Potential Applications of Proteins In IT

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ABSTRACT
The volume of digital data is increasing every day .So there is need to develop new memory architectures to provide more cost-effective storage capacity, processing speed and data transfer bandwidth. For many years, researchers have been studying organic molecules and their potential applications in information technology, such as the use of biological molecules to encode, manipulate and retrieve information. There are existing biological molecules whose two stable states of their atomic structure can be controlled. These states represent the logic states of 0 and 1 by benefiting from the photo cycle of these photosensitive proteins

A number of alternative methods to integrated circuit information storage have surfaced recently. The most promising of the new alternatives is protein-based optical memory storage using Bacteriorhodopsin (bR). In this paper we study about bR (unit of protein memory), process of protein extraction, photocycle, its application and limitations. Various computational methods like – Write -data, Read-data, Erase -data and Refresh -memory with emphasis on Bacteriordopsin are studied. We also throw light on potential areas of application of protein memory.

Keywords
Optical storage, protein based memory, two photon absorption (TPA), Bacteriorhodopsin (bR), 3-D matrix, photocycle.

1. INTRODUCTION
Biological molecules like DNA, RNA and proteins are sophisticated and efficient tools designed naturally to store information. Proteins in living systems are known to be associated with data storage in the form of memory of cells e.g. primed lymphocytes of immune system store information about exposed antigens. The information is then used for rapid production of antibodies and immune response upon re-exposure to the same antigen[12,13].

Bacteriorhodopsin is a light-harvesting protein from bacteria that live in salt marshes which has shown some promise as feasible optical data storage and computation. This bacterial protein can be fabricated in large quantities. Salt marshes have very high salinity and temperatures can reach 140 degrees Fahrenheit for the extended period of time. Unlike most proteins, bacteriorhodopsin does not break down at these high temperatures. Survival in such an extreme environment indicates that this protein can resist thermal and photochemical damages. The bacterium contains a molecular pigment which is very similar to the one which makes up the retina of our eyes. The molecule changes form when it is exposed to a luminous source and then either works like a switch or a transistor. It can therefore process information.

Bacteriorhodopsin is proven to have great sensitive thermal, chemical and holographic (3-d volumetric) features. Hence a good choice for developing protein based optical memory. This is a hybrid technology that hybridizes Bacteriorhodopsin with the solid state components of a computer. The photo cycle of bacteriorhodopsin is in fact an ideal candidate for storing binary information: the bR-state, or logic value 0, and the Q-state, or logic value 1, are intermediary structural states of the molecule and can last for several years [14].

2. ADVANTAGES
The properties of Bacteriorhodopsin make it a right candidate for use in optically coupled devices [9].The advantages of protein include:Long-term stability and resistance to thermal and photochemical degradation. bR is protected against photo-induced breakdown;

- Ability to posses stable intermediates;
- The ability of the protein to occupy different three-dimensional shapes and form cubic matrices in a polymer gel, allowing for truly three-dimensional memory storage;
- Its ability to absorb light allows it to form holograms. The process of using light to store data is known as holography. Holographic data storage reads and writes entire blocks in a single operation making it extremely fast as a storage medium. When the protein is in some of the states, its ability to absorb light allows it to form holograms.;
- Its sensitivity to light allows it to change structurally and would be a good representation of a logic gate, the primary building block of our memory cell. A series of lasers is then used to excite the protein molecules and read or set their states. Bacteriorhodopsin is being developed to represent binary data. Bacteriorhodopsin can be used in any number of schemes to store memory;
- rotein-based memory devices will not require the use of high-temperature manufacturing, and will therefore be able to incorporate much thinner materials than traditional optical and magnetic-based memory systems;

- Along with fairly rapid information recording, memory devices based on protein will likely be unaffected by magnetic interference and will remain relatively stable at temperatures lower than the typical computer;
- Finally, one can remove the small data cubes and ship gigabytes of data around for storage or backups. Because the cubes contain no moving parts, it's safer than using a small hard drive or cartridge for this task.

3. MOLECULAR MEMORY Vs SEMICONDUCTOR MEMORY

The design certainly has its merits. First, it's based on a protein that's inexpensive to produce in quantity. In fact, genetic engineering is being used to boost the output of the protein by the bacterium. Second, the system has the ability to operate over a wider range of temperatures than semiconductor memory. Thirdly, the data is stable. If you turn off the memory system's power, the Bacteriorhodopsin molecules retain their information. This makes for an energy efficient computer that can be powered down yet still be ready to work with immediately because the contents of its memory are preserved. Data recorded on a Bacteriorhodopsin storage device would be stable for approximately five years.

