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The Xanoptix Revolution

Xanoptix will enable the direct connection of hard drive buffers to optical fiber, reducing the size and power consumption of systems as dramatically as Intel's revolution of integrated electronics diminished the size and power consumption of components

Remember Josh Coates, star of stage and scene at Storewidth, our once rambunctious conference on the fertile interplay between bandwidth and storage? As founder-prophet of a company called Scale Eight, Coates touted a great simplification: using cheap standard parts to achieve global replication and distribution of data at superluminal speeds. Scale Eight's open-sesame software would run on a massively parallel clusters of Altair 8080s scrounged from dumpsters at the back of Fry's and interconnected by Berkeley issue quantum entanglement. That's how I recall it anyway. Everything gets murky and complicated when you step into the huge gap between the computing and storage capacity of electrons and the communications power of photons.

The merging of silicon and silica, crystalline and amorphous sand, microcosm and telecosm, has long proven to be a tantalizing challenge. As Carver Mead recently warned me, it is a problem on which many ambitious innovators "have broken their swords." Joining the two silicon elements, crystalline and amorphous, has long been my paradigmatic dream. The microcosm inscribes worlds on grains of sand; the telecosm spins grains of sand in webs of light around the world. What could make more sense than a merger of the two forms of silicon in new information architectures and topologies of storewidth?

Best fulfilling the first step—spinning silica into all optical networks—has been David Huber of **Corvis** (CORV) and its subsidiary Broadwing, launching the first national communications-system that transmits its contents entirely on wings of light. Now the industry is about to take the next step. In recent months, I have been investigating a company, long in stealth, that has been pursuing the paradigmatic agenda of coupling the processing prowess of microchips with the communications magic of optics. That company is **Xanoptix**, private company founded four years ago in Manchester, N.H. Xanoptix appears to be the first company to fulfill the dream of converging microcosm and telecosm in a new era of integrated electronics and optics. All venturers in the domains of bandwidth and storage—storewidth—whether in storage networks or in network processors, routers or servers, chips or systems, must come to terms with this new technology.

Governing our information economy are the constraints of information theory. Invented by MIT's Claude Shannon in 1948 to calculate the carrying capacity of any information channel in the face of interference and noise, it measures information as entropy: the element of "news" or surprise in a message. A transmission that tells you nothing you don't know is free of entropy. A series of newsworthy bits is high in entropy.

Emerging from information theory is a key law: it takes a low-entropy carrier to bear a high-entropy message. Unless the carrier is predictable and free of entropy, it will not enable the detection of a surprising message at the other end. The carrier must be free of surprise to bear indentifiable content that is full of surprise.

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Inside:

Information theory impels technology toward the simplest solutions, with the least noise and unpredictability. Under the pressure of this bias, the tides of new information, now more than 5 exabytes (10 to the 18th) annually, tend to gravitate toward the predictable carriers, the perfect sine waves of the electromagnetic spectrum from radio frequencies to light.

This global force of simplification, however, conflicts with a contrary trend toward growing complexity in electronic systems, as polyglot protocols, quality-of-service filigree, power-level cantilevers, transpedence mismatches, Rube Goldberg boards, buses and bridges, Gothic security featuritis, rococo material incompatibilities, acronymic excema, and software elephantiasis all push the industry toward combinatorial explosions of unpredictable "noise." In the midst of all the high-entropy software and hardware mazes, the creative surprises of enterprise and art sometimes fail to penetrate the blue screen.

Cheap simplicity

With 160 gigabytes of storage now available for $99, terabytes for under $600, and with petabits per second of optical bandwidth strewn across the land, Coates's vision of cheap simplicity seems to be coming into reach. The rub is connectivity across the murky micro-tundras between all that storage and fiber. That's storewidth, the interfaces between electronic storage and optical bandwidth, and they remain beset with needless complexity.

Populated with dense thickets of electronic shrubbery, this interface is a jungle of conflicting systems and protocols, technologies, and bureaucracies. It is linked by miles of microscopic metal wires feeding buses and converters, buffers and power drivers down the pins of chips or surface mounted devices and across printed circuit boards off to network interface cards on hubs and switches and routers leading to optoelectronic connectors and transceivers coupled to optical networks choked in the U.S. by a jungle of regulations from the FCC and from public utilities commissions in a hundred different jurisdictions in fifty different states. Although huge new developments in technology promise to tame the jungles of complexity in electronic and optical systems, the fastest growing industry in American telecom is still the communications bar with its acrobatic barristers swinging through the underbrush of bureaucracy in ever larger numbers, up 78 percent in seven years, driving much of the broadband economy to Asia, particularly Korea. With forty times more last-mile bandwidth per-capita than the U.S. and with a generation of cyber kids pumping out 3D images for multiplayer games from **NCSoft** (NCSCF.PK) or downloading TV programs from satellite feeds onto their **SK Telecom** (SKM) cellphones, Korea is the storewidth nation.

