GRAMMATICAL DESIGN AND CROWD BEHAVIOUR: A Study of Factors that Influence Human Movement in Urban Spaces

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Abstract. Crowd behaviour in traffic and emergency situations has been recorded and documented since the early 1990s, often using digital representations of balls as an indicator of mass and movement. This paper reports the investigation of the factors that influence human movement in urban spaces and visualises the impact on human movements of changes to an urban design space. Using an agent-oriented approach is the common method for investigating the simulation of crowd behaviour. The relation of grammatical design to crowd behaviour is proposed as an important research area. This area developed since the technology for the advanced design visualisation of avatars or animated characters became available. The authors of the software used in *Lord of the Rings* and other well-known crowd movies have contributed to knowledge of the key issues in crowd behaviour in particular contexts and general situations. This paper relates experiments in teaching grammatical approaches to architectural design with digital media as a tool with three different implementations: a café, restaurant and gallery. Using a variety of design visualisation techniques gives different understandings of the use of a design space. By representing human movement in a design space in more complex visualisations we see more alternatives for better design more readily. Using notions of grammar, contingency and play to explore simple changes in design, the resulting crowd animations present an insightful early research stage experiment with the theories and models of crowd behaviour.

1. Grammar and grammatical design

Grammar governs the way in which visual elements are modified and combined in art and design compositions. Grammatical design governs the ordered way in which forms are modified and combined in visual languages to convey complex concepts beyond the simplicities of individual “one-off” designs. In this paper we focus on the outcomes and effects of placing grammatical design and crowd behaviour in the forefront of form making with digital media in architecture and art, and how experience in these two domains can inform each other.

The term ‘grammar’ is used as a *metaphor* linking the rules, elements, transformations and compositions that might be perceived in form making in design and art. The idea of grammar in art and design draws on analogies between “visual languages” and “natural languages” and is well known as a kind of systematic design approach that has specific studio practice applications (Bruton, 2003). We suggest that using crowd behaviour as a design tool offers new insights into this area of research by reconceiving forms in relation to the movements of users of the design space. We compare computational rule-based crowd behaviour in relation to fundamental factors of design of a cafe, restaurant and gallery within the constraints imposed by commercial software. This is illustrated by several examples of architectural design work by Arus Kunkhet using Character Studio’s CROWD system and 3DS Max. Character Studio CROWD provides an architecture that couples behavioural goal direction with an intuitive avoidance system that encompasses steering-to-avoid strategies with force-based repel avoidance. Behaviours are provided, such as seeking, path following, and wandering, but users may easily customize and develop new behaviours via maxscript.

The notion of grammatical design incorporates computational systems such as CROWD and builds on the work of shape grammarians. “The benefits of a grammatical analysis of art and design have been argued and sustained, particularly by Knight and Stiny, over the last 25 years (Gips and Stiny, 1975, Knight, 1994). Grammatical approaches to design education have also been advocated (Wojtowicz; Oxman). These advantages are compounded when inherently rule-based digital media are used in creating art and design work (Bruton, 1997).

…shape grammars have been applied primarily to architectural design; however, they have been successfully used to characterise Heppelwhite chairs, Greek vases and Diebenkorn’s paintings (Lauzzana and Pocock-Williams, 1988).

This paper extends this early work by suggesting a foundation for explorations of “simulated crowd behaviour as a design agent” to open both empirical and imaginative doors for the artist/designer.

2. Approaches to crowd simulation

Crowd modelling and simulation for architectural visualization have been well researched in relation to the technological challenges facing the depiction of large numbers of avatars. The problems of generating and rendering a realistic depiction of crowds in an environment depend on efficient algorithms and computing power. However, the practical design relation of architectural design decision making to the demands of crowd behaviour has not been a subject of extensive research.

