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7

Improvisation: methods and models

JEFF PRESSING

Introduction

How do people improvise? How is improvisational skill learned and taught? These questions are the subject of this chapter. They are difficult questions, for behind them are long-standing philosophical quandaries such as the origins of novelty and the nature of expertise, which trouble psychologists and artificial intelligence workers today almost as much as they did Plato and Socrates in the fourth and fifth centuries BC.

In a previous article (Pressing 1984*a*) I summarized a number of general properties of the improvisation process on the basis of the diverse historical writings of artists, teachers, and musicologists. This material was integrated with precepts from cognitive psychology to sketch out the beginnings of a general theory of improvisation.

In this article a much more explicit cognitive formulation is presented, the first proper (though by no means necessarily correct) theory of improvised behaviour in music. The building of this theory has required input from many disparate fields with which the general musical reader may not be familiar. For this reason I begin with the survey of appropriate background research and its relation to improvisation. Some of these areas may initially seem distant from the topic at hand.

A survey of pertinent research

Some physiology and neuropsychology

Although our state of knowledge in these areas is far too meagre to have any definite repercussions for improvisation, there are a few facts which are at least strongly suggestive.

To begin with, improvisation (or any type of music performance) includes the folowing components, roughly in the following order:

(1) Complex electrochemical signals are passed between parts of the nervous system and on to endocrine and muscle systems;
(2) muscles, bones, and connective tissues execute a complex sequence of actions;
(3) rapid visual, tactile, and proprioceptive monitoring of actions takes place;
(4) music is produced by the instrument or voice;
(5) self-produced sounds, and other auditory input, are sensed;
(6) sensed sounds are set into cognitive representations and evaluated as music;
(7) further cognitive processing in the central nervous system generates the design of the next action sequence and triggers it.

– return to step (1) and repeat –

It seems apparent that the most starkly drawn distinctions between improvisation and fixed performance lie in steps (6) and (7), with possibly important differences in step (3). This chapter therefore inevitably focuses on these aspects.

The given steps are often collapsed into a three-component information-processing model of human behaviour which has ready physiological analogies: input (sense organs), processing and decision-making (central nervous system, abbreviated CNS), and motor output (muscle systems and glands).

Control of movement by the CNS is complex: the cerebral cortex sends signals to both the cerebellum and the basal ganglia, which process the information and send a new set of signals back to the motor cortex. The brainstem nuclei are also involved in details of motor co-ordination. It has been suggested that the basal ganglia and cerebellum have complementary roles, with the basal ganglia initiating and controlling slow movements while the cerebellum is active in the co-ordination of fast, ballistic movements (Sage 1977).

Motor signals from the cortex pass to the spinal cord and motor nuclei of the cranial nerves via two separate channels: the pyramidal and extra-pyramidal systems. These two nerve tracts illustrate the simultaneously hierarchical and parallel-processing aspects of CNS control, for they run in parallel but interconnect at all main levels: cortex, brainstem, and spinal cord. Hence while each tract has some separate functions there is a redundancy that can be used to facilitate error correction and motor refinement. Similar redundancy and parallel processing is found at lower levels of motor control. Alpha-gamma coactivation, for example, describes the partial redundancy of neural information sent to two distinct types of motoneurons, alpha and gamma, whose axons and collaterals terminate on the main skeletal muscles and the intrafusal muscle fibres, respectively.

The organization of behaviour has often been linked with the existence

of motor action units (or equivalent concepts), and their aggregation into long chains to develop more complex movements. The validity of the concept of motor action units can be seen mirrored physiologically in the existence of command neurons, single nerve cells in invertebrates whose activation alone suffices to elicit a recognizable fragment of behaviour. The effect is achieved by excitation and/or inhibition of a constellation of motoneurons (Bentley and Konishi 1978; Shepherd 1983). While there are no known single cells that fully trigger complex behaviour in mammals, populations of neurons in the brains of higher animals are strongly suspected of serving a similar function (Beatty 1975). It is therefore possible to speculate that skilled improvisers would, through practice, develop general patterns of neural connections specific to improvisational motor control.

Finally, it is of interest that neurological correlates have recently been discovered for a division of knowledge and memory into two separate categories: declarative and procedural. A degree of independence of these two types of memory (for facts or procedures) has been reported among amnesic and post-encephalitic patients for some time (for example Milner 1962; Brooks and Baddeley 1976). Typically, patients can not remember new facts, but are able to learn new motor skills over a period of time, yet without any awareness on successive days of having performed the tasks before. In recent studies, Cohen (1981) and Cohen and Squire (1981) have shown that declarative learning is linked to specific diencephalic and bitemporal brain structures. Unaware of this work, I drew a related distinction in a recent paper (Pressing 1984*a*) between *object* and *process* memory, based on the rehearsal strategies of improvising musicians. As Squire (1982) has pointed out, there are parallel distinctions in earlier writings: artificial intelligence (Winograd 1975), knowing how and knowing that (Ryle 1949), habit memory and pure memory (Bergson 1910), and memory with or without record (Bruner 1969). What is suggestive about these correlations is that physiological locations for some specific cognitive skills used in improvisation might very well exist.

Motor control and skilled performance

This area traditionally has centered around industrial skills, sport, typing, handwriting, specially designed laboratory tasks like tracking, and to a lesser degree music. It is a complex field of considerable relevance to improvisation, even though improvisation *per se* is scarcely mentioned. Therefore I first review general theories of motor control, and then delve into a number of special issues in skilled performance and skill development that are relevant here.

Theories of motor control and skill

The starting point for nearly all the existing theories is the three-stage information-processing model mentioned earlier, based on sensory input, cognitive processing, and motor output. To this must be added the notion of feedback (auditory, visual, tactile, or proprioceptive). Traditional 'open-loop' theories include no feedback, and hence no mechanisms for error correction. In its starkest form this theory is clearly inappropriate for improvisation; however, there is persistent evidence, dating back to the medical work of Lashley (1917), and including studies of insect behaviour and de-afferentiation techniques in monkeys that points to the existence of motor programmes that can run off actions in open-loop fashion.

In contrast stand 'closed-loop' theories, which contain feedback, and hence allow for the intuitively natural possibilities of error detection and correction. The closed-loop negative feedback (CLNF) model is one of the oldest. In this model the feedback (primarily auditory in the case of musical improvisation) is sent back to an earlier stage in the control system which compares actual output with intended output, producing a correction based on the difference between the two (see for example Bernstein 1967). Such closed-loop models have their historical roots in engineering models of servomechanisms, control theory, and cybernetics.

A wide variety of closed-loop formulations has been given. Gel'fand and Tsetlin (1962, 1971) used a mathematical minimization procedure to model the cognitive search for appropriate motor behaviour. Pew and Baron (1978) sketched out a theory of skilled performance based on optimum control (see also Kleinman *et al.* 1971). Powers (1973) proposed a hierarchy of motor control systems whereby the correction procedures of higher-order control systems constitute reference signals for lower-order systems. Another hierarchical model was given by Pew (1974), in which specific single movements are combined into sequences, and ultimately into various subroutines that make up goal-directed action. Actions are then organized and initiated by an executive programme (Fitts 1964). As is apparent, many such hierarchy theories are based on the application of computer programming principles (see Miller *et al.* 1960).

These ideas offer a more sophisticated understanding of motor behaviour, but they have serious limitations. They model motor learning either poorly or not at all, and are not based on empirical findings about human actions (Adams 1961). A closed-loop theory of motor *learning* was proposed by Adams (1971, 1976) in an attempt to rectify some of these problems. In this theory there are 'memory traces' which select and initiate movements and 'perceptual traces' which are representations of the intended movements, and are used as templates for error correction. A perceptual trace is gradually built up by repeated practice from feedback, knowledge of

results (often abbreviated KR), and error correction. Eventually the perceptual trace can function as an internalized goal, diminishing dependence on the externally based knowledge of results (Namikas 1983). Hence open-loop control characteristics are not completely excluded.

By the late 1970s the consensus was that both open- and closed-loop control must occur in skilled performance (Keele and Summers 1976; Delcomyn 1980; Paillard 1980; see Summers 1981 for a review). That is, movements are both centrally stored as motor programmes, and susceptible to tuning (adjustment) on the basis of feedback. Coupled with the well-established concept of *flexibility* characteristic of skilled (but not rote) performance (Welford 1976), this promoted approaches based on more abstract programming notions that brought the field closer to artificial intelligence (and made it more germane to improvisation).

In this spirit Schmidt (1975, 1976) proposed a theory of motor schemata that models both recall and recognition. The schema is considered to contain the general characteristics of a movement which must be organized in any given situation to satisfy environmental requirements and the goals of the performer. Context then guides the production of a series of motor commands that ultimately generate a spatiotemporal pattern of muscle actions. Feedback is based on a template-comparison idea.

Because schemata are not specific movement instructions but are 'generalized' motor programmes, this theory is capable of modelling novelty (at least in a very general way), which the others above could not (except Pew 1974, which also uses a schema notion). The possibility of novelty is also catered to by Schmidt's inclusion of degree of variability of practice conditions as one determiner of schema 'strength'. At its core, the 'novelty problem' is very close to that of improvisation.

Similar to schemata is the notion of action plan. Miller *et al* (1960) gave a general description of plans, while Clark and Clark (1977) described plans for language discourse, and Sloboda (1982) and Shaffer (1980, 1981, 1984) specified plans for playing music. As discussed by Shaffer (1980), a plan is an abstract homomorphism representing the essential structure of the performance and allowing finer details to be generated or located as they are needed during execution.

Other related theories include Allport's proposal of a system of condition-action units which are links between sensory calling patterns and categories of action (Allport 1980). Also related are adjustable control or description structures for artificial intelligence such as *frames* and *scripts* (see below).

This convergence of theory is useful in constructing a model of improvisation (see below). However, it remains rather unspecific, and has run far ahead of experiment. But as of this writing there seems only one alternative in the area of motor behaviour. This is the organizational invariant approach of Turvey, Kugler, Kelso, and others (Turvey 1977;

Kugler *et al.* 1980; see Kelso 1982 for further references). This approach draws on two sources: the ecological perspective of Gibson (1966, 1979) and the dissipative structure model of non-equilibrum thermodynamics (Prigogine 1967; Prigogine and Nicolis 1971). Essentially the theory de-emphasizes notions of cognitive process and control, replacing them with, in so far as is possible, 'organization invariants'. These organization invariants are characteristic constraint structures that allow the emergence of specific spatial relationships and dynamic processes in the behaviour of non-linear systems when the parameters controlling these systems fall in certain critical ranges. Thus if the human motor action apparatus is considered to be (as it certainly is) a non-linear system, characteristic properties of muscle groups and patterns of human limb co-ordination will naturally emerge from the constraints imposed by a given task situation (Kelso *et al.* 1981; Saltzman and Kelso 1983). The proposals are exciting, but their ultimate fate remains unclear. The theory is still being formulated, and comparable ideas from non-linear mathematics have infiltrated many fields in the last 10 years, with uneven results.

Organizational invariant theory seems also likely to apply primarily to the dynamics of motor programme execution, and not to the formulation of intentions and high-level decision-making (Wilberg 1983). Since these functions are vital elements in improvisation in any but an extreme mechanistic approach, the theory as it stands is not particularly suitable for improvisation modelling. Nevertheless, these ideas may be used in an understanding of the sources of behavioural novelty, and are discussed further below.

