TOWARD CRASH-FREE CARS: VOLVO CAR CORPORATION

EXECUTIVE SUMMARY

Volvo Car Corporation designs and manufactures cars. The company's cars run on ethanol, petrol, and diesel. The company offers its products and services through sales outlets and service workshops in the United States, Sweden, Germany, Great Britain, and internationally.

From the very beginning, Volvo's guiding principle has been safety. In 2008, Volvo stated the following vision: "By 2020, nobody shall be seriously injured or killed in a new Volvo". This statement from 2008 clearly formulates an ambition and long-term vision to create cars that will not crash. Delivering on this vision will have huge impact: the World Health Organization estimates that approximately 1.2 million people are killed and over 50 million injured in traffic accidents every year. Traffic accidents cause significant human suffering and are a large burden on society. It is a prioritized challenge to reduce accidents, where advances in several areas must occur in parallel and interact in order to yield effects. Efforts are focused on three areas: safe traffic environments, attentive drivers and safe cars.

One way of achieving the vision is Volvo's participation in a European research project that looks at African locusts, the interesting behavioral patterns these insects portray when traveling in swarms; how they tend to avoid bumping into each other when migrating.

Volvo was inspired by the locust studies of Dr. Claire Rind of Newcastle University and wanted to learn if locust sensory-input routing methodologies could be built into a vehicle safety system

THE COMPANY

Volvo Car Corporation is a Swedish automobile manufacturer founded in 1927, in Gothenburg, Sweden. Volvo was originally formed as a subsidiary company to the ball bearing maker SKF. When Volvo AB was introduced on the Swedish stock exchange in 1935, SKF sold most of the shares in the company. AB Volvo owned Volvo Cars until 1999, when the Ford Motor Company as part of its Premier Automotive Group acquired it. The Chinese Geely Holding Group then acquired Volvo from Ford in 2010.

Volvo is known around the globe for its high safety standards and safety innovations. Prior to strong government safety regulation Volvo had been in the forefront of safety engineering. But they were not only front runner in the safety realm: Volvo was very proactive 30 years ago when the CEO at the time stood up during a UN conference and said that their cars had a negative impact on the environment: they produce noise, pollution and waste. This bold statement marked the beginning of Volvo's environmental work. Many cars have a 'piece of Volvo' in them, e.g. the three-point-belt that was introduced by Volvo in 1959, and the exhaust emissions technology in the 1970's, which reduced emissions by 85% at the time.

In June 2001, Volvo engineers became aware of the possibilities biomimicry could enable, when Martti Soininen learned about the locust studies of Dr. Claire Rind of Newcastle University, UK. Locusts are grasshopper-like insects that migrate in swarms as dense as 80 million adults per square kilometer (0.4 square mile) yet avoid crashing into each other and predatory birds. Volvo wanted to learn if locust sensory-input routing methodologies could be built into a vehicle pedestrian safety system.

THE BIOMIMICRY STORY

Car crashes are responsible for over forty thousand deaths and over five million injuries each year in the US alone. Mechanisms and sensors to detect, avoid, or lessen the impact of collisions are therefore an area of important industrial research. The problem with traditional approaches to making collision avoidance mechanisms for cars lies in the huge amount of information processing needed to successfully determine if a collision will occur. This is especially important when both the car and the object with which it is colliding are moving, and involves calculations of trajectories, speeds, and many other characteristics of both the car and the colliding object.

A solution to this information overload can be found in the visual system of a locust. In 2001, Martti Soininen, engineer at Volvo at the Electric department, saw a scientific article about Dr. Rind's research on locusts. Soininen had been thinking of nature's way of collision avoidance for a while before that. He had seen birds flying through dense forest at very high speed avoiding collisions with trees and their boughs. He had also studied flies, how they move away very quickly when you try to approach them with your hand. Soininen understood that their image processing was very fast, which was really interesting to him: he had studied image processing for use in cars in 1995 and learned that there was a very long way to go before there was enough processing power to use cameras for collision avoidance. Martti Soininen contacted Dr. Rind, reader in invertebrate neurobiology at Newcastle University, about her work at the interface of biology and engineering and got invited to her lab.

