HP Labs

2011 Annual Research Report

Dear Colleagues:

Welcome to the HP Labs 2011 Annual Research Report. Here we outline our research efforts, introduce you to several of our researchers, and spotlight some of our most exciting accomplishments. I am particularly thrilled to share this report because the past year has been distinguished by several key developments.

First, technology transfers. Three years ago, we made the call to consolidate our research projects in order to increase their impact. That focus had a big payout this year. Our significant transfers include the amazing low-power servers in Project Moonshot, the IBRIX file system for managing massive databases, optical backplanes for transferring data with light, and the Vayu Internet-on-your-TV device, plus exciting technologies for photo tagging, labor strategy optimization, and live analysis of customer intelligence and sentiment. And that's just scratching the surface.

Another area is investment: With HP under the new leadership of Meg Whitman, HP Labs had the privilege of hosting our new CEO on a full Labs tour and hearing first hand of HP's renewed commitment to driving both evolutionary and revolutionary innovation. We're the revolutionary part of that and we couldn't be more energized by this news.

This year also marked the 45th anniversary of our founding. We celebrated this milestone in December with an event elevated by the presence of the former Directors of HP Labs. This provided an opportunity to reflect on the storied history of this research function and to redouble our commitment to deliver breakthrough technologies for improving business, life, and society.

Our cover art this year is the iconic mosaic at HP Labs headquarters. Much like the technologies we develop and deliver to our customers, it represents a whole greater than the sum of its parts, and is a unifying theme that motivates and drives our researchers to even greater accomplishment.

I speak for the entire HP Labs team in being as proud of 2011 as I am excited about the opportunities ahead.

Best Regards,

Prith Banerjee
Senior Vice President, Research and Director, HP Labs

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About HP Labs

HP Labs delivers innovations that enrich business, life, and society. Since 1966, our role has been to generate breakthrough technologies, create new opportunities for HP's businesses and customers, advance fundamental science and technology, and engage with customers and partners to tackle our customers' most important challenges.

We bring a broad and inclusive perspective to solving complex problems with insight from customers, businesses, governments, and the world's leading research institutions. HP's unmatched portfolio, global breadth, and market leadership enable us to deliver open and relevant innovation on a massive scale.

Our goals at HP Labs are to:

- **Deliver business value** through a variety of paths to commercialization, including technology transfer to HP businesses, demonstrators and co-innovations with customers, and licensing

- **Create thought leadership for HP** with IP generation, publications at the top academic and industry conferences, and coverage by the top analysts and press in technical and business media

- **Co-innovate with customers and research partners,** creating transformational solutions to real-world problems

Our strategy

At HP Labs, our strategy starts with high-quality research. We amplify our research agenda with innovation partnerships, turn our research into reality with co-innovation, and then put innovation into the hands of millions of customers around the world. Our strategy consists of the following:

- **Leading-edge research agenda**: Advance state-of-the-art technologies by addressing the most complex challenges and important opportunities facing our customers and society in the next decade

- **Open innovation**: Collaborate to accelerate breakthrough technologies by leveraging the strength of HP's world-class innovation network

- **Co-innovation and demonstrators**: Work side by side with our customers to transform their businesses with our leading-edge research

- **Technology commercialization**: Generate real business value by identifying the most strategic outlets for commercializing innovations, thereby increasing the impact of technology

HP Labs' impact

HP Labs' researchers tackle difficult technology problems that are relevant to HP's customers and businesses. Whether it's research in intelligent infrastructure, information analytics, mobile and immersive experiences, or print and content delivery, there's a common thread across all of our research themes: we're innovating at every touchpoint of information. Recent innovations include:

- Advancements in intelligent IT infrastructure, pioneering low-energy server designs, and an optically connected datacenter switch

- Analytics and information management improvements such as novel file metadata database technology for large-scale content archives

- Secure and scalable computing systems, including trusted virtualized client management systems for use across large enterprises

- World's first OLED display with excellent color gamut

- Novel 3D technology for new large-display immersive experiences

HP Labs operates around the world: Palo Alto, USA; Bangalore, India; Beijing, China; Bristol, UK; Haifa, Israel; Singapore; and St. Petersburg, Russia. Our global footprint expands our access to ideas, talent, and partners, and informs our research perspective through the local environments in which we do our work.

Our people

The engine of our inventiveness is our people, and our success is founded on these teams of individuals who exhibit their passion for technology and customers every day. We are proud to introduce you to just a few of them throughout this report.

Our scientists are among the most distinguished in their fields. We have leading scientists in areas such as nanotechnology; computer algorithms; thermo-mechanical architectures of chips, systems, and datacenters; color science; energy management; analytics; data management; and information theory. More than 60 percent of our researchers are Ph.D.s. Collectively they generate thousands of publications and hold thousands of patents. They've received some of the highest honors in science and engineering, including the Turing Award, the Julius Springer Prize for Applied Physics, the Feynman Prize for Nanotechnology, the ACM Edgar F. Codd Innovations Award, and the Jack S. Kilby Signal Processing Medal.

HP Labs celebrates 45 years of innovation

In 2011, HP Labs commemorated the 45th anniversary of its founding with a renewed commitment to innovation at HP. At a celebration held at HP Labs' Palo Alto headquarters, Director Prith Banerjee noted that "innovation once again really matters at this company." That leaves HP Labs with a clear purpose, Banerjee continued: "Our mission is to create absolutely disruptive innovation beyond HP's current roadmap of products. After 45 years successfully dedicated to the pursuit of innovation every single day, everyone at HP Labs is excited to help lead that charge."

Founded in 1966, HP Labs is the birthplace of the company's first computer, the HP 2116A, the first commercially available light-emitting diode (LED), the first programmable scientific desktop calculator, and thermal inkjet technology. More recently, HP Labs has pioneered the development of hybrid chip architectures for low-power, high-performance computing; a smart skin patch for painless medication injections; and the Memory Spot wireless data chip. HP Labs researchers also first demonstrated the existence of memristors—the fourth basic element in integrated circuits—in 2008, enabling a new generation of nonvolatile memory and storage solutions.

From left to right: current HP Labs Director Prith Banerjee, former Labs directors Richard Lampman (1999–2007), Frank Carrubba (1987–91), Joel Birnbaum (1984–86 and 1991–99), Don Hammond (1986–87), and John Doyle (1981–84)

HP Labs has 13 IEEE Fellows and six ACM Fellows, as well as fellows of the British Computer Society, the American Association for the Advancement of Science, the Society for Imaging Science and Technology, the American Society of Mechanical Engineers and many other professional societies—along with one technical Emmy® winner and one winner of a technical Oscar®.

Two of our scientists have been elected members of the U.S. National Academy of Engineering and one is a member of the U.S. National Academy of Sciences.

Beyond these external awards and recognition, HP Labs people are recognized technical leaders within HP as well. Our team includes five HP Senior Fellows and ten HP Fellows. Our researchers work closely with HP's businesses and customers to influence, define, and build the strategy of tomorrow, and their expertise is widely sought inside and outside of HP.

We constantly seek to recruit, challenge, and develop the best talent in the industry, and we attract employees with unique perspectives, openness to multidisciplinary research, and a passion for their work. Bringing these amazing people together helps us turn research into reality every day.

While we have some of the best minds in the world at HP Labs, we know that we don't have a monopoly on innovative ideas. So we've taken an open innovation approach and are actively partnering with leading companies, academic institutions, and government agencies to amplify our research results.

Awards and honors

Below is a sampling of the awards and honors received by HP Labs researchers in 2011:

- **John Apostolopoulos**—Distinguished Lecturer, IEEE Signal Processing Society 2012–2013, and ISO/IEC Certificate of Appreciation for contributions to the JPSEC international standard

- **Cullen Bash**—Fellow, American Society of Mechanical Engineers (ASME)

- **Sudhir Dixit**—Vice Chair Asia, Wireless World Research Forum (WWRF)

- **SJ Lee**—Distinguished Scientist, Association for Computing Machinery (ACM)

- **Jun Li**—Winner, ICWS Service Cup 2011 (with researchers from Federal University of Pernambuco, Brazil)

New leadership at HP Labs in 2011

Two of HP Labs' most respected technical leaders accepted new roles in 2011, becoming senior leaders in the organization.

Umesh Dayal is Director of the Information Analytics Laboratory, with teams in Palo Alto, Israel, and Russia, developing innovations in the timely delivery of real-time business intelligence to enterprise customers. Dayal, an HP Fellow and expert in data management, business intelligence, and analytics, is also a Fellow of the Association for Computing Machinery (ACM) and received the 2010 Edgar F. Codd Innovations Award from ACM's Special Interest Group on Management of Data (SIGMOD) for his contributions to the field of data management.

Ruth Bergman is Director of HP Labs Israel, leading a team focused on creating value from big data in enterprises and then delivering this value to users by streamlining collaboration, creating insight, and increasing automation. Bergman's background is in artificial intelligence and machine learning, and she has led several successful technology transfers from HP Labs to HP products, including Dust and Scratch Removal for scanners, Event Interpretation for HP Indigo presses, and Image-Based Automation for Business Technology Optimization (BTO) products.

- **Dejan Milojicic**—Outstanding Contribution Award, IEEE Computer Society

- **Lueny Morell**—Senior Member, Institute of Electrical and Electronics Engineers (IEEE)

- **Partha Ranganathan**—Fellow, Institute of Electrical and Electronics Engineers (IEEE)

- **Puneet Sharma**—Distinguished Scientist, Association for Computing Machinery (ACM)

- **Koushik Sinha**—N V Gadadhar Memorial Award, 2011, Institution of Electronics and Telecommunication Engineers (IETE India)

- **Jean Tourrilhes**—Outstanding Technical Contribution and Outstanding Leadership Awards, Open Networking Foundation (ONF)

- **Chris Whitney**—Board Member, Singapore National Research Foundation

Looking forward

As we look forward to 2012, our focus is on delivering crucial breakthroughs to HP and our customers while setting up the next generation of disruptive innovations that will have a lasting impact on HP over time.

We are doubling down on a number of exciting technology developments in printing and content delivery, intelligent infrastructure, information analytics, services, and cloud that promise to deliver real value to HP's businesses. At the same time, we are launching new research programs in cognitive systems, integrated systems for structured and unstructured data analytics, sustainable resource management, and enterprise security, among others. We are also applying our capabilities to research for key verticals and emerging markets, such as our sensing solutions and healthcare.

We have been charged with leading the way in a revitalized culture of innovation at HP—and we are proud to say that we're up to the challenge, building on our successes of the past several years as a global, multi-disciplinary team.

Advancing the State of the Art

As HP's central research organization, discovering meaningful advances to science and technology is at the core of everything we do. We demonstrate our leadership by publishing in journals, external conferences, and our company-internal technical conference and by generating intellectual property through invention disclosures and patents. We are especially proud when our work is featured in publications that are influential and well respected in the industry, and when our researchers are recognized with awards for outstanding publications.

HP Labs researchers authored 217 publications in 2011—in books, journals, and magazines—as well as 441 conference papers.

Leading-edge research portfolio

Our greatest impact comes from working collaboratively on large, multidisciplinary research activities, with customers and partners, to inject innovation into HP's products and solutions and enhance the customer experience. HP Labs research falls into eight broad themes:

Printing and Content Delivery focuses on technologies that smooth the flow of information between digital and physical formats, providing more automated, seamless, and secure publishing platforms to consumers and enterprises alike.

Mobile and Immersive Experience seeks to fundamentally change how people communicate, collaborate, socialize, and entertain through advancements in mobile devices, sensing, client/cloud computing, and 2D/3D display technologies and information surfaces.

Services enables new end-to-end solutions across businesses, and invests in research to support the creation of new services for specific industries (such as healthcare) as well as emerging and growth markets.

Information Analytics applies sophisticated analytics to turn massive streams of structured and unstructured data into timely, relevant information and insight, offering business solutions that enhance operations and productivity, ultimately creating better-run businesses.

Cloud and Security provides the foundational technologies to expand the use and relevance of cloud computing in the enterprise by delivering the secure application and computing end state of "Everything-as-a-Service."

Intelligent Infrastructure develops radical new approaches for collecting, processing, and storing data—harnessing the power of information to make better, faster decisions and build the backbone of a sustainable society.