Some special issues relevant to improvisation

Skill classification Various dimensions of skill classification have been proposed and improvisation can be placed within these. Two possible categories are 'open' skills, which require extensive interaction with external stimuli, and 'closed' skills, which may be run off without reference to the environment (Poulton 1957). Solo improvisation is basically a closed skill, as it relies only on self-produced stimuli, whereas ensemble improvisation is more open. Other dimensions of skill classification are gross-fine, discrete-serial-continuous, complex-simple, and perceptual-motor (Holding 1981). Improvisation is a fine, complex skill, with both perceptual and motor components; continuous actions predominate, although there are also discrete and serial motor aspects. This last point varies somewhat with the nature of the instrument played.

It is important to also emphasize the contrast between unskilled and highly skilled performance. A vast majority of reported skill studies treat simple motor tasks like tracking, under an implicity reductionistic scientific methodology. It is increasingly acknowledged, however, that highly developed skills have distinctive emergent properties missed in these earlier short-term studies, properties such as adaptability, efficiency, fluency, flexibility, and expressiveness (Welford 1976; Shaffer 1980; Sparrow 1983). These are vital components of improvisatory skill.

Feedback and error correction Feedback is a vital component in improvisation for it enables error correction and adaptation—a narrowing of the gap between intended and actual motor and musical effects. But feedback is also important for its motivational (Gibbs and Brown 1956) and attention-focusing effects (Pressing 1984*a*).

Feedback redundancy is an important concept for music. Aural, visual, proprioceptive, and touch feedback reinforce each other for the instrumental improviser, whereas the vocalist has only hearing and proprioception available (Pressing 1984*a*). Likewise the design of some instruments allows more precise visual feedback and more categorical kinaesthetic feedback than others. This is almost certainly why sophisticated improvisation using advanced pitch materials is more difficult on the violin than the piano, and extremely challenging for the vocalist. For every first-rate scat-singer in the world there must be 500 talented jazz saxophonists.

Feedback can also be considered to operate over different time scales. Thus short-term feedback guides ongoing movements, while longer term feedback is used in decision-making and response selection. Still longer term feedback exists in the form of knowledge of results (KR) for skills where external evaluation is present or result perception is not sufficiently precise or immediate. The importance of this for improvisation has been demonstrated by Partchey (1974), who compared the effects of feedback, models, and repetition on students' ability to improvise melodies. Feedback, in the form of playbacks of recordings of the students' own improvisations, was clearly superior to listening to pre-composed model melodies, or repetition, as an improvisation learning technique. In group improvisation, feedback loops would also operate between performers (Pressing 1980).

In view of the interconnectedness of the parts of the central nervous system, it is also clear that there exist internal feedback (and feedforward) loops not based on sensory processing (Brooks 1978). That is, if higher cognitive levels set the design of motor programmes while movement fine structure is specified in closed-loop fashion by lower levels of the CNS, notably the spinal cord, then copies of these lower level motor instructions are almost certainly sent directly back up to higher centres. In other words, there is some kind of central monitoring of efference. This would serve to increase overall processing speed and accuracy.

The role of errors in improvisation has been discussed previously (Pressing 1984*a*). It will simply be pointed out here that errors may accrue at all stages of the human information processing system: perception, movement/musical gesture selection and design, and execution. Minor errors typically demand no compensation in following actions, whereas major errors typically do.

Anticipation, preselection, and feedforward These three concepts have to do with preparation for acton. Physiological recording of the Bereitschaft potential (BP) and contingent negative variation (CNV) (see Brunia 1980) now provides explicit support for the long-standing idea that higher cognitive control centres bias lower ones towards anticipated movements. This is therefore a type of feedforward, and has been described from various perspectives: spinal 'tuning' (Turvey 1977; Easton 1978), corollary discharge or efference copy (von Holst 1954), and preselection (see Kelso and Wallace 1978 for discussion).

The idea of preparation is very important for improvisation, where real-time cognitive processing is often pushed up near its attentional limits. It can be formally proved, for example, that only a control system with a model of disturbances and predictive power can become error free (Kickert *et al.* 1978). For improvised performance that aims at artistic presentation, where discrepancies between intention and result must be kept within strict bounds, practice must attempt to explore the full range of possible motor actions and musical effects, to enable both finer control and the internal modelling of discrepancies and correction procedures, including feedforward.

Hierarchy vs. heterarchy Because of influences of the physical sciences and control theory, an overwhelming majority of models for motor behaviour have used a hierarchical control system. However, the interconnectedness between difference locations in the CNS and the many documented types of feedack and feedforward processes mentioned above argue that this perspective is probably too narrow. Furthermore, explicit parallel-processing possibilities exist due to the separate pyramidal and extrapyramidal neural tracts, alpha-gamma coactivation, etc., as mentioned above. Hence other types of organization, referred to as heterarchical or coalition, have been proposed (McCulloch 1945; von Foerster 1960; Greene 1972; Turvey 1977). In this perspective, executive control of the system may be transferred between different 'levels' depending on the needs of the situation (Miller *et al.* 1960).

Time scales for the control of movement This is a subject with an enormous and complex literature. For background purposes in modelling improvisation a few points only seem sufficient.

Actual neural transmission times are on the order of tens of milliseconds. According to Davis (1957; see also Sage 1977), auditory stimulus activity reaches the cerebral cortex 8–9 ms after stimulation while visual stimulation involves a longer latency of 20–40 ms. Since the two neural pathways are of comparable length, this difference points to a greater

transmission speed for audition than vision. It should, however, be noted that the auditory system contains both ipsilateral and contralateral pathways, while the pathways of the visual system are exclusively crossed. The cortical response time for a movement stimulus appears to be on the order of 10–20 ms (Adams 1976).

Reaction time is the time taken for a sense stimulus to travel to the CNS and return to initiate and execute a largely pre-programmed motor response. Simple reaction time (RT) with only one chosen motor response typically fall in the range 100–250 ms, depending on conditions and sensory modality (Summers 1981). Auditory, kinaesthetic, and tactile reaction times have typically been found to fall in the range 100–160 ms (Chernikoff and Taylor 1952; Higgins and Angel 1970; Glencross 1977; Sage 1977), while visual reaction times have been considered longer, typically reported as at least 190 ms (Keele and Posner 1968). Reaction times for other sensory modalities seem to be in the range above 200 ms, while RTs involving choice of response are in general longer and are reasonably modelled by Hick's Law (Hick 1952). Kinaesthetic and tactile choice reactions seem also to be faster than visual (Leonard 1959; Glencross and Koreman 1979). Data on auditory choice RTs do not seem to be readily available.

Error correction (EC) times vary with sensory modality and context. EC times are important for improvisation because it may reasonably be argued that they reflect minimum times for decision-making that is expressive or compositional. Visual error correction is usually reported to be about 200 ms, whereas kinaesthetic EC can occur over intervals as short as 50–60 ms (Kerr 1982), as seen in reports on tracking tasks (Gibbs 1965; Higgins and Angel 1970). However, other recent work in the case of vision has found some instances of visual EC times down in the range near 100 ms as well (Smith and Brown 1980; Zelaznik *et al.* 1983). It seems likely that the time taken for error correction would be a function of the degree of invoked processing involvement; that is, motor programme construction would take more time than selection, while exacting criteria of discrimination or motor accuracy or a wide range of response choice would naturally increase EC time. Rabbitt and Vyas (1970) and Welford (1974) have enunciated this view, one which is well supported by the introspective reports of improvisers going back for many centuries (Ferand 1961).

Explicit information on auditory error correction times does not seem to be available, but it is possible to point out a general tendency in the above data. Namely, processing speed seems to be greatest for audition and touch/kinaesthesia, of all the possible sensory systems. These are precisely the elements involved in musical improvisation and provide a vivid psychological interpretation for the historical fact that music, of all art and sport forms, has developed improvisation to by far the greatest degree. Under this interpretation, human beings, as creative agents, have as a matter of course drawn on the sensory systems most adapted to quick decision-making: in other words, a predilection for improvised sound manipulation might be genetically programmed. Of course, such an interpretation remains highly speculative.

Finally it should be noted that unexpected sensory changes requiring significant voluntary compensations require a minimum time of about 400–500 ms (Welford 1976). This is therefore the time scale over which improvising players in ensembles can react to each others' introduced novelties (about twice a second). Nuances in continuous improvised performance based on self-monitoring are probably limited by error correction times of about 100 ms (Welford 1976), so that speeds of approximately 10 actions per second and higher involve virtually exclusively pre-programmed actions (Pressing 1984*a*). An informal analysis of jazz solos over a variety of tempos supports this ball-park estimate of the time limits for improvisational novelty.

Timing and movement invariants Up to this point very little has been said about the timing of skilled performance, yet it is obviously a vital point. Considerable experimental work in the domains of fluent speech (Huggins 1978), typing (Shaffer 1978; Terzuolo and Viviani 1979), handwriting (Denier van der Gon and Thuring 1965; Viviani and Terzuolo 1980; Hollerbach 1981), generalized arm trajectories (Morasso 1983), and piano performance (Shaffer 1980, 1984) has established that invariant timing and spatial sequences, strongly suggestive of schemata, underlie skilled actions. Such performance rhythms, or 'hometetic' behaviour, as some have termed it, shows great tuneability: over wide variations in distance and overall time constraints, invariance of phasing and accelerations (equivalently, forces) can be observed (Schmidt 1983). By phasing is meant the relative timings of component parts of the entire movement sequence.

But it is also true that the relative timings of movement components can be changed intentionally, at least to a considerable degree. Hence the improviser has access to generalized action programmes (in both motor and music representation), which allow overall parametric control (time, space, force) *and* subprogram tuneability. This may well be responsible for the flexibility of conception characteristic of experienced improvisation.

Motor memory It has often been suggested that a distinct form of memory for action, called motor memory, exists. The subjective impression of improvisers (and other performers) is certainly that potentially separate yet often interconnected motor, symbolic, and aural forms of memory do exist. For a review of this extensive topic and its relationship to verbal memory the reader may wish to consult Laabs and Simmons (1981).

Skill development

All skill learning seems to share certain common features. In the early stages, a basic movement vocabulary is being assembled and fundamental perceptual distinctions needed for the use of feedback are drawn. In intermediate stages, larger action units are assembled, based on stringing together the existing movement vocabulary in accordance with the developing cognitive framework. These action units begin to enable predictive open-loop response. The ability to perceive distinctions is refined considerably, and internal models of action and error correction are developed. Expressive fluency begins to appear, characterized by a feeling of mindful 'letting go' (Schneider and Fisk 1983; Pressing 1984*a*). By the time advanced or expert stages have been reached, the performer has become highly attuned to subtle perceptual information and has available a vast array of finely timed and tuneable motor programmes. This results in the qualities of efficiency, fluency, flexibility, and expressiveness. All motor organization functions can be handled automatically (without conscious attention) and the performer attends almost exclusively to a higher level of emergent expressive control parameters.

In the case of improvised music these emergent control parameters are notions such as form, timbre, texture, articulation, gesture, activity level, pitch relationships, motoric 'feel', expressive design, emotion, note placement, and dynamics. There must also be a developed priority given to auditory monitoring over kinaesthetic and especially visual monitoring. This idea is supported by research on typists (West 1967), which showed that the dominant visual control used for optimal results in early stages of learning to type gave way later to reliance on tactile and kinaesthetic cues. It also seems likely that sensory discrimination and motor control functions make increasing use of higher order space–time relationships (velocity, acceleration) as skill learning progresses (Marteniuk and Romanow 1983).

