Digital Wires

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Electrical wires transport energy and information and often both. For example, electrical power cords deliver electrical energy from wall outlets to computers, whereas Ethernet cable transports information in the form of electrical pulses from the internet modem to the computer and back. USB cables are used to both charge the battery of MP3 players and to load digital music on the player.

Despite of the fact that electrical wires have long been used for communication as phone lines and for Cable TV, there are some reoccurring problems. Wires radiate electromagnetic fields which are picked up by other wires and disturb signals there. Such cross-talk between wires can be prevented by electric shields, but shielded wires are thick and expensive. A second problem is echoing. Signals traveling along a wire are often reflected at the end of the wire, and such echoes disturb other signals. Echoes can be suppressed with specially designed wire ending, but again, such endings are bulky and expensive. Corrosion of the connector is another common problem. Corroded electrical plugs can make electrical wires unreliable. Gold and platinum coatings prevent corrosion but such coatings are costly. Furthermore, all conventional wires have resistance and nonlinear dispersion curves, which means that pulses get smaller and broader as they travel along the wire. Repeater stations along the wire can help to maintain the pulse shape, but each repeater station requires a power source and repeater stations are a complex piece of electronics with a comparatively short life time. And finally, the speed at which signals are traveling along a regular wire depends on the speed of light of the wire material and thus the propagation speed is not easily adjustable. Sometimes, one needs to slow down the propagation of electrical pulses to synchronize them with other pulses. This can be achieved by sending the pulse through a long wire, a waiting loop, or with rather complicated electronics. Both methods are hard to implement on a microscopic scale.

Electrical wires for power distribution are inefficient. On average, about 8% of the energy is lost in transmission. In addition, high-current power lines produce a significant amount of radiation and electro smog, which can crash computers and other electronics and may harm living beings [1]. A potential solution to this problem is superconducting wires. Superconducting power lines would have no Ohmic losses and would create much less radiation. However, refrigerating the power lines to a temperature where metals become superconducting is prohibitively expensive. By far, the most significant problem with power lines are cascading power failures. Regular power lines create a complex nonlinear network between power producers and power consumers, wherein large amounts of energy can flow in an erratic fashion with the speed of light. They can potentially focus their destructive power on a single infrastructure component and make it dysfunctional. This can make the energy flow even more violent and cause even larger damage, eventually the entire system collapses.

Problems with cascading failures and extreme sensitivity to noise are not new to electronic devices. When the first analog computers where built, engineers

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quickly noticed that they become unreliable when they exceed a certain level of complexity. Rubel [2] explained this observation with the theory of universal differential equations. When a nonlinear differential equation is of third order or higher and sufficiently complicated, there is a good chance that it can mimic any continuous dynamics with arbitrary precision, i.e., there is an initial condition where the corresponding solution matches any given continuous function. However, it also means that the slightest change in the initial condition or the slightest amount of noise in the differential equation leads to a very different solution. When an analog computer has more than just a few elements, they can be modeled with higher-order nonlinear differential equation and tend to be extremely sensitive to noise like universal differential equations. Consequently, the behavior of more complex analog computers can be erratic and unpredictable.

The only way to suppress this high sensitivity to noise is digitization. This may be the main reason why we are using digital computers almost exclusively today. Analog computers with a few components are still being used for signal processing. In fact, all signal processors are simple analog computers. However, larger analog computers appear to have no applications, mostly because of their complex unpredictable behaviors.

Today, we face a similar problem with analog network for power distribution and communication networks that are based on analog wires. In fact, many of the problems with conventional wires could be avoided with digital wires.

A digital wire is a wire which propagates only patterns of rectangular pulse with a fixed height and length. In most cases, a digital wire is a two-dimensional (2D) array of cells, where the length of the array is much larger than the width. Each cell has an energy rich on-state and a zero-energy off-state. Each cell in the on-state can move its energy to a neighboring cell and put the neighboring cell in the on-state. Therefore, an on-state can travel along the wire. Similarly, patterns of on-states can travel along the wire and propagate energy and information. Periodic patterns can transport energy efficiently. Patterns which move information are irregular.

Digital wires are hardware implementations of 2D cellular automata, and thus can be used as general purpose computers [3]. One could in principle load data and a program at one end of the digital wire and while the data are traveling along the wire they would "collide" with the program and be processed. The results of the computation would arrive at the other end of the wire. If the computation is done with conservative computer algorithms, the energy loss associated with the computation can be very small [4].

Digital wires are used by biological systems. Rasmussen et al. [5] suggested that the propagation of electrical pulses along neurons can be modeled with cellular automata. Thus, neurons can be considered digital wires.

There are many possible hardware implementations of digital wires ranging from an atomic scale to a macroscopic scale. On a macroscopic level, digital wires could be implemented as LC circuits connected with phase sensitive switches. For example, a power line could be divided into 10 mile segments, which are coupled by phase sensitive switches. Each segment of the power line is an LC circuit and can be considered a cell that stores energy. By opening and closing the switches between the cells, energy can be moved in a very controlled manner. On a microscopic scale, digital wires could be implemented as a network of nanocapacitors which are connected with transistors. In this case, the nanocapacitors store the energy temporarily. On an atomic scale, digital wires could be implemented on large organic molecules, which mimic charge transport on photosynthetic molecules. In photosynthesis, electrons hop from atom-to-atom on a predefined path along the macromolecule. The sequence of atoms which guide the electron along the macromolecule can be considered as a digital wire. In this system, not only the time and space are discrete but the charge is discrete too—either there is no charge or there is the charge of one electron.

In summary, digital wires are more reliable than analog wires because they are insensitive to electric smog, cross-talk, and produce no echoes. Digital wires are useful in signal processing, since the speed at which the pulses travel can be easily adjusted, and the shape of all pulses is the same no matter if the wire is long or short. Analog wires are made of a bulk metal, and thus cannot move pulses in parallel, whereas digital wires can move information in parallel, even encrypted information. For example, a digital wire could be used in a computer to move data efficiently, with high-reliability in parallel from a memory chip to the central processing unit.

Finally, digital wires can be used as general purpose computers. There may no longer be any need for a central processing unit. It is conceivable that a future computer is just a network of digital wires, without a central processing unit, like a human brain.

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REFERENCES

1. Hubler, A. Homeopathic dynamical systems. Complexity 2008, 13, 8–11.
2. Rubel, L. A. A universal differential equation. Bull Am Math Soc 1981, 4, 345–349.
3. Wolfram, S. A New Kind of Science; Wolfram Media Inc.: Champaign, 2001; p 693.
4. Leporati, A.; Zandron, C.; Mauri, G. Conservative Computations in Energy-Based P Systems; Springer: Berlin, 2005.
5. Rasmussen, S.; Karampurwala, H.; Vaidyanath, R.; Jensen, K.S.; Hameroff, S. Computational connectionism within neurons: A model of cytoskeletal automata subserving neural networks. Physica D 1990, 42, 428–449.

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