Learning from Mother Nature: ‘biomimicry’ for the next-generation armed forces

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Introduction

Animals have been man’s best companion in warfare since ancient days. It was the cavalry horse, scout dog and messenger pigeon—among others—that supported human warfare in past millennia. However, the advent of metallurgy in warfare displaced these now ‘less reliable’ animals with mechanical machines. Without metals, the materiel culture of society is unthinkable. Metallurgy is the basis for much of the production of manufacturing, transportation and communications equipment, as well as civil construction and contemporary military operations.

However, what metallurgy gained in certainty, it lost in the human/animal touch and the unexplained irrational factors that animals deliver to the battlefield. As exemplified in an old Chinese proverb, the warhorse was able to independently evade the enemy’s pursuit and deliver its injured and even unconscious rider-owner back to base camp, something that could never be done by current-level ‘mechanical machines’.

Moreover, the utility of animals in certain situations remains, especially when the operating terrain does not favour metallurgy. For example, during World War 2, American armoured units found that the mountainous terrain and temperate forests in Sicily did not favour the mass use of armour. So some US forces used horses instead. In the Asian theatre, the unorthodox combat unit ‘Merrill’s Marauders’ employed several hundred horses and mules in its fight against the Japanese in Burma. More recently, in particularly mountainous terrain in Afghanistan, some US Army Special Forces were calling in precision-guided munitions against the Taliban from horse-back.

Regardless of terrain, the lessons of nature and man’s longstanding relationship with animals and other creatures, both domesticated and in the wild, have provided an inspiration for military technologists throughout military history—and this trend is likely to continue. One of its manifestations is ‘Biomimicry’, popularised around 1997 with the release of Janine Benyus’ book, Biomimicry: innovation inspired by nature, which is explored further in this article.

The dominance of metallurgy in modern warfare

In modern militaries, most equipment is metallic. Precision strikes (whether using small arms or large-calibre guns), precision manoeuvre (by land vehicles or aircraft and ships) and precision information networks all use equipment involving metals. Gone are the days where soldiers diligently practise martial arts to fight with spears or pikes, of which only the tip might be metal, depending on the warrior culture and historical period. Metallurgy has now become the dominant paradigm in modern weapons technology, albeit metallurgy appears to be devoid of a central essence and is often more of a means to an end.

Animal mimicry, on the other hand, has often inspired and influenced the design of modern war machines. For instance, with reference to Figure 1 (overleaf), the first generation tanks took inspiration from caterpillars (and the traction system of modern tanks is still often referred to as ‘caterpillar’ tracks).
Modern radar (range and detection) mimicks the sonar mechanism used by bats and dolphins. The Wright brothers would not have invented the prototype aircraft in 1903 if they had not attempted to mimic birds in flight. Even Leonardo da Vinci’s ‘Ornithopter’ and the Greek mythological character Daedalus, with wings fashioned of wax, feathers and twine, were a mimicry of birds. In several of these examples, metallurgy provided the ‘means’ but animal mimicry was the source of inspiration for the ‘end’.

Today, some commentators are arguing that metallurgy has lost its lustre and that it may now have reached the point, typical in the so-called ‘S curve’ of the technology life cycle, where it is increasingly providing diminishing returns. From a capability perspective, the example is cited of titanium being the hardest of metals—yet the hardest substance on earth is synthetic diamonds, which cost about 15 per cent less than real diamonds. So if it was not for the cost, we would be shooting diamonds!

Moreover, metal may be hard but it is less flexible and not stealthy in terms of electronic detection. Conceptually, from a paradigm perspective, metallurgy appears to work in binary terms—metallic platforms either shoot or get shot, they either destroy or are destroyed. There is no fuzzy middle, such as growing and self-healing after being hit, which is hardly representative of reality and nature. The golden question is what is next after metallurgy?