The change from *controlled* processing to *automatic* motor processing as a result of extensive skill rehearsal is an idea of long standing (James 1890; Shiffrin and Schneider 1977), and it undoubtedly improves movement quality and integration (Eccles 1972). The accompanying feeling of automaticity, about which much metaphysical speculation exists in the improvisation literature, can be simply viewed as a natural result of considerable practice, a stage at which it has become possible to completely dispense with conscious monitoring of motor programmes, so that the hands appear to have a life of their own, driven by the musical constraints of the situation (Bartlett 1947; Welford 1976; Pressing 1984*a*). In a sense, the performer is played by the music. The same thing happens with common actions like walking and eating. As Welford (1976) has cogently pointed out, automaticity is therefore especially likely when the actions involved are always, or virtually always, accurate to within the requirements of the task. Hence automaticity in improvisation can be frequent in both free and highly structured contexts, since task requirements are often self-chosen, but is more likely to be successful in musical terms for the less experienced player towards the free end of the spectrum.

Schneider and Fisk (1983) have proposed an interesting corollary to the above, based upon a classification of tasks into those requiring *consistent* or *varied* processing: 'Practice leads to apparently resource free automatic productions for consistent processing but does not reduce (attentional) resources needed for a varied processing task.' (p. 129) This idea is appealing and perhaps widely valid, but is too simple to encompass the full complexity of improvisation. For part of the result of extensive practice of improvisation is an abstraction to greater and greater generality of motor and musical controls to the point where highly variable, often novel, *specific* results can be produced based on the automatic use of *general*, highly flexible and tuneable motor programmes. More irrevocable constraints causing attentional loading seem to be timing and interhand co-ordination (Pressing 1984*a*).

Another relevant area is the optimum distribution and nature of practice. Generalizations here are particularly hazardous (Newell 1981) and I will confine my comments specifically to improvisation.

The extremes of massed and distributed practice typically have complementary functions for the improviser. Distributed practice develops immediacy, and consistency of results under variable conditions, whereas massed rehearsal, by perhaps bringing to the player's awareness otherwise unperceived repetitive aspects of his or her music, enables the transcendence or improvement of stale musical design. One is reminded of the opinion of master trumpeter Miles Davis that his sidemen only really got loose in the last set of the night, after they had used up all their well-learned tricks (Carr 1982).

Variability of practice conditions is vital for improvisation, for obvious reasons, and this seems to be true of nearly all skilled behaviour (Schmidt 1983). Mental practice away from the instrument can be important for performers of fixed music, based on internal hearing of scores, but there seems very little record of its use in improvisation. This is presumably due to the intrinsically vital motoric link between performer and instrument for improvisation.

Techniques used by musicians to teach improvisation will be described below. However, some general principles of skill teaching are pertinent here. The successful yet contrasting approaches of the 'discovery' method and structural prescription (the use of instructions or demonstrations) may be mentioned. The basic trial-and-error idea of the discovery method probably requires little explanation; it has often been used as an industrial training procedure, where learning sessions are arranged so that trainees must make active choices which are normally correct, and which therefore

do not lead to ingrained errors (Welford 1976). Less formalized self-discovery techniques are certainly characteristic of much learning in the arts. But structural prescription is also a vital part of skill learning. For all but very simple skills, instructions seem particularly effective when kept simple, and when focusing on goals and general action principles rather than kinematic details (Hendrickson and Schroeder 1941; Holding 1965; Newell 1981). This certainly holds for improvisation. Probably too much intellectual detail both interferes with the fluid organization of action sequences, as mentioned earlier, and strains attentional resources.

Studies and theories of musical improvisation

A cognitive overview of much of this literature has been given earlier (Pressing 1984*a*, which includes references to dance and theatre), and will not be repeated here. Historical surveys of improvisation in Western music may be found in Ferand (1938, 1961), *The new Grove dictionary of music* (1983), and Pressing (1984*b*,*c*). These deal primarily with the period to 1900. Discussion of avant-garde improvisation since 1950 is included in Cope (1984). Non-Western musical improvisation is described by Reck (1983), Datta and Lath (1967), Wade (1973), Jairazbhoy (1971), and Lipiczky (1985) for Indian music; by Nettl and Riddle (1974), Nettl and Foltin (1972), Zonis (1973), Signell (1974, 1977), and Touma (1971) for various Middle Eastern traditions; by Béhague (1980) for Latin American musics; by Hood (1971, 1975), Sumarsam (1981) for gamelans and other stratified ensembles in Southeast Asia, and by Jones (1959) and Locke (1979) for Ewe music of Ghana. Park (1985) has described the improvisation techniques of Korean shamans, Avery (1984) structure and strategy in Azorean–Canadian folkloric song duelling, and Erlmann (1985) variational procedures in Ful'be praise song. Nettl (1974) has provided thoughtful general insights from the perspective of the ethnomusicologist.

In the twentieth century, prescriptive teaching texts on Western music improvisation are legion. Few, however, have the sorts of cognitive insights useful in model building, and almost all are concerned with the specifics of jazz (a small related number with blues and rock) or keyboard (particularly French-tradition organ) improvisation. The jazz texts are too numerous to survey fully here and are in any case mostly quite repetitious. Important perspectives are however given by Coker (1964, 1975), Schuller (1968), Baker (1969), Owens (1974), Liebman *et al.* (1978), Dobbins (1978), Howard (1978), Murphy (1982), and Radano (1985). Among the better organ and piano texts may be mentioned the works of Dupré (1925/37), Schouten (no date given), Gehring (1963), Berkowitz (1975) and Weidner (1984). Analytical and prescriptive texts which stand apart from the typical stylistic conventions above are the works of Bailey (1980), Bresgen (1960), Sperber (1974), Stumme (1972), and Whitmer (1934). Except for Bailey, all of these take tonal music as their primary area of discourse. Discussions which emphasize free improvisation often take a more cognitive approach, but their usefulness is sometimes compromised by vagueness or subjectivity. Valuable readings in this area include Silverman (1962), Jost (1974), Parsons (1978), Bailey (1980), and special issues of *Perspectives of new music* (Fall–Winter 1982/Spring–Summer 1983, 26–111), the *Music educator's journal* (1980, **66**, (5), 36–147), *Keyboard* (1984, **10**(10)), and *The British Journal of Music Education* (1985, **2**(2)). Other works of interest are those on choir improvisation (Ehmann 1950, Ueltzen 1986), silent-film accompaniment (Hanlon 1975), dulcimer improvisation (Schickhaus 1978), and percussion gestures (Goldstein 1983).

Musical improvisation has also been considered as a vehicle for consciousness expansion and the tapping of deep intuitions. A full history of this 'transpersonal' approach would go back thousands of years to the sacred texts of many religions. Here I only survey recent Western opinion. Hamel (1979) has intelligently chronicled music of the avant-garde (for example Riley, Stockhausen) from this perspective. Laneri (1975) has developed a philosophy of improvisation based on different states of consciousness, featuring the concepts of synchronicity and introversion. The resultant music is primarily vocal, since the voice is considered the primal instrument. A powerful system of sonic meditation most applicable to local improvisation groups has been developed by Oliveros (1971). 'Sensing' compositions have been published by Gaburo (1968). An attempt to connect music, altered states of consciousness, and research in parapsychology has been given by Pressing (1980), while Galás (1981/82) has created a primal vocal music based on obsession, excessive behaviour, and trance states of severe concentration.

The approaches in the literature to the teaching of improvisation may be broadly grouped as follows. First, there is the perspective overwhelmingly found in historical Western texts, that improvisation is real-time composition and that no fundamental distinction need be drawn between the two. This philosophy was dominant in pre-Baroque times but had become rare by the eighteenth century. In practice this results in a nuts-and-bolts approach with few implications for the modelling of improvisation beyond basic ideas of variation, embellishment, and other traditional processes of musical development. A second approach, which historically took over as the first one waned, sets out patterns, models, and procedures specific to the improvisational situation, which, if followed by those possessing a solid enough level of musicianship, will produce stylistically appropriate music. In this category fall the many figured bass and melodic embellishment texts of the seventeenth and eighteenth centuries (for example Mersenne 1635; Quantz 1752/1966; Bach 1778/1949; Arnold 1965), as well as the riff compendia and how-to-do-it books in the field of jazz (such as Coker, *et al.* 1970; Slonimsky 1975; Nelson 1966).

A third technique is the setting of a spectrum of improvisational problems or constraints. The philosophy behind this technique shows a clear contrast with the second approach above, as described by Doerschuk (1984), referring to the Dalcroze system.

> The art of improvisation rests on . . . a developed awareness of one's expressive individuality. This knowledge grows through interactive exercises with a teacher, whose function is not to present models for imitation, but to pose problems intended to provoke personal responses. (p. 52)

Jaques-Dalcroze (1921) seems to have pioneered this approach in our century with a revealing series of improvisation exercises for piano. These include composition-like problems in rhythm, melody, expressive nuance, and harmony; muscular exercises; imitation of a teacher; exercises in hand independence; the notation of improvisation just after performing it; and what may be termed an 'interrupt' technique. In this last technique the word 'hopp' is recited by the teacher, as a cue for the student to perform pre-set operations such as transposition or change of tempo during the performance. This technique is reminiscent of a much later suggestion by Roads (1979) that musical grammars used in improvisation might be 'interrupt-driven'. This idea is developed in the model below.

Parsons (1978) has made effective use of this third technique in a collection of short pieces by many different composers defined largely by improvisational instruction sets; he also presents a taxonomy of psycho-improvisational faults and recommended exercises for correcting them. A shorter multi-author collection of improvisational exercises is found in Armbruster (1984). Jazz fake books like the *Real book* (no listed authors or dates) or *The world's greatest fake book* (Sher 1983) may also be considered to act along the lines of this technique.

A fourth approach is the presentation of multiple versions of important musical entities (most commonly motives) by the teacher, leaving the student to infer completely on his or her own the ways in which improvisation or variation may occur by an appreciation of the intrinsic 'fuzziness' of the musical concept. This imitative self-discovery approach is found in the Persian *radif*, which is a repository of musical material learned in a series of increasingly complex versions by the aspiring performer (Nettl and Foltin 1972), and in Ghanaian traditions (K. Ladzekpo, personal communication), for example. A related procedure made possible by the use of recording technology in the twentieth century is for the student to directly copy a number of improvised solos by repeated listening to recordings, and from this extract common elements and variation procedures. Song-form based improvisations, in which solos consist of a number of choruses which repeat the same underlying chord progression, are particularly suitable. This method has been widely used in jazz and blues since the end of the First World War.

A fifth approach is allied to the self-realization ideas of humanistic psychology. It is based on concepts of creativity and expressive individuality which go back in music explicitly at least to Coleman (1922), implicitly certainly to Czerny (1829/1983), and probably in a general sense at least to the Enlightenment. Important educational applications of this idea are found in the works of Carl Orff, Zoltán Kodály, Suzuki (see Mills and Murthy 1973), and particularly Jaques-Dalcroze (1976, 1930) and Shafer (1969). In the words of Jaques-Dalcroze,

> Improvisation is the study of direct relations between cerebral commands and muscular interpretations in order to express one's own musical feelings . . . Performance is propelled by developing the students' powers of sensation, imagination, and memory.
>
> (In Abramson 1980, p. 64.)