Locusts, which can consume their own weight in food each day, have a large neuron called the locust giant movement detector (LGMD) located behind their eyes (see Figure 1). The LGMD releases bursts of energy whenever a locust is on a collision course with another locust or a predatory bird. Dr. Rind's team found that the LGMD releases more energy when something is coming directly at the locust.

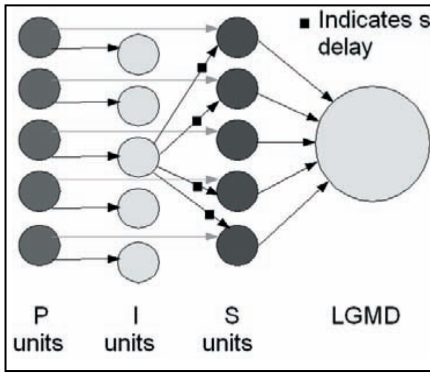

Figure 1. *The LGMD model and its input afferents. Excitation is captured from each of 100×100 pixels of an input image (only a small sample of the processing units are shown). The excitation, caused by change in luminance of each pixel, is calculated by the P units and is passed directly to the S units. Excitation is also passed to the I units where it is converted into inhibition. The inhibition is able to affect neighbouring S units after a short synaptic delay. Resultant excitation, where the change in excitation caused by the change in image exceeds the spread of inhibition, passes to the LGMD (lobula giant movement detector).*

These spikes of energy, called action potentials, prompt the locusts to take evasive action. A warning message is sent to the brain when the locust is on a collision course with another object. The entire process from motion detection to reaction takes about 45 milliseconds. Locusts, like most insects, can see many more images per second than humans do. This gives them a remarkable view of the world. For humans, it would be like watching everything go by in slow motion. Locusts can react in time to things that are approaching very rapidly and so make their escape before collision. And because the insects only detect things that are on a collision course with them, the locusts are ignorant of all other movements. It's a particularly useful trait, as the locusts travel in dense swarms akin to rush hour traffic.

The models clearly show that the simple, biologically inspired design of the locust LGMD is useful in the detection of collisions in automotive situations. The main benefits of the LGMD are that there is no need to identify objects, their approach speeds or their angles of trajectory, all of which can be computationally expensive. The only data required is the luminance values of the photoreceptors over a period of time. Also most of the complex background scenes are removed by the gradual filtering of the image through simple computations conduced in parallel, thus the entire system can be designed and operated on a single VLSI (very large silicon integration) chip.

For the last 50 years it's been easy to take measurements from this neuron in the locust. However, it wasn't known what exactly the neuron was responding to. In 1992 Claire Rind and Peter Simmons decided to show videos of Star Wars to the locusts to study how their eyes and nerve cells reacted to fast-moving objects and backgrounds. The conventional approach to creating such systems involves using radar or infrared detectors, and requires very heavy-duty computer processing. They found that the neuron responded more strongly to objects on a direct collision course. Dr Rind was then able to create a computer model to test her theory of the neuron function and build circuits for collision avoidance robots. The robots were built in 2000 in Switzerland with a mini-camera attached and can be programmed directly from the computer. The next step was to test computer models of the locust neuron circuits on video footage of car collisions. Spanish microchip designers have used these models to fabricate a microchip with light-sensitive components. The research partnership also involved multi-disciplinary collaboration with the Hungarian Academy of Sciences (Neural Computing Laboratory in Budapest), the Microelectronics Institute of Seville, and industrial partner Volvo Car Corporation. Together, they have developed and tested a VLSI-based vision system for automotive use based on the locust's LGMD.

Dr. Claire Rind settles a locust for a spot of Star Wars watching

Computer simulations of the LGMD and its input architecture have shown similar responses to visual stimuli as are shown by the LGMD of the locust, and models coupled with mobile robots have demonstrated an ability to detect and avoid collisions in a simple environment in real time. Speeds and sizes of colliding objects in automotive situations differ considerably from both natural predators of locusts and obstacles encountered by mobile robots. The use of an LGMD model in an automotive situation would require significant adaptation of the model to its intended tasks. Although considerable research has been conducted into artificially implementing insect neural networks in robots, this project is one of the first to attempt a transition from laboratory research into industrial technology. Because of the relative simplicity of insect neural networks, compared with conventional engineering approaches, it may not be long before insects inspire a large amount of everyday technology.

