A Four Strategy Model of Creative Parameter Space Interaction

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Abstract

This paper proposes a new theoretical model for the design of creativity-enhancing interfaces. The combination of user and content creation software is looked at as a creative system, and we tackle the question of how best to design the interface to utilise the abilities of both the computer and the brain. This model has been developed in the context of music technology, but may apply to any situation in which a large number of feature parameters must be adjusted to achieve a creative result. The model of creativity inspiring this approach is Wiggins' Creative Systems Framework. Two further theories from cognitive psychology motivate the model: the notion of creativity being composed of divergent and convergent thought processes, and the "dual process" theory of implicit vs. explicit thought. These two axes are combined to describe four different solution space traversal strategies. The majority of computer interfaces provide separate parameters, altered sequentially. This theory predicts that these one-to-one mappings encourage a particular navigation strategy ("Explicit-Convergent") and as such may inhibit certain aspects of creativity.

Introduction

Although enhancing creativity is often the implied goal, researchers in music technology seem wary of attacking the question of what manner of tools may augment the creativity of the musician. This is perhaps understandable: being one of the most mysterious products of our immensely complex brains, creativity is a great challenge to research. Individuals can vary enormously in how they go about being creative, and results from cognitive neuroscience are still rather contradictory (Dietrich and Kanso 2010). Therefore theoretical guidelines are scarce, and measuring success is difficult. This paper attempts to tie in some findings of cognitive psychology, computational creativity and digital musical instrument (DMI) research, to propose a simple four strategy model of creative interaction. A model that may explain many of the subjective experiences of computer musicians, and assist the design of creativity enhancing interfaces.

Creative Cognition

Guilford (1967) characterised the creative process as a combination of "convergent" and "divergent" thinking. Divergent production is the generation of many provisional candidate solutions to a problem, whereas convergence is the narrowing of the options to find the most appropriate solution. Most modern theories have similar processes present in some form, sometimes referred to by different names such as "Generative" and "Evaluative". Campbell (1960) and Simonton (1999) have considered creativity as a Darwinian process, and propose a process of idea variation and selection.

Another interesting process model of creativity is the incubation-illumination model (Wallas 1926). Illumination is more or less synonymous with "insight". Insight problems are a tool that psychologists have used to study this phenomenon. These are puzzles that no amount of step by step reasoning can solve. They often involve setting up some functional fixedness (commonly known as a "mental block"). Insight occurs when the problem is suddenly seen from a different angle. One claim is that conceptual combination processes can yield insight, but are beneath the level of consciousness. The "special process" model holds that these problems require completely different brain processes from logical or verbal problems (Schooler, Ohlsson, and Brooks 1993).

Wiggins' Creative Systems Framework (CSF) (Wiggins 2006) is a more formal descendent of Boden's theories of artificial creativity (Boden 1992). It describes creativity in terms of the exploration of conceptual space. It consists of the universe of all possible concepts $\mathscr{U}$, an existing conceptual space (for example domain knowledge) $\mathscr{C}$, rules (constraints) that define this conceptual space $\mathscr{R}$, a set of techniques to traverse the space $\mathscr{T}$, and an evaluation method $\mathscr{E}$: a way to assign value to a location c that yields a "fitness function". Exploratory creativity is said to proceed as follows: if traversal takes us outside the space of existing concepts this results in an "aberration". If the aberration proves valuable according to $\mathscr{E}$, then the new point is included in the domain, and the conceptual space is extended. Wiggins claims that transformational creativity (a fundamental shift in the rules of the domain) can be viewed as no different from exploratory creativity but on a meta-level. This is to say that a transformation of conceptual space can be achieved by exploring the conceptual space of conceptual spaces. Later we attempt to adapt this model to apply to a parameter space, to propose what creativity might mean in the (very reduced) case of adjusting continuous controls of a sound synthesis engine.

System 1 / Implicit	System 2 / Implicit
associative	rule-based
holistic	analytic
automatic	controlled
relatively undemanding	demanding
fast acquisition by biology + experience	slow acquisition by cultural and formal tuition
evolved first	evolved recently
short term reactions	long term planning
parallel	serial
large associative memory	limited working memory

Table 1: Contrasts between implicit and explicit thinking (Stanovich and West 2000).

