The untapped potential of virtual game worlds to shed light on real world epidemics

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Simulation models are of increasing importance within the field of applied epidemiology. However, very little can be done to validate such models or to tailor their use to incorporate important human behaviours. In a recent incident in the virtual world of online gaming, the accidental inclusion of a disease-like phenomenon provided an excellent example of the potential of such systems to alleviate these modelling constraints. We discuss this incident and how appropriate exploitation of these gaming systems could greatly advance the capabilities of applied simulation modelling in infectious disease research.

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For more information on ***World of Warcraft*** see http://worldofwarcraft.com

See **Online** for webfigure

Introduction

On Sept 13, 2005, an estimated 4 million players[1] of the popular online role-playing game *World of Warcraft* (Blizzard Entertainment, Irvine, CA, USA) encountered an unexpected challenge in the game, introduced in a software update released that day: a full-blown epidemic. Players exploring a newly accessible spatial area within the game encountered an extremely virulent, highly contagious disease. Soon, the disease had spread to the densely populated capital cities of the fantasy world, causing high rates of mortality and, much more importantly, the social chaos that comes from a large-scale outbreak of deadly disease (figure 1 and webfigure). These unforeseen effects raised the possibility for valuable scientific content to be gained from this unintentional game error, and it is this possibility that we will examine.

Anatomy of the outbreak

New game content for *World of Warcraft* is issued via a series of patches, released every 1 or 2 months. Patch 1.7, released on Sept 13, 2005, contained access to an area known as “Zul’Gurub”,[2] which was intended for use by players whose characters had achieved a sufficient level within the game to be considered “relatively powerful”. The centrepiece of this area was a combative encounter with a powerful creature called “Hakkar” (figure 2). Occasionally, one of the players facing this massive winged serpent would be purposefully infected by a disease called “Corrupted Blood”. This infection, as intended, then rapidly began infecting other nearby players. To the powerful players who were battling Hakkar, the infection was just a hindrance, designed to make this particular combat more challenging. However, several aspects of the disease caused this minor inconvenience to blossom into an uncontrolled game-wide epidemic.[3] The ability of many characters to transport themselves instantly from one location to another was the first factor in the game that unexpectedly set the stage for the plague. This type of travel is frequently used to return to the capital cities of the game’s geography from more remote regions for reasons of game play. Many victims of Corrupted Blood thus reached heavily populated areas before either being killed by or cured of the disease, mimicking the travel of contagious carriers over long distances that has been the hallmark of many disease outbreaks in history—eg, the Mongol horde and the bubonic plague, or the cholera outbreaks of Europe during the mid-19th century.[4] The highly contagious disease then spread to other players outside the intended, localised combat area near Hakkar.

The second factor that sustained the epidemic was that the disease could escape its origin in Zul’Gurub via interspecies transmission from player characters (ie, human beings) to animals and then back. Many players in the game have “pets”, non-player animal characters that assist them in the completion of certain functions within the game. The penalty assigned by the game for allowing a pet to die is prohibitively large, therefore players commonly dismiss their pets rather than subjecting them to dangerous effects such as disease. Dismissal temporarily removes the pet from the

Figure 1: **Urban centre in *World of Warcraft* during the epidemic**
A gathering of individuals in a town. Infected individuals walk among the uninfected, the recently dead, and the skeletons of those who died earlier. Source: archon210/YTMND. Image provided coutesy of Blizzard Entertainment Inc, 2007. All rights reserved.

Figure 2: **Hakkar, the primary source of infection in *World of Warcraft***
Source: archon210/YTMND. Image provided coutesy of Blizzard Entertainment Inc, 2007.

game, keeping them in stasis until they can be healed or otherwise safeguarded after the dangers of combat have gone. These pets, therefore, acted as carriers of the disease and also served as a source of disease by causing new outbreaks when brought out of stasis—even if their owner had recovered and was no longer infectious. Based on player accounts, pets, as opposed to the infective characters themselves, seem to have been the dominant vectors for the disease. Players would return to densely packed capital cities and retrieve pets that, being infectious, immediately triggered an outbreak. The density of susceptible characters within a specific radius was, therefore, the only apparent limit to transmission. Since players gathered in common areas, the outbreaks were characterised by staggeringly high reproductive rates (R_0), which we estimate at 10^2 per hour for the capital cities and transportation hubs, based on the few parameters known for the disease.[5] Unfortunately, the actual value is not publicly known.

