IMPROVISATION: METHODS AND MODELS

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Jeff Pressing
(text only)

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I.   Introduction
     How do people improvise? How is improvisational skill learned and taught?
These questions are the subject of this paper. They are difficult questions,
for behind them stand long-standing philosophical quandries like 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 1984a) I summarised 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 a survey of appropriate background research and its
relation to improvisation. Some of these areas may initially seem distant from
the topic at hand.

II.   A survey of pertinent research
      (a)   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
following effects, 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 paper therefore inevitably focusses on these aspects.
     The given steps are often collapsed into a three component information-
processing model of human behaviour which has ready physiological analogues:

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 extrapyramidal 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 fibers, respectively.

The organisation of behaviour has been often 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 recognisable fragment of behaviour. The effect is achieved by excitation and/or inhibition of a constellation of motoneurons (Shepherd, 1983; Bentley and Konishi, 1978). 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 been recently 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 (e.g. 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 1984a) 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.

(b)   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 (see other articles in this volume). 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.

(i)   Theories of motor control and skill

The starting point for nearly all the existing theories is the 3-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 (e.g.
Wilson 1961) and deafferentation techniques in monkeys (Taub, Heitmann and Barro
1977) that points to the existence of motor programs 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 minimisation 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,
Baron and Levison 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 organised and initiated by an excutive program (Fitts 1964). As is
apparent, many such hierarchy theories are based on the application of computer
programming principles (cf. Miller, Galanter and Pribram 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 internalised
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, cf. Summers 1981 for a review). That is, movements are both
centrally stored as motor programs, 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 organised 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 schema are not specific movement instructions but are 'generalised' motor programs, 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 so-called 'novelty problem' is very close to that of improvisation.

Similar to schema 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) specify 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 from 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 organisational invariant approach of Turvey, Kugler, Kelso and others (Turvey 1977, Kugler, Kelso and Turvey 1980, cf 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-equilibrium thermodynamics (Prigogine 1967, Prigogine and Nicolis 1971, Prigogine, Nicolis, Herman, and Lam 1975). Essentially the theory de-emphasises notions of cognitive process and control, replacing them with, in so far as is possible, 'organisation invariants'. These organisational 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 situations (Kelso, Holt, Rubin and Kugler 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 ten years, with uneven results.

Organisational invariant theory seems also likely to apply primarily to the dynamics of motor program 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 in part III.

(ii) Some special issues relevant to improvisation
Skill classification
     Various dimensions of skill classification have been proposed and
improvisation can be placed within these. One division is into '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 therefore 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 emphasise the contrast between unskilled and highly
skilled performance. A vast majority of reported skill studies treat simple
motor tasks like tracking, under an implicit 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-focussing effects (Pressing 1984a).
     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 1984a). Likewise the design of some instruments allows more precise
visual feedback and more categorical kinesthetic 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 two or more performers (Pressing 1980).
clear that internal feedback (and feedforward) loops exist not based on sensory
processing (Brooks 1978). That is, if higher cognitive levels set the design of
motor programs 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
1984a). It will simply be pointed out here that error may accrue at all stages
of the human information processing system: perception, movement/musical

gesture selection and design, and execution. Minor errors demand little or no
compensation in following actions, whereas major errors may require a complete
change of musical process or context.

Anticipation, preselection and feedforward

These three concepts have to do with preparation for action. Physiological
recording of the Bereitschaft potential (BP) and contingent negative variation
(CNV) (cf. 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' (Easton 1978, Turvey 1977), corollary
discharge or efference copy (von Holst 1954), and preselection (cf. 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, Bertrand and
Praagman 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 discrepances 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 different locations in
the CNS and the many documented types of feedback 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 organisation, 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). This possibility is incorporated into the
model of part III.

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) (cf. also Sage 1977), auditory stimulus activity
reaches the cerebral cortex 8-9 msec after stimulation while visual stimulation
involves a longer latency of 20-40 msec. 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 times (RT) with only one chosen motor response typically fall in
the range 100-250 ms, depending on conditions and sensory modality (Summers
1981). Auditory, kinesthetic 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 190ms (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). Kinesthetic 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 kinesthetic 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,
Hawkins and Kisselburgh 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 program 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/kinesthesia, 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 ten actions per second and higher involve
virtually exclusively preprogrammed actions (Pressing 1984a). 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 (Schaffer 1978, Terzuolo
and Viviani 1979), handwriting (Denier van der Gon and Thuring 1965, Viviani and
Terzuolo 1980, Hollerbach 1981), generalised arm trajectories (Morasso 1983),
and piano performance (Shaffer 1980, 1984) has established that invariant timing
and spatial sequences, strongly suggestive of schema, underlie skilled actions.
Such performance rhythms, or 'hometetic' behaviour, as some have termed it,
shows great tunability: over wide variations in distance and overall time
constraints, invariance of phasing and accelerations (or 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 generalised action programs (in both motor and music

representation), which allow overall parametric control (time, space, force) and subprogram tunability. 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).

               (iii)   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, characterised by a feeling of mindful 'letting go' (Schneider and Fisk 1983, Pressing 1984a). 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 tunable motor programs. This results in the qualities of efficiency, fluency, flexibility, and expressiveness. All motor organisation 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 like 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 kinesthetic 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 kinesthetic 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 programs, 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 1984a). 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 tunable motor programs. More irrevocable constraints causing attentional loading seem to be timing and interhand co-ordination (Pressing 1984a).

Another relevant area is the optimum distribution and nature of practice. Generalisations 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 in section (c) 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 been 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 formalised 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 focussing on goals and general action principles rather than kinematic details (Holding 1965, Hendrickson and Schroeder 1941, Newell 1981). This certainly holds for improvisation. Probably too much intellectual detail both interferes with the fluid organisation of action sequences, as mentioned earlier, and strains attentional resources.

(c)   Studies and theories of musical improvisation

A cognitive overview of much of this literature has been given earlier (Pressing 1984a, 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 (1984b,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 Datta and Lath (1967), Jairazbhoy (1971), Wade (1973), Reck (1983) 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 Behague (1980) and Charles (1982) for Latin American percussion music; by Hood (1971, 1975), Harrell (1974) and 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 dueling, 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 20th 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 pedagogic and analytic perspectives are however given by Coker (1964, 1975), Schuller (1968), Baker (1969), Owens (1974), Tirro (1974), Liebman, Beirach, Tusa, Williams, and Roy (1978), Dobbins (1978), Howard (1978), Murphy (1982) and Radano (1985). Among the better organ and piano texts may be mentioned the works of Dupre (1925/37), Hunt (1968), Schouten (no date given), Gehring (1963), and Berkowitz (1975). Weidner (1984) has also presented a detailed analysis of five improvisations by organist Charles Tournemire. 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 discursion. Discussions which emphasise 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, pp.26-111), the Music educator's journal (1980, 66(5), pp.36-147), Keyboard (10(10), October 1984), and The British Journal of Music Education (1985, 2(2). Other works of interest are those on choir improvisation (Ehmann 1950 and Ueltzen 1986), silent-film accompaniment (Hanlon 1975, Miller 1982/83), dulcimer improvisation (Schickhaus 1978), percussion gestures (Goldstein 1983), and the 'MMCP interaction' (Biasini and Pogonowski 1971).

