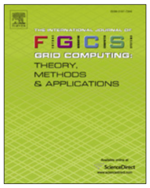
Future Generation Computer Systems 25 (2009) 109–113

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs



Editorial

# Special section: OptIPlanet — The OptIPuter global collaboratory

Larry Smarr [a,b], Maxine Brown [c,*], Cees de Laat [d]

[a] Department of Computer Science and Engineering, University of California, San Diego, CA, USA
[b] California Institute for Telecommunications and Information Technology (Calit2), University of California, San Diego, CA, USA
[c] Electronic Visualization Laboratory, University of Illinois at Chicago, IL, USA
[d] System and Network Engineering Research Group, University of Amsterdam, Netherlands

ARTICLE INFO

*Article history:*
Available online 14 August 2008

## 1. The OptIPuter and OptIPortals

The OptIPuter research project, so named for its use of *OPT*ical networking, *I*nternet *P*rotocol, and comp*UTER* technologies, was funded by the USA National Science Foundation (NSF) in 2002 for a period of six years [17,4]. The goal was to understand how to system engineer an "optical overlay" to the standard shared Internet, so that individual researchers could tightly couple computational resources over dedicated jitter-free 10 Gbps optical lightpaths, or "lambdas". Such "data superhighways" are needed because the shared Internet and World Wide Web are engineered to interactively handle megabyte-sized objects, whereas today's scientific instruments generate gigabyte- to terabyte-sized datasets. The OptIPuter project aims to make interactive access of remote gigabyte visualization data objects as easy as the Web makes access to remote lower-resolution images today.

This requires scaling up the termination device from a single PC, appropriate for the shared Internet, to a parallel cluster of PCs with tiled LCD displays (termed an *OptIPortal*), which provides much greater pixel display real estate, storage, compute power, and bandwidth I/O, while maintaining personal interactivity [20, 21].

By interconnecting scalable PC-cluster OptIPortals with lambdas, one creates "metacomputers" on the scale of a nation or even the planet Earth. The OptIPuter team has been led by the California Institute for Telecommunications and Information Technology (Calit2, a partnership of University of California, San Diego [UCSD] and University of California, Irvine) and the University of Illinois at Chicago's Electronic Visualization Laboratory, along with researchers from over a dozen campuses and multiple industrial partners. This research team has been extended to Amsterdam and other sites around the world. The details of the project and the several hundred publications can be found at www.optiputer.net.

The OptIPuter research team and its extended family of collaborators have developed new grid-computing paradigms – that is, new data and visualization techniques, middleware, transport protocols and optical signaling, control and management software – to enable applications to dynamically manage lambda resources just as they do any grid resource, creating a "LambdaGrid" of interconnected high-performance computer clusters, data storage devices, and instrumentation.

As the OptIPuter project transitions away at the end of this year, we are seeing the growth of international user communities who want to acquire and/or contribute to these high-performance computing and communications technologies that the core research team has developed. There are dozens of OptIPortals around the world, becoming interconnected by global optical networks, thereby creating a nascent OptIPlanet Collaboratory.

This special issue of FGCS summarizes some of the OptIPuter's developments to date, and looks to the future, as an OptIPlanet Collaboratory of virtual organizations in a variety of scientific and technology domains adopt, enhance and contribute to this evolving cyberinfrastructure to help solve complex global problems.

## 2. The OptIPuter: The network as backplane

The rapid build-out of fiber on land and under sea in the late 1990s, combined with the use of Dense Wavelength Division Multiplexing (DWDM) to allow multiple 10 Gbps lambdas to coexist on the same fiber, set the stage for the OptIPuter to be possible [12,20,21]. In particular, the National LambdaRail (NLR) [6] was formed in the USA as the wide-area interconnection to the many state and regional optical networks. NLR offers academics up to forty 10 Gbps lambdas, one of which is CAVEwave, which connects San Diego, Los Angeles, Seattle, Chicago, and Washington, DC, and has been extensively used by the OptIPuter project. The Internet2 is now beginning to offer similar services over its Dynamic Circuit Network.

---

[*] Corresponding address: Electronic Visualization Laboratory, University of Illinois at Chicago, 851 S. Morgan Street, Room 1120, 60607-7053 Chicago, IL, USA. Tel.: +1 312 996 3002; fax: +1 312 413 7585.
*E-mail address:* maxine@uic.edu (M. Brown).

