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Calit2: A Case Study in a Next-Generation Research Environment

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Preface

The EDUCAUSE Center for Applied Research (ECAR) produces research to promote effective decisions regarding the selection, development, deployment, management, socialization, and use of information technologies in higher education. ECAR research includes

- research bulletins—short summary analyses of key information technology (IT) issues;
- research studies—in-depth applied research on complex and consequential technologies and practices;
- case studies—institution-specific reports designed to exemplify important themes, trends, and experiences in the management of IT investments and activities; and
- roadmaps—designed to help senior executives quickly grasp the core of important technology issues.

Literature review

The study began with a review of the relevant literature on IT engagement with academic research to define the study's major themes and create a working set of hypotheses to be tested.

Interviews

Unlike the usual ECAR case study, for which interviews are done subsequent to the online survey, for this topic we conducted interviews prior to completing the online survey. We proceeded this way because the literature in the field is limited and we've noted a significant shift under way both on campus and nationally that begs further investigation. Campus visits and interviews made it clear that institutions at the vanguard of change could prove useful, both to inform the upcoming research study and as a separate case study. Calit2 at the University of California, San Diego (UCSD) and University of California, Irvine (UCI) is one such initiative.

Executive Summary

Research is increasingly becoming a team-based, collaborative activity, giving rise to the need for new modalities and methods of investigation. Calit2 is responding to this challenge by creating a next-generation research environment comprising a range of technical and nontechnical systems that collectively foster large-scale, multidisciplinary collaborations in innovative ways. This case study explores the breadth and depth of this extensive initiative, including how Calit2 is experimenting

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with multiple technological methodologies to support locally based, distributed, and virtual research collaborations.

We examine the underlying technologies that Calit2 is developing and testing, as well as several central themes related to the Calit2 initiative. These include collaboration in its many forms, the interplay between research and supporting technologies, models for working with industry partners, the role buildings can play in facilitating collaboration, and this initiative's relevance to other institutions.

The study also extracts several key lessons learned from the Calit2 initiative:

- Leadership plays an essential role in making a large, multi-institutional, multidisciplinary initiative work.
- Institutional culture and aspiration for academic excellence also influence the success of such an initiative.
- Addressing big issues requires big thinking.
- Disruptive technologies can cause positive change.
- Faculty should drive research engagement initiatives.

Introduction

The title of this study, "Calit2: A Case Study in a Next-Generation Research Environment," may appear to be overreaching. After all, who knows what a next-generation research environment may be and to what research it applies? Calit2's leaders appear to believe in Alan Kay's oft-quoted remark, "The best way to predict the future is to invent it."[1] The methodology for "inventing the future of a next-generation research environment'" is to create interplay between the needs of leading-edge research projects and the technological developments that help meet those needs. While Calit2 doesn't purport to be creating an improved environment for all possible academic research activities, it does focus on inventing the cultural and physical environment to foster large-scale, multidisciplinary collaborations, especially projects involving large amounts of data or requiring high-performance computation or unique visualization capabilities.

Even with this focus, Calit2 is an unusually expansive initiative—based at UCSD and UCI—that involves multiple institutions and hundreds of faculty, graduate and undergraduate students, and technical and academic professionals. These participants focus on all levels of the technology stack, from chip design to optical and wireless networking, data storage and analysis, and display technologies. They also contribute to the middleware initiatives that tie these elements together into a workable architecture. All this technology research and development is furthermore driven by a range of applications, including

- environment and civil infrastructure,
- intelligent transportation and telematics,
- digitally enabled genomic medicine, and
- the new media arts.

In all these applications, Calit2 social scientists study how emerging telecommunications and information technologies and the applications they enable will change regulatory policy and create socioeconomic evolution.

Calit2 participants seek to make sense of myriad working parts by taking the perspective of systems and the integration of disparate components. They are not attempting to create a next-generation production environment at UCI and UCSD but rather to view the activities at these and other partner institutions as a laboratory to test new technologies and working relationships and assess the academic and social implications of this changing environment. As such, the goal is to impact collaborative research broadly and not just that of the currently participating research groups. Based on progress to date toward this goal, Calit2 is providing some early lessons learned and transferable components from which other institutions may benefit.

In their investigation of Calit2, several ECAR Fellows visited each campus. The authors wish to thank our colleagues, Sandra Braman and Ron Yanosky, for their assistance in collecting information for this study. We also gratefully acknowledge the generous hospitality and time given by many of the faculty, staff, and administrators participating in Calit2. We particularly would like to thank Calit2 directors: Larry Smarr, director of the institute; Ramesh Rao, director of Calit2's UCSD division; and Albert Yee, director of Calit2's UCI division.

Background

In his January 2000 State of the State Address, then-Governor Gray Davis proposed an initiative, the California Institutes for Science and Innovation (Cal ISI), in partnership with the University of California (UC), then led by President Richard C. Atkinson. The motivation for the initiative was to create, within the University of California, "world-class centers for scientific discovery that fuel innovation, and for education integrated into the cutting-edge research that will train future scientists and technological leaders" (University of California, 2000). Ultimately the legislature provided $400 million to launch four multi-UC-campus institutes focused on specific science and engineering areas. Each was conceived to be broadly multidisciplinary, to combine research with industrial applications, and to assist in educating the next generation of scientists and technological leaders.

The four institutes are

- the California Institute for Bioengineering, Biotechnology, and Quantitative Biomedical Research (UC-San Francisco, UC-Berkeley, and UC-Santa Cruz; see http://www.qb3.org/);
- the California NanoSystems Institute (UCLA and UC-Santa Barbara; see http://www.cnsi.ucla.edu/);
- the Center for Information Technology Research in the Interest of Society (UC-Berkeley, UC-Davis, UC-Santa Cruz, and UC-Merced; see http://www.citris.berkeley.edu/); and
- the California Institute for Telecommunications and Information Technology (UCSD and UCI; see http://www.calit2.net).

This case study focuses on the last institute, which we refer to as Calit2.

State financing for these institutes initially was capital funding generated by lease-revenue bonds, with each institute being granted $100 million in state funding. The participating UC campuses committed to raise $2 for each $1 of state funding. Initial operating expenses were to come from 5 percent of the state funds, but the issue of permanent operating funds on the order of $10 million per year per institute was left open and has not yet been fully resolved.

Between the governor's January 2000 announcement and the December 2000 Calit2 funding award to UCSD and UCI, UCSD recruited Larry Smarr, founding director of the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign, as Professor of Computer Science and Engineering in preparation for his becoming Calit2's founding Institute Director. Now working with Smarr in leadership positions are UCSD division and UCI division directors Ramesh Rao and Albert Yee, respectively. Additionally, in 1999 UCSD had recruited Ronald Graham from his position of Chief Scientist at AT&T Labs. As Chief Scientist for Calit2, Graham serves as advisor to Smarr.