Dual Process Models of Cognition

The formal definition of intuition states that it is the ability to acquire knowledge without the use of reason. This is a rather negative definition, and inspires the question: what mechanisms are present in the brain *apart* from reason? A more positive approach to nailing down intuitiveness is to make use of the "dual process theory" of reasoning (Evans 2003; Kahneman 2011). The dual process hypothesis is that two systems of different capabilities are present in the brain. The first (System 1) is fast, parallel and associative, but can suffer from inflexibility and bias. The second (System 2) is more rational and analytical, but is slower, requires intentional effort, and has limited working memory. In this paper we shall use the more illustrative terms "Implicit" and "Explicit" to refer to System 1 and 2 respectively. Table 1 lists descriptions of the two systems, taken from Stanovich and West (2000). This portrayal is often used by social psychologists to explain why many decisions that humans take (under, for example, time constraints) seem to be irrational (De Martino et al. 2006). The theory, however, is also relevant to a great deal of other human behaviour, including problem solving, human-computer interaction, and surely creativity. It should be noted that both these systems are extremely broad high-level categorisations. Implicit processing, for instance, encompasses a whole host of perceptual, motor, linguistic and emotional systems. For this reason Stanovich (2009) proposes that implicit system should be called TASS (The Autonomous Set of Subsystems), and also suggests the explicit system breaks down into two subsystems: the "reflective" and the "algorithmic".

How might the two processes relate to creativity? Holistic thinking has historically been associated with the right brain, and also with creativity. However, whilst left/right asymmetries can be dramatic (McGilchrist 2009), creativity is unlikely to be an exclusively right-brain phenomenon (Dietrich 2007). One might also conflate divergent thinking with the fast-unconscious system, and convergent thinking with the slow-conscious. However, tacit thinking is mostly quick-access default behaviour, and can be stubbornly inflexible, exactly the *opposite* of novel idea generation.

It is also clear that explicit thinking can create wildly divergent ideas. That is, by asking new questions, intentionally avoiding the obvious by imposing constraints, or redesigning the creative process itself, a point in the solution space may be reached that is very distant from existing concepts (Joyce 2009). This nonetheless relies on a conscious, symbolic, and often systematic approach. Therefore a particularly important aspect of the explicit system's abilities is reflection, or meta-cognition: the ability to inspect one's own thoughts (Buchanan 2001). In Pearce and Wiggins' cognitive model of the composition process, at least three out of the five processes relate to reflective abilities (Pearce and Wiggins 2002). So associating artistic creativity with intuitive thinking misses this fact that transformations can result from using analytical symbolic thought to intentionally change the rules, strategies and even value systems of the creative domain. Next we shall investigate the ramifications of both fast and slow systems being able to conduct both divergent and convergent strategies, and try to define them in terms of solution space traversal mechanisms. This model then prompts consideration of how the interface may help or hinder creative work.

Creative Interaction with Synthesis Parameters

The CSF terminology becomes useful for asking what creativity might mean when navigating a finite, continuous parameter space, such as that provided by a music synthesiser. Whilst the complete CSF is not yet rigorously applied, the main components map well onto the various elements of the human-computer system. As the musician is interacting with the parameter space, and is constrained by it, it is ostensibly a space of viable compositions $\mathscr{C}_{param}$, and the interface provides $\mathscr{T}_{param}$: the mechanisms to navigate the space. Obviously there are cultural and emotional associations that sounds may possess that are not represented in this very reduced domain. Parameters such as pitch, filter cut-off frequency, and amplitude envelopes only represent the lowest levels in the hierarchical conceptual space of music. Nevertheless, for this work we assume that the the higher level concepts mainly influence $\mathscr{E}$. By assuming that the evaluation of the fitness of a given point in parameter space is carried out by the user, difficult questions such as the cultural associations of particular sounds can be side stepped. The interface designer can assume some complex fitness function is being optimised, without needing to know its exact form (though interesting work has been done both tracking users paths through solution space and obtaining value ratings (Jennings, Simonton, and Palmer 2011)). However this does not mean that the navigation of solution space is entirely carried out within the brain. The constraints and "affordances" (Norman 1999) of the tools, notations and abstractions used for composition have a significant effect on the finished product (Mooney 2011; Magnusson 2010). For example, the following situations may arise:

1. The composer will sometimes have a idea in mind, and will therefore need to optimise parameters such that the idea is realised.
2. The composer will, at other times, not have anything specific in mind, and is looking to engage in an exploratory

process that may produce inspiration.