Bandini summarises many recent approaches to these problems and suggests valuable approaches for 3D real-time applications (Bandini et al., 2004). The art work of Cavazza et al (Cavazza et al., 2004) suggests that a “causal engine” may

offer new ways of conceptualizing space. Blue and Adler's early work (Blue and Adler, 2000) on traffic flow simulation suggests possible directions for further research in relation to architectural design. Other key contributors to the field of crowd visualization are Branislav Ulicny and Daniel Thalmann (Ulicny et al.; Ulicny and Thalmann):

The challenge is how to create complex scenes resembling a variety-rich look of the real world… Our goal is to create a system that would allow authoring of freely navigable real-time 3D scenes, composed of a large number of varied animated individuals in a virtual environment. The authoring should by simple and intuitive, usable by non-programmers (Ulicny et al.).

This work has been augmented by the research of the Eindhoven University of Technology (Dijkstra et al., 2002; Tabak and de Vries) into multi-agent cellular automata models of pedestrian movement. For these approaches the problem of simulating crowd numbers over the 700–1000 delegates is that computer performance is curtailed. To represent 15000 or more delegates, systems such as *Sheep* (Trojansky et al.) that use databases to store and deliver distinctive delegate characteristics have been explored using colour systems to define elements of crowd behaviour simulation (Hanisch et al., 2003).

Crowd simulation research for the movie industry by Stephen Regelous has enabled software development for major achievements in realistic depiction of crowds such as in *Lord of the Rings*. Companies such as Massive now offer visualization tools for real-time computer game and movie making problems.

Digital creation and management of huge crowds has traditionally been done through flocking—a particle physics algorithm which instructs a group of agents (blips, birds, people, planes...) with the drive to stay close, not collide with others and to collectively move in the same direction. As we saw in Matrix Reloaded (Joe & Andy Wachowski, 2003), the hundreds of Neos and Agent Smiths behaved more like splinters, lacking authentic human movement. A different crowd manufacturing method mixes motion-capture with a cut/ paste function. This method was employed to fill the colosseum in Gladiator (Ridley Scott, 2000) by filming two hundred actors and then duplicating the image. When it came to making The Lord of the Rings, neither flocking nor cut/pasting methods convinced Peter Jackson (Merrill, 2004).

Grammatical design is prevalent in the creation of the massive software which owes its origins to the early work of Karl Sims which is based on systems of rules (Sims). By using a computer for the calculation of formal evolutionary combinations of cellular automata configurations, Sims was able to pioneer new ways of conceiving crowd behaviour with genetic algorithms.

Unlike the main filmic concerns of Peter Jackson and Stephen Regelous, the issue we wish to address is the use of real-time crowd behaviour interactions that highlight formal aspects of an architectural design space to enable better design decisions. Design decisions often need to be refined to solve functional and aesthetic issues so that the result is in keeping with a grammatical view. The use of a reflective

practice (Schön) to enable grammatical design decisions is assumed in this approach. Resources for this research were constrained to the use of off-the-shelf software 3DS Max.

Figure 1. Arus Kunkhet (2004), *Heartbreak Cafe* (still from movie).

3. Towards simulation as a real-time 3D design tool

Early gaming experiments in real-time interactive systems suggested new directions for architectural visualization. These works opened the way for designers to consider building 3D worlds in real-time that responded to the demands of the inhabitants. *SimCity* is a classic popular example where its inhabitants primarily respond to the environmental interaction: "Every city needs a power plant" (SimCity, 2005). Myriad is a traditional crowd dynamics analysis program developed by Keith Still (Still, 2005). *Menagerie* (Giroud and Amkraut, 1993), one of the first sophisticated 3D rule-based behavioral systems of Michael Giraud and Susan Amkraut inspired further research into intuitive avoidance and adaptive behaviour systems. Amkraut describes their early system:

That is, a system in which you have a set of conditionals, of rules that say if such and such circumstance happens, then the system will behave this way. In the case of the animals, if you are within a given distance of them for a given period of time, they would shift gaits and run away from you. Or with a different set of rules, they might approach you as if attacking. We could develop different scenarios by making different sets of rules to drive the animation. It's well known that if you have enough rules in a system, you can quickly arrive at a point where you can't predict what's going to happen. Menagerie was actually something of a chaotic system in that you could not predict the location or the gait of the animals twenty seconds from the time you did something. So it was always a different experience. As a simulation it was very much alive. (Kaiser, 2005)

