Creativity, Dual Process Theory, and the Navigation of Music Solution-Space

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Abstract. This paper proposes a new theoretical model for the design of creativity-enhancing interfaces. 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. Two theories from cognitive psychology have inspired this approach: the notion of creativity being composed of divergent and convergent thought processes, and the dual process theory of reasoning. These two axes are combined to describe four different solution space-traversal strategies. The majority of computer interfaces provide separate, analytical parameters. This theory claims that these one-to-one mappings encourage a particular navigation strategy ("Explicit-Convergent") and as such fails to enable, and may even inhibit, certain other aspects of creativity.

1 Introduction

Creativity, the ability to create novel and valuable ideas, is one of the most important abilities of the human mind. As one of the most mysterious products of our immensely complex brains, it is a great challenge to research. Individuals can vary enormously in how they go about being creative, and results from the cognitive neuroscience of creativity are still somewhat contradictory [5]. It is perhaps for this reason that researchers in music technology seem wary of directly attacking the question of how to design digital musical instruments that encourage "creativity". Although greater creativity is often the unstated goal, theoretical design guidelines are scarce, and measuring success is difficult. However, musical interface designers are working right on the edge of where digital data meets creative mind, and therefore may be uniquely positioned to research this topic. Composers, performers and researchers working with digital technology have gained quite a clear picture of the delights and pitfalls of music creation interfaces. This paper is an attempt to provide an initial theoretical approach to this problem.

1.1 Creative Cognition

J.P.Guilford [9] characterised the creative process as a combination of "convergent" and "divergent" thinking. Divergence 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. Whilst this is a very simple model of a (presumably) immensely complex brain process, most modern theories have these two processes present in some form, sometimes referred to by different names such as "Generative" and "Evaluative". Campbell [3] and Simonton [16] have considered creativity as a Darwinian process, and similarly propose a process of idea mutation (or recombination) and idea selection.

Another interesting model of creativity is the incubation-illumination model. Helmholtz, Wallas [19] and Hadamard each suggested similar processes involving four main stages: *preparation*: involving researching the problem in question and trying, consciously, to solve it using existing techniques, *incubation*: in which the problem is left alone for a time, but some unconscious part of the brain is still working on the problem, *illumination*: where a sudden flash of insight occurs and the solution presents itself seemingly out of nowhere, and finally *verification* when the solution is checked for its suitability. Illumination is more or less synonymous with "insight". Insight problems are tools 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"). The insight occurs when the problem is suddenly seen from a different angle. It appears that insight requires something beyond step-by-step reasoning or incremental optimisation.

Wiggins' Creative Systems Framework (CSF) [20] is a more formal descendent of Boden's theories of artificial creativity [2]. It describes creativity in terms of the exploration of conceptual space. It consists of the set of all 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 a way to assign value to a location (evaluation $\mathscr{E}$) to give us a "fitness function".

The CSF terminology becomes very useful for asking what creativity might mean when navigating a finite parameter space, such as that provided by a music synthesiser. As the musician is interacting with the parameter space, and is constrained by it, it is ostensibly a space of viable compositions $\mathscr{C}'$, and the interface provides $\mathscr{T}'$: the mechanisms to navigate the space. Obviously there are cultural, emotional associations that are not represented in this very reduced domain, nevertheless we may assume that the these mainly influence $\mathscr{E}$, which is carried out by the user. All of the actual navigation of the space can be recorded within the machine. So $\mathscr{T}'$ is open to study, and the design of a synthesiser interface will change the behaviour of this mechanism. By looking at how a musician navigates the parameter space of a musical instrument, traces of the musician's creative journey can be studied, and by changing the interface we may affect the creative process.

1.2 Dual Process Models of the Brain

A word heard repeatedly in discussions about user interfaces, and particularly music technology, is "intuitive". Obviously if a device

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is consistent with other familiar devices, then users will be familiar with the way it works and may declare it intuitive. However the notion seems to express something deeper than mere familiarity. The truly valuable intuitive interface is one that may be new, but nevertheless immediately satisfies our most basic expectations of what kind of results will follow our gestures, and not require time and effort to "figure out". The formal definition states that intuition is the ability to acquire knowledge without the use of reason. This is a rather negative definition. So the question must be asked: 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 [7] [13]. In Hunt's investigation of parameter mappings [10] there is the claim that complex mappings encourage a switch from analytic to holistic thought processes. The literature on this subject has progressed significantly in recent years, and may be key for the understanding of the difference between fast intuitive thinking and slow analytic processing of musical dimensions. This difference potentially accounts for a good deal of the objective and subjective differences between software-based editing and instrumental performance. Whilst the benefits of practice and automaticity for expert performance are well known [14] [6], what is seldom mentioned is what impact this may have on creativity, specifically in the case where a composer is using an instrument or interface to explore creative solutions.

