Aspects of a Cognitive Theory of Creativity in Musical Composition

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Abstract. While music perception is frequently studied in psychological or cognitive scientific research, composition is given far less attention and, in either case, musical creativity is rarely discussed. In this paper we attempt to address this imbalance. Our overall goal is to arrive at a clearer understanding of the psychological mechanisms which support creativity in musical composition. We adopt a cognitive scientific approach to attaining this goal and accordingly our theory is derived from psychological studies of human composers at work. Our investigation is pitched at the computational (rather than the algorithmic or implementational) level(s) of description. Five tentative hypotheses are presented which form the basis of a cognitive theory of creativity in musical composition. Each of these hypotheses makes a specific claim about the functional characteristics of the cognitive processes which support creativity in musical composition. They are motivated by previous research in a number of areas (in particular the psychological, musicological and computational literature) which we discuss in detail. Following the cognitive scientific approach, we are engaged in the implementation of the theory as a computational model and the development of a framework for the objective evaluation of the behaviour of the implemented model. We describe how this framework may be used to refute or corroborate the hypotheses.

1 INTRODUCTION

Recent years have seen a steady growth of interest in the development of computational theories and models of compositional processes. These have been developed with a range of aims in mind including algorithmic composition, the development of compositional aids, musicological analysis and the cognitive modelling of musical composition [34]. We adopt a cognitive scientific perspective and our specific goal is to arrive at a clearer understanding of the psychological mechanisms which support creativity in musical composition. In this paper, therefore, we present some important components of a cognitive theory of creativity in musical composition. In so doing, we aim to address two neglected issues in the computational modelling of music cognition. First, while studies of music perception abound, there has been relatively little work (at least in the tradition of cognitive science) that takes composition as its subject [27]. Second, of the research which does address cognitive issues in composition, very little has addressed the question of creativity.

It is common in cognitive science to use the results of psychological experiments on human behaviour to understand the constraints under which mental processes operate and to develop cognitive theories which account for what is possible within those constraints [20, 33]. In accordance with this approach, the tentative cognitive theory of creativity in musical composition to be presented here is based on previous psychological research and may be seen as a statement of some important factors constraining the psychological task of creative composition. Since composition and creativity are large-scale psychological tasks involving poorly understood cognitive mechanisms, our enquiry will be presented at the computational level rather than the algorithmic or hardware levels of description (see [30]). Therefore, we shall be concerned with the question of *what* the mind is doing during creative composition (the logical structure of the task, important constraints that are placed on the composer and the overall nature of the processes that map input to output) rather than the precise algorithmic details of *how* it is doing it.

The paper is structured as follows. In §2, we introduce some features of problem domains that seem to require a creative approach and characterise composition as a creative activity in terms of these features. Our tentative theory consists of five hypotheses about the cognitive processes which support creativity in musical composition. Each hypothesis is presented and justified in §3. Although the hypotheses are derived from psychological or cognitive scientific studies of composition, we do not feel that the existing evidence warrants their presentation as a fully fledged theory of creativity in musical composition. Following the cognitive scientific approach, we are currently engaged in the implementation of the hypotheses in a computational model and the development of a framework for the objective evaluation of the model. These aspects of our research are briefly discussed in §4, where we describe how the hypotheses may be evaluated within our framework. Finally, in §5 we summarise our enquiry and present our conclusions.

2 COMPOSITION AS A CREATIVE ACTIVITY

A problem may be characterised as being *well structured* to the extent that it exhibits some or all of the following characteristics [42]:

1. there is a formally defined criterion to evaluate any potential solution;
2. the start-state, goal-state and all states which may be considered in attempting to solve the problem can be represented in a predefined problem space;
3. all possible transitions from any given state are represented in the problem space;
4. any knowledge which can be acquired about the problem and which may help in selecting one state over another is represented in the problem space.

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Correspondingly, problems are *ill structured* to the extent that they do not exhibit these properties. The features characteristic of ill structured problem spaces correspond closely to those which seem to require a creative approach to problem solving [21, 37].