4. Factors of Motion Control

Vocabulary, rules, operations and derivations are used as part of the metaphor of a grammatical design to enframe a view of a design language. Despite the fact that "off the shelf" software often restricts the designer's capabilities it offers a fundamental experience of crowd behaviour in relation to design issues. Many rule-based design systems use similar factors with elements that compose a grammatical vocabulary of motion control for their multi-agent systems. When using 3DS Max, these vocabulary elements of motion control are represented by the following design instruments:

Biped is a 3DSMax system provided with the Character Studio product. It provides the *armature* (framework) used to pose a character, and facilities to animate it using either *footsteps* (systematically assigned) or *freeform* (variable footstep arrangement and placement) animation.

The *crowd-animation system* in Character Studio is designed to simulate the behaviour of real-life crowds. A crowd simulation emulates real-life situations by animating *delegates* (helper objects that act as representatives). Delegates are assigned overall guidelines on how to behave, and the crowd simulation calculates their motion.

Physique is a modifier that, when applied to a mesh, allows the movements of an underlying skeleton to seamlessly move the mesh-like bones and muscle under a human skin. Physique will work on any point-based object, including geometric primitives, editable meshes, patch-based objects, NURBS, and FFD space warps. It will attach to any skeleton structure, including a biped, bones, splines, or any hierarchy.

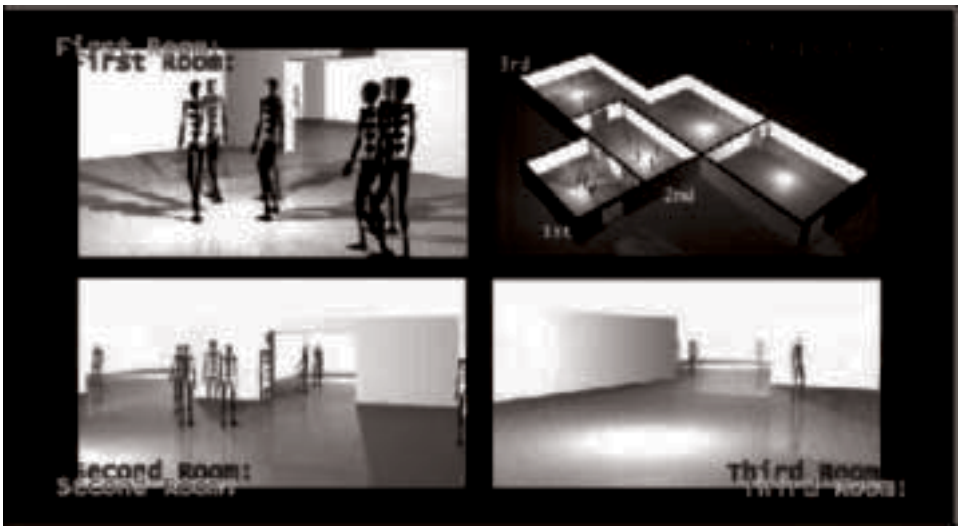

Figure 2. Arus Kunkhet (2004), Gallery crowd.

A *motion clip* is a sequence of motions assigned to a biped or other objects. A motion clip can be a *BIP* file, or a portion of a 3DSMax animation used in a crowd sequence. A BIP motion clip can be created by saving animation you have made using a biped, or by importing motion-capture data. BIP files used in *Motion Flow* and the *Motion Mixer* are called *motion clips*. You can use these tools to combine several motion clips and make a longer or different animation.

When creating a crowd animation that uses motion synthesis with non-biped objects, a motion clip is a portion of a 3DSMax animation used by the synthesis. A movement can be controlled by specifying that a range of frames in an animation are to be used when the delegate meets certain criteria, such as turning upward to exceed a certain pitch. One animation sequence can contain all the motion clips necessary to animate a crowd. For example, a bird animation might have three motion clips: flap, glide, and land. One could specify that when the delegate is pitched upward, the specific range of frames that animate the flap motion are used in the simulation.

5. Crowd behaviour simulation as a design instrument

Designing with a "top–down process" may be approached by using primarily the demands of the site in conjunction with the vision of the designer.