Smarr serves as the overall director based on the institute's philosophy that it is a "two-campus but one virtual institute." Rao and Yee oversee research, education, governance, space allocation, and related activities on their respective campuses. Together this group promotes integration

of the research activities across nearly two dozen departments on each campus, across the two campuses, and with distinguished researchers in relevant disciplines across the nation and around the world. Rao and Yee also oversee relationships with industrial partners and community supporters.

When Calit2 wrote its proposal to UC Office of the President, the institute was based on a "layer diagram" (see Figure 1), a conceptual framework to explain its activities based on broad disciplinary areas layered one on top of each other—for example, Materials and Devices (which included chemistry, physics, and materials science) and Networked Infrastructure (electrical engineering overlapping with computer science). Calit2 "living laboratories," or projects, serve as "vertical convective currents" to integrate activity across the layers. After the award was made, Calit2 identified one leader per layer on each campus; it was this set of faculty members who, in tandem with the directors, provided initial governance of the institute. As the Calit2 buildings—which were constructed as major uses of the state capital funding—became ready for occupancy, both divisions used a formal process for faculty and research groups to apply for space. This process provided a more detailed understanding of the universe of projects, faculty, and students involved in Calit2, which led to reconsideration of the governance structure and the creation of divisional councils at each campus to advise the two division directors. This change was made also under the advisement of the Calit2 Advisory Board, composed of nationally recognized academic and industrial leaders in disciplinary areas of importance to Calit2's mission.

To reinforce broad-based campus interest in the institute, Calit2 created a Governing Board consisting of vice chancellors, principal deans, and directors of organized research units from the two campuses. This board, which has met more than 30 times over the past five years, focuses on academic and financial matters important to Calit2.

From its conception, several articulated underlying principles have guided Calit2's evolution.

- *Foster collaboration at every level.* One of Calit2's core organizing principles is its focus on collaboration to advance multidis-

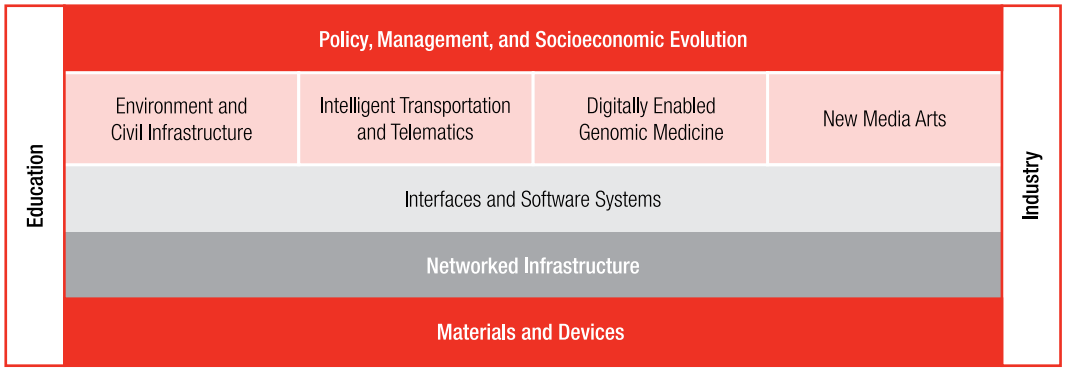


Figure 1.Initial Conceptual Model for Calit2 Framework

ciplinary research. In fact, the creation of Calit2 itself was a conscious collaboration. The chancellors of UCSD and UCI agreed from the beginning that not only would these two campuses join in applying for Cal ISI funding, but also that the institute would be a joint entity having parallel activities at all levels. Owing to this principle's importance, the next section of this case study provides further elaboration about Calit2's approach to collaboration.

- *Encourage faculty to drive the initiative.* A major Calit2 activity is the development of new technology-based systems and their applications. Still, these developments are driven by the needs of faculty research groups within the scope of what is technologically possible and affordable. As these "experiments" produce promising technologies, the technologies in turn are harvested and put to use underlying future Calit2 activity. In this way, Calit2 can amplify the adoption—in some "production" sense—of technology beyond what is normally done in a typical university research environment.
- *Leverage off-the-shelf components.* While Calit2 is developing next-generation research support technologies, the developers have used off-the-shelf, readily available components whenever possible. A good example are the large tiled displays that have been developed in collaboration with the Electronic Visualization Laboratory at the University of Illinois at Chicago, with the lab's codirector, Tom DeFanti, as a primary collaborator. The current incarnation is a 100-million-pixel wall consisting of 55 displays (11 wide by 5 tall) based on Intel components and the Linux operating system. The innovation comes in the software (Scalable Adaptive Graphics Environment, or SAGE) that supports distributed visualization and transparent data handling. This idea has been taken a step further and modified in the Highly Interactive Parallelized Display Wall (HIPerWall) project, now considered the world's largest (200-million-pixel) display, built of 50 standard Apple 30-inch monitors and driven by Apple G5 clusters. The HIPerWall can be viewed in two ways: as a single 200-million-pixel tiled wall, or as a cluster of smaller displays each driven by data streams or alternatively rendering 3D models that can be displayed simultaneously for comparison purposes.
- *Make software, based on an open source philosophy, broadly available for use elsewhere.* This approach, tied with the emphasis on off-the-shelf components, speaks to one of the natural questions others might have: What might this initiative mean to my institution? For many of the technologies being developed for Calit2, others should be able to replicate much the same capability, given appropriate resources.
- *Ensure flexibility in how researchers and projects use Calit2.* Although early in its implementation, Calit2 maintains a focus on leading-edge activities, including significant collaborative academic research that drives new infrastructure developments. As a result, researchers team up on particular projects focused on particular goals. When the goals are achieved, the projects evolve toward new goals, as appropriate, or the teams disband, thereby enabling Calit2 to continually foster new, relevant collaborative projects over time. Throughout this process, faculty retain their research labs and facilities in their home departments.
- *Introduce disruptive technologies.* Calit2 consciously seeks out technologies that allow new modalities of research (we will detail the research support technologies later in this case study). The goal is to give researchers access to emerging, disruptive

technologies that allow them to address research problems and questions in ways not previously possible. This will likely create new expectations regarding what research is possible and, in turn, stimulate research alliances that go beyond historical discipline boundaries.