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. 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. The theory, however, is also relevant to great deal of other human behaviour, including human-computer interaction, and surely creativity. Table 1 lists descriptions of the two systems, taken from Stanovich and West [18].

System 1	**System 2**
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
parallel	serial

Table 1. Contrasts between brain system 1 (implicit thinking) and system 2 (explicit thinking).

It should be noted that both these systems are extremely broad categorisations. A whole host of completely separate perceptual, motor, linguistic and emotional processes come under System 1 in particular. Stanovich [17], for instance, proposes that system 1 should be called TASS (The Autonomous Set of Subsystems), and also suggests System 2 breaks down into two subsystems: the "reflective" and the "algorithmic".

How do these processes relate to creativity? Holistic thinking has historically been associated with the right brain, and also with creativity, but this differs from what modern creativity studies are revealing [4]. Whilst left/right asymmetries are very marked for certain types of thought, there is no evidence for creativity being an exclusively right-brain phenomenon. One might also conflate divergent thinking with the fast-unconscious system, and convergent thinking with the slow-conscious, but this is also mistaken: holistic and tacit knowledge is mostly used to quickly access default "previous best" behaviour, and is therefore often stubbornly inflexible, exactly the *opposite* of novel idea generation.

It is also clear that the analytic system *can* create wildly divergent ideas by a process of meta-cognition. That is, by asking new questions, intentionally avoiding the obvious, or tinkering with the creative process itself, a point in the solution space may be reached that is very distant from existing concepts [12]. This nonetheless relies on a conscious systematic approach. So whilst it is tempting to associate expressive, creative musicality with fast holistic thinking, this misses the fact that transformational creativity can result from using analytical thought to intentionally change the rules, strategies and value systems of the creative domain ($\mathscr{R}$, $\mathscr{T}$ or $\mathscr{E}$). 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.

2 Four Strategy Model

2.1 Scope of this Theory

This theory details how a simple two stage model of creativity (divergence vs. convergence) and a simplified dual process model of cognitive systems (implicit vs. explicit) can be used 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 actual systems within the brain, or to have any predictive power outside the domain of interaction with a parameter space. Specifically, it is intended to be a categorisation of parameter search strategies, a summary of how those strategies work together (or not), and how parameters should be presented 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.

2.2 Solution-Space Traversal

First of all we define divergent and convergent (and hence creative) processes in computational terms.

Convergent processes evaluate and select solutions. These could be a series of discrete options, or they could be a continuum, for example finding the "best" setting for a synthesis parameter would be viewed as a convergent process. In the terminology of the CSF [20], convergence requires both a fitness evaluation function $\mathscr{E}$ and its gradient: which yields a parameter traversal strategy $\mathscr{T}$. For example a comparative enumeration, or a gradient descent algorithm (these algorithms are said to "converge" on a solution). It is strict, in that going "uphill" to explore worse solutions is not allowed.

Divergent processes are different in that they set aside questions of improving any fitness value, and generate candidate solutions distant to the current ones, e.g. creating lots of more or less randomly scattered points. Another divergent approach is to deliberately transform the fitness function or the constraints[2]. The reason divergent processes are required is that convergent strategies become trapped in local minima, and fail to locate overall best solution.

Convergence by itself will rarely produce novelty, as multiple runs will settle in the same location. Divergence by itself will produce

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[2] 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.

useless noise. It is the careful blending of these processes that generates progress. Examples abound from machine learning that combine both divergent and convergent behaviours, such as random forests, genetic algorithms and particle swarm optimisation.

