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Asymmetrical Multi-User Co-operative Whole Body Interaction in Abstract Domains

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INTRODUCTION

For certain application areas, such as motion capture, there is little dispute that whole body interaction is a good fit of interaction style to domain. This reflects the observation that in such applications the mapping between user gesture and the desired effect is, loosely speaking, the identity function. For more abstract application areas such as, to take two arbitrary examples, textual analysis and programming, appropriate mappings between gesture and effect are less straightforward. The creation of appropriate whole body interaction designs for such complex abstract application areas remains challenging.

However, this is not to argue that whole body interaction is unsuited to application in abstract domains in general. Indeed, there is suggestive evidence, outlined below, that whole body interaction could offer excellent affordances for some highly abstract applications areas.

In this paper we consider an argument to this end, derived from conceptual metaphor theory and sensory motor contingency theory, concerning the suitability of whole body interaction to abstract application domains in general. In particular, we analyse issues from a case study of an asymmetrical multi-user whole body interaction system for a highly abstract application area, advanced tonal harmony. This domain is highly challenging, irrespective of mediating interaction style, but whole body interaction appears to offer particularly interesting affordances for action and insight in this domain when appropriate conceptual metaphors and conceptual blends (more on these below) are harnessed in the design. We analyse issues emerging from this case study and consider implications of these issues for whole body interaction design when dealing with highly abstract domains in general.

Conceptual Metaphor and Whole Body Interaction

Conceptual Metaphor theory is an important strand in current research on Embodied Cognition (Klemmer et al., 2006). Conceptual Metaphor Theory (Lakoff and Johnson, 2003; Lakoff and Nunez, 2000; Johnson, 2005) posits that human capabilities for dealing with abstract concepts are always grounded in a small core of universal sensory-motor abilities, together with their associated low-level inferencing capabilities.

More specifically, the theory hypothesizes that all cognitive capacities for dealing with abstraction are constructed by a process of association, mapping, composition and extension of maps, applied not just to entities, but also to roles, relationships and specialised inference capabilities, and grounded universally in low-level sensory motor resources for dealing with the body, objects, space and force (Lakoff and Nunez, 2000).

Suggestive evidence for this theory comes from Linguistics and other areas of Cognitive Science including Psychology,

Neuroscience and Human Computer Interaction (Lakoff and Nunez, 2000). Conceptual Metaphor Theory has been applied variously in Mathematics (ibid) Political Analysis (Lakoff, 2002), Human Computer Interaction (Hurtienne and Blessing, 2009) Music Theory (Zbikowski, 1998; Saslaw, 1998; Larson, 1998; Johnson and Larson, 2003) and Music Interaction Design (Wilkie and Holland, 2009). Mathematics teachers have judged the theory insightful and useful in teaching abstract mathematical concepts (Gold, 2001), and the theory has given rise to forms of analysis in HCI that have been empirically demonstrated to improve the effectiveness of user interfaces (Hurtienne and Blessing, 2009; Hurtienne et al 2008).

Broadly, there are three fundamental resources described in the theory: innate cognitive capacities, sensory motor schema, and conceptual metaphors. *Innate cognitive capacities*, such as subitizing, grouping, pairing, and exhaustion detection, are shared with neonates and some animals (Lakoff and Nunez, 2000). *Sensory motor schema*, also known as image schema, such as containment, contact, centre-periphery, and source-path-goal are associated with various kinds of low-level, special-purpose inference (ibid). *Conceptual metaphors* enable the two already mentioned classes of fundamental cognitive resource to be applied to domains of arbitrary complexity by mapping innate cognitive capacities and image metaphors onto more abstract domains. Example of employment of conceptual metaphors include reasoning about classes (based, in part, on low-level reasoning about containers) and reasoning about arithmetic (based, in part, on innate reasoning about collections of objects).

