To the Editor — In their recent *Nature Photonics* commentary[1], Caulfield and Dolev presented an optimistic picture of how optical technology could transform future computing. I agree with them on several important points. Optical interconnects could substantially mitigate the energy and density problems of electrical wiring[2]. Perhaps once we have viable dense optical interconnect technologies new architectures will become feasible, such as those exploiting large-scale parallelism with optics. They have also clearly understood that power dissipation is perhaps the single most important limit on information processing systems. However, some of their other proposals require serious debate to ensure that we do not suffer from the negative consequences of over-stating or even misstating the case for using optics in such systems.

First, regarding interconnects; they cite fan-in and fan-out, in which multiple beams are combined onto a single pixel, as a distinct advantage for optics. In fact, however, it is not clear that there is any substantial advantage here, as was shown by Goodman[3].

Second, they cite recent progress in special-purpose processors, such as optical pre-processors and another version of the vector–matrix multiplier[4]. It is arguably difficult, however, to generate the necessary funding to develop a substantially different technology like optics merely on the basis of special-purpose machines; modern silicon electronics has succeeded mostly because its universal utility encourages the necessary large investment.

Third, and most importantly, Caulfield and Dolev[1] give the impression that there are zero-energy logic mechanisms available in optics that will solve the power dissipation problem for information processing. This requires clarification.

The logic they consider[5–7] can be understood by analogy with switching in a rail system[5]. An operator pulls a lever to switch between rail tracks. A rail car initially travelling along one input track ends up on a specific output track as a result. If both lever A and lever B are pulled 'on' by the operator, then the car ends up on track C. The appearance of the car on track C therefore shows the truth of the operation A AND B. Other logic operations can be implemented in a similar way. Such a logic system is 'zero energy' in the sense that no particular minimum amount of energy is apparently required for the rail car to propagate through the network of switches and tracks. The advocates of such logic point out that light is a particularly good substitute for the rail car because it moves very fast, with little loss and without any particular 'push' required for it to move at such speed. In the optical version, waveguides and Mach–Zehnder interferometric switches (or other optical switches) would be substituted for the rail track and the rail switches.

There are three major issues with such a logic scheme. First, there is certainly energy dissipated, specifically in the operation of the optical switches. Second, cascadability — the ability of the output of one stage to drive the input of the next — is very important in logic; this approach is not cascadable unless some other 'cascading' device (one that cannot be implemented in linear optics) is added. Such a device would take the presence of a rail car or optical beam on one path and use it to set the position of subsequent switches. Third, if we try to avoid such an additional cascading device, the size of the system and the number of switches that must be activated grows exponentially with the number of logical inputs[6], at least in the general case. Because in practice energy is required to activate each switch, the energy would also grow exponentially. If we instead insert a cascading device, the system can grow more linearly with the number of inputs, but then the distinction between this and a conventional electronic architecture is not so substantial. The necessary cascading device is essentially an optical transistor — something that currently does not exist with properties even comparable to electronic transistors[8].

Each of these major issues is understood by the advocates of such logic[5–7], with Hardy and Shamir[5] giving a commendable survey of the challenges in the cascading and switching approaches. Given that the energies required to activate optical switches are typically much larger than those required to run electronic transistors[8], the energy reduction advocated by Caulfield and Dolev[1] here is illusory for any practical scheme we can currently envisage. Substantial additional and unspecified breakthroughs are required. Hence advertising this 'zero-energy' logic as a significant benefit for optics is at best dubious and at worst misleading.

There are many positive reasons for the interest in optics in information processing, and there is much creative work being done in this field, including the research of Caulfield and Dolev. However, we have to be strongly self-critical in the optics community when proposing information processing schemes. We must be particularly diligent in assessing what electronics can achieve both now and in the foreseeable future. Otherwise we will repeat the past error of over-selling the role of optics in computing — a mistake that has set the field back several times in its history. ❐

References

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Caulfield and Dolev reply: We are grateful that the optics experts David A. B. Miller and Rodney S. Tucker have commented on our paper, and are happy that a fruitful conversation has resulted.

Although it is of course true that some practical issues still need to be resolved for optical computing, we feel that research on this topic is both important and promising. In particular, we have shown that an optical approach can in principle be used to create a universal processor with functionality comparable to a Turing machine, which can run any specific computation task as a subroutine. In fact, we have a design implementing a non-deterministic Turing machine[1] that is equivalent to the design of such a universal processor.

Similarly to what Intel, IBM, AMD and others have done for their general purpose microelectronic processors, we have also designed several optical architectures to support a set of specific instructions that utilize the advantages of optics. In other words, it is possible to have a general-purpose processor with a new set of machine instructions that fit the capabilities of optics (for example, a set that includes an efficient solution to difficult combinatorial problems rather than only the classical add or multiply values of registers). A general-purpose optical processor is a future necessity for environments in which soft-errors may harm the computation (as NASA so often experiences).