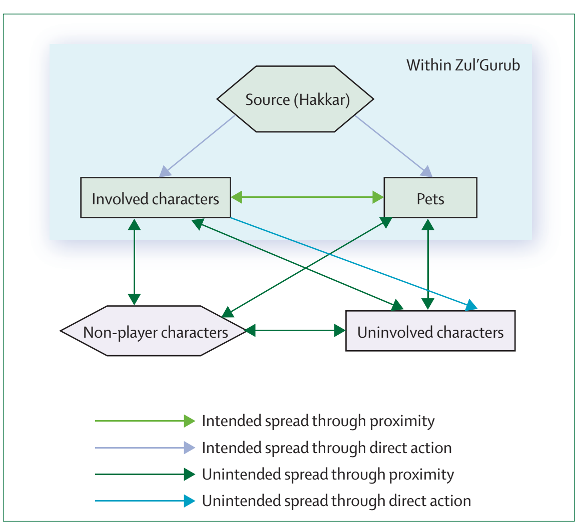

***Figure 3*: Chain of infection of novel virtual pathogen, *World of Warcarft*, September, 2005**
Flowchart shows network of intentional and unintentional interactions between characters within Zul'Gurub and those outside it that culminated in the epidemic. The proportion of transmission accounted for by each pathway is crucial for a full understanding of the dynamics of the epidemic, and must be recorded in future, intentionally triggered, outbreaks.

Although the reproductive value for this particular disease was too high to accurately reflect the dynamics of any real-world pathogen, future experiments could easily tailor the parameters controlling disease transmission and mortality to more accurately reflect a wide variety of pathogens. Smaller probabilities of transmission (rather than the simple density dependence), could cause the results of individual behaviour and social contact patterns to become even more important to disease spread. Alternatively, it may be that the ultimate use of these virtual experiments would be to examine whether or not behaviours—eg, altruistic medical attention—are subject to thresholds in the risk perceived by the individuals involved. These virtual worlds could, therefore, test human reactions to a wide range of disease scenarios—most of which could never occur in reality—to understand how people will behave if they do not know the probabilities of transmission for an infectious disease.

Although highly contagious, the disease in *World of Warcraft* may very well have run its course naturally in a very short period of time. To the game's powerful players, the disease was no more threatening than the common cold in a healthy adult. Less powerful characters (who were never intended to enter Zul'Gurub or encounter the disease), died very quickly from its effects. With most of the susceptible portion of the population (the equivalent of children, elderly people, or the immunocompromised) already dead, and the living either leaving the urban centres to avoid infection, or temporarily leaving the game entirely (to wait for the software defect to be fixed), the density necessary for a sustained chain of infection should have dropped below the threshold needed to sustain the epidemic.

Unfortunately for players of the game, a last, seemingly unrelated factor, present since the origin of the game, allowed the outbreak to continue, turning the capital cities into death traps. Computer-controlled characters, such as shopkeepers and soldiers (called non-player characters), are necessary parts of the structure and function of the game. These characters are deliberately made very powerful, to prevent them from being victimised by players exhibiting homicidal tendencies and to prevent such incidents from disrupting the normal course of game play. During the epidemic, the non-player characters served as "asymptomatic" carriers capable of spreading the disease, creating a nearly unbreakable chain of infection between highly infectious non-player characters, player characters, and their pets. Also aiding in the continuation of the epidemic, a cycle involving the resurrection of weaker characters by those with healing abilities, saw the susceptible population continually replenished (only to be reinfected and die again).

All together, these seemingly innocuous aspects of the game world, each directly mirroring an aspect of real-world epidemiology, allowed what should have been a very minor point of interest in a small area of the game, catering to a very specific subset of the players, to become the first online instance of uncontrolled plague to affect millions of Americans, Asians, and Europeans at home. Figure 3 summarises the dynamics of infection that produced the epidemic.

In an effort to control the outbreak, Blizzard Entertainment employees imposed quarantine measures, isolating infected players from as-yet uninfected areas.[6] These strategies failed because of the highly contagious nature of the disease, an inability to seal off a section of the game world effectively, and more than likely player resistance to the notion. The game's developers did, however, have an option that remains unavailable to public-health officials: resetting the computers. When the servers ravaged by the epidemic were reset and the effect removed, the outbreak came to a halt.[2]

The real–virtual connection

The modern world has two distinct types of pathogens, real and virtual. Real pathogens are, logically, those that infect real organisms, many of which subsequently cause disease and become subject to the attentions of the medical and public-health professions. The second type of pathogen, the virtual virus, infects computers through software. The outbreak we have described marks the first time that a virtual virus has infected a virtual human being in a manner even remotely resembling an actual epidemiological event. As technology and biology become more heavily integrated in daily life, this small step towards the interaction of virtual viruses and human beings could become highly significant.

