GILDER TECHNOLOGY REPORT

November 2002 / Vol. VII No. 11

Getting Physical

The digital camera chip involves twenty chips to do the combination of photodetection & processing that a single-chip system from Foveon will soon perform

Inside:

The rise of digital electronics is the paramount industrial feat of the twentieth century. At the heart of this development is the movement that I have called the overthrow of matter. It is symbolized by the microchip, which Gordon Moore observes has long been made of the three most common substances in the earth's crust: silicon, aluminum, and oxygen. Although subsequent refinements have added trace elements of many other rarer chemicals, the most valuable element in the chip remains the idea for the design.

Extending the overthrow of matter beyond the Microcosm is the technology of fiber optics. Functioning through the massless movement of photonic energy, the global telecommunications network transmits more valuable cargo than all the world's supertankers. Nicholas Negroponte in his bestselling book *Being Digital* memorably announced this process as the movement of the economy from atoms to bits, with atoms representing the smallest unit of mass and bits representing the smallest unit of information.

Another way of couching this theme of an overthrow of matter is as a great divorce: a digital separation of the logical processes, the algorithms of computation, from the physical substrate of the computer. Transistors are complex four-dimensional structures made of atoms with electrical, chemical, and physical properties changing over time. Every one is different. Operating at the physical layer, chip designers had to optimize every transistor. As the number of transistors on one chip mounted toward the millions, Carver Mead saw physical layer design would become impossible. It would be necessary to divorce the design from its material embodiment. Designers would not work directly with transistors and their physical characteristics. They would not optimize the device physics; they would optimize the digital logic. They would manipulate prefabricated functional modules placed and routed by powerful design tools.

Expounded in his canonical work with Lynn Conway, *Introduction to VLSI* (Very Large Scale Integration), which I found in the tiny desktop bookcase of every Silicon Valley engineer and CEO as I researched *Microcosm* in the early 1980s, Mead and Conway introduced the crucial concept of hierarchical design. This conceptual tower of nested modules, each one an abstraction from the level below, made very large scale integration of microprocessors possible.

Seeing that no mind or machine could organize the billions of transistors and related devices in the coming age of complex single-chip computers, Mead and Conway contrived design tools using a set of prefabricated functional modules with simple interfaces between them, optimizing at the functional level with previously perfected modules, such as arithmetic units, memories, and finite-state machines. Rendering the design "right by construction," this hierarchical system is now the basis of the entire digital industry that enriches the world with a trillion dollars' worth of annual revenues. Made possible by this digital divorce were the personal computer, web browser, digital cell phone, digital video disk (DVD), the digital camera, the industrial robot, the Internet router and switch, and a thousand other common devices that are profoundly shaping the balance and bias of global power.

In Mead's hierarchy, the millions of transistors congeal into an abstraction called a module that combines with other modules to become a still more abstract functional bloc, which is integrated into a processor, and in turn is reduced to an instruction set that is addressed by software such as operating systems and applications. Linked to the world by some array of sensors or detectors, the computer or camera thus consists of transistors at the bottom, but everything else is a mathematical abstraction. Combined into Boolean-logic gates, subsumed into finite-state machines and arithmetic logic units, memories and graphics processors, integrated at board-level on "buses" and run by an operating system and applications, the computer is a logical construct only arbitrarily made of silicon or any other material.

As computer designer Danny Hillis observes, "Current day computers are built of transistors and wires, but they could just as well be built, according to the same principles, from valves and water pipes or from sticks and strings." From the application software, the cascade proceeds down the chain of abstractions in the other direction as the software code is translated by further programs called interpreters and compilers into instruction sets and machine languages that the transistors can read at the input end and that are translated at the display by digital-to-analog converters mapping the outputs onto a screen.

This circular logic conceals a hierarchical problem. Climbing the ladder from the physical layer at the bottom, where real world inputs are collected, information is lost at each level. But as information is lost, power is increased. The model of the world distilled at the physical layer is a paltry and flat sketch of reality. But at the control panel at the top of the hierarchy it is the only world there is. Content falls away, distortions creep in, and the system becomes more complex and less predictable. The computer's output or the camera's image—their colors and proportions and scale—diverge in critical ways from the real world.

