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Reports and Surveys

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I. ARTIFICIAL LIFE

I.1. Will robots breed?

When John von Neumann gave his lecture on 'General and Logical Theory of Automata' in 1948 his ideas were met with some scepticism. The suggestion that life is a logical process which could result in making a new kind of creature, was the forerunner of all our discussions on whether 'artificial life' was at all possible.

An article in *Nature* (May, 2005) now appears to have made such a vision more likely to be realised. This issue tells us that scientists have built a self-reproducing creature, a twisting tower of cubes that can 'breed' just like the birds and bees, with, at this stage, a lot of human assistance. In the field of robotics and automation we can well ask the question does this mean we can produce robots that can breed robots? Von Neumann aimed at designing a machine that was complex enough to copy itself. To do this he devised a 'self-reproducing automation', which in the words of one science writer* as:

> "... a reproductive robot afloat in a sea of its own components; in so doing he united the apparently divergent worlds of nerve tissue and electronics with mathematical logic".

Currently, a research team led by Dr Hod Lipson† has used smart bricks to build a real-world version of von Neumann's machine.

Dr Lipson says that:

> "Although the machines we have created are still simple compared with biological self-reproduction, they demonstrate that mechanical self-reproduction is possible and not unique to biology."

This is not the first venture of Dr Lipson who has in earlier research built an automaton that can design itself and even kill itself. The new self-replicating machine was built with the help of three of his students and certainly does not resemble the conventional robot. In fact, it has been described as looking like a pile of misshapen ice cubes, each about 4 inches across. We are told that:

> "Each molecube" contains identical machinery and the computer program for replication. Electromagnets on each face allow it selectively to attach or detach from another. It is also split along a long diagonal so each half can swivel relative to the other. A complete robot consists of several cubes linked together and goes forth and multiplies on a laboratory table, living off electricity in the base plate and transferring data and power through its faces."

The cubes have been divided in two so that a multi-cube robot can bend, reconfigure itself and manipulate other cubes. Since one robot is unable to reach across another of the same height, it can help finish its own construction.

Thus a four-module robot can make a replica in 2.5 minutes by consuming cubes from easily reachable 'feeding' locations. Success in replication is by no means assured, but this real-world version of von Neumann's machine shows that progress can be made towards' artificial life'. Other scientists are actively engaged in this field. In the UK, for example, Dr Adrian Bowyer of Bath University is planning to build self-replicating robots in his RepRap project.

II. BIOMIMETICS

II.1. New field for robotics

Researchers who mimic nature's creatures in their designs for robotic systems now refer to their field as Biomimetics (Northeastern University Researches).

Dr Ayers of the Marine Science Center, Nahant, Massachusetts USA is developing a robotic lobster that he hopes will have a number of potentially useful applications. Funded by the Office of Naval Research USA, it is already in an advanced state of development. Dr Ayers is a professor at the Northeastern Univerity, Boston US. and he has been experimenting with his lobster for some time. With legs extending from the loster's abdomen the creature can move its industrial-strength plastic body and the nickel metal hydride battery along a small-rock strewn sandy seabed. It weighs some seven pounds, so to get it to move in water is an achievement itself, but he is intent on making it clamber over rocks. He hopes that by the time he is ready to demonstrate it to the military the lobster will have two claws which it can use as bump sensors. "When it walks into a rock", he explains, it will be able to decide whether to go over it or around it, depending on the rock's size.

This is one example of the challenges faced by robotic researchers who regard animals as creatures that can be mimicked in the form of robots. In addition to the lobster, flies, dogs, fish, snakes geckos and cockroaches and many more species are being used as inspiration for the new generation of robots (Kirsner, 2004) Dr Ayers is reported to believe that:

> "Animals have adapted to any niche where we'd ever want to operate a robot, RoboLobster, for instance, is being designed to hunt for mines that float in shallow waters or are buried beneath beaches, a harsh environment where live lob-sters have no trouble maintaining sure footing".

There is a great incentive to develop such machines and such machines that are based on such creatures will be able to operate in places where today's generation of robots are unable to go.

* Dr Lipson is at Cornell University, Ithaca, New York, USA.
† A discussion 'How to breed robots' by Dr Roger Highfield was published in *Science* (UK *Daily Telegraph*, 18.05.05, p. 16).

Information about this project can be obtained from the website: Lobster (2005) (see website references).

