Virtual reality and sonic cyberspaces: augmentation, hybridisation and abstraction

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Abstract: While some researchers have described virtual reality (VR) in terms of digital replication of the physical world, others have claimed that the true power of cyberspace lies in the expansion and hybridisation of the physical elements and their parameters. The pioneers of VR envisioned it as implementation of abstracted laws and ideas. This paper details three VR types in connection to three music-making modes in the sonic cyberspace, using physical modelling techniques to describe the digital expansion, hybridisation and abstraction of sound producing mechanisms and interactions. This paper supports its claims with historical departures, theoretical summaries and compositional examples.

Keywords: VR; virtual reality; augmented reality; hybrid reality; abstract reality; physical modelling synthesis; sonic cyberspace; cyberinstruments; digital music; music composition; music performance; arts; technology.

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Biographical notes: Juraj Kojs is a Slovakian composer, performer, multimedia artist, producer, researcher and educator residing in the US. His compositions received awards at Europe – A Sound Panorama, Miami New Times Best Off Award, Eastman Electroacoustic Composition and Performance Competition and the Digital Art Award. He has received commissions from The Quiet Music Ensemble, Miami Light Project and Meet the Composer. His research articles appeared in journals such as *Organized Sound*, *Digital Creativity*, *Leonardo Music Journal* and *Journal of New Music Research*. He is the Director of Foundation for Music Technologies (FETA) in Miami, FL. He holds a PhD in Composition and Computer Technologies from the University of Virginia. He taught at Medialogy Department, Aalborg University (Copenhagen, Denmark), Yale University and University of Virginia. He is presently a full time faculty in the Audio Production Department at Miami International University of Art and Design in Miami, FL (www.kojs.net).

1 Introduction

Virtual reality (VR) has been defined as a full-sensory immersive environment, which is indistinguishable from physical reality (Heim, 1993, 1998). VR research pioneer Frederick Brooks explains that this type of reality should 'look, feel and sound as much as possible like a real world to the human mind that is coupled with it' (Brooks in Rheingold, 1991, p.38). Philip Zhai likewise offers a set of philosophical arguments concluding that the perceptual distinction between actual (real) and virtual (illusory) is in fact groundless. True VR is unrecognisable to the viewer; its technology is transparent (Zhai, 1998). Thus, the viewer perceives herself or himself as a subject, who observes and acts in a projection of the physical world (Astheimer et al., 1994, p.200; Nordahl, 2010).

Yet, the creative power of VR does not rely solely on reproduction of the physical world as it does on its expansion beyond its physical limitations. According to Jaron Lanier, Marcos Novak and other VR visionaries, we can become the architects of our own multimodal experiences, creating them out of our emotions, thoughts and imagination (Lanier in Zhai, 1998). VR thus reflects the intimate relationship between humanity and its technology.

In the early 1960s, Marshall McLuhan argued that our technologies extend our bodies (e.g. our clothing and shelter extend our skin), our work and skills, (money) and finally our nervous system (electric circuitry and TV). McLuhan hinted at various levels of extensions when he stated that 'the wheel is an ablative absolute of feet, as chair is the ablative absolute of backside' (McLuhan, 1964, p.167).

Pierre Levy refines McLuhan's extensions in the 'tool in action' metaphor from which the process of virtualisation (or becoming virtual) springs. Levy recognises two hierarchically ordered levels of virtualisation: extension and abstraction. A tool may present itself simply as an extension of a human part, as when a hammer extends the hand. On a higher level, a tool may embody an abstraction of some human action. For example, a wheel constitutes a virtualisation of walking (Levy, 1998).

McLuhan went so far as to say that even the wheel metaphor fails to express the most intrinsic capacities of technology. The movement of the wheel suggests a sequential action, while synchronisation in the electric age does not occur in any particular order. In fact, one of the inherent features of e-technology is its capacity to enable simultaneous occurrence of multiple actions. Further, technology renders a plurality of time, which succeeds the temporal uniformity of the wheel (McLuhan, 1964).

Access and arbitrary interconnection possibilities to any data is reflected in Deleuze and Guattari's rhizome model. The rhizome, "…unlike trees or their roots, connects any point to any other point…[and thus] brings into play very different regimes of signs and even non-sign states" (Deleuze and Guattari, 1987, p.21). The multidimensionality and multiplicity of the rhizome model enables possibilities for determinations and directions. Each multiplication results in a change to the environment without resolving a particularly directed process. The rhizome arises without a centre and hierarchy. It is deterritorialised like a map, which can be reconfigured according to the focus and stand point of an individual contemplation.

Based on the 'hammer', 'wheel' and 'rhizome models', we can formulate three types of cyberspaces: augmented, hybrid and abstract. Whereas augmented and hybrid spaces can be primarily defined by their extensions of the physical world as we know it, the abstract cyberspace facilitates the formation of novel laws, ideas and displays.