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 (1976/1979) has intelligently chronicled music of the avant-garde (e.g. 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 vocal 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 Galas (1981/82) has created a primal vocal music based on obsession, excessive behaviour, and trance states of severe concentration.

The approaches to the teaching of improvisation in the literature may be broadly grouped as follows. First, there is the perspective overwhemingly 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 18th 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 17th and 18th centuries (e.g. Mersenne 1635, Quantz 1752/1966, Bach 1778/1949, Arnold 1931/65), as well as the riff compendia and how-to-do-it books in the field of jazz (e.g. Coker, Casale, Campbell, and Greene 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 by '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 psychoimprovisational faults and recommended exercises for correcting them. A shorter multiauthor 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 20th 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-realisation ideas of humanistic psychology. It is based on concepts of creativity and expressive individuality which go back in music explicity at least to Coleman (1922), implicity 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, Zoltan Kodaly, Suzuki (cf. Mills and Murthy 1973) and particularly Jaques-Dalcroze (1921/1976, 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).

Research on optimal techniques for teaching improvisation has seemingly only been carried out in the last two decades, with nearly all of it in the field of jazz. 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. Suehs (1979) developed and assessed (by adjudication) a course of study in Baroque improvisation techniques. Carlson (1980) described a teaching strategy based on the analysis of jazz trumpet performance practice.

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 vocalisations, and instrumental echo response patterns based on rote or procedures of generalisation. Method III supplemented the same technical procedures of Method I with an 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.

A study by Moorman (1984) analysed the pedagogic methods of selected jazz teachers, and found a common emphasis on melodic, rhythmic and harmonic foundation studies. Moorman also gave an analysis of 25 selected improvisation by 'name' jazz players, using Rudolph Reti's ideas of thematic process. Finally, Paulson (1985) examined and verified the usefulness of imitation (of master performers) in jazz improvisation instruction.

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 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 organising 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 organised. 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 1961), 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 at the piano. Related philosophical arguments have been given 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. Michel Waisvisz has developed 'The Hands', a novel performance instrument interfacing with a variety of synthesisers. And recently available software, such as the Macintosh-based M and Jam Factory, has improvisational and interactive features that seem rich with promise.

 (d) 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 formulated from Milman's intense study of the Homeric epics, particularly the Odyssey, and given further support by research work on Yugoslav folk epic poetry 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 folksong texts (Vikis-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. These 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) and Smith (1985) have used the process to describe the constraints imposed on the song-based jazz performer, including an analysis of 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 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'.

(e)   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 this 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 Intuitionism (e.g. 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, (e.g. 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 up. Knowledge gained through intuition constitutes a set of 'justifiable beliefs', which are nevertheless subject to the possibility of error. A third approach is positivistic (e.g. 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,
dis-
     torting, 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 in section II (iii) 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
preexisting 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. Certainly, general theories of creativity are legion, and a full review of them would exceed the scope of this paper. But much of the research in musical creativity of relevance to improvisation draws on the general frameworks set up by Guilford, and several aspects of his work deserve mention here. First, his structure-of-Intellect model proposed a taxonomy of factors of intelligence (Guilford 1977, Guilford and Hoepfner 1971, and earlier references mentioned therein). 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.

Second, Guilford and Hoepfner (1971) 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).

Most importantly, Guilford (1956, 1957) defined a set of six aptitudes for creative thinking: fluency, flexibility, originality, elaboration, redefinition, and sensitivity to problems. As cited in a recent useful survey of creativity research in music education (Richardson 1983), the first four of these aptitudes are considered to be objectively testable and have been incorporated into the design of improvisation tests used to evaluate creativity. Studies specifically concerned with music are those of Vaughan (1971), Gorder (1976, 1980), and Webster (1977). Gorder's work in particular demonstrates the feasibility of fairly objective assessment of Guilford-type aptitudes for a theme and variations improvisation protocol. The criteria for objective evaluation of creative work have been discussed in general terms by Amabile (1983).

Brennan (1982) used Guilford's classification scheme to investigate dance improvisation. She was able to subdivide the performances into smaller movement units, which could be used to examine the presence of specific creative aptitudes (e.g. originality, flexibility). She also found low correlation between movement improvisation aptitude and pencil and paper tests of creative ability and concluded that motor creativity is a separate faculty, which, as pointed out by Troup (1986), accords with Guilford and Hoepfner's (1971) theory that 'movement responses represent a separate category of divergent production abilities'. Music performance, based as it is on refined motor skills, must also be part of this separate category.

A further group of studies exists that looks primarily at relations between motor or musical creativity and other factors such as general creativity, intelligence, musicality, and composition training. (These issues are also raised by Vaughan 1971, Gorder 1976, and Webster 1977). These include Tarratus (1964), Roderick (1965), Vaughan (1977) and to a lesser degree Wyrick (1968). In general the results here do little more than confirm the independence of the categories of motor or musical creativity from other such factors, Greenhoe's (1966) notion (and the commonly held opinion of improvisers) that special supporting aptitudes are required for musical creativity.

(f)   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 AI 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: e.g. improvise a chorus on 'I got rhythm' changes, within the constraints of bebop 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 AI 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 AI 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 back 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 artifical 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 AI 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-tunable 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 is 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 organisation 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 schema (Rich 1983). The use of the word here is slightly different than in the area of motor behaviour (cf. 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 generalised motor schemas of section (b) (i) 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 human thinking 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 AI 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.

(g)   Spontaneous speech
     The much discussed analogy between language and music has, perhaps, some
implications for improvisation. The clearest parallel seems to be with
spontaneous speech, which has a comparable creative component. Troup (1986), in
a brief review of this parallel, points to some suggestive possibilities. For
example, spontaneous speech is often characterised by pauses, repeats, false
starts, and delaying syllables like 'um' and 'ah' indicative of real-time
cognitive processing limitations. (Goldman-Eisler 1968, Kowal, Bassett and
O'Connell 1985). Pauses and repeats presumably have this function (among
others) in musical improvisation. Are there also musical devices corresponding
to the false starts and delaying syllables of spontaneous speech?
     Petrie (1983) compared differences in cognitive processing load during
speaking and during pauses in articulations by looking at interference with a
second simultaneous task. Interference was greater during the pauses,
suggesting heightened cognitive processing demands in those periods. Does a
similar effect occur in musical improvisation? If so, this could be correlated
with the level of structural complexity or originality occurring in the music
immediately following such pauses. Further work is clearly required if such
parallels are to be developed to the point where they can make a significant
contribution to improvisation modelling.