Little actual research on optimal techniques for teaching improvisation has been carried out. The important study by Partchey (1973) which showed the value of models and particularly of subsequent aural feedback in learning to improvise has already been mentioned above. Work by Hores (1977) has shown that visual and aural approaches to the teaching of jazz improvisation can be equally effective. Burnsed (1978) looked at the efficacy of design of an introductory jazz improvisation sequence for band students. Seuhs (1979) developed and assessed (by adjudication) a course of study in Baroque improvisation techniques. Bash (1983) compared the effectiveness of three different instructional methods in learning to improvise jazz. Method I was a standard technical procedure based on scales and chords. Method II supplemented this technical dimension with aural perception techniques which included rote vocal responses to blues patterns, blues vocalizations, and instrumental echo response patterns based on rote or procedures of generalization. Method III supplemented the same technical procedures of Method I with a historical–analytical treatment. All three methods gave improved results over that of a control group, and methods II and III, though no significant difference was found between them, were both superior to method I. The results show the value of specific theoretical and technical instruction, and also of its supplementation by relevant aural training or analyses of performance strategies used by virtuoso improvisers.

One final comment on improvisation teaching seems apposite. This is the fact that the optimally effective teacher is able to direct evaluative comments on several different levels. One is the technical—'Your notes don't fit the chord', 'The piano is lagging behind the bass', etc. Another is the compositional—'Try to develop that motive more before discarding it', 'Use more rhythmic variety in pacing your solo', 'Musical quotations seem inappropriate in this free a context', etc. Yet another level is the use of organizing metaphor, a vital part of the tradition of jazz teaching—'Use more space', 'Dig in', 'Go for it', 'Play more laid-back', 'Don't force it—follow the flow', etc. Simple comments of this kind can be remarkably effective at removing improvisational blocks, when delivered at a proper time.

Pike (1974) has presented a brief but insightful phenomenology of jazz. His approach considers the projection of 'tonal imagery' to be the fundamental process in jazz improvisation. Tonal imagery is either 'reproductive' (memory-based) or 'productive' (creative). The improviser operates in a 'perceptual field' which acts as a framework in which the improviser's imagery appears and originates. This field includes not only the perception of external tonal events, but the perception of internal images, as well as the states of consciousness evoked by these images. Images in this field are combined, associated, contrasted, and otherwise organized. The phenomenological operations describing this are processes such as repetition, contrast, continuity, completion, closure, and deviation. Other aspects of improvisation defined by Pike include 'intuitive cognition', an immediate penetration into the singular and expressive nature of an image, and 'prevision', a glimpse into the developmental horizons of an embryonic jazz idea.

Although some of Pike's claims are open to question, for example his uncritical acceptance of concepts like Hodeir's 'vital drive' (Hodeir 1956), his short paper remains an important introspective analysis of the experience of improvisation. The only other extensive phenomenological treatment of improvisation seems to be Mathieu's (1984) study of musician/dancer duo performances. Other perspectives on the experiences of the improviser have been given by Milano (1984), in an interview with jazz pianist/psychiatrist Denny Zeitlin, and Sudnow (1978), who has produced a basic ethnomethodological description of learning to play jazz on the piano. Related philosophical issues have been raised by Alperson (1984) and Kleeman (1985/86).

Finally it may be proper to note that the computer age has spawned new hybrids of composition and improvisation. Fry (1980, 1982/83) has described music and dance improvisation set-ups using computer sensing and control devices. Chadabe (1984) has described a method of 'interactive composition' whereby movements of the hands in space near two proximity-sensitive antennas trigger and exert partial control over real-time computer sound generation. Interactive computer-based performance systems have also been used by trombonist George Lewis and a host of 'performance artists', including this writer. And recently available commercial software, such as the Macintosh-based *M* and *Jam Factory*, has an interactive improvisational component that seems rich with promise.

Oral traditions and folklore

The idea that traditional folk-tales from many cultures have underlying unities, which may be interpreted as narrative grammars, is a fairly well-established one (Propp 1927; Thompson 1946; Nagler 1974). Explanations of this fact have tended towards one or the other of two viewpoints.

A common (particularly European) perspective in the study of oral tradition and folklore has been a focus on their repetitive and imitative aspects, with the frequent assumption of an *Urtext* which has undergone historical and geographic transformation. A powerful opposing view, and one which seems increasingly relevant as a description of referent-based improvisation, is found in the 'formulaic composition' proposals of Milman Parry and Albert Lord (Parry 1930, 1932; Lord 1964, 1965).

Formulaic composition was derived from Milman's intense study of the Homeric epics, particularly the *Odyssey*, and given further support by research on Yugoslav folk-epic poetry conducted by Milman and Lord. It is also considered to be applicable to other oral epics such as *Beowulf* and the *Chanson de Roland*, and has been used to analyse Latvian folk-song texts (Vīķis-Freibergs 1984). In this view epic oral poetry is created anew at each performance by the singer from a store of formulas, a store of themes, and a technique of composition. There is no 'original' version; instead the tradition is multiform. A 'formula' is a group of words regularly employed under the same metrical conditions to express a given essential idea; it has melodic, metric, syntactic, and acoustic dimensions. By choosing from a repertoire of roughly synonymous formulas of different lengths and expanding or deleting subthemes according to the needs of the performance situation, the experienced performer is able to formulaically compose (in real-time, hence improvise) a detailed and freshly compelling version of a known song epic. As a result of the composition system, instances of pleonasm and parataxis are common.

The formulas considered as a group reveal further patterns. In the words of Lord (1964): 'the really significant element in the process is . . . the setting up of various patterns that make adjustment of phrase and creation of phrases by analogy possible' (p.37). In addition, the permutation of events and formulas may occur, as well as the substitution of one theme for another.

Yet the traditional singer does not seek originality with this technique, but heightened expression. Lord speculates that formulas originally grew out of a need for intensification of meaning or evocation. 'The poet was sorcerer and seer before he became artist' (Lord 1964, p. 67).

The relevance of formulaic composition to specific types of musical improvisation has recently been discussed by several writers. Treitler (1974) has argued that Gregorian chant was composed and transmitted in an analogous process to that used in the oral epics. Smith (1983) has used the process to describe the constraints imposed on the song-based jazz performer, and has gone on to analyse piano improvisations by Bill Evans. Kernfeld (1983) has examined how far formulas may be used to describe the music of saxophonist John Coltrane. Reck (1983) has produced the evocative idea of a musician's 'tool-kit', in a mammoth study of five performances by South Indian musician Thirugokarnam Ramachandra Iyer. The tool-kit is considered to be piece-specific and to contain both individually chosen and culturally determined formulas, musical habits, models of improvisational and compositional forms, aesthetic values, and social attitudes.

The application of Parry–Lord theory to musical improvisation is thus a clear contemporary trend. The limits of its validity and usefulness are still open questions, and are probably linked to whether a satisfactory agreement can be reached on the principles to be used to define musical 'formulas'.

Intuition and creativity

These are two related concepts, each with a vast literature. Their connection with improvisation is undeniable, yet explicit mention of it in either field is rare. On the other hand, 'free' musicians and many music educators commonly use the two terms, but often without a very clear notion of just what is being discussed. This section attempts to bridge that gap.

The concept of intuition is much older than creativity, and it has separate philosophical and psychological traditions. Westcott (1968) has provided an excellent general survey, enumerating three historical approaches to philosophies of intuition. First comes Classical Intuition (for example Spinoza, Croce, Bergson), which views intuition as a special kind of contact with a prime reality, a glimpse of ultimate truth unclouded by the machinations of reason or the compulsions of instinct. Knowledge gained through this kind of intuition is unique, immediate, personal, unverifiable. The second approach, called by Westcott Contemporary Intuitionism (for example Stocks 1939; Ewing 1941; Bahm 1960), takes the more restricted view that intuition is the immediate apprehension of certain basic truths (of deduction, mathematical axioms, causality, etc.). This immediate knowing stands outside logic or reason and yet is the only foundation upon which they can be built. Knowledge gained through intuition constitutes a set of 'justifiable beliefs', which are nevertheless subject to the possibility of error. A third approach is positivistic (for example Bunge 1962) in that it rejects as illusory both the notions of immediacy and ultimate truth found in some earlier views. Rather, an intuition is simply a rapid inference which produces a hypothesis.

Of all these views, it is perhaps that of French philosopher Henri

Bergson (1859–1941) which shows the greatest affinities with the common metaphors of improvisation. Bergson saw intuition as a way to attain direct contact with a prime reality ordinarily masked from human knowledge. This prime reality is an ongoing movement, an evolving dynamic flux which proceeds along a definite but unpredictable course.

> The prime reality is referred to as 'the perpetual happening' or 'duration'. The mind of man, according to Bergson, is shielded from the perpetual happening by the intellect, which imposes 'patterned immobility' on prime reality, distorting, inmobilizing, and separating it into discrete objects, events and processes. In the perpetual happening itself, all events, objects, and processes are unified'
>
> (In Westcott 1968, p. 8).

In Bergson's view, the intellect can freely interact with the fruits of intuition (special knowledge and experience) to develop an enriched personal perspective.

The notion of tapping a prime reality is very similar to the improviser's aesthetic of tapping the flow of the music, as mentioned above. The same apparent process has been eloquently described with regard to the origins of folk-tales from many cultures by English writer Richard Adams:

> I have a vision of—the world as the astronauts saw it—a shining globe, poised in space and rotating on its polar axis. Round it, enveloping it entirely, as one Chinese carved ivory ball encloses another within it, is a second . . . gossamer-like sphere . . . rotating freely and independently of the rotation of the earth.
>
> Within this outer web we live. It soaks up, transmutes and is charged with human experience, exuded from the world within like steam or an aroma from cooking food. The story-teller is he who reaches up, grasps that part of the web which happens to be above his head at the moment and draws it down—it is, of course, elastic and unbreakable—to touch the earth. When he has told his story—its story—he releases it and it springs back and continues in rotation. The web moves continually above us, so that in time every point on its interior surface passes directly above every point on the surface of the world. This is why the same stories are found all over the world, among different people who can have had little or no communication with each other.
>
> (Adams 1980, p. 12.)

There is a clear convergence of imagery in this and other descriptions that points to a likely transpersonal component to improvisation.

The psychological perspectives on intuition are many and varied, but only two seem relevant here. The first is the widely occurring idea that intuition is a special case of inference which draws on cues and associations not ordinarily used (Westcott 1968). A similarity with certain theories of skill learning mentioned above is apparent. A second and wide-ranging approach is found in the recent work by Bastick (1982), which includes a search of over 2.5 million sources for common properties underlying intuition. After the identification and detailed analysis of some 20 of these

properties, Bastick ends up describing intuition as a combinatorial process operating over pre-existing connections among elements of different 'emotional sets'. These emotional sets apparently contain encodings, often redundant, of many different life events (intellectual activities, movement, emotion, etc.). By giving strong emphasis to the role of dynamics, bodily experience, and the maximizing of redundancy in encoding, and by a series of suggestive diagrams of intuitive processing, Bastick seems to be on an important track parallel to emerging ideas of improvisation.

Research in creativity is probably more extensive than that in intuition, for intuition is most commonly considered a subcategory of creativity. Creativity research in music education has been recently surveyed by Richardson (1983). The only clear relations to improvisation she found were in specialized educational methods and a growing tendency to use improvisation tests in assessing musical creativity. Vaughan (1971), Gorder (1976), and Webster (1977) have designed and implemented such tests, but results show uneven patterns of correlation between general intelligence, creativity, musicality, composition, and improvisation, and seem to have no clear consequences for improvisation modelling.

