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Videogames: the new GIS?

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Abstract
Videogames and GIS have more in common than might be expected. Indeed, it is suggested that videogame technology may not only be considered as a kind of GIS, but that in several important respects its world modelling capabilities out-perform those of most GIS. This chapter examines some of the key differences between videogames and GIS, explores a number of perhaps-surprising similarities between their technologies, and considers which ideas might profitably be borrowed from videogames to improve GIS functionality and usability.

Keywords: Videogames, computer games, geographical information systems, virtual geographical environments, virtual environments, virtual worlds, spatial data visualization, user interaction.

"Comparisons are odious." (Gilbert of Hay, 1456)

I. INTRODUCTION

The positioning of one technology or medium relative to others is a common academic pastime. For example, numerous studies have compared GIS with other spatial and non-spatial digital technologies, including: remote sensing [1; 2], mapping [3; 2], databases [4], and CAD [4; 5]. For their part, videogames have been compared and contrasted with novels, drama, comics and film [6]. Until comparatively recently, however, the subject matter and technologies of most videogames have not been similar enough to warrant detailed comparison with GIS. However, this is no longer the case. Not only do many games present vibrant and realistic worlds on screen (Figure 1), but the spatiality of games is increasingly recognised as being a key property of these distinctive digital environments [7; 8]. For this reason, a detailed head-to-head comparison with GIS is long overdue. In undertaking such an analysis, we advance two broad propositions: that the two technologies and their uses are far more similar than might be expected; and that GIS have a great deal to learn from videogame technology and design. Although the central focus of this chapter is on videogames and what they have to offer, they will also be used as a lens through which to better understand GIS, and to identify areas for further development.

Not every kind of videogame is germane to our analysis. There are numerous genres and sub-genres of this form of interactive multimedia [9; 10], but the main focus here is on games which have recognisable geographical content. Among these are most action games (and especially first-person and third-person shooters), many role-playing and adventure games, several kinds of simulation game (including driving and racing games), and strategy games which involve the evolution of settlements, cities and civilisations. There are many videogames with a less recognisable geographical content, including: puzzle games (especially board games, quizzes and classic titles such as *PacMan* and *Tetris*), music games (such as *Guitar Hero* and *Jam Sessions*), and many children's games. Although a large number of sports games (e.g. tennis, soccer, snooker, American football, and Olympic events) have little intrinsic geographical content, others (such as golf and car racing games) are of considerable interest to GIS, because of their often fastidious and innovative approaches to micro-terrain modelling and townscape representation. These, and other less geographically relevant videogames, will be discussed where aspects of their design, role and usage are relevant in a GIS context.

Figure 1. Realistically rendered fictional landscape of first-person shooter game (Half-Life 2; courtesy of Valve Software).

Although a broad view is taken of what constitutes a videogame, it was decided to exclude virtual world software whose primary goal is to enable users (typically in online environments) to act out alternative lives in relation to one another, albeit in specially constructed spatial environments. (These include virtual social worlds such as *Second Life* and *Habbo.*) Although some of the functionality of such virtual environments is also found in multi-player role-playing games, such as *World Of Warcraft*, the primary objective of these sites is social networking rather than game playing. It is, however, recognised that this distinction is not watertight, and that at the time of writing some social networking sites are beginning to incorporate games-like activities as a means of attracting and retaining subscribers. It should also be noted that we use the term GIS throughout as a shorthand for the relatively close-knit family of software that enables analysts to manage, display, analyse and report spatial information in an integrated environment. This term therefore should be understood to include full-service GIS, desktop mapping software, spatial data visualization programs, and related software. The focus will be largely on software that models aspects of the real world for users driven by relatively serious analytical intent.

Throughout this chapter, the acronyms VG and GIS will be used respectively to refer to videogames and geographical information systems. Assiduous readers will note that while numerous videogame titles are mentioned in the text, few GIS are identified by name. This is partly because of the videogame focus of this chapter, but it also reflects the fact that there are relatively few GIS and, unlike individual games, most full-featured GIS contain a relatively wide range of functionalities characteristic of this kind of spatial analysis and display software. In contrast, there are thousands of individual VGs, and more than a dozen VG genres, and there is consequently a far greater diversity between individual products than among GIS. Where distinctive features are found in specific GIS, individual software will be identified by name.

II. SIMILARITIES BETWEEN VIDEOGAMES AND GIS

A common definition of GIS is that it is a system (part hardware, part software, and part human) that is used to solve problems with a spatial dimension, by providing tools for the acquisition, storage, integration, update, retrieval, manipulation, analysis and display of spatial information. In this section, key GIS characteristics and functionalities will be critically examined in relation to VGs, with the following three aims in mind: to evaluate how far VGs provide the capabilities of GIS; to determine limitations in the functionality of VGs in terms of spatial problem solving; and to indicate ways in which GIS might benefit from adopting VG functionality.

A. Spatial representation

Videogames may be classified on the basis of two aspects of their spatiality: the extent to which they attempt to model the real world, and the kind of representational system they use in portraying elements within their worlds. (In terms of the second of these dimensions, only visual representation is considered here, for reasons that will become clear in section IIIC.) For the purposes of the current discussion, these two aspects will be referred to as reality and realism respectively. Figure 2 maps out this reality:realism space, and indicates where three related spatial technologies (VGs, GIS, and social networking virtual worlds) are positioned in relation to these twin characteristics. It is suggested that VGs occupy a far greater territory in this space than either GIS or social networking virtual worlds. Within the area of the diagram occupied by VGs, a selection of videogames has been located. (For readers less familiar with contemporary VGs, a lookup table is provided in the Notes.) These locations are best thought of as modal locations, because a number of VGs present several contrasting virtual environments to the player.

Visual realism

The rich visual realism which many contemporary VGs present in their virtual worlds is immediately apparent to any spatial analyst who looks over their children’s shoulders. Landscapes extend across extensive areas, terrain is draped with plausible vegetation patterns and the infrastructure of human habitation, building interiors are designed with considerable attention to architectural and engineering detail, and many of these virtual environments are enlivened with the dynamic trappings of modern life, including vehicles and people in motion. Some of this visual realism is undeniably a showcase for VG talent and technology, and especially for graphic artists and graphics hardware. However, a great deal of it reflects the way in which many modern videogames place the player at ground level, and therefore represent the world as seen through the eyes of the pedestrian or the driver, rather than from the air as in most GIS. However, much of the visual realism is wrapped around a world model that is largely or entirely fictional.

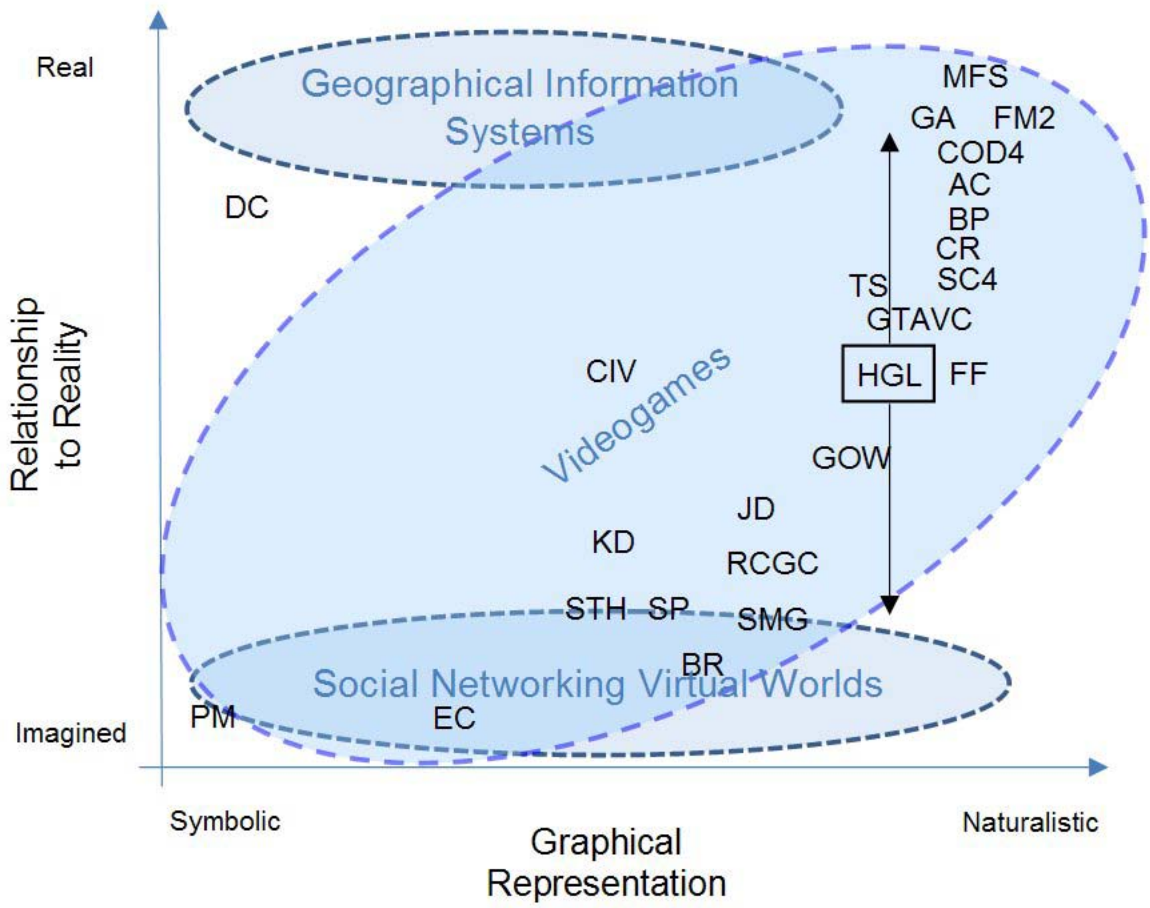

Figure 2. The reality-realism space occupied by videogames, GIS and social networking virtual worlds, with acronyms of selected videogames from the text.

