Chapter 26
An Analysis of Internal Representations for Two Artificial Neural Networks that Classify Musical Chords

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INTRODUCTION

Cognitive informatics is a field of research that is primarily concerned with the information processing of intelligent agents; it can be characterised in terms of an evolving notion of information (Wang, 2007). When it originated six decades ago, conventional accounts of information were concerned about using probability theory and statistics to measure the amount of information carried by an external signal. This, in turn, developed into the notion of modern informatics which studied information as “properties or attributes of the natural world that can be generally abstracted, quantitatively represented, and mentally processed” (Wang, 2007, p. iii). The current incarnation of cognitive informatics recognised that both information theory and modern informatics defined information in terms of factors that were external to brains, and has replaced this with an emphasis on exploring information as an internal property.

This emphasis on the internal processing of information raises fundamental questions about how such information can be represented. One approach to answering such questions — and for proposing new representational accounts — would be to train a brain-like system to perform an intelligent task, and then to analyse its internal structure to determine the types of representations that the system had developed to perform this intelligent behaviour. The logic behind this approach is that when artificial neural networks
are trained to solve problems, there are few constraints placed upon the kinds of internal representations that they can develop. As a result, it is possible for a network to discover new forms of representation that were surprising to the researcher (Dawson & Boechler, 2007; Dawson & Zimmerman, 2003).

RELATED WORK

Cognitive informatics has been applied to a wide variety of domains, ranging from organisation of work in groups of individuals (Wang, 2007) to determining the capacity of human memory (Wang, Liu & Wang, 2003) to modelling neural function (Wang, Wang, Patel & Patel, 2006). The studies described in this chapter provide an example of this approach in a new domain, musical cognition. There is a growing interest in the cognitive science of musical cognition, ranging from neural accounts of musical processing (Jourdain, 1997; Peretz & Zatorre, 2003) through empirical accounts of the perceptual regularities of music (Deutsch, 1999; Krumhansl, 1990) to computational accounts of the formal properties of music (Assayag, Feichtinger, & Rodrigues, 2002; Lerdahl & Jackendoff, 1983). Because music is characterised by many formal and informal properties, there has been a rise in interest in using connectionist networks to study it (Griffith & Todd, 1999; Todd & Loy, 1991).

There are numerous types of connectionist networks, and multiple dimensions on which they can vary. A variety of both supervised and unsupervised approaches have been used in studying various aspects of musical cognition. In many instances it is impossible to provide a complete formal specification of a set of rules that define some property of music. For instance, not all of the rules of musical composition are known or definable (Loy, 1991). Unsupervised networks like self organising maps (SOMs) and adaptive resonance theory (ART) networks are well suited for studying musical tasks that cannot themselves be completely specified. A multitude of connectionist research uses unsupervised networks to attempt to capture informal, under-defined, or undefined properties of music, ranging from connectionist models for perception (J. J. Bharucha & Todd, 1989; Desain & Honing, 1991; Laden & Keefe, 1989; Large & Kolen, 1999; Sano & Jenkins, 1989; Scarborough et al., 1989; Taylor & Greenhough, 1999), models of the physical process of sound production (Casey, 1999; Sayegh, 1991), to composition (Mozer, 1991, 1999; Todd, 1991).

Leman (1991) used self organising maps (SOMs) to study the relationships between tones. SOMs were presented major triads, minor triads, and dominant seventh chords, using twelve input units which correspond to tones. In an initial study, chords were presented in the training data with equal frequency. A weak circle of fifths representation could be discerned in the arrangements of characteristic units on the map. The circle of fifths is a theoretical structure that contains all the keys, or all 12 of the notes used in the dodecaphonic set; each step clockwise along the circle is a perfect fifth or an interval of 7 semitones (see figure 2A). In a further study, statistical data regarding the presence of chords in western music was used to adjust the frequency with which input chords were presented, and the circle of fifths representation was significantly strengthened.

Tillmann et al. (2003) used a hierarchical self organising map (HSOM) with 12 inputs (one for each pitch class, or one for each of the dodecaphonic notes) each of which was connected to the SOM which was the second layer, which was connected to layer three — another SOM. Similar to the study by Leman, the goal was to demonstrate implicit learning of tonal regularities. This study explored two different variations on the format of the input. First a straight pitch class where inputs were activated if the corresponding note was present in the chord was tried. Subsequently, the weighted sum of sub-
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