General studies of creativity abound, and follow many divergent paths. Two alone seem relevant here. Guilford's Structure-of-Intellect (SI) model proposed a taxonomy of factors of intelligence (Guilford and Hoepfner 1971 (and earlier references mentioned therein); Guilford 1977). These intelligence factors, which number 120, are classified along three dimensions:

thought content: visual, auditory figural, semantic, symbolic, and behavioural information;

kinds of operation performed on the content: cognition, memory, convergent production, divergent production, evaluation;

products (the results of applying operations to content): units, classes, relations, systems, transformations, and implications.

These classifications are related to improvisation in a general way, but despite their intuitive appeal, they have so far been fairly resistant to empirical verification.

Guilford further defined a set of six aptitudes for creative thinking: fluency, flexibility, originality, elaboration, redefinition, and sensitivity to problems. Torrance (1966) used this same set in designing a more open-ended approach to the testing and definition of creativity. Some of these six aptitudes are identical to the ones found in skilled performance above; they are considered here to be further guidelines for testing the plausibility of improvisational modelling.

Finally, Guilford and Hoepfner classified techniques of evaluation (in problem-solving), which they held to be due to appeals to logical consistency, past experiences, feeling of rightness, or aesthetic principles. Such a classification also has implications for improvisation (see model below).

Artificial intelligence

This field is concerned with programming computers to be intelligent problem solvers. The framework of action is usually formulated in terms of a problem space which must be searched for correct solutions. Since interesting problem spaces are nearly always too large to be investigated completely, a major focus of the field is the design of better heuristic search techniques. Coupled naturally with this are many methods and frameworks for the representation of knowledge.

There is traditionally no explicit mention of improvisation in the field. In making such a link, it seems clear that the successful application of artificial intelligence concepts to improvisation rests to a large degree on the appropriateness of considering improvisation to be a kind of problem solving. There is little doubt that such an analogy can be fruitful, particularly for referent-guided improvisation. For example, the process of improvisation may be divided up into a number of time points, and viewed as a succession of small problems, each of which is the production of an appropriate chunk of musical action at the current time point, where the constraints on action are the referent, goals, and musical actions at earlier time points. Alternatively, the time-scale may be drawn much coarser, and each complete improvisation may be considered a solution to a much more generally stated problem: for instances, improvise a chorus on 'I Got Rhythm' changes, within the constraints of be-bop style.

Before surveying the fruits of this approach it may be wise to spell out its limitations. Experientially, improvisation can seem to be far removed from problem solving. This is particularly so where the goals of the music making are exploration and process, rather than the presentation of artistic product. It is also very difficult to imagine how one could ever specify the 'problems' in freer types of improvisation with sufficient detail to allow specific artificial intelligence techniques to be used in modelling. Such problem formulations, even if possible, would be very personal, open ended, and sometimes contradictory.

With these provisos, we examine how various artificial intelligence problem-solving techniques might apply to improvisation. Search techniques come in several variants, including depth-first, breadth-first, and best-first. All use a generate-and-test procedure to find solutions to a problem. Clearly there are possible connections with improvisation. Generate-and-test could be applied to learning to improvise, where generation is sound production and testing is listening to generated music; or, it could describe internal cognitive selection processes, where testing is based on internal hearing of generated possibilities, before one is chosen as the actual musical output at a given time. Unfortunately with regard to this second interpretation there is a serious limitation: the inevitable use of back-tracking in the search processes cannot be very significant in improvisation

due to the cognitive limitations of real-time processing. The need of the improviser is for a good solution, not the best, for there is probably no single 'best' solution, and even if there were, it would take too long to find it. Therefore, the number of solution paths compared at any one step is probably very strongly limited, perhaps to two or three.

Another problem-solving technique is problem reduction: that is, reducing a problem to a set of subproblems. This is a common way to look at the teaching of improvisation, but seems less likely to apply to doing it, where integration of action is required. Of course there is no proof of this; we know far too little about the workings of the brain. Constraint satisfaction, on the other hand, is a technique whose principles seem to apply to improvisation. The constraints are the referent, goals of the performer, stylistic norms, etc. Finally, means-ends analysis is a technique that is based on comparing current and goal states. Because it involves considerable back-tracking, it is unlikely to apply to the improvisation process. Yet like other methods above, it seems relevant to the process of learning improvisational skill. In general, then, learning to improvise (that is, to structure musical impulses within aesthetic guidelines) is more like problem solving than is improvising itself.

Another main branch of artificial intelligence is knowledge representation. The relevance to improvisation seems clear, for any particular mode of knowledge representation makes it efficient to do certain things and inefficient to do others. And efficiency is what the improviser needs above all.

Knowledge representation in artificial intelligence is based on many ideas, including indexing, conceptual dependency, hierarchies, semantic nets, multiple representation, blackboards (actually a type of interprocess communication), frames, scripts, stereotypes, and rule models (Rich 1983; Lenat 1984). With respect to improvisation, many of these are more suggestive than readily applicable. Indexing, for example, is too artificial, whereas conceptual dependency, in which information is represented by certain conceptual primitives, is too strongly linked with natural language structure. Hierarchies have been discussed previously. Semantic nets are perhaps more promising: information is represented as a network of nodes connected to each other by labelled arcs, each node representing an object, event, or concept, and each arc a relation between nodes. Such a graph could be drawn for musical objects and events, but parametrically tuneable processes are not easy to represent, and this is a serious drawback.

Multiple representation, however, is an important idea, and one which is implicit in parallel-processing ideas mentioned earlier. The increased flexibility and efficiency possible with multiple representation argue very strongly for its inclusion in any model of improvisation. Gelernter (1963) successfully applied the idea to problems in plane geometry by using simultaneous axiomatic and diagrammatic representations. Another interesting application is the notion of the 'blackboard', an organization of the problem space into multiple levels of representation, typically along a dimension indicating level of abstractness. Thus a spoken sentence may be processed at levels of acoustic wave form, phonemes, syllables, words, word sequences, phrases, etc. Each part of the blackboard is triggered automatically as relevant information comes in. Multiple representation also strengthens the possibilities for analogy, and promotes synergy, by which is meant the co-operative action of parts of a complex system (Lenat 1984).

The last four ideas mentioned above, frames, scripts, stereotypes, and rule models, are considered to be various types of schemata (Rich 1983). The use of the word here is slightly different from that in the area of motor behaviour (see Adams 1976 for a survey). Frames are used to describe collections of attributes of an object. A frame consists of slots filled with attributes and associated values. Like most slot-and-filler structures, frames facilitate the drawing of analogies. Ideas equivalent to the frame are found in the improvisation model below. Scripts are simply normative event sequences and in so far as they apply to improvisation have much in common with the generalized motor schemata described above. Stereotypes have their usual meaning and are parts of the norms of musical style, but are often avoided by the best improvisers. Rule models describe the common features shared by a set of rules which form the basis for a 'production system'. If the improvising musician is the production system, the important rules will be largely heuristic and the rules about rules may be termed metaheuristics. Some of these will be culturally and historically based, while others presumably reflect intrinsic properties of the cognitive apparatus. Serafine (1983) has presented an insightful discussion of this distinction from the standpoint of the cognitive psychologist.

In principle it should be possible to integrate appropriate artificial intelligence techniques to construct an expert system which improvises. One of the very few such attempts is the unpublished work of Levitt (1981), which dealt with jazz improvisation. The idea awaits further development.

A model of improvisation

Any theory of improvisation must explain three things: how people improvise; how people learn improvisational skill; and the origin of novel behaviour. It must also be consistent with the numerous recurring themes reviewed above. The model given here seems to satisfy these conditions.

How people improvise

The first part of this model describes the process of improvisation. It begins with the observation that any improvisation may be partitioned into a sequence of non-overlapping sections. By non-overlapping it is simply meant that sounds are assigned to only one section, not that the sounds themselves do not overlap. Let each of these sections contain a number of musical events and be called an event cluster E_i. Then the improvisation I is simply an ordered union of all these event clusters. Formally,

$$I = \{E_1, E_2 \ldots E_n\} \tag{1}$$

From a naïve analytical perspective there is a large number of ways such a partitioning could be made. Our first major assumption is that every improvisation is actually generated by triggers at specific time points $t_1, t_2 \ldots t_n$ that instigate the movement patterns appropriate to effect intended musical actions. Each time point is thus the point at which decided action begins to be executed. Note that it is schemata for action that are triggered, not precise movement details, and subsequent motor fine tuning based on feedback processes goes on after each time point. Often time points will have clear musical correlates, with adjacent event clusters being set off from each other by local musical boundary criteria; pauses, phrase junctures, cadences, grouping by sequence etc.; but this need not always be the case.

With this interpretation, equation (1) is a unique specification of the timing of central decision making made by the improviser. The improvisation may then be viewed as a series of 'situations', where the $(i+1)$th situation is confined primarily to the time interval (t_i, t_{i+1}) and entails the generation of the cluster E_{i+1} on the basis of the previous events $\{E_1, E_2, \ldots E_i\} \equiv \{E\}_i$, the referent R (if one exists), a set of current goals $\mathscr{G}$, and long-term memory M. The referent R is an underlying piece-specific guide or scheme used by the musician to facilitate the generation of improvised behaviour (Pressing 1984*a*). The process of event-cluster generation may then be written

$$(\{E\}, R, \mathscr{G}, M)_i \rightarrow E_{i+1}. \tag{2}$$

Decision-making in the $(i+1)$th situation may in principle extend well back before time t_i, depending on the degree of pre-selection used by the performer, and will also extend slightly into the future, in that fine details of motor control will be left to lower control centres and hence may occur after t_{i+1}.

Equation (2) applies strictly only to solo improvisation. The only changes with group improvisation are that, first, all performers will have their own distinct time-point sequences (even though they would often be partially correlated), and, second, players will normally interact. Equation (2) can be readily extended to apply to all K members of an improvisation ensemble by writing

$$(\{E\}, C, R, \mathscr{G}, M)_{i_k} \rightarrow E_{i_k+1}, k=1, \ldots K, \tag{3}$$

where subscripts refer to the kth performer, and C stands for performer k's cognitive representation of all previous event clusters produced by the other performers and any expectations of their likely future actions. For simplicity, we use the formalism of equation (2) and speak primarily in terms of solo improvisation in what follows, adding in the effects of other performers in a straightforward manner as needed at certain points.

Any given event cluster E has a number of simultaneously valid and partially redundant 'aspects'. Each aspect is a representation of E from a certain perspective. Most important are the acoustic aspect (produced and sensed sound), the musical aspect (cognitive representation of the sounds in terms of music-technical and expressive dimensions), and the movement aspect (including timing of muscular actions, proprioception, touch, spatial perception, and central monitoring of efference). Visual and emotional aspects normally also play a role, and in principle there may be others. Furthermore each aspect exists in two forms, intended and actual. Each intended form is specified at a specific time point: the corresponding actual form is constructed from subsequent sensory feedback. The gap between these two forms is reduced by sound training in musicianship and improvisation practice, but it never dwindles completely to zero. Hence in equation (2) or (3) the variable $\{E\}_i$ represents intended and actual forms of all aspects of event clusters E_1 to E_{i-1}, the intended form of E_i, plus, over the course of the time interval (t_i, t_i+1), increasing feedback on the actual form of E_i. By t_{i+1}, when central commands for E_{i+1} are transmitted, the ongoing nature of improvisation probably demands that integration of the intended and actual forms of E_i be virtually complete.

The details of the proposed model of what occurs in the $(i+1)$th situation, that is, the selection of E_{i+1}, are as follows:

(A) E_i is triggered and executed (it may spill on briefly to times $t>t_{i+1}$).