0167-739X/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.future.2008.07.014

The USA dedicated optical networks are connected to innovation centers worldwide by the Global Lambda Integrated Facility (GLIF), shown in Fig. 1, which is a virtual organization, or facility, of network providers, network engineers, computer scientists and computational scientists [10,3]. These links provide researchers with guaranteed bandwidth for data movement, guaranteed latency for visualization/collaboration and data analysis, and guaranteed scheduling for remote instrument control, enabling international multidisciplinary teams to work together in an entirely new fashion. The network of interconnected optical wavelengths was first demonstrated at iGrid 2002 [5], and then more extensively featured at iGrid 2005 [19], where over 25 applications, many in development within OptIPuter, proved the viability of the GLIF concept.

With wide-area networks available, the current work is at the campus level, providing the "last-mile" connections between the regional or state optical networks, which end at a campus gateway, and the various researcher laboratories on the campus. As a complement to the OptIPuter project, UCSD received NSF funding for the Quartzite project, to investigate and compare campus-scale lambda network architectures that span from optical-circuits-only to packet-switched-only networks and a range of hybrid combinations in between. Quartzite connects over 500 individual cluster nodes on the UCSD campus with a novel switching core. OptIPuter and Quartzite preview what campuses need to evolve to: immense bandwidth, optical circuits on demand, and reconfigurable endpoint systems. Of critical importance is the evolution of large and network-capable storage clusters that can be accessed with clear paths from research labs scattered around campus [12,18].

With end-to-end optical paths, the OptIPuter project needed to develop an optical control plane — an infrastructure and distributed intelligence to control the establishment and maintenance of connections in a network (including protocols and mechanisms to disseminate that information), as well as algorithms for engineering an optimal path among endpoints. Whereas traditional control plane protocols and architectures are motivated by service-provider requirements rather than end-user requirements, future applications will make on-demand requests for end-to-end optical connections that regard endpoints as workstations, PCs, clusters, sensors, and instruments, as well as help them with their globally distributed collaborative efforts.

This awareness of the network as a prime resource has led to a sharper focus on interactions and interconnections among the optical control plane, Grid middleware, and the applications. Optical network resources are as essential and dynamic as CPU and storage resources in a Grid infrastructure, so the role of the optical control plane is essential for next-generation optical networks [7]. The OptIPuter's optical network backplane promises vastly increased transport capacity with predictable latency, determined largely by the speed of light, and development of new methods of provisioning that offer control of lightpaths, their characteristics, and traffic behavior to the application level [3].

Several papers in this special issue address these capabilities. OptIPuter partners at University of Amsterdam describe their work in: "Dynamic Photonic Lightpaths in the StarPlane Network" (Grosso, et al. [28]); "Path Finding Using the Multi-Layer Network Description Language" (Dijkstra, et al. [27]); and, "Multi-Domain Lightpath Authorization using Tokens" (Gommans, et al. [24]). Northwestern University, also an OptIPuter partner, discusses: "HD Collaboration, Control Plane/Optical Backplane, Optical Multicasting" (Mambretti [30]).

## 3. OptIPuter middleware

With these private optical paths being set up on-demand, they combine with end resources to form a Distributed Virtual Computer (DVC) [22]. The OptIPuter DVC middleware integrates a wide range of unique OptIPuter component technologies (high-speed transport protocols, dynamic optical-network configurations, real-time [9], and visualization packages) with externally developed technologies (Globus grid resource management services and security infrastructure) that are increasingly being adopted in the grid community. Our DVC middleware provides a simple, clean abstraction for applications and higher-level middleware, allowing them to easily use LambdaGrids by hiding the complexity of underlying geographically dispersed resources across sites. These sites may span multiple administrative domains, and enforce diverse resource management, naming, and security policies. However, to an application, the DVC abstraction makes this appear as a simple computing environment where the assembled resources are tightly connected via a reliable, private network and controlled under a single administrative domain. The DVC environment is described in the article "Integrated Resource Management for Lambda-Grids: the Distributed Virtual Computer" (Chien and Taesombut [23]).