Networking and Communication creates the next generation of network architectures and communications technologies that provide predictable, high-quality, power-efficient networks that are an order of magnitude faster and more cost-effective than their predecessors as they reduce management complexity.

Sustainability powers the global information economy and today's businesses with a sustainable, massive-scale, intelligent infrastructure.
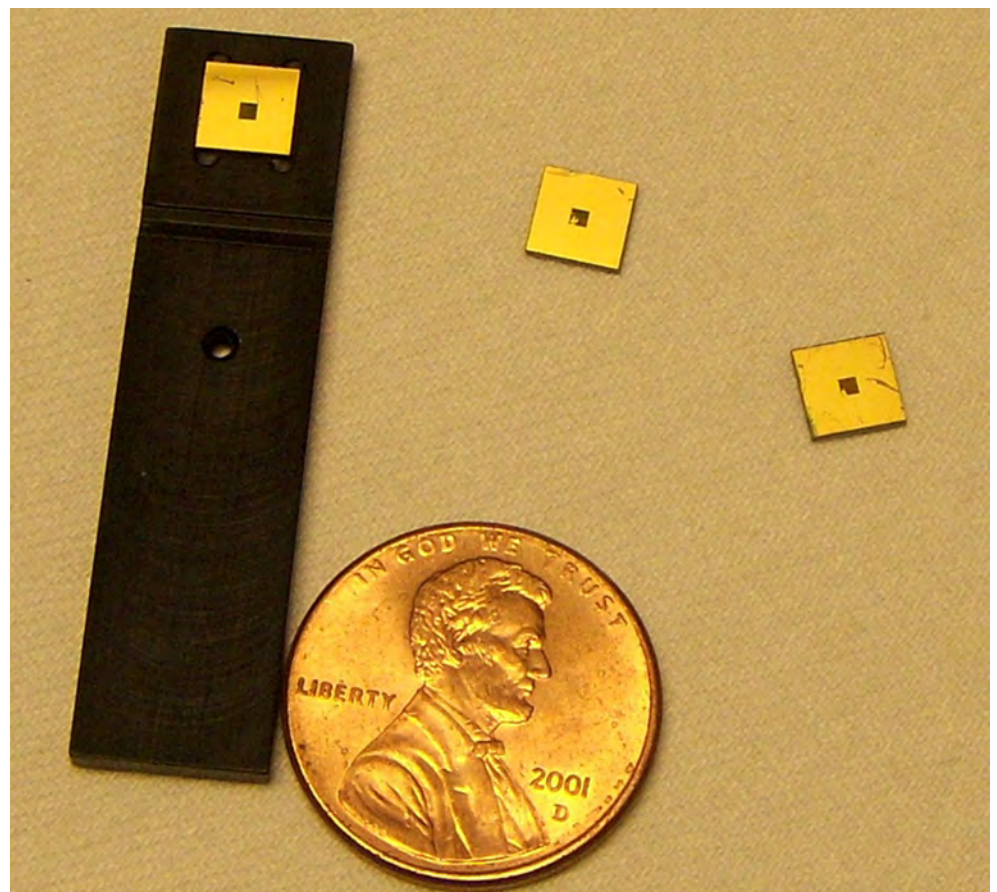
Nanofinger sensing chips capable of detecting minute molecular markers

Nanosensors that can "taste" and "smell"

Nano-scale chemical sensors—one type of "nerve endings" envisioned in HP Labs' Central Nervous System for the Earth (CeNSE) project—are capable of detecting and identifying minute molecular markers, such as environmental contaminants, chemical and biological warfare agents, special chemical markers, and disease indicators. These will be an important part of the future world, helping to ensure the wellbeing of people in a safe, secure, and sustainable environment.

A breakthrough HP Labs innovation in nanotechnology is enabling the development of a compact, low-cost, highly sensitive sensing system. Based on surface enhanced Raman spectroscopy (SERS), discovered more than 30 years ago, HP Labs' discovery of novel nanofinger structures can amplify the molecular Raman signal by a trillionfold, yielding a unique fingerprint for each molecule. The system pairs novel nanofinger sensing chips with a "mini-Raman" reader that can replace a current laboratory instrument that's the size of a car with a small, handheld device.

Researchers in the Cognitive Systems Lab envision using the new technology for inexpensive and real-time detection, identification, and quantification of contaminants in water, food, or air; for more rapid, precise testing for diseases; or for security, anti-counterfeiting, and anti-terrorism applications.

New research agenda in cognitive computing

Computing workloads are rapidly evolving towards non-computational algorithms and petabytes of unstructured and structured data. Today's challenge is in designing computational systems that are both performance- and energy-efficient. Researchers in the Cognitive Systems Lab are catalyzing recent advances, creating the Cog ex Machina cognitive computing research project in 2011.

Cognitive computing, inspired by how the human brain works, has the potential to revolutionize visually-based information analytics, leading to exciting applications in a wide range of domains including surveillance, location-based services, healthcare safety, fraud detection, sentiment
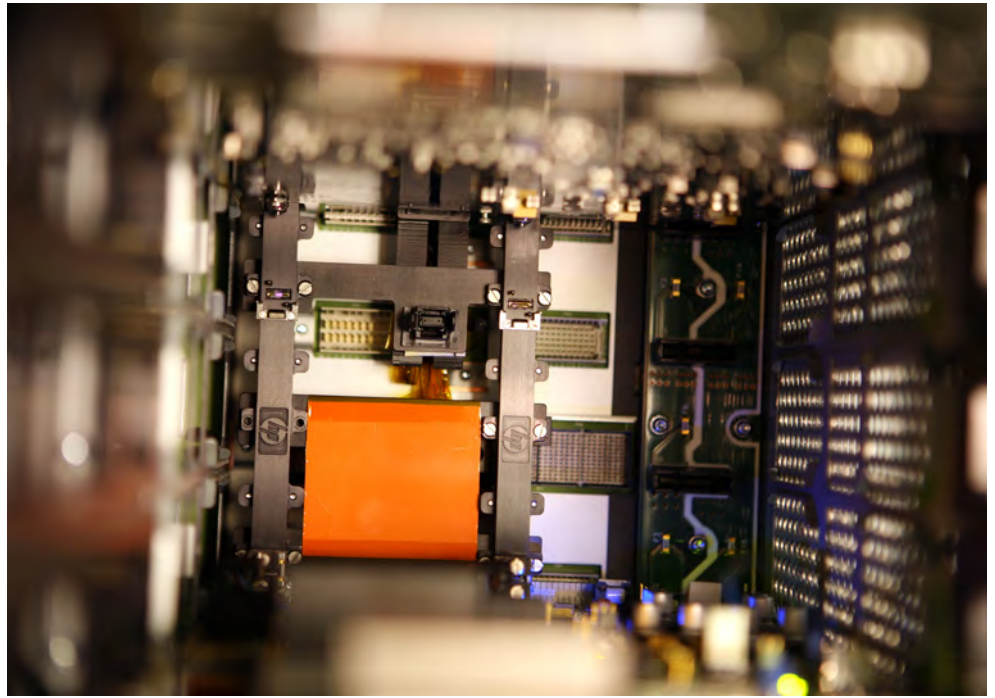
HP Labs' all optically connected datacenter switch

analysis, big data processing, and visualization.

HP Labs' approach to cognitive computing creates a massively parallel, cognitive architecture that is easy to program, supports adaptive learning, and scales to millions of cores on thousands of multi-core digital processors distributed over a network—an architecture that represents a leap beyond previous attempts at building intelligent systems.

HP Labs' "cool" optical backplane impresses in its 2011 industry debut

In 2011, HP Labs researchers demonstrated an all optically connected datacenter switch that eliminates the electronic backplane and communications fabric switch ASICs currently used. The low-cost, injection-molded optical backplane, based on a multi-drop optical broadcast bus, was shown at several important industry events. At the Interop 2011 conference, HP Labs' demonstration was a huge hit, garnering one of Larry Chaffin's third annual "Larry Awards" (*Network World*) as the winner in the "Labs or Future Products" best presentations category. Chaffin noted in his blog that he "thought this was the coolest thing at Interop," and he lauded its potential as "one of the biggest innovations I saw at the show this year. This will one day greatly speed up switches."

The switch's novel architecture incorporates a parallel, high-speed optical backplane using multiple optical broadcast buses to replace the electronic backplane and ASIC fabric layer currently used to route data streams within a switch. The switch function is distributed equally among the line cards, removing the requirement for costly, power-hungry ASICs. This use of state-of-the art optics capabilities achieves greater cost savings and lower power usage than directly replacing point-to-point electronic interconnects with optical connections—and it reduces the management complexity currently needed to reconfigure traditional copper wire-based switches.

Researcher Mike Tan believes that the team's device can be of cost equivalent to—or perhaps even 20 percent lower cost than—its electrical counterpart. Their novel design achieves this by building on existing, commercially available high-volume optoelectronic components that have the potential to offer 30x bandwidth scaling that is both cost-effective and energy-efficient.
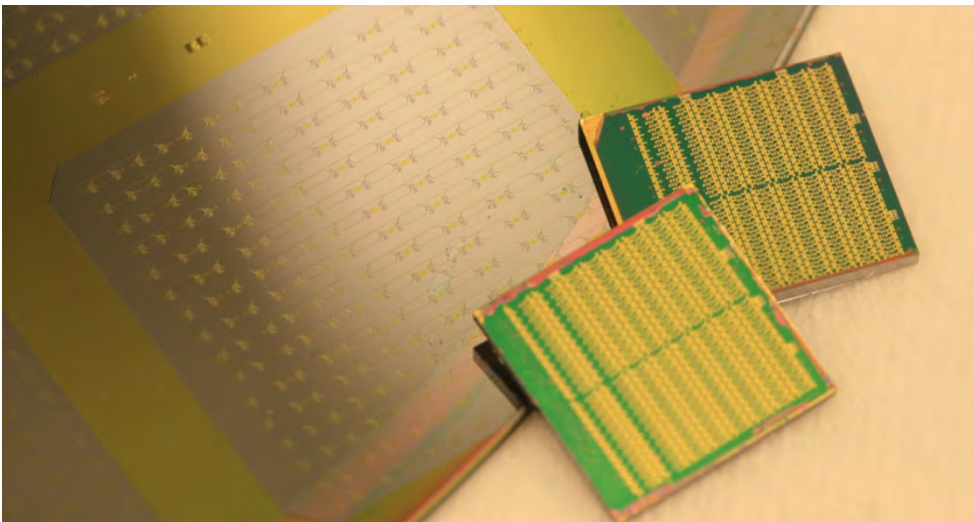
Silicon-compatible lasers developed by HP Labs and UCSB

Collaboration yields novel silicon-compatible laser

In recent years research groups and companies around the world have endeavored to demonstrate that silicon can be used to foster a new era of integrated photonics. While silicon serves as a material to build optical components such as waveguides, modulators, and detectors, a missing key component is a silicon-compatible laser.

Professor John Bowers and his group at University of California, Santa Barbara, have been pioneering a new hybrid technique to integrate lasers on a silicon photonics platform that uses wafer bonding.

Initial lasers built by the team were large (hundreds of microns) and could only be operated in the continuous-wave regime. Through an IRP collaborative project, HP Labs researchers challenged Professor Bowers' group to build a laser at least 10 times smaller and capable of being modulated at a speed of several Gigabits per second (Gbps). Such a laser would be an ideal replacement for the engines that drive many of the optical links deployed in datacenters around the world. Engines based on the new hybrid technology would be cheaper to manufacture and provide five to 10 times more bandwidth per channel than the state of the art.

The results of the team's work since 2008 have exceeded expectations. They built a 50-micron laser that emits enough light to drive a link hundreds of meters long and that can be modulated at speeds of 5 Gbps. The group also demonstrated a path toward large-scale production and tackled the thermal performance of the device.

In addition to the outstanding technical achievements, HP Labs researchers also met UCSB post-doc Dr. Di Liang, working in Professor Bowers' team. Dr. Liang subsequently worked on site at HP Labs—first as a post-doc and then as a Visiting Scholar—and was hired as an HP Labs researcher in November.