II.2. Carnegie Mellon University Research

At Carnegie Mellon University, US research is being conducted in this field. Dr Howie Choset, for example, has been testing sinuous segmented robots based on snakes and elephant trunks. These, he believes, may be the perfect machines to search for survivors inside rubble left by structures destroyed by disasters, such as fire, earthquake or other natural causes.

Details can be obtained from the website, Snake (2005) (see website references).

II.3. University of California Research Projects

Dr Shankar Sastry of the University of California is one of a research team involved with biomimetics and is currently helping to design robotic flies, fishes and the wall-climb gecko. He says that: "What has been a surprise to me is how hard it has been to make progress." More details are given on the website. Fly (1999) and Gecko (2002). (see website references)

II.4. Massachusetts Institute of Technology (MIT)

At M.I.T robotic fish such as RoboPike and RoboTuna are being developed by the Institute's researchers. More information can be obtained from the website. Fish (2005). (see website references)

II.5. Tacom group

Tacom is the abbreviated name of the Army's, Tank-Automotive and Armaments Command, Warren, Michigan, US. The group has received over $1 million to conduct research into walking robots.

A report of the project says that:

> "One is a robotic "mule" that would serve as a diesel generator, providing power to mobile units. It is being designed by a pair of former Disney employees who were responsible for building a nine-foot dinosaur robot named Lucky that sometimes roams the Disney theme parks.
>
> Another Tacom mule would carry equipment for soldiers, enabling them to march longer distances. A robotic dog, being developed for Tacom by a Cincinnati company called Yobotics, might someday serve as a soldier's best friend. "Imagine you have a sniper hiding behind a wall, and: you want to send something out, something sacrificial to draw fire, or to look around corners where you don't want to look."

II.6. Future developments

In summary, the researchers from these organisations have differing views about the prospects of developing robots that mimic the creatures of nature. In this section we have frequently described such projects. There are so many potential applications; for example, at one university research laboratory Carnegie Mellon, Dr Choset presents a very optimistic view, he reports that:

> "Advances in legged robots could eventually lead to more realistic and utilitarian prosthetic limbs for amputees. Reptilian robots could one day be used to inspect underground fuel tanks or, on a smaller scale, to perform medical tests and surgery inside the human body.
>
> One goal of ours is to be able to do surgical procedures in a minimally invasive fashion. This summer, a preliminary test, inserting a snake robot with a diameter of less than an inch in into the abdomen of a live pig was performed".

Most of the researchers engaged in these projects believe that an important advance will be the 'artificial muscle'. This is a synthetic substance that can be made to contract and relax when electricity is applied, in the same way that an organic muscle does. Dr Robert Full from the University of California says:

> "Muscles are spectacular springs, shock absorbers, struts, brakes and motors, all rolled up into a thin tissue".

An example of the development of artificial muscles is the RoboLobster, built by Dr Ayers of the Northeastern University, which has we are told:

> "delicate, wiry artificial muscles that move its legs, made of a nickel-titanium alloy called nitinol contracts when electricity is applied . . . earlier this year, a start-up company called Artificial Muscle was spun out of SRI International, a Silicon Valley research group, to commercialize a new kind of musclelike polymer."

Dr Mark Raibert of the Boston Dynamics Company, Cambridge Mass. US., gives another example of possible future trends. He watches videos of mountain goats moving over rough terrain and notes the movement and action of the goat's foot, in particular, how it gets traction on very steep surfaces. His company is working on biomimetic projects and is relying on Harvard University biologists, who dissect goats, to give a better understanding of how a robot is likely to move in a similiar manner.

There appears to be a great deal of cooperation between research groups. Boston Dynamics is developing a, climbing robot that uses a geckolike substance developed by Professor Full of the University of California for adhesion. This company is also building a six-legged robot that has spring-like legs similar to a roach's.

The company is now working on a project to produce a running quadruped called BigDog.

All of these endeavours, at different states of development, do provide us with some confidence that biomimetics will produce a new generation of robots which will replicate the designs of nature's creatures.

Website References

Cockroach (2005) **COCKROACH rhex.net RHex**, a six-legged robot inspired by the cockroach.

Fish (2005) **FISH web.mit.edu/towtank/www/media.html#pike** M.I.T.'s robotic fish, RoboPike and RoboTuna.