Meanwhile, the fastest growing broadband system in the U.S.—call it Broadband American Style—retreats to an artificial simplification that eschews the net entirely. With nearly free storage, any non-interactive program works best from local memory where it can benefit from the only reliable gigabit per second links: the PCI bus between disk and monitor in your PC and the UPS bus with its overnight deliveries of DVDs. As the top U.S. broadband delivery vehicles, **UPS** (UPS) and **FedEx** (FDX) do not exactly fit the paradigm. So this year the Storewidth conference had to be cancelled and Josh Coates disappeared into the would-work of an Internet archive "Petabox" project.

We had hoped for more. With his Billy Crudup prime-time looks and curly black hair, keynote T-shirts, world-record sorting algorithm, and $70 million of fast lane venture capital, Coates was a late nineties *Business Week* technology comer who made storewidth fun and even intelligible. "What do you do," he asked recently, "if you have unlimited storage and bandwidth and processing power." Citing the incredible plunge of the price of storage—now at about 60 cents a gigabyte, $600 a terabyte at Fry's—he asks the plausible question of why thousands of companies still spend as much as $360 thousand for 16 terabyte systems from **Network Appliance** (NTAP), **EMC** (EMC), or **Hitachi** (HIT).

Soon Isilon will go public and provide an attractive investment opportunity

His answer dramatizes the need for Xanoptix. Reducing the issue to a conventional make or buy decision, Coates takes you through the process of converting ultra-cheap simple storage into useable storewidth. First, find a rare super-tower PC at CompUSA, with room for six 200-gig ATA (industry standard) hard drives. Ply a screwdriver to the task of installing the drives. Finding only two ports on the motherboard's ATA controller, add an ATA controller card, attach it to the CD port on the first controller and cobble together a chain of disks on some ATA ribbon cables. In a matter of mere days, your new storage will show up on your computer as drives E, F, G, H, I, and J. With the installation of RAID (redundant array of inexpensive disks) software, the array blooms as a single logical unit, with the information striped across the multiple disks.

As Coates sums up: "Now you have got yourself 1.2 terabytes of storage, and it only took around a day of really tedious work. Excellent! Just 14.8 terabytes to go." It takes a week to grapple together 14 of these systems, interconnected through a cheap 100-megabit switch. Then you've got it. Right?

Well, no, says Coates, it is at this point that the real work begins.

"The last hurdle is getting your storage-hungry applications to access the storage." Applications access data in two ways: directly from the local host and indirectly via a remote host. The local host typically uses a direct-attached architecture like the disk drive on your desktop or it uses a special "fibre channel" chain of disks called a storage area network (SAN). Direct attached won't work because your application will be on one node and it won't know what is on the other 13. If you go for a SAN, you can get your single shared storage, but the tricky feature-rich circuitry and special English spelling of fibre channel will cost you the big bucks and you might as well let EMC or **IBM** (IBM) set you up in the first place.

Isilon wins

If you want cheap, you will have to use indirect access in software through **Sun's** (SUNW) Network File System (NFS) or **Microsoft's** (MSFT) Common Internet File System (CIFS), both of which can aggregate information in files across a network. Getting your application to recognize this data across 14 nodes will entail a lot more work. But don't worry; it's all SMOP (a simple matter of programming).

Coates's idea for Scale Eight was to do this programming for you, add a lot of Berkeley Distribution genius cycles and thus parlay cheap clusters of PC hardware from CompUSA or Fry's into a storage colossus. With especially ingenious SMOP, Coates and his team could create a global single shared memory across terabytes of data, distribute and replicate it on demand, and create a cheap storewidth solution.

Beginning with giant continuous files such as extended videos, x-ray images, medical records, TV streams, museum archives, photo-albums, songs, movies, and large database chunks, Scale Eight would ride the progress of technology on to the more lucrative enterprise applications that require quick accesses and responses. Soon even the primitive hardware of Scale Eight to move from megafile heavy lifting to lucrative fast dips into transactional databases such as IBM's DB2 or **Oracle** (ORCL). With the entire domain of storewidth covered, Coates's company could rule the world. We loved it. Angling for an investment edge for our subscribers, we wondered why it wasn't public yet, and recommended it for a WR Hambrecht auction like Google's.

