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Protein-Based Three-Dimensional Memories and Associative Processors[1]

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The field of bioelectronics has benefited from the fact that nature has often solved problems of a similar nature to those which must be solved to create molecular electronic or photonic devices that operate with efficiency and reliability. Retinal proteins show great promise in bioelectronic devices because they operate with high efficiency ($\sim$0.65%), high cyclicity ($>10^7$), operate over an extended wavelength range (360 – 630 nm) and can convert light into changes in voltage, pH, absorption or refractive index. This talk will focus on a retinal protein called bacteriorhodopsin, the proton pump of the organism *Halobacterium salinarum*. Two memories based on this protein will be described. The first is an optical three-dimensional memory. This memory stores information using volume elements (voxels), and provides as much as a thousand-fold improvement in effective capacity over current technology. A unique branching reaction of a variant of bacteriorhodopsin is used to turn each protein into an optically addressed latched AND gate. Although three working prototypes have been developed, a number of cost/performance and architectural issues must be resolved prior to commercialization. The major issue is that the native protein provides a very inefficient branching reaction. Genetic engineering has improved performance by nearly 500-fold, but a further order of magnitude improvement is needed. Protein-based holographic associative memories will also be discussed. The human brain stores and retrieves information via association, and human intelligence is intimately connected to the nature and enormous capacity of this associative search and retrieval process. To a first order approximation, creativity can be viewed as the association of two seemingly disparate concepts to form a totally new construct. Thus, artificial intelligence requires large scale associative memories. Current computer hardware does not provide an optimal environment for creating artificial intelligence due to the serial nature of random access memories. Software cannot provide a satisfactory work-around that does not introduce unacceptable latency. Holographic associative memories provide a useful approach to large scale associative recall. Bacteriorhodopsin has long been recognized for its outstanding holographic properties, and when utilized in the Paek and Psaltis design, provides a high-speed real-time associative memory with variable thresholding and feedback. What remains is to make an associative memory capable of high-speed association and long-term data storage. The use of directed evolution to create a protein with the necessary unique properties will be discussed.

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