DESIGNING GENERATIVE SOUND FOR RESPONSIVE 3D DIGITAL ENVIRONMENT INTERACTION

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Abstract. This paper examines three key areas of responsive sound interaction in 3D Digital Environments: designing generative sound that derives its composition and relevance from social and physical human interaction within a digital environment; the relation of sonic structure to the digital visual and spatial experience; and responsive, reactive real time sound generation activated by environmental conditions and human behaviours. The primary purposes for responsive sound design are: (1) to provide navigational cues supporting way-finding and spatial orientation; and (2) to provide real-time generative environmental sound that reflects social behaviour in a way that is meaningful and recognisable. The applied contexts for navigational cues and environmental generative sound include online (multi-user), synchronous Virtual Environments and Digital Installation Spaces (e.g. intelligent rooms, virtual reality and immersive environments). Outcomes of responsive sound design include: a trigger system of aural alerts, warnings and guidance; a computational system for generating sound in real time activated by spatial location and social interaction; and an audio (non-visual) tool aiding spatial orientation and way-finding interaction in 3D immersive Digital Environments.

1. Introduction

Throughout this paper, Virtual Environments (VEs) refer to online (multi-user) 3D environments, for example Active Worlds or VirTools, in which human users are represented by avatars and the computer keyboard interface is used to move around the environment by walking, flying or teleportation. Sensors are triggered by interaction (keyboard and mouse-operated direction, mouse-clicking on objects) and by events (collision/intersection with 3D objects in the VE, objects loading). In contrast, Digital Environments (DEs) refer to physical environments – intelligent rooms or installation spaces in which the human users move physically and interact by activating sensor triggers or in which motion is detected using tracking hardware and software. An example of the latter is the Wireless Intelligent Room in the Key Centre of Design Computing and Cognition at the University of Sydney, utilising infra-red sensing, pressure-sensitive floor mats and video motion tracking. Navigational sound is most pertinent to VEs and spatial sound is predominant in DEs.

Responsive sound for way-finding and guidance provides immediacy to warnings, feedback and constancy of guidance by the location of sound-emitting beacons or strategic landmarks in 3D Digital Environments (Beilharz, 2003a). Some existing shortcomings and inefficiencies in virtual environments (e.g. Active Worlds University of Sydney Virtual Design Studio, Indiana University World, and VirTools games-engine based constructions) highlight the need for user interface development that is less visually (mono modally) centric.

The interactive way-finding user experience can be improved by providing a clear sense of direction during navigation and related spatial orientation. Digital Environments provide a space in which multi-users can communicate, educate, learn, design, collaborate, be entertained, explore and interact. The design of the Digital Environment itself, the interface that users move about in, has a direct impact on the efficiency and effectiveness of the environment in achieving its purpose (Beilharz and Reffat, 2003b). Sound is a dimension that has been significantly neglected in digital environments. Visual cues, grid systems, constrained movement and camera views have been used to develop visual way-finding systems in virtual environments (Sherman and Craig, 2003). Using sound to assist way-finding is applicable to a broad array of situations and offers an immersive approach to navigation in 3D digital environments: in 3D games, virtual environments and digital installation spaces.

Iconic visual and text-based cues abound in 3D Digital Environments (Figure 1). By guiding the user with sound and providing feedback and responsiveness sonically, visual overload and cumbersome representations are avoided.

The objective of this research is to utilise information about the number of people participating in a space, the density of objects in it, and the location where the user activates a trigger and temporal information to shape the generation of the sounds and music the user will hear. This acts not only as a social and spatial meter of activity but guarantees a related and informative sound design.

Interdisciplinary relationships between designing sound and space and shared mathematical strategies demonstrate ways in which musical characteristics (pitch, tempo, rhythm, textural density, articulation, colour) connect with spatial dimensions and architectural characteristics (dimensions, materials, density, location). This forms the basis for translation between data sensed in the digital environment and its application to sound generation in real time (Beilharz, 2002). The semantic connection between sonic and spatial experience imbues the generative sound design with meaning and comprehensibility.