Players in *World of Warcraft* can become highly involved in the game, investing not only their monthly fee but also hours of time within the game. Some challenges in the game require players to set aside several hours on 3 or 4 days of the week. Friendships are formed within the game, large numbers of players work together for months to achieve common goals, and many players strive to create a believable alter ego in the virtual world, complete with the weight of responsibility and the expectations of others. Whereas "resurrection" most certainly allows riskier behaviours, it is not unlikely that the modification in behaviour produced could be estimated. Research into the behavioural and emotional involvement of game players, and their relationship with their virtual selves has shown that reactions to events in the game world can have serious, emotional repercussions. Sherry Turkle (Massachusetts Institute of Technology, Cambridge, MA, USA) has said: "It's not that it's not part of your real life just because it's happening on the screen. It becomes integrated into really what you do every day. And so where you have loss of that part of your life that was involved in the habits and the rituals and the daily life, it's very traumatic. It is play, but it's very serious play."[7] This level of commitment and dedication to the virtual community within the game helps to ensure that the reactions of players will approximate with the reactions of people in real-life situations of danger.

Implications for the use of virtual games as experimental models

Whereas the epidemic of Corrupted Blood within *World of Warcraft* was the result of unintended interactions between different elements of the game, it nevertheless shows the potential of such scenarios for the study of infectious disease. One of the major constraints in studies of disease dynamics in animals is that epidemiologists are restricted largely to observational and retrospective studies. In nearly every case, it is physically impossible, financially prohibitive, or morally reprehensible to create a controlled, empirical study where the parameters of the disease are already known before the course of epidemic spread is followed. At the same time, computer models, which allow for large-scale experimentation on virtual populations without such limitations, lack the variability and unexpected outcomes that arise from within the system, not by the nature of the disease, but by the nature of the hosts it infects. These computer simulation experiments attempt to capture the complexity of a functional society to overcome this challenge. Two such systems, Transportation Analysis Simulation System (TRANSIMS; Los Alamos National Laboratory, Los Alamos, NM, USA)[8] and Epidemiological Simulation System (EpiSims; Virginia Bioinformatics Institute, Virginia Tech, Blacksburg, VA, USA)[9] are particularly ambitious, using large amounts of computing power to generate realistic virtual societies in which agents (autonomous entities governed by the rules of the simulation) perform programmed actions based on incredibly detailed research of real-world behaviour under non-outbreak conditions. However, they are programmed, by necessity, using these non-outbreak data.

Whereas games can be thought of among these types of agent-based epidemiological models, the use of human agents rather than virtual agents could further illustrate human behaviours in actual outbreak scenarios, rather than relying on stochastic algorithms to approximate assumed behaviours under these conditions. Human-agent simulations, where the subjects are virtual but have their actions controlled by human beings interacting with each other, may potentially bridge the gap between real-world epidemiological studies and large-scale computer simulations. Since the influence of individual behavioural choice has been shown to greatly affect the range of societal outcomes in many fields including epidemiology,[10] differences between the human-agent simulation and a pure computer simulation of the same disease, incorporating the vast complexity of human behaviour, rational or otherwise, could examine the effects of these behaviours on the course of an outbreak.

Both types of simulation, however, share two limitations. First, they are both still simulations, and human-controlled virtual agents might not act in the same way as the human controller if presented with the same situation in the real world. Second, they are both still heavily dependent on computing power. In the case of human-agent simulations, server capacity and subscriber base represent a theoretical maximum number of agents that, although far higher than most traditional epidemiological studies, can pale in comparison to purely computational simulations. These computational limitations imply that attention will need to be paid to issues of scalability of result.

In the case of the Corrupted Blood epidemic, some players—those with healing abilities—were seen to rush towards areas where the disease was rapidly spreading, acting as first responders in an attempt to help their fellow players. Their behaviour may have actually extended the course of the epidemic and altered its dynamics—for example, by keeping infected individuals alive long enough for them to continue spreading the disease, and by becoming infected themselves and being highly contagious when they rushed to another area. Of course, this behaviour could also have greatly reduced the mortality from the disease in those they treated. Such behaviour and its effects would have been extremely difficult to capture accurately in a pure-computer model. Human response is, almost by definition, difficult to predict, requiring experiments on emotionally involved subjects to determine the proportion of the population likely to respond in various ways. This understanding would provide the groundwork for the examination of the effect of those behaviours on the system. The failure of the quarantine measure, similarly, could not have been accurately predicted by numerical methods alone, since it was driven by human decisions and behavioural choices. This ability to demonstrate unforeseen consequences of human actions within a statistically robust and controlled computer simulation is yet another benefit of such a system.