Conceptual metaphors have two principal categories of use: as *grounding metaphors*, and in *conceptual blending*. Grounding metaphors enable the simplest abstractions to be grounded directly in physical experience – for example arithmetic subtraction as grounded by taking objects away from a collection, or mathematical sets as grounded in experience of collections of objects. Conceptual blending works by allowing two or more conceptual metaphors to be used to create new expanded or composite metaphors by processes of *composition*, *completion* and *elaboration* (Fauconnier Gilles and Turner, 2002) These processes allow conceptual metaphors such *numbers are collections of objects* and *numbers are lengths* to be blended in intricate ways, as analysed in exhaustive detail in (Lakoff and Nunez, 2000) to produce more highly developed abstract concepts such as real numbers, complex numbers and related number systems.

While image schema and innate capabilities such as subitizing are considered universal, conceptual metaphors can, and do, develop differently between different individuals and cultures. The formation of conceptual metaphors is held to be affected by a combination of innate, developmental, individual and cultural factors.

At present, empirical evidence for the reality of the conceptual metaphor theory is suggestive and rapidly developing rather than comprehensive. More empirical work is needed, for example to establish grounded constraints on how the various elements of the theory can be validly applied. However, as already noted, there is good evidence from Mathematics Teaching, Psychology, Human Computer Interaction and Linguistics that conceptual metaphor theory is at the very least pragmatically useful to teachers and designers. In this paper, we apply the theory to a case study in whole body interaction to explore more general implications.

A complex abstract domain – Tonal Harmony

Tonal Harmony concerns the organisation of multiple simultaneous pitch sources, for example, two or more singers, or instrumentalists, playing independent but co-ordinated melodic lines. Tonal Harmony is generally considered the most technical part of music theory, and its reliable practice requires the mastery of demanding practical skills. Explicit understanding of tonal harmony involves understanding a wide range of entities, relationships and terminology spanning a series of interlinked semi-hierarchical conceptual levels (for example, pitch, interval, scale, chord quality, voicing, mode, key and modulation). Each of these levels is typically associated with its own extensive technical vocabulary. As well as being technically and conceptually demanding, tonal harmony is associated with practical obstacles to its mastery: namely it is technically difficult for untrained individuals without instrumental skills to get experience of the core activity of controlling simultaneous voices in a flexible but precise manner in real time – for the very good reason that our unaided bodies, with some interesting exceptions, can only generally control a single voice.

This is not a merely contingent practical issue. Rather, it strikes at the heart of the problem of effective engagement with, and enactment of tonal harmony, in a way that has wider implications for the role of whole body interaction in complex abstract domains more generally. In order to understand these implications, it will help to briefly consider two related theoretical perspectives, namely Sensory Motor Contingency Theory and Dalcroze Eurhythmics.

Sensory motor contingency theory

Sensory motor contingency theory (O'Regan and Noe, 2001) suggests that in order to learn to organize and respond appropriately to sensory input in some new domain or context, it is an essential precursor that the individual learner's motor actions have the power to perceptibly affect relationships in that domain. In diverse situations where this specific kind of feedback and experience is absent, competency has been observed to fail to develop.

This principle has been demonstrated in numerous different contexts and time scales. Notable examples include the development of the visual perception systems of neonate kittens (Held and Hein, 1958) systematic adaptation to sensory substitution in blind adults over months (Bach-y-Rita, 2005); and opportunistic learned sensory substitution in sighted adults over minutes when carrying out simple tracking tasks (Bird et al., 2008).

Sensory motor contingency, assuming its applicability here, suggests that if we wish learners to develop their skills in *engaging with, recognizing, identifying, memorizing, analyzing, reproducing adapting and composing harmonic sequences*, then their motor actions must have the capacity to actively manipulate those harmonic sequences at an adequately fine level of detail. However, most novices cannot play musical

instruments, and even if they can sing, singing only allows control of a single melodic line – not two or more independent lines, which in general is a requirement for a fully active experience of tonal harmony.