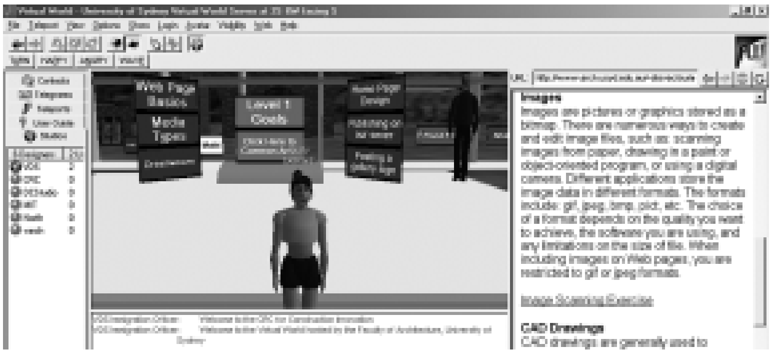

Figure 1. Instructions, links for teleportation and links to Internet pages, as well as text-based content are predominantly visual interactions and signposts in the current Active Worlds environment. Speech is also typed/read ICQ "chat"-like sessions. The text-heavy, sign-based visual interface creates visual overload.

"Successful technologies are those that are in harmony with users' needs. They must support relationships and activities that enrich the users' experiences" (Shneiderman, 2002). Metaphoric designing of the VE connects and adds meaning to the collection of web-based technologies forming the user's experience. Parameters influencing sound generation derived from environmental and social sensors include: the number of users in a digital environment, interaction between users, building / constructive intensity, proximity to sensor objects.

The potential for utilising Evolutionary Design lies in the relation between its generation and using environmental data as part of the initial values and fitness test for evolving designs and novel design. Genetic algorithms serve as a formative basis for idea/material generation. Genetic art forms and generative design are not new. Artists and designers, especially in visual domains, but also for sonic purposes, use stochastic principles and algorithmic interpolation to produce new variations and fresh material. Contemporary media artists, Christa Sommerer and Laurant Mignoneau (p.297) (Grau, 2003) build on this alliance between art and technology. Designing sound for a Digital Environment requires not only the generative process of new material but a subsequent selection process at the phenotype stage that reconnects outcomes with human users and the experience of the

Digital Environment, hence a fitness test and evaluation criteria based on environmental conditions.

Human interaction with sensors and environmental data contribute to the initiation and modification of generative procedures. The way in which generative design is musically or sonically represented determines the meaningfulness of this social compass and the characteristics of its realisation. This interaction is illustrated in Figure 2.

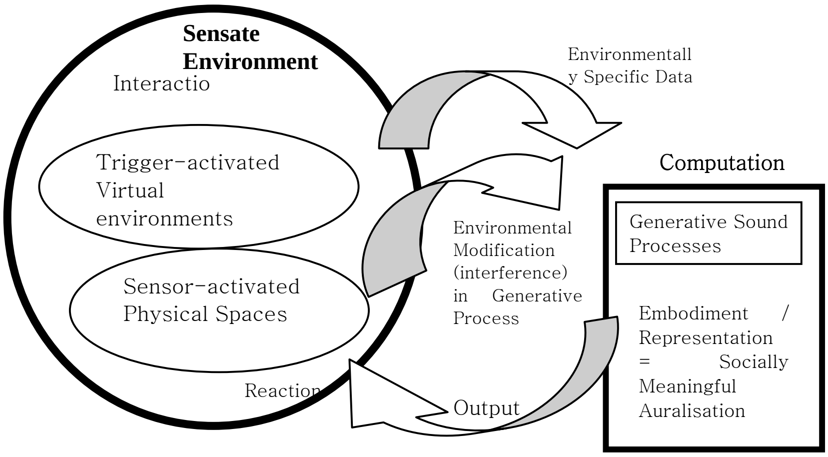

Figure 2. The structure of this paper is based on the interplay between sensate environments, environmental data, generative sound processes and people.

In summary, this paper explores the application of generative sound in 3D Digital Environments for the purpose of spatial and navigational awareness, social feedback and responsiveness.

2. 'Embodiment' / Representation and Social Information Sonification

Sensate spaces are new, emerging phenomena that require design solutions: design of the kinds of activity, interaction and sensed information that will be retrieved and design of meaningful responsiveness or feedback that arises from the large quantity of data that is captured through tracking cameras, sensors, and triggers. Most energy, to date, has been invested in developing the technologies for sensing and capturing this data and even integrating sensors into building materials and furnishings. For feedback to be most pertinent, it needs to be generated in real time, i.e. to have immediacy and also to communicate in a socially meaningful construct.