Buying time

As messages become more potent and trigger more intricate cascades of effects, there is an explosion of information "entropy" (Claude Shannon's measure of effective content). But information accuracy erodes. Internal coherence and predictability increase. But interactions multiply in the mesh of hardware and software and cause combinatorial explosions and chaotic recursions. Finally at the top you reach a 25-bit-per-second human brain baffled by Windows of high complexity and low visibility: the pilot in the Airbus facing the digital-panel paradox in which complexity and unpredictability trump efficacy in a 40-million-line tower of nested software subroutines as the plane tumbles from the sky.

The digital paradox mirrors a profound professional deformation. The computer scientist finds that the hierarchical model resonates with his deepest sense of the universe itself. All computers, so he believes, including the human brain, can be reduced to universal Turing machines, the ultimate model of computation conceived by British genius Alan Turing, who proved that given enough time and tape, cycles and memory, any computer could simulate any other. Your humblest PC could reproduce the computations of the most advanced supercomputer. A contrivance of strings and springs could simulate the human mind. Stephen Wolfram and Edward Fredkin, among others, conclude that the ultimate universal Turing machine is the universe itself. Biological evolution emerges through time as a deterministic process computed in a program called a cellular automaton that is reducible to a Turing machine. Given the initial conditions, given enough time and tape, given cellular automata reified and information massified, given a series of heroic extrapolations from a big bang or a primordial soup, given infinite multiple parallel universes, you can explain anything. Science spurns its fealty to the empirical world and adopts a fictive role of inventing new worlds.

These projections are vain and vaporous. Given enough time, anything can be computed. So what? Time is precisely what we lack. As it is, we cannot model how the brain of a fly enables it to elude the swatter, let alone reduce the human mind to a Turing plot. Materialist critics respond that it is only "in principle" that they claim the human mind or the visible universe could be modeled as a Turing machine. But as Carver Mead replies tersely, "No. In *principle*, these physical phenomena cannot be modeled. . . . The simplest representation of the galaxy *is* the galaxy." A computer that could sample it would have to have time and tape exponentially greater than the galactic span. "The computer scientists must have been nodding off in class when they explained the sampling theorem."

From logic to life

We are awed by the power and promise of digital electronics. But to consummate the system entails a new analog dispensation. Moving from digital to analog is like moving from a flat world of two dimensions to a multidimensional galaxy. Unlike digital, with its reductionist binary ones and zeroes that can be accurately extended toward the infinite, analog uses all the physical parameters of the device—its timing, its chemistry, its electrical currents and voltages, its capacitances and inductances. As Mead would prove at **Foveon**, analog could even exploit the device's parasitics and its noise, its unwanted bugs and bad behavior. Using the entire panoply of four-dimensional physics and chemistry on the chip would create huge problems of control and regulation. It would prohibit the long serial chains of flawless logic that digital could pump out at billions of cycles per second. But by employing new parallel architectures, an analog VLSI, Mead could contrive new systems that vastly outperform digital for many applications. Now Mead's analog VLSI turns out to be the most powerful technology of early twenty-first-century electronics.

For twenty years, while the profession moved from messy analog to messianic mathematics, from life to logic, Mead has been going in the other direction. Seeking life, he urges us back to a contemplation of the *givens*: "Listen to the technology and find out what it is telling you." He has sought a regeneration of information systems based not on ever taller skyscrapers of complexity but on a return to their roots in the physical layer, the foundations of material physics and biology, from which all digital functions ultimately derive. Digital logic makes sense but sensory logic is not digital. From his neuromorphic research program at Caltech have come new, more-advanced analog technologies that will enhance the sensory powers of computers as massively as the microprocessor enhanced their logical and calculative powers.

Unlike Hillis's Thinking Machine, Connection Engine, or other supercomputer, the Foveon X3 chip could not be made of valves and water pipes, sticks and springs. A silicon device, it enables a single-chip still and motion camera that can produce images of an accuracy unparalleled in existing cameras precisely by embracing silicon's unique physical properties as a processor of light. It enables pictures of airport throngs or stadium crowds in which every face can be recognizably resolved. It enables throwaway surveillance cameras with as high resolution as advanced professional cameras today. Rooted in a new understanding of the silicon image plane, the Foveon camera is merely the first and most devastating current fruit of Mead's research agenda, which embraces new breakthroughs in a range of recently intractable areas, from speech recognition to national security.