Material properties of memristor revealed

In May 2011, researchers from HP Labs and the University of California, Santa Barbara, published a paper in the journal *Nanotechnology* showing, in unprecedented detail, how memristors work at the material level. Memristors were recognized only in theory until 2006, when HP Labs researchers first performed experiments to intentionally demonstrate their existence. While the electrical properties of these devices are now fairly well understood, very little had been known about how they physically undergo reversible changes in resistance. The researchers used highly focused x-rays to localize the exact, 100-nanometer channel where the resistance switching of memristors occurs. That gave the team a detailed insight into the thermal, chemical, and structural changes that occur when the device is operating.

Representing a fourth basic passive circuit element, memristors have the ability to "remember" the total electrical charge that passes through them. As a result, they could potentially underpin a new generation of high-density, non-volatile memory chips and logic circuits that mimic biological synapses. HP is partnering with Hynix to jointly develop non-volatile memory chips aimed at replacing flash memory and solid-state drives (SSDs) in the near future. A better understanding of the physical processes that occur within memristors at the nanoscale is essential if memristors are to realize their potential as the basis for innovations in computer memory and logic, according to the team. Memristor-based devices could one day, for example, act like synapses inside computer circuits, mimicking the behavior of neurons in the human brain.
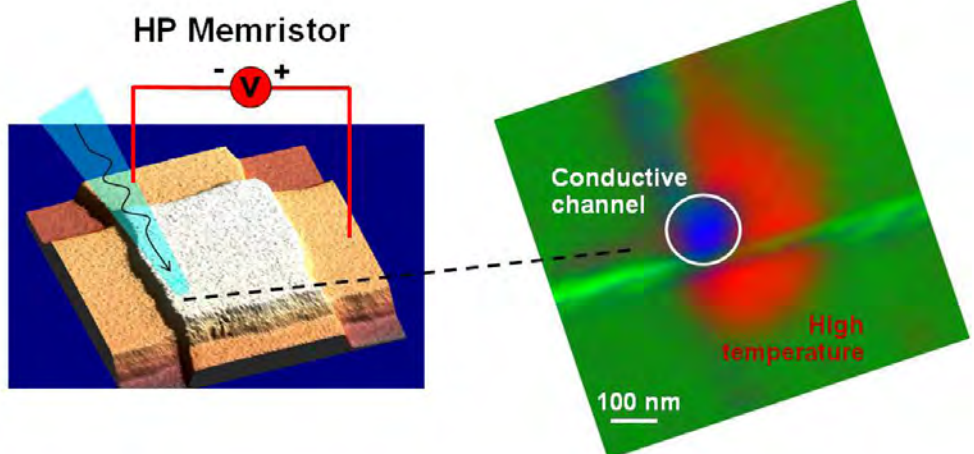
Electrical charge flowing through a memristor changes the resistance state of the device, but actually observing the corresponding material changes has been a challenge. Highly focused x-rays were used to probe the memristor non-destructively and a ~100 nm region—with concentrated oxygen vacancies (right, shown in blue), where the memristive switching occurs— was discovered. Surrounding this region, a newly developed structural phase (red) was also found, which acted like a thermometer telling researchers where and how hot it became.

Paul Congdon

Ph.D. candidate, Computer Science, University of California, Davis

HP Fellow, Network and Communications Lab

Research Interests

Congdon has worked in the networking industry for 26 years and is widely esteemed as an inventor and leader in driving a broad set of networking industry standards. He is currently leading a research effort on seamless mobility and networks for pervasive computing, which includes the creation of a cloud-connected mobile personal grid.

Spotlight

Congdon is the Vice Chairman of the IEEE 802.1 committee, and his longstanding activities with IEEE 802 standards efforts involved him in the creation of the switched Ethernet LAN. He is co-inventor of the commonly used TCP checksum offloading, a program for accelerating the networking performance of TCP/IP within servers. Congdon is also responsible for initiating, leading, and contributing to widely used IEEE 802.1 standards, including IEEE 802.1X, LLDP, and the recently completed Virtual Edge Port Aggregators (VEPA).

New research uncovers social media trends in China and Singapore

Several influential studies were published by social media researchers at HP Labs in 2011.

What trends in Chinese social media

With the tremendous growth of online social networks all over the world, networks like Twitter and Facebook have been well studied by researchers. The popular Chinese microblogging social network Sina Weibo, however, had not been studied in detail. Researchers Louis Yu, Sitaram Asur, and Bernardo Huberman published an influential paper in 2011 titled "What Trends in Chinese Social Media." The paper analyzed more than 4,400 Sina Weibo trending topics over 30 days, comparing them with over 3,300 trending topics on Twitter. The study found that trending topics on Sina Weibo tend to be more about entertainment (jokes, images, and videos) than news, and that the effect of retweets on Weibo is far greater than on Twitter.

For the Social Computing Research Group, this study is just the beginning. Tasked with creating software analytics and algorithms that can add meaningful context to the huge data sets produced by millions of social media users, they believe understanding how social media works in other regions can bring more value to HP and its customers.

Monitoring elections in Singapore through social media

During its general elections in May 2011, Singapore witnessed the emergence of social media as a platform for campaigns and open discussions. Because online information is generated at a faster rate than traditional media, many stakeholders found the flood of data feeds overwhelming.

HP Labs Singapore's Social Media Analytics (SoMA) team took this opportunity to test its Social Media Analytics platform, and was able to attack several hard problems in social media analytics research: aggregating feeds from several sites (Facebook, Twitter, etc.), detecting and summarizing significant events, discovering relations between different events, and performing sentiment analysis from the events detected.

Compared to other, less sophisticated techniques in the market (such as counting mentions of topic keywords), HP Labs Singapore's platform was fully automated—applying signal processing techniques and aspect-based sentiment analysis algorithms to the massive streams of aggregate data. The team also collaborated with researchers in Palo Alto on the development of the sentiment analysis algorithms used, making for a truly global collaboration. The novel results, which combine hot topic detection and sentiment analysis—all while tracking the entire event as it unfolds—have been demonstrated to several customers, and findings have also been featured in the *Straits Times*, Singapore's top English-language newspaper.

Weng Jianshu demonstrates the Singapore elections social media analytics project at the eGovernment event at CommunicAsia 2011.

Kar Han Tan

Ph.D., Computer Science, University of Illinois, Urbana-Champaign

Senior Research Scientist, Mobile and Immersive Experience Lab

Research Interests

At HP Labs, Tan is focused on creating seamless, immersive, and intuitive experiences for remote collaboration. His research interests include 3D capture and display, lifelike telepresence, computer vision and graphics, machine learning, and pattern recognition. Tan received his M.S. degree from University of California, Los Angeles, where he co-invented the Virtual Structures algorithm—widely recognized today as one of the fundamental techniques for mobile robot formation control.

Spotlight

Tan is an active contributor to the research community and received the IEEE Multimedia Signal Processing 2010 Best Student Paper Award for his work on the fusion of active and passive sensors for fast 3D capture. Before he came to HP, Tan managed the algorithms group at Epson R&D, where he led the invention of View Projection, a technique that enables one-touch setup of light displays on arbitrary surfaces. He also worked at Mitsubishi Electric Research Lab, where he co-invented Multi-Flash Imaging—a technology that reliably recovers depth discontinuities and can be used to produce abstracted yet realistic line drawings from photographs. The paper was presented at SIGGRAPH, where a video implementation turned real-world scenes into non-photorealistic renderings similar to the animated pencil sketches in the 1985 music video "Take on Me" by the Norwegian band A-ha. At HP Labs, Tan is currently leading a team pushing the envelope on remote collaboration technology with a new class of systems addressing longstanding challenges in conventional telepresence systems. He is also working on immersive, scalable displays that deliver realistic 3D renderings without requiring viewers to wear glasses.

Spotlight: Solutions for Healthcare

Technology has profound potential not only to improve lives, but to save them. Working on solutions specific to industries such as healthcare, offers real challenges—and real rewards—to HP Labs' researchers. Our scientists are collaborating to identify opportunities to apply their technology to solve some of healthcare's most pressing challenges. Innovations such as tiny, super-sensitive sensors, immersive information surfaces, and sophisticated analytics are being applied in new ways to help improve patient safety, enhance patient and staff experiences, and increase operational efficiency.

Improving patient care and saving lives with sophisticated analytics

Lucile Packard Children's Hospital at Stanford (LPCH) teamed up with HP Labs and HP's Global Social Innovation group in 2011 to pilot several innovative solutions that can significantly improve care and save lives.

The first, a patient safety dashboard, addresses a critical challenge for busy hospital staff. Vast quantities of highly complex data generated during normal patient care must be monitored, analyzed, processed, and acted upon. To improve insights derived from these data streams, LPCH tapped HP Labs' expertise in deep analytics to pilot an electronic patient-centered dashboard in its pediatric intensive care unit. The solution finds and integrates information at risk of being overlooked inside electronic health records, makes the information visible to the entire care team, and allows for more effective decision-making, which ultimately improves patient care.

Launched in June, the electronic dashboard replaces the traditional whiteboard that includes information such as handwritten staff names, room numbers, and detailed patient data. The solution also includes at-a-glance alerts with red, yellow, and green urgency-level lights to help prevent life-threatening complications. When in use, it prompted change in care in one-third of LPCH's patient rounds. It is currently being deployed in other LPCH units.

A second effort has resulted in the development of a pilot operating room (OR) planning and scheduling system that has received enthusiastic response from collaborators and medical experts.

Proper scheduling and planning within a hospital's surgical unit are particularly important because the unit typically utilizes the provider's most expensive resources (surgeons, anesthesiologists, critical medical equipment, etc.) and has a significant impact on the operational performance of the hospital. This complex decision process also directly impacts key hospital success metrics such as resource utilization and patient/staff satisfaction. It must take into consideration inherent uncertainties such as patient arrival times, unexpected emergency cases, patient cancellations, and imprecise surgery durations.

The solution developed by HP Labs and LPCH is based on a hybrid block scheduling process typically followed by hospitals. It automatically generates an optimized schedule that shows improvement over manual scheduling and is predictive in its ability to anticipate next-day bottlenecks. The solution may also be leveraged for tactical decisions around planning and scheduling in other hospital functions, including bed management and emergency room operations.

Keeping medications safe in India

In 2011, HP launched its Global Authentication Service, a cloud-based track-and-trace solution used to fight the global problem of counterfeit and stolen drugs, which are estimated to claim 700,000 lives every year. The service, based on HP Labs

Patient-centered dashboard in use at Lucile Packard Children's Hospital

technology, enables consumers to detect fake medications using a unique GS1-compliant 12-digit code created and managed by HP that is printed by HP's global printing partners under a scratch-off sticker on each package or carton. The consumer can send this code via text message to the service, which replies instantly with a text message that advises the user whether the medication is genuine or counterfeit.

The Global Authentication Service was rolled out first in India due to the phenomenal growth in the country's pharmaceutical industry, which is also experiencing the development of a parallel counterfeit drug market. It allows pharmaceutical companies to monitor the movement of products through their global supply chains with a much higher degree of accuracy, helping to protect consumers against dangerous and ineffective drugs.

The underlying technology engine, originally developed by HP Labs and the Software Professional Services team in Galway, Ireland, was most recently adapted and deployed in collaboration with the African social enterprise mPedigree to track, trace, and authenticate a range of lifesaving medications in Nigeria and Ghana. Rollout is planned for more countries.

Haiyan Wang

Ph.D., Operations Management, Washington University in St. Louis

Research Scientist, Information Analytics Lab

Research Interests

Wang joined HP Labs as a post-doc in January 2011 and was hired as a full-time researcher last November. She has deep interest in large-scale optimization, the application of optimization theory and modeling techniques to complex real world problems, and the development of innovative algorithms to achieve significant business impact. Her most recent research focuses on healthcare with particular emphasis on operating-room scheduling and comparative effectiveness aimed at significantly improving hospital operational efficiency and healthcare quality.

Spotlight

Wang is a key member of the HP Labs team collaborating with the Lucile Packard Children's Hospital (LPCH) to develop an integrated operating-room scheduling system. The system shows great promise over other currently available state-of-the-art systems—including LPCH's current scheduling practice—based on extensive simulation using the hospital's own data. A pilot at LPCH is being launched to see how the technology fares in the real world. In parallel, HP is exploring how the technology can address larger market opportunities.

Open Innovation

In today's globalized world, ideas and innovation can appear anywhere—both inside and outside of the corporate research lab—and the path to commercialization can take many different routes. HP Labs recognizes that successful innovation requires partnerships and collaboration, and openness to engagement with the broader innovation ecosystem that surrounds us.