- *Establish close ties with industry and community partners.* While parallelism exists at every level between the UCI and UCSD activities in Calit2, there are differences based on the needs of industry and the research strengths of the participating departments. For example, the area around UCI is home to many medical instrumentation firms, and thus UCI includes BioMEMS (micro-electrical-mechanical systems) design projects in bioengineering. Similarly, wireless technology is a strong industry in the San Diego area, and so wireless chip design and wireless application projects abound at UCSD. Calit2's industrial program fosters venture capital firms' involvement, enabling Calit2 to see where the edge of commercial practice is and to focus on what might lie beyond. Typically it is difficult for individual faculty to have such a relationship with venture capital and identify this space in which to focus their research. As a result, academic researchers may not even know about—much less leverage—investigations and developments taking place at relatively unknown start-up companies.

While the State of California's goals are tied to economic development and education, Calit2's principles also track closely to the goals of the National Science Foundation (NSF) and the National Institutes of Health (NIH) to encourage multidisciplinary research and cyberinfrastructure initiatives. The tie to cyberinfrastructure initiatives is particularly significant in that the scope of Calit2 depends heavily on infrastructure developments outside of Southern California. It is tied into broad national research projects such as the NIH's Biomedical Informatics Research Network (BIRN),[2] as well as underlying high-performance infrastructure projects such as the National LambdaRail (NLR).[3] More broadly, we see a close linkage between Calit2's foundational principles and their instantiation and the challenges articulated in the February 2003 NSF cyberinfrastructure report, which observed,

> Some of the most critical challenges to this ambitious program are to 1) build real synergy between computer and information science research and development, and its use in science and engineering research and education; 2) capture the cyberinfrastructure commonalities across science and engineering disciplines; 3) use cyberinfrastructure to empower and enable, not impede, collaboration across science and engineering disciplines; 4) exploit technologies being developed commercially and apply them to research applications, as well as feed back new approaches from the scientific realm into the larger world; and 5) engage social scientists to work constructively with other scientists and technologists (Atkins, 2003).

Clearly, Calit2 has been a "thinking big" project from its inception. That said, it doesn't aspire to impact all research activities at UCSD or UCI or even attract a predominant number of researchers. Yee estimates that "probably 15 percent of UCI faculty have self-selected themselves to participate in Calit2-related initiatives. These are faculty members who are doing highly regarded 'individual PI work' but who see the opportunity Calit2 provides to engage in serious collaborative activity." Because university campuses hire individual researchers, single PI work is still the norm. It is entirely appropriate, therefore, that only a subset of that group will want to work in collaborations such as those enabled by Calit2.

Before proceeding to a more in-depth look at the emerging Calit2 research environment, we should note the status of Calit2 as a project. Recall that the state funds for Calit2 were capital funds used to construct a Calit2 building at each participating campus. The UCI building became operational in Spring 2005 and the UCSD building became operational in Fall 2005. From that perspective, the project is hardly under way. While the buildings are an important factor in Calit2's operation, as we shall see, the actual recruitment and involvement of participating faculty researchers and research groups has been ongoing for more than five years. This is a continuing process, though some faculty have been engaged for several years. Thus, although Calit2 has been operational, the directors view the initiative as just about to really take off. As a result, the "Lessons Learned" at the end of this case study represent the initiative's preliminary returns based on early insights gleaned from the project.

Some Unique Aspects of Calit2

"The distinguishing characteristic of Calit2 is that it focuses on systems," according to Smarr. We take this to mean that Calit2 is not about technologies per se, or buildings as demonstration centers, but rather is the synthesis of all the components, technical and nontechnical alike, of a technology-enabled environment necessary to undertake multidisciplinary research. It is an institute for system integration built on strong component parts. Although Calit2 is developing and instantiating some unique technology components, as we have seen above, they are just that—components. The important thing from the organizers' perspective is that the initiative focuses not only on technology but on creating an environment encompassing a range of systems that collectively enhance the ability of researchers to work in new ways.

Collaboration

As previously mentioned, Calit2 is all about collaboration. The defining qualification for a researcher or group to come under the Calit2 umbrella is whether the proposed project involves collaboration in some way—multidisciplinary, multi-institutional, engaging undergraduates in research, developing regional services, establishing vendor partnerships, and so on. As noted previously, Calit2 itself is a collaborative initiative between UCSD and UCI and also represents collaboration on common objectives between the UC system and the State of California.

Internally, Calit2 is a partnership between groups of faculty, students, and technical professionals developing a next-generation technology-enabled research environment. This appears to be a relationship among peers rather than one of the technical professionals' purely supporting researchers. Such an arrangement allows a dynamic, iterative approach, where research needs feed supporting infrastructure development, as well as the reverse, producing new research capabilities.

Calit2 has been particularly innovative in exploring the interrelationship between collaboration and technology. The approach has been described as "supercharging locality with virtuality and vice versa," meaning that technology is used not only to make local collaborations more fruitful by bringing necessary resources to the locality but also to make collaboration at a distance more successful by bringing people together so that they appear to be working locally.

Initial Application Areas

Because the ultimate focus of Calit2 is enhancing academic research, the initial research application areas are tied to historic institutional strengths and regional industry. The current research foci include

- environment and civil infrastructure,
- intelligent transportation and telematics,

- digitally enabled genomic medicine, and
- new media arts.

Additionally, there is research engagement related to the large national multi-institutional cyberinfrastructure initiatives such as BIRN, GEON (Cyberinfrastructure for the Geosciences), and NEES (National Earthquake Engineering Simulation) and activities at the UCSD-based San Diego Supercomputer Center (SDSC), a key player in national cyberinfrastructure development for the past 20 years. Finally, Calit2 is partnering with national initiatives such as BioNet, a cooperative program sponsored by the Department of Homeland Security and the Defense Threat Reduction Agency to manage the consequences of biological attacks on major metropolitan areas; RESCUE[4] (RESponding to Crises and Unexpected Events), a multidisciplinary project to allow responding organizations gather, manage, use, and disseminate information in response to emergencies; and WIISARD[5] (Wireless Internet Information System for Medical Response in Disasters), using sophisticated wireless technology to coordinate and enhance the care of mass casualties in a terrorist attack or natural disaster.

Calit2 Buildings

Calit2 has taken an innovative approach to the task of using state-supplied capital funding to create buildings on each of the UCSD and UCI campuses. Often new campus research buildings are technology-enabled containers for research activities. In Calit2, the design of the buildings was based on the Calit2 philosophy to foster collaboration, serve as demonstration outreach sites for research results and prototype technologies, and demonstrate leading-edge technology in operation. As an example, consider project RESCUE, described above. It uses the UCI building, which has been instrumented for the purpose, to study the reactions of inhabitants under emergency alert conditions.