Musical composition exhibits the following characteristics of an ill-structured problem [7]:

- there is no well defined procedure for evaluating (partially completed) compositions;[3]
- the initial and goal states are poorly defined and there exist many solutions and points of departure;
- many of the constraints (and the rules which apply them) needed to generate a composition, are initially unspecified and must be defined during the process of carrying out the task (often as a result of choosing particular alternatives).

The process of solving an ill structured problem requires its transformation into a well structured problem by decomposing it into a series of smaller well-structured problems [42]. This involves the application of constraints suitable for solving each subsidiary problem and thereby reducing the problem space. Musical composition may, therefore, be characterised as an ill structured problem requiring creative mechanisms to transform it into a well structured one, through the identification and application of constraints throughout the process.

Psychological studies of composition shed light on three types of constraint which may be used by the composer to reduce the problem space in this manner [45]:

1. *stylistic constraints* loosely specified by the compositional type or genre;
2. *internal constraints* generated by what has already been composed, following some general principle of consistency or balance;
3. *external constraints* such as the need to ensure that it is physically possible for a musician to play her part, superordinate principles of harmony and structure (i.e., principles not dependent on previously composed elements of a composition or the musical genre) and the need to produce music which can be interpreted by the intended audience (for example, it is often hard even for musical listeners to perceive structure in twelve-note music).

Most computational models of musical composition take account of stylistic constraints in one of two ways. In the knowledge engineering approach, expert knowledge is used to code such constraints in the form of symbolic rules. An example is provided by Ebcioğlu [13], who developed an expert system for the harmonisation of chorale melodies in the style of J. S. Bach from musicological analysis of Bach's own harmonisations. In the empirical induction approach, on the other hand, a machine learning algorithm is used to induce a compositional model from a corpus of compositions in a particular style. Conklin [8], for example, has developed a system which induces a finite-state grammar from a corpus of examples and has applied the system to the chorale melodies harmonised by Bach.

Most approaches do not explicitly model the use of internal and external constraints; the theory of creativity described in §3 concerns the use of these constraints in composition.

[3] The term composition will henceforth be used to denote both completed and partially completed compositions

3 THE COGNITIVE THEORY

The tentative theory of creativity in musical composition to be described consists of five hypotheses each of which makes specific claims about the functional characteristics of the cognitive processes which support creativity in musical composition. While the first of these hypotheses concerns the use of internal constraints by the composer, the remaining hypotheses concern a particular class of external constraint resulting from the relationship between the compositional mechanisms of the composer and the perceptual mechanisms of the intended audience. In the sections that follow, we describe the hypotheses in detail and present evidence (drawn from the psychological, computational and musicological literature) supporting the inclusion of each hypothesis in a cognitive theory of creativity in musical composition.

3.1 Internal Constraints

Hypothesis 1: Creativity is supported by the ability of the composer to take account of multiple constraints on the emerging composition, in particular the dynamically changing internal constraints.

Internal constraints reflect the manner in which the developing form of a composition imposes its own dynamically changing constraints on possible continuations. The ill structured nature of the compositional task (see §2) means that new material must be constantly adjusted (to conform with earlier constraints) or existing constraints dropped or modified in order to deal with situations where multiple conflicting constraints arise [45]. In general, composition seems to proceed through the use of previous elements as the starting points for continuations which are often modified by the superordinate constraints of harmony and structure. In a study comparing the compositional strategies of novice and expert composers in a harmonisation task [7], it was found that the expert was able to simultaneously take into account not only constraints based on the elementary technical aspects of the task and typical features of the genre but also internal constraints based on the movement of parts and the overall balance of the composition. The novice composers, on the other hand, tended to focus exclusively on basic technical problems which they approached in a rather rigid manner.

We have characterised musical composition as an ill structured problem requiring creative mechanisms to transform it into a well structured one, through the identification and application of internal constraints throughout the process. According to this characterisation, the composer must devote a considerable proportion of her resources to exploring different approaches to the problem (i.e., different internal constraints that might be applied at each stage) and remain ready to change direction (i.e., add, drop or modify constraints). This pattern of behaviour has been termed *problem finding* and is strongly correlated with independent measures of creativity. In a study of art students, for example, Getzels and Csikszentmihalyi [16] found that the problem finding approach was strongly correlated with independent ratings of the creativity of the artists as well as subsequent professional success.