Meanwhile, also at Storewidth conferences was Sujal Patel of **Isilon Systems**. Anyone recall him at all? Swarthy, "aw-shucks" slouch, hair conked by Seattle drizzle, with a serioso acronymic spiel about low-latency clustered storage, also accomplished with smart software run on industry-standard clusters of chips and disks. Like Coates, he spoke of beginning with big files and then moving to transactional storage as the industry progresses in accord with Moore's law. Recently escaped from **RealNetworks** (RNWK), where he designed its streaming solutions, Sujal was at Storewidth too, with ten minutes to give his pitch, along with the crowds of folks from companies with funny names like **Zambeel**, **SANcastle**, Cereva, **Sanrise**, **Ikadega**, and **YottaYotta**. You remember the storewidth throng with their billions of venture capital, nearly all to be wasted going for the big transactional markets held by industry leaders such as EMC and NetApp. Although Sujal was going to start with the big, slow files, somehow he did not stick out, and he was not asked back. We lavished all our ink on Coates and Scale Eight.

Guess who won? Scale Eight and the rest are long gone, their racks of disks and PC blades carted from the premises and their elite San Francisco digs mostly redone for restaurants storing greenery and bamboo furniture, with menus angled toward fast-dip Asian fusion cuisines. Vinod Khosla of Kleiner Perkins no longer hovers around their protocol stacks, proposing company names starting with X or Z, no longer revs up their TCP accelerators and shakes their money trees.

The winner and likely champion is Patel and Isilon. Hidden away in the shadows under the Seattle tower, it has forty customers for its low latency clusters of storage in a globally coherent memory cache. All the same guys targeted by Coates—fifty thousand hours of **Paramount TV** streams, **FotoKem**'s 13 terabytes of post production rushes, **Technicolor** with their multifarious SGI, Linux, Windows and Mac environments, Bill Gates's omnibus of 70 million photographic images at **Corbis**, **LexisNexis** with its 50 thousand new legal documents every day, an unnamed new customer buying hundreds of terabytes, bicoastal branches of **ABC** (DIS), East Coast (for newsroom graphics) and West Coast (for digital dailies in Win Media for TV)— first dabbled with Coates and then signed up with Isilon.

During the second half of 2003 and first half of 2004, its first 12 months with available product, Isilon shipped a petabyte of storage. At ten to the 15th, a petabyte is about one full day of global Internet traffic. The Isilon load comprises JPEGs of compressed photos, MPEG3 files of video, MP3s of audio, PDF documentary bitmaps, any big lumpy flows of data. Why did it win? One secret is making no effort at all to challenge EMC and NetApp for the transactional business. A second edge was modest initial goals. Isilon did not claim more than it could deliver.

Isilon's cluster architecture of networked personal computer blades brought inherent scalability. With every new increment of disk storage came new multiprocessing power from **Intel** (INTC) Xeon micros feeding huge arrays of dynamic random access memory (DRAM) chips onto which the files are loaded for fast reception or dispatch. Isilon ends up with ten times more DRAM than typical storage systems from NetApp. For example, a 25-terabyte system from Isilon commands nine gigabytes of battery-backed RAM; a similar NetApp FAS 960 offers 500 megabytes, almost twenty times less. With RAM a hundred times faster than disks, the RAM gives an Isilon system 20 gigabits per second throughput from any single cluster and file system.

Soon Isilon will go public and provide an attractive investment opportunity. But still the Isilon system is hugely complex, far from the simple combination of advanced software and standard electronics of the vision. Imagine if all the interfaces between all the thousands of chips and boards in an Isilon system could be collapsed into one integrated electronic and optical package that incurs a tiny fraction of the power and cost and achieves orders of magnitude faster throughput.

Electronics marries optics

That is the promise of Xanoptix, transforming all of electronics and accelerating every interface between storage and the fiber optics networks now spanning the globe. The Xanoptix process will enable ever-simpler solutions at ever-higher performance—low-entropy systems that can sustain the ever-higher complexity and entropy of the global information economy.

The company was started in 2000 by John Trezza, a for-

TELECOSM TECHNOLOGIES

Advanced Micro Devices	(AMD)
Agilent	(A)
Altera	(ALTR)
Analog Devices	(ADI)
Avanex	(AVNX)
Broadcom	(BRCM)
Cepheid	(CPHD)
Chartered Semiconductor	(CHRT)
Ciena	(CIEN)
Corvis	(CORV)
Energy Conversion Devices	(ENER)
Equinix	(EQIX)
Essex	(KEYW)
EZchip	(LNOP)
Flextronics	(FLEX)
Intel	(INTC)
JDS Uniphase	(JDSU)
Legend Group Limited	(LGHLY.PK)
McDATA	(MCDTA)
Microvision	(MVIS)
National Semiconductor	(NSM)
Power-One	(PWER)
Proxim	(PROX)
Qualcomm	(QCOM)
Samsung	(SSNLF/SSNHY)
Semiconductor Manufacturing International	(SMI)
Sonic Innovations	(SNCI)
Sprint PCS	(PCS)
Synaptics	(SYNA)
Taiwan Semiconductor	(TSM)
Terayon	(TERN)
Texas Instruments	(TXN)
VIA Technologies	(2388.TW)
Wind River Systems	(WIND)
Xilinx	(XLNX)
Zoran	(ZRAN)

Note: The Telecosm Technologies list featured in the *Gilder Technology Report* is not a model portfolio. It is a list of technologies that lead in their respective application. Companies appear on this list based on technical leadership, without consideration of current share price or investment timing. The presence of a company on the list is not a recommendation to buy shares at the current price. George Gilder and *Gilder Technology Report* staff may hold positions in some or all of the stocks listed.

