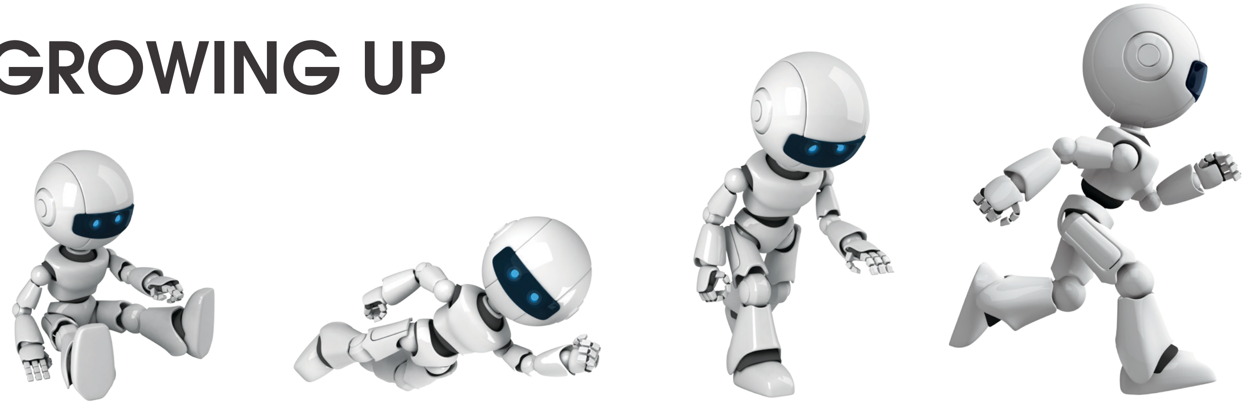
GROWING UP



Like a baby, a robot learns to predict the consequences of its movement and adapt to the environment through repeated failure and trying again.

Robots now coming into being in HKUST labs are like babies. A child initially knows nothing of the world. But using its five senses – hearing, sight, touch, taste, and smell – an infant has the capacity to rapidly learn from what it perceives in the immediate environment and how that environment changes in response to its actions.

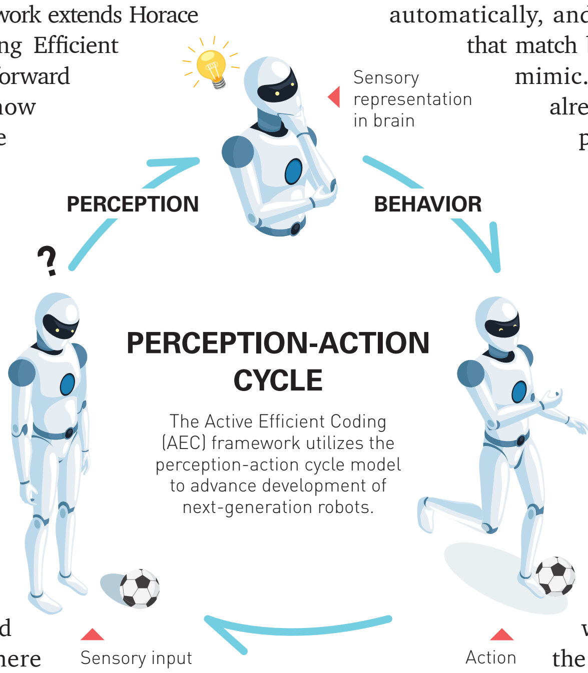
This is the perception-action cycle, understanding that is also vital for the development of the next generation of robots. The new robot may start its existence as a blank slate. But if, like a child, it has the capacity to teach and correct itself, it can do much more than a pre-programmed machine.

Prof Bertram Shi is leading research where electronics and computing meet biology and neuroscience. Prof Shi is renowned in the robotics community for his work in developing the Active Efficient Coding (AEC) framework for machine learning in collaboration with Prof Jochen Triesch's team at the Frankfurt Institute for Advanced Studies in Germany. This framework extends Horace Barlow's groundbreaking Efficient Coding hypothesis, put forward in 1961 to explain how the brain works at the neuronal level.

The brain, Barlow hypothesized, tries to form an efficient representation of the environment by switching on as few neurons as possible, thus minimizing the energy involved. Prof Shi and his team realized this hypothesis was incomplete, as it assumed a passive organism, where the properties of neurons adapt to the statistics of sensory input. What was missing from Efficient Coding was that organisms actively shape and optimize such statistics through their behavior. The researchers added the effect of active behavior to the hypothesis in work first presented at the 2012 IEEE International Conference on Development and Learning and Epigenetic Robotics.

The team's AEC framework takes into account how animals and humans utilize their motor system to facilitate the efficient encoding of relevant sensory signals. An example is the simultaneous movement of both eyes in opposite directions to align the images from the left and right eyes so that they can be fused into a coherent percept, also known as a "vergence eye movement". The framework is a powerful unifying principle for the development of neurally inspired and driven robots. It underpins technology that will enable robots to become more adaptive, structure their own behavior automatically, and predict interventions that match biological systems they mimic. Prof Shi's team has already shown this single principle can account for the emergence of a wide range of other behaviors, such as visual tracking and accommodation (focusing), and the automatic combination of multiple sensory cues.

