Embodiment as Situated Structural Coupling

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ABSTRACT

This document summarises research investigating what it means for a system to be embodied in some environment. A definition based on the concept of structural coupling is offered, which allows the term to be meaningfully applied in non-physical contexts. An ongoing program of research, embodying a dynamical system based on the bacterium *Escherichia coli* in a variety of environments, including the Internet, supports this definition.

In Behavioural Robotics, autonomous adaptive behaviour is seen as grounded in the embodiment of physical systems in their environments, and the way in which this shapes and conditions their interaction (Brooks, 1991).

However, the concept of embodiment comes with an implicit ontological barrier, limiting application of the term to 'things that have physical bodies.' This is problematic for those who would apply the concept to non-physical systems such as software agents (cf. Etzioni, 1993; Kushmerick, 1997; Franklin 1997). In Artificial Life, these ontological assumptions are a significant problem for a discipline that seeks to synthesise rather than simulate the properties of living systems — all biological examples of which are physical systems embodied in a physical world. In Behavioural Robotics, the lack of any precise definition of embodiment makes it impossible to quantify the extent to which any robot can be said to be 'embodied' in its environment. In Artificial Intelligence, powerful phenomenologically grounded critiques are difficult to respond to without a clear idea of what embodiment entails, or what it might be entailed by (Dreyfus 1985).

A precise and minimal definition expressing necessary and sufficient conditions for embodiment is proposed, taking advantage of the way in which physical embodiment is held to condition the relationship between a robot's structural dynamics and its environment in such a way as to permit coupling between them (Prem, 1995; Chiel, 1997).

This definition is purely relational, extending applicability of the term to non-physical media. It also provides a basis from which embodiment can be quantified. One possibility is to use the total complexity of the dynamical relationship between system and environment over all possible interactions.

Definition. *A system **X** is embodied in an environment **E** if perturbatory channels exist between the two. That is, **X** is embodied in **E** if for every time **t** at which both **X** and **E** exist, some subset of **E**'s possible states have the capacity to perturb **X**'s state, and some subset of **X**'s possible states have the capacity to perturb **E**'s state.*

As an hypothesis about embodiment, this predicts similar behaviour in different operational environments where the relationship between a system's structural dynamics and its environment are similar, regardless of the ontological status of the system and environment.

Experimental work is underway using a single Cellular Automata based dynamical system, *Phenomorph*. This is based on the structural dynamics of the bacterium *Escherichia coli*, coupled to a variety of environments — the World Wide Web, an abstract parameter space, and the physical world — via sensory and effector surfaces based on the receptor and flagella system utilised by *E. coli*.

Initial work using the World Wide Web as an operational environment, with keywords taking the place of nutrients and HTTP protocol requests implementing flagella rotation, suggests the emergence of a variety of behaviours, with many of the characteristics associated with physical embodiment. For example, behaviours are not explicitly codified, but emerge from the ongoing interplay between system dynamics and the environment. See Quick (1999) for more detail.

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