Representing the real world
The environments encountered by players in VGs run the gamut, from authentic reproduction of real places using real spatial data to entirely fictional places using synthetic data. The majority of VG environments, and especially those built for role-playing games, are imagined worlds, created from the imagination of the games designer. At this lower end of the reality spectrum (as depicted by the vertical axis in Figure 2), are to be found innumerable fantasy worlds (e.g. *Final Fantasy, Jak & Daxter*, the *God Of War* series and *Little Big Planet*) and several impossible ones (e.g.

Echochrome, with its Escher-like 3D geometry, and *Braid*, with its distortions of time). There are also some casual and passive games which visualise user data to create an abstract 3D scene (e.g. *Packet Garden*, which uses 3D glyphs to construct virtual landscapes from multivariate data describing the player's online surfing habits).

Also at a low level on the reality scale are worlds which may appear to be based on some form of geography or cosmology (as in role-playing games such as *Fable II*), but where the reality is only skin deep. The spherical planetoids in *Super Mario Galaxy*, for example, bear little or no resemblance to real world exemplars; and the 3D globes that may be explored in *Civilization: Revolution*, *Katamari Damacy*, *Spore*, and *Ratchet & Clank: Going Commando* lack either the dimensions or the realism of the earth as seen from space. However, numerous VGs at this relatively low point on the reality scale attempt to mimic the visual appearance of the real world. These include a number of first-person games (e.g. *Crysis*), and many racing games (e.g. *Burnout: Paradise*), while many spatial strategy games (e.g. various versions of *Civilization*, *Sim City* and *The Settlers*) also provide recognisably human landscapes and elements of real-world behaviour. In creating the level of visual fidelity evident in these games, designers are increasingly aided by software that procedurally generates terrain and buildings, often using architectural templates taken from real cities.

Many games with this reality:realism mix are set in historic locations, but designers typically model the environments with a mix of artistic licence and architectural and geographical authenticity. Examples include: *Assassin's Creed* (set in the cities of Acre, Damascus and Jerusalem at the time of the Third Crusade in the late 12th century), and *Hellgate: London* (set in a futuristic version of London). Although most videogames based on past wars (the military shooter genre) appear to recreate the look and feel of a battlefield, they tend to use a particular conflict merely as an 'inspiration' or hook; the gameplay itself often bears only passing resemblance to the battles fought. Examples include *Medal of Honor: Allied Assault*, based loosely on World War II, *Call of Duty 4: Modern Warfare*, based on modern battlezones, and the squad shooter *Conflict: Desert Storm*, based loosely on Desert Storm. Some titles (e.g. *Rainbow Six Vegas 2* and *Call of Duty 4: Modern Warfare*) take considerable pains to visualise weaponry, vehicles, soldiers clothing and insignia in true detail, but their representation of geography and historical events is much less authentic. Among VGs with a greater purchase on reality are *Call of Duty: World at War*, which aims for both geographical and historical authenticity (including the use of audio recordings of World War II weaponry), and *Brothers in Arms: Hell's Highway*, which not only models actual theatres of conflict (the Dutch countryside during in World War II), but also enables the player to participate in reasonably authentic forms of fighting. But for every title that attempts to be true to the battle that inspired the game, there are many others which make only a token effort to replicate the geographical environment of the war in which their virtual fighting is staged.

Much the same mixture of relatively low reality and high visual realism may be found in several VGs set in contemporary locations. In some examples (e.g. *Fracture*, set in the San Fransisco Bay Area), the cityscape is 're-imagined', using a mixture of familiar and unfamiliar elements. In other games, locales are described as 'inspirations' rather than replicas. Examples include the skateboard game *Proving Ground*, which is based loosely on Philadelphia, Baltimore and Washington DC, and the car racer *Project Gotham Racing*, which has been set variously -- and in most cases somewhat symbolically -- in New York, London, Tokyo, Las Vegas, Macau, Shanghai, St Petersburg and Quebec.

However, some VGs are more closely based on real world locations, altering the real geography only where it is dictated by the needs of the gameplay. An example of this approach is the car racer *Getaway*, whose designers took considerable efforts in collecting detailed streetscape information (including building textures captured through extensive field photography). Although the street layout is simplified and stylised, it bears more than a passing resemblance to the major thoroughfares in those parts of central London in which the game is set. Similarly, *Grand Theft Auto IV* involved considerable research into New York, including the taking of tens of thousands of photographs [11]. (See [12] for further examples of VGs set in replicas of real cities.) This mixture of real-world and synthetic data is also found in largely fictional VGs (e.g. *WRC: Rally Evolved* and *Forza Motorsport 2*), which use real-world data in the same way that some GIS worlds incorporate imaginary (or at least synthetically derived) data [13; 14].

Figure 3. World strategy game showing buffers around high latitude radar stations on cylindrical map projection (Defcon; courtesy of Introversion).

There is only a small number of VGs whose virtual environments are based on real geography and real spatial data, and therefore occupy the upper end of the vertical axis in Figure 2. One example is the car racer *Test Drive Unlimited*, which models the terrain and route network of the Hawaiian island of Oahu by integrating multiple sources of geospatial data for the island. (This permits the display of a realistic in-car satnav.) A second example is *Microsoft Flight Simulator*, which drapes aerial photo data onto digital terrain models, and uses accurate 3D digital models of actual airplanes and detailed airfield and airport layouts, to provide a realistic simulation of flying that unfolds in real time. (It should be noted that much of the functionality of these two games, including the virtual satnav, is available in Google Earth via user mashups [15].) A third example of a game based o real world geography is the multi-player world strategy game, *Defcon*, which charts player progress on a cylindrically projected world map (Figure 3).

Although these three examples are located towards the top of the vertical reality scale in Figure 2, they are spread across the horizontal realism scale. In terms of its real-world visual appearance, *Microsoft Flight Simulator* is closest to the naturalistic end of the horizontal scale, although for most of the time the player has a relatively high-altitude bird's eye view. A little way to the left of this is *Test Drive Unlimited,* whose visual representation of island scenery is frequently rather stylised. Finally, *Defon* is over at the symbolic end of the horizontal scale, with gameplay being organised around an atlas-like world map. It should be noted, however, that VGs evolve through time, and many titles shift their position and/or modify the area of the reality:realism space they occupy as new versions appear on the market. In this context, it is interesting to note how Google Maps, originally developed to represent the real world, is increasingly being used to display virtual worlds (e.g. *GTA IV*'s Liberty City at grandtheftauto.ign.com/maps/1/Liberty-City-Map and Second Life at: slurl.com).

Fitness for purpose

For VGs and GISs alike, the level of ground truth provided by the software is only useful to the extent that the player or the spatial analyst requires it. Indeed, the reaction from some quarters of the gaming community to increased realism in VGs has been extremely negative. One commentator [16] rails against the obsessive pursuit of realism by some games producers, suggesting that the essence of some classic games (such as *Sonic the Hedgehog* or *Pac-Man*) would be destroyed by using realistic rendering and physics. For Biffo, "one of the big appeals of games is that they are a window on to fantasy … in the more general sense of being transported to somewhere that isn't real". In a statement that serves to maintain clear water between videogames and GIS technology, he goes on to argue that: "If you're going to create a CGI world that's only one step away from our real world, then why not just make a live-action movie?" -- or, one might add, use a GIS? What GIS analysts know only too well is that unrealism, in the form of map symbols and visualization glyphs, can often serve to deliver greater understanding than photorealistic displays.

A considerable tension has been introduced into VGs by the desire to create truthful representations of the real world while at the same time designing virtual environments which provide a compelling game experience. This tension is central to the game designer's craft, as is evidenced by the critical view of a highly influential games designer [17]:

> "A game creates a subjective and deliberately simplified representation of emotional reality. A game is not an objectively accurate representation of reality; objective accuracy is only necessary to the extent required to support the player's fantasy. The player's fantasy is the key agent in making the game real."