III. 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.

     (a)   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 up 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
(e.g. a group of notes, one or more gestures or phrases, etc.) and be called an
event cluster Ei. Then the improvisation I is simply an ordered union of all
these event clusters. Formally,
I =   E1, E2,....EN   (1)
From a naive 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 t1, t2,
....tn 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 schemas for action that are triggered,
not precise movement details, and subsequent motor fine-tuning based on feedback
processes goes on after each time point. Most 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 (ti, ti+1) and entails the generation of the cluster Ei+l on the basis
of the previous events
  E1, E2,....Ei   =   E   i, the referent R (if one exists), a set of current
goals   , 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 1984a). The process of event cluster generation may then be written

$$(\quad E \quad , R, \quad , M)i \qquad E_{i+1} \qquad (2)$$

Decision-making in the (i+1)th situation may in principle extend well back before time t_i, depending on the degree of preselection 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 would 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

$$(\quad E \quad , C, R, \quad , M)i \qquad E_i +1, \qquad k=1,....K, \qquad (3)$$

where subscripts refer to the kth performer, and C stands for performer k's cognitive representations 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:
1. E_i is triggered and executed (it may spill on briefly to times t t_{i+1})
2.   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 O, F, and P, and assume that they represent all information about E_i needed by the improviser in decision-making. 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.1), for the musical aspect only. Considerable redundancy of representation has been set out in the process array, and the feature array has been based only on single objects, so that its column labels are identical to those of the object array. In a more complex case features of groups of objects could be present as additional columns.

3.   The structures of the three types of arrays are as follows. The object array is a 2xN array where row 1 components label the objects present and row 2 gives their associated cognitive strengths sk (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 vjk of associated features or process parameters and their corresponding cognitive strengths sjk. The arrays are non-rectangular because different objects may possess different numbers of significant features or process parameters. The feature and parameter process values vjk vary over ranges appropriate to their nature, whereas cognitive strengths sjk are normalised 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

and possibilities of Ei. There seem to be only two methods of continuation used: associative or interrupt generation. In associative generation the improviser desires to effect continuity between Ei and Ei+1 and picks new arrays Oi+1, Fi+1, Pi+1 whose set of strong cognitive components includes all or nearly all of the set of strong cognitive components of Oi, Fi, and Pi, with the values of these shared components being directly related (as described in point 5). In other words the Ei components with high s values carry their information on in some way to Ei+1. These new arrays act as a set of constraints which determine, in conjunction with various generation processes, the musical actions generated for Ei+1. The relative importance of different feature and process constraints in the overall event generation process is indicated by their respective cognitive strengths sjk. Note that the Ei+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 Ei (for whatever reasons) and breaks off into a different musical direction by resetting a significant number of strong components of Oi+1, Fi+1, Pi+1 without any relations to Ei 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.
4.   Production of Ei+1 occurs primarily on the basis of long term factors (R, , stylistic norms and on-going musical and movement processes), and by evaluation of the effects
5.   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 vjk with sjk's significantly above zero at time t=ti,
        (vjk)ti (vjk)ti+1. Significant object array components behave analogously. In the case   of contrast-type associative generation, at least one strong component of either the feature or process array 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 to 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 merely the very familiar musical clothing of cognitive action space.

6.   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

$K = E_{i-r}, E_{i-r+1},....E_i$, 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 , so that the formal design of the piece becomes

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

Each event cluster class K 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 Os, Fs, and Ps, then K is defined by (Os, Fs, Ps) . One of the sets Fs and Ps must be non-empty. If $(Os, Fs, Ps) =$ or (Os, Fs, Ps) , for some not immediately following , we have recursion in formal design of the improvisation. Under these assumptions the process of improvisation may be sketched diagrammatically as in figure 2.

7.   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 event cluster class, $(t - t_{i-r})$, and the size and nature of K , computes the degree of current repetition, $Z(t)$, and if $Z(t)$ $L(t)$, institutes an interrupt generation, so that $Z(t)$ jumps to a low value. Otherwise associative generation continues. Diagrammatically this is shown in figure 3 for the same improvisation as in figure 2.

8.   Once O_{i+1}, F_{i+1}, and P_{i+1} are selected for all relevant aspects, tunable cognitive and motor subprograms 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 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_o 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 Figure 4.

     Next we look more deeply at certain critical stages of the improvisation model. To begin with, it is characterised 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 kettledrum (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

(Ex.1)

may be pitch encoded as the objects D2F2A2B2, or as the object Bo7 chord in first inversion, or as a diatonic sweep to the leading tone in the key of C major, or as a iio7 chord in a minor, or as an ascending contour, and so forth. Its features include melodic motion by seconds or 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 Bo7 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 may be set up, some means of cognitive organisation and corresponding motor realisation 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, whereaby 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 tunable 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 organisational 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 hematological disorders (cf. Guevara, Glass, Mackey and Shrier 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 into
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 organising 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 coordinated 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 Ei+1 from those preceding it. To make this process clearer, we
now look at two examples.
Example 2: let Ei be

(Ex.2)

played by the right hand at the piano.
Below are a number of possible improvisational continuations, based on
attentional emphasis (i.e. cognitive strength) given to the mentioned array
components (see Figure 5). Emphasis given to a particular component means that
it will guide the generation of subsequent events. The type of arrays
emphasised 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.

Continuation   Emphasised 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 case number 5, which has as its constraint focus the
actual movement patterns for manipulating the instrument.

Example 3: Here we consider an event cluster less clearly tied to structural-
historical

processes. Let Ei 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. Ei is a coloured noise sound which subjectively is reminiscent of distant ocean waves or rain. Some possible continuations are then as follows:

Description of continuation	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 emphasises 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. To this may be added the obvious stipulation that event

generation is also informed by a vast repertoire of culturally and cognitively based musical processes and stylistic preferences for such things as motivic development, phrase design, transposition, scale usage, rhythmic design, etc. But it is only informed, not unambiguously specified. 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 characterise a number of strategies of explanation for the residual decision-making mentioned above, and subsequently explore what possibilities exist for experimentally deciding between 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 fully 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 a number 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 synthesiser-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.

(b)   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.1

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 paper 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

generalised an earlier model of Hebb (1949). The central feature of 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 paper these correspond roughly to 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

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1.   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.

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 focussing 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.

IV.   Conclusions
     This paper 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 reductionistic, in that cognitive structures of processing and
control are considered to be broken down into aspects (acoustic, musical,
movement, et.al.), each of these into types of analytical representation
(objects, features, processes), and each of these into characterising 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 nonlinear 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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References

Abramson, R.M. (1980) Dalcroze-based improvisation, Music educator's journal, 66(5), 62-68.

Adams, J.A. (1961) Human tracking behaviour, Psychological bulletin, 58,55-79.

Adams, J.A. (1971) A closed-loop theory of motor learning, Journal of motor behaviour, 3, 111-149.

Adams, J.A. (1976) Issues for a closed-loop theory of motor learning. In Motor control:issues and trends, (ed. G.E. Stelmach), Academic Press, New York.

Adams, R. (1980) The iron wolf, Penguin, Reading.