FLY (1999) **FLY berkeley.edu/news/media/releases/99legacy/6-15-1999plx.html** Robotic fly project at the University of California, Berkeley.

Gecko (2002) **GECKO berkeley.edu/news/media/releases/2002/09/rfull/robots.html** Mecho-Gecko, developed by the iRobot Corporation and the University of California, Berkeley.

Lobster (2005) **LOBSTER www.neurotechnology.neu.edu** Northeastern University's robot lobster (click on any link under Online Animations of Biomimetic Systems).

Snake (2005) **SNAKE snakerobot.com** Carnegie Mellon University's snake robot.

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S. Kirsner, (2004) "They are Robots those Beasts: Circuits", *The New York Times* (16/09/04).

III. HUMAN BODY AS A DATA CONDUIT

III.1. The human body may be the best computer

Many researchers have over the past decade considered the human body to be the best conductor of electronic data. Many experimental systems have been designed to use the body's conducting properties for receiving, transmitting and indeed processing information. One such device, for example, used the human body to receive wireless signals for communication purposes. Mobile phone designers have produced systems that use the human frame to replace receivers Researchers also suggest that the human body is the perfect conductor for information such as music, films etc. all of which could be downloaded in seconds.

III.2. Red Tacton systems

A report from the NTT Laboratories in Japan describes the Red Tacton system. The developers of this invention envisage a future in which the human body acts as a non-stop conduit for information. The information could be in any electronic form and applied to almost any application. They say, for example, that wireless networks and devices, that are often hampered by intermittent service will eventually be replaced by 'human area networks'.

The NTT researchers describe Red Tacton as having;

- The human body as path for the electrical signals which let computerised equipment communicate.
- A transmitter on the body for the body's electrical field to transmit digital messages.
- A receiver that can be attached to many types of devices: laptop computers, PDAs, mobile phones, mpeg players.
- Optical crystal and laser technology to convert the changes in the electric field back into a signal.

III.3. Red Tacton systems could change our habits

Some of the ways in which the Red Tacton, and, indeed, similarly developing systems, could change the way in which we live are:

- Shaking Hands – this simple act could allow two people (or more), to exchange information e.g. business cards etc.
- Touch – touching any object such as a door handle could allow for the interchange of information. Tacton security systems can recognise a user and allow access if permitted.
- Mobile Phones – touching a mobile phone would instantly transfer information such as address books, call history billing etc.
- Digital images – such as those obtained by computers, digital cameras could be transferred, e.g. holding a digital camera and touching a printer could print or store a picture.

III.4. Systems function

The Red Tacton has chips embedded in machines and they contain transmitters and receivers built to send and accept any form of data stored in a digital format. The chip then takes any data file e.g. email, MP3 music etc-and converts it into digital pulses that can be passed and read through a human being's electrical field. The chip in the receiving device reads these small changes and converts them back into its original form.

It is claimed that since the Red Tacton sensors are miniaturised and built into every type of device and product its functions allow it to be used in an almost endless number of potential applications.

III.5. Future applications and marketing

The product has already been publicised in the UK press* and the world's media. Developers at NTT have given an example of its use in advertising applications. An advertisement poster could contain Red Tacton sensors so that simply by touching it product, information and an order form could be sent to you via your laptop or any other electronic processor. Similar uses would allow business people a simple way of exchanging business and product information by just shaking hands or touching information documents or files.

NTT scientists say that:

> The developers are convinced that the new technology will be "highly disruptive" — undermining existing wireless industries and causing everyone to rethink the way that everyday actions could be undertaken.

III.6. Technical advance

NTT are not the only research group to experiment with the use of the human body's electrical field. Other researchers such as IBM have also been involved in similar projects. So far there have been no reports of their or other companies progress. The approach taken by IBM and others over the past five years of research has been directed at harnessing the power of the minute and unstable flow of current across the skin. NTT has taken a different one which attempts to use the body's natural electricity itself. A scientist from NTT says that they have attempt to exploit the tiny variations in the overall field and the way in which they affect highly sensitive lasers. These are changes that are collected by the electro-optic crystal that, it is said, is the key to their whole approach. It is these minute fluctuations that can be converted and then transmitted and read as digital messages so that no current passes along the body. Data, they claim, can in consequence be transferred virtually instantaneously.

This is a technical advance that will be exploited by any research group involved in data transfers. Potential applications in robotics and automation already prove attractive and, indeed, this new technology promises to be most fruitful. Field tests are already under way and we are told that the first commercial appearance of Red Tacton is expected to be in 2006.