Using modern VG technology it is now just as easy to model the geography of an actual racing circuit or a battlefield as it is to recreate an actual race or battle. However, the faithful recreation of real events runs the risk of suppressing the freedom associated with player decision-making behaviour that is the central feature of interactive games. Instead of interaction, the player would confront a digital version of the kind of event reported on a sports TV channel or staged by a battle recreation society. As one war simulation game reviewer put it [18], the challenge for developers is to tread the fine line between testament and entertainment. This important dilemma is largely absent in GIS, whose primary goal is the representation of geographical reality.

The foregoing discussion reveals as illusory the presumption that VG environments are always synthetic while GIS worlds are always real. Indeed, GIS have until very recently provided low-fidelity visual realism (in the form of cartographic symbolism), minimal fidelity in terms of non-visual data representation [19; 20], and only medium fidelity in terms of dynamic modelling (a reflection of the static map inheritance of GIS). Moreover, the central problem of spatial data uncertainty further underscores the fact that even though GIS attempt to model the real world as accurately as possible, their representations are frequently significantly flawed [21; 22]. It is therefore a crude over-simplification to suggest that while videogames have been high on realism but low on reality, GIS have been low on realism but high on reality. Each in its own way adopts blends of the real and the imagined, the naturalistic and the symbolic, as needs dictate.

Spatial modelling technologies

The technologies used by VGs and GIS in building their respective digital worlds are increasingly common to both domains, though with perhaps different emphases. Vector data models are widely used, though in VGs they are almost exclusively applied to 2.5D and 3D objects. Digital terrain models are also commonplace, with both VGs and GIS using multiple resolution terrain data. The grid-cell data model is largely absent from VGs, though a variation of it appears in the grid-based terrain models used in a number of strategy games (e.g. *Sim City*). On the other hand, image and texture data are widely used, and recent innovations in texture mapping from the VG and CGI communities are now routinely used by GIS to drape aerial photos and satellite images over terrain models. Additional realism is provided in VGs through surface rendering that uses a range of sophisticated computer graphics techniques, including: bump mapping, environment mapping, radiosity, dynamic lighting, and dirt mapping (which is put to good effect in the car rally game, *Colin McRae: DIRT*). Other technologies used in both camps include: the use of hierarchical data structures (and especially quadtrees), spatial data integration (especially of various kinds of surface data), techniques which minimise processor loads in complex scenes (e.g. tiling and level of detail or LOD), and layering (which in VGs is mainly used to model dynamic accretions on surfaces).

Various algorithms are also similar in VGs and GIS. These include: spatial search (using sophisticated spatial indexing), object buffering (used for object collision detection), and path planning algorithms (used to transport the user from one location to another). (The artificial intelligence developed in VGs for automatic camera control in third-person games is perhaps unique to VGs, and will be discussed further below.)

However, this is where VGs and GIS begin to part company. For their part, VGs have focused more on innovative and flexible methods of user interaction and navigation in 3D environments, and in developing dynamic models of environmental and human processes. Several specialist data structures are used to support fast surface rendering (e.g. indexed vertex arrays), dynamic lighting (e.g. normal maps), rapid search (e.g. BSP trees and nested voxel grids) and navigation (e.g. traversability graphs) in 3D environments, and related structures for rapid collision detection (e.g. convex hulls). In contrast, GIS have placed more emphasis on developing tools for spatial analysis, and perhaps most notably in terms of 2D spatial overlay. In general, VGs tend to adopt spatial models and data structures that ensure optimal real-time rendering and interaction, realistic sound and haptic responses, and continuous data updating during gameplay. (In *Splinter Cell: Conviction*, for example, the dynamic navigation mesh which enables realistic navigation behaviour is updated as objects in the world move or change.) In contrast, GIS have tended to adopt spatial models and data structures which are primarily optimised to support analytical operations on data that represent relatively static worlds.

B. Attribute data

One of the more distinctive features of GIS technology is its integration of attribute and locational data [23; 24]. On the surface, VGs appear to be all visual representation and action, with little obvious evidence of the attribute data associated with real-world features and objects. This perception, however, is misleading. Although VG software may run to millions of lines of code, most games also contain very large volumes of ‘content’ or ‘assets’. Like GIS, VGs also store large amounts of attribute data, describing elements of the virtual environment, including discrete objects and characters. In a typical contemporary videogame, object assets may include: vertex data (multiple attributes -- e.g. position, normal(s), texcoord(s)), texture data (multiple layers -- e.g. albedo, normal, reflection mask), collision mesh, (multiple versions of the prior data for LODs), animations and related audio files and particle effects, and physical data about the object’s surface and volume. Although such data may not be organised in the form of a relational database, for reasons of simplicity and performance, many data tables adopt the simple row-column form of the standard attribute data matrix. However, because of the highly dynamic nature of VG environments, attribute data in VGs are more frequently stored in other data structures, such as trees, sparse voxel grids and hash tables.

In both VGs and GIS, attribute data are crucial, not only for data visualization and object selection, but also for more advanced forms of simulation, spatial analysis and reporting. Indeed, there is frequently little difference between VGs and GISs in either the type or quantity of non-graphic data they require. (For example, some 80,000 lines of spoken dialogue were specially written for *Grand Theft Auto IV*, which used 740 different voices.) However, one significant feature of VGs is that a great deal of game information is not attached to objects as standardised descriptive information. Unlike GIS, much of the information stored in VGs supports elements of gameplay not normally found in GIS. Thus, for example, the text in GTA IV are delivered in an intelligent fashion based on in-game events and player actions. *Half-Life 2: Episode 1*, for example, uses a fairly generic event-driven contextual system in which dialogue is situation, event, and action specific. This makes the world and its characters react to the player in a (seemingly) more intelligent fashion. Some lines of dialogue are always heard – usually associated with events which are guaranteed to occur – but some will only be heard if certain things happen.

A second difference resides in the uses that can be made of attribute data. In contrast to GIS, much VG data are only accessible to the games software, and not directly to the player. In general, GIS analysts actively extract data, while in videogame players are passively fed data. In both cases, algorithms are at work, and user decision making and interaction is required, but the degree of control of data-extraction and display is skewed towards analysts in GIS, and to the software in VGs. Thus, while in VGs data are mainly 'pushed' to the player, in GIS, data are mainly 'pulled' by the analyst.

However, there are some notable exceptions to this general rule. Titles across several game genres (e.g. role-playing adventure games, strategy games, racing games and sports games) not only maintain large attribute databases related to their virtual environments, objects and characters (and particularly for player avatars), but they also display some of these data on screen during gameplay, and update attribute data for the player's avatar and its behaviour as the game proceeds. Stored attribute data is displayed in various ways during gameplay. In some car racing games (e.g. *Forza Motorsport 2*), detailed readouts of car settings and behaviour can be displayed, and the player is able to adjust these during the game to modify the driving behaviour of their vehicle. (In *Sega Splash! Golf*, for example, golfer statistics can be viewed in a player room.) Such data may provide players with feedback and motivation (as in many car racing and role-playing adventure games), or may aid dynamic decision-making (as in many strategy games).

In many adventure, strategy and simulation games, relevant text is provided on screen as a readout or mouseover display (akin to Windows tooltips), while many shooters provide head-up displays with summary information about the current state of the game. In *Civilization: Revolution*, visual modifiers (brief displays of summary information) are attached to objects on screen, while a street-name indicator appears at the top of the *Burnout Paradise* screen, reminiscent of GIS practice. Another genre of VG which routinely accumulates in-play data is the massively multi-player online game (MMOG). Such data are made available to game community websites which feed game statistics back to players so they can learn from others' gameplay performance. (A notable example is Bungie.net, which reports on online, multiplayer deathmatches in *Halo*.) These data are also used by game designers to help steer new feature development, and plan game marketing activities. There are lessons to be learnt here by GIS, where the actual problem-solving behaviour of expert analysts might be of considerable value to less experienced users, or peers working in the same field. In addition, the accumulation of data on trainee actions during training courses could be used to make informed decisions on further learning activities.

C. Spatial data visualization

Few (if any) VGs adopt the kind of symbolic map representation that has benefited spatial data analysts for the best part of two hundred years, and are thus able to provide little guidance on effective 2D data visualization. (One of the few exceptions is *Defcon*, the multi-player world strategy game, which displays its symbolism on a cylindrically projected world map -- see Figure 3.) However, because most contemporary VGs display realistically modelled scenes in 4D, they provide a suitable benchmark against which data visualization in virtual worlds modelled by GIS can be measured. Although few VGs would appear to adopt the strict rule-based approach to data visualization propounded by Bertin [25; 26; 27; 28; 29], it is nevertheless instructive to understand how VGs adopt the graphical sign system, albeit at an informal level, and to identify innovative applications in VGs that might be useful in a GIS context.

