Is Prediction Required? Using Evolutionary Robotics to Investigate How Systems Cope with Self-Caused Sensory Stimuli

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Introduction

Living systems process sensory data to facilitate adaptive behaviour, but the same sensors can receive inputs both from purely external (environmental) sources, and as the result of internally driven activity. We can hear sounds in the world around us, but we can also hear our own voice when talking, and our own footsteps when walking. We can see our environment, but we also see our own bodies. Not only do we perceive both the world and the results of our own actions, but the exact same sensory stimulus can be the result of an external event, or caused by our own activity. For example the sight of a hand being waved before our eyes could be your own hand or a friend snapping you out of a daydream. The phenomenology of a self-caused stimulus can be very different from that of an externally caused one. A great example of this is the sensation of touch, which can reduce you to helpless laughter when externally applied - but trying to tickle yourself just isn't the same! (Blakemore et al., 2000)

In psychology, research on the sensory attenuation of self-caused stimuli studies how these stimuli are perceived as diminished in comparison to externally caused stimuli (Hughes and Waszak, 2011). A clear example of this effect is seen in the force-matching paradigm. Here an external force is applied to a subjects finger, after which they must use their other hand to recreate that force as precisely as possible. This takes place under two conditions. In the direct condition, the subject applies force to their finger in a manner as close to pressing on their own finger as possible. In the indirect condition, they apply the force via a mechanism, such as a lever to one side. Healthy subjects consistently apply too much force when pressing directly on their finger, indicating that the perceived force is attenuated compared to the other conditions (Pares et al., 2014).

The canonical explanation of this effect is that when the brain issues a motor command, an internal model receives a copy of that command, from which it predicts the sensory consequences of the resulting motor activity. The predicted sensory input is then subtracted from the actual sensory input, resulting in the attenuation of the stimuli (Klaffehn et al., 2019).

Methods

We developed a model of a simple embodied system with self-caused sensorimotor dynamics. Following the evolutionary robotics methodology, we explored the space of possible solutions using a genetic algorithm (GA) (Harvey et al., 2005). We aimed to learn whether solutions like the predict-and-subtract approach would evolve, and to assess the viability of non-predictive solutions for coping with self-caused sensory inputs interfering with perceiving the world.

The embodiment is a simulated, two-wheeled robot with a pair of light sensors. It moves about an infinite, flat plane which contains a light source. Its motor activity is specified by a continuous-time, recurrent neural network (CTRNN) (Beer, 1995) with six fully connected interneurons and two neurons each for sensor inputs and motor outputs. The activation of each sensor is a linear combination of environmental stimulation (determined by the sensor's distance and facing relative to the light) and interference generated from the ipsilateral motor's activity by by one of three interference functions (Figure 1).

This model is designed to allow for both the canonical, representationalist solution and alternative, non-representationalist solutions to emerge. The canonical solution can be realised because the interfering dynamics are produced by simple, smooth functions, and thus can be fully modelled by a CTRNN (Beer, 2006). Since the interference is summed with the actual sensor data, the problem can be solved by predicting the interference and subtracting it out. However, as the interfering dynamics are a function of the system's motor activity, and are coupled to the controller in a tight sensorimotor loop, this model embraces situated, embodied and dynamical explanations of cognition, and allows for the emergence of other (non-representationalist) solutions that do not involve an internal, predictive model.

We used a GA to select parameters for the CTRNN, and examined the best solution found under several conditions. Our GA is tournament based, like the microbial GA (Harvey, 2011), although it does not use crossover. We evolved a population of 50 individuals to seek the light (phototaxis) without any motor-driven interference. We then evolved five populations of solutions for each of the three interference functions, in each case starting from the population evolved without interference rather than from an initially random population. This lets us study how an existing phototactic system can be adapted to continue to perform successfully in the presence of various forms of motor-driven interference.

Results

Here we catalogue the adaptations observed in the fittest single individual evolved with each interference function, none of which rely on predicting the interference. In each case, the evolved system performs phototaxis successfully.

Avoidance: When self-caused sensory interference is only triggered by certain motor outputs, and the task at hand can be accomplished while avoiding those outputs, it may be easiest for a control system to simply modify its behaviour to do exactly that. We observed this with the sigmoidal interference. With the squared interference, we instead saw interference minimisation via reduced motor activity.

Coordination: The timing of motor-driven interference with a sensor may be regulated to coincide with environmental stimulation of that same sensor. With a one dimensional sensor like those used in this model, this leads to a sort of constructive interference, where the coincidence of motor-driven and environmental stimuli amplifies the effect of the environmental stimuli on the sensor. We observed this with the squared interference.

Time scale: The previous solutions don't work for interference which is continually varying in such a manner that its extrema are not determined purely by the motor activity (e.g. Figure 1C). However if such interference is of a high enough frequency relative to the frequency of environmental stimuli, then this difference in time scale can be leveraged to separate the interference from the environmental stimuli. Slowly varying stimuli can be perceived through quickly varying interference, which we observed in the case of the sinusoidal interference. We also found that this system evolved elevated motor activity, which raises the frequency of the interference and amplifies the time scale difference.