Sounds and music have the potential to emphasise and highlight behaviour, for example the way in which Garcia uses sound to increase the emotional and semantic impact of structural analysis in buildings in order to reinforce and emphasise significant events and transformations over time (Garcia, 1998a). Typical structural simulation computer programs now take advantage of fast graphics and animation capabilities (MacLeod, 1995). Significant progress has been made in recent years in the area of auditory displays (earcons, sonification, audification, etc.) for scientific and general bimodal simulation and sonification applications (Brewster, Wright and Edwards, 1993). “Sound, however, has taken a back seat to all these developments and has not really been taken advantage of to support simulations of structural behaviour except in a few applications of data sonification” (Garcia, 1996; Garcia, 1998b). Generated sound can represent activity and interaction occurring in a space. The types of information that will be relevant and beneficial to interpret will vary from one context to another but might include features such as social convergence, busy-ness, population (popularity), regional polarities and environmental features, e.g. temperature, position, direct interaction with physical objects and room fixtures. Meaningfulness of representation is dependent on the recognition and cognition of metaphoric correspondences between social and physical characteristics and sonic equivalences.

2.1. THE RELATION OF SOUND DESIGN TO SPATIAL DESIGN

Thematic design makes the interface and environment more intelligible as well as providing a methodology for the environment designer (Beilharz and Reffat, 2003a). Arbitrary warning signals, feedback sounds, even ambient music and landmarks can be themed according to the governing metaphors of the design. Relation of musical, sound and spatial design through shared or parallel parameters is historically established, for example correlations between musical and spatial (architectural) designs by Iannis Xenakis (composer and architectural assistant to Le Corbusier) (Beilharz, 2003b). Interdisciplinary relationships between designing sound and space and shared mathematical strategies demonstrate ways in which musical characteristics (pitch, tempo, rhythm, textural density, articulation, colour) connect with spatial dimensions and architectural characteristics (dimensions, materials, density, location). This forms the basis for translation between data sensed in the digital environment and its application to sound generation in real time (Beilharz, 2002). Designing space in architecture and in music are both three-dimensional practices. While music operates predominantly in the dimensions of pitch/register, duration/rhythm and time, architectural design governs primarily the three geometric dimensions. Further parameters of condition such as colour, dynamic intensity (music) and texture apply to both. Stochastic rules of design in both disciplines are informed by a further interdisciplinary influence, i.e. rules of mathematics. Mathematical bases of both space and sound provide the computational connection between these domains.

2.2. THE RELATION OF SOUND DESIGN TO SOCIAL BEHAVIOUR AND HUMAN INTERACTION

"Successful technologies are those that are in harmony with users' needs. They must support relationships and activities that enrich the users' experiences" (Shneiderman, 2002). Metaphoric designing of the sensate or virtual environment connects and adds meaning to the collection of web-based technologies forming the user's experience. Parameters influencing sound generation derived from environmental and social sensors include: the number of users in a digital environment, interaction between users, constructive intensity, and proximity to sensor objects. Edmonds emphasises the importance of correspondences between sounds and visual images in his Video Constructs in order for the structural relationship to be understood (Edmonds, 2003a). The reverse situation, a constructivist environment in which users actively aim to determine their experience can be observed in Edmonds' Communication Games in which negotiating the logic generating computer response forms the substance of the game. Both the constructivist scenario and the responsive sensate environment rely on adequate recognition of correlations between spatial, visual and social data with experiential sound (or graphics). For these correspondences to be easily understood, direct metaphoric connections could be represented in ways explained in the following table of correspondences (by way of example) (Table 1).

TABLE 1. Correspondences between social/spatial environmental data and parameters of sound design, in which the auralisation will be affected by human behaviour in the sensate environment.