3.2 Multidimensional Representation

Hypothesis 2: Creativity is supported by the ability of the composer to simultaneously represent multiple features of the emerging composition and to move flexibly between them during composition.

An important cognitive constraint on compositional systems arises from the need to represent multiple features of musical events [29]. Regarding pitch, there is much evidence from the literature on music perception that a only a model which represents pitch class relatedness, fifth relatedness and third relatedness as well as pitch height can predict the responses of listeners in psychological experiments (see e.g., [1, 41]). The perception of metre also seems to depend on multiple features of musical events such as tempo, position in sequence, relative duration and length (see e.g., [28, 38]). Finally, psychological studies of the perception of grouping structure in music have demonstrated that this depends on the identification of perceptually salient discontinuities in many dimensions including pitch, dynamics, duration and timbre (see e.g., [11]).

If there exists a close correspondence between the manner in which listeners perceive musical structure and the manner in which the composer represents musical structure in the process of composition [29], then we may hypothesise that the ability to represent multiple features of musical events is an important feature of compositional expertise. Evidence supporting this hypothesis comes from psychological studies of the compositional processes used by expert and novice composers. In a task involving the composition of a melody satisfying certain conditions [10], for example, the expert composers demonstrated that they had a wide range of representations of the emerging composition and were able to move flexibly between them according to the context. They showed, for example, a heightened ability to include rhythmic structure in their representation of the task and to use it extensively in constructing a melody. The novices, on the other hand, tended to represent the problem in a limited number of relatively inflexible ways.

Further support for this hypothesis is provided by work on computational models of composition. *Multiple viewpoint systems*, systems which represent and model multiple attributes of musical events, can provide better compression of music [8] and model the predictions of human listeners more accurately [53] than single viewpoint systems. For example, a system with three viewpoints representing chromatic pitch, pitch interval from the tonic linked to sequential pitch interval and inter-onset interval linked to sequential pitch interval provides better compression of a subset of the chorale melodies harmonised by Bach than a system which represents chromatic pitch alone [8].

Is there evidence to suggest that the ability to represent multiple features of musical events and to move flexibly between them specifically promotes creativity (as opposed to generally promoting competence)? While the psychological evidence that the ability to flexibly represent and manipulate concepts specifically promotes creative achievement is conflicting [36], largely due to methodological difficulties with psychometric testing, the notion of cognitive flexibility has influenced many psychological theories of creativity. For example, cognitive flexibility has been related to the ability to produce artefacts which are qualitatively different from their predecessors and lead to new perspectives on the domain [19] and also to creative musical activity specifically [49]. Finally, it is often argued that a key characteristic of AI systems that enables them to exhibit creative behaviour is a flexible knowledge representation scheme (see e.g., [40, 32]).

3.3 Reflective Strategies

Hypothesis 3: Creativity is supported by the ability of the composer to represent and process musical information in a hierarchical manner and to attend to the more abstract levels of representation during composition.

Another fundamental constraint placed on compositional systems is the requirement that music be represented and processed in hierarchical fashion [29]. An absence of perceived hierarchy has been shown to impair the learning and retention of musical sequences [12] and evidence supporting the use of hierarchical processing in composition can be found in experimental studies of expert and novice composers. On a constrained compositional task [10], for example, the experts appeared to take a more global approach in that they laid out a general structure and worked down to the details in an orderly fashion using such strategies as *means-ends analysis* and *hypothesis-generate-evaluate*. The beginners, on the other hand, used local strategies and worked out the overall structure as they proceeded. The approaches of the experts and beginners are described as *reflective* and *enactive* respectively [10].

In a similar study [7] (see §3.1), it was found that while the novices worked in a chord-by-chord fashion and neglected the constraints imposed by the emerging score, the expert was able to take a broad and strategic approach. These findings are supported by evidence that children who performed compositional tasks successfully used significantly more repetition and development of previously composed material and spent significantly more time in silence (as opposed to playing on a keyboard) than children who were less successful in the compositional tasks [25, 26].

