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NANOBOTS: THE FUTURE OF MEDICINE

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ABSTRACT
The health care industry of today is focusing on developing minimally invasive techniques for diagnosis, as well as treatment of ailments. The most promising development in this field involves marriage of the latest nanomaterial science and robotics technology with biological knowledge : Nanorobotics. This paper will deal with the latest development in this field as well as the promising future it offers , mainly focusing on health care , though this is a nanoscopic fraction of the scope of this technology.

KEYWORDS: Nanorobotics, Nanomaterial, Robotics Technology, Magnetic Resonance Imaging, MEMS.

INTRODUCTION

The health care industry has seen many revolutions, from the invention of the first vaccine to much modern equipment like MRI (Magnetic Resonance Imaging). In the next decade, however, biologists and engineers hope to trigger the most significant revolution in the history of medicine. Having nanoscopic bots crawl (or swim) inside your body will no longer be science fiction. We are on the cusp of the revolution which will lead to our evolution: Evolution into what the author would like to term as REOs (Robotically Enhanced Organisms).Though a REO would not technically be a cyborg (cybernetic organism) , we could think of nanobots as 'internal enhancement'. In comparison cyborgs possess external enhancements such as robotic prosthesis. We could even use nanobots inside our body to relay vitals to a wireless monitoring system, much like cyborgs in sci-fi movies.

Minimally invasive medicine is the current buzz word. Scientists are looking for effective ways of diagnosing ailments, detecting diseases and analyzing changes in the body without having to physically cut open and observe the subject as in yesteryears. This revolution could be said to have been triggered long back, when Wilhelm Röntgen discovered the Röntgen rays, what we know today as X-rays. Similar non-invasive techniques like the MRI (also called NMRI- i.e. Nuclear Magnetic Resonance Imaging) and sonography were developed later. What these techniques provide is a view of the inside from the outside! We can gather previously inconceivable amount of data without opening up the subject, effectively and reliably. But what if we could gather the data of the inside from the inside itself! The data will be more accurate and much more reliable. The treatment as a result will also be highly specific, and as the diagnosis is more accurate, it would be custom made for the particular subject.

So what does nanorobotics involve? At the moment, it is a field of ongoing research, in which scientists and researchers are trying to build nano-scale robotic models from nanoscopic components. They are using molecular self-assembly to join the parts like a miniature jigsaw puzzle, as will be discussed later.

ADVANTAGES OF NANOROBOTICS OVER CONVENTIONAL MEDICAL TECHNIQUES

We *Homo sapiens sapiens*(advanced humans) have always been fascinated with our own anatomy. Techniques to diagnose body ailments as well as to "repair" them have been developed long ago. Ancient Indian texts describe surgery being practiced as early as 600 BC (time variable in various texts) by the great surgeon *Sushruta.* Humanity has progressed quite a lot since then , in terms of safety and reliability of the procedure. Also techniques such as endoscopy have been developed to give a better understanding of the vitals as well as aid diagnosis. But as we all know, all technology inevitably has to be phased out sometime. And as historically procedures have developed to overcome the drawbacks of their predecessors, nanorobotics will aim to overcome the following drawbacks of today's medical technology:

1. Incisions harm tissue layers which take time to heal.
2. Painful. Anesthesia can be used to limit the pain to a great extent, yet it is only for a short time.
3. Delicate surgeries such as eye surgery still do not have 100% success rate.
4. In any of the invasive techniques , the patient's life is totally in the hands of the operator/ surgeon/ physician. It is risky, as one mistake could spell disaster.

Conventional techniques of investigation and diagnosis used for over the last few centuries are thus, soon going to fall behind as the technological age advances. Also a lot of these procedures will soon become robotically controlled , as quite a few already have. Robot assisted surgery is already in successful use, as we can see from the *Da Vinci* surgical robot.

Scientists and researchers however are working on a more robust, reliable and bio-compatible approach. Instead of curing from the outside, they plan to defend the body from the inside. That is where medical nanorobotics comes in. The major advantages this technology provides are :

1. Minimal or no tissue trauma.
2. Considerably less recovery time.
3. Less post-treatment care required.
4. Continuous monitoring and diagnosis from the inside.
5. Rapid response to a sudden change.