## 4. OptIPortals: Terminating the lambdas

The OptIPuter project correctly saw PC clusters as the appropriate termination devices for the dedicated 10 Gbps "data fire hoses", which deliver as much as 1000 times the amount of data per second into a researcher's lab as researchers are now getting over the shared Internet. As a termination device, these OptIPortals need to scale in compute power, storage, and visualization real estate. The OptIPuter project developed and standardized on using tiled display walls driven by PCs with powerful commodity graphics cards. Linux clusters are managed by the SDSC Rocks software, but there are also OptIPortals which run Microsoft Windows or Apple OS. The article "The OptIPortal, a Scalable Visualization, Storage, and Computing Interface Device for the OptIPuter" (DeFanti, et al. [32]), describes the hardware and supporting software.

The Scalable Adaptive Graphics Environment (SAGE) visualization middleware was developed by OptIPuter partner Electronic Visualization Laboratory at the University of Illinois at Chicago. SAGE is essentially an "operating system" for tiled-display environments, letting users launch distributed visualization applications on remote computer clusters and stream the visualizations directly to tiled display walls of variable size, where they can be viewed and manipulated. SAGE can support collaborative scientific visualizations at extremely high display resolution [14].

Over the past year, a widely adopted OptIPortal framework developed at Calit2 by Kai-Uwe Doerr is the Cross-Platform Cluster Graphics Library (CGLX), which provides high-performance hardware-accelerated visualization on ultra-high-resolution display systems. CGLX was developed to enable scientists to write real-time graphics applications for visualization clusters, with the CGLX framework taking care of networking, event handling, and access to hardware-accelerated rendering, allowing users to focus on writing their applications as if they were writing them for a single desktop. CGLX is deployed on the world's largest OptIPortal, designed by UCSD's Falko Kuester, and hosted at Calit2 [13].

With the ability to integrate high-definition video streams into OptIPortals, global collaboration on analyzing complex visual representations of massive data sets is becoming a practical reality. For instance, SAGE Visualcasting supports global collaboration among OptIPuter partners by distributing the same ultra-high-resolution content to multiple endpoints over optical networks in real time, as well as enabling multi-point high-definition videoconferencing to multiple endpoints. This is described in the article "Enabling High Resolution Collaborative Visualization in Display Rich Virtual Organizations" (Renambot, et al. [26]).

However, OptIPortals are not limited to two-dimensional displays. A virtual-reality instantiation of an OptIPortal is described in the article "The StarCAVE, A Third-Generation CAVE and Virtual Reality OptIPortal" (DeFanti, et al. [29]).

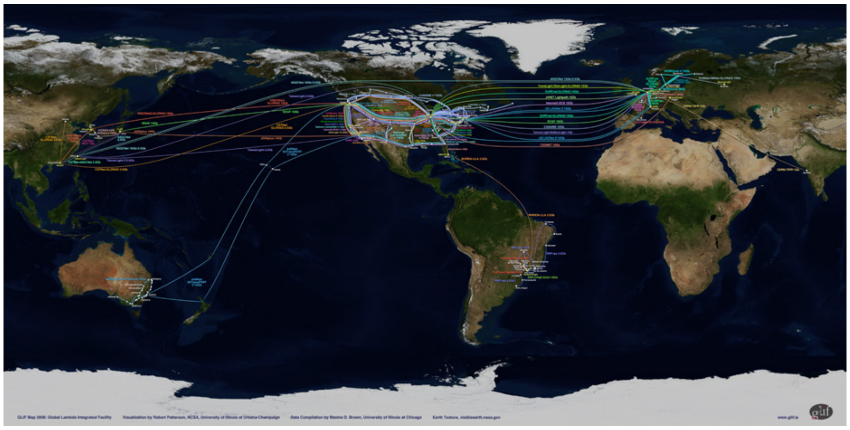


**Fig. 1.** GLIF Map 2008. Visualization was created by Robert Patterson of the Advanced Visualization Laboratory at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign, using an Earth image provided by NASA. Data was compiled by Maxine D. Brown of the Electronic Visualization Laboratory at the University of Illinois at Chicago.