2 Augmented reality

Augmented reality is a computer-generated environment, which simulates the physical world based on its appearances, laws and causes. Typically displayed on flat screens, an augmented reality system digitally replicates the user's body and extends his/her capacity for movement, self-representation and event control beyond the limits of the physical world. Augmented reality is frequently heavily vision-oriented with limited or even absent tactile and audio components.

In his *Videoplace* (1985), Myron Krueger extended the constraints of existing laws like gravity, which enabled the viewer's digitised image to float on the screen (Krueger, 1991). Multiple video cameras, projectors and custom-designed hardware and software enabled movement tracking and onscreen coloured silhouette projection of the users' bodies. The viewer would initialise, imitate and counterpoint the self-projected body silhouettes of various sizes. Furthermore, the participant could move to draw images and text that would imitate and follow their actions (e.g. the critter and human critter characters).

Camille Utterback's interactive installations[1] like *Text Rain* (1999) enable full-body projections and enhanced interaction with other projected objects (falling letters forming lines about body and language). In her later series *Untitled*, the bodies are displayed as silhouettes that leave a trail of paint behind, affecting the intricate relationships between the surrounding elements.

Typically, the viewer remains informed both of his/her own body and physical reality while experiencing augmented reality. In fact, 88% of the surveyed viewers prefer to see their body in an augmented reality, finding such experiences more enjoyable (Heeter, 1995, p.217). This double-awareness may become diminished when physics-based modelling is used for simulation of the physical world's dynamic behaviour (Astheimer et al., 1994).

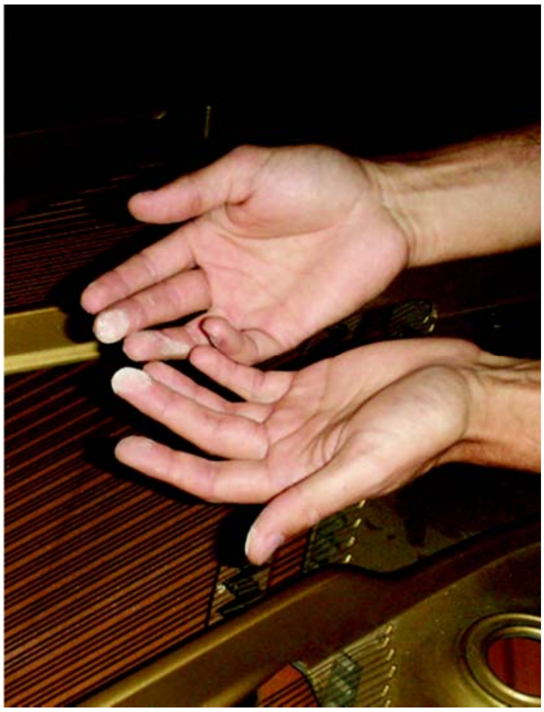
In the sonic domain, the body can be represented via physics-based interactions between the operating excitation mechanisms (e.g. bow, finger or breath) and the resonating instrumental bodies (e.g. strings coupled with bridges and corpuses). Physical modelling synthesis techniques are effective methods for digital simulation of complete sound producing mechanisms, enabling their replication and expansion (Adrien, 1991; Cadoz et al., 1993; Smith, 1992).

The replication suggests that the interactions between the performer and his/her instrument remain unidirectional and congruent with the physical world as in the example of a finger plucking a string. The properties of the instrument such as its size and material, however, can be expanded and the interaction modes between the exciter and resonator can be quantitatively augmented. For instance, hitting a digital marimba model that has crystal-like keys smaller than a light match is an example of augmented sonic design. Once engaged in music composition, such models become instruments – cyberinstruments to be precise. The author has previously theorised and demonstrated music making with such instruments (Kojs, 2008, 2009; Kojs et al., 2007). Frequently, human performers control such instruments with controllers such as keyboards, gloves and non-haptic devices and even audio signals.

All Forgotten (2006) for piano and electronics instantiates music composed with actions for a physical instrument and a choir of replica-extended (or augmented) cyberinstruments.[2] The pianist plays inside of the instrument throughout the piece, completely avoiding conventional keyboard–hammer–string interactions. Instead, the hands and fingers become the hammers, bows, scrappers and plectra, exciting the strings directly. Figure 1 shows two actions in which the performer bows the strings longitudinally.