Social / Spatial Data	**Auralisation Parameter**	**Variables/Range**
Number of participants	Textural density (number of sonic events triggered)	Ranging from none/few to many sonic events: affecting complexity of sonic experience
Rate of motion / speed	Tempo / velocity	Ranging in speed of realisation from slow to fast: affected by human motion/gestures in space or movement from one place to another within the sensate environment
Zone / Spatial location	*Timbral* (tone colour) effects	A range of filters on sonic process affecting colouration or sample utilised: affected by distinct spatial regions
Activity / busy-ness (motion tracked over) time	Rhythmic cells	Attributes characterising the generation of rhythmic cells classified by internal complexity (perceived activity)
Traffic at key juncture & Proximity to key objects	Pitch	As sound quality and particulars of pitch result from generative processes, ranges of pitches, group rules equivalent to notions of frequency create distinctions
Unusual pressure exertion (jump/stamp/impact)	Distinctive Event trigger	Specific aural events or algorithms prompted by significant environmental impacts
Lighting & temperature in the environment	'Key' / harmonic orientation of samples and generative pitch subsets	Rules affecting combinations of pitch produce harmonic inflections. Different variables in the algorithm can be assigned to degrees in temperature variation or measured in lumens for lighting intensity

3. Sensing and Detection in Online Virtual Environments

Virtual environments can provide input for environmentally connected generative processes and thus, by using the triggers and sensed data in VEs, an inexpensive simulation or model of the generative processes required for a sensate physical space can be tested before implementation. Responsive sound in virtual environments can provide information about its user and social patterns, as well as providing immediacy to warnings, feedback, sound-emitting beacons or strategic landmarks for way-finding and guidance (Beilharz, 2003a; Beilharz and Reffat, 2003b). A current restriction of the Active Worlds platform is that sound is neither individualised nor customisable and the distance-volume sound control is activated automatically by the 3D Browser. Sound increases with proximity to a sound-emitting object and reduces as the user moves away from it. All users hear the same environmental sounds. Sounds emitted by bots and other functional warnings must be subsequently terminated to avoid sonic pollution. A bot or an object may be programmed to stop sounding when an avatar is beyond a certain distance from it. The Virtual Environment detects activation of triggers, for example those available in Active Worlds: when an object is first loaded; when an object is bumped or passed through; activated by a mouse left-click; when the end of a non-looping animation is reached). This indicates social information, e.g. the number of people, type of people, time of day, location within the environment, and the number of objects in the space.

4. Modes of Interaction in Sensate Spaces

Different sensor technologies activate and detect human behaviours and interaction – with other people, within the space and with specific devices. This section categorises those sensors and briefly summarises the ways in which information is retrieved. Current technologies are divided into two types: those of which the user is intrinsically aware – wearable, invasive, wired, haptic or tactile interfaces; and embedded, discreet, unobtrusive sensing that can transmit data without requiring the user to be overtly aware of the process. The latter category refers to suitable sensors for sensate social spaces rather than performative or interactive art and entertainment spaces.

4.1. WEARABLE, ACTIVE TRIGGERING TECHNOLOGIES

This paper looks at sound design primarily as environmental sound and feedback, rather than purely as entertainment or performance, though both approaches share many technology interfaces. The following examples provide some evidence of practical implementations of sensing devices in performance (Table 2). Several performers have used off-the-shelf motion detectors and inexpensive pressure triggers, as well as custom-designed hardware, to map body location within a space into MIDI data (p.316) (Winkler, 1998).

TABLE 2. Some performance artists' application of sensor devices (Winkler, 1998; Paul, 2003; Tofts, Jonson and Cavallaro, 2003).

Artist	Title	Data sensing
David Rokeby	*Very Nervous System*	Tracks human movements in a large space using video and computer analysis of consecutive frames to detect motion; uses MAX.
Paul Garrin	Interactive video installation, *White Devil*	Dancers and other participants influence the compositional process based on location and movement. Video image projections track and respond to viewers' movement.
Rob Lovell & John Mitchell	Virtual Stage Environment	Identifies 'hotspots' within a video field of vision and actions within these areas are interpreted by MAX (2003) to control the musical process and video disk playback.
Max Matthew	Radio Drum / Radio Baton	Spatial controller consisting of radio-frequency transmitting batons moved across a receiving surface, controlling data in 3 dimensions. This system has been used in sophisticated ways by composers, Andrew Schloss and Richard Boulanger. A 'drum' object for custom MAX is designed to receive stick-position data, trigger-plane hits and velocity.
Donald Buchla	*Lightning*	Infra-red signals are used to locate the performer within a user-definable 2D grid.
Jeffrey Shaw	*The Legible City (Amsterdam)* (see Figure 3)	Bicycle interface, sensing pedalling rotational direction and handlebar steering orientation, to navigate direction and depth in immersion 3D projected environment.
Petra Gemeinboeck, Roland Blach & Nicolaj Kirisits	*Uzume*	Immersive real-time stereo projection system in a CAVE with video-sensed motion detection influencing projected patterns and triggering musical interaction (see Figure 4). *Uzume*'s sonic response, shaped by spatially moving sounds, develops individually modulated passages along the traces of the visitor's movements (Gemeinboeck, Blach and Kirisits, Web).