4. 2-D VS 3-D OPTICAL MEMORIES

In a prototype memory system, Bacteriorhodopsin stores data in a 3-D matrix. 3D cubes of Bacteriorhodopsin provides much more space that two dimensional optical memories. Three dimensional optical memories can theoretically approach storage densities of one trillion bits per cubic centimetres but there are some limiting factors which prevents in getting this high storage density. Research is going on to handle these limiting factors. A 300 folds improvement in storage capacity over 2-D devices should be possible. So a major impact of bioelectronics on computer hardware will be in the area of volumetric memory. Speed is also an important benefit of volumetric memories. As discussed in [6], storage capacity in two-dimensional optical memories is limited to approximately 1/lambda2 (lambda = wavelength of light), which comes out to approximately 10^8 bits per square centimetre. Three-dimensional memories, however, can store data at approximately 1/lambda3, which yields densities of 10^{11} to 10^{13} bits per cubic centimetre.

In the existing 2-D storage technology, data is stored directly on the surface of the medium. Optical disks such as CD/DVD are based on one photon absorption (OPA) technology. OPA is a technology where a photon is absorbed by the photo sensitive medium at a particular location. This absorption results in change of physical properties. Unlike surface storage technology, volumetric storage technologies allows entire volume of the media to be used for storage Volumetric storage uses two-photon absorption(TPA).TPA technology makes use of two photon beams that intersect at a location inside the volume of storage media where one or zero has to be written

. Depending on the bit size there is about 80 to 800 fold improvement in storage density.

Gains possible on transition from 2-d to 3-d memory [6]

Bit Diam. (μm)	Mbytes in 2-D Disk	Mbytes in 3-D Cube	Ratio (3D/2D)	Molec./ bit (10^{-5}M)
1	640	510,000	800	6,000
1.6	250	125,000	500	25,000
2	160	64,000	400	83,000
2.4	110	37,000	340	83,000
3	71	19,000	270	160,000
4	40	8,000	200	390,000
5	25	4,100	160	750,000
6	18	2,400	130	$1.3x10^6$
7	13	1,500	115	$2.1x10^6$
8	10	1,000	100	$3.1x10^6$
9	8	700	89	$4.4x10^6$
10	6	510	81-	$6.0x10^6$

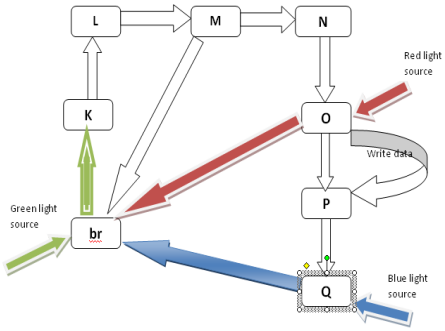
5. BACTERIORHODOPSIN PHOTOCYCLE

Bacteriorhodopsin comprises of a light absorbing component known as CHROMOPHORE that absorbs light energy and triggers a series of complex internal structural changes to alter the protein's optical and electrical characteristics. This phenomenon is known as photocycle.

In response to light Bacteriorhodopsin "pumps" proton across the membrane, transporting charged ions in and out of the cell. Bacteriorhodopsin goes through different intermediates during the proton pumping cycle. These stages have been labelled K, L, M, N and O, each one easily identifiable because Bacteriorhodopsin changes colour during each stage of the process. The native photo cycle has several spectroscopically unique steps, bR --> K <--> L <--> M1 --> M2 <--> N <-->O, which occur in a roughly linear order The photo cycle of bacteriorhodopsin or its cycle of molecular states depend on the luminous radiation that it absorbs. The initial state known as bR evolves into state K under the effect of green light. From there it spontaneously passes to state M then to state O (relaxation transitions). Exposure to red light from O state will make the structure of the bacterium evolve to state P then spontaneously to state Q, which is a very stable state. Some of the intermediates are stable at about 80K and some are stable at room temperature, lending themselves to different types of RAM. Nevertheless, radiation from blue light can take the molecule from state Q back to the initial state bR. Any two long lasting states can be assigned the binary value 0 or 1, making it possible to store information as a series of Bacteriorhodopsin molecules in one state or another.

Genetic engineering has been used to create bacteriorhodopsin mutants with enhanced materials properties. For example, some mutants have enhanced the holographic properties of the protein by producing an M state with an extended lifetime; others improve the branched-photocycle memory by enhancing the yield of the O state

Fig The photocycle



6. PROCESS OF MAKING PROTEIN CUBE

The process of making the protein cube has many different steps. First the bacterial DNA is splice and mutated to make the protein more efficient for use as a volumetric memory. Then, the bacteria must be grown in large batches and the protein extracted. Finally, the purified protein is put into the cube and used as a volumetric storage medium. The cube is read by two lasers as binary code. One laser is used to activate the protein in a section of the cube. The other laser is used to write or read binary information in the same section. The data is assigned as either a zero or a one. The binary code is then analysed by the computer as various pieces of information.