Perhaps the simplest example of the operation of data visualization rules is the use of categorical visual variables such as shape, colour and texture to distinguish between qualitatively different groups of characters, objects or events. Most videogames pay careful attention to the visual design of entities so as to allow at-a-glance disambiguation between the many entity types present. The use of color-coding to relate groups of entities is a very common practice in videogame design. In the team-based online game *Team Fortress 2*, for example, players on opposing teams are differentiated through the use of simple colour schemes (e.g. one team wears red clothing, the other blue), while in *Schizoid*, enemies of a particular kind are given distinct colours (see Figure 8). Numerous combat games also distinguish friends from enemies by the style of clothing they adopt, many role-playing games (RPGs) distinguish male and female characters b y their clothing styles, and in some shooter games the lethality level of monsters is identifiable from their 3D shapes. In *Black & White II*, the avatar changes its form based on behaviour, so that it in turn looks good or evil, fat or skinny, weak or strong. Colour is also widely used for signalling purposes. In *Mirror's Edge*, for example, features of the environment (such as ledges and machinery) that might be useful to the player in traversing the cityscape are depicted in primary colours, so they stand out from the mainly white and blue of the virtual world, and while safe paths are clearly illuminated, dangerous paths are shown in shadow. In the *Half-Life* series, interactive objects are coloured red, and lighting is commonly used to attract attention to important objects or locations.

Videogames also use gradational variations in visual variables to reflect continuous variations in numerical variables (e.g. counts or measurements). Normally, this applies to individual objects or characters in the game. Size, for example, is often related to the strength of enemies or the value of items in a game (as in *Blinx: The Time Sweeper*, in which gold ingot size implies value), and variations in lightness or hues along a colour ramp is sometimes used to convey some internal state value (e.g. brightness of a head-up display (HUD) element relates to the health of the player's avatar, the health of an enemy is reflected in a 'health bar', typically floating in the world above the enemy's head, which changes in colour from green (healthy) to yellow (damaged) to red (nearly destroyed)). Games which use a perspective projection also provide implicit scalar visual feedback, by relating an object's size on screen to its distance from the viewpoint (in addition to the obvious relation between on-screen position and virtual 3D location).

Unlike most GIS, VGs also make use of time as a visual variable. A common example is found in shooter games, where coloured bars of dynamically varying length represent the gradual decline or rapid replenishment of a player's health (Figure 4). Another example is the pulsation of an object's size or colour, where the frequency of the variation indicates the current threat level -- e.g. when an object is likely to explode (e.g. in *Left4Dead*, pipe bombs beep with increasing frequency as they near detonation, and the player's view becomes increasingly dark and blurred as their health runs out when they are in need of rescue by another player).

Figure 4. Urban night-time scene, showing dynamic health indicator bars (Left4Dead; courtesy of Valve Software)

Several VG practices may be of interest for data visualization in a geographical context. Some games eschew the normal per-symbol approach to data visualization, and adopt instead what might be termed ambient visualization. In *Brothers in Arms: Hell's Highway*, for example, a colour intensity gradient is used to darken and redden the entire screen as the risk of the player being shot increases. A variation of this technique is used in *Half-Life 2*, where threats to the player from the side or rear are indicated by the appearance of edge-of-screen red bars. With the left bar appearing if the threat is from the left, the right bar if from the right, and both bars if from directly behind the player? Also, the redness of these bars is proportional to damage, and fades over time after the damage occurs. In the case of repeated damage from a given direction, the colour will maintain a strong intensity due to the slow fade.

Another distinctive use of data visualization is to provide on-screen visual prompts derived from several relevant variables to assist the player in making spatial decisions, or undertaking complex actions. Examples include: the 3D trajectory line symbol in *Tiger Woods PGA Tour 08*; to assist the player in making a shot; and the quarterback's 'vision' cone in *Madden NFL 2006*, whose length and width is proportional to that player's level of expertise, is used to determine which receivers can be thrown the ball. The location of certain visual prompts in the virtual environment can often be of considerable importance to effective decision making by the player. A good example is the visual feedback provided by the balance bars included in early editions of the *Tony Hawks* skateboard games. Because these bars were placed next to the skater, it was found that found that they competed for the player's visual attention. Consequently, they were replaced in *Proving Ground* by a screen-wide coloured arc, which shifted the visual prompt to the player's peripheral vision. (Similar thinking was used in the design of the edge-of-screen coloured bars in *Half-Life 2*, as described earlier.)

A further lesson for spatial data visualization concerns how well 2D visual symbol coding translates to 3D. Although the approaches explored by Kraak [30; 31] do not appear to have been implemented in VGs, careful graphical design has established some working principles for effective 3D visualization. An example is found in the team-based, multi-player game *Team Fortress 2*, where the player takes on one of 9 distinct roles. Because it is important to be able instantly to identify another player's team and role, the avatar for each role has a unique silhouette, easily distinguishable from all the others, which retains its distinctiveness when viewed from various directions and under varying lighting conditions. A related technique is used to show objects even when occluded, as in the 'shadow Mario' used in *Mario Sunshine/Galaxy*, whose silhouette at least is always visible, even when the character is occluded. In general, automatic cameras and environmental design are concerned with mapping 3D worlds to effective 2D views at any given moment.

Figure 5. Atmospheric evening scene involving darkness and local lighting (Left4Dead; courtesy of Valve Software).

A final lesson for GIS concerns the way in which data visualization can often serve multiple roles in VGs. It is frequently the case that visual symbols not only represent information, but at the same time add emotional depth, invoke engagement and develop a sense of immersion for the player (see Figure 5). This suggests potentially fruitful lines of collaborative research between VG and GIS, involving such topics as denotative and connotative responses to data representations, the semiotic boundaries between monosemy and polysemy, and possible interactions between cognitive and affective responses.

III. WHAT VIDEOGAMES CAN CONTRIBUTE TO GIS

In this section, we consider areas in which VGs have surpassed GIS in their treatment of elements which may be relevant to spatial data explorers and analysts. Three areas will be discussed in which VGs can contribute in a significant way to GIS: dynamic process modelling, user interaction, and multi-sensory data representation. Space prevents discussion of several other significant aspects of VGs that may be relevant to GIS.

A. Dynamic process modelling

Videogames are change-rich environments. From their earliest appearance, videogames have provided dynamic experiences, with events continually unfolding on screen. Changes to the virtual environment are in part the result of dynamic simulations running within the software. However, they also result from user interactions with the virtual environment, including shifts in player position and viewpoint, but also user modifications to the virtual environment. Indeed, change tends to be continuous rather than episodic in most VGs, and permeates most aspects of the virtual environment, including parts that may currently be unseen by the player. The management of change therefore represents one of the key challenges to the games designer and player alike, and these challenges constitute what Poole [32] refers to as the kinetic narratives which are such a distinctive feature of videogames.

Not all change evident on screen is significant to the goal or purpose of the game; a great deal of dynamic behaviour is modelled for purposes of ambient realism. Thus, for example, offices contain working computers and fax machines, homes have TVs which play ads, vehicles have satnavs that emit spoken instructions, and in-car radios emit music and DJ banter. Some games mimic real environments by providing usable telephone booths in the street (as in *Proving Ground*) or mini-games that can be played in shopping mall arcades (as in *Sega Splash! Golf*). This dynamic modelling is taken to new levels in representing change initiated by player actions. Thus, for example, footprints appear when walking on wet sand; spray appears on a camera lens during a powerboat trip; newspapers flutter in the vortex created by a passing car; and plaster flies off a wall when hit by bullets. Some of this dynamic realism is more significant in terms of gameplay, as when a box breaks apart when hit by a crowbar, to reveal hidden ammunition.

In earlier games, the impact of change within the virtual environment was often temporary, with killed creatures fading away shortly after their death, and bullet holes disappearing or being generalised on vehicle bodies and building facades soon after they had been created. Nowadays, however, bodies will accumulate on the ground, and bullet holes will stay exactly where they first appeared. VGs thus not only represent events; they also record the accumulated effects of events, so that the evolving game environment becomes a dynamic palimpsest. What is often missing, taking a GIS perspective, are facilities to interrogate and analyse this change. However, in *Sim City 4*, the player can look at pollution or property-price colour maps as the city evolves, and in *De Blob*, the player progressively covers more and more of a 3D environment with various colours of paint.

For their part, GIS initially drew their modelling approaches from static 2D maps, with digital spatial models typically representing a synchronic snapshot -- the classic cross-sectional view. Over the past couple of decades, however, GIS technology has moved progressively from mimicking static 2D maps to providing digital representations of 4D data [33; 34]. Only comparatively recently have GIS begun to change, with the introduction of 3D viewing, brushing, and animation [35; 36]. Increasingly important is the visual representation of diachronic change, typically undertaken by creating sequences of temporally spaced snapshots (e.g. the spread of population across the UK from decennial census data; the diffusion across America of WalMart stores; or the tracks of hurricanes in the Caribbean). Objects have also begun to move and change on screen by coupling the software to real-time data feeds (e.g. from GPS or ground-based tracking technologies) or links to simulation model output.

Although most GIS can handle historical data, typically in the form of time-spaced snapshots (e.g. remotely sensed image sequences for a given area, or decennial population censuses for a particular country), the essential characteristic of dynamic representation in GIS is that it is mainly a data-driven process, where the data are the outcome of prior surveying or monitoring activity, or as a result of real-time data capture. Most do not display the output of dynamic process models. Thus, while most GIS are adept at handling spatio-temporal data, few model dynamic spatial processes. This is not to ignore the considerable success within the geoscientific community, in developing dynamic environmental and social models. These range from the geological and hydrological models of the Kansas Geological Survey during the 1970s [**37**], through to the more recent geosimulation models of the 1990s [38]. There have been numerous attempts since the 1990s to link GIS to environmental process models (e.g. [39; 40; 41]) mainly through loose and tight coupling rather than embedding. Nevertheless, these models still occupy a parallel technological space to mainstream GIS, especially in the geosciences.