The presence of a crowd helps also to give a much better idea of the size and the dimensions of buildings and roads, and also to give a "semantic" to the cities, where densely populated spots normally highlight important features of blocks or single buildings of the urban environment. Such simulations are important for applications such as architectural walkthrough, urban simulation, games and the movie industry, as well as for internet applications. (Loscos et al., 2001)

Alternatively the design may be approached from the "bottom–up" by searching for the qualities that the user may require first. By testing the designs that require

Figure 3. Arus Kunkhet (2004), Form evaluation: design using crowd movement.

crowds as users of the final product new insights may occur. Using this approach we explored changes in design that would most quickly lead the crowd to safety in emergency. This approach specifies identical parameters for the crowd delegates and then the actual design variable becomes the form of the building or container they are to exit from.

A fundamental experiment was designed to explore the idea that crowd movement might guide the formal design of a building. Four galleries, each with a different plan profile were constructed to test this idea (Figure 5). All galleries were filled with the same delegates and they were set free to roam and exit the building. The rectangular building allowed the first delegates to escape but it was not the building that succeeded in the final outcome, i.e. the removal of all delegates. The delegates are controlled by the parametric qualities assigned to the agents (Figure 6.). For example, the attraction strength to the various vector forces within the design environment controls the direction of the delegate's movement. These factors may be further programmed using maxscript to add further detail to the real-time scenario. Designing architectural spaces with crowd behaviour as a guiding factor highlights how design may also learn from precedents.

In principle, this approach contrasts with the recent impressive array of crowd movement movies, and advertisements such as those of The Mill who won an Oscar for Best Visual Effects for *Gladiator*, partly for creating "an additional 33,000 extras in CGI" (Burke, 2001). The 2004 award-winning animation software *Massive* can be seen in *I, Robot* from 20th Century Fox, the animated feature *Happy Feet* released by Warner Bros., and Universal Studio's *King Kong*. For architectural visualisation, animated low polygon 3D models may be a satisfactory solution for many projects: <http://www.lowpolygon3d.com/>. These models are limited in the realism they can provide but may be used as avatars in real-time 3D simulation projects.

6. Discussion

Moving beyond visual effects to the needs of architectural design for crowds in real situations may require a reappraisal of architectural design processes to incorporate crowd movements as a prime design factor in an architectural language. Fundamental design decisions may be enhanced by the capability of computerized real-time 3D simulations game based or otherwise (Reynolds, 1999). Using grammatical design as a basis for the understanding of parametric qualities of a simulation may benefit this proposed design protocol. Precedents for the formalisation of this approach may be seen in the 3D real-time research of traffic flow, pedestrian movement and emergency response simulations for education, police and military operations. Procedural generation has a long tradition in the field of computer graphics (Greuter et al., 2003) but this approach is problematic for designing from virtual crowd behaviour.

Functional design and its relation to multi-agent systems may utilize this comparative rule-based behaviour system approach to designing architectural forms. Rule-based systems are relatively simple ways to encapsulate a situation in which all aspects of the problem are known (Freeman–Hargis, 2005).

As the technology becomes faster and more powerful, the use of real-time 3D software such as *MultiGen*, *GeoSim*, and *Right Hemisphere* (*Virtools*) enables a new generation of designers to simulate environments. *Massive* is based on artificial life technology, a sense of hearing and touch that allows agents to respond naturally to their environment. Instead of using the standard database search approach, *Massive* animators use fuzzy logic to design their characters. Instead of a value being black or white, it can be a shade of grey or "fuzzy"—giving the character more natural responses than the on/off robotic results of binary logic. In 2004, Massive announced that:

streamlining the generation of arena spectators, crowds moving en masse and large-scale digital armies with breakthrough Ready-to-Run Agents™. These prebuilt agents can be easily dropped into shots to create 3D character-based crowd scenarios allowing animators to significantly speed up their workflow.(Holland, 2004)

We deny attempts that make the dangerous assumption that social behaviour is a straightforward extrapolation of individual behaviour and expect contingency to be part of any design simulation. Redefining fundamentals by fore-fronting crowd behaviour design instruments suggests a mental set that puts a sound design framework before visual polish for the enhancement of architectural design solutions.

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