Advanced Micro Devices (AMD)

INTERNET COMPATIBLE PROCESSORS

JUNE 16: 15.24, 52-WEEK RANGE: 5.80 – 18.50, MARKET CAP: 5.39B

AMD said it would release a "dual core" microprocessor in 2005, probably beating Intel to market by several months. As processor and memory speeds continue to diverge and pin bandwidth fails to keep up, clock speeds do not deliver proportional performance gains. Thus the dual core strategies from AMD and Intel. As this June issue of the GTR shows, however, a tiny company called Xanoptix has developed a general-purpose technology that can break all the I/O bottlenecks across the semiconductor world, including those of large AMD or Intel microprocessors. Dual cores are thus likely to be a short-lived strategy, and both companies must adapt to the new IOIO (integrated optoelectronic input-output) paradigm.

AMD stock has held up well during the spring months, when many technology stocks have retreated 20-30%.

Agilent (A)

MICROCOSMIC OPTICS, CDMA POWERAMPS

JUNE 16: 26.07, 52-WEEK RANGE: 18.35 – 38.70, MARKET CAP: 12.55B

For the quarter ending April 30, the company reported earnings of $104 million on sales of $1.83 billion. The semiconductor, automated test, and life sciences divisions are all profitable, with operating margins in the 12-13% range. But test & measurement, Agilent's largest and best known division, continues to be barely profitable and to drag down overall results. The company says it's actively addressing these "performance issues" and expects test & measurement profits to match those of the other divisions by the fourth fiscal quarter.

More important, Agilent is aligned with the key technology in a new era of integrated electronics and optics (IEO). Made possible by over a decade of research and development by a team now assembled at small (but soon to be big) Xanoptix, the easy implantation of optical devices onto any silicon chip will eliminate the crucial I/O bottleneck that consumes the whole industry and change the way most semiconductors, circuit boards, and optoelectronic systems are designed and built. Agilent is a leading provider of the microscopic optical components used in the process, such as vertical cavity surface emitting lasers (VCSELs). And, although there is no official connection between Agilent and Xanoptix, Agilent CEO Ned Barnholt has given speeches celebrating what are key elements to the Xanoptix technology, particularly large arrays of implanted VCSELs.

Agilent will have competition, but its head start in this exciting new field should relive pressure on more mature product lines and propel it to new, higher-margin heights. The stock trades close to a 52-week low, down 33% from its highs earlier this year.

Broadcom (BCRM)

LEADING FABLESS BROADBAND DESIGNS

JUNE 16: 43.82, 52-WEEK RANGE: 19.81 – 45.00, MARKET CAP: 13.76B

Broadcom said it would acquire Zyray Wireless for $96 million in stock. Zyray designs baseband chips for single-mode WCDMA 3G mobile phones as well as dual-mode WCDMA-GSM phones. Based in San Diego, Zyray says it's the first to incorporate dual-antennas for WCDMA, increasing signal-to-noise ratio and cell capacity. We guess Zyray will be a second source to its San Diego neighbor Qualcomm.

Broadcom continues to churn out excellent products in tune with the market. It also remains well valued.

Equinix (EQIX)

STOREWIDTH STAR—WHERE STORAGE & BANDWIDTH CONVERGE

JUNE 16: 32.00, 52-WEEK RANGE: 7.50 – 37.54, MARKET CAP: 579.46M

In an expansion of an existing U.S. contract, Equinix's Asian operations secured a multi-year $10-million contract from IBM Global Services to host IBM's e-services in Singapore. The company added 82 customers in the first calendar quarter, including BellSouth, MCI Asia, Tommy Hilfiger, and Viacom, and sales grew 11% sequentially and 45% year-over-year. The company further reduced debt and expects quarterly interest expenses to fall from $1.6 million to about $550,000. In a signal of the U.S. government's reliance on Equinix, the company also announced an additional 95,000 square foot data center in the Washington, D.C. area.

After we reaffirmed our enthusiasm for the stock in the $26-27 range in late February, the stock took off to the mid-30s and has since held up reasonably well during a tough spring for technology. The company has minimized financial risk by reducing debt, expanded its product line, established itself as a major presence in Asia, and cemented long-term relationships with many of the world's largest network, content, and e-commerce companies.

