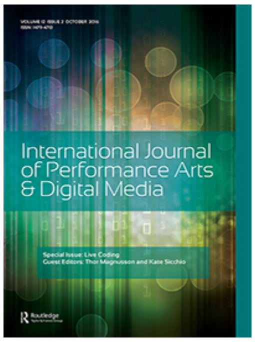

International Journal of Performance Arts and Digital Media

ISSN: 1479-4713 (Print) 2040-0934 (Online) Journal homepage: http://www.tandfonline.com/loi/rpdm20

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To cite this article: Tim Sayer (2016) Cognitive load and live coding: a comparison with improvisation using traditional instruments, International Journal of Performance Arts and Digital Media, 12:2, 129-138, DOI: 10.1080/14794713.2016.1227603

To link to this article: https://doi.org/10.1080/14794713.2016.1227603

Published online: 06 Dec 2016.

INTERNATIONAL JOURNAL OF PERFORMANCE ARTS AND DIGITAL MEDIA, 2016
VOL. 12, NO. 2, 129–138
http://dx.doi.org/10.1080/14794713.2016.1227603

Cognitive load and live coding: a comparison with improvisation using traditional instruments

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ABSTRACT

This paper explores the claim that live coding is a 'real-time' improvisatory activity by examining the difference in the temporal frame used by this and traditional instrumental improvisation, for the creation of novel musical expression. It posits the notion that because live coding requires less complex motor skills than instrumental improvisation, it may be less susceptible to certain types of mechanical modes of musical expression which inhibit musical novelty. This hypothesis is developed to include the concept of goal states, models of memory and cognitive load, as a means of mapping this territory and to provide an understanding of the various perceptual domains with which a coder engages during a live extemporised performance. This work will engage in a comparative discourse relating live coding to instrumental improvisation, as a point of departure for the understanding of cognitive functioning in this rapidly developing performance paradigm.

KEYWORDS
Improvisation; cognition; memory; reflexes; live coding

1. Goal states

Human perception works in such a way as to present a cohesive and flowing conscious experience. The resources associated with cognitive processing are managed by a plethora of neural processes in a manner that is optimised, for the most part, to keep us safe and healthy. This allows us to ebb and flow between mental states which might be processing sensory data in radically different ways but which are presented to us as a single, fluid experience. One of the key mechanisms in managing the various activities we synchronously engage in is the monitoring and maintaining of various goal states being held at any one time. Although many contemporary theories suggest that goal pursuit is the result of conscious deliberation and desire (Gollwitzer and Moskowitz 1996; Vohs and Baumeister 2004), Ruud Custers posits a convincing argument that goal pursuit can be enacted outside of conscious awareness (Custers 2009). This theory has been successfully tested using priming techniques and has led to the development of such concepts as non-conscious will (Bargh et al. 2001), implicit intention (Wood, Quinn, and Kashy 2002), or implicit volition (Moskowitz, Li, and Kirk 2004). Many studies have concluded that affective priming can have a huge influence on goal motivation (Winkielman, Berridge, and Wilbarger 2005; Aarts, Custers, and Veltkamp 2008). It is quite possible that

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many of the goal states that comprise an improviser's practice are in fact instigated by non-musical and subliminal stimuli. After all, improvising performers are not shielded from their environment or their history for the duration of their performance and the conceptual and perceptual processes that drive their musical behaviour are fuelled as much by implicitly held stimuli as real-time sensory data. The conceptual and perceptual processes that determine the specifically musical goal states in improvised instrumental music and live coding are therefore likely to be influenced by factors outside of their awareness, not least of which is the short-latency dopamine signal, believed by some to play a role in the discovery of novel actions (Redgrave and Gurney 2006). It is therefore important to understand the distinction between reflexes and reactions in relation to the conscious engagement of instrumentalists and live coders in the execution of their art. Only the simplest types of responses are generally regarded as 'reflexes', those that are always identical and do not allow conscious intervention, unlike reactions, which are voluntary responses to a sensory stimulus. This article will suggest that the pallet of reflexive behaviour available to an instrumentalist may be more extensive than for a live coder and that they may be more responsive to implicitly held goal states but this has implications for the spontaneous generation of original musical material.