2.3 The Four Quadrant Model

The central hypothesis of this section is that both fast and slow brain systems may conduct convergent or divergent searches. Figure 1 shows the four possible combinations: divergent-implicit (exploratory, top left), divergent-explicit (reflective, top right), convergent-implicit (tacit, bottom left) and convergent-explicit (analytic, bottom right). These may be the strategies carried out within the brain (conceptual space traversal), or actual manipulations of the controls of an instrument (parameter space traversal).

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, interactions enabling recombination or transformation of material, or a computational process of randomisation. Computers can be exceptionally good at generating random, transformed and recombined data but tend not to do so in a very meaningful way.

Tacit (implicit-convergent) is intended to refer to those instinctive or learned techniques that quickly produce a valuable, but unoriginal local solution to a problem. These could be genetic-instinctive or experiential-learned. This, in the solution space would be a fast multi-dimensional gradient descent algorithm, that can efficiently find a local minima in the fitness function. This corresponds to a well learned complex, multi-dimensional, space-multiplexed interface such as a traditional musical instrument, but could also refer to a interaction metaphor such as a physical model that was intuitive and instinctive.

Analytic (explicit-convergent) relates to mental processes that break a problem down into separate components, and solves them in a sequential way. In the solution space it would proceed in a city-block fashion, therefore it tends to work best with separable dimensions. An analytic interface is one such as a digital audio workstation that provides individual parameters as knobs and sliders, and sequential, time-multiplexed input devices such as the mouse and keyboard.

Reflective (explicit-divergent) refers to analytical methods that can take existing concepts and infer new ones, or propose entirely new problem spaces by asking questions or generating hypotheses. There are almost certainly analytic, conscious intentional processes that can generate very distant points in solution space, and should at least feature in our model, notwithstanding the fact that the underlying process may be beyond our current ability to model. One possible mechanism is that the analytic system *transforms* the solution space, the constraints and/or the fitness function, deliberately engineering a large jump, and forcing convergent parts out of their local solution finding complacency. This might include other strategies as use of metaphor, analogy or metacognitive introspection. For truly transformative creativity this meta-exploration ability is essential.

One might then ask, which of these quadrants is most important for musical creativity? The answer must surely be all four. Take the incubation-illumination model as a, highly speculative, illustration. 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. This fails, but you persevere. Throughout this struggle you are both activating concepts in the subconscious for recombination, and tacitly learning how to quickly select a solution: imposing a neural fitness landscape that will function as a fast unconscious solution recogniser (a process known as priming). At some point one of the many divergent subconscious combinations will be intuitively recognised and converged on, and then (seemingly miraculously) provided to the conscious mind for verification by the methodical system.

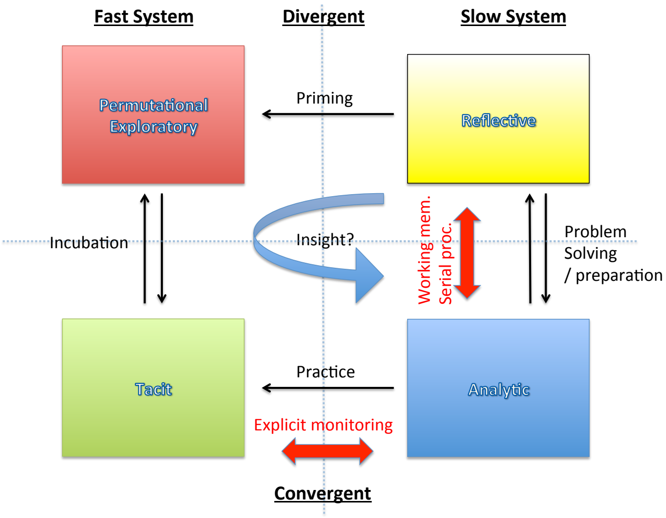

Figure 1. The four quadrants of system 1 vs. system 2 thinking (left/right) and divergent and convergent thinking (top/bottom). Transfer of information, knowledge or concepts are shown as thin arrows. Possible inhibition/interference effects shown as large arrows.

The key fact to reiterate here is that System 2 is a more or less serial process with limited working memory. Therefore, if it is fully engaged with analytic processing, e.g. dealing with many separate musical parameters, it stands to reason that there will be less resources available for meta-cognition and high level reasoning. This prediction seems to gel with users reports of using computers to make music: the fact they can get hung up on details, lose perspective and become distracted from their overall artistic intent.