National Semiconductor (NSM)

ANALOG LEADER AND IMAGER PIONEER

JUNE 16: 21.24, 52-WEEK RANGE: 9.19 – 24.345, MARKET CAP: 7.62B

National continued to exceed sales and profitability estimates, earning $126.4 million on revenue of $571.2 million in its fiscal fourth quarter ending May 30. Gross margins rose to almost 55%, an all-time high, and CFO Louis Chew said the mid- and long-term goal of the company is to achieve gross margins in the 60s.

Highly profitable analog products now account for 82% of sales. Power-management for mobile devices and consumer electronics is key to the company's growth and now accounts for 35% of sales, compared to 30% last year. According to research firm iSuppli, National is now the number one (and fastest growing) maker of power-management chips, pushing mighty TI to number two.

Although National supplies some power-management for high-speed backplanes, where we expect Power-One's (PWER) digital solution to take substantial share over the next few years (GTR, May 2004), most of National's power expertise is in smaller mobile products.

Although industry PC sales were somewhat flat in the quarter, wireless products (which account for 33% of National sales) continued rapid growth in unit volume and form-factor diversity, and National continued to put more products in more handset models.

Rising average selling prices, due to a richer product mix, boosted margins more than any other factor. Standard commodity products now account for just 13% of sales, compared to 16% last year. Capacity utilization continues at around 95-96%.

National continues to lead in driver and interface technologies for flat panel displays, recently introducing the PPDS standard (point-to-point differential signaling), endorsed by Samsung, that can support high-definition screens of up to 90 inches.

CEO Brian Halla said the company is also focused on increasing its data conversion product offerings, which today account for about 10% of sales. Sales into GSM wireless base-stations are growing, but more importantly, Halla says opportunities in new 3G CDMA base-stations appear promising, too.

During the quarter, the company repurchased $143 million in stock, bringing the total buyback for fiscal 2004 to $550 million. The stock is still attractively valued compared to its more expensive analog peers, though it probably won't resume a rapid rise like in 2003. We consider it a core semiconductor holding, blending safety with very good growth prospects.

Qualcomm (QCOM)

AIR KING—WORLD'S BEST TECHNOLOGY COMPANY

JUNE 16: 68.75, 52-WEEK RANGE: 32.85 – 69.86, MARKET CAP: 55.70B

Sixteen hundred software developers attended Qualcomm's BREW mobile software conference. Twenty-six device manufacturers now supply 140 BREW-enabled models to 30 operators in 21 countries, where by May 2004 some 30 million total BREW handsets had downloaded 130 million applications and services.

Despite continued upward revisions of financial guidance, a raft of new product offerings, and success in even secondary products like BREW, however, many analysts and investors worry that new technologies like WiMAX and Flarion's OFDM put Qualcomm in strategic jeopardy. We disagree.

Neither WiMAX nor Flarion achieve better results in the chief metric of spectral efficiency, or bits-per-second-per-hertz. Spectral efficiency largely determines economic efficiency for wireless service providers. A decade ago Qualcomm did claim, and prove, far higher spectral efficiency than the incumbent systems. By spreading transmissions over a wide band, using digital codes rather than time slots to differentiate signals, and employing sophisticated power control techniques at low power levels, Qualcomm's CDMA did substantially beat the current reigning technology of TDMA (time division multiple access, also known as GSM). The company accomplished Peter Drucker's rough rule of winning in a technology market by being 10 times better than the incumbent.

Intel is the key backer of WiMAX, and Nextel has juiced Flarion fans with a high-profile market test of its "flash-OFDM" system. Two heavyweights, to be sure. But neither system can claim anything close to the 10x advantage required to overtake the market. Some analysts claim CDMA2000 is bogged down "in the hundreds of kilobits range," while WiMAX, Wi-Fi, and OFDM offer many megabits of capacity. But the reverse is probably true. As Qualcomm upgrades CDMA2000 EV-DO to Release A, which offers 3.1 Mbps downstream and 1.8 Mbps upstream, along with 30 milliseconds of latency, all over many mobile square kilometers of coverage area, Wi-Fi remains a LAN (local area network) technology, WiMAX remains in the laboratory, now slated for action in 2006 or '07, and Flarion's chief marketing attribute is that it is not a royalty-reaping gorilla like Qualcomm.

In true gorilla form, Qualcomm just keeps executing. WCDMA, a 3G standard that competes with QCOM's CDMA2000, was once thought to be a threat. The Europeans and Japanese had engineered it to be as different from Qucalcomm's preferred flavor while still retaining CDMA's inherent advantages. But now QCOM has mastered WCDMA ahead of the competition, has 21 customers for its WCDMA chips (10 QCOM-enabled WCDMA handsets are due by year-end), and will soon integrate WCDMA with CDMA2000 EV-DO, GSM/GPRS, and Wi-Fi. The company projects the WCDMA handset market to grow quickly from 17 million in 2004 to some 45 million in 2005.