On the basis of evidence such as this, it has been argued that the ill structured nature of musical composition requires reflective planning and processing [18]. In particular, those individuals showing a commitment to higher-order understanding and the integration of new information with old follow the kind of reflective approach necessary for creative composition. Furthermore, these individuals are able to process musical information at increasing levels of abstraction by gaining automaticity in processing the lower levels of abstraction (e.g., notes, signs and intervals) and attending to higher hierarchical levels (e.g., motifs, phrases and themes).

Further support for such a hierarchical processing model in composition is provided by computational models of musical composition. Johnson-Laird [22], for example, presents an enquiry into the constraints imposed on the cognitive processes responsible for competent improvisation, which suggests that while a regular grammar (or formally equivalent procedure) is adequate for computing the contour, onset and offset of the next note, a computational procedure equivalent in power to a context-free grammar is required to compute its pitch. Furthermore, the use of techniques to allow a simple representation of grouping structure increases the ability of finite-state grammars to produce acceptable pieces in the intended style [8].

Once again, we may question whether a reflective approach specifically promotes creativity in musical composition. It seems likely that the identification, application, dropping and modification of internal constraints would occur primarily at more abstract levels of representation. If this is so, the representation and processing of musical information in a hierarchical fashion would be a prerequisite for the emergence of a problem finding approach in composition (see §3.1). Furthermore, Ward, Smith and Finke [48] discuss evidence suggesting that more abstract problem characterisations promote creativity through the affordance of less constrained representations than those which are tied to specific instances. Finally, Boden [3] invokes the theory of *representational redescription* [24] of implicit knowledge on increasingly higher (and more abstract) levels to explain the acquisition of a knowledge framework in which concepts are represented in an appropriately flexible and symbolic manner for transformation and exploration to occur (see §3.4.2).

3.4 Perception and Composition

Hypothesis 4: Creativity is supported by the ability of the composer to transform her compositional mechanisms in order to generate events which invoke an appropriate degree of expectedness, ambiguity or surprise in her perceptual model which has a degree of consistency within a culture, is relatively inflexible, is derived from culturally defined body of previous works in a genre and reflects the manner in which the listener perceives structure in music.

This is the most complex and the most important hypothesis in the theory. It falls naturally into two related parts, concerning the perceptual and compositional mechanisms of the composer respectively, which we shall discuss in turn.

3.4.1 The Perceptual Model

Our second and third hypotheses (see §3.2 and §3.3) concern one particularly important external constraint resulting from the need to compose music whose structure may be perceived by the listener: there must be some kind of alignment between the compositional mechanisms of the composer and the perceptual mechanisms of the listener [29]. This raises the question of how such an alignment can be expected to arise. It has long been recognised in philosophy that agreement in aesthetic judgements depends not only on a common body of shared experience [17] but also on a common set of cognitive schemata which produce a structured representation of the object in the mind of the beholder [23]. Furthermore, the creativity of artefacts is inferred from perceived attributes such as novelty (or originality), appropriateness (or value) and capacity for transforming one's perspective of a domain [3, 19]. Once again agreement between individuals on the attribution of these characteristics to artefacts depends not only on a shared set of experienced artefacts, but also on a shared set of cognitive schemata involved in the perception of structure in the artefacts. The creator works within a rich conceptual space of ideas and it would seem to be necessary for that space to be shared by the intended audience in order for creativity to be recognised and appreciated.

We hypothesise that composers and listeners within a particular musical culture share a *context of ideas* due to the large overlap between their individual spheres of experience. The context of ideas is defined not only by the set of existing compositions in the musical culture but also by a particular manner of perceiving structure in musical compositions. The latter refers both to the way in which the knowledge is represented defining a *conceptual space* of possibilities (see [3]) and the means of traversing that space. We call the set of mechanisms which fulfill these functions the *perceptual model* and hypothesise that it shows a degree of culture-dependent universality, is relatively inflexible and is available to both the listener and the composer.[4]

According to the hypothesis, the composer is able to use the perceptual model to evaluate the effect that her compositions will have on the intended audience. The point is well made by Otto Laske:

> "Makers of art do not know the appreciator's functions explicitly, but since they are social beings, and their own first audience, they are able to intuit and test such functions to a high degree, making use of internalised social conventions." [27, p. 244]

[4] The term *perceptual model* is not intended to imply that the composer consciously constructs a model of the perceptual mechanisms of the listener.