Analog rising

Embodying a new analog strategy that can be applied all across the universe of information systems, this achievement reflects a great paradox of the computer age. The microchip is by any reasonable measure the most important practical outcome of modern physics made possible only by an intimate understanding of the inner life of matter. Yet the supreme end to which the microchip has been directed since its creation has been to sunder our ties to the unpredictable chaos of the physical world, while creating virtual worlds that remain under our control. The most charming and seductive achievement of computer science was to eclipse the physical layer, to render the physical processes of computing ever more irrelevant to the act of computation. This was explicitly Turing's program, and it succeeded overwhelmingly. Computer scientists don't think about silicon. You can pore over the indexes of the seminal texts in the field, such as David Patterson and John Hennessy's *Computer Architecture: A Quantitative Approach*, and not find a single mention of the material that has become the physical substrate of the global economy.

Why are we bringing up a generation of kids who don't know physics but know everything about Windows?

This determination to eclipse the physical layer made Carver Mead's agenda of using neuromorphic models to design electronic devices so radical when it was announced in the early 1980s, and makes it even more revolutionary today now that it has come to amazing fruition. Carver was talking about creating a retina chip based on actual exploration of the physiology of the human retina, inspired by the work of Max Delbruck, the Nobel laureate physicist Carver studied with early on.

Delbruck focused Carver on transducer physiology as the key to the next generation of computation. Comprising all the transitional processing that transforms some outside input into significant signal in the brain—or the computer—transducer physiology is the heart of thinking and perception and pattern recognition and all the processes of the very physical brain, by which computers can be linked to real-world phenomenon.

Yet it is ignored by all the books on computer science written by the most formidable and exalted minds in the field. Computer scientists dismiss the science of inputs as relatively insignificant. If you are a computer scientist you assume that the inputs are fine—"that's not my department"—and then you show that digital electronics can do anything better than analog electronics, which supposedly settles the question.

This may seem like a purely theoretical issue or academic dispute, but the whole domain of information science—the entire infrastructure of information technology—now suffers from this decision to eclipse the physical. The hypertrophy of the digital idea is reaching a crisis with very real practical consequences. The resolution of that crisis is in a resurgence of analog processing. To the extent that resurgence is seen as threatening an information science establishment whose most fundamental principle is to deny the legitimacy of physical considerations in computing, it will be resisted. But in its success is the future of the information industry and the global economy.

TELECOSM TECHNOLOGIES

Corvis (CORV)

WDM SYSTEMS, RAMAN AMPLIFICATION, EDGE SWITCHES

November 26: 0.94 52-WEEK RANGE 0.47-3.69 MARKET CAP: 388M

GIG-BE—Focusing on information and communications as key elements in national security and defense, the federal government announced plans to build the world's largest, most advanced optical network. Named GIG-BE, Global Information Grid Bandwidth Expansion, the network will require end-to-end bandwidth management, instantaneous bandwidth on demand, information assurance, and transparency. Corvis has bid on the project and their advantage is clear. Today's networks cannot provide the functionality and performance needed by the government and are simply too expensive to build and operate. When compared to a Corvis optical network, one year of conventional leased services would pay for a new optical network with 10x lit capacity as well as seven years of operational costs.

JDS Uniphase (JDSU)

ACTIVE AND PASSIVE OPTICAL COMPONENTS

November 26: 3.31 52-WEEK RANGE 1.58-12.05 MARKET CAP: 4.7B

All's quiet at the leading manufacturer of optical components. We'll keep you posted.

Avanex (AVNX)

ADAPTIVE PHOTONIC PROCESSORS

November 26: 1.55 52-WEEK RANGE 0.63-8.79 MARKET CAP: 107M

ENGLE OUT—Chairman Walter Alessandrini has been named to the additional role of CEO, effective immediately. He succeeds Paul Engle, who had served as president and CEO since July 2001. Engle was brought to Avanex for his prowess in volume manufacturing; however, the prolonged downturn has forced the company to shift its focus away from manufacturing, back toward innovation. We view this as a positive step.

Ciena (CIEN)

METRO WDM PLATFORMS

November 26: 5.98 52-WEEK RANGE 2.41-21.19 MARKET CAP: 2.6B

CONSOLIDATION CALL—Acquiring ONI solidified Ciena's metro offering in what has become known as the "less bad" optical market segment. Chairman Patrick Nettles continues to foresee similar consolidation of both carriers and equipment vendors as fundamental to the return of optical systems market growth.