In the case that reflection does reveal an analytic strategy to change the space in which you are operating, one-to-one mappings again seem less than ideal. What is required is a means of constructing your own abstractions, for example a musical programming language [1]. However, the route from programming a new abstraction to controlling it gesturally is often a time consuming one.

2.4 Some Potential Design Guidelines

The above framework could be used to generate a number of guidelines by which to design creative interfaces. Some of these correspond with those already put forward within the HCI and DMI literature. For example, the three design objectives of reducing system 2 cognitive load, encouraging the development of system 2 automaticity and expertise, and enabling divergent exploration, can be summed up by the guiding principle: “low barrier, high ceiling and wide walls” [15].

Another underlying principle applies: just as the dimensional structure of the interface mapping must match the perceptual nature of the task [11], so also the structure of the interface must be able to match the current creative strategy of the artist. Every computer interface expects a certain form of input, therefore frames the creative question in a certain way. In the case of the provision of separate controls for timbre parameters, the technology prompts the user: which control are you going to alter? In the case that the user has no precise idea (yet) of what kind of sound they wish to create, this is already the wrong question: a case of premature specification. It does not matter in which direction you travel, only that you can explore sounds as effortlessly as possible, and leave the higher cognitive functions free to evaluate and possibly be inspired. This scenario requires a divergent-implicit exploratory interface, not a tacit or methodical one. In the case where the user does have an idea, this idea must be either (a) broken down in the user's mind into its separate properties and then built up step by step (explicit-convergent) or (b) performed real-time using the performers expert implicit-convergent skills. The more the musician can rely on (b) the more high-level creative reflection their frontal lobes can engage in.

The contruction of gesture to synthesis parameter mappings can be an awkward task. It is often another case of premature specification: no specific composition has been constructed, no instrumental expertise has yet been aquired, and yet the user must painstakingly connect many synthesis parameters before exploring the possibilities. Machine learning seems to offer a good approach to this problem [8]. By using a supervised learning algorithm, intuitive gestures can be mapped to complex parameter changes. This may establish the kind of complex multi-dimensional connection that is suited to system 1 processing, freeing the user from analysis of individual parameters in either the mapping or performance stages. The higher levels of variability in the early stages of the training process may actually be a good thing: the early stage of composition is more likely to require divergence, therefore unpredictable results may be welcomed (as long as convergence is available when needed). The ideal system should provide an interface that can provide just the right amounts of unpredictability at any point.

Finally, machine learning also has the potential to enable control of higher level musical abstractions, enabling meta-level (reflective) manipulations of content.

3 Conclusion and Future Directions

Well practiced, effortless navigation of a musical instrument enables the musician to carry out higher level executive functions, these include planning, introspection, social cognition, emotional awareness and so much more. Some of these higher level processes are essential for divergent thinking and hence the creation of novelty.

A goals and tasks based approach to interface design aims to enable the user to realise their ideas as easily and as faithfully as possible. This contains the mistaken assumption that the artist approaches the computer with an idea fully formed, ignoring the exploratory nature of the interaction. The principal recommendation of the above model is that it should be possible for the computer interface to follow the human thought process as closely as possible, not only in terms of rendering a final product, but also in terms of the different geometries of the search strategies employed to reach that final product. Therefore the interface must support exploratory, reflective, tacit and analytic modes. The vast majority of musical tools seem to occupy the lower two quadrants of this model, and these have been the focus of research so far. It may be interesting to explore designs enabling the upper two divergent modes, and note their effect on the composition process.

A further topic of research is whether it is even possible or desirable to enable all four interaction modes simultaneously. Some musicians find they have to deliberately separate sessions: diligent practice, wild experimentation, careful editing housework and mapping and programming need to be allocated their own chunks of time. Others find they need to switch between these modes as the situation arises. What seems clear is that the transition is very difficult, is this because switching modes (or moods) is difficult for the brain? Or is it the interface holding them back? How could all four modes be provided without merely increasing the cognitive load?

Currently, this is just a theoretical model, albeit informed by other research and experience 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 subjective experience of artists using computers to be creative. If nothing else, this discussion may provide technologists further motivation for the investigation of multidimensional instruments, and provide electronic composer-performers with further motivation to practice them!

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