Figure 1 Juraj Kojs' *All Forgotten* (2006) for piano and electronics in which the performer (a) bows the string regions with palms, (b) applies resin on fingertips and (c) bows individual strings (see online version for colours)

(a)



(b)

Figure 1 Juraj Kojs' *All Forgotten* (2006) for piano and electronics in which the performer (a) bows the string regions with palms, (b) applies resin on fingertips and (c) bows individual strings (see online version for colours) (continued)

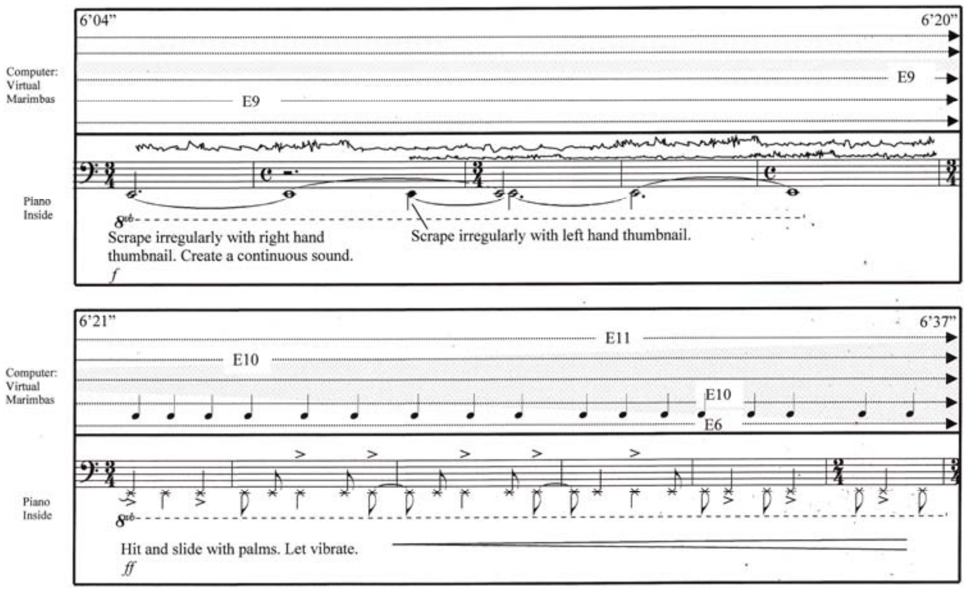
(c)

The amplitude information of the real piano string signal is tracked and used to control an ensemble of cybermarimbas designed with physical modelling synthesis (modal synthesis to be exact) and implemented in MAX/MSP for real-time application by Stefania Serafin. Both piano and cybermarimba pitch materials correspond with the 'musical' letters extracted from the eighth verse from Saint John of Cross' *Dark Night*. The alphabet letters are directly mapped to the musical pitches, however, their registration varies. The pitches for cybermarimba are stored in lookup tables, which are recycled at various speeds and transposed throughout the composition. While the piano textures descend over four octaves in nearly nine minutes, the cyberinstruments ascend to register beyond the range of the piano keyboard.

Augmenting the possibilities of physical marimbas, the cybermarimbas enable the production of high and low tones not performable on the physical instrument, the sustained excitation of those tones, otherwise unfeasibly rapid tone repetition (as fast as one event per 1 msec), the real-time change of the beater qualities and the extremely rapid repositioning of the beater on the bar. It is the audio signal produced by fingers and palms interacting with strings that excites and informs the sonic cyberspace, imaginatively stretching the performer's body to the virtual sonic domain. Figure 2 shows a notation example from *All Forgotten*. Note that the 'E' letters suggest pitch regions vastly augmenting the regions of the physical instruments.

Augmented reality thus has the capacity to remediate and expand our experience as viewer, listener and performer (Bolter and Grusin, 2000). Augmented reality enables the user to interact with remediated bodies via digital screen digital projections, foregrounding the visual feedback. In the digital music domain, the interaction mechanisms between a performer and an instrument can be simulated and expanded using physical modelling techniques. Composing music with such cyberinstruments demands that a physical body reaches into the digital cyberinstrumentarium and excites it, thus unlocking the door to novel timbral and textural explorations.

Figure 2 A score example from author's *All Forgotten*, which details scraping and tapping actions on the pianos strings and shows augmented pitch regions of cybermarimbas



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3 Hybrid reality

Hybrid reality too remediates and expands the physical reality. A participant manipulates physical objects to enter into contact with and control digital simulations. Enhanced visual, tactile and audio feedbacks are often present to reinforce such experience. The nature of hybrid reality in fact lies in the exploration of multimodal feedback and the engagement of the viewer's body parts in the operation of digital articles.

Interactive tangible interfaces such as tables, blocks, music sequencers, musical toys and everyday objects are the styli that enable the participant to manoeuvre physical objects for the purpose of controlling parameters of digital multimodal simulations (Kaltenbrunner, 2011). For example, moving a wooden block on a table interface can excite a virtual sound source or crop an audio sample. The ERGOS multimodal interface developed at ACROE centre in Grenoble, France, enables sophisticated audiovisual and haptic feedbacks (Florens et al., 2004). The projection of physical actions via tactile interfaces can even fabricate physical artefacts (Willis et al., 2011). In hybrid reality, feedback prompts further development of the mutual relationship between the human operator and technology, resulting in a stronger sense of immersion.