Shaping environmental stimuli: The solution evolved with no interference made use of sharp spikes of environmental stimuli. We found that spikes like these could be completely lost in the high frequency sinusoidal interference. In addition to raising the frequency of the interference, the behaviour of the solution evolved with sinusoidal interference tended to lower the frequency of environmental stimulation compared to the no interference solution.

Incorporating interference functionally: Removing motor-driven interference from a system optimised to perform a task in the presence of that interference does not necessarily improve performance, and may instead degrade it significantly. Furthermore, we found that motor-driven sensor stimulation played a functional role in the successful phototactic behaviour of some evolved systems.

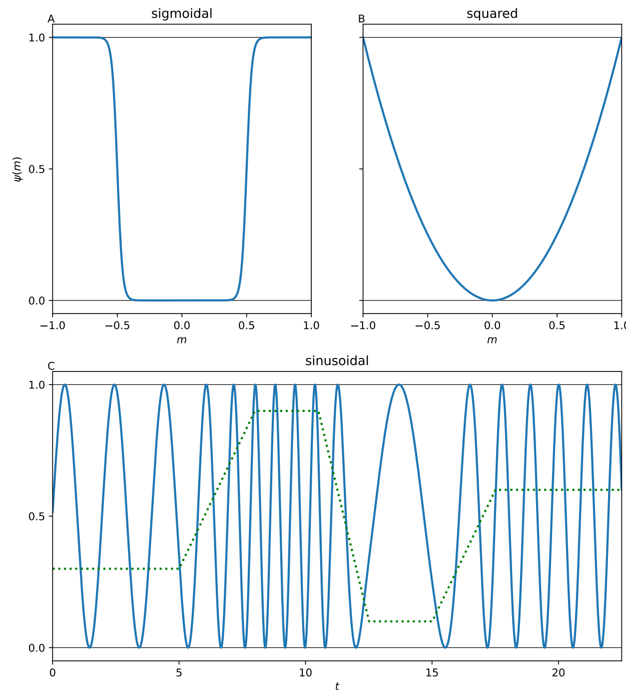

Figure 1: Three functions which depend on motor activity are used to generate sensory interference. Interference determined by the right motor is added to the right sensor's input stream, and likewise for the left sensor and motor. Figures A and B plot pure functions of motor activity, while Figure C plots a function of time whose frequency is determined by the motor activity. The solid blue line shows the interference, while the dotted green line shows the motor activity.

Conclusions

This all suggests that prediction and subtraction do not tell the whole story when it comes to coping with self-caused sensory stimuli. In some ways this is obvious, as self-caused sensory stimuli are involved in a range of activities in which they do not play an interfering role. For example, the sensation of self-touch when kneading an aching muscle, or occlusion of the visual field when engaging in visually guided reaching and grasping. In these activities, self-caused sensory stimuli are actually desirable. However, our model shows that even in a situation where clear perception of the environment seems obviously beneficial, self-caused sensory stimuli may not play an entirely interfering role. Furthermore, we can see that even when responsiveness to the environment is needed, prediction and subtraction are not the only games in town.

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References

Beer, R. D. (1995). On the Dynamics of Small Continuous-Time Recurrent Neural Networks. *Adaptive Behavior*, 3(4):469–509.

Beer, R. D. (2006). Parameter space structure of continuous-time recurrent neural networks. *Neural computation*, 18(12):3009–3051.

Blakemore, S.-J., Wolpert, D., and Frith, C. (2000). Why can't you tickle yourself? *Neuroreport*, 11(11):R11–R16.

Garner, J. and Egbert, M. (2022). Embodiment enables non-predictive ways of coping with self-caused sensory stimuli. preprint, `https://arxiv.org/abs/2205.06446`.

Harvey, I. (2011). The Microbial Genetic Algorithm. In Kampis, G., Karsai, I., and Szathmry, E., editors, *Advances in Artificial Life. Darwin Meets von Neumann*, pages 126–133, Berlin, Heidelberg. Springer Berlin Heidelberg.

Harvey, I., Paolo, E. D., Wood, R., Quinn, M., and Tuci, E. (2005). Evolutionary Robotics: A New Scientific Tool for Studying Cognition. *Artificial Life*, 11(1-2):79–98.

Hughes, G. and Waszak, F. (2011). ERP correlates of action effect prediction and visual sensory attenuation in voluntary action. *NeuroImage*, 56(3):1632–1640.

Klaffehn, A. L., Baess, P., Kunde, W., and Pfister, R. (2019). Sensory attenuation prevails when controlling for temporal predictability of self- and externally generated tones. *Neuropsychologia*, 132:107145.

Pares, I., Brown, H., Nuruki, A., Adams, R. A., Davare, M., Bhatia, K. P., Friston, K., and Edwards, M. J. (2014). Loss of sensory attenuation in patients with functional (psychogenic) movement disorders. *Brain*, 137(11):2916–2921.