Figure 3. Jeffrey Shaw's The Legible City (Manhattan) (1989). This kind of performative, interactive art work requires deliberate, conscious, single-user interaction.

Figure 4. Uzume projects a visual representation of the performer's choreography. The work responds sonically and in stereo projection in real time in a CAVE system. Video-sensed motion detection influences projected patterns and

triggers musical interaction. *(Gemeinboeck, Blach and Kirisits, Web).*

Body sensor devices are those attached to participants' bodies: especially arms, legs, hands, fingers (Waisvisz, 1985), e.g. an extreme case would be Stelarc's *Exoskeleton* (1999) or *Ping Body* (1996) (Edmonds, 2003b; Paul, 2003) (see Figure 5. In comparison, body sensor devices can include wireless devices for ease of motion and in order to be as unobtrusive as possible. The glove object, for example, receives eight gestural variables from simple interfaces like the Mattel Power Glove for the Nintendo Entertainment System: X, Y, and Z location, rotation and bend of the thumb and fingers. The object reports these values whenever a trigger (or "bang") is received. Numerous compositions have successfully utilised this gestural information. Potential for these sensor devices relates input to collection of environmental data that results in relevant, informative sonic feedback – not purely entertaining or performance-oriented.

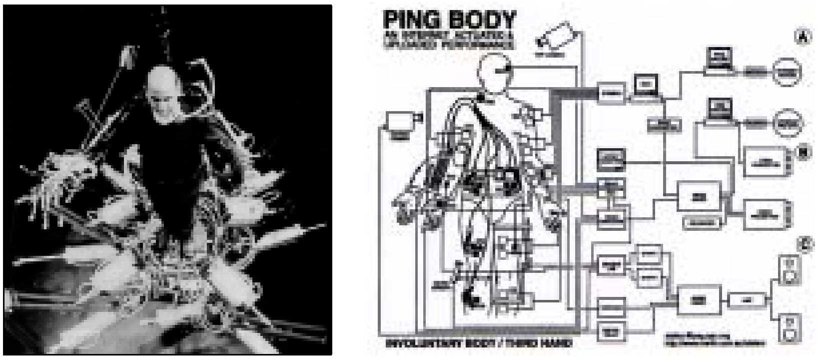

Figure 5. Stelarc's Exoskeleton and the schema for Ping Body (Paul, 2003). In the fo rmer, the artist's gestures activate mechanical, electronic and software components: th e machine's choreography derives entirely from arm gestures. The latter is designed f or Internet actuated and uploaded performance and an involuntary third arm.

Design and fabrication of textile-based computing - washable, wearable technologies (Post, Orth, Russo et al., 2000) may lead to more common-place integration of computation with fashion and mobility beyond our current array of portable wireless devices. The MIT Responsive Environments Group projects (MIT, Web-b) include a number of wearable devices for transmitting and transceiving data: the UberBadge and Radio Frequency Random Access Integrated Node (RF and IR communication with extensive memory and storage expandability); and the Gait Shoe (measuring parameters from each foot using the Sensor Stack to provide data for analysis of gait). Sensate tactile objects and purpose-specific devices include: sensate cook-tops (transduction in glass ceramic surfaces for sensing pots); and the Trible (Tactile Reactive Interface Based on Linked

Elements – multimodal sensate "skin" on a ball). These devices are clearly intended for deliberate, specific interaction.

