Reasoning, imagining, and creating

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Stuart Sutherland (1976) tells the story of a patient at the Maudsley who was suffering from chronic depression. He had been on a regime of antidepressants and he had received a course of ECT treatment. The treatment was stopped due to a lack of improvement. Sutherland also mentions the use of psychotherapy in treating depression.

My theme in this paper is thinking of various sorts, particularly reasoning and imagining. Students of deductive reasoning often argue that people are not very good at it because they are too imaginative: they introduce extraneous premises and fail to stick to the logical task (see e.g. Henle, 1962). Students of creativity, however, often argue that people are not very good at generating new ideas because they are too logical: their thoughts run only along well-worn rational tracks. In the best tradition of British compromise, I want to say: a plaque on both your houses. Reasoning is an imaginative process.

Reasoning and imagining

The best way that I can demonstrate the role of imagination in reasoning is to give you a simple reasoning task. Suppose that you are trying to get on the jury of a murder trial and that two points are established beyond reasonable doubt:

1. The victim was stabbed to death in a cinema during the afternoon showing of Bambi.
2. The suspect was on an express train to Edinburgh when the murder occurred.

What conclusion would you draw?

At this point in the lecture, a dialogue occurred between the audience and the lecturer. The gist of it is reported below.

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your conclusion is invalid, and no matter how much information you are given about the circumstances of the murder, you are unlikely ever to be able to infer validity, that the suspect is innocent. Inference in daily life are seldom deductively closed. Yet, although your conclusion is invalid, if it is challenged, then you can test its validity. When Tivio Anderson and I epitaphetically queried such conclusions in a series of unpublished experiments, our subjects (like the audience in the lecture) searched for alternatives and often produced scenarios in which the subject is guilty. These various phenomena imply that people do not ordinarily reason by following the formal rules of inference of some tacit mental logic (pace Inghofer & Piaget, 1958; Henle, 1962; Osherson, 1975; Johnson-Laird, 1975; Braune, 1979; Rips, 1983; and many others). On the contrary, they reason by carrying out three main operations (Johnson-Laird, 1983):

1. They imagine the state of affairs described by the premises, i.e., they construct a mental model based on the meaning of the premises and on their general knowledge.
2. They formulate an informative conclusion true in the state of affairs characterized by the model.
3. They search for alternative models of the premises that would be counter-examples to their conclusion.

In short, reasoning is not a formal syntactic process that proceeds in a mechanical way; it is a semantic process that depends on imagining states of affairs and on searching for counter-examples.

How might such a search proceed? It probably depends on several distinct procedures. One method consists in straightforward spatial manipulation. The train is in the cinema, the train is in the city, the cinema is at a distance from the train. The train and cinema are spatially separate. They can be moved together in the mind's eye. This manipulation suggests, as subjects are wont to do, either that there might be a cinema on the train, or else that the train is a representant of the cinema, or near to it, and the suspect was able to leave out of the window and stab his victim with a long knife. Another method depends on thinking of the specific event as an instance of a general class, and then using general knowledge about that class to yield a specific method. For example, the murder at an instance of a crime, and part of general knowledge about crimes is that they can be committed by an accomplice.

A variation on this method calls for a species of analogical thinking. If it occurs to you that the murder could be an instance of an action at a remote distance, then part of general knowledge about such actions is that they can be carried out by automatic devices. This idea in turn readily leads to the notions of spring-loaded knives, robots, etc. The difficulty is to think of remote action in the first place. Likewise, if it occurs to you that the victim could have killed himself, then you may be led to a specific way in which the suspect might be guilty. Of the several hundred people to whom I have given the problem, two spontaneously suggested the following ingenious possibility: the suspect gave the victim a post-hypnosis suggestion to stab himself during a certain climactic scene in the film. (Jerry Brunner was one of the people who made this suggestion; the other, according to my informant, was a Swedish princess.)