(B) Each aspect of E_i may be decomposed into three types of analytical representation: objects, features, and processes. An 'object' is a unified cognitive or perceptual entity. It may, for example, correspond to a chord, a sound, or a certain finger motion. 'Features' are parameters that describe shared properties of objects, and 'processes' are descriptions of changes of objects or features over time. At t_i this decomposition is based only on intended information (efference); by t_{i+1} much of the actual form of E_i, received through the senses and internal feedback, has been used to refine the cognitive representation of E_i. This may continue after t_{i+1}. Let this decomposition into objects, features, and processes (for each aspect) be represented by three variable-dimension arrays $\mathbf{O}$, $\mathbf{F}$, and $\mathbf{P}$, and assume that they represent all information about E_i needed by the improviser in decision making.

(C) The structures of the three types of arrays are as follows. The object array is a $2\times N$ array where row 1 components label the objects present and row 2 gives their associated cognitive strengths s_k (explained below). The

feature and process arrays are typically non-rectangular. Their first rows consist of object and process labels respectively, and each column below that row is built up of a number of pairs of elements which give the values v_{jk} of associated features or process parameters and their corresponding cognitive strengths s_{jk}. The arrays are non-rectangular because different objects may possess different numbers of significant features or process parameters. The feature and parameter process values v_{jk} vary over ranges appropriate to their nature, whereas cognitive strengths s_{jk} are normalized to vary between 0 and 1. Cognitive strength is essentially an indicator of attentional loading, that is, the importance that the given factor has in the performer's internal representation. Thus even though certain features may be objectively present, as analysed by others, if the player does not use them in his or her cognitive representation, their s values would be zero. Sample object, feature, and process arrays for the following event cluster (a short trombone motive) are given by way of example (Fig. 7.1), for the musical aspect only. Considerable redundancy of representation has been set out in the process array.

(D) Production of E_{i+1} occurs primarily on the basis of long-term factors (R, $\mathscr{G}$, stylistic norms, and ongoing processes), and by evaluation of the effects and possibilities of E_i. There seem to be only two methods of continuation used: associative or interrupt generation. In associative generation the improviser desires to effect continuity between E_i and E_{i+1} and picks new arrays $\mathbf{O}_{i+1}$, $\mathbf{F}_{i+1}$, $\mathbf{P}_{i+1}$ whose set of strong cognitive components includes all or nearly all of the strong cognitive components of $\mathbf{O}_i$, $\mathbf{F}_i$, and $\mathbf{P}_i$, with the parameter values of these shared components being directly related (as described in (E) below). In other words the E_i components with high s values carry their information on in some way to E_{i+1}. These new arrays act as a set of constraints which determine, in conjunction with various generation processes, the musical actions generated for E_{i+1}. The relative importance of different constraints in the generation process is indicated by their respective cognitive strengths s_k and s_{jk}. Note that the E_{i+1} arrays may contain new strong components (constraints) that were previously weak or completely absent. In particular, it is possible to add a new independent musical process to a continuing one to produce an associative continuation which has a clear sense of novelty (e.g. the introduction of a new part in polyphonic music). In the case of interrupt generation the improviser has had enough of the event train ending with E_i (for whatever reasons) and breaks off into a different musical direction by resetting a significant number of strong components of $\mathbf{O}_{i+1}$, $\mathbf{F}_{i+1}$, $\mathbf{P}_{i+1}$ without any relations to E_i except possibly those chosen to be normative with regard to style in the piece, or intrinsic to the referent (if present) or goals. Clearly, the more strong components that are reset, the greater the sense of interruption.

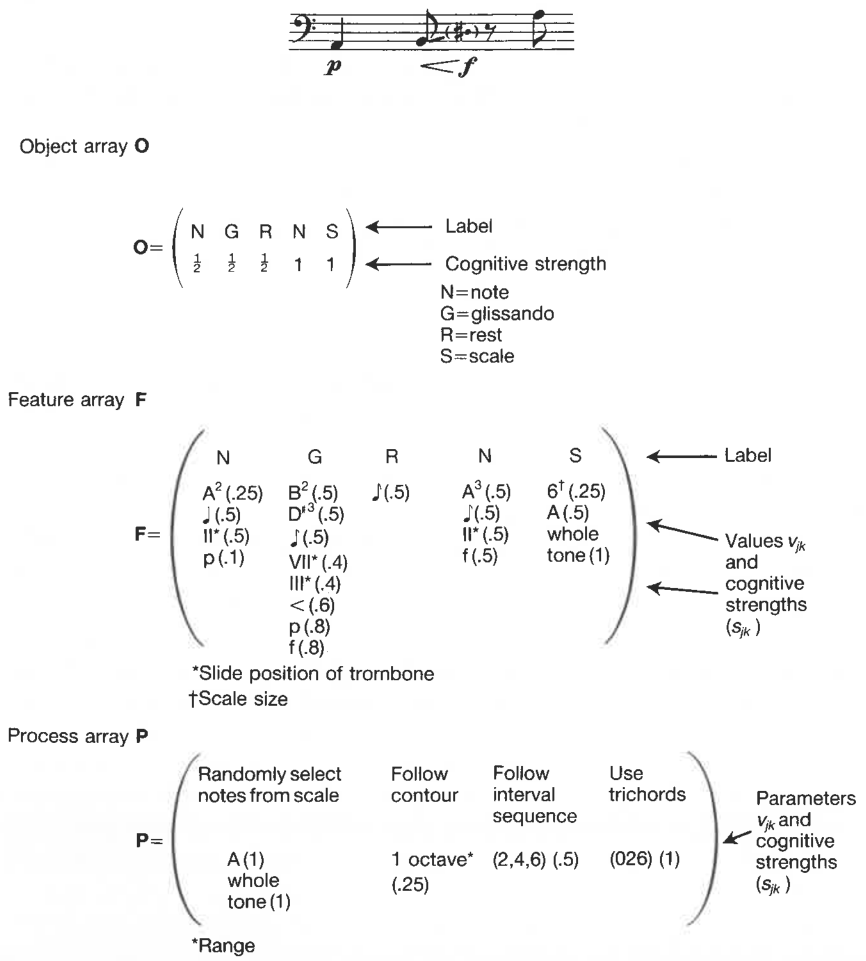


Fig. 7.1. Possible object, feature, and process arrays corresponding to a short trombone motive.

(E) Associative generation is based on either similarity or contrast. In the case of similarity all or nearly all important (important as determined from the vantage point of the improviser) array components stay approximately the same. In other words, for those components v_{jk} with s_{jk}'s signicantly above zero at time $t=t_i$, $(v_{jk})_{t_i} \approx (v_{jk})t_{i+1}$. Significant object array components behave analogously. In the case of constrast-type associative generation, at least one strong component of either the feature or process arrays must either move from near one end of its possible range of values to near the opposite end, or cross some perceptually significant boundary. Meanwhile, all other strong components change either very

little or not at all. Examples are when a group of high notes is followed by a group of low notes, or an accelerando changes of decelerando, or bright timbres are replaced by dull timbres. The idea behind this classification is that the most powerful and general types of improvisational control are those that are cued to features and processes. The objects, though a crucial part of the entire procedure, are at the same time often merely the very familiar musical clothing of cognitive action space.

(F) Interrupt generation is based on the resetting of all or a significant number of the strong array components without regard to their values in the current event cluster E_i. A decision to interrupt brings to an end a sequence of related event clusters, say $K = \{E_{i-r}, E_{i-r+1}, \dots E_i\}$, where the number of event clusters in this 'event-cluster class' is $r+1$. Hence interrupt decisions partition the entire improvisation into A discontinuous event-cluster classes K_α, so that the formal design of the piece becomes

$$I = \{K_1, K_2 \dots K_A\}. \qquad (4)$$

Each event-cluster class K_α contains at least one event cluster, and may be defined in terms of the strong components of the object, feature, and process arrays shared by all the member event clusters. If these special components are represented as $\mathbf{O}_s^\alpha$, $\mathbf{F}_s^\alpha$, and $\mathbf{P}_s^\alpha$, then K_α is defined by $(\mathbf{O}_s, \mathbf{F}_s, \mathbf{P}_s)^\alpha$. One of the sets $\mathbf{F}_s^\alpha$ and $\mathbf{P}_s^\alpha$ must be non-empty. If $(\mathbf{O}_s, \mathbf{F}_s, \mathbf{P}_s)^\alpha =$ or $\approx (\mathbf{O}_s, \mathbf{F}_s, \mathbf{P}_s)^\beta$, for some β not immediately following α, we have recursion in formal design of the improvisation. Under these assumptions the process of improvisation may be sketched diagrammatically as in Fig. 7.2.

(G) The choice between association and interrupt generation may be formally modelled by a time-dependent tolerance level for repetition, $L(t)$. An interrupt tester, whose inputs are presumably the time since the onset of the K_α event cluster class, $(t-t_{i-r})$, and the size and nature of K_α, computes the degree of current repetition, $Z(t)$, and if $Z(t) \geq L(t)$, institutes an interrupt generation, so that $Z(t)$ jumps to a low value. Otherwise associative generation continues. Diagrammatically this is shown in Fig. 7.3 for the same improvisation as in Fig. 7.2.

(H) Once $\mathbf{O}_{i+1}$, $\mathbf{F}_{i+1}$, and $\mathbf{P}_{i+1}$ are selected for all relevant aspects, tuneable cognitive and motor subprogrammes are set in motion that generate, on the basis of these higher constraints and current motor positions, a specific action design. At this point we have reached t_{i+1} and this loop of the process $(E_i \rightarrow E_{i+1})$ is complete. By iteration, then, the entire improvisation is built up. The starting point E_1 may be considered a situation of interrupt generation (where E_0 is silence) and the final event cluster E_n is simply a second case of interrupt generation where $E_{n+1} =$ silence, after which the improvisation process is turned off.

These, then, are the salient features of the model in outline. They are diagramatically displayed in Fig. 7.4.