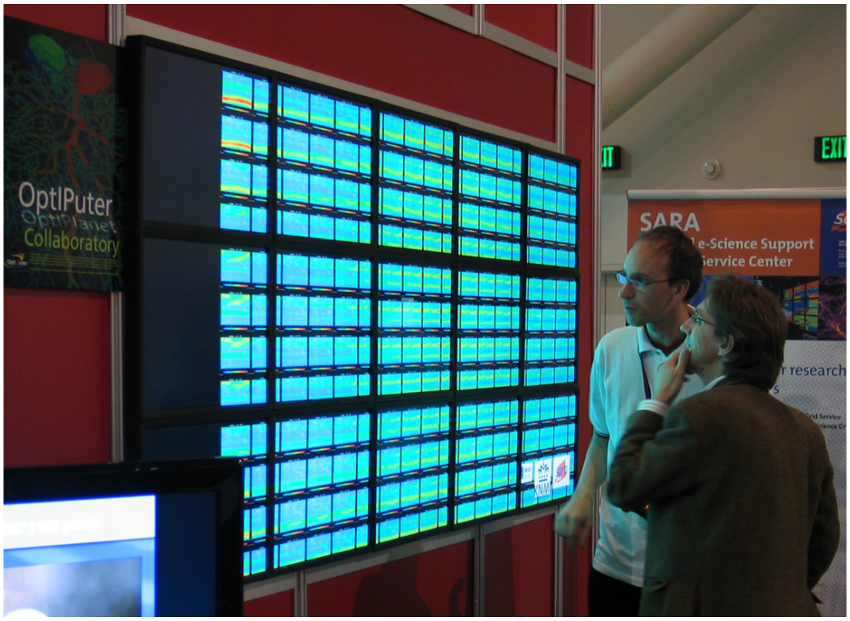


**Fig. 2.** SARA's ESSENCE, project, part of the DEISA Extreme Computing Initiative, computes a statistical estimate of internal climate variability to obtain a signal-to-noise ratio to better distinguish internal variability from the forced signal due to the increase of greenhouse gases. In large parts of the world, the observed warming over the last 60 years is statistically indistinguishable from the warming forced by increased greenhouse gas concentrations. This methodology is proving effective in both verifying the existence of known phenomena, such as El Niño, and finding possible new phenomena, such as superstorms and new modes of oceanic and atmospheric variability. SARA designed and implemented a web-based system so scientists could select a subset of the data, select a representation form, optionally perform statistical operations on the data, and then stream over lightpaths to a scientist's local OptIPortal.

## 5. Data, visualization and collaboration

As originally proposed, the OptIPuter had two major scientific drivers, the NSF-funded Earthscope (facilitated by UCSD Scripps Institution of Oceanography [SIO]), and the National Institutes of Health (NIH)-funded Biomedical Informatics Research Network (BIRN) (facilitated by UCSD National Center for Microscopy and Imaging Research [NCMIR]). We chose these two drivers primarily because it was virtually impossible for these science domains [8, 16] to do interactive analysis of remote multi-gigabyte data objects (e.g., a volumetric 3D brain image or a very-high-resolution 2D terrain dataset) over the regular Internet. Dedicated lightpaths, as well as more advanced data, visualization and collaboration software and hardware, were important outcomes to OptIPuter's success.

Therefore, during the OptIPuter research project, a great deal of emphasis was placed on efficient movement of large amounts of scientific data over uncongested lightpaths. It was shown that end users could routinely access 90% of the 10 Gbps bandwidth of a lambda on national or global scales [2]. This sets the stage for storage clouds discussed in the article "Compute and Storage Clouds Using Wide Area High Performance Networks" (Grossman, et al. [25]), which examines the limitations of traditional databases, particularly as they grow larger than a few hundred terabytes. It examines the value of data clouds, storage clouds and compute clouds optimized for high-performance, wide-area networks, and designed to support the ingestion, data management, analysis, and distribution of large terabyte-size datasets.

## 6. Enabling e-science

Computational scientists want to study and better understand complex systems – physical, geological, biological, environmental, and atmospheric – from the micro to the macro scale, in both time and space. This complexity means that no single researcher has the necessary expertise in all the disciplines required to analyze the data and solve the problem. Today's problem solving requires multi-disciplinary teams who, in turn, require new levels of persistent collaboration over continental and transoceanic distances, coupled with the ability to process, disseminate, and share information on unprecedented scales [1].

For example, ecologists want to better study entire ecosystems in estuaries, coral reefs, lakes and along coastlines. Biologists want to perform multi-scale, correlated microscopy experiments, zooming from an entire system, such as a rat cerebellum, to an individual spiny dendrite. Geoscientists want to explore the structure and evolution of the North American continent and understand processes controlling earthquakes and volcanoes. Atmospheric scientists want to model, analyze and predict severe weather patterns before they become natural disasters. Scientists and cinematographers want to explore the production, use and exchange of very-high-quality digital media over photonic networks. And, crisis management strategists want an integrated joint decision support system across local, state, and federal agencies, combining massive amounts of high-resolution imagery, highly visual collaboration facilities, and real-time input from field sensors. [11].

