Hormonally moderated neural control

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Abstract

Traditional Artificial Neural Networks have proven their worth since they were first developed, but they have also proven to be very inflexible in certain situations. Nevertheless, development in neurological research has allowed us to take those networks a step further and produce an architecture based on the role biological hormones have in the neural system. Three sets of experiments were performed with the goal of achieving autonomy through cyclic behaviour based on the surrounding environment. Having achieved the ability to create emergent complex behaviours through the interaction of simple structures opens the door to attaining emotional behaviours.

Introduction

Hormonal based control architectures are not a completely novel idea, as neurologists have known the general biological effects of hormones for some time now. As a result, some computational approaches into control structures have drawn inspiration from this knowledge. Cañamero's work in 1997[Cañamero 97] holds a very strong position in this field, as the "abbotts" behaviours were very well engineered with their physiology and environment. The "Abbotts" were again used by Stephen Allen [Allen 01] to develop a system orientated towards cognitive theories. Neal and Timmis [Neal and Timmis 03] developed a sub-symbolic system, where homeostasis was intended through the interaction of an artificial endocrine, nervous and immune system. These concepts have been used to further this research as the results obtained by Neal and Timmis demonstrated the system's ability of emergent behaviour through simple interactions. Other researchers have taken different approaches to the implementation of endocrine or hormonal systems [Velásquez 98; Ogata 00].

The starting point for this experiment was derived partially from the effect that hormones have in the mammalian system [Squire et al. 03]. Hormones levels affect behaviours composed by sets of actions at many levels in the body [Squire et al. 03]. Although, metaphorically hormones can be considered to work as a selective switching system, changing from one set of potential actions to another.

From this principle, the first part of our goal was to assess if hormones could provide a control mechanism for more than one neural network working together, without straying into a "winner takes all architecture". The hormonal concentration levels, when upon high values, allow the networks sensitive to that particular hormone to take control over the system, thus choosing an action or set of actions for the network.

The synapses on the neural network have a sensitivity term which controls how sensitive each synapse is to a particular concentration of hormone in the system. At this stage, in order to maintain simplicity each hormone is related to a single action, therefore each neural network has synapses sensitive to only one hormone signature.

The second part of our goal, regarded the automated control of those hormones. In order to achieve such, a feedback loop is desired as to allow for each of our actions to have been influenced by the previous. Despite the neural network mechanisms allowing for recursive links, a simpler approach was possible through the use of the surrounding environment to create the feedback loop. Much like biological glands, which can receive inputs from different sources, as they monitor and are influenced by different parts of the body, so can the glands in our system. This feature, allows the artificial glands to receive stimulus from different types of inputs, which can range from vision sensors to motor sensors or even other glands. The use of vision sensors allowed us to use the world as our feedback loop.

The last part of the goal intended, concerned the achievement of a cyclic behaviour, based only on the environment and on hormonal concentrations. This meaning that the unit can drive itself from one task to another without the need for another agent's intervention.

Neural Control through hormones

The system was designed mainly through biological inspired techniques, not as an attempt to achieve a higher biological plausibility than other systems, but as an attempt

to harness some of the potential demonstrated by biological systems. In general, the artificial system retrieves ideas from the interaction of the nervous system with the endocrine system. The neural networks, more specifically the synapses, in our artificial system are sensitive to the available concentration of specific hormones. These hormones are produced by gland cells and their concentrations are system wide. The cells of type gland will produce a hormone at a variable rate which is based on the minimum production rate of the gland and the stimulus being received by the environment. For the hormonal release mechanisms two different approaches were taken. One being through direct production of hormone into the system and the other through the production of hormones into pool storages which would be released under certain conditions. Once the hormone is present in the system its concentration will decay at a linear rate, independent of stimulus.