4.2. MODES OF PASSIVE SENSING FOR RESPONSIVE SENSATE SPACES: WIRELESS, EMBEDDED AND UNOBTRUSIVE SENSING TECHNOLOGIES

In the sensate environment, spatial sensors respond to the location and movement of a person/performer in space, often without the user consciously touching any hardware devices (e.g. infra-red sensor grids, pressure-sensitive floor mats). Edmond's Creativity and Cognition Studios, for example, use infra-red and pressure-sensitive mats in installation performative works such as *Elysian Fields.* [1] Pressure sensors usually function by piezoelectric conductivity. There are a range of commercially available sensate or pressure sensitive floor mat solutions for embedding discreetly under carpet or flooring surfaces. Similarly, the Magic Carpet (MIT, Web-a) uses carpet on top of a mesh of piezoelectric wire (tracking foot position and dynamic pressure) and a pair of Doppler microwave motion sensors (to respond to movement of the arms and upper body) for immersive musical installations. Radio frequency (RF) transmitting devices and magnetically coupled resonance (LC tag) technologies that can be embedded (or comfortably wearable) and networked widely, wirelessly and inexpensively represent the greatest potential as availability becomes ubiquitous (Mitchell, 2003). Gesture Sensing Radar developed by the MIT Responsive Environments Group explores microwave sensing for detecting non-contact gesture. Z-Tiles "develop a sensate floor made from networked sensor tiles, each of which contains small pressure sensors connected to an embedded computer". Smart walls developed at MIT with infra red and video, using computer vision, provide a non-tactile alternative to most commercial digitising tablets and smart whiteboards that require contact and pressure. Gesture walls and laser range finding detect human motions and interactions with wall-mounted displays and the LaserWall provides an inexpensive scanning laser rangefinder that can be retro-fitted, requiring fairly direct interaction and intention.

5. Approaches to Real Time Generative Design

"Creative steps may be found in inventing a new structure, for example serial music … the search for order is a fundamental attribute of human

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1 Brigid Costello, Ian Gwilt, Andrew Martin and Dave Burraston: *Elysian Fields* (2003) is an investigation invoking passive (observational), ambient (undirected) and goal oriented interaction. Edmonds, E. (2003b). Sparks CD-ROM, Creativity and Cognition Studios, University of Technology, Sydney.

perception" (Edmonds, 2003a). In musical compositions and architecture by Iannis Xenakis, and architectural rules applied to designs by Le Corbusier, the expertise lies in designing the grammatical, generative system rather than the artefact itself. Stochastic, algorithmic and genetic evolutionary systems provide underlying generative processes for designing sound and interpreting environmental data.

5.1. STOCHASTIC PROCESSES FOR GENERATION AND TRANSFORMATION

Stochastic / probabilistic processes provide a related group of algorithms capable of generating complex sets of values for representation as new sonic or visual material. Stochastic and serial processes have been applied to musical composition and architecture by Iannis Xenakis (Beilharz, 2003b). The underlying mathematical bases for his application exemplify some methodologies for augmenting and creating design. Due to the interdisciplinary nature of mathematical processes, this foundation transcends the barrier between visual and sonic representation with the potential that like structures can generate material in both domains from a common process, reinforcing the structural integrity of design works.

5.2. ALGORITHMIC GENERATIVE PROCESSES

In general, algorithms are procedures or formulae for solving problems. This broad class includes many stochastic and serial methodologies as well as those algorithmic techniques pertaining to genetic transformations or other generative elaborative processes, such as the *cellular automata*) (Johnson and Trick, 1996). In the broadest sense, algorithmic generation incorporates all classes of solution-generating algorithms, including linear functions, network growth and fractal algorithms, and those based on genetic evolution (Kreveld, Overmars, Schwarzkopf et al., 1997; Skiena, 1997). For any algorithmic process, the relation to its environment lies in the way in which modification and selection occurs within the system, extrapolated in Section 6 for Genetic algorithms.

Jalbert connects generative art and music with generative grammar in the field of linguistics, deducing that music and the visual arts are really languages that have their own grammars (Jalbert, Web). Beilharz concurs that musical compositional structures by Complexist composers are a form of design grammar (Beilharz, 2001). Jalbert's discussion raises interesting issues that relate to designerly or artistic implementations of algorithmic generation: that certain sequences or juxtapositions, whether by an artist or a programmer, can create effective communications; that certain systems use a small set of rules with various permutations; other systems use loose sets of rules and a large vocabulary; some algorithms provide little or no permutation within but sequencing the algorithms turns into a language or grammar. It is interesting that generative design is related to grammar, the vehicle of meaning. Algorithmic generative systems have been used by designers and artists as diverse as Brian Eno, Francois Morellet, Simon Penny (Jalbert, Web) and Marvin Minsky (Minsky, 1981). Roman Verostko's *Algorithmic Fine Art: Composing a Visual Arts Score* (pp.131-136) (Candy and Edmonds, 2002) claims that algorithmic processes in the production of designs has burgeoned in the last quarter of the Twentieth Century due to computational possibilities, a view corroborated by Ernest Edmonds. "The creation and control of these instructions [code for generating forms] provides an awesome means for an artist to employ form-growing concepts as an integral part of the creative process" (Candy and Edmonds, 2002). Section 6 of this paper connects generative processes with environmental context as a means to retain social meaningfulness. The direct relation to sensate spaces is in the methodology for integrating environmental conditional data with generative designing.