Our objective in pursuing open innovation is to join together new ideas, resources, and global talent, catalyzing them to amplify our research investments for greater impact on HP and the state of the art. We are actively engaged in joint research partnerships with over 60 universities and research institutes around the world; research and education programs co-funded by governments in the U.S., UK, Europe, Singapore, Brazil, and Mexico; and collaborations with leading-edge customers and partners.

During 2011, HP Labs funded 62 research projects at 50 universities in 11 countries through the IRP.

Innovation Research Program: collaboration on a global scale

Since launching in 2008, the HP Labs Innovation Research Program (IRP) has provided several million dollars of support to academic projects aligned with the HP Labs research agenda. The program, which enters its fifth year in 2012, was created to bring new ideas into HP Labs while offering the global university research community an opportunity to partner with HP Labs on the latest research topics. It has attracted more than 1,500 research project proposals, gaining broad attention in the academic community worldwide.

Each IRP award provides up to $100,000 in project funding for an academic year, renewable up to a total of three years. Supporting graduate students is a focus of the IRP, and follow-on summer or semester internships often deepen the engagement. Shorter collaborative faculty and student researcher visits to HP Labs are also common.

Over its first four years, the program has supported more than 150 research projects. Most of these projects were renewed for a second year, and nearly a quarter of the total progressed to a third year. Several projects have involved joint collaboration of two institutions with one another and with HP Labs. Proposals have been received from more than 40 countries, and awards have been made to institutions in 17 countries.

The impact of IRP-facilitated collaborations has been significant. Several have played roles in HPL demonstrator projects and the resulting technology transfers to HP business units. To date, more than 37 patent filings and over 200 scholarly publications have resulted from IRP projects. And as originally envisioned in 2008, collaborators who have worked with HP Labs through the IRP have contributed new ideas, outstanding talent, and unique technical and scientific contributions.

Addressing the challenge of exascale systems

HP Labs is partnering with researchers from Oak Ridge National Laboratory, University of Michigan, and The Pennsylvania State University on the Blackcomb project, a collaborative research effort sponsored by the U.S. Department of Energy (DoE). Their aim: leverage emerging nonvolatile memory technologies to address energy, resilience, and performance challenges in exascale systems.

Future exascale high-performance computing systems are likely to face several challenges. These systems may be comprised of as many as a billion cores, capable of 10-billion-way concurrency in simultaneous operations. Data movement and power constraints will be key limiting factors, and multi-level storage architectures spanning multiple types of hardware will require new approaches to runtime data management and analysis.

In response, the Blackcomb team has designed a new distributed computer architecture that addresses these requirements. Specifically, the proposed novel architecture replaces mechanical-disk-based storage with energy-efficient nonvolatile memories (NVRAM), places low-power compute cores close to the data store, and reduces the number of levels in the memory hierarchy. The team is building on the novel design to determine how to build software to best exploit nonvolatile memory—and is also evaluating the impact of the proposed architecture on the performance of critical applications such as turbulence in combustion, advanced reactors, materials in extreme environments, and global climate modeling.

Real Steel: imagining the future of technology with DreamWorks

What will technology look like in the year 2020? This question served as the basis for a partnership between HP Labs and DreamWorks Studios for the making of a movie blockbuster where technology had a starring role. *Real Steel* premiered in 2011 as a live action movie set in a not-too-distant

A scene from DreamWorks' Real Steel showcases one of HP Labs' future technology ideas

Rob Schreiber

Ph.D., Computer Science, Yale University

Distinguished Technologist, Intelligent Infrastructure Lab

Research Interests

Schreiber is known for basic research in sequential and parallel algorithms for matrix computation, and compiler optimization for parallel languages. He is currently focused on research in algorithms and architectures for high-performance computing and data analysis, along with projects related to programming exascale systems and the use of nonvolatile memory and nanophotonics in exascale architectures.

Spotlight

Prior to joining HP Labs, Schreiber was a Computer Science professor at both Stanford University and Rensselaer Polytechnic Institute, Chief Scientist at Saxpy Computer, and a research scientist at the NASA Ames Research Center. He was a developer of the sparse-matrix extension of Matlab, a leading designer of the High Performance Fortran programming language, and one of the developers of the NASA Supercomputing Division's parallel benchmarks. At HP Labs, Schreiber was the technical leader for and helped implement PICO, a tool for hardware synthesis from high-level specifications. In 2010, he also began collaborating with researchers from Oak Ridge National Laboratory, University of Michigan, and The Pennsylvania State University on the Blackcomb project, an effort sponsored by the U.S. Department of Energy to create and advance emerging nonvolatile memory technologies to address energy, resilience, and performance challenges of exascale systems.

future in which robot boxing is a popular sport. Before filming started, a team of HP Labs researchers gathered to brainstorm personal and immersive technology solutions to present to the DreamWorks production team at the studios' offices in Universal City, California.

Not only was this an opportunity for the team to share its creative ideas with a long-time HP partner, but it was also an opportunity to reach out to the film's audience by influencing the showcased technology, which served as a bridge between the robots and the actors. One concept in particular appealed to the production team: the use of a see-through screen with the ability to overlay digital content on real-world items led to four different HP-inspired prototypes built for the film. While the technology concepts seemed futuristic to movie-goers, the team at HP Labs is confident they can one day make these concepts a reality.

Artificial intelligence helps automatically reconfigure cloud services

Cloud applications are in a continuous state of flux, changing in size according to demand. Managing the dynamic nature of these cloud applications in a complex and fast-changing environment, however, is a challenge.

Through an IRP award, researchers from the Cloud and Security Lab have partnered with the University of Edinburgh to apply artificial intelligence techniques to automate the planning of changes to cloud services. This means the cloud infrastructure can react quickly to system failures or changes in demand by automatically creating and executing a plan to reconfigure an application. The project aims to generate plans that will guarantee the application continues to provide a service, even during the transition to a new configuration.

In the second year of a three-year project, the team recently won a best student paper award and is continuing to focus on automated planning of complex system configuration and reconfiguration in the cloud.

World's first OLED flexible display with R2R backplane demonstrated

Bringing a complex technology like flexible displays to fruition requires collaboration—and HP Labs has been partnering with the best from academia, government, and industry to make it happen. For example, HP Labs has partnered with researchers at the Flexible Displays Center at Arizona State University for the past several years to research and develop advanced flexible displays technology.

Active-matrix organic light-emitting diode (AMOLED) displays are a highly promising display technology, thanks to their power efficiency and lack of limitations in size, color gamut, or screen resolution. Currently available OLED manufacturing technologies are still very limited, especially in terms of cost, size, and flexibility. Researchers have been applying HP Labs' novel roll-to-roll (R2R) manufacturing technology—self-aligned imprint lithography (SAIL)—to fabricate flexible active matrix OLED displays. Their goal: create AMOLEDs that are lightweight and flexible, have brilliant color, and are extremely low-cost. They believe fabricating these displays directly on plastic is the key to enabling this goal; the alignment-free method could one day enable large-area interactive displays, such as interactive wallpapers or information surfaces.
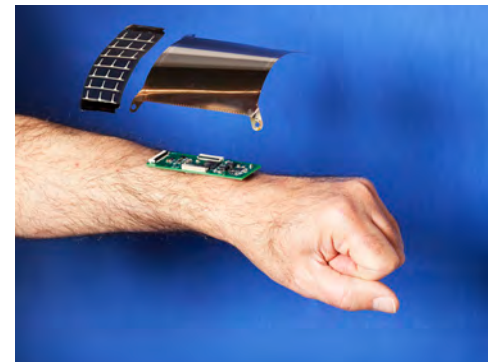

Components of the wrist worn display prototype developed at HP Labs, which incorporates a working flexible display powered by solar cells

In 2011, the team demonstrated the world's first flexible display with a micro-OLED frontplane integrated with an active-matrix backplane using alignment-free processes.

In another project supported by funding from the U.S. Army Research Lab, in 2011 HP Labs and Phicot, a subsidiary of PowerFilm Solar, demonstrated a functional lightweight, solar-powered wrist display designed for use by soldiers in the field to view digital maps and data. The flexible plastic screen won't shatter or crack, can be sewn to fabric, consumes very little energy, and requires no power to hold an image.

The team's current work is focused on integration of the display with flexible solar cells in a wrist-worn appliance.
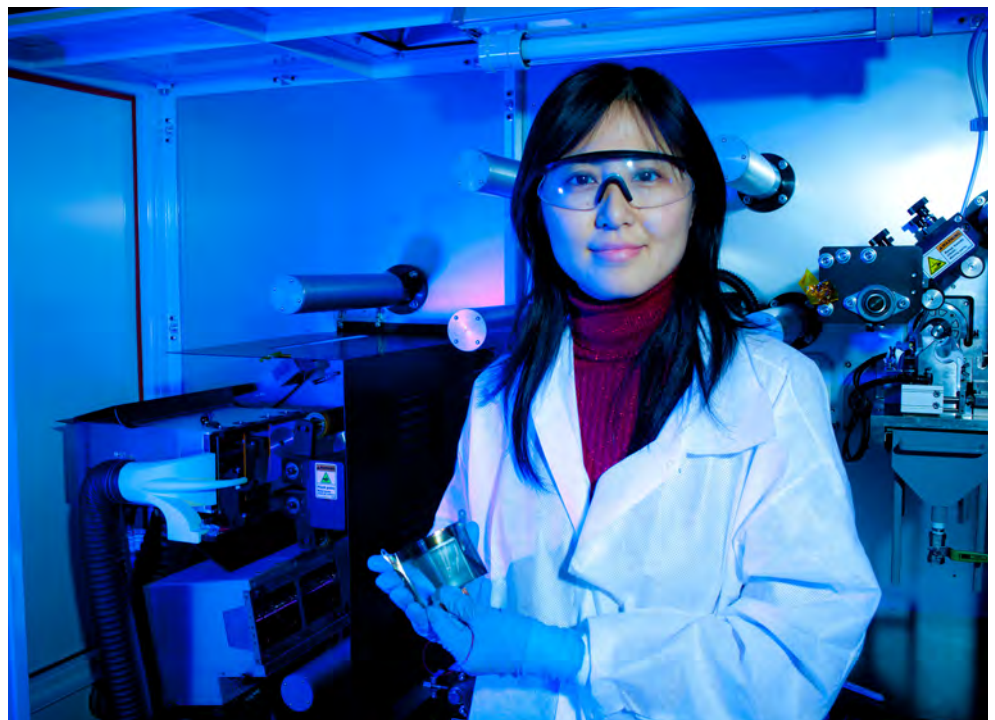
Researcher Lihua Zhao shows off a flexible AMOLED display with SAIL backplane created using HP Labs' R2R fabrication process.

Ryan Ko

Ph.D., Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore

Researcher, Cloud and Security Lab, HP Labs Singapore

Research Interests

Ko's graduate studies focused on services computing, semantic Web, and automated workflow modeling. His Ph.D. work introducing an automated workflow synthesis methodology clinched the top prize in the fourth IEEE Service Cup in Los Angeles in 2009. Since joining HP Labs in 2010, Ko has been working on cloud computing accountability and security, data analytics, and the challenge of large data transfer bottlenecks in Web services. He is currently leading the TrustCloud research project, which is focused on monitoring data lifecycles and transfers in the cloud—including tackling key security issues such as cloud data leakages and cross-national data transfers.

Spotlight

Ko believes in working on impactful, disruptive innovation and is a key thought leader in the global cloud and security space. He co-invented TrustCloud's Flogger—kernel-space "sensors" planted in cloud infrastructures that log all virtual machine file activities and their corresponding physical machine locations and activities. Not currently found in the industry, such cloud-scale logs could empower automated governance and cloud data provenance. Ko is founder/co-chair of the Cloud Security Alliance's (CSA) Cloud Data Governance working group and Director of Research for CSA's Singapore chapter. He has co-authored several prominent papers in cloud security and data analytics, including a winner of USEWOD workshop's Best Paper Award in WWW 2011. Ko regularly contributes to HP's "Grounded in the Cloud" blog and is an active volunteer, grassroots leader, and vice president of a 26-year-old nonprofit theater company.