Videogames, unlike GIS, do not tend to store a great deal of time-varying data, other than music or recorded sounds. (Exceptions include character or object animation, which is often canned rather than simulated in real-time, which is discussed further below). Unlike GIS, most modern videogames, across several genres, embody numerous dynamic process models which not only enable various elements of the virtual environment to appear to behave realistically, but also permit the environment to respond in realistic ways to player interactions. Many car racing games (e.g. *Forza Motorsport 2*) combine a high degree of visual realism with a high degree of process realism. These simulation-heavy not only replicate circuits with considerable geographical and architectural fidelity, and highly realistic vehicles with every detail of the bodywork precisely modelled, but the behaviour of the vehicles is accurately replicated in the player's driving experience. For example, specific vehicular sounds are replayed during the game, and dynamic vehicle handling characteristics are also faithfully modelled based on a wide range of actual performance variables, to give the player the experience of real vehicle driving. Another example of an embedded process model is found in *Hydrophobia*, in which a fluid dynamics model, encapsulated in a specialised software engine, manages the dynamic behaviour of water bodies and its effect on objects. This model not only handles realistic water movement in complex spaces, and modifies the acoustics of the enclosed spaces it occupies, but it also models interactions between the water and the game protagonists.

The difference between VGs and GIS in this respect is crucial. While the outcome of a game's dynamic processes may appear to be realistic, and indeed may be generated by physically accurate models, they are synthetic outcomes, and will typically vary each time they are produced, usually in context-dependent ways. GIS also display the outcomes of real-world processes but, in contrast to VG outputs, this realism derives from the fact that what is being modelled usually consists of recorded occurrences. Here we find a contrast not only between the synthetic and the real, but also between the what-might-be and the what-was, between the possible and the actual, and between the fictional and the factual.

Dynamic realism in VGs is closely related to notions of real-world time, both chronological and perceptual. The representation of cyclic time, and changes associated with it, is relatively common. Several games track the circadian cycle, for example by moving the sun across the sky (e.g. the *Jak & Daxter* series), by revealing changes in urban air pollution (as in *Midnight Club: Los Angeles*), or by modelling inhabitants' daily routines (e.g. retiring to bed at night in *The Elder Scrolls III: Oblivion*). Others unfold their story through the seasons of the year (e.g. *Animal Crossing* and *Harvest Moon*), with some (e.g. the *Harvest Moon* series) modelling vegetation, crop and landscape changes through the seasons, while some games (e.g. *Grand Theft Auto 3* and *The Elder Scrolls III: Morrowmind*) also introduce varied weather during gameplay. Several epic adventure and role-playing games (e.g. *Day Of The Tentacle* and *Eternal Darkness: Sanity's Requiem*) simulate change through far longer periods of time.

Process distortion
Not all games behave strictly in tune with chronological time or Euclidean space. For example, some games set in extensive virtual worlds (e.g. *The Elder Scrolls III: Morrowmind* and *Legend of Zelda: Ocarina of Time*) permit players to traverse long-distances between widely separated locations almost instantly, while others permit time to be frozen (e.g. *Timeshift* and *Blinx: The Time Sweeper*), sped up (e.g. *Frontier: First Encounters* and *Sim City 4*) or slowed down (e.g. *Proving Ground*, *Burnout* and *Max Payne*). (*Braid,* being a game entirely based around time manipulation, allows you to do all of these things and more.) In *Mirror's Edge*, the 'Runner Vision' tool slows down time during gameplay to assist the player in executing complex moves, and is similar in visual style to 'bullet time' adopted in Matrix-inspired games. In a GIS context, maps have long been distortable through map projection or topological restructuring (as in cartograms). As for temporal distortion, modern data visualization software permits analysts to vary the speed and duration of events in spatial animations and in dynamic brushing, while spatial simulation software has always enabled models to be run in other than real time. The key difference between VGs and GISs, in this respect, lies in the purpose of temporal and spatial distortion. In the

former it enhances various elements of gameplay, while in the latter it supports effective analytical interpretation.

Even when VGs provide an accurate simulation of the world, they sometimes permit the player to select the degree of realism they wish to see operating. This is particularly common in car racing games. Thus, for players who enjoy the fidelity of precise simulation, vehicle handling realism might be set at a high level, while those who prefer a more thrill-seeking driving experience might set the vehicle's handling system at a lower and far more forgiving level. Although visual, aural and behavioural realism are the primary goals of this often costly modelling effort, other liberties are also taken to enhance playability at the expense of temporal realism. *Midnight Club: Los Angeles*, for example, permits its high-performance cars to be raced at speeds in excess of 200mph around the streets of Los Angeles. Another interesting deviation from behavioural realism occurs in those squad-based combat games (e.g. *Brothers in Arms: Hell's Highway*), in which the game storyline requires that if key squad members are wounded in battle, they can be revived to rejoin the action. In a similar fashion, the AI which directs non-player characters in numerous games genres may be varied between a level of optimal decision-making efficiency (where the human player has little chance of winning) to a much more flawed level where it makes human-like errors (which gives the player some chance of winning). These and many other examples suggest that while VGs may be increasingly adept at creating accurate models of real-world processes, the fidelity of such modelling will always need to serve the maximisation of player satisfaction, in terms of the balance to be struck between challenge and reward.

Figure 6. Countryside scene showing farmhouse being torn apart by alien creature (Half-Life 2; courtesy of Valve Software).

Dynamic world modification
Unlike GIS editing software, which is typically used to build and modify spatial data models prior to analysis, most VGs facilitate the dynamic modification of their game environments during gameplay, based on player actions and decisions. This requires sophisticated software not only to model multi-way interactions between player, environment and objects, but also to update spatial and attribute data models on the fly. Dynamic landscape modification takes several forms. Buildings and other items of infrastructure are blown up in many games (Figure 6), while in *Fracture*, players can use various kinds of grenade and firearms to modify the land surface itself, in order to gain tactical battle advantage [42]. More constructive changes include the moving of objects (e.g. *Elebits*), altering the look and feel of the existing environment by pulling on the ground surface to change its shape (as in *Civilization* and *Age of Wonders*), by planting or cutting grass (as in *Viva Pinata*), or by extending the environment by adding land and infrastructure (as in *SimCity*). The virtual worlds of many videogames are becoming almost as malleable as the real world.

Terraforming, deformation, destruction and construction are not restricted to landscape elements. In car racing and shooter games, for example, it is common for discrete objects such as opponents, furniture, vehicles and roadside objects (such as lampposts or fire hydrants) to be damaged or destroyed. (The earlier but innovative *Red Faction* game had a geomod, or geographical modification, feature which enabled players to incrementally destroy infrastructure, while the more recent *Crysis* and *Mercenaries 2: World in Flames* have more extreme destruction capabilities.) Some games also permit damage to be undone. In *Burnout Paradise*, for example, drivers of damaged vehicles may visit a virtual repair shop to have them instantly repaired, while in *Grand Theft Auto*, layers of dirt accumulated on vehicles may be removed by passing through a carwash.

Human behaviour and social processes
Human behaviour is also simulated with increasing realism in VGs. In games which involve competition between player and software, most titles incorporate some form of artificial intelligence (AI) to operate non-player characters (e.g. monsters or zombies) and competing drivers' vehicles in a realistic fashion. In many shooter games, for example, combatants may be given varying degrees of intelligence, which may be selected by the player to match their skill level. In car racing games, competing cars are also driven with increasingly sophisticated software. In at least one such game (*Forza Motorsport* 2), the player may select several AI drivers to drive for them.

Squad-based behaviour is increasingly evident in combat games, and is increasingly modelled using sophisticated AI. In *Brothers in Arms: Hell's Highway*, and the World War I title, *To End All Wars*, the squad behaviour mimics multi-level military decision-making behaviour, down to squad and individual levels. Human behavioural modelling is taken further in the tactical shooter *BlackSite*, in which a squad morale system is used to influence the battlefield behaviour of individual members of the player's team. (The player indicates what squad members are expected to do, but the current squad morale level affects how they do it.) Even more remarkable is the growing practice of developing and communicating the emotions of game characters, as in the trait and 'moodlet' system implemented in *The Sims 3.*

Many strategy and role-playing games involve large numbers of humans, with which the player can interact and/or control. At a relatively simple level, some games (e.g. *Assassin's Creed*) provide realistic simulation of crowd behaviour. At a more sophisticated level, are the strategic games, often set in cities (e.g. *Settlers: Rise of an Empire*), which have evolved through several iterations to present high-fidelity urban environments in which citizens are seen acting out their daily lives in transparent detail. AI is particularly important in such games (e.g. *The Sims 3*), which often involve large numbers of inhabitants, because it would be virtually impossible for the player to micro-manage the behaviour of all of the individuals inhabiting the game. Some RPGs mimic society in other ways. *The Elder Scrolls III: Morrowmind*, for example, models a character-class system, in which attributes and behaviours are established for game characters (usually including the player) in a way that resonates with socially stratified societies in the real world. Although some of these class systems are caricatures of the real world, they do represent a form of social simulation that is likely to achieve greater realism as in-game AI is further refined. At a higher social level, some games attempt to model cultural differences, but this is currently done rather poorly. The crude national stereotyping in such games as *Battalion Wars 2*, for example, fares poorly when compared with the heavily researched national cultural classifications of Hamden-Turner and Trompenaars [43], Hofstede [44] and others.