These two scenarios map very well to notions of convergent and divergent thinking. In the first case the creative act has already occurred in the brain of the composer, and all that is necessary is an interface that enables the user to adjust parameters such that the data converges to the idea. Such would be the case in live performance of a score: the piece exists, but should be realised accurately, and according to the performers expressive intent. This is of course a great design challenge. But the second scenario is just as important: the composer embarks on an interactive journey, and unpredictability is a key ingredient. Accidents and surprise are often seen as key components of the creative process (Kronengold 2005; Fiebrink et al. 2010). Therefore would appear that some of the divergent thought can be outsourced to the technology. These technological flukes are analogous to the aberrations in the CSF. Thus the design of the instrument affects creativity, not just in the surface sense that different instruments have varying timbres, but in a deep sense of the interface frames and guides the process, similar to the way language guides thought, or that unconscious priming may change behaviour. A previous experiment has shown that divergent and convergent stages can be best served by different types of interfaces (Tubb and Dixon 2014).

Divergent and convergent modes seem also to have a different relationship to $\mathscr{E}$. Many musicians and sound designers intentionally put themselves into states of mind where they temporarily suspend criticism[1]. This implies that it is useful to disengage evaluation, in order that local minima in that fitness function may be escaped.

The mapping of physical controllers to sound synthesis parameters has been an active research topic for at least twenty years (Winkler 1995; Wanderley and Depalle 2004). Mapping has a significant effect not only on what sounds are easy or difficult to create, but also the subjective experience of the user.

The principal distinctions between types of mappings are as follows (Hunt, Wanderley, and Kirk 2000).

- One-to-many: one control dimension is mapped to many synthesis parameters.
- Many-to-one: many control parameters affect one synth parameter.
- Many-to-many: a combination of the above.

Research has shown (Hunt and Kirk 2000) that complex many-to-many mappings appear to be more effective for expressive performance, and may lead to greater performance improvements with practice. This seems to imply that if a mapping is multi-dimensional, and confounds the users' attempts to analyse and manipulate the dimensions separately, then implicit learning cognitive systems are employed. Dimensions that are amenable to being bound together perceptually are termed "integral" (Jacob et al. 1994). For example colour space is formed of 3 integral dimensions, however colour and position are mutually "separable". Timbre space is large;y integral, therefore one may question the approach of providing dimensions separately. Practice of a complex controller is less like carrying out a series of commands, and more like learning to ride a bike. Eventually this leads to increased processing bandwidth in the action-perception loop. Hunt also suggests that implicit learning frees up explicit resources to work on other things.

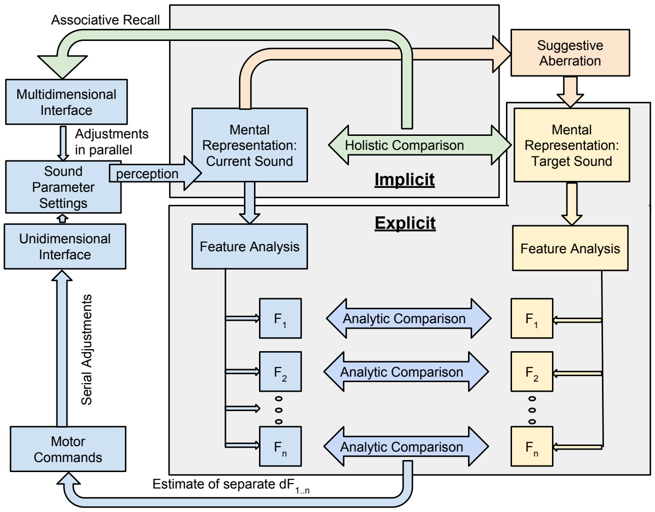

Figure 1: A cognitive model of altering synthesis parameters to match a desired goal. With the use of complex multidimensional controllers (the upper action-perception loop), implicit processes are hypothesised to compute mappings from multidimensional feature sets to motor movements beneath conscious awareness.