There are three theories of analogical thinking. They concentrate on the process by which high-level relations, either structural (Geistet, 1983) or semantic (Gick & Holyoak, 1983), can be transferred from one domain to another as an aid to solving a problem. But the critical difficulty, as I have argued elsewhere (Johnson-Laird, in press), is to find the right domain in the first place, that is, to think of action at a distance or of suicide as relevant to the murder in the cinema. There are too many potentially relevant domains for a simple search procedure to succeed. I conclude that the search for counter-examples in everyday reasoning often depends on an exercise of creativity.

Creativity from a computational standpoint

If reasoning depends on a creative search, one is bound to ask: what is creativity? Psychologists, of course, have made many attempts to answer this question (see Perkins, 1981, for an excellent review). However, in my opinion, the best way forward depends on an analysis from a computational standpoint. I will begin with a working definition of creativity that has three classes. First, the process of creativity does not depend merely on recalling some existing idea. When you remember that criminals have accomplices, you are hardly being creative. Second, creative processes do not amount to a calculation or of some other deterministic mental process. When you multiply two numbers together in your head, then you are hardly being creative, even if you get the wrong answer or the result is not what you have never thought of before. Third, creation always requires that its products meet some existing criteria or constraints. A creative event for the murder in the cinema must meet the constraints of the problem. Likewise, novels and poems, jokes and similes, theories and hypotheses, all have their own constraints. There are definite limits of creativity, and even the creation of a new genre must meet certain constraints—not anything goes.

The only clause in this working definition that may cause trouble is the second one: the notion that creative processes are not deterministic. This concept comes from the theory of computability and I need to explain what it is at stake here.

Consider a grammar of English. Somewhere amongst it there will be a set of rules for verb phrases. One rule will allow that a verb phrase can consist of a transitive verb followed by a noun phrase, as in the sentence 'John told a story':
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VP → Verb- transitive NP
and another rule will allow that a verb phrase can consist solely of an intraverbal verb, as in “Mary laughed’.

VP → Verb-intransitive.
Which rule should be used in producing a sentence? The grammar allows either rule and says nothing
about how the choice should be made. In this
respect, the grammar is non-deterministic, to use
an ugly but useful piece of jargon.

If you have seen Clouton’s film, The
Mystery, you will recall that you watch Picasso
painting several pictures. If the film is stopped just
before he makes a brush stroke, then he might be
about to do a stroke that curves upwards or one that
curves downwards. In either case, the result will be a
Picasso painting. Hence, whatever it is that consti-
tutes a Picasso painting does not determine the
precise stroke that should be made at each point in
the making of a picture. From a computational
standpoint, the mental processes underlying the
production of a Picasso—or any other creative product—are not deterministic.

There are different interpretations that you might
wish to place upon this claim. You might say that if
we knew the state of Picasso’s bank balance, or of
his digestion or love life, or the direction in which
the wind was blowing, then one day we would be
able to predict precisely which brush stroke Picasso
would make. In other words, non-determinism is
merely a label for our ignorance. Or you might say
that human beings have the capacity to make
arbitrary choices, and that Picasso merely makes an
arbitrary choice amongst various possible brush
strokes. Experiments have shown that people are
not good at performing in a purely random manner
(Baddeley, 1966), but it does not follow that they
have no machinery for making arbitrary choices.
Perhaps they can make such choices—even unconsciously—by the mental equivalent of spin-
ning a coin (albeit a procedure in which one trial is
not altogether independent from another). Still
another interpretation is that mental processes
ultimately depend on quantum events, which are
totally non-deterministic, and this property is accor-
dingly reflected in Picasso’s decision. I do not know
which, if any, of these interpretations of non-
determinism is correct, though I suspect that human
beings do have the ability to make arbitrary choices.
Since there is no obvious way to decide amongst
them on empirical grounds, I shall be agnostic.
Fortunately, in what follows it makes little differ-
ence which interpretation is made.

