PerAdaMagazine
towards pervasive adaptation
10.2417/2200911.1837

The secret life of the immune system: inspiring pervasive systems

Emma Hart

The immune system performs more than simply defence and exploiting its additional functionality can lead to the design of better pervasive adaptive systems.

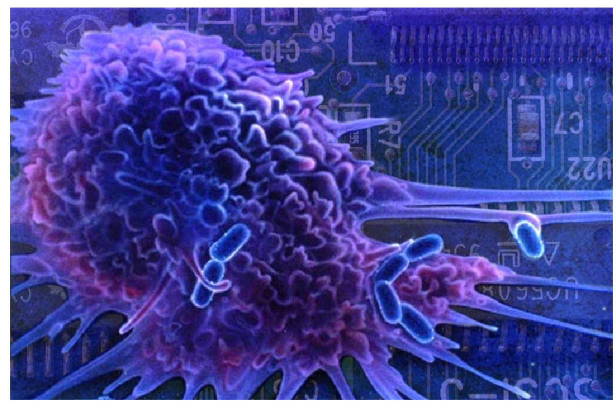

Figure 1. The functionality of dendritic cells, which act as the sentinels of the natural immune system, is providing inspiration for applications ranging from computer security to wireless sensor networks. (Figure courtesy of Julie Greensmith, University of Nottingham, UK.)

Winter approaches. Adverts offer advice and products to strengthen our immune system and help it fight those winter bugs. More reported swine-flu cases cause people to rush for vaccinations to prime their system for attack. This popular view of the immune system as the primary defender of our bodies has not been lost on engineers and computer scientists. For nearly 20 years now, they have attempted to endow computer systems with digital immune systems to defend our machines and networks against digital viruses or intruders. The metaphor has been generalized in applications to any system where it is necessary to distinguish *self* (good) from *nonself* (bad).[1]

This view of the immune system as defender clearly has appeal, yet a glance through immunology literature reveals that the system is vastly complex, and in fact plays a much greater role than mere defender of the body. For example, one school of thought[2] views the immune system as a cognitive system whose primary role is to provide body maintenance. Another advocates that its first and primordial function is to provide an intercellular communication pathway.[3] Other schools of thought—looking more microscopically at some of the many mechanisms that collectively comprise the immune system—highlight its many diverse features. For example, it copes with multiple data sources, performs information fusion, takes decisions, operates over multiple timescales, has a memory and can learn and adapt, to name just a few. These properties are greatly appealing to the engineer trying to build pervasive systems, yet remain elusive to traditional engineering methods. Attempts to engineer pervasive systems may have much to learn from taking a broader view of the immune system. Indeed, existing efforts to use some of its less well-known aspects show what can be done.

The common notion of the role of the immune system as defence stems from studies of adaptive immunity: the ability of the body to detect and respond to unknown pathogens entering the body. There are, however, two interacting subsystems: the innate system, which we are born with, and the adaptive system, which evolves uniquely over our lifetimes. The innate immune system has tended to be ignored by computer scientists, yet it is clear that it plays a key role in immunology. Consider dendritic cells (see Figure 1), one of the main components of the innate system. These act as sentinels, patrolling body tissues and scouting for signs of danger and possible invaders. Information on potential suspects and, crucially, the context they were observed in, is collected by these cells, which then return to lymph nodes strategically placed around the body to present their information. The lymph nodes function as both molecular courts and dating agencies: decisions on whether a response is necessary are made by a committee of cells, based on the aggregated information returned by dendritic cells, and dendritic cells are able to locate t-cells that recognize a specific antigen and initiate the correct adaptive response.

Continued on next page

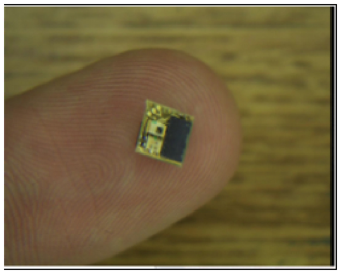

Figure 2. *Specks, developed by the SpeckNet research consortium,[4] are miniature semiconductor grains (around 1mm*^{3}*) that can sense and compute locally. They communicate wirelessly and each device operates on the basis of its own captive, renewable energy source. (Figure courtesy of the Speckled Computing Consortium.)*