IV. HUMAN–MACHINE INTERFACE

IV.1. Neurons on chips

For decades the use of computer systems has relied on users communicating information via keyboards. More sophisticated input peripherals have, of course, been

* See report 'Human body is the best computer, say scientists' – Leo Lewis UK '*The Times*' (14.07.05).

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developed such as voice, touch screens and others, but none has replaced the traditional typing-in or keying-in as the main means of access to what is a much more advanced computer machine.

Hopes were raised therefore last year when the leading computer company Microsoft applied for and secured a US patent covering the use of the human body as a conductor in connection with electronic appliances. The company, however, are more reticent about their research programme and have said that they have no specific product in mind.

Researchers in the human-interface have for some time advocated a computer-user interface where access is gained by linking the human body directly to the machine. Indeed, in this section we have on a number of occasions included reports of such systems. In the main these have linked the human brain directly to the machine and they have already demonstrated a degree of success when for, example, a computer user was able to command the machine to perform certain tasks. In most cases this has been achieved by monitoring the actions of certain parts of the brain and translating the signals via digital pulses to the computer system.

In a recent article* (Gross, 2004) this challenge to link user to machine was discussed and a new line of research was described. Dr Peter Fromherz, a director of the Max Planck Institute for Biochemistry, at Martinsried, near Munich, Germany, has been engaged in research for some time studying possible connections between silicon electronics and biological cells. What struck Dr Fromherz was indeed obvious. Both computers and our brains communicate with electrical signals so why therefore should it not be possible to create a direct interface between them. No need, he says, for eyes, monitors, ears and speakers, hands or keyboards, if the computer is so clever, why can't it just read my mind?.

To address this challenge, we are told that he:

> "set out to grow neurons from the medicinal leech (*Hiruds medicinalis*) on silicon chips and persuade the two parties to talk to each other. Transmission of a signal from the neuron to the chip first succeeded in 1991, the reverse process four years later. Essentially, the recording of the neuron signal by the chip relies on a field effect transistor, while the electronic stimulation of the neuron arises from a voltage pulse applied to a capacitor, so both processes are absolutely non-invasive and don't affect the survival of the cell in any way."

Leaving the University of Ulm where he then worked he moved to the Max Plank Institute and set about his pioneering research with goals to establish the precise nature of the chip/neuron interface. He expanded his work to calls from other sources and built more complex systems consisting of neurons and semiconductors. Dr Fromherz and his researchers established that

> "an ordinary silicon chip, with the outermost 15 nm oxidised, is an ideal substrate to cultivate neurons on. The silicon oxide layer insulates the two sides and stops any electrochemical charge transfer, which might damage the chip or the cell. Instead, there is only a capacitative connection, established by a so-called planar core-coat conductor. Proteins sticking out of the lipid membrane ensure that there is a thin (50–100 nm) conducting layer between lipid and silicon oxide, which constitutes the core of the conductor."

Indeed, the whole setup could be represented as a simplified electrical circuit. This is described as one where;

> "both the membrane and the silicon oxide have a defined capacitance, and the electrolyte layer between them (which is part of the medium surrounding the whole cell) has a given ohm resistance. The dynamic properties of the system are dominated by the ion channels within the cell membrane, which determine the ohmic conductance of the membrane and thus the propagation of the electrical action potential, which are the typical neuronal signals."

The neuron-to-chip experiment also produced the following explanation of the signal transfer:

> "In the neuron-to-chip experiment, the current generated by the neuron has to flow through the thin electrolyte layer between cell and chip. This layer's resistance creates a voltage, which a transistor inside the chip can pick up as a gate voltage that will modify the transistor current. In the reverse signal transfer, a capacitative current pulse is transmitted from the semiconductor through to the cell membrane, where it decays quickly, but activates voltage-gated ion channels that create an action potential."

Further details of this investigation are available from the researchers and Gross (2004, pp. 31).* In summary, the interface aims at:

- Passage of electrical signals between both brain and computer by getting nerve cells and silicon chips to interact directly
- Transmissions of electrical signals between chips and neurons can already be achieved on a small scale without invasive connections or damage to either transmitter.
- Potential use of combining this technology for many other applications, e.g. computer designs, vision, hearing, control for the disabled and others etc.

