure of each subset of the experiment room's tracking surface. It consists of $9 \times 9$ linked prims: one master tile containing scripts for receiving chat channel command messages and collecting resource-tracking events, and all tiles containing resource and avatar tracking scripts.

The in-world modeling process of the avatar tracking surface is shown in Fig. 13 with individually highlighted linked prims. 

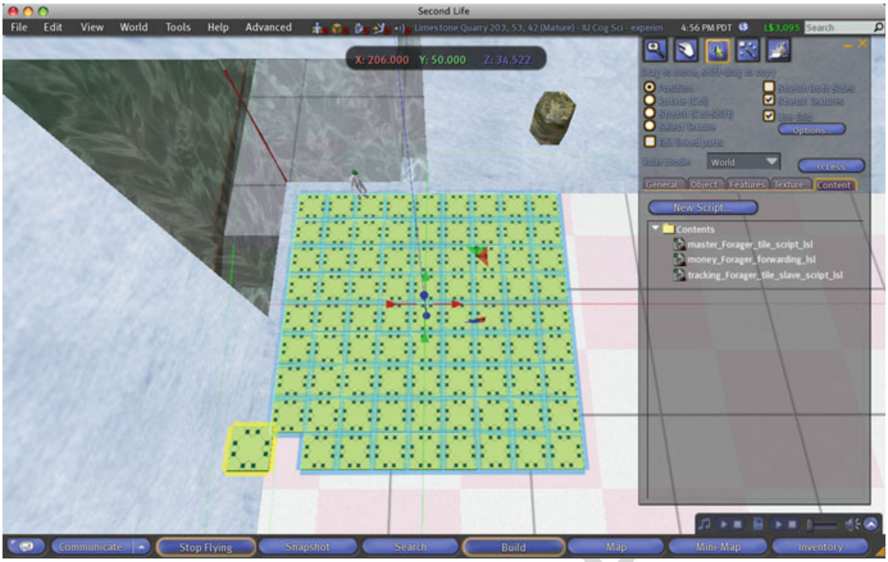



**Fig. 13** Modeling the avatar tracking surface: the master tile is shown extruded from the $9 \times 9$ structure. The LSL scripts contained in the master prim are listed in the editing window on the *right side*

#### 4.4.6 Reward Process

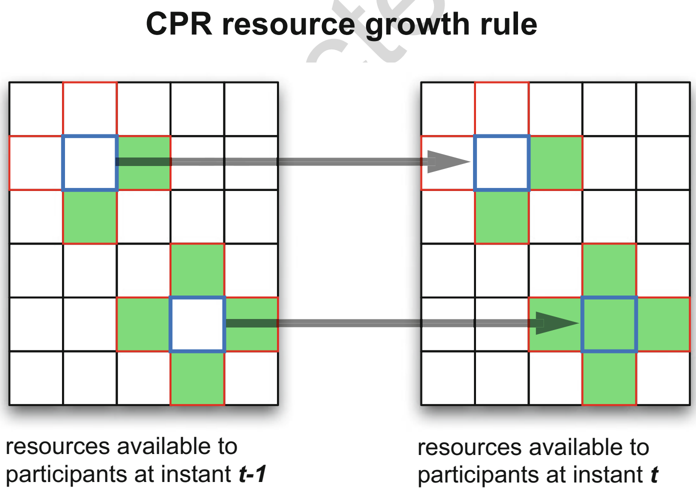
Participants could be rewarded immediately every time they discover and enter a tile containing a resource, and there would be two implications: firstly, being immediately rewarded would not encourage participants to continue playing until the end of the experiment. Secondly, virtual monetary transactions would have to happen continuously during the experiment. Neither of these is desirable for the purposes of the Reference Studies. Therefore, at resource discovery time, participants only receive a notice of having collected a resource, and instead of starting a monetary transaction process, this specific resource-collection event gets recorded by a bookkeeping script.