1. Neo-Darwinian

Combine/modify
existing elements
arbitrarily

Constraints filter out non-viable products

2. Neo-Lamarckian

Combine/modify
existing elements
acc. to constraints

Make arbitrary choice amongst viable products

3. Multi-Stage

Combine/modify
existing elements
acc. to some constraints

Further constraints
filter out non-viable products

Make arbitrary choice amongst viable products

Figure 1. Three classes of creative algorithm.
The architecture of creative algorithms

Any process that does not depend on magic can be modelled by an algorithm, i.e. a finite set of instructions for an automation such as a computer. This claim, which is sometimes known as Turing's thesis, lies at the heart of the theory of computability. It cannot be proved, but it could be refuted by showing that it is possible to characterize an effective procedure for some task, which could not be executed by an automation such as a computer. Perhaps human creativity does depend on magic—on processes that cannot be given a scientific explanation. Perhaps it depends on quantum events that are not algorithmic and that would refute Turing's thesis. If we take an optimistic view, however, even a rather striking consequence emerges from our working definition of creativity. There are only three possible sorts of algorithms that could underlie creative mental processes.

A creative process must start with some existing 'building blocks', and our working definition entails that it must be both non-deterministic and meet some criteria. One class of algorithms combines the building blocks in an arbitrary way, and then tests the criteria to filter out the rubbish. The arbitrary generative stage ensures that the process is non-deterministic, but obviously most of its products will be non-meaningful. The procedure is analogous to the neo-Darwinian theory of the evolution of species, and I shall use the same label to refer to this sort of creative algorithm. Another and much more efficient class of algorithms uses all the initial generative stage. This procedure, which I shall refer to as 'neo-Lamarckian' for obvious reasons, ensures that only viable products are retained by natural selection. If a feature is desirable, it is often more than one possible step at a given stage of the generative process, it will be necessary to choose which particular step to take. Since all the criteria are taken into account in generating the rank of fitness, the creative result will be a mixture that will not have to be made neutral. The neo-Darwinian algorithms apply the criteria to select amongst the products of the generative stage, and the neo-Lamarckian algorithms apply the criteria to an earlier stage of the generative process. There remains only one other possible class of algorithms: those that use some criteria in generating initial ideas and other criteria in subsequent evolution stages. Indeed, there may be whole breezes of such stages, or equivalently feedback loops, in a sequence to a generative stage. Even when all the criteria have been applied, however, there will still be more than one possible result because the process is non-deterministic. Hence, at various points, arbitrary choices will have to be made to these algorithms as 'multi-stage'. Figure 1 summarises the three classes of algorithm.

Musical improvisation: A case history

When you have a set of just three classes of algorithm for carrying out a task, it is an excellent idea to determine which of them might be employed by human beings. Rather than consider reasoning, which is a difficult task because it depends on meaning, I am going to examine a domain that is more approachable from an algorithmic standpoint, namely music. The profound Psychological question about music is why it should be so popular. Music consists of essentially abstract patterns in time, and these patterns usually have no denotation outside themselves. Music, therefore, might be about in popular as, say, the paintings of Jackson Pollock, which are also abstract patterns. (Pollock was a fine painter, but not even his most ardent admirers would claim that his work has a popular appeal.) Psychologists often say that music is popular because it fits the emotions, but this response merely replaces one question with two: how does music move the emotions? and why do people like having their emotions stirred in this way? I confess that music's popularity remains extremely puzzling to me.