**The potential of biomimicry**

Imagine the following scenario in which you, as a lone soldier, are tasked to capture a terrorist in a building. While making your way to the building by night, your clothing changes patterns to meld with your surroundings, just like a chameleon. On reaching the building, you climb the outside wall like a gecko to the third floor where the terrorist is hiding. Once inside, you scan the room like a snake, sensing the image of your target in the darkness. You move towards him but he shoots first. Your abalone shell outer armour is penetrated but rapidly self-heals, while your spider silk inner armour stops the bullet. You are able to move near enough to stun your target like an electric eel. As you carry his inert body out, you avoid a number of booby traps and improvised explosive devices through your sense of smell.

This scenario may seem fanciful. But it could become a reality in the not too distant future. That is not to suggest the paradigm of metallurgy dominance is over. However, as a potential complement to metallurgy, it is useful to understand the philosophical underpinnings and specific areas where biomimicry appears likely to make a useful contribution to next-generation armed forces.
From a philosophical perspective, biomimicry can be said to represent a holistic solution because its envisaged bio-designs are not a collection of parts but a synthesis of a whole. This accords with the 'system of systems' thinking of the 'Revolution of Military Affairs' of the 1990s and its advocacy of network centric warfare.

Philosophically, animals by nature are a complete ecosystem (system of systems) and studying how they 'operate' will help find parallels that military technology and weaponry might emulate. From an evolutionary perspective, biomimicry could also provide the next 'revolution in military affairs', with the development of weapons systems paralleling the evolutionary changes in nature, where a constant iteration reflects the dictum of Charles Darwin that 'only the fittest survives'.

From this chain of logic, it seems reasonable to contend that by adopting biomimicry, future armed forces will be able to indirectly harness nature's evolutionary processes as part of their force development. That would be in stark contrast to metallurgy, where linearity and individualism appear to prevail.

A digress to contrast physics and biophysics is needed to illustrate this point. Physics describes brute strength. In linear terms, it theorises that a top-notch, 60 kilogram weightlifter can clean-and-jerk about 180 kilograms, typically three times their own body weight. Contrast that to a leaf-clutter ant carrying 50 times its own weight, a male rhinoceros beetle 850 times and a tiny mite 1180 times its own weight. The exoskeleton and biophysical make-up of these insects, which typically operate in hordes, have tremendous implications for military technology. However, biomimicry has far wider applications, as will be discussed in the following sections.

**Individual survival and protection**

**Water**

For soldiers, water is more critical than food. Humans die from dehydration within three to seven days but can survive without food for around 30-40 days. In battle, we must always foresee the scenario that an adversary will seek to cut off our lines of communications. Jungle survival skills teach us how to find water sources and drink from rivers using water purification tablets. However, what if there are no rivers and dynamic operations do not afford troops the opportunity to retrieve water by condensation or similar means.

Here, beetles in the Namibian desert appear to have evolved a solution. Although it lives in one of the driest deserts in the world, the Namib Desert Beetle is able to obtain all the water it needs from the ocean fog, using the unique surface of its back. During the day, its matt black shell radiates heat. But at night, it becomes slightly cooler than its surroundings, causing fog to condense on its shell. In the morning, the beetle simply tips itself up and lets the water trickle into its mouth.

As illustrated at Figure 3, researchers from the Seoul National University of Technology have designed the 'Dew Bank Bottle', based on the biodesign of the Namib Desert Beetle, which can harness water even in the most unlikely environments, potentially enabling soldiers to condense water on the move.

Figure 3. Desert beetle and the Dew Bank Bottle (overleaf)
Camouflage

In Soldiering 101, camouflage is used to prevent enemy detection. The Singapore Armed Forces have evolved from first to second-generation camouflage, from using plants and synthetically pre-designed camouflage to digitally-pixelated camouflage whose design has been proven by the US Marine Corps to play tricks with the human eye. However, wearing a green pixelated uniform while fighting in urban terrain does not intuitively translate to a sense of being ‘protected’ by pixelated technology, whereas a grey pixelated uniform would seem more useful.

However, it does not make logistical or operational sense to change from green to grey just before entering an urban terrain, especially given the dynamic nature of next-generation warfare, where soldiers are likely to have to fight in both urban and rural terrain interchangeably and in compressed tempo. Active or adaptive camouflage as inspired by chameleons and the octopus is useful here.