The messaging mechanism requires a complex strategy to accommodate the computational and communication constraints. In both experiments, each active floor tile contains a script that passes a message (relayed by the master prim in each $9 \times 9$ subset) to a command center listener script, which is ready to act on this information. The command center listener script keeps track of monetary transactions belonging to each participant. This communication still relies on chat-channel messages: instantiating a listening event callback function is in itself considered computationally demanding for the LSL API, but having only one listener for this particular functionality is acceptable. One listener can process a sufficient number of messages without being overloaded by the incoming data arriving from nine master prims, one for each $9 \times 9$ subset. The command center script keeps track of all these transactions for each participant in a local list, which is then emptied at the end of each experiment run, when all subjects are rewarded with the actual Linden Dollars corresponding to their total collected resources.

During the experiment there would therefore be no explicit message given to participants each time they discover a resource. In the case of visible resources, the tile containing Linden Dollars turns from red back to its neutral color, but in the invisible resources case, there is no such visible change. However, in both cases a brief message is sent out by the individual tile to the chat channel, showing that a resource has been acquired by the named participant at a specific location. It is not an immediately helpful aid for finding transaction locations, but it gives participants feedback about the progress of the foraging.

By disallowing immediate monetary transactions, the game's user interface became more fluid and less cluttered for participants—specifically by avoiding visual interruptions. By default, every time one's avatar is given Linden Dollars, the SL Viewer signals the transaction with a bright dialog box that requires explicit action to acknowledge and dismiss the box. In the Reference Implementation, this happens only once for each participant, at the end of an experiment run.

Another important advantage in using a deferred payment mechanism is its implicit ability to counteract money-detection radar tools, known to many (but not all) Second Life participants. Removing money-giving functionality entirely




$$p_c(t) = p\frac{n_c(t\quad 1)}{N}$$

$n_c$ = number of active adjacent cells

$p$ = growth parameter

$N$ = 4-connected (or 8-connected) neighborhood

**Fig. 14** CPR experiment: resource growth step

This figure will be printed in b/w

from all parts of the virtual world and activity monitors prevents us from being gamed by participants using scavenging tools; the overall integrity of the experiment is thus increased by the employed reward mechanism.

#### 4.4.7 Continuously Monitoring Monetary Acquisitions in the CPR Experiment

The deferred payment mechanism just described is necessarily implemented in all the presented Reference Studies experiments. In addition, in the SL CPR Harvesting experiments, monetary transactions are also part of the resource growth mechanism that constitutes the main characteristic of the harvesting scenario. Therefore, these transactions need to be constantly monitored for the correct computation of each subsequent cycle. Any empty floor tile in the SL CPR Harvesting game has a probability of generating a new resource, depending on the presence and proximity of neighboring resources, as shown in Fig. 14. This process happens in cycles, and therefore a separate monitoring mechanism is required.

To conclude, Table 5 summarizes the required properties for a platform capable of supporting well-controlled experiments on group behavior in 3D3C Worlds.

**Table 5** Requirements for "lab-like", well-controlled group behavior experiments in 3D3C Worlds

| | Characteristic |
|---|---|
| 1. | *Topological Consistency*. Primitives and building blocks used for every construction within the 3D3C World, their size, orientation and location need to be consistently represented in a Cartesian coordinate system that extends throughout the virtual world |
| 2. | *Immediate Accessibility*. Every aspect of avatar interaction and scripting capabilities need to be immediately available to all participants. There should be no levels to be reached, nor abilities that a participant's avatar needs to achieve in order to start moving. Unlike some 3D3C Worlds where gaming characteristics dominate (such as World of Warcraft), this characteristic effectively requires the leveling of the entry field for all users |
| 3. | *Tracking Avatar and Object Locations*. Each avatar's position within the virtual world needs to be fully determined at any given time, i.e., the current simulator region, the current (x, y, z) coordinates within that region. Likewise, each primitive and each object needs to be uniquely determined in their location. In the Reference Implementation, this is achieved with distributed micro-processes and problem-dependent data optimization |
| 4. | *Permanent Data Logging*. A continuous and detailed data trail has to be provided, either within the 3D3C World, or by logging facilities hosted on remote off-world servers. Our Group Behavior Virtual Platform employs layered communications to this effect, with on-demand buffering and data logging |
| 5. | *Data Access and Searchability*. For data with inherent spatial properties, it is beneficial to pre-organize data in a structure reflecting such properties, to allow localized interactive features and front-end localized storage |
| 6. | *Interactivity*. A decision policy needs to be established about which computing instances to keep active within a Reference Implementation, in order to maintain the required interactivity for expected groups of simultaneous users. Anomalous load increases need to be handled by graceful degradation |