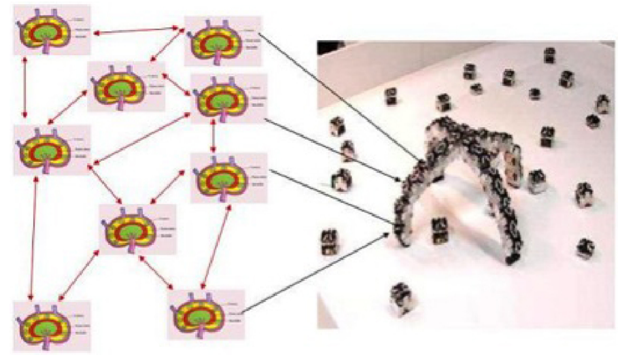

Figure 3. *An artificial lymphatic system provides a mechanism for robotic swarms to exchange beneficial information and maintain homeostasis. (Figure courtesy of Jon Timmis, University of York, UK.)*

At Edinburgh Napier University, we have demonstrated the usefulness of this concept for a specialized type of wireless sensor network built from 'specks.' These are miniature devices equipped with their own battery, processor, sensors and memory (see Figure 2). Controlling networks of specks poses considerable challenges for engineers due to the unreliablity and scarce resources of individual devices. Their limitations make it difficult to apply traditional engineering approaches. Our team has developed a protocol inspired by dendritic cells, in which radio messages circulating through the network function as dendritic cells. The messages gather internal information from specks and external input from sensors as they circulate and return this to special specks acting as artificial lymph nodes. There, the accumulated information is used to determine the local network state and orchestrate any appropriate action. The protocol has been applied in simulation to a situation that requires random topologies of specks to regulate temperature within an environment.

Another aspect of the immune system has been successfully used by others to detect network attacks as well as in some robot applications.[5] According to 'danger theory,' the immune system does not respond to nonself, but only to danger, by detecting different kinds of signal apparent in body tissues that reveal whether cells are sensing danger or behaving normally. Dendritic cells process these signals, weighing the relative proportion of each type of signal found to be able to classify the antigens as malicious or not according to their context. Although subtle, the point is that the immune system need not respond to 'foreign-ness' per se, but only to foreign elements causing trouble. This results in a response driven by context rather than identity, and ought to be readily transferable to engineered systems, where it is often easier to measure the effects on a system of some action, rather than identify the signature of the action itself.

Other research taking inspiration from lymph-node processes is being undertaken as part of the Symbrion project.[6] Researchers at the University of York are investigating novel principles of adaptation for symbiotic multirobot organisms in which robots can move individually and also physically aggregate into larger structures (see Figure 3). They are developing a novel software architecture whose aim is to maintain the internal state (homeostasis) of both individual robots and collective robotic systems. Individual robots contain a single artificial lymph node which provides an artificial environment in which agents monitoring sensor inputs congregate, leading to the ability to predict deviations from a stable state that may lead to undesirable behaviour of the robot. When individual robots coalesce to form a larger robotic system, an artificial lymphatic system propagates the state of one robot from its own lymph node to other robots in the collective organism, and ensures that homeostasis of the entire system is achieved and maintained, for example by ensuring that faulty units cannot connect to other robots.

These examples are far removed from the early research efforts in artificial immune systems, which focussed almost exclusively on distinguishing 'good' from 'bad,' and relied mainly on the immune mechanism known as negative selection. This article gives just a glimpse of some of the other mechanisms apparent in the rich and complex immune system with which we are born, and which I am convinced remain ripe for exploitation in equally rich and complex pervasive, adaptive systems.

Continued on next page

10.2417/2200911.1837 Page 3/3

Author Information

Emma Hart
School of Computing
Edinburgh Napier University
Edinburgh, UK
http://www.dcs.napier.ac.uk/~emmah

Emma Hart is professor of Emergent Computing. She obtained a BA (Hons) from the University of Oxford (UK) before going on to study artificial intelligence, obtaining an MSc in knowledge-based systems in 1995 and a PhD in artificial immune systems in 2002, both from the University of Edinburgh (UK). Her research interests lie in the application of biologically inspired computing techniques to adaptive systems.

References

1. E. Hart and J. Timmis, *Applications of AIS: the past, the present and the future*, **Appl. Soft Comput. 8** (1), pp. 191–201, 2008.
2. I. R. Cohen, **Tending Adam's Garden: Evolving the Cognitive Immune Self**, Academic Press, London/San Diego, 2004.
3. J. Stewart, **The Primordial VRM System and the Evolution of Vertebrate Immunity**, R. G. Landes Company, Austin, 1994.
4. http://www.specknet.org SpeckNet research consortium. Accessed 14 October 2009.
5. U. Aickelin and J. Greensmith, *Sensing danger: innate immunology for intrusion detection*, **Elsevier Inform. Secur. Tech. Rep. 218**, pp. 218–227, 2008.
6. http://www.symbrion.eu Symbrion project. Accessed 14 October 2009.