However, some commentators (e.g. [45]) suggest that AI can become too clever for its own good, in that it can make a game too difficult to play against. Dumbing down the AI also has its limitations, however, because of the danger of mismatches appearing between the visual realism of game characters and the relative stupidity of their behaviour. As a result, in games such as *Unreal Tournament 3* and *Burnout*, the designers attempt to create AI that behaves in ways that humans would behave, and makes the same mistakes that humans would make.

There are several lessons here for GIS. One might be in terms of monitoring the behaviour of spatial analysts during and across sessions to provide intelligent context-sensitive help (as in the case of *Left4Dead* described earlier). It is also worth noting that since the AI would be used entirely on behalf of the protagonist (i.e. the analyst) in the case of the GIS, there would be few of the problems associated with over-intelligent antagonists. In GIS, the AI would always be on the player's side; the problem to be solved would play the abiding role of combatant. A second lesson might be drawn from those racing games (e.g. *Forza Motorsport* 2) which provide both a highly realistic simulation mode and a more forgiving 'arcade' driving mode (also described earlier), with the latter permitting the player to accumulate considerable physical damage to their vehicles without incapacitating them. The principle that is useful in a GIS context is that the degree of simulation realism must always be fit for purpose. Thus, for example, while a highly realistic dynamic spatial model might be necessary for environmental planning purposes, a 'dumbed down' version might be more appropriate in an educational context.

B. User interfaces

While the effectiveness of a GIS may largely be measured in terms of the power and flexibility of its toolset, "a computer game, unlike most other computer applications, lives or dies by the effectiveness of its user interface design" [8]. Because several thousand games are published each year, and many introduce innovative interface ideas, the games scene represents a huge experimental laboratory for interface design. This provides a major resource that may be raided by GIS designers in developing more effective methods for spatial exploration, search and interrogation [46; 47] In this section, a number of VG interface ideas will be described, and their GIS potential indicated. (See [48] for a fuller discussion.) The discussion will focus primarily on software rather than on game hardware devices.

Figure 7. Highly stylised landscape of a first-person game with player's avatar temporarily on display (Team Fortress 2; courtesy of Valve Software).

Viewpoint

One of the most important aspects of the videogame user interface is its viewpoint -- i.e. the location of the player in relation to the virtual environment. Three viewpoints are especially evident: the first-person viewpoint, in which the player moves through a virtual environment using the eyes of the largely unseen protagonist (see Figure 1); the third-person viewpoint, in which the player is distanced from the game's protagonist, which is represented by an avatar which they control (see Figure 7); and the god viewpoint, in which the player looks down on, or obliquely across, the field of play, directing events from a location that affords high situational awareness (see Figure 8). (It should be noted that while the player's control of characters in *The Sims* have led to it being called a 'god-game', it does not adopt what is commonly referred to as the god viewpoint.) There are variations on these main viewpoints, such as the 'over-the-shoulder' approach of some third-person shooters, in which the player is partly immersed in the scene by following closely behind the seen protagonist, and the 'through-the-rear-window' viewpoint in some car racing games. The viewpoint serves multiple functions in VGs, not only providing a degree of immersion (as in the first-person viewpoint), or situational awareness (as in the other two viewpoints), but also providing opportunities for user identification with the seen protagonist (as in the third-person viewpoint).

Most games adopt a single viewpoint throughout. However, in recent years, some popular games (e.g. *Metroid*) have switched from one viewpoint to another in successive releases, and in other games, it is possible to switch between viewpoints during gameplay. In the first-person *Brothers in Arms* and *Ghost Recon*, the player can momentarily switch to a third-person camera to provide a tactical overview when the combatant has taken cover. The RPG game *The Elder Scrolls III: Morrowmind*, for example, offers both first- and third-person viewpoints, with the latter being useful when the player's avatar wishes to display its winnings. In some games, the viewpoint is switched automatically, either to reveal important events (as in *Civilization: Revolution*), to taunt opponents with amusing character animations or for replay purposes (as in *Team Fortress 2*, Figure 8), or to reveal the player's avatar when it is injured (as in *Left4Dead*). The temporary switch between viewpoints to make use of their particular advantages highlights the benefits of making both available in the same game.

Figure 8. Urban infrastructure and irregular terrain as modelled in a grid-based strategy game (Sim City IV; courtesy of EA Games).

In contrast, most GIS traditionally adopt the map-based, god viewpoint. Recent innovations in Web mapping, however, are introducing alternative viewpoints more akin to the first-person and third-person viewpoints found in videogames. (The elevated camera position in the terrain-following viewpoint in Google Earth, however, still maintains most of the elements of the god viewpoint.) As GIS introduce more 3D scenes into the analyst's working life, the need for additional and alternative viewpoints and interaction methods is likely to increase markedly ([49]). One of the striking things about most GIS is that little attempt is made to use viewpoints to develop a sense of immersion, or to encourage user identification with a protagonist (the analyst does not normally appears as an avatar in GIS scenes). By and large, the analyst stays outside the scene, keeping his or her distance, and essentially playing god.

Viewpoint choice has major implications for GIS design. Detailed studies have been undertaken in a military context (e.g. [50; 51; 52; 53]) which reveal that the egocentric and exocentric viewpoints are suited to different tasks and benefit users with different levels of experience. Since some of the tasks undertaken in these military studies (e.g. judgements of relative position, mobility assessment and line-of-sight visibility) are similar to those undertaken in GIS, it may be important for GIS software to enable users to switch as needed between the two types of viewpoint. A required first step might be to consider inserting an avatar into the scene, and using a third-person viewpoint rather than the conventional god-like viewpoint.

Camera position and movement

Camera control is an important means by which players are able visually to explore the game environment, and is critical for rapid decision making. In some games (e.g. the first-person shooter, and some car racing games), the camera equates to the player's eyes, and is locked to the player's movement through the game environment, which the player controls with mouse, keyboard or games controller. However, in games where both the camera and the protagonist's avatar have to be controlled simultaneously (e.g. those with a third-person viewpoint), this poses a heavy interaction load on players. To help resolve this problem, many such games take over camera control, leaving players to control the movement of the avatar. There is therefore a balance to be struck between player and software camera control, with some games (e.g. *Resident Evil 4*) offering higher levels of player control, and others (e.g. *Super Mario Galaxy* or *God of War*) offering lower levels of player control.

In some games (e.g. *Ratchet & Clank*), the player may opt either to control the camera or to cede control to the program's AI. A further distinction is made between, on the one hand, character-relative motion, in which the avatar moves relative to their current state in the game world (the classic example is the early *Resident Evil* series of games), and on the other hand camera-relative motion, in which the avatar moves relative to the viewpoint's current state in the game world (the recent *Resident Evil 4* finally switched to this approach). At root, this is a choice of how the user controls map to in-game state change, with the primary purpose of automatic camera control being to reduce the player's control burden, especially in fast-moving and stressful situations. However, in some games camera movement is also used for dramatic effect. In *Gears of War*, for example, the camera shakes as the player runs, which adds to the sense of immersion.

Fitness for purpose

A common feature of VGs is that specific interaction methods are designed to fit particular player actions and operations. For example, methods to control various locomotory actions by players are provided in a wide variety of games, and especially those adopting a third-person viewpoint. However, because of the god-like perspective adopted by the majority of GIS, their potential role in assisting spatial exploration and analysis has been largely unexploited. (For example, the grip and climb systems available in several action games, including *Ico* and *Assassin's Creed*, could be adapted for the exploration of mountainous terrains in GIS.

Interface diversity is a significant feature of videogames, with the same action often controlled in different ways in different games. This can be illustrated by the process of targeting characters and objects, which supports a variety of purposes, including shooting, path planning, information extraction, selection, and general 'trigger' interactions. In *Metroid Prime 3: Corruption*, for example, a complex trigger facility allows players to lock onto an enemy, and then either fix their perspective on the target or look straight ahead. Players can also move the crosshair around the target extremely rapidly after they have locked onto it, which makes it extremely easy to handle multiple small targets within a clearly defined area. Finally, individual games may provide several options for weapon-targeting, as illustrated by *Grand Theft Auto IV* whose alternatives include: free aim; snap from target to target; target and modify; and lock-to-objects (i.e. the camera's anchor point locks to the object), all of which operate on both static and dynamic objects. Many of these innovative interface methods have potential applications in GIS.