Alperson, P. (1984) On musical improvisation, Journal of aesthetics and art criticism, 43, 17-29.

Allport, D.A. (1980) Attention and performance. In Cognitive psychology: new directions, (ed. G. Claxton), Routledge and Kegan Paul, London.

Amabile, T.M. (1983) The social psychology of creativity, Springer-Verlag, New York.

Armbruster, G. (1984) First steps in improvisation, Keyboard, 10(Oct.), 37-44.

Arnold, F.T. (1931/65) The art of accompaniment from a thoroughbass as practised in the XVIIth and XVIIIth centuries, Dover, New York.

Austin, L., Oliveros, P. et.al. (1982/83) Forum: Improvisation, Perspectives of new music, Fall-Winter 1982/Spring Summer 1983, pp.26-111.

Avery, T.L. (1984) Structure and strategy in Azorean-Canadian song duels, PhD thesis, Indiana University.

Bach, C.P.E. (1778/1949) Essay on the true art of playing keyboard instruments, Norton and Co, New York.

Bahm, A. (1960) Types of intuition, University of New Mexico publications in social sciences and philosophy, no.3.

Bailey, D. (1980) Improvisation: its nature and practice in music, Moorland Pub, London.

Baker, D. (1969) Jazz improvisation, Maher, Chicago.

Bartlett, F.C. (1947) The measurement of human skill, British medical journal, i, 835 and 877.

Bash, L. (1983) The effectiveness of three instructional methods on the
    acquisition of jazz improvisation skills, PhD thesis, University of New
    York at Buffalo.
Bastick, T. (1982) Intuition: how we think and act, Wiley, Chichester.
Beatty, J. (1975) Introduction to physiological psychology, Brooks/Cole,
    Monterey.
Behague, G. (1980) Improvisation in Latin American musics, Music educator's
    journal, 66(5), 118-125.
Bentley, D. and Konishi, M. (1978) Neural control of behaviour, Ann. Rev.
    Neurosci, I, 35-59.
Bergson, H.L. (1910) Matter and memory, authorised transl. N.M. Paul, W.S.
    Palmer, Allen, London.
Berkowitz, S. (1975) Improvisation through keyboard harmony, Prentice Hall,
        Englewood Cliffs, New Jersey.
Bernstein, N. (1967) The coordination and regulation of movements, Pergamon
    Press,London.
Biasini, A. and Pogonowski, L. (1971) MMCP interaction, Americole,
    Bellingham.
Brennan, M.A. (1982) Relationship between creative ability in dance and
    selected attributes, Perceptual and motor skills, 55, 47-56.
Bresgen, C. (1960) Die improvisation, Quelle and Meyer, Heidelberg.
Brooks, D.N. and Baddeley, A. (1976) What can amnesic patients learn?
        Neuropsychologia, 14, 111-22.
Brooks, V.B. (1978) Motor programs revisited. In Posture and movement:
    Perspectives
        for integrating sensory and motor research on the mammalian nervous
    system Raven Press, New York.
Bruner, J.S. (1969) Modalities of memory. In The pathology of memory, (ed.
    G.A.
        Tallard, N.C. Waugh), 253-59, Academic Press, New York.
Brunia, C.H.M. (1980) Motor preparation, recorded on the cortical and spinal
    level. In
        Tutorials in motor behaviour, (ed. G.E. Stelmach and J. Requin),
    North-Holland, Amsterdam.
Bunge, M. (1962) Intuition and science, Prentice-Hall, Englewood Cliffs, New
    Jersey.
Burnsed, C.V. (1978) The development and evaluation or an introductory jazz
    improvisation
        sequence for intermediate band students. Dissertation Abstracts
    International, 39, 4578A.
Carlson, W.R. (1980) A procedure for teaching jazz improvisation based on an
    analysis of the
        performance practice of three major jazz trumpet players: Louis
    Armstrong, Dizzy Gillespie and Miles Davis. Dissertation Abstracts
    International, 41, 1214A.
Carr, I. (1982) Miles Davis, Paladin, London.
Chadabe, J. (1984) Interactive composing: an overview, Computer music
    journal, 8(1), 22-27.
Charles, D. (1982) Conga, bongo and timbale techniques - live and in the
    studio, Marimba
        Productions, New York.
Chernikoff, R., and Taylor, F.V. (1952) Reaction time to kinesthetic
    stimulation
        resulting from sudden arm displacement, Journal of experiemental
    psychology, 43, 1-8.
Clark, H.H. and Clark, E.V. (1977) Psychology and language, Harcourt Brace
        Jovanovitch, New York.

Cohen, N.J. and Squire, L.R. (1980) Preserved learning and retention of pattern
        analysing skill in amnesia: dissocation of knowing how and knowing
    that, Science, 210, 207-9.
Cohen, N.J. (1981) Neuropsychological evidence for a distinction between procedural and
        declarative knowledge in human memory and amnesia, PhD thesis,
    University of California at San Diego.
Coker, J. (1964) Improvising jazz, Prentice-Hall, Englewood Cliffs, New Jersey.
Coker, J. (1975) The jazz idiom, Prentice-Hall, Englewood Cliffs, New Jersey.
Coker, J., Casale, J., Campbell, G., and Greene, J. (1970) Patterns for jazz, Studio
        productions, Lebanon, Indiana.
Coleman, S.N. (1922) Creative music for children, G.P. Putnam's Sons, New York.
Cope, D.H. (1984) New directions in music, William Brown, Dubugue, Iowa.
Czerny, C. (1829/1983) Systematic introduction to improvisation on the piano.
        Translated by A.L. Mitchell, Longman, New York.

Datta, V. and Lath, M. (1967) Improvisation in Indian music, World of music,
        1967, 9(1), 27-34.
Davis, R. (1957) The human operator as a single channel information system, Quarterly
        journal of experimental psychology, 9, 119-129.
Delcomyn, F. (1980) Neural basis of rhythmic behaviour in animals, Science, 210,
        492-498.
Denier van der Gon, J.J. and Thuring, J.Ph. (1965) The guiding of human writing
        movements, Kybernetik, 2, 145-148.
Dobbins, B. (1978) The contemporary jazz pianist, Jamestown RI, GAMT Music Press
        (4 vols)
Doerschuk, B. (1984) The literature of improvisation, Keyboard, 10 (Oct.),
    48-52.
Dupre, M. (1925/37) Cours complet d'improvisation a' l'orgue, Paris, A. Leduc, (2 vols).
Easton, T.A. (1978) Coordinative structure - the basis for a motor program. In
        Psychology of motor behaviour and sport, (eds D.M. Landers and R.W.
    Christina), Human kinetics, Champaign, Ill.
Eccles, J.C. (1972) The understanding of the brain, McGraw-Hill, New York.
Ehmann, Wilhelm (1950) Chorische Improvisation in der Kantorei, Kirchenchor, X
        (September-October, 1950), 65-71.
Erlmann, V. (1985) Model, variation and performance. Ful'be praise song in Northern
        Cameroon. Yearbook for traditional music, 17, 88-112.
Ewing, A. (1941) Reason and intuition, Proceedings of the British academy, XXVII,
        67-107.
Ferand, Ernst (1938) Die improvisation in der musik, Rhein-Verlag, Zurich.
Ferand, Ernst (1961) Improvisation in nine centuries of western music, Arno Volk Verlag,
        Hans Gerig KG, Cologne.

