Position Paper: Measuring Users' Cognitive and Affective State to Develop Intelligent Musical Interfaces

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Abstract
Traditional musical interfaces have a limited capacity to receive input from the musician or composer. In this position paper, we posit that by measuring users' cognitive and/or affective state *implicitly* in real-time, that intelligent musical interfaces can be created that can respond to users' needs. Such interfaces do not require any additional effort on the part of the user. The user carries out their musical tasks as normal, while the system implicitly measures the cognitive and affective and responds intelligently in real-time. We use the fields of learning and creativity to provide examples of this increase in implicit communication bandwidth between the human and musical interface.

Author Keywords
Musical Interface; Cognitive Workload; Affective Computing; Learning; Creativity; Music; Piano.

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
In a musical interface, such as a piano keyboard, there is a limited communication bandwidth between the human and the interface. The communication channels are limited by the input devices, body parts, and attention levels

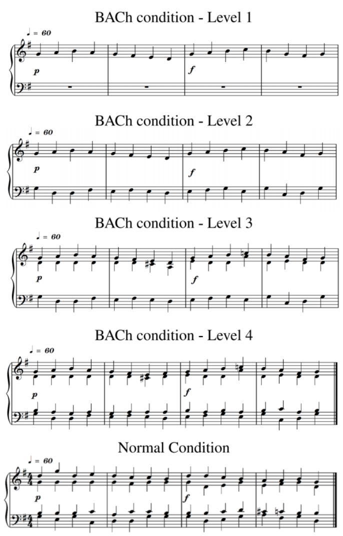

Figure 1: Scores used by Yuksel et al. 2016 [10] to increase task difficulty as learner cognitive state decreased compared to normal condition.

of the human and machine. By providing the musical interface with *passive or implicit* information about the human, a more intelligent musical system can be built that can adapt to users' differing states, without any additional effort on the part of the user.

In this position paper, we posit the idea that measuring users' cognitive and/or affective state can develop intelligent, adaptive musical interfaces that allow users to carry out their tasks as normal. By using physiological sensing and facial expression recognition, users' states can be measured in the background without detracting from the musical task at hand. We present examples of two fields in music where this can and has been applied: learning and creativity. However, this argument can be applied to other uses in musical interfaces, such as listening to music.

User State While Learning Music

Cognitive Workload

The measurement of user cognitive workload is an important topic in learning in all fields. The fundamental idea behind Cognitive Load Theory (CLT) is that learners have a limited cognitive capacity to handle information. It is important, therefore, to design instructional material that does not overload the learner in order to maximize the user's ability to form schemas in long-term memory [8]. In the example of a piano player, a more skilled pianist has the ability to group together notes to form chords in their schemata, whereas a beginner would need to process each note individually.

There has been an increasing trend in measuring cognitive workload in HCI studies in recent years including the field of musical interfaces [9, 10]. Yuksel et al. [10] built a intelligent tutoring system, BACh (Brain Automated Chorales) using functional near infrared spectroscopy (fNIRS) to teach

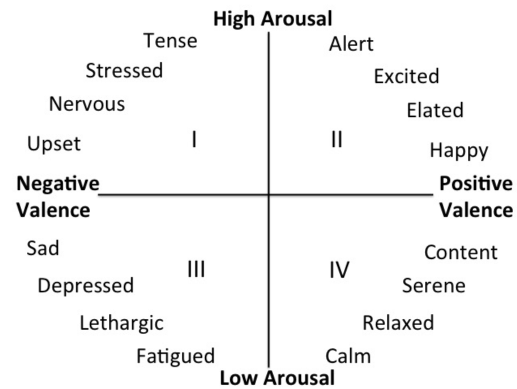

Figure 2: The valence-arousal model of emotion.

Bach chorales on the piano. BACh increased task difficulty (Figure 1) as learners' cognitive workload fell below certain thresholds, indicating that they could cognitively handle more information. This was the first time that cognitive workload measured by physiological sensing was used as a *determining factor* in a musical learning task in real-time. Results showed that, compared to a control condition where users learnt the pieces the way they normally would, learners had significantly increased accuracy and speed using the adaptive system [10].

Affective State

Emotion also plays a key role in learning [7]. The importance of emotion in learning has been demonstrated in many fields and has been shown to correlate negatively with boredom and positively with flow [2]. By bringing in the additional measurement of affect, user states such as frustration or anxiety can be used as determining factors in musical learning.

The role of emotion in learning has been described as a counter-clockwise movement through the four quadrants of the valence-arousal model of emotion by Kort et al. [5] (Figure 2). For example, the learner could start off in quadrant I where they are excited to learn a piece of music (or an instrument). They then might move into quadrant II as they hit a point of confusion or puzzlement, yet at this point they are still motivated to overcome the problem as they are in a state of high arousal, being in the top half of Figure 2 [5]. At some point it would not be uncommon for the musician to slip into the lower half of Figure 2 into quadrant III where there is negative valence in response to a self-perceived sense of failure. This section of the quadrant is the point at which it is most likely for the learner to give up, as frustration precedes discarding the learning attempt [7]. As the learner makes progress from this point by consolidating what works and what does not work, they move into quadrant IV [5].

This movement through the valence-arousal model of emotion has yet to be explored in real-time with a musical interface and could provide a powerful tool both by itself or in conjunction with cognitive workload. Just as cognitive workload can be measured passively in real-time, there are emerging technologies facial expression recognition and physiological sensing that make the measurement of emotion an non-invasive and passive occurrence.

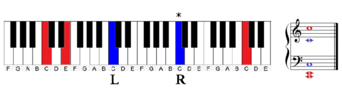

Figure 3: Musical harmonies used in Yuksel et al. 2015 [9]. BRAAHMS (red) adapted to user's notes (blue) of the left (L) and right (R) hands (* indicates middle C).

User State in Musical Creativity

Cognitive Workload

There has also been a recent increase in the use of cognitive workload in musical interfaces the field of creativity [3, 9]. Grierson et al. [3] used the EEG device Neurosky's attention and meditation levels to control Brainemin and Brain Controlled Arpeggiator in live performances.

Yuksel et al. [9] built BrAAHMS (Brain Automated Adaptive Harmonies in a Musical System) to aid piano players in a musical improvisation task. BrAAHMS measured piano players' cognitive workload using fNIRS to determine when to add and remove musical harmonies (Figure 3) to aid creativity. Results showed that users preferred BrAAHMS to the control conditions and because they felt more creative.

Affective State

Emotion is considered to be the essence, if not the purpose, of music [6]; more recently, the affective impact of music has been studied neurologically [1].

An intelligent, musical interface that could respond in real-time to a musician or composer could be a very powerful one indeed. There has been some work in selecting music for individuals based on affective state [4], however, this could be such a benefit to musical creativity such as improvisation or composition.

Conclusion

There is a paucity of information flowing from the user in traditional musical interfaces. The next generation of musical interfaces could measure user cognitive and/or affective state in the background to aid musicians in their learning and creative tasks. Such measurements would occur passively, in the background, without detracting from the musician's efforts or task at hand.

The long-term goal of such interfaces would ideally be the combination of measuring cognitive workload in conjunction with emotional state to draw a far more precise picture of the musician's overall state. This would allow the musical interface to respond in a much more intelligent, personalized, and adaptive way to musical tasks such as learning, improvisation, or composing.

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