Although the inclusion of a perceptual model would appear to be extremely important in a theory of creativity, it is often neglected in computational models of musical composition. The underlying mechanisms for representing and traversing the space of possible compositions are often taken, either explicitly (see e.g., [2]) or implicitly (see e.g., [22]), to be the same for the composer and the listener: all the constraints imposed on composition arise from within the compositional mechanisms of the composer. In contrast to this approach, we propose that the perceptual mechanisms of the composer constitute a psychologically distinct system for the imposition of constraints through evaluation of the perceptual effects of her compositions. The composer and the listener share similar perceptual systems but the composer possesses, in addition, a distinct set of compositional mechanisms.

Finally, we may ask what kind of musical structure the perceptual model encodes. What is communicated in a piece of music? This question is considered by Sloboda [47] who reports on his work with an autistic man who was able to memorise piano music and reproduce it with a high degree of accuracy but whose performances were mechanical and lacked expressiveness. Since one of the central characteristics of autism is an inability to understand other human beings as conscious and intentional beings, it is argued that the meaning of music resides in the emotions which music has the potential to evoke and, in particular, that what is conveyed by music are "dynamic sensations of flux, tensions and expectations fulfilled and violated" [47, p. 28].

Since music clearly does not have a precise language-like semantics, this analysis leads to a further question. How are such sensations of the generation, resolution and violation of expectancies conveyed by music? One answer is that "music's meaning is *in* its structure rather than being *carried by* its structure" [51, p. 23]. In support of this claim, there is evidence that different emotional reactions to music are related to structural features in a manner that shows some consistency both between and within subjects and which is insensitive to style [46].

To summarise, we hypothesise that the perceptual model exhibits the following characteristics:

- it encodes the structural, context-dependent expectations of the listener engaged in perceiving structure in a piece of music;
- it is derived from the experience of a (culturally specified) corpus of musical compositions;
- it is relatively stable across individuals in a musical culture and over time;
- it is available to both the listener and the composer.

3.4.2 Compositional Mechanisms

In §3.4.1, we argued that a distinction must be made between the perceptual and compositional mechanisms of the composer and that the former reflect the expectations of the listener which are relatively stable both across individuals within a musical culture and over time. In discussing the compositional mechanisms of the composer, we begin with the observation that the composer must have mechanisms available which are capable of generating music which violate the musical expectations of the listener. This follows from the argument that musical communication consists of the manipulation of musical structure by the composer to invoke the generation, resolution and violation of expectancies in the listener (see §3.4.1).

A descriptive account of creativity inspired by computational metaphors holds that:

"A merely novel idea is one which can be described and/or produced by the same set of generative rules as are other, familiar ideas. A genuinely original, or creative, idea is one which cannot." [3, p. 40]

The process of generating "merely novel" artefacts is described as *exploratory* creativity, while the generation of "genuinely original" artefacts is described as *transformational* creativity [4]. A formalisation of this account as an abstract AI system [52], has allowed two extensions:

1. transformational creativity may be characterised either as transforming the rules, $\mathcal{R}$, defining the search space, $\mathcal{C}$, of possible (partial) solutions or those rules, $\mathcal{T}$, defining how to traverse such a space;
2. transformational creativity may be characterised as exploratory creativity over the meta-level spaces of $\mathcal{R}$ and/or $\mathcal{T}$.

In terms of musical composition, Wiggins [52] suggests that $\mathcal{R}$ and $\mathcal{T}$ correspond respectively to the rules defining a musical genre and those defining a particular individual's compositional technique. The framework is illustrated by a discussion of the development of Baroque music as a transformation of $\mathcal{R}_{Modal}$ into $\mathcal{R}_{Tonal}$ thereby expanding $\mathcal{C}_{Modal}$ into $\mathcal{C}_{Tonal}$ and of twelve-note music as a transformation of $\mathcal{R}_{Tonal}$ into $\mathcal{R}_{Twelve-note}$, thereby defining a new conceptual space $\mathcal{C}_{Twelve-note}$.[5]

According to this account, the creative compositional mechanisms of the composer may be characterised as transformations of $\mathcal{T}$ and $\mathcal{R}$. Here we concern ourselves exclusively with the former as a simplifying first step towards understanding creativity in musical composition. Two arguments may be made in defence of such a simplification. First, most creative achievement in music does not involve transformations of $\mathcal{R}$ to generate new conceptual spaces but rather the exploration of existing spaces: "the origins of the symphony are lost in history and its major triumphs are the work of composers who did not invent the basic symphonic form" [15, p. 543]. Second, exploration of a given $\mathcal{C}$ may produce results that are deemed more creative than those generated by transformation of $\mathcal{R}$ especially when the space is large and complex and the product is generated from a little explored part of that space [5].