Fitts, P.M. (1964) Perceptual-motor skill learning. In Categories of human learning, (ed.
        A.W. Melton), Academic Press, New York.
Fry, C. (1980) Computer improvisation, Computer music journal, 4(3), 48+.
Fry, C. (1982/83) Dancing musicians, Perspectives of new music, Fall-Winter
        1982/Spring-Summer 1983, 585-589.
Gaburo, K. (1968-) Twenty sensing compositions, Lingua Press, La Jolla, California.
Galas, D. (1981/82) Intravenal song, Perspectives of new music, Fall-Winter
        1981/Spring-Summer 1982, pp.59-62.
Gehring, P.K. (1963) Improvisation in contemporary organ playing, PhD thesis, Syracuse
        University.
Gelernter, H. (1963) Realisation of a geometry-theorem-proving machine. In Computers
        and thought, (ed. E.A. Feigenbaum and J. Feldman), McGraw-Hill, New York.
Gel'fand, I.M. and Tsetlin, M.L. (1962) Some methods of control for complex systems,
        Russian mathematical surveys, 17, 95-116.
Gel'fand, I.M. and Tsetlin, M.L. (1971) Mathematical modelling of mechanisms of the
        central nervous system. In Models of the structural-functional organisation of certain biological systems, (eds I.M. Gel'fand, V.S. Gurfinkel, S.V. Fomin, and M.T. Tsetlin), MIT press, Cambridge, Massachusetts.
Gibbs, C.B. (1965) Probability learning in step-input tracking, British journal of
        psychology, 56, 233-242.
Gibbs, C.B. and Brown, I.C. (1956), Increased production from information incentives in
        an uninteresting repetitive task, Manager, 24, 374-379.
Gibson, J.J. (1966) The senses considered as perceptual systems, Houghton Mifflin,
        Boston.
Gibson, J.J. (1979) The ecological approach to visual perception, Houghton Mifflin,
        Boston.
Glencross, D.J. (1977) Control of skilled movements, Psychological bulletin, 84, 14-29.
Glencross, D.J. and Koreman, M.M. (1979) The processing of proprioceptive signals,
        Neuropsychologia, 17, 683-687.
Goldman-Eisler, F. (1968) Psycholinguistics: Experiments in spontaneous speech,
        Academic Press, London.
Goldstein, M. (1983) The gesture of improvisation: some thoughts, reflections and
        questions regarding percussion music, Percussionist, 21/3, 18-24.
Gorder, W.D. (1976) An investigation of divergent production abilities as constructs of
        musical creativity, Ed. D. dissertation, University of Illinois at Urbana- Champaign.
Gorder, W.D. (1980) Divergent production abilities as constructs of musical creativity,
        Journal of research in music education, 28, 34-42.
Greene, P.M. (1972) Problems of organisation of motor systems. In Progress in

theoretical biology vol.2, (eds R. Rosen and F.M. Snell), Academic Press, New York.

The new Grove dictionary of music and musicians (1980) (ed. S. Sadie), 6th edition;
        Macmillan, London: listings under improvisation, aleatory, cadenza, continuo, division, prelude non mesure.

Guevara, M., Glass, L., Mackey, M., and Shrier, A. (1983) Chaos in neurobiology, IEEE
        transations on systems, man, and cybernetics, SMC-13(5), 790-798.

Guilford, J.P. (1956) The structure of intellect, Psychological Bulletin, 53, 267-293.

Guilford, J.P. (1957) Creative abilities in the arts, Psychological Review, 64, 110-118.

Guilford, J.P. (1977) Way beyond the I.Q., Creative education foundation, New York.

Guilford, J.P. and Hoepfner, R. (1971) The analysis of intelligence, McGraw-Hill, New
        York.

Hanlon, E.S. (1975) Improvisation: theory and application for theatrical music and silent
        film, PhD thesis, University of Cincinnati.

Hamel, P.M. (1976/79) Through music to the self, Shambhala, Boulder.

Harrell, M.C. (1974) The music of the gamelan degung of West Java, PhD thesis UCLA.

Hayes-Roth, B. (1977) Evolution of cognitive structures and processes, Psychological
        review 84(3), 260-278.

Hebb, D.D. (1949) Organisation of behaviour, Wiley, New York.

Hendrickson, G. and Schroeder, W.H. (1941) Transfer of training in learning to hit a
        submerged target, Journal of educational psychology, 32, 205-213.

Hick, W.E. (1952) On the rate of gain of information, Quarterly journal of experimental
        psychology, 4, 11-26.

Higgins, J.R. and Angel, R.W. (1970) Correction of tracking errors without sensory
        feedback, Journal of experimental psychology, 84, 412-416.

Hodeir, Andre (1956) Jazz: its evolution and essence, translated by David Noakes, Grove
        press, New York.

Holding, D.H. (1965) Principles of training, Pergamon, London.

Holding, D. (1981) Skills research. In Human skills, (ed. D. Holding), John Wiley and
        Sons, Chichester.

Hollerbach, J.M. (1981) An oscillation theory of handwriting, Biological cybernetics, 39,
        139-156.

Hood, M. (1971) Aspects of group improvisation in the Javanese gamelan. In Musics
        of Asia, (ed. Jose Maceda), Manila, pp.17-21.

Hood, M. (1975) Improvisation in the stratified ensembles of Southeast Asia, Selected
        reports in ethnomusicology, (UCLA), 2(2), 25-33.

Hores, R.G. (1977) A comparative study of visual- and aural-orientated approaches to
        jazz improvisation with implications for instruction, Ed. D. thesis, Indiana University.