New Reality: While Ciena continues to believe that the economics of carrier networking favor an all-optical topology, the company has invested in two ATM switch vendor start-ups, namely, Equipe and Wavesmith. The RBOCs will continue to invest in ATM for the next few years, and Ciena is seeking to broaden its product offering to better penetrate this account base.

KEY

DEBT WARNING
CASH RICH — $
INTELLECTUAL PROPERTY — ©
IPO WATCH — IPO
NEW ADDITION TO LIST — +
MERGER & ACQUISITION — M&A
TECH BREAKTHROUGH
ADDITIONAL FINANCING
CUSTOMER WIN

Essex (ESEX.OB)

OPTICAL PROCESSORS

November 26: 2.57 52-WEEK RANGE 1.50-8.25 MARKET CAP: 20M

WE'VE GOT PRODUCTS—Revenues of $1.6 million during Q302 compared to revenues of $745,000 for Q301 signify Essex's ongoing transition from stealthy WDM innovator to end-market participant. With the large costs of initial development largely behind them, the company is shifting its focus and spending toward the promotion and management of its commercial optoelectronic technologies. Further evidence of this transition came with the announcement that the company had won a telecommunications services contract and subsequently formed the Communications Services division that will generate a minimum of $3 million in annual revenue.

StorageNetworks (STOR)

DATA STORAGE MANAGEMENT, SOFTWARE

November 26: 1.44 52-WEEK RANGE 0.82-8.10 MARKET CAP: 143M

STOR announced the creation of two branded service offerings, "Storage Metrics Evaluation" and "Enterprise Storage Utility Planning and Design," designed to assist large companies evaluate their current storage infrastructure. Separately, the company also launched a backup module for its STORos StorageManager software, which aggregates reporting information from various tape backup management software applications, allowing centralized backup management.

Scale Eight

MASSIVELY PARALLEL GLOBAL STORAGE

PRIVATE

Melinda Gross has been named VP of sales, focusing on Scale Eight's new NAS systems. She's an old cohort of new CEO Bo Ewald, from their days together at SGI, and she has since spent two years at Network Appliance. Melinda has been very successful selling into high-performance computing environments.

Mirror Image Internet

GLOBAL CACHING AND STOREWIDTH PLATFORM

PRIVATE

The NYC Marathon Web site used Mirror Image's instaContent delivery service for the third consecutive year to distribute fresh content and images to marathon enthusiasts worldwide. The site receives 1.8 million hits per day during race month, and on race day traffic swells to more than 12-million hits.

Equinix (EQIX)

SECURE INTERNET BUSINESS EXCHANGES

November 26: 0.34 52-WEEK RANGE 0.19-3.53 MARKET CAP: 34M

Asian telecommunications stalwarts, Chunghwa Telecom and Japan Telecom, joined the Equinix aggregation of networks with a presence in the Los Angeles area Internet Business Exchange (IBX) center. Equinix also announced the expansion of its GigE Exchange service. GigE Exchange facilitates ISP and content data traffic exchange among Equinix customers via a gigabit Ethernet central switching fabric and is currently available in five IBX centers.

MEAD'S ANALOG REVOLUTION

NATIONAL SEMICONDUCTOR (NSM)
SYNAPTICS (SYNA)
SONIC INNOVATIONS (SNCI)
FOVEON
IMPINJ
AUDIENCE INC.
DIGITALPERSONA

COMPANIES TO WATCH

ANALOG DEVICES (ADI)
AVISTAR (AVSR)
COMCAST (CMCSK)
COX (COX)
ENDWAVE (ENWV)
POWERWAVE (PWAV)
SAMSUNG
SEMITOOL (SMTL)
XILINX (XLNX)

Sprint PCS (PCS)

NATIONWIDE CDMA WIRELESS NETWORK

November 26: 5.46 52-WEEK RANGE 1.75-27.50 MARKET CAP: 5.5B

AWAKENING ENTERPRISE—Pointing to the relative immaturity of mobile data solutions, a recent report from Aberdeen states that enterprise users are increasingly beginning to realize significant and quantifiable benefits from this nascent technology. As this awareness grows and more enterprise IT managers look to outfit their sales forces, field service engineers, and executives, Sprint PCS's combination of the most advanced and robust data network and handsets, such as the Handspring Treo 300, keeps PCS well positioned.