Spotlight: Thought Leadership around the World

As technology leaders, we are passionate about HP, our research, and sharing our knowledge with our colleagues. We are often called on to represent HP among customers, the media, analysts, partners, and our academic and industrial peers. In 2011, HP Labs hosted over 700 customer visits at our sites across the globe, including over 300 in Palo Alto alone, from a wide range of industries including utilities, banking, retail, telecommunications, entertainment, and transportation, among many others, as well as from academia and the public sector.

We also contribute to the technical community by serving as chairs and organizers of industry conferences, providing our expertise as members of industry standards boards and government steering committees, and leading high-profile externally-funded research efforts on behalf of HP.

Networking researcher honored by Open Networking Foundation

Jean Tourrilhes

In 2011, HP Labs made significant standards contributions to the Open Networking Forum (ONF)—the main industry group working to describe software-defined networking—led

by Jean Tourrilhes of the Networking and Communications Lab. Tourrilhes chaired the ONF working group that developed the OpenFlow 1.2 specification. He was recently honored by the Forum's board with the Outstanding Leadership Award for his chairmanship of the working group, leading the team to produce this important update. At the same time, he also received the Outstanding Technical Contribution Award for his significant contributions to the technical aspects of OpenFlow 1.2.

HP Labs promotes two leading researchers to HP Fellows

HP Fellows are considered pioneers in their fields, setting standards for technical excellence and pushing the boundaries of technology in their respective disciplines. They are futurists whose contributions impact HP and our industry as a whole. In 2011, HP Labs was proud to add two Fellows to the ranks: Parthasarathy Ranganathan and Steven J. Simske.

Partha Ranganathan, who joined HP Labs in 2000, currently leads a research program on future data-centric datacenters at HP Labs. His broader research interests are in energy efficiency and systems architecture and modeling. He has worked extensively

in these areas, making key contributions in areas such as energy-aware user interfaces, heterogeneous multi-core processors, power capping and federated enterprise power management, energy modeling and benchmarking, disaggregated blade server architectures, and—most recently—storage hierarchy and systems redesign for nonvolatile memory. Ranganathan received his B. Tech. degree from the Indian Institute of Technology, Madras, and his M.S. and Ph.D. from Rice University, Houston.

Steve Simske is an HP Fellow in the Printing and Content Delivery Lab. He also leads the HP Labs Document Ecosystem program, which seeks to merge the electronic and physical representations of composite documents, and supports HP's document cloud and document security efforts. Enterprise applications for his research range from track-and-trace and document inspection to security printing, authentication, policy enforcement, and forensics. He has authored more than 300 technical publications and has nearly 50 U.S. patents. He is a member of the World Economic Forum Global Agenda Council on Illicit Trade as well as an IS&T Fellow. Simske has a B.S. and an M.S. in Biomedical Engineering, a Ph.D. and a post-doc in Electrical Engineering, and a post-doc in Aerospace Engineering.

Sitaram Asur

Ph.D., Computer Science, Ohio State University

Research Scientist, Social Computing Research Group

Research Interests

Asur officially joined HP Labs in 2009 after a post-doc internship through the National Science Foundation–supported Computing Innovation Fellows program. His research involves mining and extracting value from data, particularly from the large volume of collective intelligence present in social media. His recent work has been on using Twitter feeds for predictive analytics, and measuring social influence, popularity, and trends.

Spotlight

Asur's work on predicting movie box-office revenue on the basis of comments and sentiments collected from Twitter was nominated for the Best Paper Award at IEEE/ACM WI-IAT 2010 and broadly featured in the news, including the BBC, the *Los Angeles Times*, *New Scientist*, and *The New York Times Magazine*'s annual "Year in Ideas." His other honors include being named #26 in *Fast Company*'s "100 Most Creative People in Business" for 2011, and receiving Ohio State University's Outstanding Research Award in Computer Science in 2009 as well as a Best Paper Award at ACM SIGKDD in 2007.

Demonstrators and Customer Co-Innovation

Turning research ideas into business impact often hinges on making our innovations real—putting them to work in a demonstration environment to solve a customer problem. HP Labs' Demonstrator and Customer Co-Innovation programs provide our technologists with the means to do exactly that: showcase how our technologies can benefit customers directly, in partnership with HP's business groups.

Demonstrator program

Demonstrators are proofs of concepts that take HP Labs technologies that are almost market-ready to the next phase of feasibility. We began the program in 2010, selecting seven projects to receive a jumpstart toward commercialization. Many of these projects have since been transferred or their teams are working closely with our businesses—for example, our optical backplane; HP Photon Engine 3D technology; and our G-Cloud (government-grade cloud) platform, which is serving as the base for a new public sector demonstrator project in 2012.

Building on strong support we received for our 2010 program, we continued our investments in 2011 with five more projects. These exciting projects and their outcomes are all featured in this year's report.

In 2012, we are already working on our third class of demonstrators, with a particular focus on cloud applications and services:

- Cloud service assistants to enable reliable communications between mobile apps and the larger cloud ecosystem and computing infrastructure
- A self-scaling, high-quality, yet low-cost network that can satisfy the evolving requirements of a cloud datacenter
- A camera app that uses smartphone photos for color analysis and product recommendations in retail settings

- Cloud service that aggregates content from multiple sources, curates personal content collections, and delivers a rich content consumption experience to the end user in digital and print formats
- The next generation of sentiment analytics over structured and unstructured data for timely and actionable customer intelligence analysis
- Cloud service for enterprise knowledge sharing and discovery using sophisticated analytics and user interface innovations
- Situational awareness for healthcare, aimed at improving patient safety, patient and staff experiences, and efficiency using sensors, analytics, and optimization coupled with mobile devices and large-screen displays
- A secure and auditable public-sector decision support platform for data analysis and decision-making during civil emergencies

Customer co-innovation

Working side by side with our customers has long been a part of our DNA, and by working with our most forward-thinking customers, we are able to tackle challenging real-world problems, jointly innovating the next generation of HP products and services.

Just a few of our customer collaborations are featured in this year's report, but our list of projects continues to grow. Our collaboration with Shell, ongoing since 2010, generated impressive results in 2011: a breakthrough allowing our high-precision sensors to capture seismic data with higher sensitivity and at ultra-low frequencies. Other projects underway include sophisticated personalization analytics with a leading news website; numerous events showcasing HP's immersive 3D technology, including a Diane von Furstenberg fashion show in Beijing and the 2011 Art Masters Festival in St Moritz; and expanding partnerships in the healthcare and financial services sectors.

Managing safe concurrent personal and business use of a client device in the enterprise

Today people want to be able to use their device of choice, from smartphone to tablet, laptop, or desktop, to simultaneously access all their digital personas (work, personal, banking, gaming). But maintaining control over the security of enterprise applications and protecting intellectual property remains a priority for businesses, and the cost of achieving appropriate security management makes it challenging for IT departments to embrace this so-called "consumerization" of user endpoints.

To address this tension, researchers in the Cloud and Security Lab are developing a device architecture and security management framework designed to support safe concurrent use of personal applications and business applications deployed and managed by multiple different IT departments. Each business's risk management department can then define and monitor controls appropriate for the business's applications on an endpoint—without encroaching on user privacy or on the confidentiality of applications managed by other IT departments on the same device. The design is based on a cloud client device architecture and corresponding cloud-based manageability framework. Researchers have demonstrated a technical solution that supports end users and IT departments making their own choice of applications and even operating systems, and managing their own security controls over business applications.

From an IT department perspective, this allows "cloud communities" to be defined and securely managed end to end, from

Gareth Gale

B.S. Management Science and Statistics, University of Wales

IT Consultant, Strategic Innovations and Research Services (SIRS)

Research Interests

Gareth Gale is part of SIRS' Solution Engineering team, which provides research computing services to facilitate HP Labs' research productivity. His interests include developing solutions using distributed team-based agile software development methodologies, building Web 2.0 applications for multiple platforms, and working across the HP Labs research community to support demonstrators, customer co-innovation efforts, and research projects.

Spotlight

Gale's key focus in 2011 was on a project transferring security analytics research from HP Labs' Cloud and Security Lab to HP's Enterprise Security Business Unit. Gale led the team that delivered a cloud-based service and scalable tool allowing the business unit to deliver security analytics modeling engagements to major customers. Models are templated and allow for stochastic what-if examination of a range of future risks together with comparative analysis of alternative policy and operational responses.

end-user cloud client devices to the datacenter. HP Labs' approach is designed to allow end-user devices to be registered with multiple such communities rather than being limited to just one personal and one business persona. This end-to-end cloud community model relies on the ability to securely extend a cloud-based infrastructure to client devices, based on HP Labs' research in security management for cloud-based IT services. Looking ahead, HP Enterprise Services, HP Labs, and HP's Personal Systems Group are working together to make their vision a reality.

More secure documents across the enterprise

Documents and the environments in which they are used take on new, richer meaning in the fully connected, mobile, distributed world. As information flows through the enterprise, it moves from digital to physical form and often back to digital; as it does so, it must move between these two worlds seamlessly and securely. Researchers in the Printing and Content Delivery Lab began a demonstrator project in 2011 that addresses this challenge, aiming to transform HP printing and scanning devices into enterprise workflow kiosks that integrate document workflow technologies. Users will be able to send a confidential or sensitive document to an HP multifunction printer, and ensure that document is only printed when the proper authentication code is entered. The same device will also be able to identify a printed document via scanning and verify whether it is authentic or has been changed.

Novel technologies such as progressive barcodes mean that the progression of a document can be tracked over its lifetime using the same incremental identifying object (IIO), such as a progressive barcode. Security can be built into documents and their workflows thanks to the team's Automated Policy Enforcement Exchange (APEX), which helps to prevent unauthorized

data leaks and allows documents to be posted on public clouds without fear of security compromise. Finally, the team has developed techniques to analyze document forensics, singling out specific, unique attributes of printed documents via specialized hardware and software.

Combined, these technologies are being integrated into HP Imaging and Printing Group's technology portfolio. The demonstrator's technologies are being used as pivotal projects in large systems tied to the integration of printing and electronic information, security workflows, and inference (relationships between different elements in a larger system).

HP Collective and DiscoverEase help professionals automatically build knowledge networks

A company's most valuable resources are its employees and the assets they create. In large companies, however, many of these assets remain accessible only to other employees through direct interactions. What if a sales manager needs to find resources for a customer presentation, but doesn't know who to contact in his organization or where to start looking for information? Researchers at HP Labs Israel, in collaboration with HP Enterprise Services, are developing tools to help professionals find contacts and content, through entirely automated processes that take into account the context of each user. The HP Collective tool automatically discovers networks for professionals in an enterprise through semantic analysis of the content they produce, such as email, papers, reports, blogs, wikis, presentations, and patents.

The team's approach uses deep analytics of document content to infer relations between documents and automatically build communities between authors of

The DiscoverEase project aims to facilitate information sharing and discovery among a company's employees.

related documents. Beyond simply matching metadata about the document and/or its author (commonly used by social networking tools) or relying on users to find and tag their friends, the team's analytics require no intervention on the part of the user—no tagging, no explicit profile.

In 2011, the team demonstrated the technology by powering a Technologist Network Application at HP's annual internal technical conference. Conference attendees were able to network and meet others with similar interests thanks to the tool's suggestions. In 2012, the team is further developing capabilities through the DiscoverEase demonstrator project, which, in conjunction with the Services Research Lab, explores sharing and discovery in an enterprise context. The work is also supported by a collaborative engagement with a university and a research lab in Brazil, leveraging arXiv.org, an open publications website, to apply the technology to the scientific community.

## HP Labs Singapore designs cloud services for digital media professionals

Since launching in 2010, HP Labs Singapore has been actively engaged with Singapore's fast-paced innovation ecosystem, including starting an exciting project at Mediapolis, a government-sponsored project aiming to create a media-centric hub that brings together state-of-the art infrastructure and an active community of innovators and creators.