Free and constrained exploration

Most early videogames constrained the player to movement in 2D space. The advent of full 3D in the 1980s (e.g. *Elite*) and 1990s (e.g. *Quake*) provided players with increasing freedom to explore and navigate in three dimensions. In parallel with this increased freedom emerged numerous ways of mapping player manipulations of their interface devices (mouse, keyboard, handheld controller, etc.) to a growing repertoire of exploratory movements in space (walking, running, climbing, jumping, flying, etc.). In time, extensive experimentation across thousands of game titles led to the emergence of a handful of classical interface mechanisms whereby spatial exploration and action could be undertaken. Among these were the first-person running and jumping (*Quake*), the third-person running and jumping (*Jak & Daxter*), the third-person per-scene viewpoints (*Alone In The Dark*), and the god's eye view (*Sim City*).

Although there has been a progressive move in VGs towards increasing freedom of spatial exploration, this freedom has often been deliberately constrained by games designers, chiefly because of the challenge to players of controlling free movement in three spatial dimensions. One form of constraint is found in those games (e.g. *Jak & Daxter, Ratchet & Clank* and *World of Warcraft*) which, although they present a highly realistic 3D virtual environment on screen, constrain the movement of the player's avatar mainly to the degrees of freedom of the ground surface. Another technique adopted in shooter games is to adopt an 'on rails' style during intense fighting episodes (as in *Resident Evil: The Umbrella Chronicles*), in which the camera follows a fixed path through a battle zone, and the player merely controls the direction it faces in order to shoot at large numbers of objects and assailants en route. In a similar manner, the circuit racer game largely prescribes where the player is able to drive during gameplay. Although they may have extensive rooms, the castle (as in *Wolfenstein 3D*) and the underground laboratory (as in *Half-Life*) offer similarly constrained spaces. The 'constrained navigation' approaches for moving across complex 3D terrains using 2DOF of movement [54] is of particular relevance in this context.

The recent emergence of non-linear, free-roaming games (championed by *GTA III*, and taken up by such titles as *Far Cry 2*, *Burnout Paradise* and *Tony Hawk's American Wasteland*) is beginning to challenge the hegemony of titles which keep the player within confined spaces or moving along constrained courses. This spatial opening up of games has led to players needing on-screen orientation and navigation aids. Although games have tended to avoid displaying on-screen aids, in order to sustain a sense of immersion, the emergence of 'open world' VGs set in extensive environments has led to the re-appearance of devices such as the inset map or minimap (e.g. *GTA San Andreas*, which has both an inset minimap and a fullscreen map view). *Metroid Prime* goes further than most games with its simplified, rotatable and zoomable 3D wireframe map. GIS have much to learn from videogames in this respect, especially as and when they adopt third-person user modes involving an analyst avatar.

Simplification

A notable feature of VG interfaces is the way in which often complex on-screen behaviour is achieved by relatively simple interface actions on the part of the player. This process of interface simplification is enabled by the games software, which undertakes the necessary behavioural elaboration. In *Super Mario Galaxy*, for example, the protagonist's avatar is not directly controlled by the player (nor, indeed, is the camera, as discussed earlier). Moreover, not only are Mario's jump trajectories -- especially between planetoids -- software generated, but the use of modified gravity makes walking across planet surfaces or up walls without falling off as simple as walking across the ground. Indeed, this would be an entirely different game if players were required to take fine-grained behavioural control of their on-screen avatar, with no distortion of real-world physical laws to help them.

Many games (e.g. those involving driving, unarmed combat, skateboarding and parkour) require the player to control complex on-screen behaviour, either of vehicles or their personal avatars. In most such games, these behaviours (e.g. the trick repertoire in successive editions of the *Tony Hawk's* skateboarding game, or the skyline leaping and running behaviour of the hero in *Assassin's Creed*) are achieved by far less complex control manipulations, and in some cases only a single button press is required [55]. Much of this complex on-screen behaviour is pre-animated, and in some cases (e.g. when the player wiggles their joystick around to control their avatar), several animations are cross-blended and phased in and out to produce plausible walking animation. In *Splinter Cell: Conviction*, not only are the player's relatively simple control actions (e.g. pressing a button) translated into more complex on-screen behaviour (e.g. throwing an opponent across a room), but the software also intelligently analyses the current context, and elaborates the behavioural response to the player's control action in a way that is most appropriate for a given situation. A context-dependent approach is taken in several games, so that the action triggered by using a particular control depends on the current state of play. In *Mirror's Edge*, for example, instead of providing a 'grab' button, the software uses edge-detection routines to determine whether the player's avatar is close enough to a building ledge to invoke a gripping action. Similar techniques are used in *Fable II*, which generates moves for its melee fights that reflect their immediate context. It is in ways like these that the design of virtual environments in VGs is able to guide and encourage player behaviour, in ways that are largely absent from GIS.

Although the advantages of interface simplification and behavioural elaboration are relatively obvious, there are also dangers to be avoided. One is the player frustration caused when the software takes autonomous decisions about the game context, especially when there are several potential actions available at a given game point, and the software chooses one that does not match the player's intention. Also, many commentators and players part company with games designers when elaborate cut scenes or heavy AI are used to animate spectacular action sequences (as found in the introductory sequences of many VGs, and in the destruction sequences in *Half-Life: Episode 2*). Because player interaction with the game is normally suspended while cut scenes are playing, the player's role is reduced to little more than that of a spectator.

C. Multi-sensory representation

In an earlier section, data visualization was shown to be an important ingredient of effective gameplay. However, not only is it an informal craft in most VGs, but the rule-based creation of visual symbols from data is intermixed with the design of graphical symbolism which serves other, less representational roles. Although the advantages of presenting spatial information to more than the visual human sense are well established [19; 20], most GIS still privilege the sense of sight. In plotting the future development of data representation, GIS designers could therefore do far worse than examine the track record of VGs, many of which have mastered the art of multi-sensory information presentation [56]. We will begin by examining how sound and haptics are used to convey information to players, and then consider the effective combination of multi-sensory information.

Sound

Sound, and especially music, is used mainly for emotional effect in videogames, as is exemplified by the mood established by the soundscapes of such games as *Defcon* and *Ico*. However, there are cases where music is also used to represent information. For example, it can indicate different states of play, including the presence of danger and a lack of remaining time, and can also provide notification of certain events. In *Left4Dead*, for example, one music track begins just before a 'horde' (of zombies) attacks, another starts up as a 'tank' (a super-powerful zombie) approaches (and continues playing until it is dead), and yet another gradually increases in volume and sound layers as the player approaches the hiding place of a 'witch' (another extremely dangerous zombie). In one scene of *Super Mario Galaxy*, the tempo of the music increases and decreases in step with the player's movement of a star ball. Such redundant representation, in which sounds reinforce visuals, is found in many games. In *Ratchet & Clank*, for example, sound encodings are used to convey the nature of the contrasting surfaces on which the protagonists are walking. In *Crysis*, however, the game deviates from the rather strict rules of data visualization, in that weapons which sound similar in the real world are given distinctive sounds in the game because of the importance of players distinguishing aurally between them. A similar form of aural exaggeration, this time for emotional effect, is used in the *Thief* games, in which the volume of the protagonist's footsteps on certain surfaces is enhanced to alert them to the fact that they might be heard by others.

It is very common for classes of entities to be identified by means of audio 'tags' in VGs. In *Half-Life 2*, for example, each type of enemy has a distinctive aural signature, and will emit easily recognised sounds when distinctive events occur. (These sounds are of crucial importance when those events are off screen or obfuscated by other on-screen events.) Similarly, audio tags are used to provide aural confirmation and identification as the player collects types of item (e.g. medical supplies or ammunition), or defeats types of enemy. Sound can also be used to reflect measured data, through variations in pitch or frequency (though not amplitude, which is generally used to encode distance-from-viewpoint). For example, puzzles in the *Zelda* series of games give timing information to the player in this way.

A further role for sound in VGs is in providing locational information. Variously named spatial audio, localised sound, spatialised sound, positional audio or 3D sound, the ability to alert players aurally to the location of characters and events in 3D space is an important element of the soundscape of most modern VGs. 3D spatialisation of audio implicitly provides scalar feedback by changing audio volume on the basis of a sound source's distance from the player or viewpoint. Most game designers have extensive soundscape-building tools, which means they are able to add sound to a virtual environment by identifying the location of sound emitters interactively and drawing boxes around spaces affected by individual sounds.

Haptics

Due to the widespread availability of interface devices (including joysticks and game controllers) that emit vibrations or output force feedback, many games are able to harness the haptic senses (the vibrotactile, which is mainly located in the skin, and the kinaesthetic, which is mainly located in the joints) to transmit information to the player. (The kinaesthetic sense has the unique property of both receiving and issuing force or stress, and is thus uniquely able to engage in active exploration of environments.) Many games (e.g. *Ratchet & Clank: Tools of Destruction*, *Motorstorm*, and *Heavenly Sword*) adopt rumble -- i.e. vibrotactile feedback -- to identify events occurring in the virtual environment, with the 'profile' of a rumble (that is, how its strength varies over time) commonly used to differentiate between different kinds of event. Controller rumble is also used to generate a sensation which indicates that the player's avatar is in contact with certain surfaces in the virtual environment. Scalar feedback can also be provided by the controller, as when the amplitude of a sound or the frequency of an aural pulse is used to convey proximity to otherwise secret (e.g. underground) items.