The advantage of studying music is that it can be treated as a purely formal, syntactic, and at least one great composer, Stravinsky, argued in his book Music that such music should be composed and listened to as purely formal patterns in time. By studying musical improvisation, a psychologist can set another advance: improvisers perform in real time, that is, they cannot go back and change what they have played. Hence, the principles of musical improvisation must be represented within their minds, and these principles must be sufficiently general to make certain continuities in their improvisations. In the case of modern jazz, the basic structure consists of sequences of notes, often borrowed from popular music, and the musician improvise novel melodies that fit the particular chord sequence of the group. These structures are readily accessible to consciousness; musicians can describe them in detail, teach them explicitly, and compose new structures. The tacit skill of improvisation, however, is no more accessible to consciousness than our skill in peeling words together when we speak spontaneously. The skill is acquired first by imitating what other musicians play, and then by attempting to improve on oneself. One learns to improve by improvising—at first disadvantageously, skill can be mastered by those that define with their own hand.

A critical datum for improvisation is a 10 x 10 notes per case of modern compositional makes such tests need to explain the gen- eral power, which is somehow greater than the others. They are unable to power therefore the richer set of results, although such in- formation is to be carried essential for an across a given a certain is a generalization of the power is men. Consider, for example: I give you working from ring the current with the next pari have to research since the curry, automation can be in a way that whatever for things it just has to dig, one set for set for where it task of similar equivalent to us but some art in music can say recourse to a more immediate core so such that it is the one by which a component for a component that the device.

The output (a composer's) in a grand modal power so now I can't even improvise. I can improve melody still compare to any memory b. put a sequence of the generation of a the two little pair of musical notes if you don't have to in order to ensure
Just three classes of a task, it is an excellent itself they be employed that consider reasoning, because it depends on examine a domain that is no a logical standpoint, and psychological question should be so popular.

About them in qually have no denotation ought, therefore, to be the paintings of Jackson's exact patterns. (Pollock of even his most ardent his work has a popular say that music is propos-

ons, but this respondion to two with: how does it and why do people like ed in this way? I confess nains extremely puzzling ng music is that it can be syntactic exercise; and at Stravinsky, argued in his should be composed and nal patterns in time. By iteration, a psychologist age: improvisers perform make go back and change. Hence, the principles of be represented within neoplastic must be sufficient to the musician is to ment. So I will begin with

items of improvisation are in due distinct psychological use structures that are d a set of talk skills that iteration from a particular of Indian classical music, set of scale-like patterns in which the musicians weave a case of modern jazz, the equances of the world, often music, and the musicians s that fit the particular rone. The basic state is consciousness: musicians state to explain, ires. The talk skill of is no more accessible to skill in putting words ponsaneously. The skill is in what other musicians opt to improvise for revocation—of first disastrously, but with perseverance the basic skill be mastered. The great improvisers are those that define the genre by setting the standard with their own highly original performances. A critical datum is the speed with which musicians can improvise a genuinely novel melody. Tempo of 10 to 12 notes per second are not uncommon in the case of modern jazz. I am going to advance a computational conjecture about the mechanism that makes such feats feasible, but as a preliminary I need to explain the fundamental notion of compu-

tional power, which plays a central role in my conjecture. One computational device is more powerful than others if it can compute things that they are unable to compute. You might imagine that power therefore depends on having access to a richer set of basic instructions. Surprisingly, although such instructions may enable a computa-

tion to be carried out more efficiently, they are not essential for an increase in what can be computed given a certain minimal set of instructions. The root of power is memory.

Consider, for example, the task of mental ad-

dition: you give a digit from each of two numbers, working from right to left, and you reply with the sum of the current two digits before I present you with the next pair from the two numbers. All you have to remember is whether there is a carry or not, since the carry, if there is one, is always 1. An automaton can be programmed to carry out this task in a way that does not require any memory whatsoever for the results of intermediate compu-

trations: it has just two sets of rules for adding pairs of digits, one set for where there is a carry, and another set for where there is no carry. Now consider the task of multiplying two numbers. This task is equivalent to summing, not just a pair of integers, but some arbitrary number of integers. No auto-

maton can carry out this task without having recourse to a storage mechanism to store intermediate computations—just as you would need to store such results if you were trying to multiply two numbers in your head. Thus, multiplication is *not* for a computational device that has *more* power than the device that is capable for *less* power.

