巻頭言

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An information technology based economy requires a cyberinfrastructure in analogy to the industrial infrastructure necessary for the viability of an industrial economy. This cyberinfrastructure consists of the systems for information processing, communication, and storage. Among these three, information storage systems have very much become victims of their own success. Years of remarkable technological advances have caused many to believe two conflicting notions. On the one hand there is a sense that information storage is a “mature” technology in which new “game changing” developments will not take place and that only incremental advances are possible. Yet at the same time there is an expectation that information storage systems’ performance, primarily storage densities, will continue to increase exponentially with storage capacities perhaps doubling every year even as the cost of storage continues to decrease. It is now clear that neither perception is true.

For many years it was the case that magnetic hard disk drive information storage densities increased at a rate of about 60% per year with that rate increasing to 100% per year between the years of 1998 and 2002. However, in the past eighteen months or so that rate of increase has declined dramatically to between 30% and 40% per year. This has been, in large measure, a consequence of the difficulties in overcoming the superparamagnetic effect. Optical recording systems are also facing challenges to further increases in density as numerical apertures have been pushed as high as 0.85 and laser wavelengths as short as 405 nm. At the same time scaling in the lithography systems used to produce devices that read and write data are also facing limits as it becomes increasingly expensive and difficult to advance to the 45 nm node and beyond. Thus it is becoming clear that simply scaling existing systems is not likely to be viable for many more years to come and that we cannot continue to take for granted “exponential” increases in information storage system performance. Are we to understand from this that storage systems have reached the ultimate limits imposed by nature? The answer is not at all.

One can measure information storage limits in various ways but any analysis of the challenges facing storage systems today quickly reveals that the so called limits we are facing are a consequence of the engineering paradigms being used rather than of the fundamental sort imposed by nature. In terms of limits set by nature one should consider the ultimate discretization of space, time, and energy as a measure of the maximum storage density, data rate, and efficiency with which one may store information. In terms of our present understanding these are the Planck length ($\sim10^{-35}$ m), Planck time ($\sim10^{-43}$ sec), and the thermodynamic minimum energy that must be dissipated in setting the state of a two state system ($\sim10^{-2}$ eV at room temperature). But even before one considers such extreme limits evidence that present day systems do not operate in any sense near the limits of information storage can be surmised from any one of a number of perspectives. For example, a typical magnetic hard disk drive employs a thin film head which is supplied with a current to generate the magnetic write field. This current is typically about 50 mA and the head represents a resistive impedance of about 6 Ω. Thus in 10^{-9} sec the energy dissipated simply by resistive heating is about 10^{8} eV or about ten orders of magnitude greater than the thermodynamic limit. This energy dissipation is not required in order to achieve the write speeds of today's systems but rather is a consequence of the fact that today's systems do not operate at a level of performance approaching the limits set by nature. In addition we can observe "systems" in nature that are far better in performance than today's engineered systems. For example, a virus such as the human cytomegalovirus has a nucleopcapsid that is approximately icosohedral and about 100 nm in diameter. The genome of this virus contains 200,000 base pairs. Thus with each base pair corresponding to 2 bits this corresponds to 400,000 bits per 100 nm or an areal density of about 3 x 10^{16} bits/inch^{2}. We therefore have an example of an information storage "system" that is stable and rewriteable and which employs an effective areal density about 10^{5} times greater than today's most advanced systems.

This is not to say that it is necessarily the case that viruses (and DNA) are the best model for how information storage systems should be designed. Rather in much the same way that birds have always been a proof of the viability of heavier than air flight so too are viruses and DNA a proof of the viability of information storage at densities far in excess of today's systems. Indeed while it is important to learn from nature it is equally important not to learn too much from nature. In designing manmade heavier than air flying systems engineers separated the function of lift and thrust. Birds essentially produce both lift and thrust through their wings. The highest performance aircraft primarily use their wings to produce lift while having engines to produce thrust. The separation of these two functions has allowed engineers to optimize each independently and produce heavier than air flying systems that achieve performance in terms of altitude and speed far in excess of known naturally occurring flying systems. So too with DNA and viruses. These systems have evolved over time for more than simply information storage and it therefore seems likely that storage densities far in excess of even "viral" densities are possible.

Realizing that information storage system performance far better than anything we have today is possible may lead one to question the need for improved systems of greater capacity, data rate, and efficiency. In my mind however there is no question that such systems will be developed and find immediate use. Throughout history great changes have taken place in societies when capabilities reserved for large institutions have been made available to individuals. This was true when books were made generally available after the invention of the printing press, when individual mobility was made possible through the development of the automobile, or when powerful computers were placed into the hands of individuals. Today even as information storage capacity has increased it nonetheless remains the case that libraries of information are still managed and controlled by large organizations. When entire libraries can be reproduced cheaply and made available to the individual at low cost tremendous social change will take place. What this change will be is perhaps impossible to predict but that it will take place and will be a change for the better is a certainty.

Thus we can conclude that "game changing" innovations and advances are possible in information storage systems. These will require broad based interdisciplinary efforts that bring together workers in diverse fields and across multiple institutions. The pages of this journal present articles on the work being done at Sharp on recordable information storage systems. This work touches on many systems all of which are aimed at providing individuals with improved system performance be it through higher storage capacity, increased data rate, or greater efficiency. In doing this work Sharp is contributing in a very real way to those technologies which will help to put more information into the hands of individuals and therefore to the advancement of society.