A sonic hybrid reality can also be built around manipulation of reconfigurable blocks and enhanced feedback, expanding the qualities of physical instruments and interactions. For example, the exciter-resonator paradigm can be parsed and reconfigured by reversing the functions of its components. While *bowing the string* is an interaction congruent with the physical world, *stringing the bow* is an example of the hybrid mode. Further, the order of exciters and resonators may be preserved while an unmatched pair from the physical reality is introduced, as in *plucking a drum membrane*. Multiple exciters and resonators can be organised to form networks of hybrid interactions and instruments with multidirectional energy flow.

Hybrid interactions are indeed characterised by the qualitative alterations in energy flow and type, and such interactions can be controlled directly in the computer environments such as MODALYS (Eckel et al., 1995), TASMAN (Applied Acoustics Systems DVM Inc., 2010), GENESIS (Castagne and Cadoz, 2002), MAX/MSP (Puckette, 2002; Zicarelli, 1998) and Pure Data (Puckette, 1996). In real-time performances, the musicians use substitute controllers to operate the hybrid instruments (Burtner and Serafin, 2001).

The treatment of hybridisation as a biological process of combining related elements into new forms inspired *E-clip-sing* (2008) for amplified clarinet, guitar, cello, double bass and electronics. The composition fuses musical elements, instruments and performative actions, metaphorically referencing biological cross-breeding of orchid genus. Hybridisation is commonly considered artificial, but in nature orchids have proved that the genetic barriers between species may be much more fluid than we may think. Such is the orchid's predisposition to adapt, fuse and transform whether in its natural habitat or domesticated environment that out of ~70,000 known orchid species less then half are the pure genera.[3]

Hybrid instruments, cyberinstruments, performative actions and cyberactions facilitate a creation of unique musical colours and forms in *E-clip-sing.* Physical actions are embedded in the score which consists of graphical gestures mirroring the physical movement of the performers. In particular, the author explored performance actions that are not native to the instruments such as plucking the cello, and by doing so, produced original timbres. The e-part of the composition engages hybrid cyberinstruments designed in TASSMAN, a modular software synthesiser, which enables the construction of modal synthesis-based physical models. The cyberhybrids combine parts of multiple instrumental parents in a single vibrating structure via parallel, serial and network connections. This 11-min long composition is organised in three movements *Buiara*, *Psychopsis* and *Odontocidium*, named after three contrasting orchid hybrids.

In the first movement (*Buiara*), the electronics engage serially ordered virtual plectra exciting other plectra and mallets hitting other mallets, suggesting hybrid cyberinstruments. Performance actions like plucking a plate with plectrum further accentuate the hybrid nature of the cyberinstruments. Implemented in various feedback loops, such mechanisms highlight the percussive portion of the performance action, effectively complementing the instrumental timbres. Figure 3 exemplifies a serially connected cyberhybrid with an embedded feedback loop.

The second movement *Psychopsis* begins *attacca* with sustained clarinet tones which quickly turn into air tones and solo with electronics in which the instrument is reassembled. The electronics feature cyberhybrids with a single exciter (a plectrum) connected to multiple resonators in parallel. The hybrids gain in complexity when the outputs of individual parts are cross-bred with additional parts. Furthermore, a hybrid cyberaction results from the plucking of resonating structures such as beams, membranes and plates as shown in Figure 4.

Figure 3 A hybrid cyberinstrument emphasising the excitation mechanisms of plucking and hitting and a possible feedback loop

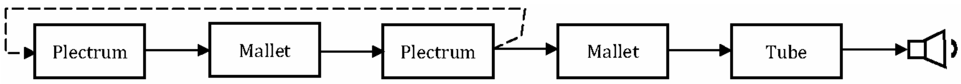
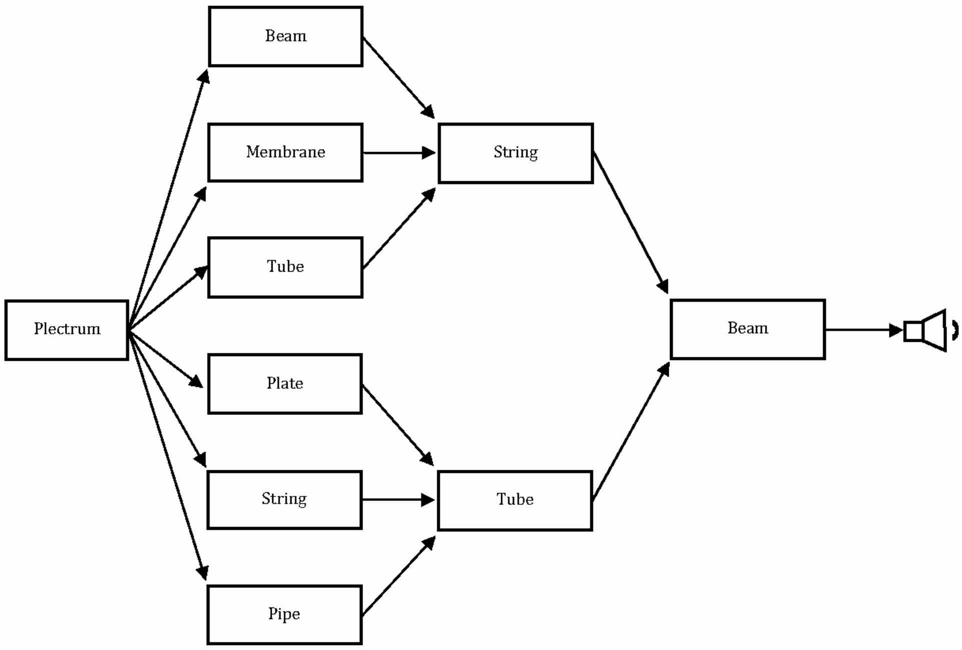