The matrix can be build by placing the protein into a cuvette (a transparent vessel filled with a polyacrylamide gel). The protein, which is in the bR state, gets fixed in by the polymerization of the gel. A battery of Krypton lasers and a charge-injection device (CID) array surround the cuvette and are used to write and read data. Two-photon absorption (TPA) technology is used which makes use of two photon beams that intersect at a location inside the volume of storage media where one or zero has to be written

7. DATA OPERATION

For computers, the two or three most stable states of the protein would be used to record data in binary form. Molecules changes states within microseconds. Combined steps to read or write operation takes about 10 milliseconds. Devices obtain data pages in parallel. Speed is currently limited by data addressing. Following Data operation can be done using Protein memory:

- Write data into memory
- Read data from memory
- Erase data from memory
- Refresh memory.

7.1 Data Writing Technique

Cube of bacteriorhodopes is surrounded by two arrays of laser beams placed 90 degree from each other. Green laser, called pagging beams, activates the photocycle of proteins in any selected square plane or page within the cube. When the number of O intermediates reaches near maximum, the other laser array of red beams is fired. Second array illuminates the activated square where the data bits are to be written, switching the molecules to the P structure.

The P intermediate then quickly relaxes to the highly stable Q state. We then assign the initially-excited state, the O state, to a binary value of 0, and the P and Q states are assigned a binary value of 1. This process is now analogous to the binary switching system which is used in existing semiconductor and magnetic memories. However, because the laser array can activate molecules in various places throughout the selected page or plane, multiple data locations (known as "addresses") can be written simultaneously - or in other words, in parallel.

7.2 Data Reading Technique

The system for reading stored memory, relies on the selective absorption of red light by the O intermediate state of Bacteriorhodopsin. Data is read by shining laser beams on molecules and noting the wavelengths that don't pass through the detector. First, the green paging beam is fired at the square of protein to be read. After two milliseconds (enough time for the maximum amount of O intermediates to appear), the entire red laser array is turned on at a very low intensity of red light. The molecules that are in the binary state 1 (P or Q intermediate states) do not absorb the red light, or change their states, as they have already been excited by the intense red light during the data writing stage. However, the molecules which started out in the binary state 0 (the O intermediate state), do absorb the low-intensity red beams. A detector then images (reads) the light passing through the cube of memory and records the location of the O and P or Q structures; or in terms of binary code, the detector reads 0's and 1's. The process is complete in approximately 10 milliseconds, a rate of 10 megabytes per second for each page of memory.

7.3 Data Erasing

Brief pulse from a blue laser returns molecules in the Q state back to the rest state. The blue light doesn't necessarily have to be a laser; you can bulk-erase the cuvette by exposing it to an incandescent light with ultraviolet output.

7.4 Refreshing Memory

The read/write operations also use 2 additional parity bits to guard against errors. A page of data can be read non-destructively about 5000 times. Each page is monitored by a counter, and after 1024 reads, the page is refreshed via a new write operation.

8. OTHER APPLICATIONS

Most successful applications of bacteriorhodopsin has been in the development of holographic and volumetric three-dimensional (3-D) memories.Other applications of bacteriorhodopsin are

- When nutrients get scarce, this Bacteriorhodopsin becomes a light-converting enzyme. It's a protein powerhouse that in times of famine flips back and forth between purple and yellow colours. If controllable, this could be valuable in building battery conserving and long lasting computer display panels.

- Quick change proteins like Bacteriorhodopsin, if controllable could also be used in kind of electronic ink.
- Protein's photoelectric properties could be used to manufacture photo detectors.
- Bacteriorhodopsin could be used as light sensitive element in artificial retinas. Japanese researchers were the first to develop protein-based artificial retinas
- German scientists have used holographic thin films of bacteriorhodopsin to make pattern-recognition systems with high sensitivity and diffraction-limited performance.
- Nanobiotechnology based medical diagnostics may use this proteins in imaging devices.
- Molecules can potentially serve as computers switches because their atoms are mobile and change position in a predictable way. By directing the atomic motion two discrete states can be generated in a molecule, which can be used to represent either 0 or 1.This results in reduction of size, that is, a bimolecular computer in principle is one-twentieth of the size of the present day semiconductor computer
- bR has all desired properties for usage in associative memory applications. Associative memories operate rather differently from the memories that dominate current computer architectures. This type of architecture takes a set of data often in the form of an image and scans the entire memory bank until it finds a data set that matches it .Since human brain operates in a neural associative mode, many computer scientists believe large - capacity associative memories will be required if we are to achieve artificial intelligence. Associative memory device may rely on the holographic properties of thin films of Bacteriorhodopsin. Associative memories have significant potential for applications in optical computer architectures, optically coupled neural network computers etc.