The above table corresponds to the main features provided by the "Reference Implementation" of our Group Behavior Virtual Platform as deployed in Second Life.

## 4.5 *Experiments in Second Life: The SL Forager Game and the SL CPR Harvesting Game*

The structure allowing interactive experiment control from authorized Second Life avatars (i.e., the experimenters) is shown in Fig. 15. The presented Group Behavior Virtual Platform satisfies the computational requirements necessary for running controlled group experiments entirely within Second Life, employing in-world native LSL scripting capabilities, and transferring all data collection and storage tasks off-world. The framework provides control over experimental settings such as avatar room access, parcel access, preventing participants running scripts, and flying.

The methods, design and implementation presented in this chapter, were successfully deployed in two sets of experiments in Second Life: the SL Forager game

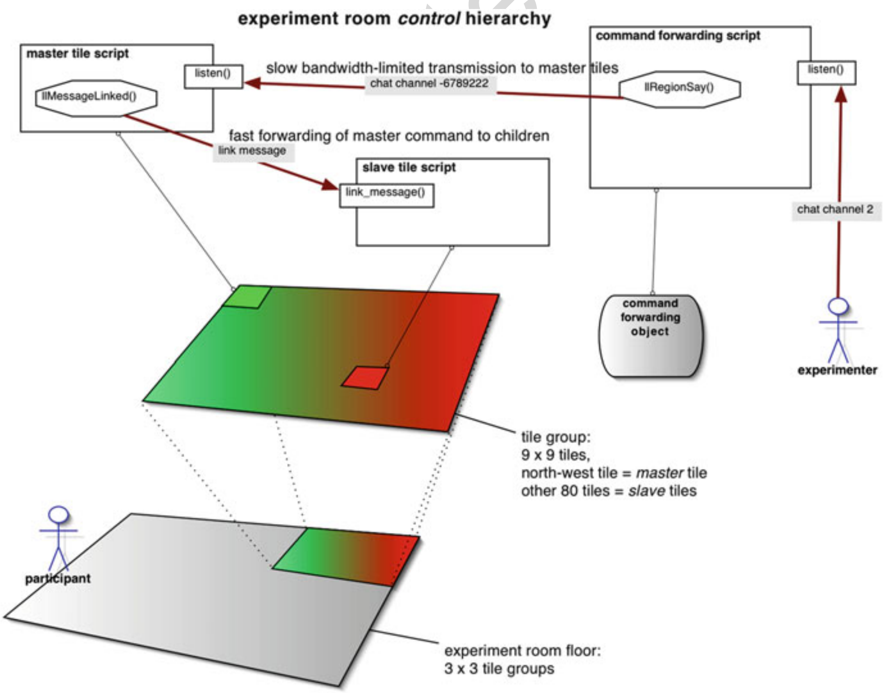



**Fig. 15** Second Life Forager experiment control structure

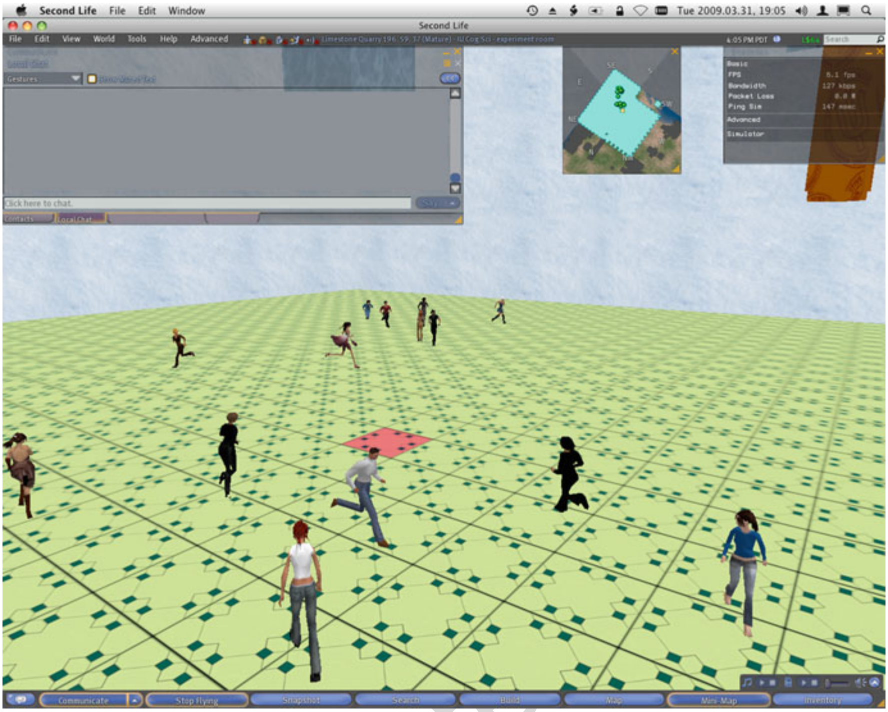



**Fig. 16** *SL Forager* experiment snapshot: a typical view of a game run. The participants forage for resources, represented by *red-colored tiles* on the experiment room floor

and the SL CPR Harvesting game, as described in Hmeljak (2010). Runs from these two experiments are shown in Figs. 16 and 17.

## 5 Conclusions

This chapter presented examples of social behavioral research in virtual worlds, their methodologies and goals. For this review, the chapter considered the requirements for a Group Behavior Virtual Platform providing the experimental environment for well-controlled group behavior studies in SL, comparing its functionalities to established social behavioral research tools in Second Life. By leveraging the existing community of a 3D3C World, these studies can scientifically analyze the patterns that motivated people make when they are given tasks that require group adaptation, coordination, and cooperation. The chapter also provided a description of the employed methods of subject tracking and experimental condition controls in the virtual world, highlighting relevant aspects of the proposed design dictated by platform constraints.