Figure 4 A hybrid cyberinstrument connected in parallel

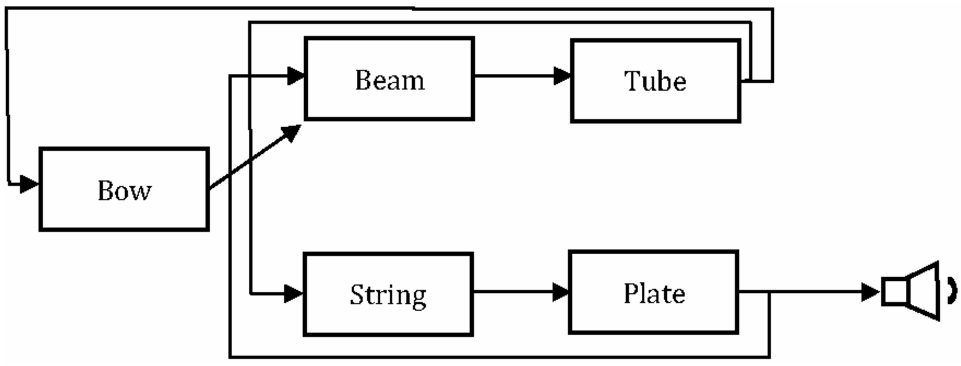


Note: The virtual plectrum plucks physically *unpluckable* elements.

The final movement *Odontocidium* features hybrid performance actions such as rubbing the bow and plucking the hair with fingers and plucking the plectra. To complement the various physical hybrid actions, the electronics present closed hybrid networks as shown in Figure 5. Any single control parameter change within any constituent part will result in behaviour alteration of the complete network.

Hybrid reality engages the body in manipulation of modular objects (physical and digital) often supported by highly developed multimodal feedback. While the ATM machines, iphones and ipads enable such experiences in the everyday life, multimodal interfaces and tables provide a ground for the body-technology explorations in the arts. Mapping physical gestures to the behaviours of digital objects is a vast area for creative investigation. Increased audio, visual and haptic feedbacks facilitate an enhanced sense of immersion, in particular when the technologies are applied directly to sensory channels. In the sonic realm, exciters and resonators become modular blocks that can be connected into serial and parallel networks, often reconfiguring the music making beyond the scope of the physical world.

Figure 5 A hybrid cyberinstrument connected in a closed network



4 Abstract reality

While hybrid reality enables the formal reconfiguration of elements of the world, abstract reality facilitates substance and function modifications. For example, *a teapot becomes tea* and *a painting brushes the painter*. Taking his inspiration from the unsurpassable morphing ability of the sea cephalopods, Lanier explains such modifications as follows:

> "For instance, instead of saying, 'I'm hungry; let's go crab hunting', you might simulate your own transparency so your friends could see your empty stomach, or you might turn into a video game about crab hunting so you and your compatriots could get in a little practice before the actual hunt." (Lanier, 2006)

The body can become a rematerialisable substance usable as a display. Transforming oneself into environment's agents can stimulate a complete immersive experience. While becoming virtual in this way, the participants create a mutually influential and dependent, perhaps symbiotic, relationship within the system. Deleuze and Guattari exemplify becoming virtual as the wasp becoming a piece in the orchid's reproductive apparatus. Becoming – wasp of the orchid and a becoming – orchid of the wasp signifies *inner* dependencies and changes in the participant's existence (Deleuze and Guattari, 1987). Such changes enable a materialisation of imagination, and indeed Lanier envisioned VR as a fluid music-making process, manifesting mind-stretching cross-modal experiences:

> "I have considered being a piano. I'm interested in being musical instruments quite a lot. Also, you have musical instruments that play reality in all kinds of ways aside from making sound in Virtual Reality.… With a saxophone you'll be able to play cities and dancing lights, and you'll be able to play the herding of buffalo's plains made of crystal, and you'll be able to play your own body and change yourself as you play the saxophone. You could become a comet in the sky one moment and then gradually unfold into a spider that's bigger than the planet that looks down at all your friends from high above." (Lanier in Zhai, 1998, p.177)[4]

Morphing signifies a fundamental functional transformation in communication, *post-symbolic communication*, which stretches far beyond the invention of new mapping systems and avatars for words (Lanier, 2006). Post-symbolic communication manifests via attunement with the environment, others and oneself. In 1996, M. Novak announced a creation of the esoscope, 'the instrument with which to examine the inner worlds of the self' (Novak, 1996, p.307).

