Emergent Behaviour: Learning From An Artificially Intelligent Performing Software Agent

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Abstract
This research investigates the possibility for emergent choreographic behaviour to arise from the interactions between a human dancer and a learning, digital performing agent. The cognitive framework is extended through theories of distributed cognition to take into account the two interacting agents rather than a single agent and its environment. The Artificial Neural Network based performing agent demonstrated emergent dance behaviour when performing live with the human dancer. The agent was able to follow the dancer, create movement phrases based on what the dancer was performing and recognize short movement phrases, as a result of the interaction of the dancer’s motion captured movement data and the agent’s artificial neural network. This emergent behaviour was not explicitly programmed, but emerged as a result of the learning process and the interactions with the human dancer.

Keywords
Emergent behavior, dance, motion capture, distributed cognition, artificial neural network.

Introduction
In Embodied Cognition: A field guide, Mark Anderson puts forward an argument for the development of robots using developmental approaches based on embodied or situated approaches to cognition. (1) Instead of emphasizing formal operations on abstract symbols, this new approach focuses attention on the fact that most real-world thinking occurs in very particular (and often very complex) environments, is employed for very practical ends, and exploits the possibility of interaction with and manipulation of external props. p.91 Anderson goes on to suggest that this situated activity can allow behaviours to emerge that are the result of the interactive relationship between the robot and its environment.

This project was one of the outcomes of research into collaborative performing agents undertaken at Motion.Lab. The goals of the research were to develop a performing agent capable of recognising and responding to human movement data generated by a live human dancer. The agent was developed utilizing a creative workflow that attempted to be familiar to a dancer, modeled on a collaborative performance making process between two dancers. From conception, through the rehearsal process and on to performance, the relationship between the dancer and agent was considered as a means of supporting the agent’s capabilities and learning. This allowed the dancer, Steph Hutchison, to follow a performance-making trajectory that was familiar to her and enabled the relationship with the agent to be viewed in similarly familiar terms.

The research made use of Deakin Motion.Lab’s 24 camera Motion Analysis motion capture system. The system was used to both pre-record the dancer’s movement to train the Artificial Neural Network (ANN) and to allow the dancer to interact with the agent by passing her live movement to the ANN. The Motion.Lab has a 6 metre passive stereo screen on the rear wall onto which was projected the avatars of the dancer and agent. These avatars were at times humanoid, at other times of more abstract representation. The work was viewed from the front as a studio proscenium performance.

Artificial Neural Networks for Learning
We chose a type of ANN called a Self Organizing Map (SOM) (2, 3) The SOM is an unsupervised form of ANN and as such it is not directed towards a particular goal, but rather attempts to find its own relationships in the data presented to it. We chose the SOM because it proved able to both classify (recognize) the dancer’s movement as well as synthesise movement from the same neural network. Even though the SOM is a relatively simple structure, it proved quite versatile in terms of its responses to the dancer’s movement data.

The initial experiments were successful in suggesting that the SOM would be a suitable structure as the basis for the performing agent’s learning and performing capabilities. Experiments with SOM suggested simple choreographic structures that could be used in the creation of the performances, such as the simple task of one dancer following the other. After the ANN had been trained using motion capture data from Steph’s dancing, subsequent live motion captured data succeeded in eliciting a response from the neurons in the neural network and the information contained in the neuron was used to animate the agent’s avatar. In this manner a simple type of following behaviour
arose as the movement of the dancer triggered a response from the agent’s neural network. This prompted investigation of choreographic tasks that made use of this type of naturally occurring behaviour in the SOM, and which could inform the development of shared movement for the performances. The related performance *Emergence* is described more fully in McCormick et al. (4)

The human dancer developed movement phrases through structured improvisation based on the kind of relationships that would be used in the performance; being followed by or following the agent, providing starting postures for the agent to begin a movement phrase with, making short movement gestures that the agent might recognise. These movements were passed on to the agent for learning. Once the agent had gone through the learning process, the dancer reacquainted herself with the movement and to investigate how the agent had assimilated her original movement and the relationships envisaged when developing the original movement material. We used a familiar rehearsal and performance process in order to embed not only the movement itself but also the relationship between dancer and agent into the development process. This allowed the dancer to follow a familiar creative trajectory, and supported the agent’s capability by providing a close association with the dancer. (Figure 1)