Further challenges were tackled which could have a dramatic effect on future applications. Details of the construction of an imaging network and hopes for commercially valuable spin-off products. There are also indications that the developments by Dr Fromherz have now received a great deal of attention both in the media and in research centres worldwide. His bio-electronic hybrid systems will undoubtedly form part of future systems and applications.

Further Reading

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IV.2. Poker playing robots

A report from the US describes how a computer will challenge the human world poker players to determine whether a machine can outbluff man. We are told that there is a search for a machine that is capable of beating the world's

* M. Gross, "Plugging brains into computers" Chemistry World, 30–33 (Sept. 2004). Also website: www.proseandpassion.com

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top poker players. Such poker-playing robots are called 'poker bots' and the aim is to have them enter events and run in tandem with their more established human equivalents. In these competitions the winners of each contest can then compete with each other to decide whether a machine can really bluff Man. This will then provide an opportunity for software engineers such as those, who designed the Chess programs for IBM's computer Deep Blue, to show their skills. Darren Shuster, an entrepreneur and publicist from California highlights the problems and the challenge to software designers, he writes that:

> "Chess is a game of pure strategy. To play it well involves the absence of emotion. Poker is the opposite. It involves skill and strategy but it is a also a game of chance."

Developing poker-playing robots is not without its social and business consequences. Automation has always affected the traditional pattern of human activity. In this case the emergence of Bots has caused alarm among online casinos which have experienced a rapid growth in gambling over the internet. In other words, we see one innovative use of technology competing against another. Online casinos are concerned, it would appear, that some clients are using robots against unsuspecting opponents and winning huge prizes. As a result, because of the enormous financial implications members of the poker robot community are said to be going in fear that the source codes behind their secretive programs will be exposed and used, particularly by online casino operatives, to build better defences against them.

Meanwhile the search continues for the computer system that can emulate the computer chess programs that are capable of beating the top players in the world. Whilst the media calls these systems robotic to give the impression that a robot actually sits in chair dealing out cards; in practice, the game is played with a computer system and the interface is more likely to be the latest interactive device available. Currently, this would be a screen or a handheld device with a display. Already, we are told, more secretive concealed devices are used so that human players can base their game on information and strategies worked out by a remote computer system. Success, as usual, will depend on the skill of the programmers and the algorithms they have developed. This has been summed up by one writer who says that:

> "The problem facing programmers is to create a computer that is capable of cheating and lying a technique that has so far eluded artificial intelligence experts."

V. INNOVATIONS

V.1. Interactive beer mat

Automation is now reaching the parts that have so far escaped its attention. The thought that customers for beer in Germany should wait for a refill was hardly bearable. This has spurred students at Saarland University, under the supervision of Professor Andreas Butz, who teaches human computer interaction, to devise the interactive beer mat.

This 'smart mat' uses weight and motion sensors to detect whether a glass is almost empty. The device fits under a traditional cardboard mat and sends radio signals to a computer at the bar to alert staff that the customer is awaiting a top up.

Not content to restrict its use to drinking, they claim, it is also effective as a voting device in pub games. The sensors, we are told would react to different movements.

These enterprising students say that sports bars have already shown a particular interest in the device. It is dishwasher proof and comes with a recharger. It costs about £50 although they say that the price could be reduced once they are produced in bulk. Popular applications of automation should be encouraged and student projects that have an instant appeal to the public can stimulate interest in our endeavours.

V.2. Computer vision surveillance system

There can be no greater reward for a researcher in robotics and automation than to have the system he/she has developed save a life. *Poseidon*, the name given to a computer vision surveillance system that recognises texture, volume and movement in a swimming pool has, for the first time in the UK, helped lifeguards at Bangor, North Wales, to save a swimmer from drowning.

The system is manufactured in France and is already credited with saving three swimmers in that country. This 'state-of-the art' system has the following features:

- It is comprised of a network of eight cameras in the pool itself and another ten overhead.
- A software system is built into the computer that controls the operation
- The software system is designed to analyse in real-time the trajectories of swimmers monitored by the cameras.
- The system can alert lifeguards in the first seconds of a potential accident to the exact location of the swimmer in danger.

In the recent rescue in the UK the alarm sounded after 3-seconds and the entire rescue executed in 62 seconds. A young girl swimmer was pulled unconscious from 12 ft. of water at the deep end of a public pool. The girl could not be seen at the bottom of the pool and would have undoubedly drowned but for the *Poseidon* system and the prompt response of the life guard.