A tentative cognitive model of how the implicit and explicit systems navigate parameters is shown in figure 1. This applies to the case when the composer has a specific target in mind, although there is always the possibility that a chance discovery will produce an aberration and an alternative target may be suggested. On the left is the technology, the sound parameters, synthesis engine. Two interfaces are shown, the lower one a unidimensional (slider or WIMP interface) interface and a multi-dimensional (physical controller with complex mapping). If the multi-dimensional interface is well learned, then automatic, holistic processing can process in parallel a large number of features that must otherwise be sequentially adjusted, whilst the goal and its features are held in working memory. The drawbacks of the fast action-perception cycle are firstly, that to become accurate it requires large amounts of practice, and secondly, that it will be poor at adapting to unencountered target sounds or interface mappings. It is worth noting that these drawbacks only apply in the convergent case. For divergence, even an unlearned multidimensional interface may be beneficial (Tubb and Dixon 2014).

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[1] It is unlikely that musicians turn off *all* judgement. It could be that they switch to assessment using fast "gut feeling" assessments (Implicit), rather than more demanding evaluations using analytical, art-theoretical evaluations or a theory of other minds (Explicit).

A Four-Strategy Model of Creative Interaction

This theory details how a simple two stage model of creativity (divergence vs. convergence) and dual process theory (implicit vs. explicit) can be combined to inform the design of creative composition interfaces. It is worth setting out the exact scope of this model. It is not intended to be a model of separate systems within the brain. It is not intended to have any predictive power outside the domain of interaction with a parameter space, though it may prove useful in other areas, and we speculatively propose how these four strategies may interact to produce insight. Furthermore, important cultural, personality and emotional considerations have been ignored. It only addresses what Boden (Boden 1992) terms P-creativity, rather than the H-creativity found in culturally significant achievements. Specifically, it is intended to be a categorisation of parameter search strategies, a summary of how those strategies work together (or not) to create novelty and value, and how parameters should be mapped to gestures to assist each of these processes. This design methodology should prevent the designer forcing the user into the wrong creative problem solving strategy at the wrong time.

Divergent and Convergent Solution-Space Traversal

First of all we attempt to define divergent and convergent processes with reference to the CSF (Wiggins 2006).

Convergent processes are traversal mechanisms that improve the fitness of solutions. These could be a series of discrete options, for example selecting the best sound from a number of candidates, or they could be a continuum, for example finding the "best" setting for a synthesis parameter is a convergent process. Convergence requires both a fitness evaluation $\mathscr{E}$, and some prediction of what change will increase value, which yields a parameter traversal strategy $\mathscr{T}$. $\mathscr{E}$ is therefore actively employed in guiding $\mathscr{T}$. This is analogous to a gradient descent algorithm (these algorithms are said to "converge" on a solution). So whilst some models of creativity postulate generative and evaluative stages, where convergence is just evaluation and selection, in our model convergence can still change the solution (i.e. incremental improvement rather than just evaluation or selection c.f. the "honing" theory of creativity (Gabora 2005)). A second method of convergence is more analytical: where $\mathscr{E}$ can be broken down into smaller individual success criteria, each of which requires a non-creative solution.

Divergent processes are different in that they set aside questions of improving any fitness value, and generate candidate solutions distant from the current ones, e.g. creating lots of more or less randomly scattered points. $\mathscr{E}$ may still operate in the background in order to spot promising new ideas, but is disengaged from directly determining $\mathscr{T}$, in order to prevent it revisiting unoriginal ideas. An alternative divergent approach can be carried out on the meta-level: deliberately transforming the fitness function or the constraints.

Convergence by itself will rarely produce novelty, as multiple runs will settle in the same local minimum. Divergence by itself will produce useless noise. It is the careful blending of these processes that yields progress. Examples abound from machine learning that combine both divergent and convergent behaviours, such as random forests, genetic algorithms and particle swarm optimisation. Balancing the two tendencies is also known as the exploration-exploitation trade-off (Barto 1998). Often such algorithms progressively reduce the diversity component as the search progresses.

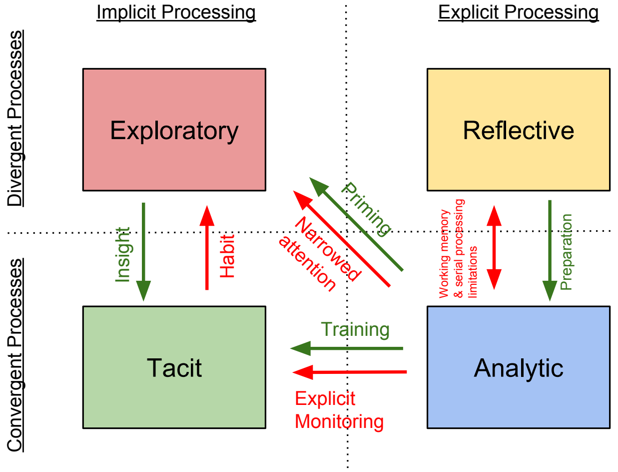

Figure 2: The four quadrants of implicit vs. explicit thinking (left/right) and divergent and convergent thinking (top/bottom). Examples of useful information transfer are shown in green. Examples of detrimental interference effects shown in red.