HP Labs Singapore and HP Singapore are currently working with Infinite Frameworks, a Singapore-based digital media company, to build a media cloud, based on a "Studio of the Future" concept. The Studio of the Future will provide a comprehensive platform
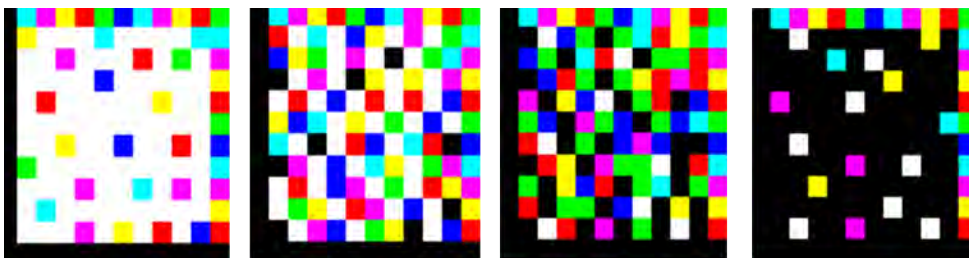
Progressive barcodes, an HP Labs innovation based on the familiar data-carrying mark, can have information added to them over time, turning them into a means to track the lifecycle of a printed object
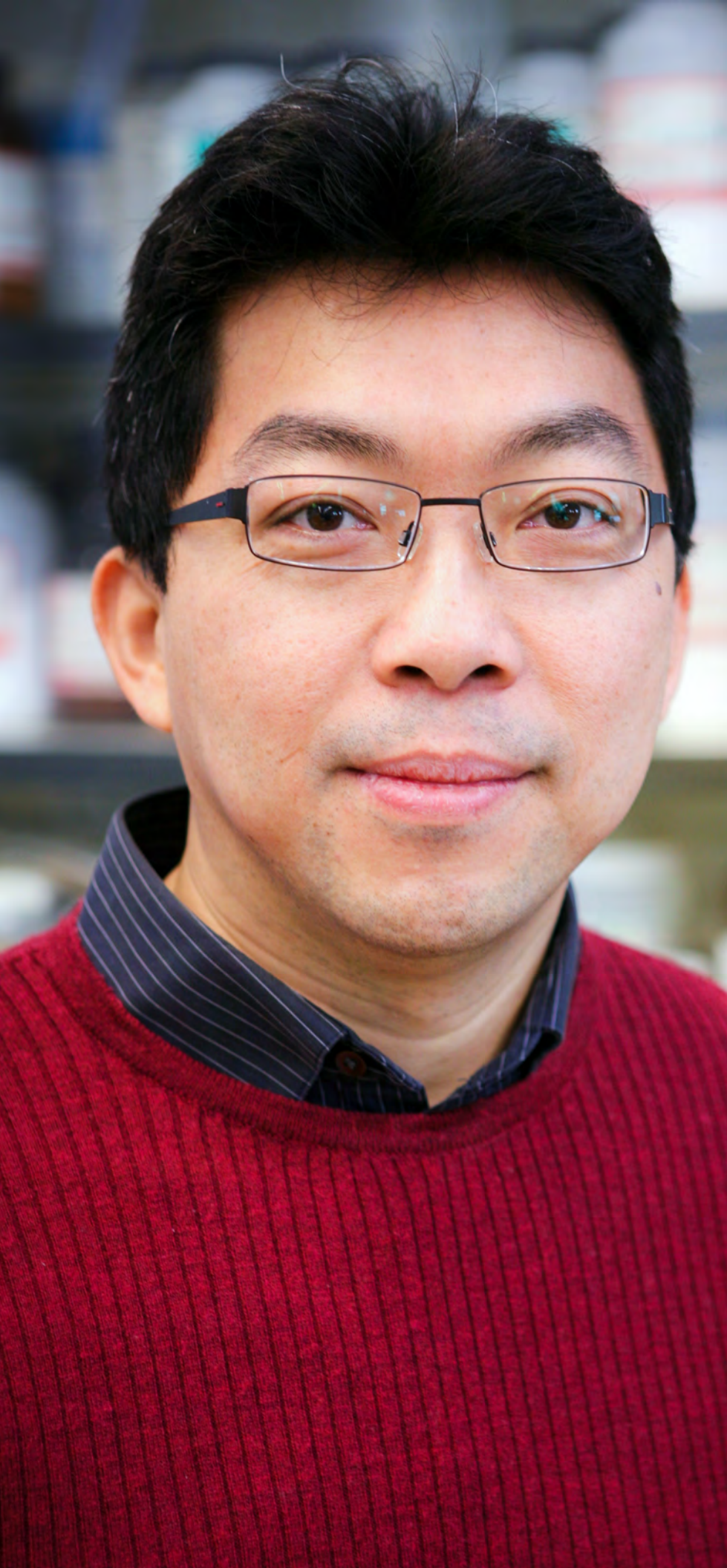
Hou T. Ng

Ph.D., Chemistry, National University of Singapore

Principal Scientist and Research Manager, Printing and Content Delivery Lab

Research Interests

Ng is passionate about research related to next-generation functional nano-materials, printed electronics, advanced digital printing technologies, the environmental sustainability of print products, and advanced computational methods for exascale materials systems.

Spotlight

Ng led an HP Labs team to innovate breakthrough de-inking chemistry, which significantly enhances the removal of printed digital and traditional offset ink materials from paper; low-cost, high-performance, environmentally-friendly aqueous latex nano-materials for commercial inkjet printing applications; and predictive chemical modeling of next-generation printing materials. He also collaborated with Purdue University and co-developed advanced colloidal dispersion theory and methodology to accelerate the understanding of ink performance. Ng has published a number of highly cited articles in the field of nano-materials synthesis related to carbon nanotubes and one-dimensional nanowires and nanodevices. He is an active member of the American Chemical Society, the Materials Research Society, and the Technical Association of the Pulp and Paper Industry (TAPPI), and he is co-inventor on over 60 granted patents or patent applications.

for services to the digital media industry in Singapore. HP Labs Singapore is building a unifying social platform and providing a set of APIs that tie the community to specific and relevant industry services.

One of these is a set of collaborative, task-oriented services that focus on helping individuals and groups work together. For example, creating a script is a collaborative, task-driven piece of work that is worked on by multiple people with multiple roles, such as scriptwriters, artists, proofreaders, and editors. Another is a set of domain-specific services—such as rendering, digital asset management, and project pipelining— that can be provided through a standard interface. HP's partner, Infinite Frameworks, will work with HP Technology Services to offer this service to its tenants at Infinite Studios.


HP Labs Singapore researchers on the Media Cloud team, from left to right: Ang Yun Quan, Kelvin Teh, Ng Tze Yang (standing), Jeffery Lim, Aneeth Ahmed, Peer Mohammed

Predictive analytics help companies better understand their businesses

Making sense of "big data"—massive streams of data from across the enterprise— is the Information Analytics Lab's specialty. The team had a number of impressive live demonstrations in 2011, tailored to specific industries and showcasing the team's leading-edge technology.

Live Operations Intelligence: oil and gas industry

The oil and gas industry generates and employs time-series data collected from sensors in all aspects of operations, often utilizing this data to form a "system of record" for audits of activity and occurrences. The time series data is often used for process alert purposes in real time, and subsequently for trending analysis; however, it is not extensively used to characterize and interpret the underlying process or root cause of any problems that may be identified.

HP Labs and HP Enterprise Services have been collaborating with an independent producer of oil and gas on extracting business value from the massive amounts of sensor data collected by the company. The analysis resulted in considerable insight into its drilling operations. After establishing a model for *total data*—including a taxonomy to baseline the attributes, process-based classification of information, trending of key attributes, and predictive analytics— researchers performed analytics on the data obtained from drilling operations on 200
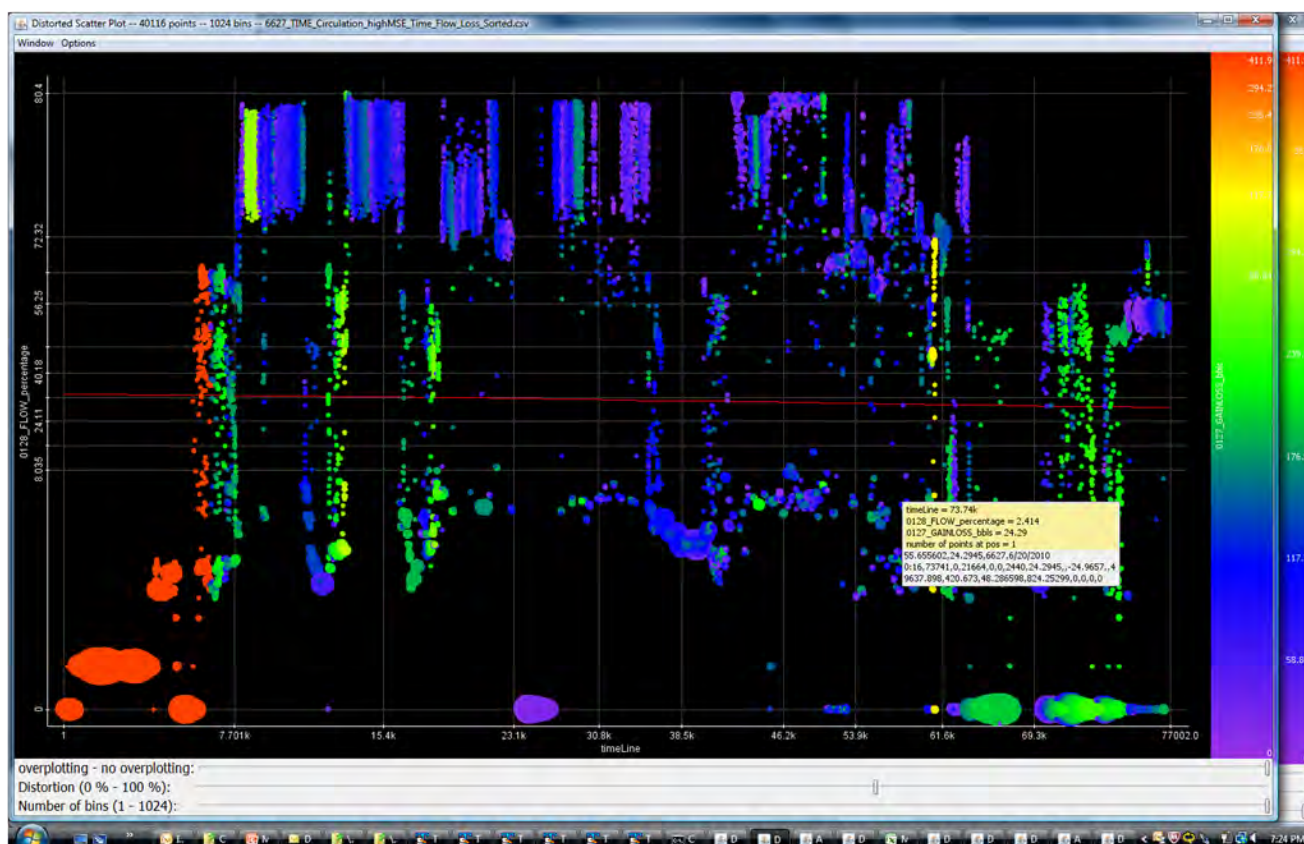
Visualizing complex operations data from the oil & gas industry.

natural gas wells, including sensor data from these wells and some 25,000 text files that contained operator logs.

The analysis provided considerable insight into its drilling operations, demonstrating a predictive analytics solution for the problem of determining the duration of "tripping windows"—a significant cause of operations downtimes—increasing prediction accuracy by 25 percent.

Live Customer Intelligence (LCI): merging social media and company data

With the explosion of social media content, businesses face an increasingly large challenge in analyzing and making sense of this data. It is especially challenging to connect business data with the insights derived from analyses of social media.

A pilot project completed by HP Labs and HP Global Customer Intelligence in 2011 showed that there is a high correlation between signals mined from social media and customer data captured in the company data warehouse. This illustrates how data from social media can be merged with company data to predict customer behavior with significant accuracy and demonstrates the value of close collaboration between marketing and IT departments.

Using HP Labs' new text analytics technology, the team first converted the unstructured data into a structured format; then, human analysts could use standard data-mining and statistical tools to analyze the two data sets together. The system can correlate social media conversations about specific product features to actual customer transactions in real time. In the study, social signals are shown to have a 90 percent correlation with support requests and sales under certain conditions. "The results are significant enough to act on," explains Prasanna Dhore, Vice President, Customer Intelligence, HP. "Applying this methodology can improve both the customer experience and the bottom line." For example, he said, if HP can anticipate product issues, it can deploy specialized support staff before customers call for help. The signals could also be used to fine-tune a company's marketing spend while a campaign is still running.

Collaboration yields new data visualization techniques

The research team led by Professor Keim at the University of Konstanz has long had a strong research program in information visualization and data mining. In 2008, Professor Keim was awarded one of the first HP Labs Innovation Research awards.