Force-feedback devices are not normally used to provide categorical information to players, but are commonly used to emit the values of continuously varying parameters. In some flight simulator games, for example, force-feedback joysticks are used to mirror the forces felt through the control column in real aircraft, and force-feedback steering wheels available for some driving games convey the resistance of the car's wheels to turning based on physical simulation of the vehicle in contact with the road.

Combining sensory outputs

Multi-sensory output has two broad roles: sensory substitution, in which one sensory modality is replaced by another, and sensory combination, in which one sensory output is used to reinforce another through redundant data coding, or to encode multiple data variables [56]. A great deal of sensory fusion plays a redundant encoding role. In *Zelda: Twilight Princess*, for example, the Wii controller combines both sound and tactile feedback (by emitting a 'twang' sound and rumbling) when the player fires a bow and arrow. Similarly, in *Super Mario Galaxy*, the Wii controller rumbles when the player's avatar lands from a great height. Audio cues can help players focus on a critical visual element, for example, by teaching the player to associate a distinctive audio cue with a given enemy action (and its related animation, such as raising an arm high prior to striking the player). In several games, spatial distance and audio volume are often used together to help separate the camera from the player avatar, or conversely to make them feel more tightly bound to them. An interesting (but rather rare) effect found in some third-person games (in which the player controls an avatar), is where the visual and audio information is decoupled, in that audio effects are spatialised as if heard from the avatar's location (i.e. as if a virtual microphone was positioned there) rather than from the camera position.

The multi-sensory output of multivariate information is perhaps less frequently used than redundant encoding of individual variables. However, in some car racing games (e.g. *Forza Motorspot 2*), the driving experience is fully multi-sensory in a multivariate sense, with a combination of visual, aural and tactile (e.g. rumble) feedback being continually provided. The non-visual information is highly nuanced, conveying a variety of engine, exhaust and tyre noises with both a high degree of realism and emotional impact.Some other games also use multi-sensory output to reflect multivariate information. For example, *Pikmin* has a hundred or so little creatures running around following the player's avatar, and colour is used to represent the type of pikmin and sound (in addition to animation) is used to represent their current state (i.e. whether they are working, running, endangered, hurt, etc). It should be borne in mind that the integration of multiple sensory outputs in VGs combines with tightly integrated storylines and compelling game mechanics to transcend mere information presentation, enabling the player to participate in an immersive experience. While this might give VGs the capacity to support marketing activities, it might not mesh in an obvious way with the typical requirements of the spatial analyst.

IV. CONCLUSIONS

In this chapter, we have examined two kinds of spatially intelligent software: the videogame and the GIS, and have compared several of their key characteristics and capabilities. One of the major conclusions drawn from our analysis is that some of the differences between videogames and GISs are more apparent than real, and that the former have a surprising number of similarities with the latter. A second conclusion is that VGs constitute a public laboratory in which numerous innovative ideas have been road-tested with large numbers of highly demanding users. The results of these experiments are freely accessible to GIS designers, and can serve to short-circuit the improvement of existing features as well as the introduction of additional functionality.

Videogame contributions

We have evaluated VGs against key GIS capabilities to reveal their strengths and weaknesses, and have identified several areas in which VGs could make potentially significant contributions to tasks normally undertaken with GIS. Of course, this is not to suggest that particular videogames could be used off the shelf as fully-fledged GIS, but it is to suggest that some widely exhibited functionalities in VG technology could contribute in significant ways to the future development of GIS.

It has been argued that in three specific areas (dynamic process modelling, interfaces and multi-sensory representation), VGs exhibit more developed capabilities than GIS, and have much to offer the spatial analyst. Firstly, VGs may be characterised as dynamic, process-based simulation systems, in which the interactions between players and modelled processes provide much of the software's functionality and appeal. In contrast, GIS are essentially spatial data handling environments, which for the most part display spatio-temporal data rather than model spatio-temporal processes. In this context, VGs arguably have more in common with dynamic, process-based geospatial simulations than with GIS. Nevertheless, given numerous past attempts to enable dynamic modelling in a GIS framework, VG achievements in this field are well worth examining.

Secondly, it has been shown how VG interfaces and interaction styles are highly diverse, and may be selected according to the needs of individual players and the tasks they are required to perform. The way in which VG interfaces are designed for exploring 3D virtual environments offers GIS designers many ideas for providing analysts with additional interactive approaches for exploring their own geographical worlds. Finally, we have shown that while GIS are generally more advanced in rule-based data visualization, the leadership roles are reversed when the representation of data to other sensory modalities is concerned. We have demonstrated ways in which VGs might help to rectify a longstanding gap in GIS functionality.

Both VGs and GIS may be broadly interpreted as being concerned with solving problems in a spatial context. While it is readily apparent that GIS tools for spatial modelling, display and analysis provide support for environmental and social problem solving and decision making, this role may not be so evident with VGs. Nevertheless, games present players with considerable perceptual, motor and cognitive challenges in spatial environments, and innumerable tools with which to solve spatial problems, at several levels of challenge and complexity. VG approaches and tools may therefore be relevant for undertaking tasks equivalent to those found in a GIS context. For example, given the highly developed capability of VGs in assisting players to navigate, explore and interrogate virtual environments, many of the innovative techniques developed for 3D navigation and interaction might also be useful in digital GIS worlds. In this context, it is instructive to note Google's current positioning of its own GIS-related functionality in term of: 'Explore, Search and Discover'. However, VGs offer considerably more than quasi-3D map browsers in application areas such as virtual tourism and virtual heritage exposition [57] which require the use of highly realistic 4D technology. The fact that an increasing number of today's youth generation is already well versed in using VG technology should give GIS developers considerable food for thought.

Charting the future
A not insignificant question raised by this chapter concerns the means by which VGs might contribute to GIS in the future. Several possible scenarios may be outlined whereby spatial analysts might be able to acquire more game-like tools. The first would involve analysts modifying selected VGs to undertake GIS-related activities. There are already indications of this happening in several other application areas,

including: scientific visualization [58], marketing [59], education [60], scientific research [61], military training [62; 63], and environmental planning [64]. A second route might see developers using VG design toolkits (e.g. VG middleware) for rapidly prototyping and deploying games technology for GIS applications. This approach is perhaps most attractive for 3D data visualization applications [65]. A third scenario sees games developers broadening their target markets to include spatial exploration applications. There are several indications (e.g. in serious games, passive games and some casual games) that the industry might have an appetite for this. A fourth scenario might be based on interoperable collaboration between GIS and VGs, creating powerful software federations that capitalise on the individual strengths of each technology [5]. A final scenario would be for the developers of GIS and other spatial software to adopt ideas read-tested in VGs in their own software, to deliver added value to users. An example of this approach may be seen in the adoption of MMOG game mechanics in business software designed for trans-national organisations [66].

It remains an open question as to whether 'entertaining GIS' will become as popular or as relevant as 'serious games'. Equally uncertain is whether there will be increasing convergence of videogame and GIS technologies in the future. It remains to be seen, for example, whether continuing innovations in videogame technology will contribute to major improvements in GIS, whether videogames will chip away at the GIS consumer base with products that are increasingly able to model worlds for insight as well as for entertainment, or whether a visionary product might appear that encapsulates the best that both technologies currently have to offer. Amongst this exciting uncertainty, one conclusion emerges with clear-cut outlines: those of us who use technology to understand and manage the world we inhabit are facing a future of ever-increasing possibilities, with technological options becoming increasingly available from complementary sources. Without succumbing entirely to the hubris of a former political leader, it may truly be said that never in the history of spatial science have we had it so good.

NOTES

The names of the videogames included as acronyms in Figure 2 are:
AC (*Assassin's Creed*), BiAHH (*Brothers in Arms: Hell's Highway*), BP (*Burnout Paradise*), BR (*Braid*), CIV (*Civilization*), CoD4 (*Call Of Duty 4*), CoDWaW (*Call of Duty: World at War*), CR (*Crysis*), DC (*Defcon*), EC (*Echochrome*), FR (*Fracture*), F2 (*Fable II*), FF (*Final Fantasy*), FM2 (*Forza Motorsport 2*), GA (*Getaway*), GoW (*God Of War*), GTAVC (*Grand Theft Auto: Vice City*), HGL (*Hellgate: London*), J&D (*Jak & Daxter*), KD (*Katamari Damacy*), LBP (*Little Big Planet*), MFS (*Microsoft Flight Simulator*), PM (*Pacman*), RCGC (*Ratchet & Clank: Going Commando*), SC4 (*Sim City 4*), SMG (*Super Mario Galaxy*), SP (*Spore*), STH (*Sonic The Hedgehog*), TS (*The Settlers*), and WoW (*World of Warcraft*).

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