Chameleons and certain species of octopuses can alter their colour through the use of chromatophores that control the type and amount of light reflected. Work along these lines is being carried out at the Sandia National Laboratories in Albuquerque, New Mexico (with funding from the US Department of Energy), where scientists have started to create a synthetic, biomimetic material that will mimic an animal’s ability to colour-shift.

Team leader George Bachand notes that ‘military camouflage outfits that blend with a variety of environments without needing an outside power source—blue, say, when at sea, and then brown in a desert environment—is where this work could eventually lead’.

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Armour protection

Currently, infantry soldiers wear heavy armour to protect against small arms fire. However, it comes at the expense of mobility. Spiders offer a solution to light weight yet durable body armour. Scientists at the University of California have identified the genes and DNA sequences for two key proteins used in the ‘dragline’ silk of the tiny but lethal spiders found in the region. This discovery could lead to a variety of new materials for industrial, medical and military uses. Dragline silk from black widow spiders is regarded as superior to that from other spiders because of its strength and extensibility, which enables the silk to absorb enormous amounts of energy.

The silk’s properties have interested the US military, which is keen to explore the possibility of copying the structure of the silk for lightweight body armour. This is not necessarily a new revelation, given that the Mongols issued silken body armour to every warrior, which was extremely light yet sufficiently resilient to protect them from enemy arrows. But it is certainly a new age rendition of a historical concept.

Beyond lightness, the unique materials in the exoskeleton of certain animals may also prove useful in augmenting human abilities. For instance, both the shells of the Mantis Shrimp and common garden snail have inspired the composite use of hard ceramic and elastic organic materials. For example, a partnership between Harvard University, the University of California and the Nanyang Technological University in Singapore has been established to study the makeup of the Mantis Shrimp's claw. Researchers have found that the claw comprises an outer layer of very hard crystalline calcium-phosphate ceramic material that is about 60 micrometres thick. While it is actually quite fragile and can shatter on relatively minor impact, the team also discovered a much thicker region beneath it, comprising layers of fibres made from an elastic material often found in sea fish exoskeletons. The team believes that the multiple layers of fibres help prevent the claw from fracturing. With this design in mind, body armour could be designed in a similar way, using composites of hard ceramic and elastic organic materials.

Head armour in the form of a helmet is equally if not more important, since a head wound typically requires immediate evacuation from the battlefield. We often joke that ‘one cannot think after putting on the helmet’. That is likely a comment in jest to illustrate the weight and discomfort from wearing a helmet. However, the importance of a lightweight and durable helmet cannot be overstressed.
A particularly relevant biophysical wonder is in the design of a woodpecker’s skull, which can withstand a shock of 60,000 grams of force without damaging the brain. Researchers at the University of California, Berkeley, have identified four critical features, relating to strength, flexibility, the minimisation of vibrations and the reduction of force, which have already been utilised in the design of new products subject to high impact, including crash helmets and flight data recorders.21

How about self-healing armour? In metallurgy, the paradigm is binary opposites. Armour which has been damaged has to be replaced entirely or risk its user being put out of action. But from a biological perspective, the skin is capable of self-healing (unless it is subject to a particularly serious burn), so why should armour be any different?

The abalone shell is a case in point. Besides being tasty, abalone shells are light yet extraordinarily tough—1000 times more energy is required to break the shells than to fracture the toughest man-made ceramics. And when cracked, the shells can repair themselves. The abalone’s toughness derives from layers of tiny calcium-carbonate plates that when struck, glide over one another to absorb the shock. If cracks develop, the plates simply grow back together. Researchers at Princeton University are modelling the abalone’s self-healing property in relation to structures that can be built in space, although similar principles could apply to military vehicles which are prone to damage in battle.24

Individual combat performance

From an operational perspective, urban operations are difficult because buildings are hard to clear. But a gecko can scale up and down buildings effortlessly. Its secret lies in the composite structure of its feet, where every single toe pad is covered with millions of keratinous hair-like bristles called setae. Each one in turn branches into hundreds of flat tips called spatulas, which make intimate contact with surfaces. This fibrillar array achieves adhesion primarily by what is known as non-covalent interaction between the spatulas and the surface. Theoretically, gloves incorporating such spatulas could generate an adhesion force comparable to the body weight of 500 men.25 If it was integrated into an exoskeleton incorporating the weight-carrying properties of insects, its user would have both tremendous strength and the ability to scale significant heights.