Howard, J. (1978) Improvisational techniques of Art Tatum, PhD thesis, Case Western
        Reserve University.
Huggins, A.W.F. (1978) Speech timing and intelligibility. In Attention and performance
        VII, (ed. J. Requin), Lawrence Erlbaum, Hillsdale N.J.
Hunt, R. (1968) Extemporisation for music students, Oxford, London.
Jairazbhoy, N.A. (1971) The rags of North Indian music, Faber and Faber, London.
Jaques-Dalcroze, E. (1921/1976) Rhythm, music and education, B. Blom, New York.
Jaques-Dalcroze, E. (1930) Eurythmics, art, and education, Ayer, New York.
James, W. (1890) Principles of psychology (vol.1), Holt, New York.
Jones, A.M. (1959) Studies in African music, Oxford University Press, London.
Jost, E. (1974) Free jazz, Universal, Graz.
Keele, S.W. and Posner, M.I. (1968) Processing of feedback in rapid movements, Journal
        of experimental psychology, 77, 353-363.
Keele, S.W. and Summers, J.J. (1976) The structure of motor programs. In Motor
        control: issues and trends, (ed. G.E. Stelmach), Academic press, New York.
Kelso, J.A., Holt, J.G., Rubin, P., and Kugler, P.N. (1981) Patterns of human interlimb
        coordination emerge from the properties of non-linear, limit cycle oscillatory processes: theory and data, Journal of motor behaviour, 13, 226-261.
Kelso, J.A.S. (1982) Two strategies for investigating action. In Human motor behaviour
        (ed. J.A.S. Kelso), Lawrence Erlbaum, Hillsdale, N.J.
Kelso, J.A.S. and Wallace, S.A. (1978) Conscious mechanisms in movement. In
        Information processing in motor control and learning, (ed. G.E. Stelmach), Academic press, N.Y.
Kernfeld, B. (1983) Two Coltranes, Annual review of jazz studies, 2, 7-66.
Kerr, R. (1982) Psychomotor learning, Saunders, Philadelphia.
Kickert, W.G., Bertrand, J.W., and Praagman, J. (1978) Some comments on cybernetics
        and control, IEEE transactions on systems, man and cybernetics, SMC-8, 805-809.
Kleinman, D.L., Baron, S., and Levison, W.H. (1971) A control theoretic approach to
        manned-vehicle systems analysis, IEEE transactions on automatic control, AC-16, 824-832.
Kleeman, J.E. (1985/86) The parameters of musical transmission The journal of
        musicology, 4, 1-22.

Kowal, S., Bassett, M.R. and O'Connell, D.C. (1985) The spontaneity of media
        interviewers, Journal of psycholinguistic research, 14, 1-18.
Kugler, P.N., Kelso, J.A.S., and Turvey, M.T. (1980) On the concept of coordinative
        structures as dissipative structures: I. Theoretical lines of convergence. In Tutorials in motor behaviour (ed. G.E. Stelmach and J. Requin), North-Holland, Amsterdam.
Laabs, G.J., and Simmons, R.W. (1981) Motor memory. In Human skills (ed. D. Holding)
        Wiley, New York.

Laneri, Roberto (1975) Prima materia: An opus in progress. The natural dimension of
        music, PhD thesis, UCSD.
Lenat, D.B. (1984) Computer software for intelligent systems, Scientific American,
        251(3), September, 152-160.
Leonard, J.A. (1959) Tactual choice reactions, Quarterly journal of experimental
        psychology, 11, 76-83.
Levitt, D.A. (1981) A melody description system for jazz improvisation, M.S. thesis,
        M.I.T.
Liebman, D., Beirach, R., Tusa, F., Williams, J., and Roy, B. (1978) Lookout farm, Almo
        Publications, Hollywood.
Li, T.Y. and Yorke, J. (1975) Period three implies chaos, American mathematical
        monthly, 82, 985-992.
Lipiczky, T. (1985) Tihai formulas and the 'composition' and improvisation in North
    Indian music, The musical quarterly, 71, 157-71.
Locke, D. (1979) The music of atsiabeko, PhD thesis, Wesleyan University.
Lord, A.B. (1964) The singer of tales, Harvard University press, Cambridge, Mass.
Lord, A.B. (1965) Yugoslav epic folk poetry. In The study of folklore, (ed. A. Dundes),
        Prentice-Hall, Englewood Cliffs.

Marteniuk, R.G. and Romanow, S.K.E. (1983) Human movement organisation and
        learning as revealed by variability of movement, use of kinematic
    information, and Fourier analysis. In Memory and control of action, (ed.
    R.A. Magill), North-Holland, Amsterdam.
Mathieu, L. (1984) A phenomenological investigation of improvisation in music and
        dance, PhD thesis, New York University.
May, R.M. (1976) Simple mathematical models with very complicated dynamics, Nature,
        261, 459-467.
McCulloch, W.S. (1945) A heterarchy of values determined by the topology of nervous
        nets, Bulletin of mathematical biophysics, 7, 89-93.
Mersenne, (1635) Harmonie Universelle.
Milano, D. (1984) The psychology of improvisation, Keyboard, 10 (Oct), 25, 30-35.
Miller, G.A., Galanter, E., and Pribram, K. (1960) Plans and the structure of behaviour,
        Holt, Rinehart and Winston, New York.
Miller, P. (1982/83) Music and the silent film, Perspectives of new music, Fall-Winter
        1982/Spring Summer 1983, 582-584.
Mills, E. and Murthy, T.C. (1973) (eds) The Suzuki conception: an introduction to a
        successful method for early music education, Berkeley, California.
Milner, B. (1962) Les troubles de la memoire accompagnant des lesions hippocampiques
        bilaterales. In Physiologie de l'Hippocampe, Cent. Natl. Recherche
    Scientifique, Paris.

Moorman, D.L. (1984) An analytic study of jazz improvisation with suggestions for
        performance, PhD thesis, New York University.
Morasso, P. (1983) Three dimensional arm trajectories, Biological cybernetics, 48, 187-
        194.
Murphy, F. (1982) The cornet style of Leon Bix Beiderbecke (1903-1931), PhD thesis, La
        Trobe University

Nagler, M.N. (1974) Spontaneity and tradition: a study in the oral art of Homer,
        University of California Press, Berkeley, Ca.
Namikas, G. (1983) Vertical processs and motor performance. In Memory and control of
        action, (ed. R.A. Magill), North-Holland, Amsterdam.
Nelson, O. (1966) Patterns for improvisation, Nelson music, Hollywood.
Nettl, B. (1974) Thoughts on improvisation, Musical quarterly, 60, 1-19.
Nettl, B. and Foltin, B. Jr (1972) Daramad of Chahargah, Information
        coordinators, Detroit.
Nettl, B. and Riddle, R. (1974) 'Taqsim Nahawand: a study of 16 performances by Jihad
        Racy', Yearbook of the international folk music council, 5, 11-50.
Newell, K.M. (1981) Skill learning. In Human skills, (ed. D. Holding), John Wiley and
        Sons, Chichester.
Oliveros, P. (1971) Sonic meditations, Smith publications/sonic art editions,
        Baltimore, Md.
Owens, T. (1974) Charle Parker: techniques of improvisation, 2 vols, PhD thesis,
        UCLA.
Paillard, J. (1980) The multichanneling of visual cues and the organisation of a visually
        guided response. In Tutorials in motor behaviour, (eds G.E. Stelmach and J. Requin), North-Holland, Amsterdam.
Park, M. (1985) Music and Shamanism in Korea: a study of selected ssikkum-gut rituals
        for the dead, PhD thesis, UCLA.
Parry, M. (1930) Studies in the epic technique of oral versemaking: I. Homer and
        Homeric style, Harvard studies in classical philology, 41, 73-147.
Parry, M. (1932) Studies in the epic technique of oral versemaking: II. The Homeric
        language as the language of poetry, Harvard studies in classical philology, 43, 1-50.
Parsons, Will (1978) Music for citizen's band, W. Parsons, La Jolla, California.
Partchey, K.C. (1973) The effects of feedback, models, and repetition on the ability to
        improvise melodies, D.Ed. thesis, Pennsylvania State University.
Paulson, J.C. (1985) The development of an imitative instructional approach to
        improvising effective melodic statements in jazz solos, DMA thesis, University of Washington.
Petrie, H.L. (1983) Measuring cognitive processing during spontaneous speech, Bulletin
        of the British Psychological Society, 36 A100.