Together with Professor Keim, researchers Ming Hao, Umesh Dayal, and Mei Hsu have dramatically advanced their approaches to visualizing data using familiar visual metaphors such as bar charts, scatter plots, time series, and maps, and they have combined these with analytic techniques such as correlation, similarity, and prediction.

The unique core of the work is pixel-based techniques—every pixel in visualized bar charts, scatter plots, time series, and maps, for example, is linked to a data item. These charts provide bird's-eye views of a large quantity of information while allowing individual data points to be accessed directly from the visualization, pixel by pixel. Users can interact with the visualizations of both structured and unstructured data and can drill down to the details in real time, enabling powerful business intelligence applications.

Together with Professor Keim and his Ph.D. students, the visual analytics research team collaborated closely with Manish Marwah, Cullen Bash, and Chandrakant Patel from the HP Labs Sustainable Ecosystems Research Group to incorporate new ideas on managing thermal sensor data using pixel cell-based visualization technology. In addition, with various HP business division partners, the team invented a number of advanced pixel-based visualization techniques. Together, they have filed over 60 invention disclosures with about 20 U.S. patents granted, published about 50 journal and conference papers, and participated in two important demonstrators: Live Customer Intelligence and Live Operations Intelligence.
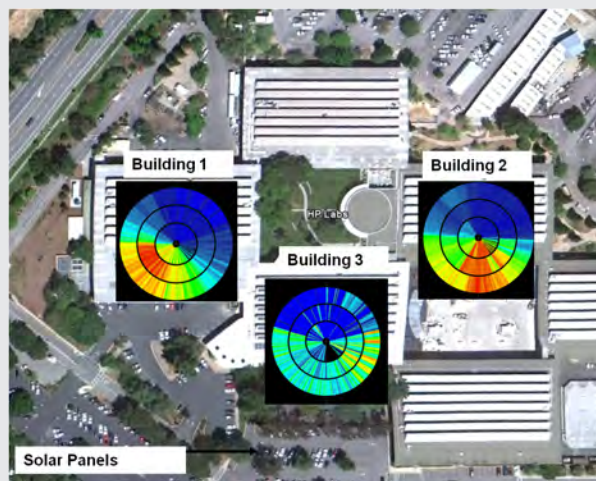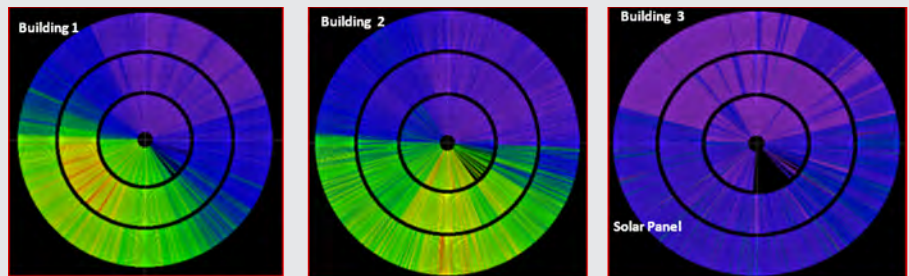
Joint research by HP Labs and the University of Konstanz has produced new ways to visualize complex data, such as this set of "tree ring plots" showing power output in a facility over time.

Spotlight: Global and Social Impact

A fundamental part of our mission is to turn our expertise into meaningful impact in the communities where we live, and the global ecosystem in which we operate. We make contributions to areas such as education, healthcare, and sustainability.

Our scientists donate their time and energy to developing tomorrow's scientists and engineers—teaching at leading academic institutions, supervising doctoral theses, and serving on advisory boards.

Our regional labs focus on addressing local challenges. For example, our lab in Russia helps develop the next generation of IT professionals through its HP Institute of Technology program, through a research and education center in St. Petersburg State University. Our China team actively contributes to local standards and technology strategy dialog, and maintains close collaboration with Tsinghua University, thanks to its location right on campus.

HPL India's Vayu team, from left to right: Geetha Manjunath, Sudhir Dixit, Praphul Chandra, Siva Katru, Bhushan Mathad, Sriganesh Madhvanath

HP Labs India brings the Internet to TVs—no PC required

HP Labs India emphasizes developing innovative solutions to regional challenges. The team recently announced a new way for consumers in India to access the Internet without knowing how to use a PC. For the millions in India who have never used a PC, this simple idea could open up a world of possibilities.

The solution is enabled by the HP Labs-designed Vayu Internet Device (VInD),

a set-top box that can connect with even the most basic TV sets. With VInD and a WiFi connection, users can interact with Internet content using a basic TV remote, a wireless keyboard and mouse, a printer, or even a mobile phone. Users can also interact via gestures, speech, touch, and paper, and use the built-in Zigbee host to turn their devices into a "smart" connected home.

The team has also provided a variety of apps to pay bills, check train schedules, or research stock prices; Web categories that organize users' bookmarks for easy access; the ability to videoconference with other Vayu users; and storage on the included hard drive for personal photos, videos, or music. The device can be paired with mobile phones to send information to the device using a simple text message—or use a photo of a railway ticket to automatically get the train's status.

HP Labs Bristol supports science and technology in the community

HP Labs Bristol plays host to a number of professional and educational activities each year, as part of its commitment to community outreach.

In March 2011, 25 top-notch cyber security professionals gathered at the Bristol site to compete in the UK's first Cyber Security Challenge. Supported by the Minister of State for Security and Counterterrorism and leaders from the UK's cyber security, education, and political communities, the competition is designed to excite and inspire anyone considering a career in the cyber security industry and to get more people interested in the field.

The competition—a unique way for sponsors to work together and solve one of the greatest problems facing the profession—received over 4,000 entries. The 25 finalists spent a weekend at the HP Labs site, where they were tested in a range of cyber security simulation exercises developed by Challenge sponsors Cassidian and HP. In all, more than

30 prizes such as university scholarships were awarded, each selected to help winners advance their career opportunities in the cyber security profession.

Dan Summers, Champion of the UK Cyber Security Challenge, during the competition

Each year, the Bristol team also welcomes the UK South West regional final of the Lego Robotics championships. The program's mission is simple: to get children excited about science and technology—and to teach them valuable employment and life skills along the way.

Over 600 children, comprising 52 teams from primary and secondary schools, competed in the 2011 event, whose theme revolved around food. Each student team had to design, build, and program an autonomous robot to carry out missions on a specially devised mat. They also had to complete a research project requiring them to identify and explore a problem associated with food—for example, hygiene, transport, or preservation of food. The teams presented their research and solutions to judges from HP and local education organizations. The winners of the regional competition go on to compete at the UK and National Finals, with hopes of continuing to the European and U.S. tournaments.

Children ages 9-16 compete enthusiastically at the Lego Robotics Championships hosted at HP Labs Bristol each year.

Natalia Vassilieva

Ph.D., Computer Science, St. Petersburg State University

Senior Research Scientist, Information Analytics Lab/HP Labs Russia

Research Interests

Vassilieva's background is focused on image processing and information retrieval. Her interests also include information extraction from unstructured data, and text and multimedia analytics. She is currently exploring how to embed multimedia data—largely untapped for data-indexing and information-extraction purposes—into common information extraction pipelines, resulting in better insight and decision-making from a broader dataset.

Spotlight

Vassilieva is an active member of the information retrieval community and passionately promotes education and scientific research in information retrieval and data management in Russia. Beginning as a lecturer for the Russian Summer School in Information Retrieval (RuSSIR) in 2008, Vassilieva has been a key organizer for the school including program committee member since 2009, local chair of the joint RuSSIR/Extending Database Technology (EDBT) summer school in 2011, and steering committee member in 2012. She has also chaired the image track of ROMIP (the Russian Information Retrieval Evaluation Seminar) since launching the program in 2008, and she regularly serves on program committees at many national and international conferences.

Technology Commercialization

What motivates us, above all else, is to see our research ideas made real and our technologies in the hands of our customers. We deliver business impact to HP through a steady stream of technologies that support our existing businesses, as well as technologies that may open up new markets for HP.

We measure ourselves, and our contribution to the company, on the basis of technologies—both those making an impact in the current fiscal year and those expected to have impact in the upcoming year—as well as on technologies influencing longer-term business roadmaps.

In 2011, we recorded 138 total technology transfers recognized as having business impact in the current fiscal year. Key transfers, which are mentioned throughout this report and the Appendix, include significant advancements in intelligent infrastructure, analytics, storage and archiving, immersive experiences, social networking, printing and imaging, and sustainability.

HP's Moonshot launched, based on pioneering HP Labs research

For one HP Labs research team, 2011 ended with a bang: the announcement of Project Moonshot—an HP program featuring a breakthrough extreme low-energy computing platform for hyper-scale computing environments exemplified by cloud and on-demand computing. Project Moonshot builds on years of extensive low-energy computing research conducted by a multi-disciplinary research team from the Intelligent Infrastructure Lab, the Sustainable Ecosystems Research Group, and open innovation partners at the University of Michigan.

Featuring state-of-the-art low-power processors such as ARM and Atom, Moonshot's platform is differentiated by its unique, holistic approach to optimizing shared resources across thousands of servers to radically reduce energy consumption, space requirements, and management complexity. As project lead Partha Ranganathan recently observed, "It's not just about the box anymore. It's about shared chipsets, power, cooling, and storage—the entire fabric—and optimizing them all to work together. That's really what Moonshot does."

To extend HP's industry-standard server business beyond its successful blade server solutions, the HP Labs team invented an unconventional new server architecture. The "microblade" was an initial HP Labs breakthrough in low-power computing. Most recently, the team was able to prove that for specific workloads and applications, extremely low-power processors—typically used in mobile phones and tablets—could be deployed in ultra-dense server configurations, resulting in estimates of up to 94 percent less space usage, 89 percent less energy consumption, and up to 63 percent reduction in overall costs in comparison to traditional x86 server systems.

As part of Project Moonshot, HP's Redstone Server Development Platform will be the first HP server line to feature ARM processors. Another Moonshot solution, the HP Discovery Lab, will use benchmarking and optimization tools developed by the HP Labs team. But the team is not resting on its laurels; with plans to incorporate HP Labs breakthroughs such as memristor-based memory (nanostores) and photonic interconnects, the team will extend the vision that gave rise to Project Moonshot with further disruptive innovation.

Nanostores will enable energy-efficient computing

The nanostore is a revolutionary new concept in data-centric systems architecture that promises to drastically limit the energy used by computers through a marriage of memory and computing power.

With nanostores, all data can be stored in memristor-based nonvolatile memory chips that are closely co-located with processors. Multiple levels of storage hierarchy—such as traditional disks and DRAM—can be eliminated, providing wide, low-energy data paths between processors and nanostores. In one possible configuration, a single nanostore chip could consist of multiple 3D-stacked layers of dense silicon nonvolatile memories with a top layer of power-efficient compute cores, forming a fully fledged system with a network interface.

HP Labs' Partha Ranganathan outlined the nanostore vision in his January 2011 IEEE Computer cover article, "From Microprocessors to Nanostores: Rethinking Data-Centric Systems," noting that "As stand-alone building blocks, a large number of individual nanostores can communicate over emerging optical interconnects and support large-scale distributed data-centric workloads. The key aspects of this approach are large-scale distributed parallelism and balanced energy-efficient compute in close proximity to the data. Together, these features allow nanostores to potentially achieve significantly higher performance at lower energy."

Core members of the HPL Project Moonshot team: from left to right, Jichuan Chang, Partha Ranganathan, and Kevin Lim

Janice Nickel

Ph.D., Materials Science and Engineering, University of California, Berkeley

Senior Research Manager, Cognitive Systems Lab

Research Interests

Nickel is passionate about applying creative solutions to technical problems drawn from her deep knowledge of electronic and electrochemical materials and devices. She has 19 years of research experience at HP Labs and held a post-doctoral position at Los Alamos National Laboratory before joining HP.