According to this perspective, the common ground between composers and listeners of a particular historical period is to be found in $\mathcal{T}$, $\mathcal{R}$ and the corresponding conceptual space, $\mathcal{C}$. Creative composition involves the transformation of $\mathcal{T}$ to produce compositions which although they are representable in $\mathcal{C}$ cannot be reached by the $\mathcal{T}$ of the listener. To take an illustrative example, we define a set of rules, $\mathcal{T}_{Twelve-note-perception}$, which define how the typical listener traverses the space $\mathcal{C}_{Twelve-note}$. Furthermore, this set of rules allows us to specify a subset of that space, $\mathcal{C}_{Twelve-note-perception}$ which may be reached by $\mathcal{T}_{Twelve-note-perception}$. If, as we have argued, the composer has mechanisms which allow her to compose music containing events which are not predicted by the perceptual mechanisms of the listener, we may characterise such a process as a transformation of $\mathcal{T}_{Twelve-note-perception}$ to generate compositions in $\mathcal{C}_{Twelve-note} \setminus \mathcal{C}_{Twelve-note-perception}$.

To make the example concrete, consider *Le Marteau sans Maître* composed by Pierre Boulez in 1954. Lerdahl [29] argues that the compositional processes consciously employed by Boulez do not align with the perceptual processes of the typical Western listener. In other words, Boulez has transformed $\mathcal{T}_{Twelve-note-perception}$ into $\mathcal{T}_{Boulez}$ which generates compositions in parts of the space $\mathcal{C}_{Twelve-note}$ that $\mathcal{T}_{Twelve-note-perception}$ is unable to reach. In fact, it took 30 years for musicologists to demonstrate that the piece was, in fact, an example of twelve note music [29].

Our argument, therefore, is that the composer is able to transform her compositional mechanisms (which are closely related to the mechanisms embodied in the perceptual model) in order to generate compositions which violate the expectancies of the listener as encoded in their own perceptual model. However, intuitively we would not value as creative a composition in which all the musical events violated our musical expectations. Support for this intuition comes from the field of experimental aesthetics. The relationship between novelty and aesthetic response to musical sequences appears to follow an inverted *U*-shaped curve [9] suggesting that intermediate degrees are generally considered optimal. Furthermore, compositions with moderate levels of originality (by comparison to the entire repertoire of classical music) also tend to be the most popular [43]. On the basis of evidence such as this, we argue that, in addition to a perceptual model, the composer has a context-dependent model of the degree of expectedness, ambiguity or surprise to invoke in the perceptual model.

To summarise, we hypothesise that the composer has mechanisms which allow the transformation of $\mathcal{T}$ to generate events which invoke the appropriate degrees of predictive surprise, ambiguity or expectedness in the perceptual model and lead to the composition of pieces of music that are appraised as creative.

3.5 Persistent Creativity

Hypothesis 5: Creativity is supported by the ability of the composer to repeatedly transform their compositional mechanisms (as new compositions are added to the repertoire) in order to continue to generate original works.

A characteristic feature of creative individuals is their ability to continue producing artefacts which are appraised as creative works and psychological studies of creative individuals suggest that a preference for originality and complexity are stable attributes that lead to consistently creative work [36]. This is supported by research on two aspects of creativity: the creative individual and the creative product. Regarding the former, Feist concludes his review of research on individual differences and creativity by noting that "the literature overwhelmingly points to the consistency of the creative personality" [14, p. 285].