No automatic regardless of its computational power can always be characterized by a grammar. Just as automata differ in their computa-
tional power so too grammars differ in their power. Now I can tell you any conjecture about musical improvisation. It is that the talk principles used to improvise melodies should have the weakest possible computational power. They should not rely on any memory for the results of intermediate com-

putations; rather they should immediately lead to the generation of a note—just as you generate the sum of the two integers by speaking out loud the sum of each pair of digits. The advantage of producing musical notes in this way is speed: things go faster if you do not have to remember intermediate results. In order to ensure that the results of improvisation are interesting, however, the other half of my conjec-

ture is that the basic structures that are composed 'off line' are constructed with a high degree of computational power. How can we test this conjecture? Obviously, we have no direct method of examining the principles underlying an improvisation. Our situation is en-

terly analogous to that of a linguist, who wants to characterize the principles of an unknown language. Our best hope is to examine a corpus of musical improvisations, such as those of modern jazz, with the aim of determining the sort of grammar that is needed to characterize them. We need to construct at least two different grammars: one that underlies the generation of the basic structures—the chord sequences—and one that is used in a transducer that takes a chord sequence as input and then generates an improvised melody that fits it. The prediction that follows from my conjecture is, of course, that the grammar underlying chord sequences will be of a greater computational power than the grammar underlying the tact skills in the transducer. My method has indeed been to try to characterize a corpus of improvisations, but with one important caveat: unlike the majority of linguists, I have attempted to test the adequacy of my grammars by embodying them in a computer program that generates music. The advantages of this procedure are twofold: it readily reveals inadequacies in the grammars, which otherwise would be very difficult to detect, and it establishes that the algorithmic claim that I am making is at least coherent and does not take too much for granted. The disadvantage of this procedure is the difficulty of explaining how an algorithm works without swapping you with an overwhelming amount of technical detail I have implemented three different algorithms, which pro-

duce, respectively: improvises bass lines, impro-

vised melodies, and total chord sequences of the same form. I will leave it to the outlines of each of them.

These are possible hypotheses about how a bass player makes up a bass line. One possibility is that the player merely chooses the notes to play any note that corresponds to making up the current chord in the chord sequence. For example, if the current chord contains the notes G, B, D, and F (G dominant seventh), then the player chooses any of these notes. Since the range of a double bass is rather large, the player will have on average about 8 notes to choose from on each beat of the bar. That is enough degrees of freedom to allow a vast number of possible bass lines for any given chord sequence. However, it is obvious that bass players do not behave in this way. On the one hand, they often choose so-called 'passing notes', which are not amongst the notes in the current chord, but which typically lead from one such note to another in a way that enhances the melodic character of the improvisation; on the other hand, bass players do not leap wildly around
from a low note to a high note—a manoeuvre that is perfectly within the bounds of the present hypothesis.

Another possibility is suggested by Ulrich's (1977), and more recently Levitt's (1981), general account of jazz improvisation. They suggest that musicians learn by heart a vast repertoire of motives, i.e., melodic fragments, from which they select a series of imitations that they tie together to form a melody. While it is true that all improvisers use motives some of the time, I do not believe that any competent improviser uses them all the time. It is much less of a load on memory (and therefore requires much less computational power) to learn to make up new melodies than to remember a vast number of existing melodic fragments, to select instances of them one after another, and to modify them to fit the current harmonic sequence. This view is confirmed by the intimations of the performer's own repertoire, by the ethnomusicologist David Sudnow (1978) who recounts how he learnt the art of jazz improvisation, and by the examination of corpora of improvisations (see e.g. Perlmutter & Greenblatt, 1981). A grammar is a machine for generating motives, but it will generate ones that the musician has never played before. Some such machine appears to be necessary even assuming the theory of Ulrich and Levitt, since the motifs to be learned must be invented by someone.