BACKGROUND OF THE PROCESS

PROBLEM

Volvo Car Corporation is aware that driving cars have negative side effects, amongst which accidental deaths and injuries is one. The World Health Organization (WHO) in its first ever Global Status Report on Road Safety revealed that every hour, 40 people under the age of 25 die in road accidents around the globe. According to the WHO, this is the second most important cause of death for 5 to 29 year olds. The report pointed to speeding, drunk driving and low use of helmets, seat belts and child restraints in vehicles as the main contributing factors.

One of the most difficult safety issues involves the dangerous coexistence of cars and pedestrians. All too often, human reflexes are just not fast enough to enable a driver to avoid hitting something, even at low speeds. When that “something” is a human being, a collision becomes a tragedy, an avoidable tragedy in the minds of Volvo engineers, but a viable solution was proving elusive.

A chance encounter with insect studies opened up a new approach to the problem. Scientist discovered how clouds of swarming bugs manage to roam relentlessly over long distances without running into one another. "Our original thoughts centered on pedestrian safety. If we could trace how the locust is able to avoid each other, maybe we could program our cars not to hit pedestrians, says Jonas Ekmark, Preventive Safety Leader at Volvo Car Corporation."

CHALLENGES

During the study, Dr. Claire Rind learned that visual input, the signals from the LGMD, is very quickly (especially compared to humans) transmitted to the insect's wing nerve cells, seemingly bypassing the brain. The connections can be direct involving no intermediate neurons. It takes about 50 milliseconds to transmit from the brain down to the thorax and then out to the muscles. Dr. Rind calls this “the Locust Principle.”

Primary to the Locust Project research was to synthesize a locust algorithm that could be applied to a car. As it turns out, the locust information processing system is much more sophisticated than the hardware/software currently available. In the end technology was no match for nature.

Another downside of the biologically inspired approach is that the locust LGMD has evolved to respond with a collision avoidance reaction in a certain situation. This is thought to be the approach of a small (~ 7 cm diameter), fast moving (~ 5 m/s) predator whilst in flight. In addition this reaction occurs only a short time before the collision would have occurred (~ 100ms). In automotive situations there is a need to detect collisions sooner – due to the comparative sluggish reactions of a car. Also, there are differences in the colliding objects speed and size, slower refresh rates of images and lower temporal frequencies of the LGMD, which present challenges with the model design. In a locust the feed forward inhibition can be triggered by large, fast moving translating objects to suppress false collision alerts. Because of the size and speed of cars and the slower rate of growth of larger approaching objects no distinction can be made between an approaching object and a translating car using the feed forward mechanism. In addition the smaller size of road markings, such as zebra crossings, compared to cars, create a faster rate of growth near to the point of collision with the car. Even though they are not on a direct collision course with the sensor the excitation caused by the markings can be similar to that caused by a colliding car.

Clearly the locust LGMD has not evolved to cope with large objects such as cars or to deal with road markings. This has resulted in the need to adapt the models to cope with these situations. The challenge is building circuits that can function wherever car and driver may go. The chip should be able to see under a huge range of illumination conditions. Another difficult point is the climatic conditions, since the chip should work from really low temperatures to real hot.

SOLUTION

Jonas Ekmark said that what they learned was very encouraging. However, rather than wait for technology to catch up to Dr. Rind's Locust Principle, Volvo created a pedestrian alert feature that has been introduced under the name of: "City Safety," a collision detection and avoidance system. This suggests that perhaps technology is gaining. At low speeds, City Safety is able to automatically engage the brakes to bring the Volvo XC60 to a complete stop in the event vehicle in front of it suddenly stops. Beyond City Safety, the next step will be a first pedestrian avoidance feature. Although City Safety is not related to the Locust research, Volvo is confident that their first pedestrian auto brake feature will be very good at taking actions to help avoid hitting pedestrians.