Also, treatment can be started before the medical condition escalates. Some added features of nanobots would also enable us to do the following:

1. Store and process previous data, identify patterns and hence, help to predict onset of an ailment.
2. Guide nanobots externally or as per programmed, targeting specific locations.
3. Deliver payloads such as drugs, or healthy cells to the specific site.
4. Disassemble and get excreted after completion of task, if required.

An added advantage is that these nanobots will navigate through natural biological pathways, hence we could liken them to customized (and often more durable) body cells, manufactured externally.

There are two possible approaches to building nanobots. One relies on molecular assembly i.e. assembling the nanobot from basic molecules, piece by piece. We could term this as a "bottom-up " approach. The other approach, which we will refer to as the "top-down" approach deals with using current technologies, such as Micro Electro Mechanical Systems (MEMS) and scaling them down further to nano level. In the following sections, we will see the opportunities as well as limitations of both these approaches.

SCALING DOWN : NANOFYING THE MEMS

MEMS technology has revolutionized a lot of fields. We can now get more raw power in much smaller dimensions. Just as an example SMART sensors , made using this technology , now contain the sensor, signal conditioning circuit , signal processing and sometimes even the wireless transmitter, all in a single module, often very small! They can fit in the palm of your hand!

Currently, sensors based on micro cantilevers are being developed. They may soon be scaled down further, allowing for their use in the first prototype nanobots. These sensors, in general, use deflection of a cantilever beam to detect a specific analyte. They are usually coated with a chemical with reacts with the analyte to be detected. On reaction, the reacted substance is deposited on top of the cantilever, causing it to bend. Stress caused in the cantilever is proportional to the amount of deposited substance and consequently, to the concentration of the analyte in the medium.

The challenge today in order to use this technology in nanobots is to scale it down further, which is easier said than done. The basic reason for this is that as we go down to the molecular level, a lot of things change. Fundamentally, it seems improbable that this technology could be scaled down further. Even today, MEMS devices in use are either sensors or actuators, never both. Obviously, a nanobot needs both to function. Also , as we go smaller, power generation becomes a big problem. Physical limitations means MEMS motors can only be scaled down so much. Alternative power generation ways have been suggested; though most involve scavenging more than generation. And even if we do manage to generate power, storage of this energy becomes an even bigger problem as, getting smaller means increasing energy density to such a scale that shrinking down of storage batteries becomes infeasible.

One method suggests using the Peltier effect (thermal energy from the body) for energy generation. Another method could be to use glucose from the blood itself as a fuel. We could also use the natural flows in the body such as blood circulation for moving our nanobots, however it won't be of much use for guiding them. Another problem arising at the nanoscale is that viscous drag becomes predominant. Hence, to overcome this resistance, we need to generate a lot more power.

A solution to these problems could be to use an external power source instead of an internal one. This would take out the problem of energy generation, as well as give us a better guidance system. The inspiration for this technique again comes from mother nature. A certain kind of bacteria , called as magnetotactic bacteria (discovered in 1975 by Richard Blakemore) have been found to be sensitive to magnetic fields. Most of them tend to naturally orient themselves along the magnetic north. A similar guidance system could be used in future nanobots . They could contain small magnets which could be used as steering wheels under influence of an external magnetic field such as that of an MRI machine. Another way of generating power could be by electromagnetic induction. An external magnetic field could be used , in this case to charge internal batteries of our nanobots by induction. Of course , the primary challenge remains- our current inability to scale down MEMS technology to the nano level. New materials capable of storing energy at higher energy density would be required to make use of this technique of navigation.