2. Memory

Sperber states that perceptual processes have, as input, information provided by sensory receptors and, as output, a conceptual representation categorising the object of perception (Sperber 1996). The notion that perceptual processes have as their input the continuous data stream of sensory information and that the outputs from these processes become an input to conceptual processes, can be used to formulate a model of improvised behaviour, where the parameter (sensorial) space in which the behaviour exists is split between the internal and the external. The function of memory acquisition and retrieval therefore has an important role in pursuing goal states (Avery and Smillie 2013).

For improvised musical behaviour of the type exhibited by live coders, the notion of perceptual and conceptual processes governing their behaviour should be put in the context of memory, particularly as there are significant differences between the role of memory in live coding and improvisation using traditional instruments. Motor learning is of particular importance to instrumental performers and there is a consistency across all physical motor skills in the manner of acquisition (Newell 1991). The process begins with the repetition of small units of activity, which may be undertaken and evaluated using multiple senses. In terms of a musical instrumentalist, this obviously utilises audible feedback but also uses a visual and tactile mode of feedback too, such as observing and feeling finger movement on a fret board. The process continues by constructing larger units from the primitive units of activity and so placing them in a range of contexts. At this stage, the parameters and variants in the activities and their triggers can be developed. The repetitive act is in effect embedding a neural programme into semantic memory that can then be triggered and passed a range of parameters. The effect of this is to significantly lighten the cognitive load, as once the activity has been triggered, the detail in the activity can be undertaken with minimal conscious control, responding only to changes in its parameter space. A pianist could practice a scale in this way and when the motor units had been fully committed to memory the activity could be executed without conscious control over each of the component parts. In fact, conscious attention is regarded by some to be detrimental to the accurate execution of highly complex motor skills (Wulf 2007). The motor programme may have a speed parameter that the pianist can control but is perhaps unlikely to have a parameter to change the intervals between the notes. In this way, a whole catalogue of functional units can be triggered and left to run, leaving enough cognitive capacity to be able to undertake other tasks.

There is a distinction that needs to be made between the acquisition and retrieval of the activity units and the mode and manner in which they are assembled into larger conceptual units. Pressing (1984) makes this distinction by describing 'object memory' and 'process memory' as the place where the two exist. Loosely speaking, 'object memory' for an instrumental musician would hold the activity units associated with playing the instrument, often identified by the blanket term 'technique'. The information required to make use of the instrumental technique resides in 'process memory'. This is where the methods for what Pressing describes as 'compositional problem-solving' are held (Pressing 1984). Methods of sequencing and systems for manipulating the parameter space of an activity unit are stored in 'process memory' and retrieved in accordance with the particular mode of performance. It is perhaps worth returning to the notion of cognitive capacity in the light of the processing that 'process memory' feeds.

Motor activities, such as tying up a shoelace or shaving, are reasonably cheap on effort and attentiveness, because the pathway through the activity units is comparatively static and can be easily predicted. However, the computational overhead will increase with human activities that require a higher level of monitoring and real-time manipulation. In the former case, it is possible for a person to experience a sensation of 'switching off' or diverting attention elsewhere. However, in the case of creative activities, routines executed from 'process memory' are likely to be more dynamic, requiring monitoring and parameter adjustment thus making greater cognitive demands. In this case, the brain has a complex resource management problem to address in order for the activity to be undertaken effectively. Activities such as game playing and musical improvisation fall into this category but, as with all other activities, they exist on a continuum somewhere between the extremes of static and dynamic. Their position on the continuum moment-by-moment, is determined by the resource management of the brain but over a period of time can be influenced by the level of pre-programming, or practice that is undertaken.