The buildings have a wide range of 2D and immersive display capabilities. They have access to Calit2's unique technology components—described in the next section—potentially everywhere, and they have 10-Gbps backbones to buildings connected to the 10-Gbps high-performance research network provided by the California Research and Education Network. As one might expect, the buildings offer pervasive wireless access, but UCSD also includes a rooftop "antenna garden" on its building to support satellite communications and wide-area regional wireless communications. This facilitates research based on sensornets installed in regional transportation sites as well as regional environmental sensornets.

To further enhance collaboration, most of the work space in both buildings is open, and, to minimize the perception of hierarchy, the UCSD building has no coveted corner offices. Specially ordered furniture can be easily reconfigured (for example, table height) to accommodate various needs and includes wheels for easy mobility around the building. Network drops from the ceiling are pervasive. Each closed-door office has as many as a dozen Gigabit Ethernet ports to link to remote digital resources. Each building also has specialized facilities such as clean rooms for chip design and fabrication. Finally, the buildings will have spaces to support both collaboration at a distance (distributed collaborators and resources) and collaboration via specially designed rooms that have access to remote resources, local tools, and support staff to enhance researchers' ability to work. In particular, Calit2 plans to implement an always-on portal between the two buildings to enable extemporaneous interaction. We describe these facilities in more detail below.

The buildings are intended to be inherently experimental research spaces, not just spaces to support research. Many aspects

can be easily and inexpensively reconfigured. Cable trays are either exposed or easily accessible. Because space is allocated to researchers based on their coherence with the Calit2 mission, people will move in and out, and thus what occurs in each building will necessarily change over time with a goal to stay at the cutting edge. Because one of the prime application areas is new media arts, the buildings have active display spaces and innovative performance spaces in the form of technology-enabled auditoria, and the UCSD building has already been used for projection of art on its exterior.

Calit2 and Researchers of the Future

In addition to engaging current researchers, Calit2 has several programs to engage future researchers. For example, for the past five years, UCSD's Undergraduate Research Scholarship program has engaged a competitively chosen group of undergraduates in Calit2 research projects. Similarly, starting in 2005, UCI initiated the Summer Undergraduate Research Fellowship in Information Technology, again sponsored by Calit2 and bringing undergraduates into real, ongoing research. The experience has already shown that undergraduates are eager to take advantage of these opportunities to complement their classroom experience and build their résumés.

Undergraduates at UCSD apply to one of six colleges. The college oversees their residential experience and the requirements for their major. The newest college, Sixth College, is closely aligned with Calit2. The Sixth College theme of "Culture, Art, and Technology" provides the educational context for student studies. The educational experience in Sixth College was conceived from the beginning to be technology-based. From its inception, its facilities were fully wireless, and incoming freshmen were given wireless PDAs to provide a seamless faculty-student interaction capability. Sixth College enrolled its third freshman class in 2005. It is intended to be an ongoing laboratory supporting the interaction between new technology and undergraduate education.

A related Calit2-sponsored research project, ActiveCampus (Griswold, et al., 2004), studies the educational impact of PDA-based, wireless, location-aware computing. Its developers state, "ActiveClass supports classroom activities such as anonymous asking of questions, polling, and student feedback. ActiveCampus Explorer supports several location-aware applications, including location-aware instant messaging, and maps of the user's location annotated with dynamic hyperlinks of nearby buddies, digital graffiti, etc." (Griswold, et al., 2004).

Calit2 is pushing this educational outreach down yet another level. The Preuss School UCSD is a public middle/high school at UCSD dedicated to providing a college prep education for low-income students whose parents didn't go to college. The Preuss School is connected to Calit2 technology resources, and its 3D visualization center is a collaborative project among the school, Calit2, and the SDSC. The school also collaborates with Sixth College in piloting the use of new technology for educational purposes. Calit2 staff oversee students during semester-long internships, a required part of the senior year, to gain practical experience in the working world.

Components of the Research Infrastructure

Since Calit2 aspires to provide a new environment in which to undertake collaborative research, there is an active initiative within Calit2 at almost every level of the technology stack. This extends from chip design and fabrication through network infrastructure to data gathering and analysis, computation, and visualization. As technologies prove promising

in research projects, Calit2 in turn attempts to implement them in the buildings to continually enhance the research environment and collaboration capabilities for all projects.

Network Expectations for Calit2 Initiatives

Larry Smarr has frequently observed that a once-in-two-decades transition is under way: "Bandwidth is getting cheaper faster than storage. Storage is getting cheaper faster than computing. Exponentials are crossing."[6] The past two decades have seen a continual crossing of interdependencies among the key resources necessary for scientific research: computation, storage, and access (networking). Researchers, especially for collaborative projects, need all of these resources and will typically use whatever is available until they encounter a limiting factor. The response of funding agencies and institutional computing service organizations has changed over time, focusing at various times on supercomputer centers, the Internet and next-generation Internet projects, and mass network-attached storage farms. We have seen the changing balance in the rise of computation clusters built from commodity components in recent years, which has caused a more distributed view of how computation is provisioned. However, the cost of *managing* highly distributed clusters has more recently led to a trend of centralizing these clusters, which, together with the large storage requirements of experiment-based research, has put pressure on network deployment. Smarr observes that we are entering an era where bandwidth is no longer the practical limiting factor for the foreseeable future. Calit2 is putting this into practice and exploring its implications for research.

The justification behind his premise is the same as that underlying NLR: there is a huge amount of dark fiber available due to the overbuilding of fiber infrastructure in the late 1990s and the tech bubble burst of the early 2000s. Relative to other research institutions involved in projects such as NLR, Calit2 complements the regional optical networking infrastructure with on-campus infrastructure that will provide dedicated wavelengths (lambdas) to specific researchers and networked resources (computation devices, mass storage, and visualization facilities). This is managed by both a Chiaro Enstara[7] (a large router based on an optical core) and a standard Cisco 6509 switch-router. This instantiation supports both 10-Gbps and 1-Gbps signals from each research lab to the central core. In a follow-on NSF-funded project, Quartzite, a switching complex, will augment this structure by adding dense wave division multiplexing (DWDM) signaling using existing fiber plant, a transparent optical switch from Glimmerglass, and, sometime in 2006, a wavelength selective switch from Lucent (Papadopoulos & Smarr, 2005). When complete, the Quartzite switching complex will be able to switch packets, wavelengths, or entire fiber paths. This will also allow testing of different network layouts. When fully deployed, this configuration will support nearly half a terabit of lambdas leading into a central, reconfigurable complex (Papadopoulos & Smarr, 2005). Note that this depends on dedicated usage of lambdas on-demand, using IP. The dedicated usage renders TCP unnecessary as there is no need for congestion management.