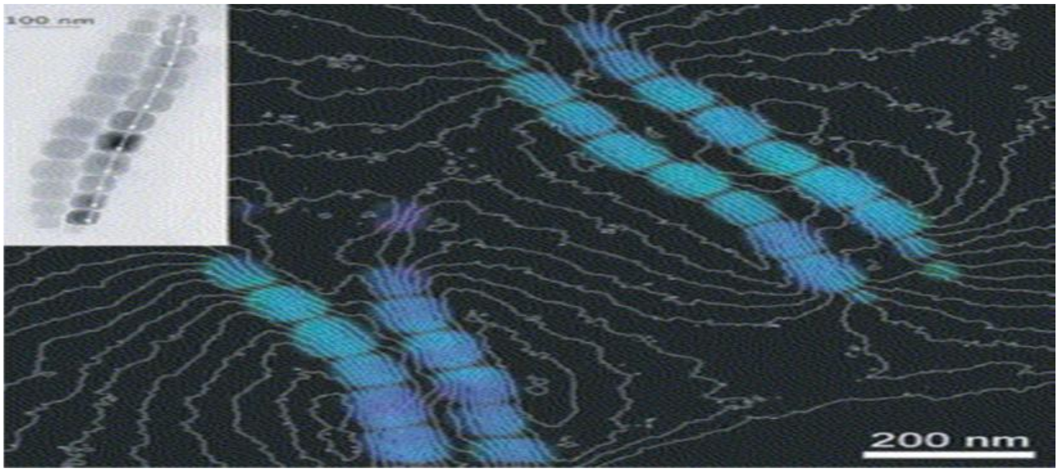

Figure 1: Magnetotactic bacteria -(inset) shows magnetosomes Image courtesy
Source: http://www.sciencedirect.com/science/article/pii/S1369702105710786

BUILDING FROM THE BOTTOM: THE MOLECULAR APPROACH

We have discussed some of the very prominent limitations with scaling down of MEMS technology. Though newer materials and technology could bypass this wall , for now, the molecular approach seems the most promising.

Molecular chemistry has played a significant role in this field in the last decade or so. We could soon be building nanoscale versions of macroscopic actuators like motors from the bottom up. Montemagno and Bachand were the pioneers in this field, creating the first artificial hybrid motor. Recent developments suggest that we could soon have nano gears and nanobearings at our disposal. Now comes the assembly part. Molecular self-assembly is possible using various methods already being employed. One could think of it as biological or chemical programming. One of the methods of self-assembly is called as SAM (Self-Assembled Monolayers). It involves a monolayer of molecules, fixed to a surface upon which a structure can be built vertically, as if a building being built floor by floor. An innovative idea is to "program" bio-bots to use in-situ molecules to create copies of themselves. This would help keep a healthy bot count, just like our body replaces worn out blood cells.

Atomic force microscopes can be used for nanoscale manipulation. In 2005, a nanoswimmer was developed which uses external magnetic field to beat a filament attached to a red blood cell [3]. Also, a nanocar using buckyballs (fullerenes) as wheels has been developed . These developments are a few among many in recent years, and could lead to the first nanobots in the near future. The development of nanofabrication techniques such as electron beam lithography and scanning probe lithography have been a huge leap forward, allowing for fabrication of features as small as 3nm in size [8].

We also have a lot of aid from nature in making artificial bio-bots, with respect to availability of biological resources. A lot of the materials needed to build a bot are naturally available, such as proteins that capture solar energy like rhodopsin and bacteriorhodopsin. Now that we have an energy source, we need an actuator. ATP synthesized by the above proteins can be used by certain molecules such as F_1-ATPase to rotate nanoscopic shafts. A lot of research is going on to develop more and more efficient motors, which can be actuated by a variety of signals, such as certain chemicals.

CHALLENGES

A significant challenge posed today by nanorobot designers is related to our understanding of physics on the nano scale. As we scale down to the nano-level, that is, our machines (nanobots in our case) become smaller, the forces they are subjected to change completely. Fluid effects such as viscosity and surface effects such as electrostatics dominate over conventional forces due to mass (which is now negligible). Viscosity is now about five orders of magnitude greater; co-efficient of friction is load and velocity dependent (which is not the case in classical physics). Also since nanobots are about the size of molecules in which they swim, they behave as if they themselves are "pseudo-molecules". They are affected by thermally triggered collisions between molecules, what is known as Brownian motion. They cannot be considered as classical rigid bodies; they do tend to undergo deformations due to the relative large amount of forces they are subjected to (about 10^{21} collisions per second). Deformation also means change in characteristics of the body, mainly due to the shift in centre of mass. So, a deformed nanobot may need to re-learn how to move, much like a person with paralyzed leg has to re-learn to walk. This is because a shift in the centre of mass leads to change in motion dynamics; a force applied along the centre may now be offset, or at an angle to what it should be to produce the same motion as before. Embedding artificial intelligence on such a small scale seems unlikely, and hence we would need to build nanobots which are essentially rigid for all practical purposes. Biological bots may provide a solution to this due to the fact that they would be made by molecular self-assembly and strong inter-molecular forces will render them practically rigid.