The instinct to efficiently resource cognitive activity can be a double-edged sword when engaging in a creative process such as improvisation. After years of encoding object and process memory, it becomes possible for the whole 'creative' process to be undertaken by traversing chains of previously stored units of activity. Pressing summarises opinion on this matter when he stated that Fitts (1964) labelled this the 'autonomic phase', while Schmidt (1968) referred to it as 'automatization'. The result for the performer is a sensation of automaticity, an uncanny feeling of being a spectator to one's own actions, since increasing amounts of cognitive processing and muscular subroutines are no longer consciously monitored (Welford 1976). If one considers the difference in the function of object memory in the operation of a piano keyboard and a computer keyboard, the activation of spatial awareness, tactile feedback, pressure sensitivity, range of muscle sets, calibration of stretch movements and so on provide a more complex parameter space for a pianist than a coder.

The significance of object memory, in terms of influencing creative output, is therefore less for a live coder than for a traditional instrumentalist and the sensation of observing one's own actions is perceptually less polarised. Evidence of a tighter bind between object and process memory in coders is borne out by Logan and Crump's (2010) study of skilled typists, which reveals what they term 'illusions of authorship'. This phenomenon suggests the dissociation of a typist's perception of errors in their typing and their subconscious response to those errors. The study shows that a typist will believe what they see on the screen, even when it contradicts what their fingers have typed. The typists took responsibility for errors they did not type and took credit for correcting errors which the system corrected automatically. However, their embodied response contradicted this conscious evaluation. The speed at which their fingers operated the keyboard revealed that all mistakes caused an automatic slowing of the fingers and mistakes which were 'planted' by the system and not typed, caused no slowing (Logan and Crump 2010). This study suggests that there could be an embodied dimension to the process of coding which dissociates the thoughts about what is being coded and the physical act of coding, at least in terms of monitoring what is appearing on the screen.

The role of feedback in the perceptual loop, which gives rise to the 'spectator' type of experience described by improvising musicians, is important to consider. In this context, the self-referential nature of activity units drawn from 'object memory' and subsequent evaluation for the purpose of error correction could be viewed as a closed-loop system. Pressing describes one such feedback model, known as 'closed-loop negative feedback' (CLNF) (Bernstien 1967), in which an evaluation of intended and actual output is fed back to an earlier stage in the control chain. It is perhaps this process of evaluation that problematises the existence of closed- and open-loop feedback systems in improvisation. The submission by Pressing (1988) that a consensus exists which suggests that both systems coexist seems reasonable, if one acknowledges that material drawn from process memory is also subjected to an evaluatory process, the result of which bears influence on the subsequent use of activity units. In this scenario, evaluation is undertaken at two levels simultaneously, but the nature of the evaluation is necessarily very different.

It seems appropriate to apply the principles of closed-loop theory to the evaluation of the primitive motor units, which suggest that a 'perceptual trace' of an activity unit is built up from its previous executions to form a template against which to gauge the success of its current execution. This theory (Adams 1976) is applicable to motor actions undertaken by improvising instrumentalists rather than live coders, because of the autonomous manner of their execution but is not sufficiently flexible to cope with this situation at the 'process memory' level. Pressing recognises why this should be the case when he asserts that in an improvising instrumentalist:

> the ability to construct new, meaningful pathways in an abstract cognitive space must be cultivated. Each such improvised pathway between action units will sometimes follow existing hierarchical connections, and at other times break off in search of new connections. (Pressing 1984)