The on-campus fiber infrastructure is complemented by regional services provided via CENIC (Corporation for Education Networking Initiatives in California). In particular, this ties UCSD and UCI together with high-performance networking and allows partner organizations/institutions such as SDSC, San Diego State University, and the University of Southern California to collaborate. Calit2 is also working with CENIC to implement the CalREN-XD infrastructure "tip of the CENIC pyramid"[8] to support experimental networking

research that will continue pushing development of the network at the leading edge and mainstream the use of end-to-end lambdas.

While the model is scalable in performance and geographic scope, however, it is not currently envisioned to scale for the number of participating end-node connections. As a research support network, this is acceptable. One needs to connect perhaps hundreds of collaborators, resources, and remote instruments but not millions of users as would be necessary for a commercial network.

Of course, optical networking isn't the only network resource underlying Calit2 projects—both campuses have separate robust campus networks. Calit2 also has ubiquitous computing projects that rely on broadly available wireless networking infrastructure. Each campus has largely pervasive Wi-Fi wireless access, and some projects also depend on regional wireless capabilities. In particular, the following projects are developing environmental and public safety testbeds via wireless sensornets.[9]

CalRadio

Calit2 is developing several generations of broad-application radio/networking test platforms for wireless research and development. CalRadio I, the first generation, provides a simple, low-cost platform for 802.11b development from the MAC layer up. It accomplishes this by putting all the MAC functionality into C code that runs on a DSP. It uses the Intersil (Conexant) Prism chip set for the physical layer. Additionally, the C5471 Texas Instruments DSP contains an ARM processor that hosts a small Open Linux operating kernel to provide easy access to programming, downloading, and data display and monitoring. CalRadio I functions as a test instrument, an access point, and a Wi-Fi client. As with other Calit2 developments, the design, schematics, software, and documentation are for public use under the conditions of the open license.

CalMesh: Extreme Networking for Response and Recovery

Calit2 academic researchers have developed a rapidly deployable networking infrastructure, CalMesh, which is a group of wireless network nodes for ad hoc local area networking and always-best-connected, wide-area networking. CalMesh provides a quickly deployable system for meeting crisis voice and data needs. CalMesh nodes are small, lightweight, and easily reconfigurable, and they quickly self-organize to form a reliable wireless mesh network. They are powered by built-in batteries with a life of up to 12 hours. CalMesh nodes use popular IEEE 802.11b-based Wi-Fi technology for users (including first responders and civilians) to easily set up communication during emergencies. Each node communicates with the others using an advanced wireless multihop relaying. Nodes can use any of a variety of backhaul communication technologies (including Ethernet, 1xEVDO, 1xRTT, WCDMA, UMTS, and WiMAX point-to-point radio) to connect to the Internet and can support data and VoIP-based voice traffic. The use of peer-to-peer VoIP-based voice communication provides high-quality, local voice communication.

PulseOX

As part of the WIISARD project, Calit2 is developing low-cost, 802.11-based solutions to monitor vital signs in mass casualty situations. The goal is to allow responders to use the Wi-Fi bubble surrounding a coffee house or a home to support improvised aid station/hospitals. The WIISARD pulse oximeter system uses embedded-systems 802.11 technology, with the DPAC Airborne module at its core. The module features a highly integrated 802.11b wireless module with radio, baseband, and application processor; a built-in Web server application; integrated RTOS and TCP/IP stack; and configurable serial digital and analog I/O ports

in a small, rugged package designed for high- and low-temperature operation. The DPAC unit is powered by a Ubicom processor that supports application programming in the C language. The DPAC module is mated to a Nellcor MP100 pulse oximeter sensor controller, which uses a novel forehead sensor developed by Nellcor to offer advanced ergonomics and performance for field operations. The pulse oximeter is packaged in a waterproof and rugged enclosure (IP65), with displays and sounds for alert conditions. Estimated battery life is nine hours, and the parts cost about US$360. The pulse oximeter can work collaboratively with the WIISARD environment using Web services or with a stand-alone Windows XP application called WizMon that supports the monitoring of hundreds of victims on an ordinary laptop computer.

OptIPuter

Driving dedicated lambda network fabric development is the OptIPuter (optical networking, Internet Protocol computer),[10] which is supported by one of the largest NSF Information Technology Research Grants awarded. We can think of this project, led by Smarr, as a virtual metacomputer in which the individual "processors" are widely distributed clusters, the "backbone network" is provided by the dedicated lambda network, and the "mass-storage systems" are large distributed scientific data repositories fed by scientific instruments as near-real-time peripheral devices (Smarr, Chien, DeFanti, Leigh, & Papadopoulos, 2003). While OptIPuter output could be via standard displays, Calit2 is also introducing advanced visualization displays (such as the tiled displays described earlier) as output devices, which will be more fully explored later. Such display technologies require interfaces to large-scale data storage, and such interfaces are not supported by traditional commercial, proprietary storage I/O capabilities. Thus, OptIPuter researchers are investigating high-speed cluster storage services in which each node contributes to an aggregated, globally accessible storage pool (Smarr et al., 2003). This will support aggregated distributed data collection, the ability for distributed researchers to analyze shared data, and display at distributed sites.

An example of the OptIPuter in action is described in a press release of a collaborative demonstration involving UCSD, Scripps Institution of Oceanography (at UCSD), and Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. "At GSFC, researchers led by Christa Peters-Lidard were able to call up large Land Information System (LIS) data sets consisting of more than 20GBs residing at Scripps and being visually rendered on the OptIPuter visualization cluster at Scripps. The graphic images then traveled over the NLR to Goddard and were displayed at Goddard on a large, tiled display called a HyperWall [this is a different technology from the HIPerWall, described earlier]. Simultaneously, on the same screen, the Goddard group was viewing a high definition (HD) video stream of Calit2 Director Larry Smarr and Scripps scientists V. Ramanathan and Jean-Bernard Minster sitting in front of the VizCluster. Observes Smarr, 'It really is like the two research centers are just next door to each other!'"[11]

Basic networking that interconnects dedicated lambdas passing high-bandwidth traffic to high-speed routers and switches is only one level of the technology needed. Also necessary for resource management is middleware that allows applications to recognize these network resources and use them effectively. The OptIPuter team uses the term distributed virtual computer (DVC) to describe the middleware environment that accomplishes this goal. Specifically, "the OptIPuter system software architecture uses the concept of a DVC to integrate a wide range of unique OptIPuter component technologies (high-speed transport protocols,

dynamic optical-network configurations, real-time, and visualization packages) with externally developed technologies (Globus grid resource management services and security infrastructure) that are increasingly being adopted in the grid community. A key benefit to [OptIPuter] applications [is] control of a distributed resource abstraction, which includes network configuration, grid resource selection, and a simple uniform set of APIs for communication. For OptIPuter tools and technology development, it enables large-scale, flexible experimentation with a wide range of application configurations, enabling better evaluation and more rapid research progress" (OptIPuter Annual Report, 2005).