Smile: Sprint PCS unveiled the first built-in camera phone available to the U.S. market. The Sanyo 5300 sports a digital zoom and portrait flash as well as an incredibly vibrant screen supporting 65K colors.

Qualcomm (QCOM)

CDMA INTEGRATED CIRCUITS, IP, SOFTWARE

November 26: 41.90 52-WEEK RANGE 23.21-62.25 MARKET CAP: 33B

CONSUMMATE QUARTER—Qualcomm exceeded lofty expectations, then instantly raised the bar another notch forecasting sales of 25-27 million chipsets in fiscal Q103. CDMA2000 1x chipset demand is just beginning to grow in earnest with 75% of the chipsets shipped this quarter being 1x compared to 69% in the previous quarter. Only 10% of Verizon Wireless's 30 million subscribers are using 1x devices, and even the most mature CDMA2000 1x carrier, SK Telecom, has upgraded slightly more than 50% of its base. A handset upgrade cycle that had stalled over the past couple years is springing back to life with the advent of data-enabled phones with color displays, embedded cameras, location-based services, and longer battery life.

Qualcomm has established a beachhead into the European market with news that Vodafone is testing handsets using the MSM 6300 series chipset. This solution would enable GSM/GPRS Vodafone subscribers to roam onto Verizon Wireless's CDMA2000 network, of which Vodafone owes a 44% stake.

Soma Networks

BROADBAND WIRELESS ACCESS, NETWORK SOFTWARE

PRIVATE

Broadcom (BRCM)

BROADBAND INTEGRATED CIRCUITS

November 26: 20.00 52-WEEK RANGE 9.52-53.35 MARKET CAP: 5.5B

GAME OVER?—Speaking at the UBS Warburg Telecom Conference, Broadcom stated its domination of wireless LAN (WLAN) design win opportunities in the notebook market. Though not willing to go as far as Henry Nicholas's often-used phrase "game over" when discussing the competition, the companies WLAN presence in Dell has been confirmed. Broadcom also asserted that it held a greater than 70% share of the Fast Ethernet market and a greater percentage than that of the Gigabit Ethernet opportunity. Broadcom claims some 300 Gigabit Ethernet design wins to date with product shipping to customers such as Cisco, Dell, HP, IBM, and Nortel, among others.

Synaptics (SYNA)

TOUCH-SENSORS, FOVEON IMAGERS

November 26: 8.75 52-WEEK RANGE 3.13-20.75 MARKET CAP: 204M

Synaptics chose the COMDEX stage to unveil its new end-to-end biometric security solution. The company's OmniPass application software, bundled with Synaptics's Fingerprint TouchPad module, features single-touch log on allowing users to securely perform pre-booting and Windows authentication. For added security, the file encryption feature enables users to selectively encrypt and decrypt specific files such as e-mail and web sites.

Terayon (TERN)

BROADBAND CABLE MODEMS, HEAD-ENDS

November 26: 2.622 52-WEEK RANGE 0.86-14.75 MARKET CAP: 192M

OPPORTUNITY—By winning the DOCSIS 2.0 standards war, August 2001 became the most important point in Terayon's history; December 2002 has the potential to become the second most important if Terayon achieves DOCSIS 2.0 qualification for its CMTS and certification for its CM.

ARPU Extensions: Terayon unveiled its line of cable-modem extensions, which are external add-on devices that attach directly to Terayon's cable modems and allow cash-strapped operators the opportunity to initially deploy modems for high-speed Internet access. These add-ons allow the operators to then provide additional broadband services such as cable telephony and wireless home networking to subscribers as requested.

Altera (ALTR)

PROGRAMMABLE LOGIC DEVICES

November 26: 14.87 52-WEEK RANGE 8.32-27.59 MARKET CAP: 5.7B

CHINA BOUND—Xilinx, which already has one office in China, has opened a second in Shenzhen, a manufacturing hub for telecom equipment and electronic goods. Altera has opened a customer-support center in Shanghai and hopes to open a full-fledged design center in China as soon as two years from now.