The function of object memory and its relationship to motor skills in instrumental improvisation and live coding differs significantly due to the interfaces they employ to deliver the results of their creative practice using process memory. The overhead of encoding motor skills for live coding is less burdensome and consequently the cognitive resource gains of 'automaticity' are reduced compared with instrumentalists. It is true that the act of typing is a motor skill but there is less opportunity to build complex amalgamations of primitive units that facilitate direct control over the sound elements in a rich parameter space. That is not to say that fine control over sonic material is not available to live coders, but the means of accessing it is more heavily reliant on process memory than pre-encoded units of behaviour from object memory. Although William James said in 1890, 'habit diminishes the conscious attention with which our acts are performed' (Pressing 1984) I am suggesting that live coders may be less susceptible to the influence of habit and mechanical modes of musical expression because the motor skills required are less complex than instrumentalists and consequently less of their behaviour is activated outside of their perceived conscious control or awareness. There is the possibility that habitual behaviour can develop via conceptual processes fed by process memory but in this instance, there is a much greater opportunity for conscious intervention. Berkowitz surveys the various metaphors used by instrumentalists across a range of cultures to describe the ebb and flow between consciously controlled and automatic musical behaviour during improvisation (Berkowitz 2010). These are often characterised by a sensation of 'letting go' of conscious control and yielding to subconscious processes, described by Stephen Slawek as 'an ecstatic state of effortless' (Slawek 1998). The instrumentalist has at their disposal a vast resource of pre-encoded units of behaviour which will sustain their music making once they have relinquished conscious control, which I would suggest is not available to the live coder.

For live coders, the pre-encoding process takes the form of a repertoire of syntax and algorithmic schema called upon at speed during performance. The act of typing may become very fluid and intuitive but this is someway from Slawek's ecstatic effortlessness. The live coder does not have access to such an extensive repository of embodied knowledge but that does not deny, in live coding, the type of focused attention that Csikszentmihalyi describes as 'flow' (Csikszentmihalyi 1998). In fact, the three prerequisites for a state of flow to be achieved suggested by Csikszentmihalyi, of goal states, immediate feedback and a perceived challenge, are evident in both instrumental improvisation and live coding. In a study into the physiological concomitants of 'flow' in the performance of a classical pianist, it was observed that 'a task of great attentional load may be experienced as less effortful in a state of positive affect' (de Manzano et al. 2010). The distinction I am drawing between the two scenarios in experiencing this is that in the case of instrumental improvisation, effortless is not just a perceived phenomenon resulting from positive affect but actually correlates with the lightening of cognitive load bought about by prior investment in object memory. The rigours of coding syntax and the demands of algorithmic construction do not, for example, afford the opportunity for the live coder to experience the effortlessness of a subconscious flow of automatic writing espoused by the surrealists.

3. Cognitive load

I am suggesting that the live coding paradigm differs significantly from instrumental improvisation in its relationship to cognitive load. Pressing identifies that speeds of approximately ten actions per second and higher involve virtually exclusively pre-programmed actions (Pressing 1984). An informal analysis of jazz solos over a variety of tempos supports this estimate of time limits for improvisational novelty. (Pressing

1988). In instrumental improvisation, the need to reduce the cognitive burden of conscious monitoring at high speeds is clear, but philosophically, this can be a problematic notion for many musicians. It is probably fair to say that for some musicians, there is a principle at stake in calling a musical activity 'improvisation' that overtly reuses 'learnt' material. Of course, certain types of improvisation rely on the use and reuse of material through convention and to maintain stylistic integrity but for exponents of non-idiomatic forms of improvisation, often referred to as 'free' playing, this aspect is an anathema. John Eyles alleges that Derek Baily described free improvisation as 'playing without memory' (Eyles 2005). The saxophonist Steve Lacy, in conversation with Derek Bailey, expresses his frustration accordingly when he says:

> why should I want to learn all those trite patterns? You know, when Bud Powell made them, fifteen years earlier, they weren't patterns. But when somebody analysed them and put them into a system it became a school and many players joined it. But by the time I came to it, I saw through it – the thrill was gone. Jazz got so that it wasn't improvised any more. (Bailey 1993)