Data Analysis, Visualization, and Displays

Data analysis and visualization are key elements in scientific research and are major Calit2 components. Again, the magnitude of resources inherent in the OptIPuter forces one to rethink the model for data analysis and visualization. Calit2 uses the following data analysis and visualization pipeline: "Large collections of real or simulation data are fed into a data-correlation or filtering system that generates subsampled or summarized results from which a visual representation can be created and displayed on individual screens, tiled displays, and virtual-reality systems" (OptIPuter Annual Report, 2005). Additionally, the tiled walls as display devices can form a distributed system in which widely separated collaborators each see components of a common display. For these purposes, the pipeline must support multicast to multiple endpoints.

We find an example of this model in the UCSD laboratory of Mark Ellisman, professor in the School of Medicine and affiliated with the neurosciences and bioengineering departments as well as with the SDSC. Ellisman is also director of the Center for Research in Biological Structure, the National Center for Microscopy and Imaging Research, and the NIH BIRN Coordinating Center. In these roles, he and his laboratory investigate how the nervous system functions at the cellular level. A principal tool in these investigations is advanced electron-microscope imaging. His laboratory has developed many of the components for data acquisition, analysis, and high-definition imaging. However, not all of the electron microscopy can be done in his laboratory. In fact, the world's most powerful electron microscope currently is in Osaka, Japan, and Ellisman's lab has developed the software and related technologies to remotely control this microscope. Similarly, they have integrated into their workflow the ultra-high-voltage electron microscope configured for electron tomography at the Korea Basic Science Institute. An experiment using these instruments can generate data sets as large as one gigabyte. Thus, the lab's research directly involves all components of the data pipeline described above: large data sets, possibly from multiple instruments including some at a distance, being aggregated, filtered, analyzed, rendered, and displayed. The output may be via a large display in the laboratory, simultaneously across several laboratory displays, or on the tiled displays now becoming available.

Another component of innovative large-display technology use is also represented in the working of Ellisman's laboratory. The physical laboratory is actually distributed across several buildings on the UCSD campus, and researchers in these locations work with collaborators at UCI. The OptIPuter infrastructure already present in these laboratories, in conjunction with the multipanel displays, permits creating an environment for collaboration at a distance. The tiled display walls at several locations are left in an always-on mode and enable drilling down through the data through several degrees of magnification, depending on team interests. Thus, entering

a room with such a display, one can engage a remote collaborator in an impromptu, real-time conference. The images can be full size. The display technology's distributed nature allows segmentation of display tiles for simultaneous visualization of scientific output at each participating location.

A variation on this theme of using technology for collaboration occurs in a space called VizClass, an instructional environment at UCI. "VizClass features multiple touch-sensitive digital whiteboards, a wall-size virtual reality display, and a surround-sound system. It also incorporates many unique data input devices such as data gloves, wireless gyroscopic mice and keyboards, and digital pointers and pens to provide access to a fully digital workspace. The environment is powered by an eight-node computer cluster, interconnected via a dedicated gigabit subnet. Users have access to a broad range of wireless technology that allows students and researchers to interface with VizClass, using their personal laptops or tablet PCs, while the system itself can detect their presence via RFID [radio frequency identification] tracking technology."[12]

Another variation on collaboration is the Calit2/SDSC Synthesis Center.[13] Like a classroom such as VizClass, the concept is the inverse of collaboration at a distance. This center provides a physical location where collaborators can meet and use cyberinfrastructure to bring in all the data, computation, and analytic tools that might enhance their discussions and support the analysis of conjectures. It is connected to the OptIPuter and has advanced display capabilities. The facility's stated goal is "to enable groups of researchers/scientists to meet together in a resource-rich environment and address cutting-edge science questions that can be solved only by teams of interdisciplinary scientists meeting together to enable face-to-face discussions and 'what if' computations."[14]

Potential Success, and Success Factors

While Calit2 clearly is a rich and dynamic environment, it is too young for anyone to know whether it is, or will be, successful—a fact acknowledged both inside and outside Calit2. Additionally, when asked, the participants and others on the campuses had varying definitions of what success might mean.

Faculty are research-outcome-oriented, of course. Calit2 will be successful from their perspective if they can do things that they couldn't do without Calit2. Similarly, Albert Yee contends that that Calit2 will be successful *if it makes a difference* in how research is done, how teaching and learning are done, and as measured by the success of faculty and student outcomes. Thus, for him, Calit2 is about nurturing the success of others.

William Parker, vice chancellor for research at UCI and former interim director of Calit2's UCI division, observed that success should be measured by whether the state believes there was return on the initial investment in the Cal ISI projects in terms of maintaining leadership in technology and economic development. These would be measured by the willingness of CEOs of appropriate companies to testify to the state legislature that they have gained from this investment.

Included in Calit2's "layer" conceptual framework is a focus on policy, management, and socioeconomic evolution. In this group are social scientists who are watching Calit2 as a socioeconomic and organizational experiment. Ultimately they will report on lessons learned and no doubt will apply their own definitions of success and failure gleaned from the experiment.

No matter what definition of success is being used, those interviewed uniformly felt that current direction and progress augur well for success. Thus, Calit2 is young but has the aura of a successful initiative.

In a complementary vein, we can ask

about factors that might encourage success. Many of those involved in Calit2 point to the history of UCSD and UCI as important factors. While their histories differ in some regards, both are young institutions, created in the mid-1960s during a period of growth in the UC system. They each had the opportunity to create a new academic culture and were free to establish focal areas appropriate to the late 20th century. Many Calit2 participants point to the youthful outlook of these two institutions as a main cause for current success in the initiative. As Smarr said, "We couldn't have done this elsewhere" (Smarr, personal communication). Both institutions have long encouraged multidisciplinary research activities, and both were founded with a view that IT, though very immature at their founding, would make a difference to both education and research. The institutions have continually followed the track of IT in these regards. Finally, the institutions recognized that a project as broad and possibly intrusive as Calit2 had the potential to be organizationally disruptive, and each administration was open to that. Significantly, because the two campuses together are predicted to account for approximately 35 percent of the UC system's total growth over the next 10 years, they are in a privileged position to be risk takers.

Another factor noted is that Calit2 has been "remarkably lightweight" in state oversight (Smarr, personal communication). The state has given money for the buildings and required 2:1 fund matching, but it hasn't been micromanaging or otherwise intrusive regarding how the initiative is run. Similarly, the institutions have been supportive and have not insisted on a lot of top-down oversight. Thus the directors have largely been able to proceed as they see fit and, if anything, have received encouragement in their efforts rather than running into organizational constraints.