Next we look more deeply at certain critical stages of the improvisation

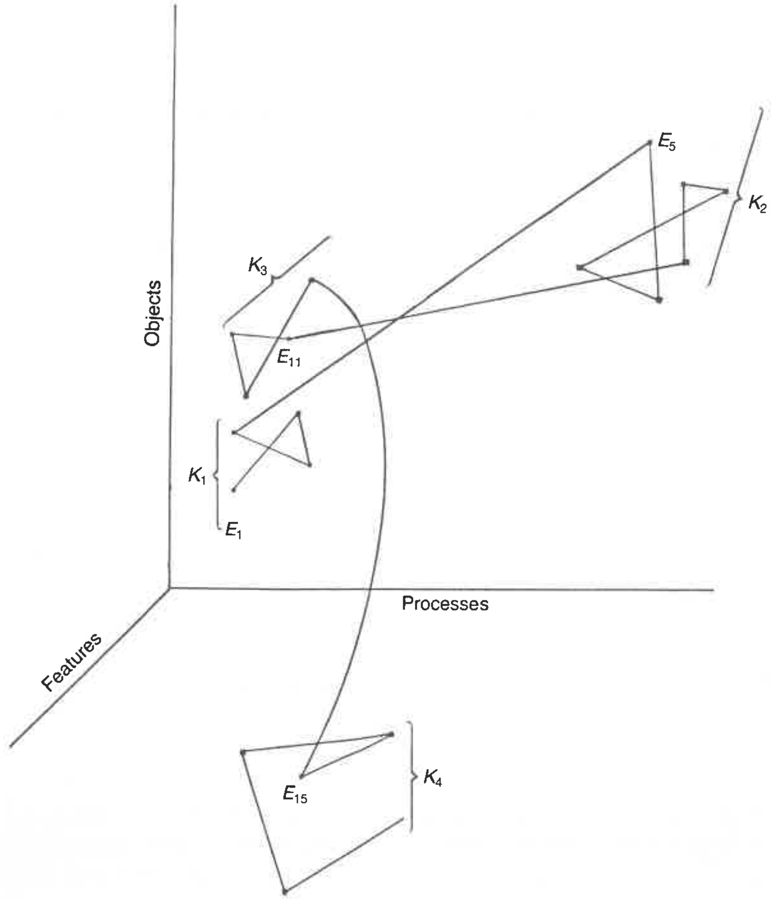


Fig. 7.2. An improvisation in musical action space, showing four event-cluster classes, and form ABA'C.

model. To begin with, it is characterized throughout by extensive redundancy. There is first of all redundancy between the aspects of each event cluster. The performer knows, for example, that certain motor actions involved in striking a kettle drum (motor aspect) will correspond to a particular sound (acoustic aspect), with associated musical implications (musical aspect). Furthermore, each aspect is decomposed into extensive object, feature, and process representations which contain considerable redundancy. For example, the musical motive of Example 7.1 may be pitch encoded as the objects $D^2F^2A^2B^2$, or as the object Bϕ diminished 7 chord in first inversion, or as a diatonic sweep to the leading tone in the key of C major, or as a ii ϕ diminished 7 chord in a minor, or as an ascending contour, and so forth. Its features include melodic motion by seconds or

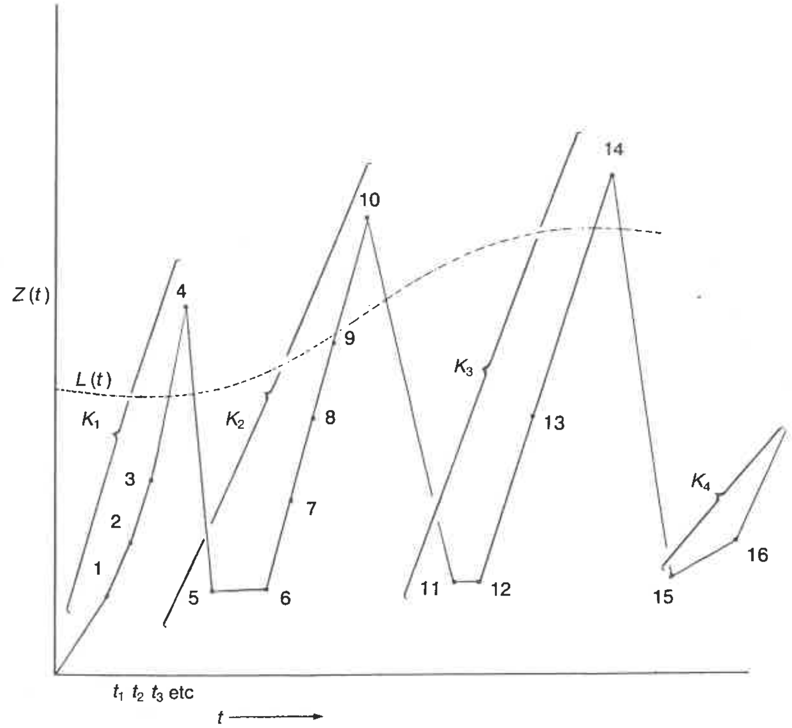


Fig. 7.3. Interrupt generation via the repetition functions *L* and *Z*.

thirds, diatonic note choice, the degree and speed of crescendo, rhythmic regularity of attack, certain values of finger force and velocity used by the performer, and so forth. Many processes could be implicated to generate the given motive: arpeggiate a Bϕ diminished 7 chord, pick notes consistent with a triplet feel in C major, move the fingers 4321 of the left hand in such a fashion as to depress keys on the piano, and so forth. If the nature of improvisation entails the seeking out of a satisfactory trajectory in musical action space, such redundancy of description and generation allows maximal flexibility of path selection, so that whatever creative impulse presents itself as an intention, and whatever attentional loadings

Example 7.1

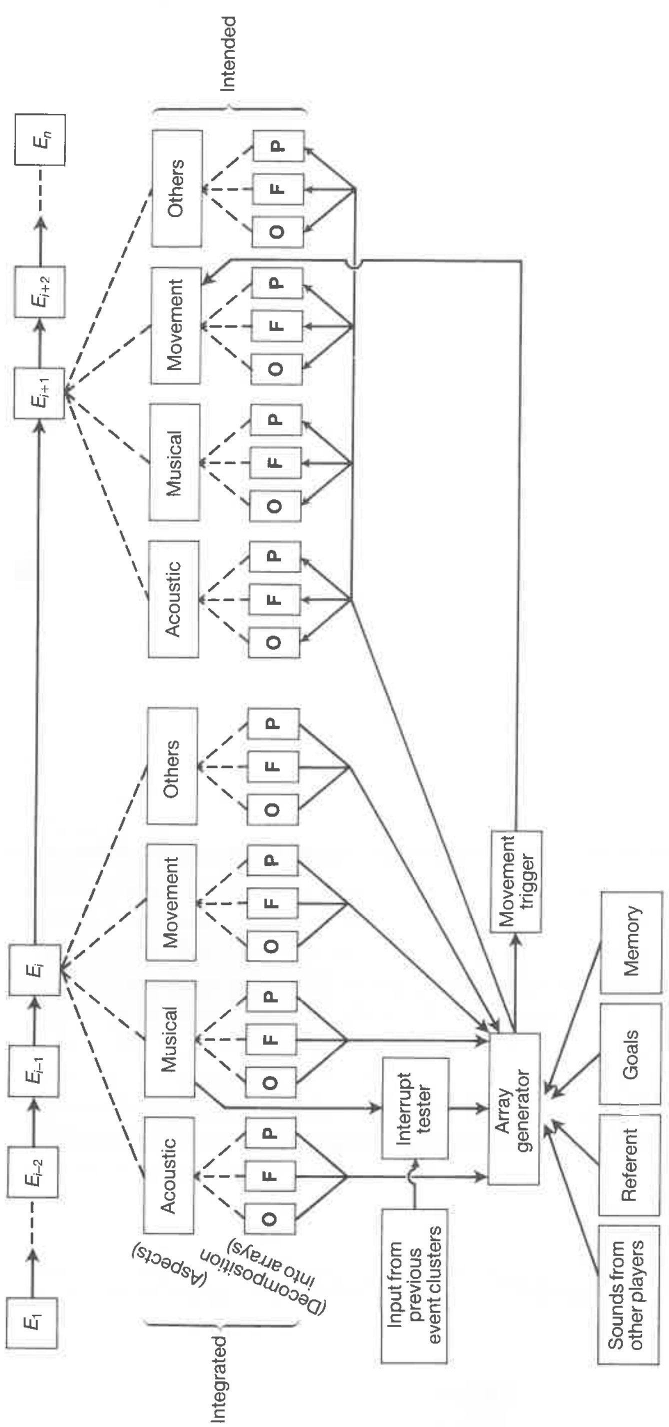


Fig. 7.4 The improvisation model in diagrammatic form. Only the process $E_i \rightarrow E_{i+1}$ (intended) is detailed. Each event cluster E_i is present in a number of partially redundant aspects, and each of these is decomposed into object, feature, and process arrays. Largely on the basis of musical representation a decision about type of continuation is made by an interrupt tester. In accordance with this decision an intended array decomposition is generated, with input from E_i arrays, referent, goals, and memory. This decomposition acts as a set of constraints in the generation of musical action, and production of E_{i+1} is subsequently begun by a movement trigger at t_{i+1}. The diagram detail shows what happens in the time interval (t_i, t_{i+1}), so that the indicated decomposition of E_i is integrated (that is, intended plus actual forms of E_i are combined), whereas the indicated decomposition of E_{i+1} is intended (no feedback has been received yet). Hence **O**, **F**, and **P** at time point t_{i+1} do not have indicated outputs.

may be set up, some means of cognitive organization and corresponding motor realization will be available within the limiting constraints of real-time processing.

Such extensive redundancy I take here to mean that control of event production is heterarchical, and may potentially shift rapidly from one cognitive control area to another. Indeed this must be considered the most effective strategy for improvisation. Experientially it very probably corresponds to 'letting go', or 'going with the flow' as described earlier, whereby central hierarchical control, identified here with conscious monitoring of decision making, yields to heterarchical control (and corresponding unconscious allocation of attention).

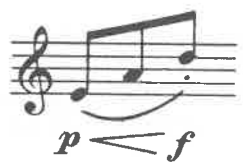
Next we look further at the object, feature, and process arrays that are critical in the representation and generation of event clusters. First of all it may well be asked how such arrays are formed. The answer given here is based on an ecological perspective, which considers that the capacity to extract or create such arrays is neurologically innate, but that they are only brought into being by interaction with the environment. More specifically, cognitive objects are inferred to exist on the basis of perceived invariance in sensory input over time, and boundedness in a space (whether physical, musical, or abstract). Features are tuneable parameters and come to be abstracted on the basis of perceived similarity or contrast in sensory input. Processes come about from perceived change in an object or along a feature dimension with time.

Thus over the course of one's life new arrays and array components are constantly being created by new perceptions and new perceptual groupings. During any given improvisation at most very few new features or processes will be created, and only a limited number of new objects. In general, though, this is one source of novel behaviour: the evolution of movement control structures for newly discovered objects, features, and processes. However, there seems to be another, probably more common source of behavioural novelty: the motor enactment of novel combinations of values of array components. This second possibility is shown for example by considering a child musician who has learned motor actions corresponding to the distinctions loud/soft and fast/slow separately, but without encountering soft and fast simultaneously. By combining these two dimensions an action novel to the child's experience can result. Furthermore, the results of such novel parametric combinations need not be so predictable. If we recall that the human performance system is non-linear, then, as mentioned above in the paragraphs on organizational invariant theory, novel, strikingly different behaviour may follow when controlling system parameters assume certain novel combinations of ranges. It can further be shown mathematically that behaviour described as 'chaotic' may occur under such conditions (Li and Yorke 1975; May 1976), even for simple systems. This perspective has led to a biomathematical analysis, for example, of many so-called 'dynamical' diseases, including schizophrenia, AV heart block, epilepsy, and some haematological disorders (see Guevara *et al.* 1983 for a survey). The point with regard to improvisation is that the same sort of smooth parametric tuning can be used to generate abrupt intentional novelties in movement and musical expression. The integration of the results of novel ranges of array components is presumed to be handled by control structures of the CNS responsible for timing and smoothness of action.

During any given improvisation, when possible object, feature, and process array types are basically fixed, novel sensory input will be analysed and assigned to existing categories, or, if the fit is too poor, into existing categories plus deviations. In this model such a description is also considered to apply to the generation of action. That is, novel actions are built primarily by distorting aspects of existing ones. This sheds light on the organizing power of the metaphor, mentioned earlier, since it may be considered to be a global link across categories, one that facilitates movement integration. In other words, the image or metaphor enables the co-ordinated modification and resetting of whole classes of array components in a fashion ensuring spatial and temporal coherence.

The central core of the model is the generation of a new set of array components for E_{i+1} from those preceding it. To make this process clearer, we now look at two examples.

(1) Let E_i be



Example 7.2

played by the right hand at the piano.