My hypothesis is that bass players choose their notes in order to meet both the harmonic constraints of the chord sequence, and a vast knowledge of what constitutes a pleasing melodic contour. Roughly speaking, players know that after a certain number of small steps in the pitch of the bass line it is about time to take a large step in pitch, and vice versa. Such a variety makes for a pleasing melodic contour. My algorithm has a bass line that takes a chord sequence as input, and produces an appropriate melody according to the approach that use only a minimum of computational power. On each step of the program, it generates a musical interval according to the rules of a regular grammar of chords, and then selects a note that meets the constraints of the size of the interval, i.e., the harmonic principle, e.g., if the note is on the first beat of the bar and coincides with the start of a new chord, then it should be a note within the chord rather than a passing note. Where more than one note meets the constraints, then a random choice is made between them. (In a computer program, arbitrary choices depend on a technique borrowed from the Cmaso at Monte Carlo: a random number is generated, and its magnitude is used to determine which choice to make.)

A fragment from a typical output of the algorithm is shown in musical notation in Fig. 2. Some outputs are slightly better than this example, and some are slightly worse, but it is typical. The output of the program, which also generates a rudimentary accompaniment, is played by way of a further program devised by my colleague Roy Patterson and Bob Mooy, which synthesizes the sound of a double bass and the accompaniment.

If I had a group with such a bass player, then I don't think I would sack him or her immediately, but there are some obvious defects in the improvisation. The major solecism reveals the existence of a special category of passing notes. Until I heard the output of the program, I did not realize that 20-called 'flattened fifths' had to be treated with more care than other passing notes: the preceding note should tend to be the root or fifth of the chord, or else the sequence may have entirely the wrong harmonic implications (cf. the eighth bar in Fig. 2, which does not sound right). The other defects of the program are that it makes no use of chromatic runs, motifs, or complicated rhythms. It is not my aim, however, to render human bass players obsolete.

Even if these various defects were corrected, the program would still make use of only a minimal memory. It stores the current item generated by the contour grammar until a note is selected, but, as I have mentioned, this grammar is regular, which means that there are no results of intermediate computations to be recorded. The program also has a working memory for the current position in the chord sequence, and a buffer that stores the previous note produced by the program. My conclusion is that viable bas lines can be generated by an algorithm that use only a minimum of computational power. A melody consists of a sequence of notes that each have a specified pitch, duration, loudness, and manner of articulation; it may also contain rests, i.e., silences of a specified duration. My algorithm for melodies ignores loudness and manner of articulation in order to concentrate on pitch and rhythm. Hence, it merely adds a grammar for generating rhythms to the bass program. It takes as input a total chord sequence and produces a sequence of notes and rests on the basis of two regular grammars: one that generates melodic contours, and one that generates rhythms, i.e., the relative durations of notes and rests. If you tap in synchrony with a tune, then you are tapping out a rhythm; and, since you can recognize tunes 'performed' in this way, the critical durations must be the intervals between the onsets of notes. Jazz improvisations like any other melodies are made up of phrases—much as discourse is made up of separate utterances—and the program generates separate phrases. It uses a regular grammar to generate
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grammar to generate the next duration in a phrase. If the item is to be a note as opposed to a rest, the contour grammar generates a step in melodic contour, and finally the program selects a note on the basis of this information and harmonic con-

trasts like those of the bass programs. (I'm not sure whether this consequence of this design, which again relies on a minimum of computational power, is that the choice of the current pitch and duration are not governed by any information about the specific notes to be played next. They are constrained, but only by the information that can be built into the regular grammars for rhythm and contour, and into the set of harmonic prin
ciples.

The grammars that I have so far used to test the program were derived from Christiania's cards. Cards have a simple structure in comparison with modern jazz. Figure 3 presents two representative examples of the output of the program, which to my ear sounds typical of Christiania cards. Whether the same minimal degree of computational power will suffice for the melodic improvisations of modern jazz remains an open question, but in the process of developing the required grammars I have yet to discover any phenomena that would force me to

shod the format of regular grammars.