Pew, R.W. (1974) Human perceptual-motor performance. In Human information
        processing: tutorials in performance and cognition, (ed. B.H.
    Kantowitz), Erlbaum, New York.
Pew, R.W. and Baron, S. (1978) The components of an information processing
    theory of
        skilled performance based on an optimal control perspective. In
    Information processing motor control and learning, (ed. G.E. Stelmach),
    Academic press, New York.
Pike, A. (1974) A phenomenology of jazz, Journal of jazz studies, 2(1), 88-
    94.
Poulton, E.C. (1957) On the stimulus and response in pursuit tracking,
    Journal of
        experimental psychology, 53, 57-65.
Powers, W.T. (1973) Behaviour: the control of perception, Aldine, Chicago.
Pressing, J. (1980) Music, altered states of consciousness, and psi. In
    Proceedings of the
        psychic orientation conference, (ed. A. Gabay), La Trobe University,
    Melbourne.
Pressing, J. (1984a) Cognitive processes in improvisation. In Cognitive
    processes in the
        perception of art, (ed. W.R. Crozier and A.J. Chapman), North-
    Holland, Amsterdam, pp.345-363.
Pressing, J. (1984b) A history of musical improvisation to 1600, Keyboard,
    10(11), 64-68.
Pressing J. (1984c) A history of musical improvisation: 1600-1900,
    Keyboard, 10(12),
        59-67.
Prigogine, I. (1967) Introduction to thermodynamics of irreversible
    processes,
        Interscience, New York.
Prigogine, I., and Nicolis, G. (1971) Biological order, structure and
    instabilities,
        Quarterly review of biophysics, 4, 107-148.
Prigogine, I., Nicolis, G., Herman, R., and Lam, T. (1975) Stability,
    fluctuations, and
        complexity, co-operative phenomena 2.
Propp, V.I. (1927/1968) Morphology of the folk tale, translated by L. Scott,
    University of
        Texas press, Austin.
Quantz, J.J. (1752/1966) On playing the flute, translated E. Reilley, The
    Free press, New
        York.
Rabbitt, P.M.A. and Vyas, S.M. (1970) An elementary preliminary taxonomy for
    some
        errors in laboratory choice RT tasks, Acta psychologica, 33, 56-76.
Radano, R.M. (1985) Anthony Braxton and his two musical traditions, the
    meeting of
        concert music and jazz (2 vols), PhD thesis, University of Michigan.
Reck, D.B. (1983) A musician's took-kit: a study of five performances by
        Thirugokarnam Ramachandra Iyer, 2 vols., PhD thesis, Wesleyan
    University, 939 pp.
Rich, E. (1983) Artificial intelligence, McGraw-Hill, New York.
Richardson, C.P. (1983) Creativity research in music education: a review,
    Council for
        research in music education, 74 (Spring 83), 1-21.
Roads, C. (1979) Grammars as representations for music, Computer music
    journal, III, 48-55.

Roderick, J.L. (1965) An investigation of selected factors of the creative thinking ability
        of music majors in a teacher training program, Dissertation Abstracts International, 26, 409.
Ryle, G. (1949) The concept of mind, Hutchinson, London.
Saltzman, E.L. and Kelso, J.A.S. (1983) Toward a dynamical account of motor memory
        and control. In Memory and control of action, (ed. R.A. Magill), North-Holland, Amsterdam.
Sage, G.S. (1977) Introduction to motor behaviour: a neuropsychological approach,
        Addison-Wesley, Reading, Mass.
Schickhaus, K-H. (1978) Neues Schulwerk fur Hackbrett, Musikverlag Josef Preissler,
        Munich.
Schiffrin, R.M. and Schneider, W, (1977) Controlled and automatic human information
        processing: II. perceptual learning, automatic attending, and a general theory, Psychological review, 84, 127-190.
Schmidt, R.A. (1983) On the underlying response structure of well-learned motor
        responses: a discussion of Namikas and Schneider and Fisk. In Memory and control of action, (ed. R.A. Magill), North-Holland, Amsterdam.
Schneider, W. and Fisk, A.D. (1983) Attention theory and mechanisms for skilled
        performance. In Memory and control of action, (ed. R.A. Magill), North-Holland, Amsterdam.
Schouten, Hennie (no date given) Improvisation on the organ, translated by J.L. Warren,
        W. Paxton and Co Ltd., London.
Schuller, Gunther (1968) Early jazz: its roots and musical development, Oxford
        University press, New York, 1968.
Serafine, M.L. (1983) Cognition in music, Cognition, 14, 119-183.
Shafer, R.M. (1969) Ear cleaning, Universal, London.
Shaffer, L.H. (1978) Timing in the motor programming of typing, Quarterly journal of
        experimental psychology, 30, 333-345.
Shaffer, L.H. (1980) Analysing piano performance: a study of concert pianists. In
        Tutorials in motor behaviour (ed. G.E. Stelmach and J. Requin), North-Holland, Amsterdam.
Shaffer, L.H. (1981) Performances of Chopin, Bach and Bartok: studies in motor
        programming, Cognitive psychology, 13, 327-376.
Shaffer, L.H. (1984) Timing in solo and duet piano performances, Quarterly journal of
        experimental psychology, 36A, 577-595.
Shepherd, G.M. (1983) Neurobiology, Oxford University press, New York.
Sher, C. (1983) The world's greatest fake book, Sher Music, San Francisco.
Signell, K. (1974) Esthetics of improvisation in Turkish art music, Asian music, 5(2),
        1974, pp.45-49.

Signell, K. (1977) Makam: Modal practice in Turkish art music, Asian music
        publications, Seattle.
Silverman, M.L. (1962) Ensemble improvisation as a creative technique in the

       secondary instrumental program, Ed. D. dissertation, Stanford
  University.
Sloboda, J.A. (1982) Music performance. In Psychology of music, (ed. D.
  Deutsch),
      Academic press, New York.
Slonimsky, Nicolas (1975) Thesaurus of scales and melodic patterns,
  Duckworth, London.
Smith, G.E. (1983) Homer, Gregory, and Bill Evans? The theory of formulaic
      composition in the context of jazz piano improvisation, PhD thesis,
  Harvard University.
Smith, J. (1985) Children of the same spirit: a comparative examination of
      improvisation in oral epic poetry and jazz. Proceedings of NAJE
  Research, 5, 129-42.
Smith, W.M. and Bowen, K.F. (1980) The effects of delayed and displaced
  visual
      feedback on motor control. Journal of motor behaviour, 12, 91-101.
Sparrow, W.A. (1983) The efficiency of skilled performance, Journal of motor
  behaviour,
      15, 237-261.
Sperber, Martin (1974) Improvisation in the performing arts: music, dance
  and theatre,
      Ed. D. thesis, Columbia University.
Squire, L.R. (1982) The neuropsychology of human memory, Ann. Rev. Neurosci.
  5, 241-
      273.
Stocks, J. (1939) Reason and intuition, (ed. D.M. Emmett), Oxford University
  press, New
      York.
Stumme, W. (1972) Uber improvisation, B. Schott, Mainz.
Sudnow, D. (1978) Ways of the hand, Harvard University press, Cambridge.