Regarding the creative product, Simonton [43] found in a study of 15,618 melodic themes by 479 classical composers that melodic originality (as measured by note transition frequencies) was an inverted backwards-*J*-shaped function of the composer's age: originality tends to increase throughout a composer's life (until the average age of 56) and then to fall slightly.[6] This finding holds when originality is calculated by comparison both to the entire repertoire of Western classical music and to the works of the age and has been interpreted in terms of the theory that creators are under constant pressure to produce ever more original work: "Composers cannot sit

[5] It is interesting to note that Simonton [43], in an analysis of 15,618 classical themes (see §3.5), found characteristic peaks of originality with the music of Monteverdi in the Baroque period and of Schoenberg in the twentieth Century.

[6] This measure of melodic originality finds some empirical validation in that the originality scores computed correlate positively with subjective human ratings of the arousal potential of a melodic theme [31]. The measure also correlates with various significant attributes of compositions such as relevant co-occurrent historical events and life events of the composer as well as independent measures of aesthetic success [44].

still and repeat themselves" [44, p. 105]. This interpretation is supported by the finding that the most popular compositions also tend to be those which which depart from the conventions of the day: they have *zeitgeist melodic originality* [43].

Our fourth hypothesis suggests a cognitive mechanism that might underlie the ability to consistently produce (increasingly) original compositions. The composer (under continual internal and external pressure to compose original music) continues to find new compositional techniques for exploring the conceptual space throughout her life, corresponding to a continual transformation of $\mathcal{T}$. This hypothesised relationship between melodic originality and technique is supported by the work of [6] who showed, using an information theoretic analysis of melodic originality, that the compositions of students showed an increase in melodic originality (signified by higher pitch entropy) following a course in composition.

To summarise, Hypothesis 5 states that the composer continually transforms her compositional mechanisms (as suggested in §3.4.2) in order to continue producing original works as the repertoire of existing compositions constantly expands.

4 IMPLEMENTATION AND EVALUATION

Although our hypotheses are derived from previous research on creativity and musical composition, we feel that the existing research provides insufficient evidence to develop the hypotheses outlined above into a general theory of creativity in musical composition. Each hypothesis does, however, make refutable claims about the cognitive mechanisms supporting creativity in musical composition. Following the cognitive scientific approach, we are currently engaged in implementing the hypothesised mechanisms in a computational model of creativity in musical composition. The advantages afforded by implementation are twofold: first, it ensures that all assumptions are clearly stated and that the theory takes as little for granted as possible [20]; and second, it enables the objective comparison of the behaviour of the model with the human behaviour it purports to explain, in terms of accordances and discrepancies with the human data and the generation of currently untested predictions about human behaviour [33].

In accordance with the latter advantage, we are in the process of developing a framework within which the creative behaviour of the implemented model may be objectively evaluated (see [34, 35] for further details). Specifically, the framework is designed to allow the empirical evaluation of the effect each hypothesised component of creativity has on the perceived creativity of the compositions generated by the model.

The framework has several phases. First, it is necessary to precisely define a corpus of compositions; the cognitive model is intended to account for some aspect (in this case the mechanisms underlying creativity) of the compositional competence able to generate that corpus. Second, the goals of the research must be clearly stated as hypotheses regarding the cognitive mechanisms involved in composing pieces in the corpus (see §3). The nature of the hypotheses define the level of abstraction at which the cognitive model is to be evaluated. Third, a program is constructed (using either a machine learning or a knowledge engineering approach) which embodies these hypotheses at an appropriate level of functional abstraction and is used to generate a test set of compositions. Any assumptions guiding the choice of corpus, the development of the hypotheses and decisions made during the development of the representation scheme and algorithms employed by the program are potential sources of bias and "must be made explicit, as they also determine what conclusions may legitimately be drawn from the results of the experiments" [50, p. 72].

Following Ritchie [39], there are two components in the evaluative phase of the framework: first, a set of formal criteria for assessing the creativity of the artefacts generated by the model; and second, a set of rating schemes which use the judgements of human subjects to obtain actual ratings of the perceived creativity of the compositions produced by the model and the corpus of human compositions from which it derives its musical knowledge. The formal criteria and rating schemes may be designed to evaluate any proposed properties of compositions (e.g., non-typicality of the genre or appropriateness) or affective responses to compositions (e.g., surprise) which might be related to perceived creativity.