These researchers require considerable help to set up LambdaGrids supporting their multi-institutional science projects. To help with this, some supercomputer centers, such as The Netherlands' SARA Computing and Networking Services Center, now provides an "e-science support center", to assist its users adapt and apply advanced technologies to unique application challenges, as shown in Fig. 2. SARA is actively involved in several e-science efforts, notably bio-informatics, climate modeling and molecular biology, and the OptIPuter paradigm has provided them with new solutions and new ways to deal with data. Other e-science support centers are emerging around the world.

Over the life of this award, several new user communities, in addition to our original biomedical and geophysical imaging application drivers, are either using or in the process of evaluating OptIPuter technologies for their e-science applications.

One of the most advanced international user communities to adopt OptIPuter technologies is CAMERA, the Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis [15], a project funded by the Gordon and Betty Moore Foundation and under the leadership of Calit2/UCSD and the J. Craig Venter Institute; its development is chronicled in the paper, "Building an OptIPlanet Collaboratory to Support Microbial Metagenomics" (Smarr, et al. [31]).

NASA Goddard Space Flight Center became an early OptIPuter affiliate partner in order to better understand what new tools and techniques were required to optimize the use of advanced networks for severe storm forecasts. They are now working with the Electronic Visualization Laboratory at University of Illinois at Chicago to tailor OptIPuter technologies to facilitate the speed with which they compute global forecast models, as described in the paper "Accelerating Tropical Cyclone Analysis Using LambdaRAM, a Distributed Data Cache Over Wide-Area Ultra-Fast Networks" (Vishwanath, et al. [33]).

As high-definition (HD) video becomes ubiquitous, media-intensive entertainment, education and scientific applications are moving toward "4K" imaging, which is four times the resolution of HD. CineGrid [21], a non-profit, interdisciplinary community of scientists and artists, works closely with OptIPuter researchers on the research, development, and demonstration of networked collaborative tools for the production, use and exchange of very-high-quality digital media over optical networks. The group has accomplished many "firsts", and describes the first transpacific and transatlantic real-time transmission of uncompressed 4K animations in the paper "Real Time Switching and Streaming Transmission of Uncompressed 4K Motion Pictures" (Shirai, et al. [34]).

## 7. Conclusions

Lambdas are a simple means of achieving guaranteed quality of service; i.e., end-to-end deterministic, scheduled connectivity. However, dedicated lambdas allow OptIPuter researchers to experimentally dedicate entire end-to-end lightpaths and devote OptIPuter middleware research to enabling applications, rather than perfecting congestion control. In the same way, 20 years ago, software shifted from optimizing mainframe timesharing to human factors on workstations and PCs. Thus, the OptIPuter project is not optimizing toward scaling to millions of sites, a requirement for commercial profit, but empowering networking at a much higher level of data volume, accuracy, and timeliness for several advanced OptIPlanet Collaboratory virtual organizations working to solve complex problems of global proportion.

## Acknowledgments

Major funding for the OptIPuter is provided by NSF cooperative agreement #OCI-0225642 to UCSD. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the funding agency.

The OptIPuter is a $13.5-million NSF-funded project, for the period 2002–2008. It is enabling scientists who generate massive amounts of data to interactively visualize, analyze, and correlate their data from multiple storage sites connected via optical networks. University of California, San Diego and University of Illinois at Chicago lead the research team, with academic partners at Northwestern University; San Diego State University; University of Southern California, Information Sciences Institute; University of California, Irvine; Texas A&M University; and, University of Illinois at Urbana-Champaign, National Center for Supercomputing Applications. Affiliate partners include the US Geological Survey's National Center for Earth Resources Observation and Science, NASA, Purdue University, and University of Michigan in the US; University of Amsterdam and SARA Computing and Network Services in The Netherlands; CANARIE and Communications Research Center in Canada; the Korea Institute of Science and Technology Information (KISTI) in Korea; and the National Institute of Advanced Industrial Science and Technology (AIST) in Japan. Industrial partners include Big Bangwidth, Calient Networks, Chiaro Networks, Cisco, Glimmerglass Networks, IBM, Lucent Technologies, Rincon Research Corporation, Sun Microsystems and Telcordia Technologies. For more information, see www.optiputer.net.