Currently, militaries fight with night vision goggles but they frequently get foggy in our tropical climate when we sweat, even at night! Bats use echo-location and snakes use pit organs to feel the presence of warm bodies. Based on the echo-location used by bats to find their way and avoid even small objects in total darkness, a UK technology company has designed and manufactured an ‘UltraCane’ to assist the vision-impaired.26 It uses sound waves to locate objects in front of the user via a small electronic echo-location device attached to the cane, which provides sensory feedback through the cane’s handle. While this was intended for the visually-impaired, it could be adapted for soldiers to use in the dark.

In another study, scientists have discovered that vipers, pythons and boa constrictors have holes on their faces called pit organs, which contain a membrane that can detect infrared radiation from warm bodies up to one metre away.27 At night, these pit organs allow snakes to ‘see’ an image of their predator or prey. This is akin to an infrared camera and its adaptation, as a complement to night vision goggles, might allow soldiers to see through camouflage or foliage that would otherwise fool their eyes.

Systems warfare

The current intelligence assets of typical military forces are composed largely of assets that extend the coverage of sight and sound beyond the range of human limitations. With ongoing technological improvements, these collection assets have reduced in size and improved in durability. However, they pale in comparison to what abounds in nature, where unmanned aerial vehicles in the form of flies can take off and land in any direction, change course in thousandths of a second, and use different wing motions to create backspin and air vortices that create lift.28 Imagine the potential uses if those capabilities could be replicated in military UAVs.

Similarly, land reconnaissance, bomb diffusion and counter-mining operations might be done by nanomachines with the capabilities of cockroaches, which are highly manoeuvrable in complex terrains and undaunted by hip-height obstacles and slopes up to 24 degrees.29 They could be augmented by
technologies incorporating the olfactory faculties of lobsters and silk-moths, both of which are able to detect friends, foes and TNT far more efficiently than any human or any current technology. Lastly, imagine a horde of sand flea-like nano-machines, jumping forward 30 feet into the air as they reconnoitred an enemy position. If the imagery from each could be pieced together to form a macro-picture, the potential battlefield awareness would be unprecedented.

Or what about the auto-sensing of chemical and biological threats? Here, the sensing capabilities of the Morphos butterfly are a useful case in point. In 2010, the US Defense Advanced Research Projects Agency (DARPA) awarded General Electric a US$6.3 million grant to further develop a project to replicate the nano-structures from the wing scales of butterflies. Research has uncovered that the scales on the wings of Morphos butterflies can detect molecules in the atmosphere, changing their spectral reflectivity depending on exposure to different vapours, with their response ‘dramatically outperforming’ that of existing nano-engineered photonic sensors. Scientists are working on the development of similar sensors that could be embedded in clothing, with the capability to change colour on detecting chemical or biological threats.

A further biomimicry development relates to the detection of objects by radar. Metallurgy is the natural nemesis of radar systems, as the cross section of a metallic object ‘bounces back’ radio waves to expose its presence. Modern technology has tried to reduce this bounce-back through the use of graphite-based advanced materials, rounder edges and by painting surfaces to absorb radiation. However, in nature, all moths have naturally-occurring anti-reflective surfaces in their eyes, consisting of tiny protruding bumps that keep moths safe from predators by preventing light from reflecting in their eyes.

Researchers at the University of Delaware have adapted these anti-reflective ideas and created surfaces in which microwave energy is transmitted with very little reflection over large ranges of frequency and bandwidths. A particular application is the development of anti-reflective surfaces within an antenna system, enabling it to transmit yet avoid detection by radar.