Intel (INTC)

MICROPROCESSORS, SINGLE-CHIP SYSTEMS

November 26: 20.48 52-WEEK RANGE 12.95-36.78 MARKET CAP: 136B

Intel Communications Group (ICG) held an analyst day on November 12 stressing its continued goal of bridging the gap between computing and communications. Intel's much ridiculed previous efforts in communications have turned into fear among incumbents. The downturn of the last two years caused most companies to slash cap-ex and R&D budgets; Intel, however, has spent $11.7 billion in R&D and $18.7 billion on cap-ex from 2000-2002. This effort is impressive in both breadth and depth with the company targeting a multitude of market segments including: wireless networking, enterprise networking and storage, telecom/wireless infrastructure, and optical components.

CONTINUED ON PAGE 6

CONTINUED FROM PAGE 5

National Semiconductor (NSM)

SINGLE-CHIP SYSTEMS, ANALOG EXPERTISE, FOVEON IMAGERS

November 26: 19.64 52-WEEK RANGE 9.95-37.30 MARKET CAP:3.6B

SHOW STOPPER—National Semiconductor was the star of this year's COMDEX trade show culminating with CEO Brian Halla's highly anticipated keynote address. Halla discussed the coming chip recovery and boldly predicted the actual date that will mark the start of the next technology boom. Throughout the show, announcements of partnerships with the likes of Microsoft, Ericsson, and Foveon demonstrated the company's progress as an innovation leader. Several additions to National's family of microprocessors highlighted the company's focus on leveraging its core analog, wireless, and microcontroller technologies to address serious deterrents to end-market adoption, such as digital image processor delay, lack of comprehensive connectivity solutions for the embedded world, and debilitating power consumption in mobile phones and other handheld devices.

Image Integrator: National Semiconductor launched a CMOS imaging product line last spring; so far they have captured several design starts in low-end digital cameras and next-generation cell phones. Now they are introducing a complementary, highly integrated image-processing chip and accompanying software and design tools. Most sensor-only companies have had difficulties in the current downturn. National's higher value-added, integrated sensor/image processor strategy is the wave of the future.

EZchip (LNOP)

10 GIGABIT NETWORK PROCESSORS

November 26: 7.39 52-WEEK RANGE 3.79-16.45 MARKET CAP: 54M

Recent strength in LanOptics's stock price has returned the company to compliance with Nasdaq's national market requirements of a minimum $50M market value.

Texas Instruments (TXN)

DIGITAL, ANALOG, MIXED-SIGNAL PROCESSORS

November 26: 19.52 52-WEEK RANGE 13.10-35.94 MARKET CAP: 34B

One month into the current quarter, Texas Instruments reiterated its outlook but restated limited sales visibility. The company also shared that its 2002 R&D spending will come in at $1.6 billion.

Narad Networks

IPO

GIGABIT ETHERNET COAXIAL CABLE NETWORKS

PRIVATE

MO' MONEY—Narad secured an additional $16.25 million during its Series B financing round, led by Bob Metcalfe's Polaris Venture Partners.

The Telecosm Technologies list is not a model portfolio. It is a list of technologies in the Gilder Paradigm and of companies that lead in their application. Companies appear on this list only for their technology leadership, without consideration of their current share price or the appropriate timing of an investment decision. The presence of a company on the list is not a recommendation to buy shares at the current price. Mr. Gilder and other GTR staff may hold positions in some or all of the stocks listed.

The digital dilemma

Why are we bringing up a generation of kids who don't know physics but know everything about Windows? Why are there entire nations such as India whose economies are increasingly devoted to this and other totemistic excesses of software? Why has software become the medium through which we deal with the physical world? We fly airplanes with software; our bombs hunt our enemies with software; we run switches with software whose annual upgrades are the single-largest operating cost in running a network. Across the global economy we ritualistically do in software, functions that could be far better accomplished with applications-specific hardware, the all-optical network being perhaps the supreme example.

The science of application-specific hardware has atrophied in part because every young information scientist is taught that the physical layer doesn't matter to the universal computer. But since the challenges the world gives us are messy, the decision to use a generalized machine to solve them necessarily entails a parallel and ponderous effort to represent the specificity of the world in the machine's terms—the software. Software is proverbially the bottleneck of the information economy—because under the Turing model that's where all the work is done.

Many crucial information functions are naturally digital. Digital is superior for storing as well as creating content.

And what work it is to represent to that universal computer all the problems of the world, natural and man-made alike, using a language that itself moves ever farther away from any physical primitive, rising above machine language to assembly language to ordinary programming language and thence to the hyper-programming language. And each level, no matter how great and complex the tasks it addresses, masks complexities that must ultimately be resolved on the chip by exploiting the tremendous processing clock-rates to accomplish hugely complex procedures.