## References

[1] M.D. Brown (Ed.), Blueprint for the future of high-performance networking (Intro), Communications of the ACM 46 (11) (2003), 30–33.

[2] Maxine Brown, Larry Smarr, Tom DeFanti, Jason Leigh, Mark Ellisman, Phil Papadopoulos, The OptIPuter: A national and global-scale cyberinfrastructure for enabling lambdagrid computing, in: TeraGrid '06 Conference, June 12–15, 2006.

[3] Tom DeFanti, Cees de Laat, Joe Mambretti, Kees Neggers, Bill St Arnaud, TransLight: A global-scale lambdagrid for e-science, Communications of the ACM 46 (11) (2003) 34–41.

[4] Thomas A. DeFanti, Jason Leigh, Maxine D. Brown, Daniel J. Sandin, Oliver Yu, Chong Zhang, Rajvikram Singh, Eric He, Javid Alimohideen, Naveen K. Krishnaprasad, Robert Grossman, Marco Mazzucco, Larry Smarr, Mark Ellisman, Phil Papadopoulos, Andrew Chien, John Orcutt, Teleimmersion and visualization with the OptIPuter, in: Susumu Tachi (Ed.), Telecommunication,

Teleimmersion and Telexistence: Proceedings of the 12th International Conference on Artificial Reality and Telexistence, Ohmsha/IOS Press, 2003, pp. 25–71.

[5] Thomas A. DeFanti, Maxine D. Brown, Cees de Laat, iGrid 2002: The international virtual laboratory (editorial), Future Generation Computer Systems 19 (6) (2003) 803–804.

[6] David Farber, Tom West, The National LambdaRail: Cyberinfrastructure for tomorrow's research and education, CTWatch Quarterly 1 (2) (2005). www.ctwatch.org/quarterly/archives/may-2005.

[7] Gigi Karmous-Edwards, Global e-science collaboration, Computing in Science and Engineering (March/April) (2005) 20–27.

[8] Graham Kent, John Orcutt, Larry Smarr, Jason Leigh, Atul Nayak, Debbie Kilb, L. Renambot, S. Venkataraman, Tom DeFanti, Y. Fialko, Phil Papadopoulos, Greg Hidley, David Hutches, Maxine Brown, The OptIPuter: A new approach to volume visualization of large seismic datasets, in: Ocean Technology Conference, May 2004.

[9] Kane Kim, Steve Jenks, Larry Smarr, Andrew Chien, Liang-Chen Zheng, A framework for middleware supporting real-time wide-area distributed computing, in: Proceedings of 10th IEEE International Workshop on Object-Oriented Real-Time Dependable Systems, WORDS 2005, pp. 231–240.

[10] Cees de Laat, Erik Radius, Steven Wallace, The rationale of the current optical networking initiatives, in: iGrid 2002, Future Generation Computer Systems 19 (6) (2003) 999–1008 (special issue).

[11] Jason Leigh, Luc Renambot, Maxine Brown, Grid network requirements for large-scale visualization and collaboration, in: Franco Travostino, Joe Mambretti, Gigi Karmous-Edwards (Eds.), Grid Network Requirements Defined By Driver Applications (chapter 2), Grid Networks: Enabling Grids with Advanced Communication Technology, John Wiley & Sons, Ltd, 2006, pp. 18–23.

[12] Phil Papadopoulos, Larry Smarr (Eds.), Introduction—The Cyberinfrastructure Backplane: The jump to light speed, Cyberinfrastructure Technology Watch Quarterly 1 (2) (2005). www.ctwatch.org/quarterly/archives/may-2005.

[13] http://ucsdnews.ucsd.edu/newsrel/general/07-08HIPerSpace.asp.

[14] Luc Renambot, Byungil Jeong, Ratko Jagodic, Andrew Johnson, Jason Leigh, Collaborative visualization using high-resolution tiled displays, in: Proceedings CHI Workshop on Information Visualization and Interaction Techniques for Collaboration Across Multiple Displays, Montreal, Canada, 2006.

[15] R. Seshadri, S.A. Kravitz, L. Smarr, P. Gilna, M. Frazier, A community resource for metagenomics: CAMERA, PLoS Biol 5 (3) (2007) e75.