Meanwhile, Qualcomm is having trouble keeping up with chip demand from the popular South Korean handset makers and is said to be considering a deal with one of Korea's chip makers (Samsung? Hynix?) to produce chips closer to the handset factories.

Qualcomm appears well valued to the conventional eye. But its unique mix of low risk and high growth (lower risk than most believe, and higher growth prospects, likewise), along with a stunningly consistent history of execution, should make it a core holding in any technology investor's portfolio. Buy on any dip.

Terayon (TERN)

MOVING CDMA INTO CABLE

JUNE 16: 2.05, 52-WEEK RANGE: 2.03 – 2.12, MARKET CAP: 154.87M

Dual resignations of CEO and co-founder Zaki Rakib and COO Doug Sabella helped push the stock down to $2, a level not seen in more than a year. With a market cap of about $155 million, it trades at a price-to-sales multiple of just 1. Wall Street has never been partial to Terayon, a factor that has at times created buying opportunities. Sentiment is once again at a nadir and appears to be worse than the fundamentals and technology prospects would suggest. But despite intermittent flashes of promise, like the recent marketing deal with Juniper, and despite claiming all major U.S. cable operators as customers, Terayon management has never been able to inspire confidence. Even though Zaki Rakib will remain as chairman, are we to believe the Rakib brothers have thrown in the towel? Is there bad news just over the horizon? Or can a new CEO forge a new relationship with the Street and if nothing else push the stock back to a respectable level, which could mean returns from this level of some 200% or more?

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mer Stanford professor of electrical engineering who for more than a decade had been pursuing the long-elusive goal of integrating electronics and optics. Many entrepreneurs and academics misunderstand this goal; they see the challenge of creating optical chips or embedding optical devices onto silicon. From the SEED project at Bell Labs to the optical chips at **Bookham** (BKHM) in the UK to the stealthy new claims from **Infinera** in Silicon Valley, teams of engineers have repeatedly announced false dawns of optical

Intel's $4 billion wafer fabs are largely devoted to producing low margin on-chip memory cells

computing. All these claims involve the creation of optical transistors or other photonic logic devices on silicon or compound semiconductors.

All these efforts founder on the great fact of physics that for digital computing light is about as useful as peanut butter. Except in bizarre laboratory experiments, you can't stop or store a photon. You cannot even make a photon durably displace or affect another photon. Divide an optical signal down a tree of logical branches or Boolean operations and it drains away until there is no signal left. Traveling at the ultimate speed of physics, light was made by God for communications, not calculations.

Electrons, on the other hand, are superb for computing. Electrons durably affect one another. Their charges can be stored in memories. You can divide their voltages down a long cascade of logical branching operations without significant loss at the end. But for communications, electronics is inferior to spectronics—the use of the electromagnetic spectrum, from radio waves to light.

Trezza saw that there is no advantage in creating optical devices to displace the immense existing array of electronic computing gear. He leaves essentially unaltered all the logic and memory designs of the semiconductor industry, all the arduously developed microprocessors, gate arrays, custom ICs, DRAMs, and flash memories woven together in every electronic system. Instead, he set out to banish the electronic *communications* devices and input-output links on chips. It is these electronic channels that currently render the off-chip bandwidth of electronics thousands of times slower than on-chip bandwidth. To break the storewidth bottleneck entails banishing all the power drivers and pins, pads and coils and capacitors, buses and boards that slow the movement of data from storage to the network.

Chips get pinned down

Governing all existing electronic architectures are two constraints, called Amdahl's law and Rent's rule. Named after legendary computer designers at IBM—Eugene Amdahl and E.F. Rent—these two edicts still shape the topologies of electronic systems.

Amdahl's law decrees that *the performance of any computer is determined by the speed of the slowest component on its data path*. It doesn't matter how fast in gigahertz you make the internal clock rate of the Pentium; the speed of your computer will still be determined by the slower components that surround this microprocessor.

Moving the signals off the silicon surface, driver circuits boost the tiny electrical charges on the chip down the metal pins of the package that are the "legs" of the centipede-like device. Then these signals run out onto the expanse of the boards and backplane buses of the computer or the printed circuit cards of the mobile teleputer. All this takes time and power.

In this process, Rent's rule takes over. Rent's rule ordains that *the number of pins on a chip should rise by roughly the square root of the number of transistors. Otherwise a bottleneck arises*. Yet the industry has not managed to sustain a pace close to the requirements of Rent's rule. While the number of transistors rose from 7 million on a Pentium 2 to 178 million on a Pentium 4 and to over 300 million on new generation processors—a rise of a factor of 40—the number of pins eked up by a factor of four, with many of them devoted to ever-increasing power and ground connections, not data.