6. Evolutionary Sound Design Related to Social Context

Generative processes provide the means for real time sound creation. Environmental modification of the generative process shapes the generative outcome to be socially indicative.

6.1. INTEGRATING EVOLUTIONARY DESIGN METHODOLOGIES WITH SOCIAL INDICATORS TO REFLECT THE ENVIRONMENT

The potential for utilising evolutionary design lies in the relation between its generation and using environmental data as part of the initial values and fitness test for evolving designs and novel design. Genetic algorithms serve as a formative basis for idea/material generation. Genetic algorithms were developed by John Holland in an attempt to explain the adaptive processes of natural systems and to design artificial systems based upon natural systems (Holland, 1975; Holland, 1992; Bentley, 1999). So-called genetic art-forms and generative design are not new. Artists and designers, especially in visual domains (but also for sonic purposes) use stochastic principles and algorithmic interpolation to produce new variations and fresh material, e.g. Lorenz linear functions, Network growth drawing evolving designs to screen using Flash ActionScript.

Two important contemporary media artists, Christa Sommerer and Laurant Mignoneau (p.297) (Grau, 2003; Sommerer and Mignonneau, Web) build on the alliance between art and technology. They pioneered the use of natural interfaces that, together with Artificial Life ("A-Life") (McCormack, Web) and evolutionary imaging techniques, allow people to interact with natural spaces and patterns (exotic worlds of luxuriant plants, swarms of butterflies, microcosmic organisms, growing ecologoies) applied to installations. Jon McCormack's *Future Garden* (McCormack, Web) is an installation in which the patterns displayed are generated using the algorithmic technique, *cellular automata,* also utilised by Creativity and Cognition Studios sound designer, Dave Burraston to produce a continuous stream of permutations and evolving generative designs. McCormack's *Universal Zoologies* is an interconnected series of autonomous, self-generating, poetic spaces that are navigated by people experiencing the work. The project aims to represent emotive, abstract, artificial life digi-scapes, each based around a thematic metaphor evoking the qualia of the natural world. The work creates a rich and elaborate visual space –of strange and numinous creatures that have been evolved through a complex process of rule-based selection. *Eden* - a networked self-generating sonic ecosystem environment, and *Future Garden* - an electronic "garden" of Artificial Life as part of the Federation Square development in Melbourne, represent installations of generative processes in large-scale publicly interactive spaces (McCormack, Web). Successive generations of artificial fauna tend to become more complex. Bernd Lintermann's *SonoMorphis* ZKM, Karlsruhe, 1999) involves user interaction to perpetuate the mutation process.

In building design and architectural processes, generative algorithms have been designed to provide multiple interpolations, i.e. for idea generation, e.g. Mike Rosenman and John Gero 'Evolving Designs by Generating Useful Complex Gene Structures' (p.345-364) (Bentley, 1999) for generating house shape designs using different room configurations.

6.2. SYSTEM RELATIONS TO THE SENSATE ENVIRONMENT

Bentley explains a simple interrelation between genetic processes and design, between creativity, optimisation and evolutionary forms utilising algorithmic knowledge based on biomorphic procedures. Genetic algorithms present a way in which evolutionary and infinitesimal variations of design coordinates can be implemented. The interest and usefulness lies in the adaptation of the system to relevant virtual or sensate environment indicators – social and motion attributes or interaction. Initial values are derived from the sensate environment, and the fitness test and evaluation phases measure against extant conditions in the environment. Below is an adaptation of Bentley's general architecture of evolutionary algorithms indicating opportunities to relate the evolutionary design to its context (Figure 6). Some non-algorithmic controls can augment the outcome in order to offset any occurrences of repetitious or banal features. Sample variation, filters, time distortion and delay techniques serve to destabilise predictable processes without detracting from the sensed and social input in the generation process.