Figure 3. Two examples of phrases generated by the program for inclusion.

The third algorithm that I have developed pro-
duces tonal chord sequences. Tonality is the basis of most of the familiar forms of Western music, and it relies, as Christopher Le Queux-Higgins (1979) has shown, on a three-dimensional conceptual space that organizes the relations between pitches. Although there is a large theoretical literature on tonal chord sequences (see, for example, Forte, 1979), when the theories are translated into explicit terms, they invariably turn out to be equivalent to regular grammars. But such grammars are not powerful enough to account for the chord sequences of modern jazz, or, I assume, for those of other sorts of tonal music. The basis of this claim is a phenomenon that is familiar to musicians. In many
cases, a jazz chord sequence is developed as a variation on an underlying sequence, which is either traditional or else borrowed from popular music.

Mark Steedman (1982) has outlined a grammar that
generates variations on a given underlying form. His work has inspired my algorithm since it seemed pos-
sible that if I devised an algorithm that generated the underlying forms too, then some principles in

Steedman's grammar would no longer be necessary. In fact, my algorithm vindicates his analysis.

The algorithm contains three stages. The first

stage uses a simple grammar to generate sequences involving the tonic, dominant, and a few other chords. The second stage takes the resulting se-

quence as input and then uses 'context-sensitive' rules like those in Steedman's grammar to make various interpolations and substitutions. The third

stage uses a further set of context-sensitive rules to

make some final substitutions of one sort of chord

for another.

Jazz musicians recognize that there are many

variations on, for example, the following se-

tence:

(1) (non-musicians need not worry about the interpreta-
tion of these symbols, and should treat the word as one in which acceptable strings in an abstract symbolic language have to be generated.) This sequence, which is produced by the first stage of the algorithm, can be transformed by the second stage, which makes interpolations according to the so-called 'cycle of fifths', into the following sequence:

(2) T? V? (3) Alternately, the second and third stages can produce such variations as:

(4) mi7 h7 (5) or:

(6) V7 V7 V7 V7 (7) Of course there are many possible algorithms that could generate the required chord sequences, but what is clear is that any method must make use of a considerable amount of memory for the results of intermediate computations. Each interpretation or substitution is an underlying chord sequence obviously requires a memory for the previous state of the chord sequence. Hence a considerable com-

putational power is required to generate tonal chord sequences, and certainly a greater degree than is implicit in the informal writings of music theorists.

Critics are sometimes sceptical about the use of

grammars. They argue that people 'often break the rules' in order to produce a more original work of art. They also say that although a grammar may capture a genre, individuals have their own unique styles. Both objections are instructive, but not decisive. If a creative process breaks the rules, then it must either make an arbitrary choice regardless of the consequences or be governed by further criteria. Either way, the end result can be captured in a grammar. Similarly, if an individual has a unique style, then it must either depend on arbitrary departures from the criteria of the norm or on slightly different criteria. Either way, the end result can be captured in a grammar. Indeed, a grammar can fail to capture the output of any computational process, whether it is random, prob-

abilistic, or of maximal computational power.

127
Conclusions

The case of musical improvisation is an example of creativity within a genre in 'real time', that is, there is no opportunity for revision. The pressure to produce an adequate performance imposes a considerable computational load on the mind. The solution, I have argued, is for the procedure that runs in real time to have a neo-Lamarckian architecture (see Fig. 1). Such a procedure uses all the constraints of the genre in the generative stage of the creative process, and in this way guarantees that the result is always within the genre. The procedure is efficient, and it can also employ an algorithm of weak computational power. The basic and inviolate programs depend on a long-term memory for chord sequences and for regular grammars of contour and rhythm, but they require only a minimal working memory for intermediate results. They also need a memory that keeps track of the current position in the chord sequence, and a buffer for the most recently produced note. They are psychologically plausible because they would enable a musician to improvise a melody rapidly and without having to carry out complex computations.