William Dally of Stanford estimates that between the mid-1990s and 2010, the number of transistors on a typical chip will rise about a thousand-fold while the number of pins rises tenfold. With millions of times more transistors than links to the outside world, the chip industry devotes an increasing proportion of every device to memory cells in an effort to bring the information closer to the processing devices. Today, 80 percent of an average logic chip is devoted to memory cells that serve as caches for data deemed likely to be needed for a calculation.

But cache hits are never 100 percent. Therefore the average processor still spends as much as 80 percent of its time in "wait states" standing by twiddling its flip-flops and shuffling its buffers while seeking data on off-chip memories. As Trezza points out, this means that Intel's $4 billion wafer fabs are largely devoted to producing low-margin on-chip memory cells and that microprocessors end up much larger than they would have to be without their hierarchy of caches. Larger chips are far more expensive to build because fewer can be put on a single wafer and fewer chips on a wafer means lower yields of good die in the manufacturing process.

The wages of Amdahl's law and Rent's rule affect every chip-based electronics design in the world, including all the designs done by our listed companies. For example, one of **EZchip**'s (LNOP) early breakthroughs that attracted it to us five years ago was its success in using an IBM process to embed hundreds of thousands of tiny DRAM memory cells on its network processor. All EZ's rivals, including Intel, used six to ten times larger static random access memory cells that are more compatible with the CMOS circuitry of logic devices. In the existing architectures, more on-chip memory means faster processing. Now EZ is moving from the IBM fab to a cheaper fab in **Taiwan Semiconductor** (TSM) that has succeeded in reducing SRAM cells to a small enough size to accommodate the EZ chip. But as on nearly all other complex microchips, most of the EZchip's silicon is still devoted to memory cells.

EZchip is sufficiently agile to benefit from the new technology. But all American electronics companies should be deeply exploring these new possibilities that will be rolled forth over the next five years. Connector companies **Tyco/AMP** (TYC) and **Molex** (MOLX) are already on board. But few American systems firms are paying attention. Intel still is engaged in building ever-more intricate and cantilevered copper cages for its microprocessors. Whether or not American companies enlist, major Chinese and Korean companies are sure to embrace a technology that would give them world leadership in electronics.

Rent's rule reflects deep constraints of information and network theory that manifest themselves even in biological systems. In his canonical book on *The Physics of VLSI*, Robert Keyes observes that the human brain also seems to follow the general relationships of Rent's rule: "The relation is extended to numbers of components in the nervous system, in particular the eye and the optic nerve that connects it to the brain, and the two halves of the brain [that link through] the *corpus callosum*, a body of nerve fibers that connects them." Keyes extends his logarithmic graph of Rent's rule computer gates and pins through data points for the more densely populated brain systems. The graph makes a straight line.

Although such analogies are only suggestive, the fact that two human eyes can perform more image processing than all the supercomputers in the world put together indicates some of the costs inflicted by the orders of magnitude more limited off-chip connective tissue of computers. The result in systems is Byzantine architectures, epitomized by any telco or cable hub or enterprise SAN, that employ intricate tower-of-Babel designs to compensate for the storewidth bottlenecks. The result in chips is a bias toward ambitious single-chip systems that combine processors, memories, and analog input/output in an extremely complex mix of incompatible elements. This trend is driving the industry toward a new and unfavorable Moore's law—the doubling of the cost of a wafer fab every four years—and a steady increase the sales volumes necessary to make a particular chip design pay off.

Xanoptix out of stealth mode

John Trezza and his team at Xanoptix are changing all this. Think of him as a new Robert Noyce. Working at **Fairchild Semiconductor** (FCS) thirty-five years ago, Noyce invented the integrated circuit and in 1969 was co-founder of Intel. Just as Noyce succeeded in aggregating previously separate transistors and other components on a single chip, Trezza has surmounted the even more formidable challenge of putting many chips in a single package and interconnecting them to the world with optical pins. Just as Intel could launch a "new era of integrated electronics," Xanoptix can inaugurate a new era of integrated electronics and optics (IEO). Trezza's breakthrough potentially closes the Rent's rule gap between on-chip and off-chip bandwidth.

Trezza's invention has two parts, joined in a seamless manufacturing system. Taking finished silicon die or wafers from any fabrication line, he can laminate them together in one package. Using a proprietary fusion process that overcomes all the incompatibilities among different semiconductors and metals, he implants one chip on the other. Thus he can replace on-chip memory with equally fast off-chip memory directly fused to the top of a microprocessor that in turn might be fused to a graphics processor or other silicon logic. Then he can fuse an optical die of gallium arsenide or indium phosphide with up to 300 thousand light sources and receivers onto the top of the laminar silicon stack for direct linkage to optical devices, such as a fiber optic network.