Suehs, H.C. (1979) The development, implementation, and assessment of a
  course of
      study for instruction in certain improvisational techniques in the
  performance of Baroque music from 1679 to 1741, PhD Dissertation, Catholic
  University of America at Washington.
Sumarsam (1981) The musical practice of the gamelan sekaten, Asian music,
  12/2, 54-73.
Summers, J.J. (1981) Motor programs. In Human skills, (ed. D. Holding),
  John Wiley and
      Sons, Chichester.
Tarratus, E.A. (1964) Creative processes in music and the identification of
  creative
      music students, Dissertation Abstracts International, 25, 6679-6680.
Terzudo, C. and Viviani, P. (1979) About the central representation of
  learned motor
      patterns. In Posture and movement, (eds R. Talbot and D.R.
  Humphrey), Raven press, New York.
Thompson, S. (1946) The folktale, Holt, Rinehart and Winston, New York.
Tirro, F. (1974)   Constructive elements in jazz improvisation, Journal of
  the American
      Musicological Society, 27, 285-305.
Torrance, E.P. (1966) Guiding creative talent, Englewood Cliffs, New Jersey.
Touma, H.H. (1971) The maqam phenomenon: an improvisation technique in the
  music of
      the middle east, Ethnomusicology, 15, 38-48.
Treitler, L. (1974) Homer and Gregory: the transmission of epic poetry and
  plainchant,

Musical quarterly, IX, 333-72.

Troup, G. (1986) Psychological processes in musical improvisation, unpublished
        manuscript, Department of Psychology, La Trobe University, Victoria, Australia.

Turvey, M.T. (1977) Preliminaries to a theory of action with reference to vision. In
        Perceiving, acting and knowing: toward an ecological psychology, (eds R. Shaw and J. Bransford), Lawrence Erlbaum, Hillsdale, N.J.

Ueltzen, D.R. (1986) Improvisation in Kirchengesang und mit dem Kirchenlied und am
        Gesangbuch fur das Jahr 2000 Gottesdienst und Kirchenmusik, 3, 71-7.

Vaughan, M.M. (1971) Music as model and metaphor in the cultivation and measurement
        of creative behaviour in children, Ed. D. thesis, University of Georgia.

Vaughan, M.M. (1977) Musical creativity: its cultivation and measurement, Bulletin of
        the council for research in music education, 52, 72-77.

Vikis-Fribergs. (1984) Creativity and tradition in oral folklore or the balance of
        innovation and repetition in the oral poet's art. In Cognitive processes in the perception of art, (eds. W.R. Crozier and A.J. Chapman), North-Holland, Amsterdam.

Viviani, P. and Terzudo, C. (1980) Space-time invariance in learned motor skills. In
        Tutorials in motor behaviour, (eds G.E. Stelmach and J. Requin), North-Holland, Amsterdam.

von Foerster, H. (1960) On self-organising systems and their environments. In Self-
        organising systems, (ed. M.C. Yorits and S. Cameron), Pergamon press, New York.

Von Holst, E. (1954) Relations between the central nervous system and the peripheral
        organs, British journal of animal behaviour, 2, 89-94.

Wade, Bonnie (1973) Chiz in Khyal: The traditional composition in the improvised
        performance, Ethnomusicology, 17(3), 443-459.

Webster, R.P. (1977) A factor of intellect approach to creative thinking in music, PhD
        dissertation, University of Rochester, Eastman School of music.

Weidner, R.F. (1984) The improvisation techniques of Charles Tournemire as extracted
        from his five reconstructed organ improvisations, PhD thesis, Michigan State University.

Welford, A.T. (1974) On the sequencing of action, Brain research, 71. 381-392.

Welford, A.T. (1976) Skilled performance, Scott, Foresman and Co., Glenview, Ill.

West, L.J. (1967) Vision and kinesthesis in the acquisition of typewriting skill, Journal of
        Applied Psychology, 51(2), 161-166.

Westcott, M.R. (1968) Toward a contemporary psychology of intuition, Holt, Rinehart
        and Winston, New York.
Whitmer, T. Carl (1934) The art of improvisation, New York: M. Witmark and Sons.

Wilberg, R.B. (1983) Memory for movement: discussion of Adams and Saltzman and
        Kelso. In Memory and control of action, (ed. R.A. Magill), North-
    Holland, Amsterdam.
Winograd, T. (1975) Frame representations and the declarative-procedural controversy.
        In Representation and understanding, (ed. D. Bobrow, A. Collins),
    Academic press, N.Y.
Wyrick, W. (1968) The development of a test of motor creativity. Research quarterly,
        39, 756-765.
Zelaznik, H.N., Hawkins, B., and Kisselburgh, L. (1983) Rapid visual feedback processing
        in single-arming movements, Journal of motor behaviour, 15, 217-236.
Zonis, Ella (1973) Classical persian music: an introduction, Harvard University press,
        Cambridge, Mass.

Figure 1   Object, feature and process arrays (musical aspect) corresponding to a short trombone motive

Figure 2   An improvisation in musical action space, showing
four event cluster classes, and form ABA'C.

Figure 3   Time behaviour of the Improvisational Interrupt
Function

Figure 4

The Improvisation Model in diagrammatic form. Only the process Ei   Ei+1 (intended)
is detailed. Each event cluster Ei 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 Ei
arrays, referent, goals, and memory. This decomposition acts as a set of
constraints in the generation of musical action, and production of Ei+1 is
subsequently begun by a movement trigger at ti+1. The diagram detail shows what
happens in the time interval (ti, ti+1), so that the indicated decomposition of
Ei is integrated (that is, intended plus actual forms of Ei are combined),
whereas the indicated decomposition of Ei+1 is intended (no feedback has been
received yet). Hence O, F, and P at time point ti+1 do not have indicated
outputs.

Figure 5   Examples of continuation of an event cluster under the emphasis of selected array components (see text example 2).

Example 1

Example 2

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This paper presents a model for Collective Free Improvisation (CFI), a form of improvisation that can be defined as referent-free. While very simple, it captures some interesting mechanisms of CFI. We use two variables: the intention and the objective. Both variables are used to describe the production and organization of the improvisers' signals. Using a system of Landau equations, we propose a non-linear dynamics for the intention evolving on a short time-scale while the objective evolves on a long time-scale. In this paper, the model is used to determine if, and within which conditions, a c