Animal-like robots are another development. Unmanned drones reportedly spied on Osama bin Laden the night before the special operations raid that killed him in Pakistan. And combat engineers use robots to assist in detecting and neutralising chemical, biological, radiological and explosive devices. Now, imagine
unmanned land vehicles as fast as a cheetah and armed with weaponry. Such a four-legged robot is under development by the US company Boston Dynamics, with funding from DARPA.\(^3\)

It is envisioned that the Cheetah robot will be faster than any human, as well as having incredible agility, with the ability to make tight zigzagging turns, similar to its namesake, and being able to stop suddenly. How it might be used in combat is speculative, noting that 'DARPA won't directly say there's a military application for RoboCheetah itself, but the program was kicked off in order to address mobility limitations of [current] bomb-disposal robots.'\(^3\)

Figure 6. Boston Dynamics' Cheetah robot

Yet another area of development is in cyber warfare. While information communication technology has facilitated 'Information Knowledge-Enabled Command and Control' and network-centric warfare, the reliance by modern militaries on such technology has also exposed their vulnerability to its degradation. Hence, cyber defence has become increasingly important, as affirmed in a recent address by Singapore's Minister for Defence.\(^4\)

As unlikely as it may seem, the operating concept of ants is one area of biomimicry under examination. By looking at the way ants call for backup and overpower invaders through sheer numbers, scientists at the Pacific Northwest National Laboratory in the US have devised a 'digital ant' to help human operators spot threats to computer systems more quickly.\(^4\) Unlike traditional security devices, which are static, these 'digital ants' wander through computer networks looking for threats, such as 'computer worms' or viruses. When a threat is detected, an army of ants will converge on the location and help draw the attention of human operators, including by generating an automated 'scent' to attract more ants and thus produce the swarm that marks a potential computer infection.

**Conclusion**

Biomimicry presents many exciting possibilities for military technology. While it is clearly an unconventional form of technology, it arguably is one that modern militaries should embrace, albeit biomimicry is not without its challenges. Akin to most research and development programs, extensive resources of time and money are essential. And even then, the results may be problematic, as there are many uncertainties in learning from nature.

Notwithstanding its challenges, military technologists should be doing more to bridge the current research between academia, commercial companies and the military into biomimicry. Collaborations through these networks would better allow next-generation armed forces to benefit from biomimicry ideas and technologies and customise them to their local needs.
Whether biomimicry will prove to be the next paradigm shift in warfare will largely depend on such collaborative endeavours, as well as the ability of ‘futurists’ to break through the mindset that warfare involving metallurgy and fires is the most reliable mode.

History would tell us that when China invented fire powder and used it for celebratory fireworks in the Song dynasty, Europeans were still happily fighting with pikes and swords in the Middle Ages. It was the curiosity and willingness to venture into uncharted waters that enabled these scientific breakthroughs. The same can be same for the invention of the atomic bomb during World War 2.

One thing is clear, nature is unique and wonderful. Learning from and about nature, since the Age of Enlightenment, has led to the immense knowledge creation of the modern day. Incorporating biomimicry into the next-generation armed forces is in line with this never-ending human quest of introspective learning and zealous discovery.

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Notes

1 This is an abridged and edited version of an article, titled ‘Learning from Mother Nature for the Next Generation SAF’, published in Pointer (the Journal of the Singapore Armed Forces), Vol. 41, No. 1, 2015. The article was the top prize-winning essay in the Singapore Armed Forces’ 2013-14 Chief of Defence Force Essay Competition. It is reprinted with kind permission of Pointer.


3 See, for example, Steven J. Zaloga, US Armoured Units in North Africa and Italian Campaign 1942-45, Osprey Publishing: Oxford, 2006, p. 84.


33 Mobile Magazine, ‘Darpa’s Butterfly’.

34 Sourced from Mobile Magazine, ‘Darpa’s Butterfly’.


39 Farquhar, ‘Robot Cheetah used to dodge’.