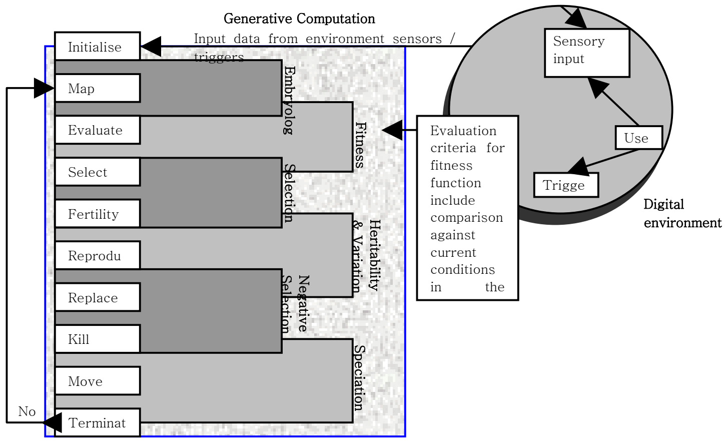

Figure 6. The general architecture of evolutionary algorithms (p.28) (Bentley, 1999) modified with initial values derived from the sensate/digital environment (not random values) and running the fitness function against criteria in the sensate/digital environment to ensure an interrelation between new growth and extant conditions.

An example of the way in which this modulation of the generative process might occur in evolutionary response to the sensed environment would be a situation in which the harmonic and pitch context remained relatively constant due to steady temperature and lighting conditions in an artificially controlled environment. Emergent novel ‘builds’ on different parameters would dominate perception. If the generative algorithm constantly measured against and affected by current conditions, large-scale shifts in sonic character might evolve as a clustering of parametric attributes concur due to the interrelatedness of the sensed physical and social traits, i.e. busy-ness, a temperature rise, more frequent incidences of unusual pressure exertion, higher indications of participants, greater traffic and increased interaction at key points, maybe even convergence in a specific zone are all likely and interrelated results of heavy population. This would have, in the scenario described, a combined effect on values generating sonic density (texture), pitch, harmony, tempo, timbre (tone colour) and initiation of recognisable distinctive events.

Further extrapolation of this genetic system to generate contextualised evolution can be manipulated by taking phenotype data and feeding it back into the genotype formative data. That is, like in the physical ‘real’ world, evolutionary transformations take place based on characteristics of the current generation (with latent inherent genetic qualities) rather than always originating from the primal source genes. A reflection of social morphology occurs in this way. This would be interesting applied to a social sensate space in which behaviours may change to reflect socially-influenced evolutionary trends over long periods of time.

Poignancy of the sonic representation to extant environmental conditions is maintained in the generative process by implementing the fitness test on the phenotype and by choosing a test that measures validity according to temporal conditions or a fitness evaluation that endows human participants with some selectivity for an interactive, customised result. Limitations include the number of generations that can realistically be calculated in real time and translated into sonic representation according to the rules of correspondence.

7. Potential Applications

There are several contexts in which a socially relevant generative approach to responsive sound design has potential. Passive sensate spaces are likely to emerge in the foyers, open, transitional and shared spaces of cultural and professional buildings. Social spaces where people interact provide an ideal situation for implementation and innovative human feedback. Sensate spatial design should not be restricted to cultural and mono-purpose contexts: sensate spaces invite an expansion of interaction and responsiveness into decentralised networked wireless spaces.

In electronic game environments, generating socially indicative or informative sound to provide real time customised music generation and context-determined alerts, warnings and helpful indicators is beneficial to the interactive entertainment industry.

In Virtual Environments, used variously for collaborative designing, meeting, education, social and other purposes, again original sound content needs to be addressed and generating sound that is socially determined increases the pertinence and relevance of generative sound.

Increasingly building materials, pre-fabricated sensing panels and materials, nano-sensors and ubiquitous distributed networks of radio-frequency sensors and transmitters will allow existing and new spaces to be imbued with sensing capacity for data capture. The significant question remains, with the emergence of innovative new technologies, what will be done with the information and by whom? Video tracking systems, for example, collect copious quantities of data. Such data can be utilised in intelligent systems for assisting occupants but that realisation is still some way off, requiring complex analysis of human behaviour and pattern recognition in order to be useful. Much hype surrounds the creation of new materials and technologies. This paper addresses one socially relevant way in which these merging technologies can be designed for in order to invoke human interactivity and engagement.

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