The digital crisis is so pervasive we have begun to assume it as part of the background. Six-hundred-thousand bugs in Windows XP is a crisis. Winnowing them down to two-hundred-thousand bugs is a crisis that has gone chronic, to be coped with rather than resolved. Windows Home XP has some paradoxical bugs that can't be eliminated without transforming the program. Mega-software has reached some kind of wall, one manifestation of the crisis.

Another manifestation can be seen in Pentium as it moves up toward 60 gigahertz, which Intel now proposes as a feasible goal. Power increases linearly with clock-rate and exponentially with voltage. Voltage has declined to the point where it generates leakage faster than it relieves power consumption. So there is a real question of whether we can continue to increase the clock-rates that mega-software increasingly demands.

Sacrificing efficiencies

As hierarchical design, the very process that shielded us from the growing complexities on the surface of the chip, ascends multiple levels of abstraction it becomes impossible to test all the resulting designs in all their possible combinations. So you must incorporate built-in self-test (BIST), devoting more and more of the processor to testing itself, and even then you don't test it adequately. The tests become increasingly tests of interfaces. Since those cannot be fully assured as the chip gets bigger and bigger, you include a lot of redundant cells. The structures for incorporating the redundant cells become themselves increasingly complex. As this process advances, the device becomes increasingly suboptimal. At some point it becomes inferior to using a set of separate chips of a manageable size and modularity—reversing the essential teleology of the integrated circuit. But that doesn't solve the problem; it merely shifts the complications and conflicts to the bus.

At current speeds and densities, the universal clock doesn't work anymore, so you have to have separate clock pulses all across the chip, sacrificing many of the fundamental efficiencies of the digital system. Asynchronous designs are a partial and valuable solution. But in isolation every one of these problems can appear solvable. Taken together they entail a set of fundamentally irresolvable conflicts that suggests the whole digital endeavor is reaching an impasse. The clock problem, the power problem, the leakage problem, the interface problem, the pad-limited problem, the failure of memory technology to keep apace with processor clock-rates, so that most of the clock cycles are wait-states. All these together represent a technology in climacteric.

Moore's law in crisis

My colleagues *Dynamic Silicon* editors Nick Treddenick and Brion Shimamoto have been wandering around the office with graphs showing not that Moore's law is reaching the end of its run, but that its continuation may be irrelevant. They point out that the last four generation of chip geometries, 0.25 microns, 0.18 Microns, 0.13 microns, and now 0.09 microns (90 nanometers) account for only 20 percent of chips made by the major foundries such as **TSMC**. The adoption curves for the next cycle of Moore's law used to be nearly vertical—as soon as we could squeeze more circuits on a chip, everybody wanted the capacity. Today the adoption curves for new technologies are nearly horizontal, even though theoretically the marginal cost to make a 90-nanometer function on a 300-millimeter wafer is less than 20 percent of the cost of a 130-nanometer chip made on a 200-millimeter wafer.

We spent quite a bit of time in the office recently trying to explain this through the Clayton Christensen overshoot theory (the personal computer already overserves its real market), through mismatch theory (memories cannot keep up with the processor cycle times), and design complexity (design tools have once again fallen behind the complexities of single-chip electronics). In any case, it seems that the bounty of Moore's law which for so long appeared to drive the information industry is increasingly shunned. Whatever the explanation, the phenomenon tends to confirm the existence of a crisis of digitization.

Au naturale

Nothing so epitomizes the hypertrophy of the digital as the idea, even the phrase, *digital camera*. There is, after all, really no such thing. The digital camera is an oxymoron because the camera is just a basic transducer, addressing an analog problem. The camera's job is to take an incredibly complex image with all kinds of difficult features and dimensionality and proportion and light and color and very rapidly convert it to an accurate replica. That is fundamentally an analog mission.

The so-called digital camera has been an unsatisfying device, precisely to the extent that it attempted to recast these as digital functions. The standard digital camera starts with failure—by throwing away two-thirds of the image information. Measuring only one of three colors at each pixel, then attempting to compensate with massive, power-hungry digital processing, trying to create again the inputs nature gave us for free, the digital camera epitomizes the computer scientists' presumption that inputs don't matter because digital processing can fix anything.