To achieve the 2020 vision Volvo's efforts are focused on three areas: safe traffic environments, attentive drivers and safe cars. Both the Locust Project and City Safety fall under 'safe cars'.

In the mean time, Dr. Rind's research is making progress. The locust LGMDs have been extensively studied and this has lead to the development of a LGMD model for use as an artificial collision detector in robotic applications. To date, robots have been equipped with only a single, central artificial LGMD sensor, and this triggers a non-directional stop or rotation when a potentially colliding object is detected. Clearly, for a robot to behave autonomously, it must react differently to stimuli approaching from different directions. In a new study, the project team implements a bilateral pair of LGMD models in robots equipped with normal and panoramic cameras. Integrated are the responses of these LGMD models using methodologies inspired by research on escape direction control in cockroaches. Using various algorithms for LGMD model integration, the robots could escape an approaching threat in real time and with a similar distribution of escape directions as real locusts. The results significantly advance the development of an artificial collision detection and evasion system based on the locust LGMD by allowing it reactive control over robot behavior. The success of this approach may also indicate some important areas to be pursued in future biological research.

OUTCOMES FOR:

CONSUMER

If Volvo happen to find a way to integrate the Locust Principle into their cars, the potential for it saving lives is enormous. Not to mention it's likely viable for extensive use in other industries as well. The benefits to the consumer, when the system is working well, are obvious: less tragedies, improved quality of life.
Consumer adoption of crash-avoidance technologies will depend on how efficient they are at giving out warnings without annoying the driver with excessive false alarms. The system is envisioned as something that would detect approaching danger before a human notices it. The system would sound an alarm so that the driver could take evasive action. If the situation gets worse, it would apply the brakes, initiate defensive features, such as tensioning of the seatbelts, and arming inside airbags. In the future the system may also deploy external airbags on the front bumpers to protect pedestrians. Initiatives requiring such pedestrian-safety oriented technologies are on the books in Europe and in discussion in the U.S.
For the acceptance by users it will be key to warn a driver in an unambiguous way that gets their attention and warns them when they want to be warned and not when they don't, so they are not annoyed by it.

COMPANY

For Volvo this would mean another break through safety innovation that potentially could be licensed to the whole automotive industry, and beyond. This will most likely generate a positive cash flow as well as strengthen the safety reputation. When the Locust project is successful, Volvo may look at nature again for innovative ideas, so this project doesn't become a stand-alone project. And when looking differently at things (e.g. what can we learn from nature instead of just protecting it) and doing things differently, Volvo may achieve their sustainability ambition and safety ambition – zero impact – even quicker.

ENVIRONMENT

A decrease of car accidents will impact the environment (both directly and indirectly) in many different ways:
Since 1899 car crashes have killed more victims than all U.S. wars combined. 40% of the victims were under the age of thirty. Fatal and serious injuries (caused by car accidents) do not only cause pain and grief but also have an economical impact, particularly in developing countries already suffering from poverty. Fewer accidents mean less income loss, less ambulance expenses, treatment and care in hospitals and burials.
Mass-produced automobiles entailed the use of a wide variety and vast quantities of resources, the need for great amounts of human labor and mechanical power, and the generation of copious waste products. Historian Mark Foster has estimated that "fully one-third of the total environmental damage caused by automobiles occurred before they were sold and driven." The locust project could extend the car's life cycle: fewer collisions mean less material loss, damaged vehicles and related spare parts and replacement of damaged public property and cost of road congestion, having a positive impact on energy and material use.