Dalcroze Eurhythmics

A related theoretical perspective, Dalcroze Eurhythmics, properly applies to musical rhythm rather than harmony, but we will identify a common underlying issue that allows the core of Dalcroze's approach to be applied equally well, in adapted form, to tonal harmony. The music educator Emil Dalcroze (1865-1950) noticed that his students seemed unable to deal with technical and written aspects of music connected with rhythm if they lacked experience of enacting and feeling those rhythms with their own bodies. Simply *hearing* examples did not appear to be sufficient. Dalcroze proposed that students had to become competent in *enacting* representative rhythms with their own bodies. Once this had been achieved, problems in dealing with technical and abstract aspects of rhythm seemed to be relatively easily solved. In some cases, the requirement for bodily enacting a rhythm can be relatively undemanding, for example if the rhythm is a simple pattern that can be tapped with a single finger (a monophonic rhythm). However, more challengingly, some rhythms consist of more than one rhythm played in parallel, such as are generated by a group of musicians, each playing a different rhythm. Such polyphonic rhythms are generally harder to recognize, memorize, analyze and reproduce than monophonic rhythms.

In order to encourage competency in enacting rhythms, particularly polyphonic rhythms, Dalcroze invented a system of rhythmic 'gymnastics' or 'eurhythmics'. Amongst other things, this involved asking students to walk at a regular pace, while moving their arms in synchrony at, for example, twice or three times the rate. Dalcroze's approach, and its modern refinements, now represent established strands within rhythm education.

We propose that these insights from Dalcroze Eurhythmics can be applied in principle fairly straightforwardly to tonal harmony. Students typically seem unable to deal securely with technical and written aspects of music connected with harmony if they lack experience of enacting and directing those harmonies. Simply *hearing* examples does not appear to be sufficient. We propose that students have to become competent in *enacting* representative harmonic sequences with their own bodies (including, where appropriate, use of the voice). Once this has been achieved, problems in dealing with technical and abstract aspects of harmony are likely to be more readily soluble.

Harmony Space – a system for tonal harmony

With these ideas in mind, Harmony Space (Holland et al, 2009) is an interactive digital music representation system designed to give insight to both beginners and experts into a wide range of musical tasks in tonal harmony ranging from analysis to composition.

In order to encourage competency in enacting tonal harmony, whole body Harmony Space offers a system of harmonic 'gymnastics' driven by physical movement in space.

From the point of view of music theoretic concerns, Harmony Space employs a minimal, principled set of spatial mappings to offer control of interlinked relationships between root movement, inversion, voicing, chord quality, altered chords, diatonicity, tonality, key, and modulation. This is achieved not by some arbitrary mapping between spatial movement and the abstract relationships of tonal harmony, but by a highly constrained conceptual blend with very specific sensory-motor,

music-theoretic and information-theoretic properties, as we will outline below.



System details

As already noted, Harmony Space is designed to allow users to enact harmonic concepts physically using relatively direct mapping between bodily gesture and conceptual metaphors for musical abstractions. To this end, the current system is driven by four dance mats and four wireless accelerometers (wii controllers) controlling in real time multiple graphical objects on a large projection screen, a music synthesizer, all integrated by a Harmony Space server communicating by OSC (Open Sound Control) over Bluetooth.

Basis for the spatial metaphors and conceptual blends used in Harmony Space

It is useful to consider some of the constraints on the fundamental spatial metaphor used in Harmony Space. Starting from the single assumption that the twelve notes used in tonal harmony are perceived as twelve objects with a circular ordering (which readily holds assuming octave equivalence) Harmony Space uses Balzano's (1980) theory of Tonal Harmony to identify the notes of the chromatic scale (and thus the pitches produced by western instruments) with the cyclic group of order 12. Based on this assumption, mathematical group theory can then be applied to prove that the *unique* well-formed, non-redundant co-ordinate system for these objects is a two dimensional space whose axes are semitone step sizes of three and four respectively. Adding the octave (step size 12) as a third axis maps the space into the full pitch range. Technically speaking, the 2D co-ordinate system is unique in the sense that it contains the only two other valid co-ordinate systems - both 1 dimensional: the chromatic scale and the circle of fifths. The tonal space generated is effectively a torus, but to allow the vision system to apply appropriate image schemas and forms of low-level inference more easily, this pattern is unfolded and reproduced like wallpaper. There is suggestive evidence that this representation is a good description of how aspects of music perception work. Other candidate models are available, but this model has the unique property described above, which give it excellent affordances for visual inference and manipulation by low-level sensory motor schema.