Although the causal relationship between the expression of ideas in code and the execution of those ideas by the computer is more asynchronous and less rigidly fixed to a time frame than instrumental improvisation, live coding, like all other human activities, still has to exist within the confines of an available cognitive resource. It is important to emphasise that information being processed consciously at any one time is only a small subset of the overall cognitive workload that is being undertaken. Consciousness could be described as a mental juggling act, with a limit on the number of balls in the air at any one time (Miller and Buschman 2015). Working memory, the repository for managing conscious thoughts, is fed information and sits beside a multitude of other biological systems needing physical resources. That is not to say that if all other competing systems relented, consciousness's performance could be enhanced ad infinitum. Perhaps the most enduring observation relating to the limitations of the human capacity for processing information is from 1956, when Miller suggested the 'magic number 7 +/- 2' (Miller 1956). This 'magic number' represents the amount of information threads or 'chunks' that could be retained in working memory at any one time. The theatre metaphor proposed by Baars suggests a spotlight of selective attention representing consciousness, into which actors move in and out, surrounded by the darkness of the unconscious, where all the other roles which facilitate the production reside (Baars 1997). In Wiggin's adaption of Baars global workspace theory to a musical context, he asserts that his concern is not with what consciousness is, but what is presented to it. He presents a model of creative cognition in which the non-conscious mind comprises a large number of expert generators, performing parallel computations and competing to have their outputs accepted into the global workspace (Wiggins 2012). Wiggins' distinction suggests a significant difference between instrumentalists and coders in that which is offered to the global workspace. Instrumentalists have a physical relationship with their instruments which provide feedback and access to a fixed set of functions, a relationship which is embodied and distributed through many physiological systems. Apart from exceptional circumstances, the instrument will respond with reasonable predictability to the will of the performer, almost passively, and provide a level of sensorial feedback in return. Conceptually, Wiggins' 'expert generators' in this context are dependent on the instrumentalists ability to deliver the functionality required to realise the idea.

Occasionally, this process is subverted and for some, this is where real rewards can be found, as Derek Bailey describes.

> A lot of improvisers find improvisation worthwhile. I think, because of the possibilities. Things that can happen but perhaps rarely do. One of those things is that you are 'taken out of yourself'. Something happens which so disorientates you that for a time, which might only last for a second or two, your reactions and responses are not what they normally would be. You can do something you didn't realise you were capable of or you don't appear to be fully responsible for what you are doing. (Bailey 1993)

Live coders have at their disposal functionality which extends beyond that which they can retain as an immediate personal resource. Their musical gestures are embodied in a code narrative which spills onto the screen as a co-located repository of their thoughts. This can extend even further from the immediate representation on screen into libraries of functionality and data structures which provide something akin to Clarke's notion of an extended mind (Clark and Chalmers 1998), where, in this instance, human long-term memory is augmented by data held on the computer and working memory is mirrored in the code window. Bailey implies, in his description above, that something happens to the instrumentalist for which they are not responsible. Indeed, it is hard to imagine how an instrumentalist could intend to play something they deem themselves not capable of. Live coders, not restricted by the limits of their physicality to the same extent, have their capability extended into the machine and are therefore 'taken out of themselves' as a matter of course in the execution of their art. The affordances of the computer offer them the potential to more easily avoid the situation described in John Cage's criticism of improvisers as performers who 'slip back into their likes and dislikes, and their memory, and … don't arrive at any revelation that they're unaware of' (Turner and Cage 1990). The time frame in which they codify their musical expression is not necessarily synchronous with musical time and so the imperative to conceptualise, encode, and transmit musical material is relieved of the 'ten actions per second' restriction that Pressing identifies as the limit of improvisational novelty.

The distinction in the way instrumental and live coding improvisation plays out in the global workspace is important and supports Berliner's 'creator–witness' mode of improvised instrumental behaviour (Berliner 1994). In both activities, the spotlight of attention is responsive to the wider performance environment and also to the behaviour of others actively taking part in the performance. However, in many instances, an improvising instrumentalist could happily engage in verbal dialogue with someone while continuing to play their instrument but a live coder would probably struggle to talk and code at the same time. It therefore seems plausible that live coders require at their disposal, more cognitive resource to engage conceptual processes and process memory, which will tend to produce behaviour that is reactive rather than reflexive.