Although we have now begun to understand nano-mechanics and the problems it may pose, our nano size machines overcoming these physical challenges is another story altogether. Inspiration from mother nature seems to be the best way forward at the moment.

In nature, we see all the microbes executing an asymmetric motion. This is pretty much evolution at its best. Consider a one degree of freedom rower who is rowing with a motion in the vertical plane. One half of his rotation is in air while the other half is in water. The half rotation in the water pushes the water backwards and hence, by Newton's third law , pushes the boat forward(reaction force). The half rotation in the air does the opposite, it actually pushes the boat back. However, the viscous force that produces reaction in the water is much greater than that of the air. Hence, we can neglect air effects and safely say that there will be net forward motion. Now, imagine that the rower is completely inside water. The two half cycles now cancel each other out, such that at the end of the cycle the rower is at the very same place again. This example explains why symmetric motion is not of much use in nano domains. Hence, nature has developed cilia or flagella in micro-organisms such as bacteria, which beat asymmetrically, such that after one beat there is always a net displacement in one direction.

Also among the main technological challenges today, for development of useful nanorobots, is the generation and storage of power, as mentioned previously. Another challenge, would be developing engineering materials which are usable for the purpose of manufacture of nanobots using NEMS or NEMS-like technology, and be bio-compatible at the same time. Effective ways of power generation still have to be figured out. A much bigger challenge is on-board storage (NEMS bots), or continuous generation (as in case of biological bots).

WHAT TO EXPECT IN THE NEAR FUTURE: PREDICTED USES OF NANOROBOTICS

If the ideas mentioned above do become reality any time soon, every branch of medicine ought to benefit. Frankly, nanorobotics holds such a vast scope, that a single paper can't cover it all. Hence, the focus here is limited only to its revolutionary impact on the field of medicine.

Central Nervous System(CNS): Nanobots could be used to treat the cancers in the CNS too. At times, they themselves could act as implants, replacing damaged neurons in some patients . Nanobots will also be able to perform neural surgeries as well as surgeries of the brain, with a high success rate. It would also prevent the necessity of today : drilling a hole in the skull to gain access to the brain.

Nanobots can also be used to help people suffering from motor neuron diseases, as well as paralysis. Once injected into the patient, they can locate themselves at specific places in the brain, and pick up impulses which would normally be delivered to the body's motor neurons. These impulses can be used to drive external prosthetics , such as a robotic arm. Thus, it would help a lot of people from overcoming their disabilities.

Cancer treatment: This is probably the main reason for the development of nanorobotics. Drug delivery for cancer today is difficult to control. Chemotherapy harms healthy tissue in addition to cancerous tissue. We cannot prevent adverse effects of chemotherapy on other parts of our body. Nanorobotics will change it all. Nanobots could be used to deliver drugs specifically to the tumour only, thus preventing the peripheral impact of the drug.

One of the many methods to achieve this is the following: Primary nanobots are sent to the target tissue (tumour) to inflame it. This is partly a machine gun approach; a lot of the bots will be wasted. However, only the tumour is inflamed and not any other tissue in the entire body. Now, a second wave of bots is sent, to target the inflamed tissue. This wave of bots contains the actual chemotherapy drug. It releases its payload i.e. the drug only after sensing the inflamed tissue. Thus, we have a highly concentrated targeted action, with no peripheral impact. We could liken it to a sniper's rifle.