Experiments

The materials used for this experiment consisted of a mobile robot Pioneer Dx2 equipped with a camera, providing 360° vision. The experiment was arranged as to have two surfaces, one black and the one white, being of equal sizes (150cm by 102 cm), placed on a grey surface background. In addition to the materials directly involved in the experiment, a Vicon tracking system (www.vicon.co.uk) was also used to provide accurate positioning of the unit, from which trajectories could be extracted. These trajectories, along with the logged data of several internal and external variants were used for statistical analysis. In order to test the robustness and autonomy of the unit, several sets of experiments were performed under different conditions. Each trial was terminated upon the unit leaving the designated area, where the sensory data would no longer be relevant.

The first experiment was run at the simplest level of this control mechanism, as it was necessary to conclude if our first hypothesis was valid. Therefore two networks were trained separately, one to seek black surfaces and one to seek white surfaces. Hormonal system concentrations were kept at a value of 1 during the training phase, meaning that our artificial system can be trained like traditional ANN's. The synapses which formed the MLP network for the black seeking action, had a sensitivity value of 1 to the "black seeking" hormone, whilst the white seeking MLP network had synapses with sensitivities values of 1 to the "white seeking" hormone signature. The concentrations of white and black seeking hormone were controlled by a sin function, bypassing growth and decay rate variables of the gland.

The glands for the hormone production progressed throughout the experiment, starting at the stage of using only a simple direct release mechanism pumping out hormone straight into the system. This direct production mechanism, was dependant on the stimulus received in order to modify the rate that such hormone would increase in the system. Once in the system each hormone concentration has its own decay rate, which at the present time does not capture the full dynamics of reuptake and enzyme systems, but behaves linearly. The "progressed" architecture, which is present in the final experiment, already takes into account the hormone storage in pools allowing for a large and fast release of hormone at given circumstances. These pools of hormone, much like the previous architecture, make use of a standard hormone production rate (minimum rate at which the gland will produce a hormone) to control how much hormone is added to the pool relative to the environment stimulus. The combination of high pool values and environment stimulus will cause the hormone that is being kept in the pool to be released into the system.

Once present on the system, the concentrations behave as previously described, and will linearly decay down to nil.

The first set of tests, was directed at proving the initial part of our goal, therefore no environment stimulus was used to control the hormone concentrations. The "white seeking" hormone concentration was controlled through a sin function and the "black seeking" hormone concentration was also controlled by a sin function but a with phase shift of Pi. The combination of the two wave functions provided an oscillatory behaviour in the concentrations, with opposite peak values and crossovers at midpoint values. This allowed for the unit to cyclically move between the black and white areas.

The second set of trials, had the purpose of testing our second and third hypothesis. The desired outcome of these trials was a behaviour, which could prove there was an automation of the hormone control through stimulus, and furthermore achieving cyclic behaviour. For these trials, again two glands were used, one destined for the production of a "white seeking" hormone and one for "black seeking" hormone. The glands were receiving stimulus from a high brightness intensity sensor, which tracked the highest value of brightness present in the unit's field of vision. According to the stimulus received the gland would produce a higher quantity of "white seeking" hormone or a higher quantity of "black seeking" hormone, being the stimulus respectively high or low. In the event of absence of stimulus i.e. when the values were at the threshold line, the gland would produce hormone at a set rate. The underlying neural networks were trained as standard ANN's, with hormone concentrations values of 1. At the beginning of the each trial those concentrations were set to the values of 0.9 for the "black seeking" and 0.1 for the "white seeking". During this set of trials the unit demonstrated that it was indeed possible the use of the

environment to achieve cyclic behaviour, nevertheless it also demonstrated that the mechanism being used was incomplete. The unit displayed the ability, much like in the previous experiment, of cyclically moving between the white and black areas, but this time a lack o momentum in the concentrations was noticeable leading inevitably the unit to adapt to the environment and find a stable point where it could get enough stimulus from both hormones, not to allow either behaviour to prevail.

The final set of trials presented at this stage was required as the previous set of results were not satisfactory leading us to further develop the gland architecture from the very simplistic mechanism it was. Once again, we are attempting to achieve cyclic behaviour from this set of trials. This trial was run using the same methods as the previous with the only changes being to the already described gland architecture and to the starting value of the "black seeking" concentration which was now valued at 1.