[16] Rajvikram Singh, Nicholas Schwarz, Nut Taesombut, David Lee, Byungil Jeong, Luc Renambot, Abel W. Lin, Ruth West, Hiromu Otsuka, Sei Naito, Steven T. Peltier, Maryann E. Martone, Kazunori Nozaki, Jason Leigh, Mark H. Ellisman, Real-time multi-scale brain data acquisition, assembly, and analysis using an end-to-end OptIPuter, Future Generation Computer Systems 22 (8) (2006) 1032–1039.

[17] L. Smarr, A. Chien, T. DeFanti, J. Leigh, P.M. Papadopoulos, The OptIPuter, Communications of the ACM 46 (11) (2003) 58–67.

[18] Larry Smarr, Shaya Fainman, Joseph Ford, Phil Papadopoulos, Tom DeFanti, Maxine Brown, Jason Leigh, The OptIPuter, Quartzite, and Star Light projects: a campus to global-scale testbed for optical technologies enabling lambdagrid computing, in: Optical Fiber Communication Conference & Exposition and the National Fiber Optic Engineers Conference, OFC/NFOEC, Anaheim, California, CD ROM, March 6–11, 2005.

[19] L. Smarr, T.A. DeFanti, M.D. Brown, C.T.A.M. de Laat, iGrid 2005: The Global Lambda Integrated Facility (editorial), Future Generation Computer Systems 22 (8) (2006) 849–851. iGrid 2005 (special issue).

[20] Larry Smarr, Riding the light towards new science, Nature Photonics 1 (3) (2007) 133–135.

[21] L. Smarr, L. Herr, T. DeFanti, N. Ohta, P. Otto, CineGrid: A new cyberinfrastructure for high resolution media streaming, Cyberinfrastructure Technology Watch Quarterly 3 (2) (2007). www.ctwatch.org/quarterly/archives/may-2007.

[22] Nut Taesombut, Frank Uyeda, Larry Smarr, Thomas A. DeFanti, Phil Papadopoulos, Jason Leigh, Mark Ellisman, John Orcutt, Andrew A. Chien, The OptIPuter: High-performance, QoS-guaranteed network service for emerging e-science applications, IEEE Communications Magazine 44 (5) (2006) 38–45.

[23] Andrew Chien, Nut Taesombut, Integrated Resource Management for Lambda-Grids: the Distributed Virtual Computer (DVC), Future Generation Computer Systems 25 (2) (2008) 147–152.

[24] Leon Gommans, Li Xu, Fred Wan, Yuri Demchenko, Mihai Cristea, Robert Meijer, Cees de Laat, Multi-domain lightpath authorization using tokens, Future Generation Computer Systems 25 (2) (2008) 153–160.

[25] Robert Grossman, Yunhong Gu, Michal Sabala, Wanzhi Zhang, Compute and storage clouds using wide area high performance networks, Future Generation Computer Systems 25 (2) (2008) 179–183.

[26] Luc Renambot, Byungil Jeong, Hyejung Hur, Andrew Johnson, Jason Leigh, Enabling high resolution collaborative visualization in display rich virtual organizations, Future Generation Computer Systems 25 (2) (2008) 161–168.

[27] Freek Dijkstra, Jeroen J van der Ham, Paola Grosso, Cees de Laat, A path finding implementation for multi-layer networks, Future Generation Computer Systems 25 (2) (2008) 142–146.

[28] Paola Grosso, Damien Marchal, Jason Maassen, Eric Bernier, Carol Meertens, Li Xu, Cees de Laat, Dynamic photonic lightpaths in the StarPlane network, Future Generation Computer Systems 25 (2) (2008) 132–136.

[29] Thomas A. DeFanti, Gregory Dawe, Daniel J. Sandin, Jurgen P. Schulze, Peter Otto, Javier Girado, Falko Kuester, Larry Smarr, Ramesh Rao, The StarCAVE, a third-generation CAVE and virtual reality OptIPortal, Future Generation Computer Systems 25 (2) (2008) 169–178.

[30] Joe Mambretti, OptIPuter: Enabling advanced applications with novel optical control planes and backplanes, Future Generation Computer Systems 25 (2) (2008) 137–141.

[31] Larry Smarr, Paul Gilna, Phil Papadopoulos, Thomas A. DeFanti, Greg Hidley, John Wooley, E. Virginia Armbrust, Forest Rohwer, Eric Frost, Building an OptIPlanet collaboratory to support microbial metagenomics, Future Generation Computer Systems 25 (2) (2008) 124–131.