![Figure 1. Process for creative development of the agent learning for rehearsal and performance.](image)

The agent took the human data and learnt its salient features in an attempt to better understand the human’s motivations, a form of data mining. These goals necessitate a consideration of how an agent might need to be conceptualised, if it were to be able to interact with a human performer. For this to occur, it is not sufficient to generate a system that can respond to motion data per se. The meaning of the motion data in a human performance, and specifically a dance context, must be considered part of the interactive process in any system involving a human dancer.

The use of a cognitive model to guide development, as suggested by Anderson, offers an alternative to a purely computational model on which to develop the agent. This research used the framework of distributed cognition which provided a conceptual structure whereby we could envisage the agent and dancer as a single supportive system rather than developing the agent with self-contained capabilities. We chose the distributed cognition model rather than the embodied cognition model presented by Anderson, as it seemed a more appropriate model to develop the relationship between the dancer and agent. Both models consider cognition to be a result of complex interactions with the environment, however distributed cognition allows for cognition to be shared between humans or in this case a human and digital agent. This framework supported the idea that the agent’s cognitive abilities could be directly supported by the dancer’s. Allowing the dancer to support the agent throughout the process enabled the achievement of a significant outcome using relatively simple processes. The agent could share the dancer’s structuring abilities to augment its own. There was a strong support system for the agent’s development already in place in the form of the dancer’s honed dance experience.

The dancer was also learning how the agent learnt, what patterns and movement it recognised and how to support the agent in performance. The feedback and learning loops informed the learning and subsequent capabilities of both the artificial and human agents, and provided the human dancer with a source of inspiration for developing duet relationships with the agent performer. (5)

**Emergence**

One of the most exciting outcomes of this research has been what Anderson descriptively terms “emergence”. (1) Emergent behavior is seen in many natural systems, such as weather systems, insect construction behavior, and human social organisation behavior. Artificial systems that attempt to mimic natural systems and allow for emergent behavior have been around for decades. Early digital examples of emergent behavior are Conway’s *Game of Life*, (1970) (6) and Reynolds’ *Boids* (1987), a simple set of rules that could be used to simulate bird flocking and schools of fish swimming. (7) In these and many other
examples, relatively complex behavior emerges from very simple rules. As an example of emergence, Anderson offers the work of Steels in artificial life as the roots for artificial intelligence. (8) Steels describes a simple robot with two programmed behaviours; the first instruction is to take a zigzag path toward any light source, the second is to turn before moving again if it comes into contact with any obstacles. The robot must replenish itself by moving to recharging stations when the light at the recharging station turns on. There is no explicit programming to tell the robot to recharge itself. However this emergent behaviour occurs naturally when the robot is placed into the environment. The programmed rules provide the opportunity for the emergent behaviour, yet do not explicitly control the behaviours. Rather the behaviours emerge through the dynamic interaction between the robot and its environment.

The performing agent similarly displayed emergent behaviour in its ability to recognise movement the dancer was performing and to then respond with movement based on what it had learnt from the dancer. However unlike Steels’ example, the performing agent in this research was not programmed with any initial simple behaviours, and its behaviour was attributable to the learning process with no directed behaviour. Steels’ example saw the robot’s movement being subject to simple rules to enable its behaviour to emerge. The agent in our study sees the dancer’s data being simply presented to the SOM where it stimulates particular neurons to effect behavioural changes. The use of an Artificial Neural Network to encapsulate the interactions between the agent and its environment (in this case the dancer’s motion-captured movement data) proved very successful in enabling the agent’s performing behaviour to emerge.

This was most evident in the performance piece, *Instrumental* (2014), where the dancer’s movement data stimulated the agent’s neural network, creating a response in the closest matching neuron, which in turn caused reverberations in the Artificial Neural Network’s Synaptic Map. (Figure 2) The synaptic map was a second layer of the neural network that contained the pathways of neurons as they sequentially fired. By using the links formed between neurons during the learning process that agent was able to create movement sequences from the data contained in the neurons. The result was the emergence of recognition behaviour of the dancer’s current movements and creation behaviour in the agent’s response with appropriately themed movement synthesis.