Carver Mead's obvious but profound insight that eventually led to Foveon was to focus on silicon as a transducer, to perfect the input and minimize the digital compensation, rather than the other way around. He did this, or learned how to do it originally not by trying to build a computer that would be better than an eye, but to build an eye, actually a retina in silicon. To do this he had to embrace the silicon as the physical layer, to let it reveal its analog capabilities. The Foveon camera was the outcome not of an attempt to transcend analog processes or render them irrelevant, but an attempt to understand the best imager we know, the human eye. In that way, for all the technological virtuosity the project evoked over more than fifteen years of work, what ultimately distinguishes the Foveon project from the general trend of computer science is its sanity.

Many crucial information functions are naturally digital. Digital is superior for storing as well as creating content. What you wish to process and compute, functions that you want to control rather than simply communicate, all want to be digital. Far more interesting, however, is the long list of functions usually assumed to be essentially digital problems that could be handled better in analog.

Security, for instance. At the most basic physical level, photons are more secure than electrons. You catch a photon and it dies; you catch an electron and the diminished power is measurable at the other end. Thus tapping an optical line is both more readily detectable and far more difficult than tapping an electronic device. All-optical communications are inherently safe. They become insecure when they are repeatedly converted to digital forms that can be processed and manipulated. Whenever we insert opto-electronics into the network, we give handles to the hacker.

Every kind of system that has to deal with electromagnetism of any dimension is far better performed by analog devices than by digital processors

The most secure forms of identification we know about are all analog. Fingerprints, retinal scans. Nobody thinks of a fingerprint as a crackable code, until we reduce the rich analog image to simple digital renditions, at which point they can be counterfeited.

The new economy

Consider the digital camera vs. the analog electronic camera and the digital router switch regenerator vs. the analog all-optical network. The digital camera chip involves twenty chips to do the combination of photodetection and processing that a single-chip system from Foveon will soon perform. Similarly the router or electronic switch-driven network requires hundreds of thousands of devices to drive a signal across the country, where a **Corvis** (CORV) express network may use a few dozen.

Every kind of system that has to deal with electromagnetism of any dimension is far better performed by analog devices than by digital processors. All the Fourier devices that are critical to every kind of communications system become incredibly difficult exercises in computation when implemented in digital. A Fourier transform apes naturally analog and instantaneous processes that primitive systems such as your eyes and your ears and a prism accomplish continuously. Functions every raindrop can achieve are converted to an equation so complicated that in its unsimplified form it is all but uncomputable. Even supercomputers couldn't really do it until they simplified the equation heroically down to the Fast Fourier Transform (FFT) that functions well enough and can be implemented in DSPs in what approximates real time.

To identify particular calls in a busy cell, digital CDMA phone systems entail high-speed digital signal processing that consumes time and power and restricts the degree to which noise from other transmitters can be annulled. By comparison Terry Turpin's OPERA system, which does this processing in analog-optical form, is so powerful that, even after converting CDMA digital inputs to analog and back, time still remains to null out all competing callers and to give each user an effectively clear channel to the base station.

Throughout computer science, people are figuring out how to convert signals from analog to digital in order to process them more effectively, and here Terry is proposing with cogent evidence that it's worthwhile to convert digital functions to optics in order to perform Fourier transforms on them in real time. That's how much a reversal of the usual assumptions the analog alternative implies.

As analog, or relatively less digital alternatives (including digital functions specified in hardware) regain their natural role in information systems, and offer to relieve the digital crisis, information science and the entire silicon enterprise will be reordered to an extent not seen since the introduction of the microprocessor. Starting next month, a primary mission of this newsletter will be to propose the paradigms and uncover the opportunities that will govern, and profit from, the new analog economy.

—George Gilder,
November 27, 2002

GILDER TECHNOLOGY REPORT PUBLISHED BY GILDER PUBLISHING, LLC AND FORBES INC. • Copyright ©2002, by Gilder Publishing, LLC

291A MAIN STREET, GREAT BARRINGTON, MA 01230, TEL: (413) 644-2100, FAX: (413) 644-2123 • EMAIL: INFO@GILDERTECH.COM

EDITOR: George Gilder
EXECUTIVE EDITOR: Bret Swanson
ANALYSTS: Mary Gorski & John Hammill
MANAGING EDITOR: Marie Lavinio
ART DIRECTOR: Charles Bork
SUBSCRIPTION DIRECTOR: Rosaline Fernandes