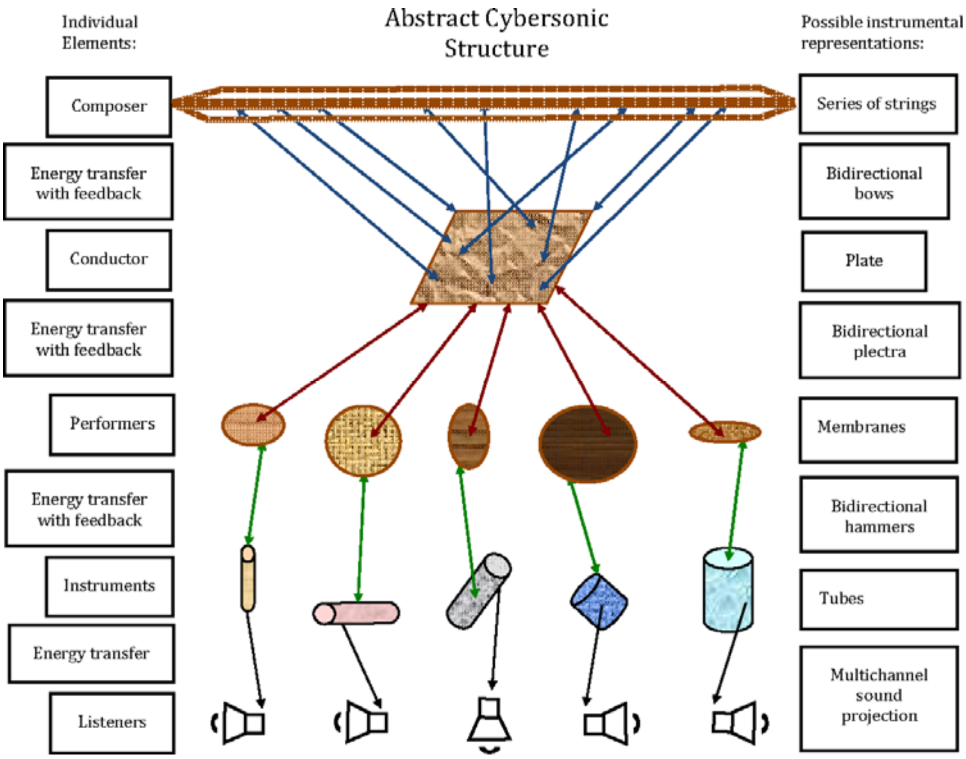
Thus abstract reality builds on communication that transcends the principles of physical reality, resulting in a spectrum of novel sensory stimuli. The abstract reality suggests thought- and emotion-bending, an experience that has been compared to lucid dreaming. Its complexity has yet to find a technology for materialisation, but some promising projects that enable morphing include interactive clothing and wearable design (Cutecircuit, 2011; Oobject.com, 2011) and online interactive environments (Second Life, 2011).

The creation of sonic abstract reality via physical modelling syntheses stretches the principles of design interactions to the composition and performance domains. These elements morph into each other, switching or overlapping their functions. For example, *bowing a performer* or *clarineting the composition's form* become possible. Exciters and resonators can be derived from music and everyday life: any potentially vibrating structure or phenomenon becomes sonically valid, creating a reality supracongruent with the physical world. It is in fact a formalisation of new principles, ideas and causes that nurtures development of sonic abstract reality.

Whether set in vibration or existing in equilibrium, the state of manifestation is just one subject of investigation. The inactive mode can disclose much information about its source and serve as a behavioural control mechanism for expressions of other entities. When excited, an object produces a specific physical movement like the Helmholtz motion of the bowed string. Such movement can be dissected without being ever heard and used as a control mechanism for another instrument or musical process. Energy transduction can initiate behaviours that may be (self-)organised into temporal and spatial orders and even eventually heard.

In the author's composition *At and Across* (2007) for Slovak bells and cyberbells, the abstract structures are created through the modelling of all of the elements of music making such as composition, conducting, performance and instruments. The composition is a vibrating cyberbell structure that produces certain energy patterns depending on the excitation mode and place of excitation. That energy is transmitted and transduced to the conductor structure and then to the performance and instruments. (All of the structures are actually bells made of various sizes and materials.) The links between the components enable various types of energy transmission and transduction via bowing, plucking and hitting mechanisms. The links also facilitate bidirectional flow, perpetuating continuous feedback. Since each substructure consists of modular elements such as masses, springs and dampers, considerable reconfiguration of the system is possible. The models were created in the GENESIS physical modelling environment as previously described in another paper by Kojs (2009). Figure 6 shows a diversified abstract cybersonic structure in which the digital simulations of various instruments and excitation mechanisms represent the music elements such as composer, conductor, performer and instrument.