So by defining divergence and convergence in this way, we see that by strategically connecting and disconnecting judgements of fitness from the parameter navigation strategy, the musician can produce both novelty and value.

The Four Quadrant Model

The central hypothesis in this section is that both fast and slow brain systems may conduct convergent or divergent searches. This results in four distinct parameter space traversal strategies.

Figure 2 shows the four categories: divergent-implicit (exploratory), divergent-explicit (reflective), convergent-implicit (tacit) and convergent-explicit (analytic). These may be strategies carried out within the brain (conceptual space traversal), or actual manipulations of the controls of an instrument (parameter space traversal). Below, each quadrant is described in more detail, both in terms of cognitive processes and interfaces that may augment them.

Exploratory (implicit-divergent) refers to stochastic, associative, combinatorial or transformational processes that can quickly generate a large number of points across a solution space. Examples may be the unconscious process of conceptual recombination, techniques such as brainstorming, or simple playfulness. Computers effectively generate random, transformed and recombined data, therefore exploration is easily augmented.

Tacit (implicit-convergent) is intended to refer to those instinctive or learned techniques that quickly produce a valuable, but probably unoriginal local solution to a problem. These could be instinctive, or learned well enough to become automatic. The appropriate interface is a well learned complex, multi-dimensional, space-multiplexed interface such as a traditional musical instrument, but could also be interaction metaphor such as a physical model that makes use of instinctive understanding of the physical world.

Analytic (explicit-convergent) processes break a problem down into separate components, and solve them in a sequential way. In the solution space it would proceed in a city-block fashion, one dimension at a time. An analytic interface is one such as a DAW[2] that provides individual parameters as knobs and sliders, and sequential, time-multiplexed input devices such as the mouse. These tend to rely on the perceptual aspects of the parameters themselves being fairly independent and separable. The great advantage of this mode is that complex problems can be broken down into simpler parts. With well defined goals and predictably behaved parameters, accurate location of desired solutions can be achieved in linear time, despite the exponential increase in the size of the space.

Reflective (explicit-divergent) refers to meta-cognitive analytical methods that can take existing conceptual spaces and infer new ones: proposing entirely new problem spaces by asking questions or generating hypotheses. One mechanism is that the analytic system *transforms* the solution space, the constraints and/or the fitness function, deliberately forcing converged points out of their local solution finding complacency[3]. Other reflective strategies may be use of metaphor and analogy. For truly transformational creativity this meta-exploration ability is essential. A reflective musical interface might be one that offers the ability to create new musical abstractions, for example a musical programming language (Blackwell and Collins 2005; Bresson, Agon, and Assayag 2011).

The final component to add to this model regards the evaluation process. Judgement too can be divided into implicit and explicit manifestations. Implicit judgement is fast and affective ("I like this" or "I don't like that"). Explicit judgement is more demanding but it is more of a sighted process i.e. also providing the value function gradient ("I like this because..." or "I don't like that, it needs the following...").

All four quadrants play a part in creativity. Take the incubation-illumination model as a, highly speculative, illustration, purely in the cognitive domain. Preparation is the process of asking a new question, or finding a new problem (reflective), and attempting to solve it, consciously via the (methodical) solutions of the past. Applying methods based on past rules and concepts leads to repeated failure, but this process is both activating concepts in the subconscious for recombination (a process known as priming), and tacitly learning how to quickly select a solution (constructing a neural fitness landscape that will function as an unconscious solution recogniser). At some point one of the many divergent (exploratory) subconscious combinations will be implicitly recognised, and then "miraculously" provided to the conscious mind[4]. In this way implicit parallelism can be set to work exploring large regions of a complex solution space.