The Self-Organising Map (2, 3) enhanced with a Synaptic layer, was termed a Self-Organising Synaptic Map (SOSM). This allowed the agent to create movement which was stylistically compatible with the dancer’s movement, emerging from the trained SOSM. As the synaptic layer is also developed through learning, it has a strong relationship with the dancer’s movement, yet because of the multiple, weighted pathways developed between the neurons there is still scope for variability in the movement created by the agent. (Figure 3)

The choices that led to these emergent potentials were derived from the framework used from the beginning of the research project, namely, the concepts of embodied and distributed cognition. Embodied cognition focused attention towards devices that would allow the agent to learn from the sensory input provided by its environment, in this case the dancer’s movement data. (9, 10) The emphasis was not on developing a model of the performance environment or the dancer relationship, through programmed symbolic representation as in traditional approaches to cognition and programming, but rather to allow the interactive engagement of the agent with the dancer to become the key component of its environment, thereby allowing behaviours to develop. Distributed cognition provided a framework for imagining the co-creative relationship between the dancer and agent during creative development and performance and hinted at the potential for allowing the agent to naturally embed its learning and potential using the dancer’s evolved intelligence. (11-15) Adopting

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Figure 2. The agent creates movement based on the current movement of the human dancer.

Figure 3. Using the Self Organising Synaptic Map (SOM) to enable the agent to generate its own movement based on the movements it has learnt from the dancer. The dancer’s avatar (white) is animated by the live motion data stream, the agent’s avatar (red) is animated from its SOSM in response to the dancer’s movement.
This approach allowed the dancer to guide the agent where appropriate and also allowed the dancer in turn to respond to the agent’s reactions. While the dancer was the most experienced partner in the performance relationship, the creative energy was not all one way. The dancer was able to feed her creative choices from the agent’s performance as well.

This research also pointed towards a new approach for the development of the performing agent. Rather than attempting to build a comprehensive internal model to represent the system and its inputs and outputs, a model similar in characteristics to a traditional, computational view of cognition, the software centres on learning from the interactions between the agent and environment through the sensory engagement with the dancer through her data. This follows methodologies proposed by roboticists and AI researchers Brooks and Steels into the application of Artificial Life to Artificial Intelligence. (16) This change in paradigm has proven extremely liberating - the author no longer needs to control the behaviour of the agent, but rather provide the circumstances whereby the agent can learn from interactive experience allowing behaviours to emerge.

Current extensions to this research involve applying the movement learning capabilities to small humanoid robots to allow them to learn how to perform with human dancers and with each other. The evolution from a software based agent to a physical body is a great challenge. The neural network movement recognition techniques are also being applied to the task of generating haptic information to describe dance to vision impaired audience members.

References


Authors Biographies

Steph Hutchison is a choreographer, performer, and artist-researcher. She is an experienced and sought after artist with background in contemporary dance, improvisation, circus arts, physical theatre, dance video and dance technology. Steph is completing her PhD at Deakin University’s Motion.Lab meta: discourses from dancers inside action machines. Dr. John McCormick has worked in the areas of new media dance, motion capture and telematics performance. John is currently researching movement visualisation and analysis, and with the Centre for Intelligent Systems Research for the past three years investigating machine learning of movement and its application in the performing arts.

Professor Kim Vincs is the Director of the Deakin Motion.Lab, Deakin University’s motion capture studio and performance technology research centre, which she established in 2006. She has been a choreographer for over twenty years, and has focused on interactive dance technology for the last ten. Kim has five Australian Research Council projects in dance, technology and science, and has established numerous industry collaborations in motion capture, movement analysis and digital art. Dr. Jordan Beth Vincent is an Associate Research Fellow at the Deakin Motion.Lab researching dance and digital technology, a position she has held since 2013. Jordan’s background is in dance history and criticism, and she holds a PhD early 20th century Australian dance history from the University of Melbourne. Since 2008, she has been a critic for The Age newspaper, and has contributed to a range of online and print publications in the areas of dance, physical theatre and circus.