Figure 6 An abstract reality system portraying all music-making elements as digital simulations (see online version for colours)



Note: The only structure to be heard is the instruments.

5 Conclusion

Digital expansions are based on the study of the physical world and the laws that rule it. We analyse and then resynthesise.

> "In this process we discover a new set of laws that govern how things can be put together. These laws, the ones that govern how a computer or car can be built, are as natural as gravity. We like to say we invent them, but they are there, waiting to be discovered" (Krueger, 1983, p.243).

While the expansion and combination of existing laws forms augmented and hybrid realities, new laws that describe irrational human behaviours with tools going beyond Boolean algebra are needed to oversee the construction of the abstract reality (Porush, 1996). Interaction with the virtual domain is not one-directional. The head-mounted displays, gloves, bodysuits and other paraphernalia of VR enable us to reach into digital worlds. However, the virtual domain also permeates back to physical reality via the haptic feedbacks in these systems, as well as holographic tactile displays (Iwamoto et al., 2008) force tactile interfaces such as gaming vests (TN Games, 2011) and body transfer illusions (Slater et al., 2010).

In digital music, physical modelling synthesis techniques have acted as vessels for augmentation, hybridisation and abstraction of sound producing mechanisms and also enabled novel music-making processes. The expansion of physical parameters such as size and material beyond the limitations of the physical world offer new possibilities for the augmentation of sound sources. The imaginative reconfiguration of exciters and resonators (as in the example of *plucking a clarinet*) has acted in hybridisation. Abstract models have stimulated the redefinition of conventional design, opening new territories for laws and ideas, and the possibility of morphing the composition–performance instrumentation cycle modules into each other has opened the door for unique investigations of what it means to create music in the VR.

References

Adrien, J.M. (1991) 'The missing link: modal synthesis', in G. De Poli, A. Picalli and C. Roads (Eds.), *Representations of Musical Signals*. Cambridge, MA: MIT Press.

Applied Acoustics Systems DVM Inc. (2010) *TASSMAN 4: Sound Synthesis Studio*. Montreal, Quebec, Canada. Available at: www.applied-acoustics.com.

Astheimer, P., Dai, F., Goebel, M., Kruse, R., Mueller, S. and Zachmann, G. (1994) 'Realism in virtual reality', in N.M. Thalmann and D. Thalmann (Eds.), *Artificial Life and Virtual Reality*. New York: John Wiley & Sons.

Bolter, J.D. and Grusin, R. (2000) *Remediation: Understanding New Media*. Cambridge, MA: MIT Press.

Burtner, M. and Serafin, S. (2001) 'Extended techniques for physical models using instrumental controller substitution', *Proceedings of the International Symposium on Musical Acoustics*, Perugia, Italy.

Cadoz, C., Luciani, A. and Florens, J. (1993) 'CORDIS-ANIMA: modeling and simulation system for sound and image synthesis – the general formalism', *Computer Music Journal*, Vol. 17, No. 1, pp.19–29.

Castagne, N. and Cadoz, C. (2002) 'GENESIS: a friendly musician-oriented environment for mass – interaction physical modeling', *Proceedings of the International Computer Music Conference*, Gothenburg, Sweden.

Cowell, H. (1926) 'The process of musical creation', *The American Journal of Psychology*, Vol. 37, No. 2, pp.233–236.

Cutecircuit (2011) Available at: http://www.cutecircuit.com. London, UK.

Deleuze, G. and Guattari, F. (1987) *A Thousand Plateaus: Capitalism and Schizophrenia*. B. Massumi (trans.). Minneapolis: The University of Minnesota Press.

Eckel, G., Iovino, F. and Caussé, R. (1995) 'Sound synthesis by physical modeling with Modalys, the successor of the modal synthesis system Mosaïc', *Proceedings of the International Symposium on Musical Acoustics*, Dourdan, France.

Florens, J.L., Luciani, A., Cadoz, C. and Castagne, N. (2004) 'ERGOS: a multi-degrees of freedom and versatile force-feedback panoply', *Proceeding of the Eurohaptics Conference*.

TN Games (2011) Available at: http://www.gamingvests.com/index.html. Redmond, WA.

Heeter, C. (1995) 'Communication research on consumer VR', in F. Biocca and M.R. Levy (Eds.), *Communication in the Age of Virtual Reality*. Hillsdale, NJ: Lawrence Erlbaum Associates Publishers.

Heim, M. (1993) *The Metaphysics of Virtual Reality*. New York: Oxford University Press.

Heim, M. (1998) *Virtual Realism*. New York: Oxford University Press.