LESSONS LEARNED

- Working in a multidisciplinary team was a pleasure, as well as seeing what committed researchers, engineers at Volvo, and chip designers can achieve.
- Getting management support for 'odd' research ideas is very important. Martti Soininen, who was leading the work at Volvo and doing a great part by himself, said it took some time before the managers and the director of R&D were fully on board to support the idea. Without the courage and support of his managers Soininen could not have done the project.
- Biomimicry research takes time. Downside was that the EU funding didn't give the project team time to truly explore the system it had designed. The ambitious project to design a vision system on a chip in 3 years came together at the review meeting but then the funding ran out and that coincided with the economic crisis. The team did apply to the EU for funding to continue with the project but it was not successful that time. The EU has another call later in 2011 that the team could apply to.
- The elegance of the locust system has not yet really been captured, just the basic features. There still is a lot to learn that will really help to differentiate colliding objects verses non colliding and general motion flow fields created by your moving from ones generated by an object approaching. Seeing potential in biomimicry solutions is not that difficult; making it happen is!
- Volvo could still be interested in the Locust principle if Dr. Rind could show how to make it work well enough in cars. Anyhow, Volvo will continue to follow interesting paths in their efforts to reach their safety vision: to design cars that do not crash.

Life's Principles

In the field of biomimicry, 'Life's Principles' represent the overarching patterns found amongst species surviving and thriving on earth. They are the critical success factors of evolution. When incorporating these Life's Principles into design, chances of sustainable success will increase. Below are a number of Life's Principles that are demonstrated in this case study.

Be Locally Attuned and Responsive

The core characteristic of the Locust project is about adequately signaling dangerous traffic situations, more specifically, to avoid collisions. Locusts are known to detect looming objects via a large neuron in the brain called the Lobula Giant Movement Detector (LGMD). This neuron is tightly tuned to only respond to objects on a direct collision course and also appears to be tuned to only avoid objects of a certain size and approach velocity, such as avian predators. This aligns very well with the more generic definition of 'being locally attuned and responsive', which is to fit into and integrate with the surrounding environment. The underlying sub-principles 'Use Feedback Loops', which is to engage in cyclic information flows to modify a reaction appropriately and 'Leverage Cyclic Processes, which is to take advantage of phenomena that repeat themselves, also come at play in the Locust project. The device will constantly have to 'tune in' to the environment, registering objects (by taking repetitive photos) that are on a collision course, and decide when and when not to send warning signals to the user of the car (feedback) to change course or stop in time.

Be Resource (energy and material) Efficient

As stated earlier, the problem with traditional approaches to making collision avoidance mechanisms for cars lies in the huge amount of information processing needed to successfully determine if a collision will occur. This complex information processing requires a lot of energy input and is therefore expensive and unsustainable. Locusts use a very energy-efficient information transmission system: there is no need to identify objects, their approach speeds or their angles of trajectory, all of which can be computationally expensive. The only data required is the luminance values of the photoreceptors over a period of time. The entire system can be designed and operated on a single chip because most of the complex background scenes are removed by the gradual filtering of the image through simple parallel computations. So the locust-inspired device will use low energy processes and reduce (chip) material.

Adapt to Changing Conditions

This principle is about responding appropriately to dynamic contexts. A critical success factor of the locust-inspired system will be the reliability of the system. Car drivers should be able to trust the system works well under all circumstances, and has a good back up mechanism in case of failure or send a warning signal about malfunctioning. Also, as mentioned earlier, the system should not annoy drivers by sending warning signals all the time; signals should be relevant, otherwise the car driver will ignore them. One way to adapt to changing conditions is to maintain integrity through self-renewal. This can be achieved if the system persists by constantly adding energy and matter to heal and improve the system. An example could be that the system 'learns and adapts' by integrating responses from the car driver to signals sent by the system, so that the system can build it's set of appropriate warning levels. In here feedback loops play an important role as well.

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Locust Range

Fast Facts

Type: Bug
Diet: Herbivore
Size: 0.5 to 3 in (1.2 to 7.5 cm)
Weight: 0.07 oz (2 g)
Group name: Swarm
Average life span: Several months
Size relative to a paper clip:

- Locusts are the most frequently named bugs in the Bible
- The desert locust, Shistocerca gregaria, is one of the world's most destructive insects. A large swarm can eat 80,000 tons of corn in a day. To make matters worse, they can cover 300 miles overnight
- Locusts can jump 70 cm (2.3 ft). This is like humans jumping 18 m (60 ft)
- The first insect ever drawn by humans is a locust. This drawing was found in a bison (wisent) bone, 10,000 years old, encountered in a French cave