The *Poseidon* system was developed by the French Vision IO company and at this pool site cost £65,000 to instal. The company say that the series of cameras in and outside the pool:

> "monitors the movements of swimmers, matching the images with a database to detect those in distress or apparently unconscious. It constantly scans the pool, analysing the trajectories of swimmers. *Poseidon* sounds an alarm on a screen at the lifeguard station, picturing the stricken swimmer and indicating the position."

The system took six years to develop and includes a very complex piece of software. It has been fitted in more that 120 pools across the world, including the US and Japan. There is no doubt that it is virtually impossible for lifeguards to see everything that is happening in a pool all of the time and *Poseidon* is a welcome application of automation to lifesaving.

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V.3. Robots perform gastric surgery

Surgical operations performed by robots are now, it seems, becoming much more common. It is now not a question of reporting the different types of operation but rather of indicating how many hospitals are being equipped with the robotic systems required to carry them out. Surgery, in so many cases has now been made easier and quicker when robotic arms with tools are used.

A recent report from the *Archives of Surgery* by surgeons from the Stanford University School of Medicine, California, USA., confirm that using robotic arms operated by remote control in gastric surgery has been successful.

In the particular operation described, robotic arms were used in operations to help obese people to lose weight. The surgeons say they have been able to develop a safe and efficient way for the surgical robot to carry out gastric bypass operations. This, they claim, is an improvement on the traditional techniques known as laparoscopic surgery. In both techniques, special tools with cameras attached are inserted through small holes in the patient's body. Whilst traditional tools are held in the surgeon's hands, the robotic tools are operated remotely from a control station.

The impact on the current number of such operations, when robotic systems are used, is yet to be seen. We are told that gastric bypass operations in the US has increased from 29,000 in 1999 to some 141,000 in 2004. The need for successful robotic surgical systems is now self-evident.

VI. ROBOT SOLDIERS

A report from the *New York Times* (20.02.05) tells us that there really are plans to produce robot soldiers. It says that

> "the Pentagon is planning to spend tens of billions of dollars over the next decade to perfect computerized warfare sound like science fiction. But the plan, Future Combat Systems, is the realization of an old dream."

What is envisaged is a completly automated army for use in combat on the ground, in the air and on the seas. We can all accept that existing military equipment from tanks to helicopers are being automated already. There are automated remote missile launchers, automated unmanned spy planes and many other innovated devices being researched and produced. All of these new systems are designed to be coordinated by selfconfiguring networks of satellites, sensor arrays and supercomputers.

These developments are easily accepted as part of the systems of military equipment whose design reflects the considerable advances in technology. What is not so easy to contemplate is the concept of robot soldiers. This report tells us that there are already presentations of systems that aim to 'get the human out of the loop'. Some are called, 'soldier systems', 'networked lethality', and' 'war fighter interfaces'.

George Johnson who compiles the report on these developments indicates that:

> "The Pentagon's promotional material doesn't mention whether the contract for the Future Combat Systems, said to be the biggest in American military history, includes a line item for philosophers. But they may be best equipped to judge whether computers, despite their faster speeds, greater bandwidth and bigger memories, are inherently different — less trustworthy than the gut feelings and hunches of their keepers."

Much of this speculation fails to take into account the difference between producing 'soldier systems' that have 'intelligence', that is 'smart soldier systems', or merely putting a military uniform on robots that have been manufactured to our current levels of competence. This, we are told, leads to the question: Can robot soldiers rise above human fraility? The military has always been plagued with the scenario of misunderstood orders, kneejerk decisions, etc. Will our understanding of the human brain allow us to design anything other than purely autmated creatures that are still remotely controlled by their decision-making keepers?

There are so many different views about how the mind functions and we certainly need to focus on a particular research strategy if such military systems are to be built. We are told that John Searle in his book *Mind: A brief Introduction* (2004) has argued for decades that the brain is not just a computer strung together from neurons. The view that the mind is some form of information processor is still the current thinking. If this view persists then we will continue to tackle the task of producing such systems for military and other uses by aping our present computing devices which remain the basis for the design of smart robots.

If, as this report indicates, the U.S Pentagon is seriously bidding for future combat systems to be developed in this way, then those who respond are, indeed, facing an enormous challenge.

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