Iwamoto, T., Tatezono, M., Hoshi, T. and Shinoda, H. (2008) 'Airborne ultrasound tactile display', *Proceedings of the SIGGRAPH Conference*.

Kaltenbrunner, M. (2011) *Tangible Musical Interfaces*. Linz, Austria (self-published). Available at: http://modin.yuri.at/tangibles/.

Kojs, J. (2008) 'Cyberactions and cyberinstruments via physical modeling synthesis: extending musical realities', PhD Thesis, University of Virginia.

Kojs, J. (2009) 'The language of action and cyberaction-based music: theory and practice', *Journal of New Music Research*, Vol. 38, No. 3, pp.285–294.

Kojs, J. and Serafin, S. (2008) 'Augmenting sonic reality. Cyberinstruments designed with digital waveguides', *Digital Creativity*, Vol. 19, No. 2, pp.77–90.

Kojs, J., Serafin, S. and Chafe, C. (2007) 'Cyberinstruments via physical modeling synthesis: compositional applications', *Leonardo Music Journal*, Vol. 17, pp.61–66.

Krueger, M.W. (1983) *Artificial Reality*. Reading, MA: Addison-Wesley Publishing Company, Inc.

Krueger, M.W. (1991) *Artificial Reality II*. Reading, MA: Addison-Wesley Publishing Company, Inc.

Lanier, J. (2006) 'What cephalopods can teach us about language', *Discover Magazine*, (April). Available at: http://discovermagazine.com/2006/apr/cephalopod-morphing/.

Levy, P. (1998) *Becoming Virtual. Reality in the Digital Age.* R. Bononno (trans.). New York: Plenum Press.

McLuhan, M. (1964) *Understanding Media. The Extensions of Man*. New York: McGraw Hill.

Nordahl, R. (2010) 'Evaluating environmental sounds from a presence perspective for virtual reality applications', *EURASIP Journal on Audio, Speech, and Music Processing*, Vol. 2010, Article ID 426937, 10 pages, doi:10.1155/2010/426937.

Novak, M. (1996) 'Dancing with virtual dervish: worlds in progress', in M.A. Moser and D. MacLeod (Eds.), *Immersed in Technology. Art and Virtual Environments*. Cambridge, MA: The MIT Press.

Oobject.com (2011) Available at: http://www.oobject.com/category/best-interactive-clothes/. on-line portal.

Porush, D. (1996) 'Hacking the brainstem: postmodern metaphysics and Stephenson's snow crash', in R. Markley (Ed.), *Virtual Realities and Their Discontents*. Baltimore, MD: The John Hopkins University Press.

Puckette, M. (1996) 'Pure Data', *Proceedings of the International Computer Music Conference*. San Francisco: International Computer Music Association.

Puckette, M. (2002) 'MAX at seventeen', *Computer Music Journal*, Vol. 26, No. 4, pp.31–43.

Rheingold, H. (1991) *Virtual Reality*. New York: Summit Books.

Second Life (2011) Available at: http://secondlife.com. San Francisco, CA: Linden Lab.

Slater, M., Spanlang, B., Sanchez-Vives, M.V. and Blanke, O. (2010) 'First person experience of body transfer in virtual reality', *PLoS ONE*, Vol. 5, No. 5, p.e10564. doi:10.1371/journal.pone.0010564.

Smith, J.O. (1992) 'Physical modeling using digital waveguides', *Computer Music Journal*, Vol. 16, No. 4, pp.74–91.

Willis, K.D.D., Xu, C., Wu, K.J., Levin, G. and Gross, M.D. (2011) 'Interactive fabrication: new interfaces for digital fabrication', *TEI'11: Fifth International Conference on Tangible, Embedded, and Embodied Interaction*, Madeira, Portugal.

Zhai, P. (1998) *Get Real: A Philosophical Adventure in Virtual Reality*. New York: Rowman & Littlefield Publishers, Inc.

Zicarelli, D. (1998) 'An extensible real-time signal processing environment for MAX', *Proceedings of International Computer Music Conference*, Ann Arbour, MI.

Notes

[1] Responsive environments (as 1980s researchers and artists called their works) are now referred to as interactive installations, highlighting the human technology relationship and their location (often a gallery space).

[2] Other compositions using this type of cyberinstruments are described in Kojs and Serafin (2008).

[3] Perhaps this is due to the fact that unlike other species such as mammals, orchid cross-breeding, especially when involving closely related classes, frequently leads to a 'hybrid vigour' which signifies faster growth, longer bloom, vicissitude of cultivated life and other enhanced properties. A creation of flowers with unique colours, forms, shapes and smells drives the breeders to combine multitude of species from various geographical locations.

[4] In a paper titled 'The process of musical creation', published in 1926, Henry Cowell (1926) claimed that a composer 'can hear not only the sound of any instrument or combination of instruments, but also an almost infinite number of sounds which cannot as yet be produced on any instrument'. Lanier extends Cowell's statement and suggests that a composer can *be* all that and much more.