9. POTENTIAL APPLICATION AREA

One of the potential application areas for protein based high efficiency memory storage is Bioinformatics. Sequence search tools like BLAST use large databases for searching and alignment of the `query' sequence.[10] The existing popular and quick sequence search tools also reflect more dynamic memory requirements, especially while processing a cluster with multiple jobs at a time. Although, search for a single query is effective the limitation lies in complex queries . The search programs can exhaust all memory on a machine if the input is too large or if there are too many hits to the database. For many applications ,like BLAST, performance deteriorates precipitously once real (solid-state RAM) memory is exhausted. Users may face problem performing Blast searches, particularly when whole chromosomes or genomes are involved. In this case the real focus is on increasing the amount of real (RAM) memory available.. Bacteriorhodopsin-based high-density optical memory logic device would have potential for superior performance compared to conventional electronic computers. .[2,3,8]

10. RESEARCH DEVELOPMENT

[6] Branched- photocycle memory is developed at the W.M. Keck Centre for Molecular Electronics at Syracuse University. This memory stores from 7 to 10 gigabytes (GB) of data in a small 1 × 1 × 3-cm3 cuvette containing the protein in a polymer matrix Data are stored by using a sequential pair of one-photon processes, which allows the use of inexpensive diode lasers to store one bit into the long-lived Q state. The read/write/erase process is fairly complicated.

The 10-GB data cuvettes used in the 3-D memory described above can withstand substantial gravitational forces and are unaffected by high-intensity electromagnetic radiation and cosmic rays. They can even be submerged under water for months without compromising the reliability of the data. 3-D protein memory cuvettes are already being designed and optimized for archival data storage in office environments. Many millions of dollars have been spent on this research and development. We have learned a great deal in recent years about proteins and it's applications. However, lot more has to be done in this area to produce practical applications Research work is going on to develop commercially viable applications discussed in section 8.

11. CONCLUSIONS

A thinner, faster computer with large storage capacity is what most consumers want and protein-based memory devices do seem to hold a lot of potential in that area. With fast random access capability, better reliability and transportability, we are definitely moving to a new era in computing. Large pools of data could serve as a unique platform for investigation of artificial intelligence. With ultra high density RAMs, the machine would handle large databases with very high speed.

12. ACKNOWLEDGMENTS

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13. REFERENCES

[1] Jeffrey A.Stuart , Duane L. Marcy, Kevin J. Wise Robert R. Birge, "Volumetric optical memory based on bacteriorhodopsin ", in Synthetic Metals (2002), Volume: 127, Issue: 1-3, Pages: 3-15 Change

[2] R. R. Birge, "Protein-Based Computers," Scientific American, pp90-95, March 1995.

[3] R. R. Birge, "Protein-Based Three-Dimensional Memory," *American Scientist*, pp.348-355, July-August 1994.

[4] V. Renugopalakrishnan, S. Khizroev, H. Anand, Li Pingzuo, and L. Lindvold," Future Memory Storage Technology: Protein-Based Memory Devices May Facilitate Surpassing Moore's Law", IEEE TRANSACTIONS ON MAGNETICS, VOL. 43, NO. 2, FEBRUARY 2007 773

[5] Felix T. Hong ,"Bacteriorhodopsin as an Intelligent Material, A Nontechnical Summary"in Molecular Computing Overview (Jan. 1, and Jan. 15, 1996, issues of 21st) .

[6] Edward J. Schmidt, Jeffrey A. Stuart, Deepak Singh, and Robert R. Birge, "Bacteriorhodopsin-Based Volumetric Optical Memory" , Nonvolatile Memory Technology Conference, 1998. 1998 Proceedings. Seventh Biennial IEEE ,pp 84 - 90 .

[7] Draganescu, M., "From solid state to quantum and molecular electronics, the deepening of information processing", Semiconductor Conference, 1997. CAS '97 Proceedings., 1997 International, pp 5 – 21, vol.1

[8] M. Hampp and D. Ziesel, "Mutated Bacteriorhodopsins," *IEEE Engrg. in Medicine andBiology* **13**, pp.67-74.

[9] Robert R. Birge ,"Protein based optical computing and memorie" in computer,vol 25,pp56-67, IEEE Computer Society.

[10] Altschul, S. F., Gish, W., Miller, W., Myers, E. W. and Lipman, D. J. Basic local alignment search tool. (1990) *J Mol Biol*, **215,** 403-10.

[11] Be´ja`, O., Spudich, E. N., Spudich, J. L., Leclerc, M. & DeLong, E. F. (2001) *Nature* 411, 786–789.

[12] Special Issue of *Scientific American*, "Life, Death, and the Immune System," September1993.

[13] T. Boon, "Teaching the Immune System to Fight Cancer," *Scientific American*, pp82-89,March 1993.

[14] Waldner, Jean-Baptiste (2007). Nanocomputers and Swarm Intelligence. John Wiley-ISTE, p93-99. ISBN 1847040020.