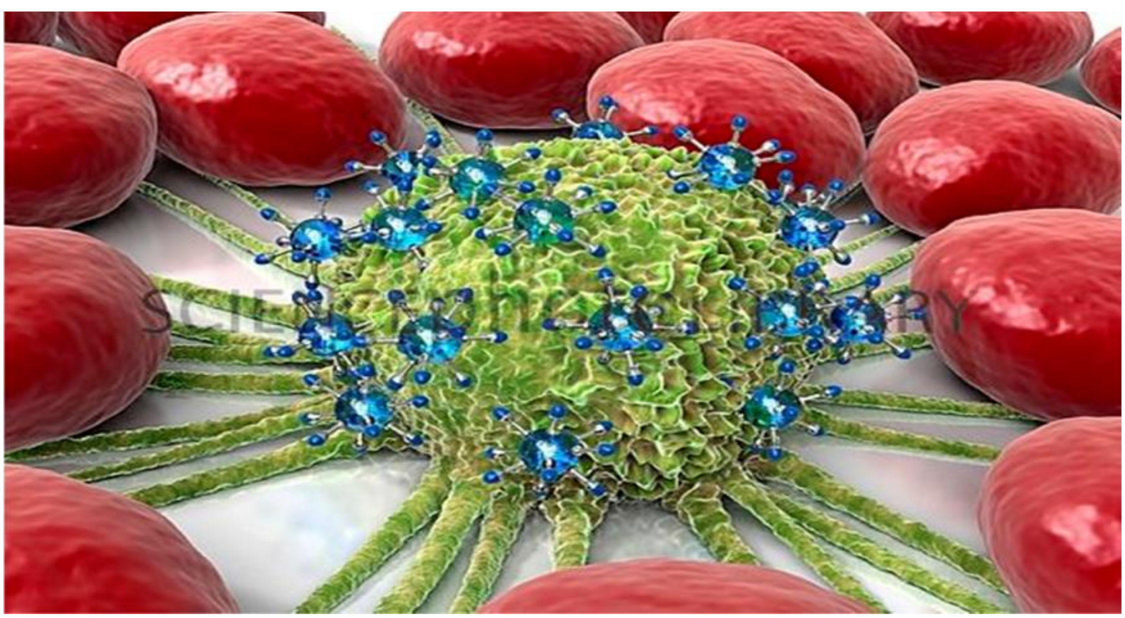

Figure 2: Nanobot targeting tumour site

Source: Image courtesy http://www.sciencephoto.com/media/154352/enlarge

Body surveillance: Continuous monitoring of vitals and wireless transmission could be possible using nanobots, leading to a quantum leap in diagnostics. This would also help in rapid response in case of sudden change in vitals, or could warn against a possibility of a risk, such as high blood glucose in case of diabetics. Also multi-functional bots could convert themselves into stents, say to open up a blockage in an artery. The bot itself can be used as a tool , to remove unwanted materials such as blockages in the circulatory system. Nanobots could be used in large quantities inside the body to sense and repair anomalies/ abnormalities. Current macroscopic robots are being programmed and tested with what is known as "swarm intelligence" , in which they share information available to each one of them, pool it together , and take collective decisions. Such behaviour is seen in ant colonies too; they communicate with the help of chemicals and behave like one large organism, often referred to as a "super organism". Using the strategy of swarm intelligence, in intra-body nanobots could help in creating a single strong defensive shield against pathogens and toxins. It would also help prevent vitals from going out of medically defined bounds.

Delicate surgeries: Surgeries such as those of the eye are even today performed successfully only by a few skilled surgeons. Immense risk is involved in these delicate surgeries and they require a steady hand as well as a strong constitution. It may soon be possible to take the human element of risk out of this equation. Micro surgery of the eye as well as surgeries of the retina and surrounding membranes could soon be performed using nanobots. In addition, instead of injecting directly into the eye, nanobots could be injected elsewhere in the body and guided to the eye to deliver drugs, if necessary. Similarly, other difficult surgeries will also benefit from advances in nanorobotics. Foetal surgery, risky even today due to high mortality rate of either the baby or the mother, could soon have a 100% success rate, due to the fact that nanobots can provide better access to the required area inducing minimal trauma.