Finally, as young institutions, established in a geographic area that is rapidly growing in terms of population and commercial activity, the two campuses have always had close ties to both the region and its industries. UCSD is the most research-intensive of the post-WWII UC universities. Rather than trying to be competitive in all fields, UCSD endeavored to establish leadership in selected areas of research with an emphasis on interdisciplinary research. It also built close working relationships with the Scripps Institution of Oceanography (founded in 1904 and located adjacent to the current UCSD site) and later with SDSC (which began under management of a private company, General Atomics, before becoming part of UCSD in 1996). UCSD also has a campus tradition of believing in the benefits of government, corporate, and community partnerships that have reaped important dividends.

UCI's connection with the community is equally strong, though of different character. UCI's initial focus was on undergraduate education, though graduate and professional programs were always envisioned. Additionally, UCI is located in the greater Los Angeles metropolitan area and thus had to establish itself in competition with more established local research institutions such as UCLA and USC. As a result, UCI has worked to establish close relationships with Orange County public entities and industries.

Major Issues Impacting Future Success

Calit2 faces a constant challenge to keep research needs and technology closely aligned. Some technological capabilities of Calit2 may currently exceed research needs—for example, few experiments presently take advantage of 10-Gbps pipes. This is understandable: researchers don't design projects for capabilities they aren't likely to have. On the other hand, experience has shown that many researchers will eventually use all the resources available and then ask for more.

Also, the underlying technology is fairly immature, lacking appropriate standards for data flows and visualization protocols, for example. The middleware to handle authentication and resource allocation at this level of distributed resources is at best a work in progress. Not all of these issues are under Calit2's control because what is needed are accepted standards. This initiative hopes to help establish some of the bases and tests of standards, but standards development is a long process. In the meantime, researchers participating in Calit2 will need to be flexible.

The idea that researchers come together for a period of time at Calit2 and then return to their home departments is intriguing. This permits a steady stream of fresh ideas and new collaborative projects to benefit from the Calit2 experience and allows the initiative to avoid dealing with the infrastructure and related issues associated with ongoing production activities. At the same time, the question of how researchers can sustain their research efforts when they return to their home labs poses some interesting issues that will require resolution once the first wave of projects reaches this point.

Funding agencies, such as the NSF, have strongly encouraged the type of developments in which Calit2 is engaged. Still, there are competing demands for resources, and Calit2 is a long-term initiative. Currently, close alignment exists between this initiative and external funding, but how this plays out over time remains to be seen. That Calit2 is also closely aligned with industrial partners may help develop resources that will sustain the initiative even if funding agencies adjust their priorities.

Transportability to Other Institutions

The scope of Calit2 is extremely broad, but the components can be considered somewhat independently. There are several aspects of Calit2 that individually might be more appropriate for other institutions to adopt. All software is open source and usable by others. Many of the hardware systems are built from off-the-shelf components. The value Calit2 brings is in the integration, but this knowledge also is transferable. Calit2 additionally tries to incorporate middleware standards, such as Globus, as they currently exist.

The Calit2 leadership, particularly Smarr, spends a substantial amount of time speaking about the initiative to encourage others to adopt some of the new research engagement technologies and techniques. However, they are also clear that Calit2's underlying philosophy is to develop, learn, and move on. They do not intend for this initiative to become a production environment per se. While they hope to run workshops on the lessons learned from Calit2, the intent is for others to put the results into production. Calit2 will give professional advice but does not intend to undertake implementations for others. Additionally, Calit2 periodically convenes workshops that collect experts on a given topic to discuss, for example, an emerging technology or discipline and suggest future funding programs to federal agencies to foster research and development in that area.

Some softer aspects of Calit2 may be transportable if the receiving institution's culture is capable of adopting them. For example, the willingness to engage in working relationships with corporate or governmental partners in applied research activities, rather than focusing research on pure knowledge creation, depends on the views of an administration and faculty. Technology transfer is very much in vogue, and thus the model of Calit2 might well provide substantial lessons for many other institutions.

Because Calit2 focuses on creating new modalities for collaboration, many of the successful strategies they identify over time can be studied and should prove transportable

as appropriate to local conditions at other institutions. In fact, both the UCSD building's architect and students in the UCSD cognitive science department are embarking on studies to determine how the facility is used in practice.

Another cultural component relates to the Calit2 buildings. Many campus buildings are designed to be functional but not necessarily closely integrated with the activities held within them. As we have seen, the Calit2 buildings are tightly integrated with the breadth and depth of Calit2 projects. While the buildings are inherently flexible, it likely required substantial institutional flexibility to allow the construction of buildings so tightly tied to a specific multidisciplinary initiative.

Finally, although the OptIPuter might appear to require such unique and expensive components—such as dedicated fibers and special optical switches—that most institutions wouldn't be able to exploit it for some time, UCI offers a learning vehicle to understand how an institution might proceed. The UCI networking environment at the start of the initiative was typical of a research university. Additionally, while the UCI Calit2 building had OptIPuter capabilities from the beginning, for reasons of economy it didn't install OptIPuter connections as broadly as had been desired or as broadly as UCSD has done. They do have substantial conduit and cable tray space for future expansion, but many new buildings elsewhere may also feature these. Of course, also necessary are a fiber backbone and optical-switching capabilities that would allow dedicated lambdas for such an initiative. Many campuses have already installed optical backbones, however, which may offer available lambdas with the appropriate switching equipment. Thus, while an OptIPuter interface may be a reach for many campuses currently, it might provide a goal for future investments, especially regarding networking and display technologies.

Lessons Learned

While still in its early stages, the Calit2 initiative illustrates how a collaborative effort among academia, government, private industry, and the community can make progress toward realizing a significant vision for the future. In this case, the vision pertains to developing a next-generation research environment in which technology enables researchers to explore research questions and problems that otherwise would not be addressed. The Calit2 story to date provides early returns about some important keys to success for making this type of collaboration a winning proposition and for how other institutions can go about bringing their own research enterprise to a new level.

Leadership Matters

As in several of the other research engagement case studies, the role of leadership in this initiative is particularly apparent. Calit2 is an undertaking with broad focus and many working parts. It would not have occurred at all without the leadership of the campus chancellors and senior officers. Having gotten things in motion, however, it became the responsibility of the directors and leaders of general academic research initiatives to establish and maintain focus and momentum. Recall that while the goals relate to multidisciplinary academic research, the participating faculty are only intended to be directly affiliated with Calit2 for limited periods. Thus, by design, the future and sustainability of Calit2 will require strong leadership on an ongoing basis.