Both instrumental and live coded improvisation exists in a context where there is an expectation that novel musical material will be produced in a temporal domain that is often referred to as 'real-time' or 'in the moment'. In order to achieve this, instrumental performers have to conceptualise, encode, transmit and evaluate musical material in a manner that is perceived as a single fluid action. This action comprises cognitive processes that are fed by sensory information, implicitly held memories, such as motor skills and more executive conceptual functioning driven by the performance context, and knowledge and experiences held in long-term memory. This seamless sequence of actions is a fragile parameter space that is susceptible to reflexive responses and conscious and unconscious responses to internal and external stimuli. The performance being undertaken always exists within the context of available cognitive resources and could be terminated in an instant should the need arise to divert resources to a higher priority undertaking.

4. Conclusion

This article has aimed to argue that the significant difference in the embodied relationship the live coding and instrumental performer has to the method of performance suggests that live coders are less susceptible to low-level automaticity and consequently less likely to exhibit mechanical modes of musical expression which have the potential to inhibit novelty. The relationship between the temporal aspect of each undertaking and the allocation of cognitive resource differs significantly for instrumental and live coded improvisation. In both instances, there is a need to access 'technique' stored as object memory but the process of encoding this memory in instrumentalists is much longer and more systematic and the resulting resource plays a much more significant part of the activity, providing elemental units of pre-programmed musical behaviour. An instrumental improviser will dynamically move up and down a continuum that stretches between perceived conscious control of individual elemental actions and executive control of pre-programmed units of material. Moving between these modes of engagement is, for the most part, outside of the performer's perception but is at the heart of the trade-off between novel musical expression and the reuse of musical material. I would suggest that this is a significant point of divergence between improvisation for an instrumentalist and a live coder. The live coder does not need to maintain the sense of a single fluid action that exists in the analogue world of the instrumentalist and so is more likely to maintain attention on working memory functionality, undertaking what Pressing termed 'compositional problem-solving' (Pressing 1984). It is true that coders can achieve keyboard activation at speeds which render the elemental motor units outside of conscious control but the languages they are typing are chunked into semantic units which are controllable by conscious thought processes. The elemental motor skills required do not have the same relationship with the production of musical gestures and consequently the evaluation and feedback cycle is not bound to the same temporal frame. As soon as the 'real-time' shackles are loosened, the freed up cognitive capacity can be utilised in musical behaviour that is guided more by compositional considerations, derived from process memory and conceptual processes. If an instrumentalist ran the risk of initiating a musical gesture which could unintentionally bring the flow of a musical performance to a standstill, their willingness to relinquish conscious control and hand over the detail of their musical gestures to an automated process, would be very much inhibited. Live coders have to perform within a strict syntax, which through extensive training, can be navigated at great speed but at the point of execution (typing), their attention has to be focused on the gesture they are offering to the performance. In either performance context, there is the potential for the performer to formulate ideas which are not original, with the intent of reusing material but for the live coder, this is unlikely to be outside of conscious awareness.

Disclosure statement

No potential conflict of interest was reported by the author.

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Tim Sayer is Faculty Director (Research) for the Faculty of Culture and Language Sciences at the University of St Mark and St John Plymouth and a senior lecturer in the psychology of sound, composition, new media and sound design. His research interests centre on human computer interface design in the context of improvised musical performance, exploring the perceptual parameter space that exists between performer and technology as a means of investigating cognitive/behavioural mappings. He has written a number of published articles and papers relating to this research, most recently presenting work at the 9th Conference on Interdisciplinary Musicology – CIM14. Berlin and the International Conference on Live Coding 2015 at University of Leeds, UK.

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