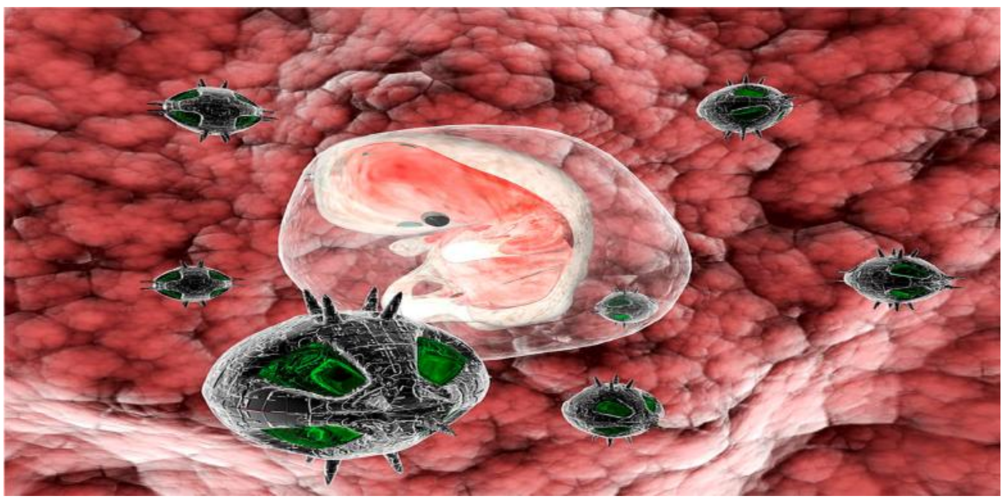

Figure 3: Nanobots being used in foetal surgery (concept)

Source: Image courtesy: http://fineartamerica.com/featured/nanorobots-with-human-embryo-christian-darkin.html

Miscellaneous : Nanobots could be used for endoscopy as well. They would be injected orally and used to get data of the condition of the digestive system, from the stomach to the intestines. Even a nanobot mouthwash has been envisioned , which would use nanobots to clean up food particles stuck in between the teeth. Nanobots could be used for external treatment, such as in creams to treat skin diseases or remove accumulated dust and dirt from pores.

Another possible use is as a cochlear implant in the ear. Since the ear has very sensitive parts , such as small bones and a lot of nerve endings, it would always be better to reduce the trauma induced by current procedures . Also nanorobots injected into the ear would mean an almost zero chance of infection.

Nanobots are also being considered as a way of delivering differentiated stem cells to various locations in the body. Stem cell research has been a huge leap in regenerative medicine. Nanobots hope to enhance their impact on medicine in the near future by providing an effective way of delivering them.

CONCLUSION

Use of nanorobotics in the field of medicine has a wider scope than any other sub-field that has emerged to date. It can be used pretty much anywhere in conjunction with human physiology. It provides numerous advantages over conventional medicine such as lower cost, quicker rehabilitation, low or almost no invasion. In an age of inter-disciplinary activity, we hope that we will soon witness a great revolution in medicine, comparable to the industrial revolution which reshaped the world. With a swarm of nanobots protecting us from inside, we could realistically be free from disease in the next few decades, with life expectancy which is unheard of today.

REFERENCES

1. Anitha, E.- "Nanorobots "GRA - global research analysis Nov2012 vol.1 issue 5 issn 2277-8160 pg45-48
2. Cavalcanti,A. Rosen, L. Kretly,L.C. Rosenfeld,M. Einav,S. - "Nanorobotic challenges in biomedical

applications, design and control" IEEE ICECS Int'l conf. on electronics, circuits and systems Tel-aviv, Israel, December 2004

3. Dreyfus, R. Baury, J. Roper, M.L. Fermigiev, M. Stone,H.A Bibette,J. “Microscopic artificial swimmers”, Nature, vol. 437, 862, (2005).

4. Freitas Jr.,R.A-"Current status of nanomedicine and medical nanorobotics", Computational and theoretical nanoscience vol.2, 1–25, 2005

5. Nelson, B.J-"Microrobotics in medicine" , ETH Zurich http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.98.994&rep=rep1&type=pdf

6. Nelson, B.J Kaliakatsos,I.K Abott,J.- "Microrobots for minimally invasive medicine" -Annu. Rev. Biomed. Eng. 2010.12. By Eidgenossische Technische Hochschule, Zurich

7. Requicha ,A.G"Nanorobots, NEMS, and nanoassembly" proceedings of the IEEE, vol. 91, no. 11, November 2003 invited paper

8. Sharma, N. N Mittal, R.K. "Nanorobot movement: challenges and biologically inspired solutions" International Journal on Smart sensing and Intelligent Systems, vol. 1, no. 1, march 2008

9. Shirai, Y. Osgood,A.J Zhao,Y K Kelly,K.F Tour,J.M "Directional control in thermally driven single-molecule nanocars", nano lett., vol. 5, 2330-2334, (2005).

Wikipedia: Quantum computer http://en.wikipedia.org/wiki/quantum_computer

10. Wikipedia: Magnetotactic bacteria http://en.wikipedia.org/wiki/Magnetotactic_bacteria