Online games provide an intriguing experimental laboratory

Massively multiplayer online role-playing games (MMORPGs) represent a particularly tantalising pool of experimental laboratories for potential study. With very large numbers of players (currently 6·5 million for *World of Warcraft*),[1] these games provide a population where controlled outbreak simulations may be done seamlessly within the player experience. However, MMORPGs are, at their core, still games, and as such enjoyment and entertainment are their central focus. It may therefore prove difficult to motivate players to participate in an epidemiological simulation. However, plagues and epidemics already have prominent places in fantasy settings: the spread of disease, intentional and otherwise, has occurred as a major plot in several major software titles within the franchise. Researchers will have to allow players to feel not as if they are in a deliberate epidemiological simulation where they may die based on statistical whims, but rather that they are immersed in a coherent, logical setting where death is a major risk—essentially unifying epidemiological experimentation with game design and development. These efforts will likely involve careful consideration and partnership with the gaming industry, mirroring the outreach, partnering, and involvement of community representatives often needed to make traditional epidemiological studies palatable to real-world populations being studied. Studies using gaming systems are without the heavy moral and privacy restrictions on patient data inherent to studies involving human patients. This is not to say that this experimental environment is free from concerns of informed consent, anonymity, privacy, and other ethical quandaries. Players may, for example, be asked to consent to the use of their game behaviour for scientific research before participating in the game as part of a licence agreement. Studies impossible to undertake on actual populations can be run as in-game events, and the data collected would be free from any biases because they would be recorded from servers. Lastly, the ability to repeat such experiments on different portions of the player population within the game (or on different game servers) could act as a detailed, repeatable, accessible, and open standard for epidemiological studies, allowing for confirmation and the alternative analysis of results.[11]

Although the use of these systems opens the possibility for new methods of experimentation, it remains subject to the need for external validation before any understanding gained from these experiments could be applied to real-world outbreak scenarios. Some of this validation could be achieved in the same way that many mathematical and simulation modelling results are already tested: by comparing the outcomes observed in virtual scenarios that have been tailored to reflect the conditions of real-world, historical outbreaks as closely as possible with the outcomes of the real-world outbreak. However, as with many simulation modelling techniques, having a framework available for experimentation, even in the absence of external validation, can lead to potentially crucial insights into the dynamics of the system as a whole.

Conclusion

The Corrupted Blood outbreak in *World of Warcraft* represents both a missed opportunity and an exciting new direction for future epidemiological research.

Although the infrastructure needed to accurately record data on the outbreak to research standards was not in place, and the outbreak was largely a series of unexpected interactions between different factors within the game, it offers a view of potential further study. Virtual outbreaks designed and implemented with public-health studies in mind have the potential to bridge the gap between traditional epidemiological studies on populations and large-scale computer simulations, involving both unprogrammed human behaviour and large numbers of test participants in a controlled environment where the disease parameters are known; something neither type of study can manage alone. We believe that, if the epidemic is designed and presented so as to seamlessly integrate with the rest of the persistent game world, in such a way as to be part of the user's expected experience in the game, a reasonable analogue to real-world human reactions to disease might be observed and captured within a computer model. This human-agent model of disease dynamics can then be used to provide reproducible empirical analyses, yielding greater insights into the behavioural reactions and individual responses of people threatened by outbreaks of disease. By using these games as an untapped experimental framework, we may be able to gain deeper insight into the incredible complexity of infectious disease epidemiology in social groups.

Conflicts of interest
We declare that we have no conflicts of interest.

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References

1 Woodcock BS. An analysis of MMOG subscription growth. August, 2002. http://mmogchart.com (accessed July 12, 2007).
2 Patches. World of Warcraft Wiki, 2006. http://www.wowwiki.com/index.php?title=Patches&action=history (accessed July 12, 2007).
3 Ward M. Deadly plague hits Warcraft World. London: BBC News, Sept 22, 2005. http://news.bbc.co.uk/1/hi/technology/4272418.stm (accessed July 12, 2007).
4 McNeill WH. Plagues and peoples, 2nd edn. New York: Anchor Books, 1989.
5 Thotbott World of Warcraft: corrupted blood. Thotbott, 2005. http://thotbott.com/?s=Corrupted+Blood (accessed July 12, 2007).
6 Reimer J. Virtual plague spreading like wildfire in World of Warcraft. Ars Technica, Sept 21, 2005. http://arstechnica.com/news.ars/post/20050921-5337.html (accessed July 12, 2007).
7 Sydell L. All things considered: "virtual" virus sheds light on real-world behavior. Washington: National Public Radio, Oct 5, 2005. http://www.npr.org/templates/story/story.php?storyId=4946772 (accessed July 12, 2007).
8 Los Alamos National Laboratory. TRANSIMS 3.0 documentation set. 2002.
9 Eubank S, Guclu H, Kumar VS, et al. Modelling disease outbreaks in realistic urban social networks. *Nature* 2004; **429:** 180–84.
10 Keeling MJ, Eames KT. Networks and epidemic models. *J R Soc Interface* 2005; **2:** 295–307.
11 Peng RD, Dominici F, Zeger SL. Reproducible epidemiologic research. *Am J Epidemiol* 2006; **163:** 783–89.