Above are a number of possible improvisational continuations, based on attentional emphasis (that is, cognitive strength) given to the mentioned array components (see Fig. 7.5). Emphasis given to a particular component means that it will guide the generation of subsequent events. The type of arrays emphasized are also indicated; note that this is not uniquely determined, since the model makes a feature of redundancy. Continuations 1–8 exemplify associative continuation, with numbers 7 and 8 more abstract than the others, while number 9 is interrupt based.

Fig. 7.5. Examples of continuation of an event cluster under the emphasis of selected array components.

Continuation	Emphasized components used for continuation	Type of arrays
1	key of A major; quaver durations	**O,F,P**
2	perfect fourth interval	**F**
3	notes E, A, D; rhythmic displacement	**O,P**
4	melodic contour	**O,F**
5	motor generation with right-hand fingers 1, 2, and 4	**O,F**

6	gesture (note use of contrast), perfect fourth interval	F,P
7	phrase design (antecedent/consequent), interval class 2	F
8	notes E, A, D: chromatic decoration	O,P
9	interrupt generation: new motive	O,F,P

If the same line had been played on flute, the continuations might all have been very similar except for continuation number 5, which has as its constraint focus the actual movement patterns for manipulating the instrument.

(2) Here we consider an event cluster less clearly tied to structural-historical processes. Let E_i be a segment of sounds produced by a single slow tilting and rotation of a tambourine one-quarter filled with a single layer of small lead shot. E_i is a coloured noise sound which subjectively is reminiscent of distant ocean waves or rain. Some possible continuations are then as follows:

Continuation	Description	Type of arrays
1	continue tilt but speed up rotation of tambourine	F,P
2	shake tambourine from side to side	F,P
3	stop motion of tambourine	F,P
4	toss lead shot in air and catch it	F,P
5	perform a drum roll on the bottom of the tambourine skin with fingers of the right hand	O,F,P

Continuations 1 and 2 are of associative type, whereas 3, 4, and 5 are interrupt type. Notice that here description emphasizes the motor aspect, since there is no extensive tradition of music theory which applies to such a sound source.

If these examples succeed in illustrating how continuations may be constructed, they are mute on the details of how one continuation comes to be chosen over all other possible ones. What has been said so far is only that, in associative generation, a set of constraints is produced associatively, while in interrupt generation the set of strong constraints on action includes uncorrelated resetting. Obviously, event generation is informed by a vast panorama of culturally and cognitively based musical processes and stylistic preferences (motivic development, phrase design, historical forms, transposition, rhythmic design, etc.). But a considerable degree of residual decision-making remains, as for example the choice of array components that will be singled out to act as strong constraints or to be reset. How are such residual decisions made?

It does not seem possible to give a final answer to this question, for it has at its ultimate root the question of volition and hence the mind-body problem, about which there is no general philosophical agreement in our culture or even among scientists. There is also no conclusive empirical evidence to support one view or another, despite the opposing claims of some positivists and phenomenologists. It seems useful therefore to characterize a number of strategies of explanation for the residual decision-making mentioned above, and subsequently explore what possibilities exist for experimentally decided among them.

It is first of all possible to take the intuitive perspective, that the individual acts best when he or she merely taps a certain powerful source that dictates the course of musical action in a naturally correct fashion, one that may not be analysable or predictable in physical or musical terms. Although this perspective is usually transpersonal and may seem romantic to some, this does not imply that it is untestable and therefore unscientific.

A second perspective is to assume that this residual decision making actually reflects the effects of individual free will. In other words, the improviser is a unique conscious entity, and residual decision making rests to some degree on internal variables not predictable even in principle from a fully detailed knowledge of the physical-state variables of the improviser and his or her environment.

A third perspective is the physicalist one. Here complex decision making is seen to be an emergent property of the fantastically complex physical system known as a human being, in interaction with a series of environments. Free will in this perspective is either illusory, or simply a somewhat misleading metaphor for certain complex characteristics of the system. There are a number of models possible within this perspective for residual decision making: interactive control with lower CNS centres, network statistical voting models, distributed memory-type models, decision making based on fuzzy logic, etc.

Fourth and last is the perspective of randomness. Here the unconstrained residual decision making is simply modelled by use of random generators. As the improviser becomes more and more expert through practice and more and more control procedures are built up, random processes need to be invoked less and less frequently and overall error levels decrease, perhaps approaching a minimum threshold.

To experimentally distinguish between these points of view a high resolution improvisation transcription system has been built here at La Trobe University. Co-worker Greg Troup and myself, as well as technical staff of the departments of psychology and music, have designed and set up the apparatus. It is a synthesizer-based system, using modified MIDI format, and enables detailed recording, to millisecond resolution, of musical actions at a keyboard. It is also possible to input sound from other (non-keyboard) instruments. Simultaneously as music is recorded a videotape of the performance can be made. The results of this investigation are not yet complete and will be reported elsewhere, but it seems likely that the limits of validity of intuitionist and random perspectives will be determinable. There seems to be, however, no obvious experimental design that will decide between the physicalist and free-will perspectives. Hence the two may be considered co-existing formulations. The problem in deciding between the two rests with setting up the repeatable conditions which should theoretically lead to the same 'improvised' result in the hard-core physicalist model and to a different improvised result under conditions of free will. But since each event potentially affects all those that follow, all initial conditions are intrinsically unrepeatable.

The development of improvisational skill

The modelling of this process remains in a less developed state and only a brief discussion is included here. Its starting point is the emergent results of practice found in all types of skill, as mentioned earlier: improved efficiency, fluency, flexibility, capacity for error correction, and, less universally, expressiveness. But there are at least two additional components of improvisational skill: inventiveness and the achievement of coherence. In more fixed skills these are less important, since inventiveness provides few tangible advantages, and coherence is built in by the rigidity of the task demands.*

The specific cognitive changes that allow these properties to develop in improvised musical behaviour are considered to be:

(1) an increase in the memory store of objects, features, and processes—in musical, acoustic, motor (and other) aspects;

(2) an increase in accessibility of this memory store due to the build-up of redundant relationships between its constituents and the aggregation of these constituents into larger cognitive assemblies;

(3) an increasingly refined attunement to subtle and contextually relevant perceptual information.

The build-up and improved access to memory of points (1) and (2) is presumably central to any learning process. In the language of the model of this chapter this involves the use of extensive redundancy, and also the aggregation of memory constituents (objects, features, processes) into new cognitive assembles which may be accessed autonomously. Because such a procedure can presumably be nested to arbitrary depth, very complicated interconnected knowledge structures may develop.

This last idea is not new here. It has a considerable history and has been most clearly outlined for the purposes of this paper by Hayes-Roth (1977), who generalized an earlier model of Hebb (1949). The central feature of

* It is interesting to note that these two skills push in opposite directions, for inventiveness comes from the commitment to avoid repetition as much as possible, while coherence is only achieved by some degree of structural unity, which is only possible with repetition.

aggregation of memory elements Hayes-Roth termed *unitisation*, and her knowledge-assembly theory was built up around the presence of elemental 'cognitive units'. In the terminology of this chapter these are object, feature, and process array components. In knowledge-assembly theory such cognitive units are associatively activated and may combine to form assemblies, whose 'strengths' are increasing functions of recency and frequency of activation, and decreasing functions of their own complexity. From these strengths are derived probabilities and speeds of activation. There is a level of redundancy appropriate to improvisation in this model, since for example a cognitive unit may be activated individually or as part of a larger assembly of cognitive units. In her paper, Hayes-Roth shows that knowledge-assembly learning theory is consistent with a large body of experimental results. It is also consistent with the introspective reports of improvisers and the review given above of improvisation teaching methods. But a decision on the superior applicability of this theory to improvisation over those of other related formulations must rest upon experimental work as yet undone. For this reason I give no further speculation.

The third point mentioned above may be elaborated as follows. The refinement of improvisational skill must depend partly on increasing the efficiency of perceptual processing to allow the inclusion of more and better-selected information in the improviser's decision-making procedures. The need for this efficiency is imposed by every performer's more or less limited individual capacity, per unit time, to process novel sensory input. It seems likely that practice leads to the increasingly efficient use of information in two ways: by reducing the effective amount of information by the recognition of patterns of redundancy in the sensory input, and by focusing attention increasingly on the information that is most relevant for producing a successful improvisation. The increased use of such subtle and 'higher-order' information leads to the higher-order skill characteristics mentioned earlier. The main differences in this process between fixed and improvised actions may be said to reside in the nature of the attention focus used in the two situations. The fixed-skill situation evolves towards a minimal size attention set, whereas the unpredictability of improvisation demands that the attention focus remain wide. To go beyond such insufficiently specific observations experimental work is clearly required.

Conclusions

This chapter has attempted to illuminate the process of musical improvisation by first examining the modelling tools available from a number of different disciplines. Based on this examination, a cognitive model has then been presented for the process itself, followed by a brief discussion of its relation to improvisational skill acquisition. The central features of the model are as follows. It is reductionist, in that cognitive structures of processing and control are considered to be broken down into aspects (acoustic, musical, movement, etc.), each of these into types of analytical representation (objects, features, processes), and each of these into characterizing elements (array components). At the same time the model is synergistic and capable of behavioural novelty, due to the extensive redundancy of the cognitive representations and the distributed and non-linear character of the outlined control processes. The extensive presence of feedback and feedforward contributes to this. The fundamental nature of the improvisation process is considered to be the stringing together of a series of 'event clusters' during each of which a continuation is chosen, based upon either the continuing of some existing stream of musical development (called here an event-cluster class) by association of array entries, or the interruption of that stream by the choosing of a new set of array entries that act as constraints in the generation of a new stream (new event-cluster class).

The model seems to be specific enough to allow its use as a basis for the design of 'improvising' computer programs. Work in this direction is in progress. At the same time some fundamental philosophical questions remain about the origin of certain kinds of decision making in any such model, and four types of answers to these have been outlined: intuition, free will, physical causation, and randomness. Some of these alternatives should be distinguishable on the basis of experimental work currently in progress at our laboratories, which also has as its aim the testing of the basic assumptions of the model. This will be described in subsequent publications.

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Experimental research into musical generative ability*

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One of the projects carried on for about 15 years in the Institute for Culture of Hungary has been concerned with analysing human creative faculties; in particular, artistic creativity. We have been concerned to discover the place, role, and modes of creativity in Hungarian culture, and we have attempted to relate different levels of creativity to economic, social, and educational factors. Our empirical studies have been extended to differnt arts, including music, fine arts, fiction, and poetry.

This chapter describes part of our research into musical creativity. Music is a particularly suitable idiom for our purposes. Its abstract character makes it easy to react to on many different levels. Also, music has deeply penetrated many different social groups, thus 'pre-conditioning' a wide range of subjects for giving relevant responses. In addition, the wide use in Hungarian education of the Kodály method has placed great importance on the practical development of musical creativity.

The music-psychological research to be described below was provoked by the view widespread in the literature both of the psychology and the sociology of art that two kinds of artistic experiences can be distinguished: that of the creator and that of the receiver. This is a view we do not share. Proponents of this view tend to argue that only a narrow group in contemporary society takes a creative part in music (for example from Hungary's population of 10 million, taking into account all the composers of popular songs and rock music, only about 2 to 3000; that is 0.02 to 0.03 per cent).

A contrasting view is provided by Weber's (1921) and Blaukopf's (1972) ideas on the role of sound systems. According to them, the systems of musical structures adopted by a composer form a language, a semiotic system to which the most ingenious composer can merely add something and which he is unable to create himself.

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