Insight may be an example of when these strategies gel, however there may also be inhibition effects (some are shown as red arrows in figure 2) when they work against one other. Probably the single most important inhibition effect is that explicit processing is serial, with limited working memory. Therefore if it is fully engaged with analytic processing, e.g. dealing with many separate musical parameters, there will be less resources available for meta-cognition and high level reasoning. Tasks such as critical listening have been shown to suffer under interface-induced higher cognitive load (Mycroft, Reiss, and Stockman 2013). Other inter-quadrant interference effects include "explicit monitoring", also known as "analysis paralysis": a phenomenon where if an attempt is made to consciously control an automatic action, performance suffers (Masters 1992; Wan and Huon 2005). Habit naturally inhibits exploration: an automatic action will tend to be repetitive and inflexible (Barrett 1998).

One final inhibition effect is that analytic thought involves narrowed attention: users may be less open to peripheral cues and remote associations emerging from exploratory processes (Ansburg and Hill 2003). This prediction seems to align with many users' reports of using computers to make music: the fact they can get hung up on details, lose perspective and miss the big picture of what they are attempting to express. Evaluation of one's own work requires taking a step back to get a "perspective" of structure at longer time scales (Nash and Blackwell 2012). Lack of perspective can be a problem when manipulating complex interfaces:

> Participants voiced strong feelings that computer-music systems encouraged endless experimentation and fine-tuning of the minutiae of sound design, in conflict with pushing forward and working on higher-level compositional decisions and creating finished works. (Duignan, Noble, and Biddle 2010)

Unfortunately the reflective attention monitoring system may itself be inhibited, therefore preventing the realisation that perspective has been lost. So, in summary, there seems to be a high risk that explicit-convergent interfaces may inhibit high level transformational creativity.

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[2] The Digital Audio Workstation. Effectively a software reconstruction of an entire recording studio.

[3] A useful analogy would be tipping the surface of a "tilt maze" in order to extract a ball from a hole, and help its progress to the final goal.

[4] Wiggins proposes that the criterion for admission into consciousness is not only the certainty of the idea as a good solution, but also an information theoretic measure of surprise: implying that novelty generation is practically hard-wired into the threshold between implicit and explicit thought (Wiggins 2012).

Discussion

The principal application of the above framework is to generate a number of guidelines by which to design and evaluate creative interfaces. Some of these will already correspond with those put forward within the HCI and DMI literature, some may be novel. However, we propose one underlying principle: just as the dimensional structure of the interface (how the parameters are presented and mapped) must match the perceptual nature of the task (Jacob et al. 1994), so also the structure of the interface must be able to match the current creative strategy of the artist. The computer interface should follow the human thought process as closely as possible, not only in terms of the steps required to *render* a final product, but also in terms of the different geometries of the search strategies employed to *discover* that final product. Therefore the interface must support exploratory, reflective, tacit and analytic modes.

We propose that the incubation-illumination cycle outlined in the previous section is already somewhat mirrored in creative technological interaction. However, to date this has not been specifically designed for, so there is surely room for improvement. Technologies exist that augment each individual quadrant, but principally lacking are easy *transitions between* strategies. For example switching between instrumental play to computer based editing to designing one's own musical abstractions is currently quite demanding, and generally stalls any creative flow. How could all four modes be provided without merely increasing the cognitive load? How, specifically, are these twelve possible[5] transitions to be carried out? This is our topic of further research.

Almost all user interfaces for creative software provide parameters such that features are edited in a separate, serial fashion. These interfaces are used to create music, animation, industrial design, architecture and computer games. They find their way into almost every aspect of 21st century digital culture. If this interaction paradigm really does change the way that people are creative, this seemingly innocent and logical arrangement may already have had significant consequences for the quality of artistic innovations. Will new multidimensional interaction devices encourage a different approach?

Currently, this is just a speculative model, albeit informed by and retrodicting other research and experiences in the electronic music community. Further work will attempt to find evidence for the efficacy of this approach via experiments, interaction data analysis and interviews regarding the artists own strategies of using computers to be creative.

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[5] Enumeration of all of these is beyond the scope of this paper. However one illustrative example would be to start by improvising with a complex tacit interface, but then abstract major themes (perhaps automatically) from that improvisation. These themes would be then gathered in a reduced space, to be explored, recombined and performed using the *same* multi-dimensional interface. Themes in the explorations in this new space could again be extracted, producing a recurrent exploratory/reflective process that also leverages tacit skill.

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