The effect of the employment of this mapping (together with an appropriate set of graphical conventions, visual and spatial metaphors, visualisation tools, music computations and interaction techniques) is that Harmony Space mirrors more than half a dozen interlinked layers of conceptual abstraction

related to pitch, scale, interval, mode, degree, quality, progression, key, diatonicity, modulation, sequence, genre and corpus, otherwise generally accessible only via specialised symbology, terminology and abstractions.

In this way, each of these abstraction layers becomes amenable to concrete, visible manipulation by simple spatial movements. Thus, most relationships in tonal harmony are rendered accessible, in principle, to low-level inference using image schema, such as containment, contact, centre-periphery, and source-path-goal, in place of abstract symbolic reasoning.

Asymmetrical Multi-User Co-operative Whole Body Interaction vs. desktop

Harmony Space has previously existed principally as a variety of desktop prototypes (Holland, 2009). Compared with the asymmetrical collaborative dance mat version, the visual and audible aspects are similar or identical. However the interaction styles in the two cases contrast markedly. These differences in interaction design have consequences for the extent to which novices can engage with the conceptual metaphors and blends reflected by the design, and thus the extent to which players can rely on universal low level reasoning, rather than learned expertise in using the system.

When a user controls a harmonic sequence in real-time on the desktop system using a mouse and alphanumeric keyboard, some operations must be carried out on the keyboard more or less simultaneously. This requires a certain amount of learning and expertise about the details of the keyboard control system, which may get in the way of direct engagement with the domain. Furthermore, spatial movements of various kinds in the various dimensions of the harmonic domain are much more simply mirrored using dance mats and wii controllers than by alphanumeric controllers.

When two or more players control a harmonic sequence in real time using the dance mat version, appropriate simple spatial movements can be collaboratively taught with minimal preamble, with lawful, directly perceived results. Thus the affordances offered by the design that relate to conceptual metaphors and conceptual blends in the conceptual structure of the domain can be enacted and experienced more directly using the dance mat version,

Asymmetrical collaborative roles

As well as the relatively obvious advantages of this style of control for engaging with spatial phenomena, asymmetrical co-located collaborative roles are readily supported.

Typically, when musicians collaborate to produce harmony, each musician contributes one or more voices. From many points of view, especially for experts, this more or less symmetrical distribution of roles has many advantages. However, where players are novices, or where there is a desire to gain insights into the abstractions of tonal harmony, one drawback of the conventional approach is that that this process leaves these very abstractions intangible and invisible.

By contrast, in Harmony Space, when used collaboratively to produce harmonic sequences, the roles are not split voice-wise, but are split asymmetrically in a way not possible with other existing musical systems, to the best of our knowledge. Asymmetrical roles available include real time control of: the root path, changes of key, inversions and voicing, chord size, chord quality map, altered chords, and an independent bass line – although for simple pieces of music, only two or three of these roles are typically needed, and may easily be split between two or three players.

It is precisely the combinatorial interplay of these diverse factors that yield the full harmonic sequence. In the case of homophonic sequences, this gives complete expressivity – i.e. anything can be played. (In fact Harmony Space may also be used polyphonically, though in that case the specific set of advantages we are considering here are less clear.)

Loosely speaking, one key motivation for the particular asymmetrical approach we are advocating here is that experiencing these different roles allows players to enact the distinct conceptual metaphors whose blending together we believe plays a key role in the analytical understanding of tonal harmony. With multiple dance mats, players can readily see what other players are doing, and the rhythm in which they are working.

By rotating roles, beginners can understand how these different metaphors can be fitted together to create an overall understanding of how tonal harmony works.

Empirical Observations of use

The asymmetrical Multi-User Co-operative Whole Body has only recently become fully operational, hence to date we have had only had limited experience of novices using the system. However in preliminary trials, soon to be extended, pairs of novices were able within seconds to learn the moves required to play relatively complicated harmonic sequences with correct inversions and altered chords – for example Pachelbel's Canon. Clearly considerably more empirical work is required to explore these very preliminary results in more depth.

Conclusions

This is preliminary speculative work towards a theoretical framework by which the more general implications of whole body interaction applied to abstract domains might be better understood. We have outlined an approach based on conceptual metaphor theory and sensory contingency. More empirical and theoretical work is needed for a fuller understanding of this approach, and its practical efficacy.

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