Results

The first set of trials produced the anticipated results as the sin function control allowed a one-to-one alternating dominance of each network, thus demonstrating the alternation from one behaviour to the other. Mentioning the achievement of a one-to-one alternation was important here as it demonstrates a cyclic behaviour without any perturbances, i.e. a "perfect" environment, meaning that every task would have the same importance and thus only performed once every cycle. Having successfully passed the first stage, we were ready to allow the environment to take control.

The second set relied on the stimulus that the unit received to directly affect its hormone concentrations. Unexpectedly, the results showed a dampening in the hormone concentrations after each cycle leading to a convergence at a mid point. Once analysed, these results were not surprising as the stimulus was affecting directly the hormone concentrations, which led to a lack of momentum in the system, not allowing each network to have dominance long enough for the behaviour to be fully accomplished. With this factor in mind, a closer look was taken as how biological systems deal with this problem and a modified design of the glands was introduced.

The final set of results meant the achievement of our final goal, as the unit would move from one behaviour to the other based on the stimulus of the environment, thus achieving a cyclic behaviour independent from any user or agent interference. The unit would from time to time repeat a behaviour, which was caused by the environment not being a "perfect" environment, as one of the colours (white) would provide a stronger stimulus. Once again the analyses of these results helped us understand the potential of our currently handcrafted hormone decay rates, and by using a smaller decay rate on the less frequent behaviour it was noticeable a behaviour alternation closer to the one-to-one ratio.

Discussion

The results achieved from this architecture demonstrated the potential to achieve complex behaviours through the interaction of very simplistic structures. At this stage, these complex behaviours need not to be carefully designed as they are emergent properties of the system. Nevertheless, as the number of behaviours grows so would the amount of design required to achieve an emergent meaningful behaviour. Inevitably, this leads to a change from a design based networks approach to a developmental approach in order to allow the network to grow and develop itself whilst keeping unwanted properties to a minimum, may these be nodes, connections, hormones or even synaptic sensitivities. Effectively, from a neurological point of view, this architecture is building up a platform which already possesses many of the structures required for basic emotions to arise. The system is capable of being affected partially or entirely with short term or long term effects, these being from near instantaneous to slow build up's over time. Not being a complete system yet, one of the structures that we are missing is a structure that can interpret the stimuli received as to invoke interaction leading to a resulting behaviour similar to the basic emotional behaviours that mammals display. This structure has not yet come into play at this stage as the incoming stimulus has been simplified enough that it does not require an interpretation of its meaning or even a dissection of its different parts. Nevertheless, one emergent property that the system has already demonstrated is attention as it provides an allocation of limited resources to one goal whilst still allowing for greater importance events to be noticed.

As all systems, this architecture also comes with potential disadvantages, some of which are actually caused by the same details that lead to the advantages. One of the most prominent one are the emergent behaviours, which upon scaling the system will become harder to predict allowing for the possibility of unforeseen behaviours in the presence of unusual stimulus. Although, this disadvantage is already well know in our object of inspiration, the mammals. Another biological potential disadvantage which also comes side by side to any biological inspired system, addresses the complexity of the modelling being done and whether it captures enough of the biological counterparts to function accordingly. The last disadvantage addressed at this stage is less likely to come into play, but nevertheless it is a lingering possibility and concerns the computational demand of such system. This is considered to be less worrying as the most expensive units in the network are the

neurons, which are mathematically less expensive than traditional neurons as the synaptic operations are performed on the synaptic units which are present in between every connection. Although, there is a potential bottleneck that may arise from the number of interactions between the cells considering that the number is greater than in standard feedforward MLP networks. The number of cells is typically greater, as synapses are treated as separate units

Conclusions

We have presented an alternative approach to the control of neural networks, allowing for the modelling of many emergent properties of biological systems whilst maintaining simplicity and little computation expense. Many details of the effects of hormones, like system adaptation to hormone concentration exposure, hormone synthesis and breakdown through other chemicals or even singular neuron firing characteristics, have not been included yet as they would cause the networks to have too much flexibility causing them to be extremely hard to assess and further develop.

The architecture demonstrates scalability and multi-purpose use as a controller, which we are looking to further develop in the direction of emotional based systems.

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