Let's call it laminar light technology (LLT). It laminates stacks of devices of any material, planar or lumpy, and then enables light links to the world. Thus it obviates all the power-hungry boards and buses, pads and drivers, on-chip memories and off-chip transceivers. It replaces them with a stack of chips incorporating an optical communications plane with up to eight million contacts per square centimeter. All the limitations of Amdahl's law and Rent's rule give way to connections as fast as the device's on-chip bandwidth allows.

The optical contacts can consist of vertical-cavity surface-emitting lasers (VCSELs), edge-emitting lasers, or light-emitting diodes combined with an equal number of photoreceptors. The non-optical connections are made through metal-filled vias or vertical tunnels on the edge of the device. Reaching down to the level where the pins would otherwise attach and eschewing power drivers needed to push signals down long off-chip wires, these vias and optical links drastically reduce the total time and power used by an electronic system. The vias play the role of board buses or connectors while the optics perform the function of off-board links, whether to other processors in a multiprocessor architecture or to fiber optics communications networks. Subsuming the printed circuit card, the backplane, the local area network, the metro area network, the wide area network is the chip area network (CAN), and it functions drastically faster, with radically less power at hugely lower cost than all the incumbent architectures of electronics.

Xanoptix currently calls its products "Hybrid Integrated Circuits," but this name suggests conventional hybrids that consist of silicon die linked together by their pins in a piggyback array or embedded in ceramic modules. All these different processes render the production of hybrids an exquisitely demanding craft ill suited for mass manufacture. With the devices combined directly in laminar stacks in batch mode often at the wafer level, Xanoptix hybrids transcend all the cumbersome crafting of metal pins, flip-chips, ball-arrays and other packaging contraptions (though it can work with any of them where necessary in legacy systems).

Their first products on the market are transceivers that take in electronic signals and send out optical signals. Currently on sale are modules for 72 fibers with each channel running at 3.4 gigabits per second, for a total throughput of 245 gigabits per second. Also available is an off-the-shelf electronic crossbar switch with its optical transceiver integrated in a single module. Done in conjunction with **Analog Devices** (ADI), **Vitesse** (VTSS), and **Velio** and several other unannounced partners, such products serve as demonstrations of the technology performing their functions in conventional architectures.

Soon, however, Trezza plans to realize his decade-long dream of eliminating most of the pins and boards from the electronics universe, replacing them with seamless Xanoptix connections. Fueled with some $80 million in venture capital the company perfected its technology in stealth mode over the last four years in its own clean rooms in New Hampshire. It is now preparing to move the process off shore, closer to the industry's existing foundries, and to project its breakthroughs into the public eye.

The revolution consists not merely of better connections for existing architectures but in the ability to batch process any devices from the semiconductor industry into architectures with no bandwidth or transpedance mismatches. Like human vision, the entire system should function at the processing bandwidth, with the data path of the processor extending out into the world with no delays and the world responding at its own speed of light.

Rather than waiting on the next-generation heroics of Intel and **Advanced Micro Devices** (AMD), **Samsung** and **Micron** (MU), **Seagate** (STX) and **Maxtor** (MXO), **Xilinx** (XLNX) and **Altera** (ALTR), **Broadcom** (BRCM) and **PMC-Sierra** (PMCS), Josh Coates and Sujal Patel should meet John Trezza. Xanoptix will enable the direct connection of hard drive buffers to optical fiber, bypassing all the thickets of converters and brambles of wire that currently infest the storewidth wasteland. The result will be a new era of integrated optics and electronics (IOE) that will reduce the size and power consumption of systems as dramatically as Intel's revolution of integrated electronics diminished the size and power consumption of components. This new era should expand the markets and wealth of the information economy as dramatically as the integrated circuit enhanced the markets and wealth of the computer industry.

Technology tends to follow cycles of complexity and simplification. Over the last decade, the industry has been undergoing a siege of complication, manifest in software operating systems in which bugs multiply faster than fixes, in routers and switches with ports and codecs for scores of protocols, in policy-based hubs with quality-of-service mazes that diminish the performance of networks, in motherboards and backplanes with thickets of electrical shrubbery, coils, resistors, capacitors, bricks, and transformers, in personal computer architectures with a data dance of buses and bridges and buffers, secondary and tertiary caches, pipelining and prefetching steps more complex than supercomputers of the past, in storage networks with more labyrinthine links than a biological brain—all leading to a combinatorial explosion of technology that can end by subverting the promise of the information age.

To bear the surprising messages of human creativity, information systems must be predictable and free of surprise. Emerging today is an array of candidate technologies for the simplicosm. Linux in operating systems, voice-over-IP in telecom, Ethernet switches in the enterprise, passive optical networks in the neighborhood, and all-optical backbones from Corvis/Broadwing. Xanoptix can be the most important of all, opening the way for optical networks reaching into every nook and niche of the information economy, simplifying every computer and storewidth system, and opening the way for a huge new upsurge of growth and prosperity.

—George Gilder
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