Each rating scheme is based on experiments which may refute claims (based on the stated goals) made about the system generated compositions. In order to illustrate the nature of the experimental procedures involved, we shall consider the concrete example of Hypothesis 2 (see §3.2) and a rating scheme for originality. This example is provided for the purposes of illustration only. Since many attributes of artefacts (e.g., originality and appropriateness) and affective responses to them (e.g., surprise) are likely to be related to the perception of creativity, the fully developed framework will include a number of different rating schemes. Note also that the other four hypotheses may be evaluated using analogous procedures to those described for Hypothesis 2.

Two programs are developed using the corpus, one of which represents multiple features of musical events and one which does not (see §3.2 for examples of these features). Sets of experimental stimuli are composed consisting of equal numbers of compositions generated by the first and second programs. Subjects are required to listen to the experimental stimuli and to judge the originality of each composition (in relation to the style) on a scale of between one and five.[7] In the final phase of the evaluation, statistical methods are used to test the hypothesis that the mean originality rating of the compositions produced by the first program are higher than that of the compositions produced by the second program. If this test fails to reject the hypothesis, we may consider Hypothesis 2 to have been scientifically corroborated *given the assumptions made in implementing the model*. It must then be tested using different kinds of model embodying different assumptions. Otherwise, the hypothesis is considered to have been refuted *given the assumptions made in implementing the model*. Consequently, the theory and/or the assumptions of the model must be modified, re-implemented and re-evaluated.

Besides allowing hypotheses about the cognitive processes involved in musical composition to be empirically refuted or corroborated, the framework has the advantage that it does not place any restrictions on the genre of music to be modelled, the cognitive hypotheses proposed or the computational techniques used. Once the theory has been corroborated at one level of functional organisation, it may be broken down to a finer level of detail. In the case of our example, this might mean stating hypotheses concerning the particular kinds of feature that are represented. These hypotheses are then implemented and evaluated in the same manner.

5 SUMMARY AND CONCLUSIONS

While music perception is frequently studied in psychological or cognitive scientific research, composition is given far less attention and musical creativity is rarely discussed. We attempt to address this

[7] This is clearly a rather simplistic measure of perceived originality but it will serve for the purposes of illustration.

imbalance by taking as our goal the attainment of a clearer understanding of the psychological mechanisms which support creativity in musical composition. We adopt a cognitive scientific approach to attaining this goal and our investigation is pitched at the computational level.

In §2, we introduced some features of problem domains that seem to require a creative approach and characterised composition as a creative activity in terms of these features. In §3, we presented a tentative cognitive theory of creativity in musical composition consisting of five hypotheses. Each of these hypotheses makes specific and refutable claims about the functional characteristics of the cognitive processes which support creativity in musical composition. We have justified each hypothesis through extensive reference to previous research on creativity and music cognition. Although the hypotheses are derived from psychological or cognitive scientific research on musical composition and creativity, the status of the theory is tentative for several reasons:

- the hypotheses are derived from a small amount of research and speculative argument;
- the necessity of the hypotheses in a cognitive theory of creativity in musical composition is currently unevaluated;
- the hypotheses as a group may not be sufficient to form a full account of creativity in musical composition;
- the hypotheses are stated at a high level of functional abstraction – ideally we would like a more specific account of the hypothesised mechanisms;
- the hypotheses only concern cognitive mechanisms and a full account of creativity will need to account for biological, social and environmental aspects of creativity.

Although the status of the theory is tentative, we are currently engaged in the development of a framework with which the hypotheses may be empirically evaluated, refined and extended. Following the cognitive scientific approach adopted in this enquiry, the first step is to implement the hypothesised mechanisms in a computational model of creativity in musical composition. In §4, we described a framework for evaluation and how it may be used to refute or corroborate the hypotheses.

Although the implementation of the theory presents its own set of difficulties, we have argued that the methodological framework described in §4 will allow the further investigation of the hypotheses and their development into a detailed theory of creativity in musical composition. The tentative theory discussed in this paper, therefore, represents the initial stages of a research programme which shows significant promise for advancing our understanding of the psychological mechanisms underlying creativity in musical composition.

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