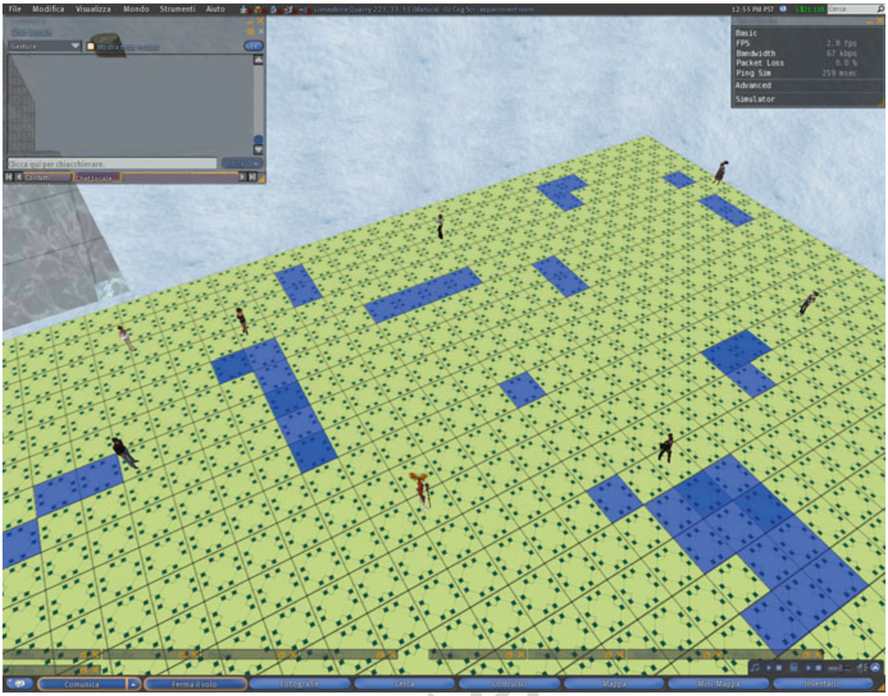



**Fig. 17** *SL CPR Harvesting* experiment snapshot: during the harvesting game runs, some participants would choose to gather resources right away, while others chose to wait for more resources to grow

There are also possible settings and controls that could not be fully controlled within Second Life at the time of our Reference Implementation. While not impacting the kind of experimental applications supported by our Group Behavior Virtual Platform, it is appropriate to add here a list of some of these experimental aspects that fall outside the scope of the work presented in this chapter:

- The visual perception of SL objects cannot be precisely controlled: the rendering options of each individual participant's SL viewer client software can be set to widely different settings. The only partial workaround for work requiring at least partial visual uniformity among participants is to choose neutral colors for all prims, to avoid bump mapping or additional shininess properties that may require post-processing, and to forego any complex polygonal structures that may get automatically reduced by individual SL viewer's optimization settings.
- The point of view of participants within the experiment room cannot be imposed by in-world scripts. Each SL resident can freely move their camera point of view away from the default "eye" position.
- SL instant messaging and chat-channel communications between participants cannot be prevented in any way. SL chat between participants can at most be

monitored—at acceptable additional processing expense—but the current experimental applications enabled by the described Group Behavior Virtual Platform do not include such requirements.

**Acknowledgements** The authors wish to express thanks to Andrew J. Hanson, Peter M. Todd and Larry S. Yaeger for helpful suggestions during the design and implementation of the studies presented in this chapter.

## References

Bailenson, J. N., Yee, N., Merget, D., & Schroeder, R. (2006). The effect of behavioral realism and form realism of real-time avatar faces on verbal disclosure, nonverbal disclosure, emotion recognition, and copresence in dyadic interaction. *Presence: Teleoperators and Virtual Environments, 15*(4), 359–372.

Bainbridge, W. S. (2007). The scientific research potential of virtual worlds. *Science, 317*(5837), 472–476.

Bakioğlu, B. S. (2007). Collaborative story-telling: Performing the narrative of the griefer. In *Proceedings of the Second Life Education Workshop 2007* (pp. 41–46). Chicago: Second Life Community Convention.

Bell, M. W., Castronova, E., & Wagner, G. G. (2008). Virtual Assisted Self Interviewing (VASI): An expansion of survey data collection methods to the virtual worlds by means of Virtual Data Collection Interface (VDCI). *Data Documentation* 37, DIW Berlin, German Institute for Economic Research, 2008. Retrieved from http://ideas.repec.org/p/diw/diwddc/dd37.html

Bell, M. W., & Robbins, S. (2008). *Second Life researcher's list, 2008*. Retrieved from http://list.academ-x.com/listinfo.cgi/slrl-academ-x.com

Bishop, G., & Fuchs, H. (1992). Research directions in virtual environments. *Computer Graphics, 26*(3), 153–177.

Boellstorff, T. (2008). *Coming of age in Second Life: An anthropologist explores the virtually human*. Princeton, NJ: Princeton University Press.

Brooks, F. P. (1998). *Is there any real virtue in virtual reality?* Chapel Hill, NC: University of North Carolina. Retrieved from http://www.cs.unc.edu/~brooks/RealVirtue.pdf.

Brooks, F. P. (1999). What's real about virtual reality? *IEEE Computer Graphics and Applications, 19*(6), 16–27. doi:10.1109/38.799723. ISSN 0272-1716.