Prof Shi explained: "In developmental robotics, ideally we want to put a robot in the environment and let



it structure its own interactions. It has to learn from its interactions, like a baby. We then have something that is adaptive."

By combining the latest advances in unsupervised machine learning and reinforcement learning, the team formulated a mathematical model for the simultaneous development of perception and action that encapsulated a simple idea. Perception develops in order to enable an organism to understand the environment based on the input from its sensory organs. Behavior develops to stabilize the sensory input to simplify the process of understanding the environment.

The focus for their application of AEC is the visual system, which is vital for the more autonomous machines of the future if they are not only to "see" but can also respond to what they "see". For the robot, this involves creating a sight system that can track and follow an object and then stabilize the image of the object captured by video camera to make it easier to understand. It then creates an internal representation of the environmental state. The team is experimenting with robots that can control the angle incline of the eyes, moving their position as an object comes closer, and with an arm programmed to move to that location.

The system continuously recalibrates itself, learning by failing and trying again – a process that Prof Shi also describes as "babbling", like a baby babbles as it learns to talk. This process happens dynamically whenever the system is operating, just as learning is always active in biological organisms. In another breakthrough, the team has demonstrated that the system exhibits another important biological capability: self-repair. Using the framework, a robot, if injured, can automatically readapt itself.

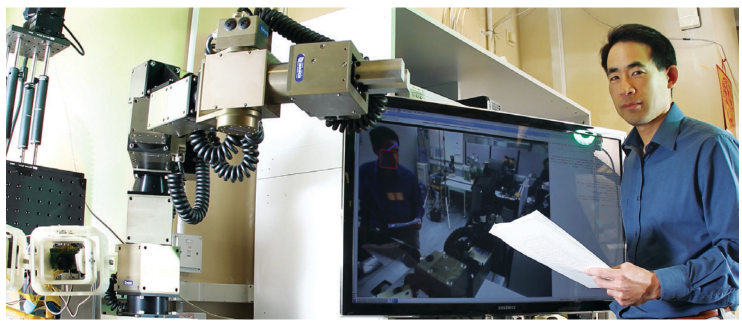
While the HKUST researchers are now refining this technology, Prof Shi is confident that it will not be long before the eye movement system is ready for application outside the laboratory, for medical, consumer, and industrial uses. He expects this capability to be built into robots used in industrial settings to support greater automation in manufacturing processes that require more human-robot interaction – where the human understands the robot, and vice versa.

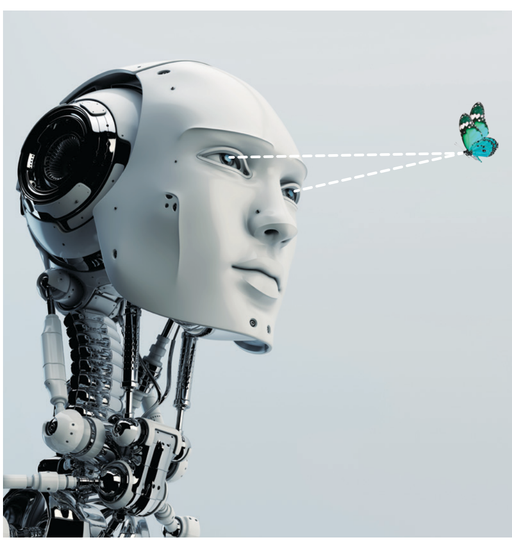
Medical applications for systems using the AEC framework are also being developed. For example, Prof Shi's collaborators in Germany are now working to apply the principle to the development of virtual reality training systems to improve sensorimotor coordination in patients with eye movement disorders. "Robots that mimic the brain's ability to adapt might one day be able to help the biological system when things go awry," said Prof Shi.

Prof Shi's team comprises a group of multidisciplinary talents who are at the core of its success. "They need strong math skills to understand the algorithms, and coding skills, and a focus informed by engineering, neural science, and physics, as well as creativity and imagination," he said.

> "From human biology we can draw much to inspire our understanding of the development of robotics"

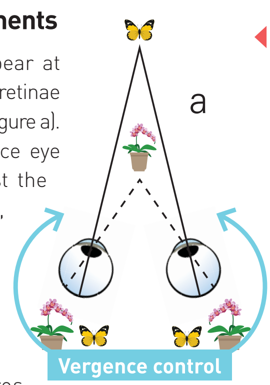
PROF BERTRAM SHI
Professor and Head, Department of Electronic and Computer Engineering





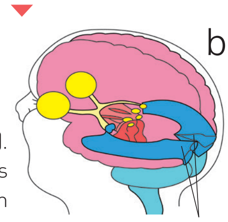
Vergence Eye Movements

Objects in the world appear at different points in the two retinae depending on their depth (Figure a). Humans perform vergence eye movements, which adjust the angle between the two eyes, to align the images on the two retinae so that they can be fused into one coherent percept. Generating the correct control signals requires information from the two eyes to be combined (Figure b). Human babies normally learn how to do this four months after birth. The Active Efficient Coding (AEC) provides an account for how this behavior emerges.



Objects at different depths appear at different points in the retinae of the two eyes.

In humans, visual information from the two eyes is routed separately to an area of the brain in the back of the head known as the primary visual cortex, where information from the two eyes is combined.



Primary visual cortex