[32] Thomas A. DeFanti, Jason Leigh, Luc Renambot, Byungil Jeong, Alan Verlo, Lance Long, Maxine D. Brown, Daniel J. Sandin, Venkatram Viswanath, Qian Liu, Mason Katz, Gregory Hidley, Gregory Dawe, Kai-Uwe Doerr, Javier Girado, Jurgen P. Schulze, Falko Kuester, Larry L. Smarr, Philip Papadopoulos, Joseph Keefe, Raj Singh, The OptIPortal, a scalable visualization, storage, and computing interface device for the OptiPuter, Future Generation Computer Systems 25 (2) (2008) 114–123.

[33] Venkatram Vishwanath, Robert Burns, Jason Leigh, Michael Seablom, Accelerating tropical cyclone analysis using LambdaRAM, a distributed data cache over wide-area ultra-fast networks, Future Generation Computer Systems 25 (2) (2008) 184–191.

[34] Daisuke Shirai, Tetsuo Kawano, Tatsuya Fujii, Kunitake Kaneko, Naohisa Ohta, Sadayasu Ono, Sachine Arai, Terukazu Ogoshi, Real time switching and streaming transmission of uncompressed 4K motion pictures, Future Generation Computer Systems 25 (2) (2008) 192–197.

**Larry Smarr** became founding director in 2000 of the California Institute for Telecommunications and Information Technology (Calit2), a partnership of the University of California, San Diego (UCSD) and the University of California, Irvine. He is the Harry E. Gruber professor in the UCSD Jacobs School's Department of Computer Science and Engineering, and is the principal investigator of the NSF-funded OptIPuter Information Technology Research initiative. For the previous 15 years, as director of the National Center for Supercomputing Applications and the National Computational Science Alliance, Smarr helped drive major developments in the planetary information infrastructure: the Internet, the Web, scientific visualization, virtual reality, and global telepresence. He was a member of President Clinton's President's Information Technology Advisory Committee, and served until 2005 on the Advisory Committee to the Director of the National Institutes of Health and the NASA Advisory Council. He was a member of the California Governor's Task Force on Broadband in 2007. He is a member of the National Academy of Engineering and is a Fellow of the American Physical Society and the American Academy of Arts and Sciences. In 2006, he was presented with the ESRI Lifetime Achievement Award and received the IEEE Computer Society Tsutomu Kanai Award for distributed computing systems achievements.

**Maxine Brown** is an Associate Director of the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago (UIC). She currently serves as co-principal investigator of the USA National Science Foundation (NSF) International Research Network Connections Program's TransLight/StarLight award, and was previously co-principal investigator of the NSF-funded Euro-Link and STAR TAP/StarLight initiatives. Brown is the project manager of the NSF-funded OptIPuter project. Brown was one of several American technical advisors to the G7 GIBN activity in 1995, is a member of the Pacific Rim Applications and Grid Middleware Assembly (PRAGMA), is a founding member of Global Lambda Integrated Facility (GLIF), and is co-chair (with Larry Smarr) of the GLIF Research & Applications working group. Brown served as an officer of the ACM SIGGRAPH organization and has been very active in ACM SIGGRAPH and ACM/IEEE Supercomputing conferences. She also co-created and co-chaired the international Grid (iGrid) Workshops. In recognition of her services to UIC and the community at large, Brown is a recipient of the 1990 UIC Chancellor's Academic Professional Excellence (CAPE) award; the 2001 UIC Merit Award; and the 1998 ACM SIGGRAPH Outstanding Service Award.

**Cees de Laat** is associate professor and group leader of the System and Network Engineering Science group in the Informatics Institute at the University of Amsterdam. Current research in his group includes optical/switched networking for Internet transport of massive amounts of data in TeraScale eScience applications, RDF to describe networks and associated resources, distributed cross organization Authorization architectures and Systems Security. With SURFnet, he develops and implements projects in the GigaPort Research on Networks. He collaborates in the NSF OptIPuter project. He serves in the Open Grid Forum, previously as Grid Forum Steering Group (GFSG) Infrastructure Area Director, and now as IETF Liaison and co-chair of the Grid High Performance Networking Research Group (GHPN-RG). He is a co-founder and organizer of several of the past meetings of the Global Lambda Integrated Facility (GLIF). http://www.science.uva.nl/~delaat