Castronova, E. (2001). *Virtual worlds: A first-hand account of market and society on the cyberian frontier* (CESifo Working Paper Series No. 618). Retrieved from http://ssrn.com/abstract=294828

Castronova, E. (2005). *Synthetic worlds: The business and culture of online games*. Chicago: University of Chicago Press. ISBN 0226096262.

Castronova, E. (2008). *A test of the law of demand in a virtual world: Exploring the Petri Dish approach to social science* (CESifo Working Paper Series No. 2355). Retrieved from http://ssrn.com/abstract=1173642

Cruz-Neira, C., Sandin, D., DeFanti, T., Kenyon, R., & Hart, J. (1992). The CAVE audio visual experience automatic virtual environment. *Communications of the ACM, 35*(6), 64–72.

Goldstone, R. L., & Ashpole, B. C. (2004). Human foraging behavior in a virtual environment. *Psychonomic Bulletin and Review, 11*, 508–514.

Goldstone, R. L., Roberts, M. E., & Gureckis, T. M. (2008). Emergent processes in group behavior. *Current Directions in Psychological Science, 17*(1), 10–15.

Goldstone, R. L., Roberts, M. E., & Roberts, M. E. (2005). Knowledge of resources and competitors in human foraging. *Psychonomic Bulletin and Review, 12*(1), 81–87.

Hmeljak, D. (2010). Design and evaluation of a virtual environment infrastructure to support experiments in social behavior. *ProQuest Dissertations and Theses, 328*.

Janssen, M. A., Goldstone, R. L., Menczer, F., & Ostrom, E. (2005). *The dynamics of rules in commons dilemmas*. Retrieved from http://www.nsf.gov/sbe/hsd/hsd_pi_mtg/abstracts/janssen.pdf

Novak, T. P. (2007). *Consumer behavior research in Second Life: Issues and approaches*. Association for Consumer Research Pre-Conference, Memphis, TN.

Sutherland, I. E. (1965). The ultimate display. In W. A. Kalenich (Ed.), *Information processing 1965: Proceedings of the IFIP congress 65* (Vol. 2, pp. 506–508). Washington, DC: Spartan Books.

Wadley, G., Gibbs, M., & Ducheneaut, N. (2009). You can be too rich: Mediated communication in a virtual world. OZCHI 2009 Proceedings, Melbourne, Australia.

Weusijana, B. K. A., Svihla, V., Gawel, D., & Bransford, J. (2007). Learning about adaptive expertise in a multi-user virtual environment. In *Proceedings of the Second Life Education Workshop 2007* (pp. 34–39). Chicago: Second Life Community Convention.

Yee, N. (2006). The demographics, motivations and derived experiences of users of massively multi-user online graphical environments. *Presence: Teleoperators and Virtual Environments, 15*(3), 309–329.

Yee, N., & Bailenson, J. N. (2008). A method for longitudinal behavioral data collection in Second Life. *Presence: Teleoperators and Virtual Environments, 17*(6), 594–596.

Yee, N., Bailenson, J. N., Urbanek, M., Chang, F., & Merget, D. (2007). The unbearable likeness of being digital: The persistence of nonverbal social norms in online virtual environments. *Journal of Cyber Psychology and Behavior, 10*, 115–121.

# Author Queries

Chapter No.: 7 317531_1_En

| Query Refs. | Details Required | Author's response |
|---|---|---|
| AU1 | Please check if the affiliation is presented correctly. | |
| AU2 | Please note that Section numbers have been retained as given in the manuscript. | |
| AU3 | The text in the figure is unclear. Please provide a better quality figure with 300 dpi and font size 8 pts. | |
| AU4 | The citation "Fig. 2" has been changed to "Fig. 6". Please check if appropriate. | |
| AU5 | Please check the layout of Table 4. | |
| AU6 | "Crooks et al. (2009)" is cited in text but not given in the reference list. Please check. | |
| AU7 | "Figure 5.12" has been changed to "Fig. 13". Please check if appropriate | |