Another interesting feature of the programs is that even though they are well understood, it is impossible to predict their output on any particular occasion. They are not deterministic, but they do meet the criteria of the genre, in just the way I claim, that creative processes characteristically operate.

The creation of chord sequences, and works of art such as novels and paintings, is typically carried out within the constraints of an existing genre. The creative processes of scientists normally occur, as Kuhn (1970) has stressed, within the constraints of an existing paradigm. Likewise, the search for counterexamples in everyday reasoning must meet the constraints of the problem. All these types of creativity are likely to depend on a multi-stage architecture, in which constraints are used to generate ideas, and further constraints are used to judge, to monitor, or to revise, the initial products. The search may be spread over many stages, and it need not occur in real time. Musicians, for example, can write down chords, compose, and work on them in the same way as composers. There is therefore no reason for them to rely on an extensive working memory, unlike my program, because they can consult the written chord sequence. Literacy ensures that computational power exacts no psychological price: notation functions as a memory for the results of intermediate computations. It also enables successive generations of composers to contribute to the development of an idea.

The creation of a new genre or paradigm is the most profound and rarest form of creativity. There can be no neo-Lamarckian algorithms for this type of creativity. In an art such as painting, the revolutions that occur—the invention of perspective, say, or the transition from late Cézanne to Cubism—do not seem to be governed by any common set of constraints. Similarly, in a science such as physics, the shifts in paradigm—the introduction of Newtonian mechanics, say, or the subsequent transition to the theory of relativity—do not seem to be governed by any common underlying principles. The success of new genres and new paradigms may depend on criteria of which their creators are ignorant. These criteria include social and economic factors, and, in the case of science, the results of subsequent empirical studies. If there are no common criteria underlying such revolutions, then it follows that a neo-Lamarckian approach is impossible.

There is a long tradition of proposals that innovation depends on tautology, or what I have termed 'neo-Durkheimian'. Some proposals have been satirical, such as Mozart's scheme for composition by the shake of a dice (see O'Brien, 1971), or Swift's machine for invention in the Academy of Lagado in Gulliver's Travels. Other proposals are serious, and a number of authors have urged that the results of randomisation are the only possible creative process (see e.g. Skinner, 1955; Campbell, 1960). The trouble is that the procedure is grossly inefficient. Evolution works because it depends on millions of experiments with billions of organisms over millions of years. As a method for generating ideas in a single lead in a single lifetime, it is the question—a point that was discovered the hard way, when computer scientists tried to construct intelligent programs by assembling them at random from simple components (Fogel et al., 1966).

The conclusion is inescapable. The search for a faultlessly original idea depends on a multi-stage architecture, but it will succeed only if it is guided, at least in part, by constraints of some sort. Knowledge is a potent source of constraints, but knowledge alone is not enough. To return from the promontory to the prosaic, everyone recognizes the importance of the post-hypothesis scenario in the course of the murder in the yard. Nearly everyone has enough knowledge to construct this scenario; yet few people succeed in thinking of it for themselves. Is there perhaps some mental commodity that, if enhanced, would lead to success both here and in other domains—a higher degree of intelligence, a longer working memory, a more rapidly functioning brain, a larger number of associative connections, a higher degree of motivation, or a greater capacity for taking pains? I suspect not. What evidence there is suggests that creativity is not a result of some such commodity; there are plenty of highly intelligent and dedicated individuals (by any measure) who lack the spark of originality. My conjecture is that geniuses need to have their knowledge in a form that can directly generate the generative stages of creativity. Conscious critical knowledge, which is relatively easy to acquire, is in unconsolable generative mood is that perhaps creativity is to be encouraged within a specific, but that we have acquired the rule.

References


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References


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