Institutional Culture and Areas of Academic Excellence Are Key

The history of collaboration on the UCSD and UCI campuses, particularly in multidisciplinary research, is an important factor underlying the initiative's progress to date. The strategy of fostering collaboration at

every level of Calit2's operation fits with the participating universities' culture more generally. "Going with the culture" in this case did not mean coasting along behind it. Rather, the Calit2 leadership was able to find the right places to amplify to make each institution stronger, adding value and momentum to the new research environment being created.

Choosing initial research application areas that were tied to institutional and regional strengths also proved pivotal. The decision to build on existing areas of excellence enabled the Calit2 team to more quickly obtain faculty and industry buy-in; create a cadre of research programs within the Calit2 umbrella that had breadth and depth; and develop new technologies to support these programs, forming a cornerstone of the next-generation environment they envisioned. Calit2 also provides a level of service to faculty that goes beyond what's normally available in their departments, including

- pre- and post-grant award support,
- advice on finding needed expertise for large projects,
- access to shared facilities and prototype infrastructure across the two campuses,
- the opportunity to connect and work with industry and community partners,
- seed funding to initiate promising projects,
- special-events support to put on large-scale events in the Calit2 buildings,
- promotion (media relations and video production) related to their research successes, and
- letters of support from Calit2 leadership for their grants.

Technological, Social, and Organizational Systems Go Hand in Hand

Although interesting new technological systems are being developed, Calit2 is clearly not about technology per se. As observed earlier, a primary Calit2 focus is creating an environment to further the research enterprise by accomplishing objectives such as bringing faculty and researchers together, developing close interactions with regional businesses and government, and engaging undergraduates in the academic research milieu. These objectives have been met by paying significant attention to social and organizational systems at the same time that the development of relevant new technologies is taking place. For example, the Layer Leader role helped ensure proper coordination of the extensive research activities in different areas already taking place at Calit2. Similarly, Living Laboratories activities help ensure substantial interchange of applied research output and and commercialization by the private sector. The academic research community gets ideas from the companies, and the companies try out new product ideas within the academic community. While this may not be a new idea, its scope and institutionalization appear noteworthy. In particular, we see more interaction and cross-fertilization occurring here than in typical academic technology transfer models.

To achieve the desired level of synthesis among the various systems, Calit2 leadership regularly exerts clear administrative focus and persistence to make sure new technology does not overshadow researchers' functional activities. This has been especially important given Calit2's broad scope. Overall, the work at Calit2 has revealed the need for a careful balance between advancing technology and meeting the needs of faculty, collaborative research teams, and other partners in the undertaking.

Addressing Big Issues Requires Big Thinking

As previously mentioned, Calit2 appears to be about inventing the future more than predicting it. Creating totally new ways to work and engage in multidisciplinary

research is a tall order that requires a compelling vision, bold plan, and expansive approach. From the beginning, Calit2 set out to change an impressive array of major components of the research endeavor in significant and innovative ways, beginning with the concept that the initiative would serve as a test bed for new research methods and technologies to support them. For example, even the approach taken in the design of the physical space for research was different. While buildings are, after all, only buildings, closely integrating the Calit2 buildings into the conceptualization and implementation of the Calit2 program may also provide new ideas about how to design specific features of some academic buildings. And, not surprisingly, the approach toward constructing the technical infrastructure was comprehensive, at all levels of the technology stack from chip design through visualization, and at all geographic levels, including local, regional, national, and global. Ultimately, the outcomes of these impressive efforts could wind up being applied in ways not originally envisioned at Calit2 or elsewhere.

Disruptive Technologies Can Create Positive Change

Intentionally, Calit2 introduced technologies and systems that were expected to create new ways to work and engage in research. Interestingly, some of these technologies require significant development, such as the middleware environment for the OptIPuter, while others such as the tiled displays use basic off-the-shelf components. In all of these cases, researchers typically want to focus their efforts directly on research, not on the tools to undertake research. The UCSD and UCI leadership recognized that a project as broad and possibly intrusive as Calit2 had the potential to be organizationally as well as technologically disruptive, and each administration was open to that. While senior administrators at both institutions appear open to having this project possibly shake up the traditional stovepipes in the organizations, academic institutions in general tend to be glacial in their movement toward new approaches to organization and working relationships. It has yet to be seen whether Calit2 will offer lessons from which others may learn in this regard. Trends toward multidisciplinary research and instruction, and funding agencies' interest in encouraging multidisciplinary activities, may mean that academia is ripe for some of the lessons of this initiative.

Faculty Should Drive Research Engagement Initiatives

The importance of having faculty at the forefront of a research-based initiative such as Calit2 is another theme that emerged in the other research engagement case studies. Faculty research sets the stage for new technologies that are developed. At the same time, the creation of partnerships between researchers and technical professionals is vital to developing a dynamic, interactive exchange between the research and the technology, with each informing and benefiting the other. These partnerships also help build an overall spirit of collaboration across research teams, which is key to forming a level of trust necessary to give up ways of working based on independent silos and adopt new, organizationally disruptive approaches to conducting research. In keeping with its underlying principles, Calit2 seems to demonstrate that while new technologies are extremely important, successful collaboration is at the heart of IT-enabled multidisciplinary research.

Conclusion

Calit2 is large in vision and in instantiation. Although young, it appears to have established substantial momentum already at UCSD and UCI, as well as at several partner institutions. This momentum is not only expected to

continue but also seems to be increasing as the Calit2 buildings come fully online this year. This will allow full recruitment of participating faculty research groups. Of course, issues such as establishing sustainable funding will pose challenges in the years ahead. Nonetheless, Calit2 appears well on its way to achieving its primary goal of developing and testing a next-generation research environment. All institutions supporting research will want to watch this initiative closely for the next several years at least, and perhaps they can already learn from it.

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Endnotes

1. This quote is often referenced back to a 1971 Xerox PARC planning meeting.
2. See <http://www.nbirn.net/>.
3. See <http://www.nlr.net/>.
4. See <http://www.itr-rescure.org/index.php>.
5. See <http://www.wiisard.org/>.
6. See, for example, the recent presentation at <http://www.calit2.net/newsroom/presentations/lsmarr/2005/html/Telluride_Aug_05_final_small_files/v3_document.html>, slide 15.
7. See <http://www.chiaro.com>.
8. See <http://www.cenic.org/calren/>.
9. Described for this study by Ramesh Rao, director, Calit2 UCSD Division.
10. See <http://www.optiputer.net/>.
11. See <http://www.calit2.net/newsroom/release.php?id=660>.
12. See <http://www.calit2.net/newsroom/article.php?id=127>.
13. See <http://www.syncenter.org/>.
14. See <http://www.syncenter.org/About_Us/Vision>.