Spotlight

Nickel is currently leading a joint development effort with Hynix Semiconductor Inc. to create a new kind of computer memory—one that will employ memristor technology pioneered by HP Labs researchers and that leverages CMOS-compatible memristor fabrication processes she initially developed utilizing a contract fabrication facility. Prior to her work with memristors, Nickel invented and showed a proof of concept of a novel programmable drug delivery platform that repurposes HP's mature inkjet technology to address new markets. The technology is currently being developed jointly by Janisys Ltd. and a major pharmaceutical company. She has also been a leader in promoting diversity at HP Labs in her roles as a founding member of the Technical Women's Development Program and past director of HP Tech Camp—an effort that provides underprivileged middle school-aged girls with exposure to scientific careers. Nickel has 44 granted U.S. patents, over 40 scientific papers published, and numerous invited presentations.

Eric Anderson

Ph.D., Computer Science, University of California, Berkeley

Distinguished Technologist, Intelligent Infrastructure Lab

Research Interests

In addition to his main research focus on computer systems, Anderson has deep knowledge in the fields of storage systems, software engineering, distributed systems, networking, and systems administration. He is also well versed in related topics including graphics, systems architecture, and theoretical computer science, and is respected as a strong systems builder and architect aside from his research contributions.

Spotlight

Since beginning his career at HP Labs as an intern more than a decade ago, Anderson has been the driving force behind most of the projects he's been involved with and has ensured the success of many projects by addressing both the research and customer requirements. Anderson's recent work facilitated the creation of two new businesses for HP. He was the technical lead for a scalable storage project that built a cloud object storage prototype, and transferred it into HP Cloud Services. Previously, Anderson built a utility rendering service with DreamWorks Animation. Content from the movies *Shrek 2* and *Madagascar* were rendered via an HP service, and the project led to the formation of a new HP business: Flexible Computing Services.

HP Labs takes on "big data" with innovative archiving system

Businesses are creating and storing unstructured digital files by the billions, from x-rays to PowerPoint presentations to scanned-in photographs. In tandem with this information explosion, digital data needs to be archived to meet compliance and regulatory requirements. The healthcare and media industries in particular, along with scientists in many fields, are generating huge data sets that need to be processed, stored, analyzed, and archived utilizing highly scalable technology. But for all this data to be useful, people need the ability to find and analyze it quickly and easily.

Researchers from HP Labs, in collaboration with technologists from HP Storage, have developed an innovative data archive system to solve these mounting challenges: IBRIX Archive. A combination of HP Storage's highly scalable IBRIX file system and a scalable metadata management system developed in HP Labs, IBRIX Archive enables data objects (digital data stored in the file system) to be synchronized with the metadata describing these data objects (stored in the HP Labs metadata database).

The innovation in the IBRIX Archive is its ability to improve the speed of metadata searches by utilizing the high-performance features available in HP Labs' technology. IBRIX Archive bridges the tradeoffs inherent in existing information management solutions, which offer either scalability or rich metadata-based management—but not both—and use a range of less optimal techniques to try to enable faster queries in large-scale information systems. Because you can't fit a large-scale database with 100 million files on a single server, IBRIX Archive can scale up to hundreds of machines.

State-of-the-art router design transferred to HP Networking's H3C

The IP lookup module is a core element of high-performance networking routers. Due to the large number of Internet Protocol (IP) prefixes and the high throughput required of routers, the IP forwarding table must work at very high speeds. Current solutions widely used in high-performance routers are extremely costly and consume too much power. Researchers in the Networking and Communications Lab in the U.S. and China tackled the challenge of designing fast algorithmic IP lookup modules and implementing them in software to leverage relatively economical devices while achieving high forwarding throughput. They designed and implemented a fast algorithm for routing table compression and for fast packet forwarding.

In addition, the team also set out to understand the energy consumption in switches and routers. They developed an energy benchmarking and monitoring tool, algorithms for energy-aware operations, and a network power controller. HP Networking's H3C unit, based in China, has adopted the team's energy benchmarking tool, porting it to their system with some H3C-specific extensions. H3C is also evaluating the power monitoring and control software for their Green IT project, an energy-efficiency management solution for IT equipment, including both networking and computing devices.

Autophotobook.com makes your photobooks in a snap

Thanks to multimedia sharing sites and social networks, people are increasingly capturing and sharing their lives through photos and videos. Putting their photos together in photobooks allows people to more easily share stories and events with one another. However, because photo selection, pagination and layout can all be time-consuming tasks, creating photobooks continues to be a challenge for many users. Researchers in the Printing and Content

Carnegie Mellon University collaboration advances scalable storage agenda

HP Labs' scalable storage work has benefited from its IRP collaboration with the Carnegie Mellon University (CMU) Parallel Data Lab since 2008. The university's graduate students improved and added features to the advanced HP Labs database technology that is now moving into HP Storage products. These tools allow HP's enterprise file-serving software to more efficiently manage massive numbers of unstructured files.

The CMU collaboration focused on increasing how many file-information data items the new software could absorb, and how quickly it could accurately store and assess them. Current file-serving systems do not scale adequately to handle the billions or even trillions of files that must be addressed in today's operating environments.

Teamwork between HP Labs and HP Storage was highlighted in 2011 with funding for a joint demonstrator that combined the scalable IBRIX storage system with HP Labs' scalable metadata-management technology.

Delivery Lab have tackled the challenge with their photobook creation system that helps users quickly create high-quality custom photobooks while keeping complexity at bay.

Using a series of novel image analysis and composition algorithms, the pilot service analyzes a user's photos and automatically creates an initial photobook that groups similar photos together, eliminating duplicates and low-quality images. It then automatically crops photos and creates dynamic photo layouts to fit images to photobook pages. This streamlines the initial creation phase so that the user is never staring at a blank page wondering where to begin. HP Labs' composition engine then allows users to easily edit the book—adding captions, swapping or moving objects, exploring different page layouts and themes, and even dynamically adjusting the size of the final book.

Users can create photobooks at HP Labs' **www.autophotobook.com** website using the HP Photobook iPad application, or via the Auto Photobook Facebook application. Photobooks can be printed locally, shared as PDF files, or uploaded to HP MagCloud for sharing. Many of these technologies have also been integrated into HP's Snapfish site and HP retail kiosks.

Printing from the Web made smarter

The web is full of useful information—but when you want to print it, the experience is often less than ideal. Today's browsers use the WYSIWYG (What You See Is What You Get) principle when it comes to Web printing: what you get on paper is a duplicate of what you see on the screen—including menus and a profusion of colorful ads. Thanks to HP Smart Print, however, it's easy to get a better printing experience

HP's Auto Photobook Facebook application makes creating photobooks from your Facebook pictures easy.

from the Web. HP Smart Print automatically selects the part of a Web page that it thinks you want to print—like a recipe and its photo, or a news article—but removes all the content you don't want. Need to add something to HP Smart Print's automatic selection? HP Smart Print lets you adjust the content selection before printing.

This simple but useful tool was made possible by research from HP Labs' Printing and Content Delivery Lab. An automatic selection algorithm divides the source Web page into blocks and assigns an importance score to each block of content based on an analysis

HP MagCloud, invented by HP Labs, was nominated for a prestigious 2011 Webby Award in the Web Services and Applications category and named an honoree in the Magazine category

of over 50 different features. This analysis yields an accurate guess as to the relevant content to be printed. The title and text body of a news article, for example, will be assigned much higher importance than an advertisement to the right of it. It works in any language, on any type of Web page.

HP Smart Print is currently available for free as part of the Microsoft Bing Bar for HP on Internet Explorer (**http://www.hp.com/go/ smartprint).** Since its launch in 2011, it has been downloaded by hundreds of thousands of users.
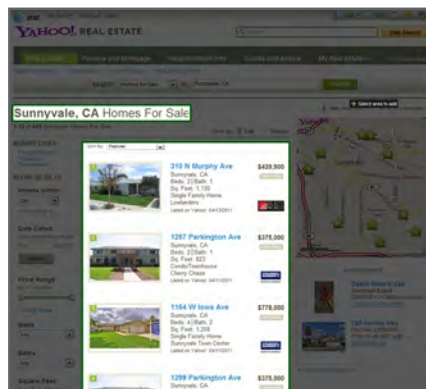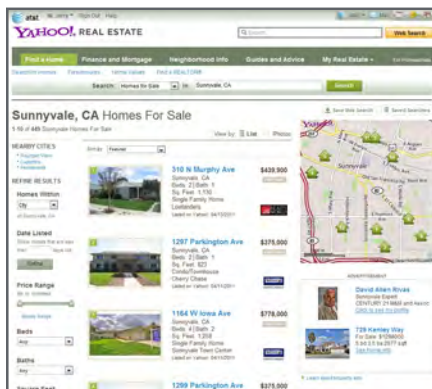
HP Smart Print improves the web printing experience with automated content selection.

HP Labs 3D research powers HP Photon Engine solution

HP Labs' research in immersive 3D display technologies has been garnering customer interest for several years, and now customers have the opportunity to put our research to work for them with HP's recently announced Photon Engine solution.

The HP Photon Engine solution is powered by HP Labs' breakthrough technology that uses multiple low-cost projectors to create a scalable "super projector." Image processing software mathematically blends the light sources to generate high-resolution images in 2D or 3D. It is capable of broadcasting true-to-life 3D content on straight or curved surfaces, and may enable a variety of businesses—such as manufacturing, fashion, automotive and consumer retail—to create vivid 3D experiences and decision support applications for customers.

For example, top fashion house Marchesa recently used the HP Photon Engine solution to present its Spring 2012 collection in 3D to a select audience of retail buyers, editors, and industry insiders during Fashion Week and, more recently, to the public at large during its 2012 Spring trunk-show at the Bergdorf Goodman department store in New York City and the Nieman Marcus store in Bal Harbour, Florida.

HP Labs researchers have also applied the technology to aid users in viewing large amounts of structured or unstructured data—including unlimited streams of 2D video, Internet content, documents, and photos—on single or multiple surfaces to support rapid decision-making. Users can seamlessly move and manipulate data from a wireless device such as a tablet or smartphone onto a shared surface and collaborate to quickly solve complex problems. HP is already using the technology's 2D capabilities to run global datacenter operations centers, enabling the visualization of real-time network traffic, system integrity, and security status.

HP Labs technology enabled fashion house Marchesa to showcase its collections in 3D.

Researchers Chris Willis (left) and Nelson Chang (right) demonstrate an immersive operations center powered by HP Photon Engine technology.

Spotlight: Sustainability Research

HP Labs researchers in the Sustainable Ecosystems Research Group (SERG) believe that the massive-scale, intelligent infrastructure required to power modern business can and should be sustainable. They are exploring and modeling the way resources are utilized in datacenters, and also applying many of the principles and efficiencies of this research to planning and design at city scale. The team is also looking ahead with a new research project, Resource Management as a Service, whose goal is to provide facilities, companies, and even cities with a solution to dynamically manage supply and demand for scarce non-renewable resources.

The multidisciplinary SERG team is not alone in HP Labs in making energy- and resource-efficient solutions a priority in their research. Teams in the Intelligent Infrastructure and Cognitive Systems labs are working on developing tomorrow's energy-efficient computing architectures using breakthrough HP Labs discoveries like nonvolatile memory and photonics. The Networking and Communications team is studying how to decrease the power consumption of enterprise networks. And scientists in the Printing and Content Delivery Lab have helped establish HP as a leader in the field of de-inking printed matter for more environmentally friendly recycling.

HP EcoPOD showcases HP Labs sustainability research

In 2011, HP introduced its next generation of modular HP Converged Datacenters: the highly energy-efficient HP Performance Optimized Datacenter (POD) 240a, also known as the EcoPOD. HP Labs contributed to the EcoPOD from initial concept through product delivery, having pioneered HP's work on low-powered datacenters and guided its design.

Researchers are continuing their collaboration with HP's Enterprise Servers, Storage, and Networking (ESSN) division, particularly EcoPOD cooling and controls. HPL's Multi-Scale Energy Modeling (M-SEM)

tool—conceptualized in a joint program between HP Labs and the University of Limerick (Ireland)—helps determine the projected energy consumption and costs of the POD. Users input the EcoPOD location and some operating parameters. M-SEM displays results in terms of datacenter efficiency (PUE), carbon footprint, capacity, etc. Users can also compare the energy use of PODs in different locations.

EcoPODs will be the building blocks for new and expanded HP datacenters to support HP's global cloud services, including HP's public cloud. The EcoPOD is an important part of HP Labs' ongoing sustainable datacenter research roadmap as new advances are incorporated into future HP modular datacenter products.

Sustainable datacenter innovation captures industry attention in 2011

In 2011, the SERG team demonstrated its Sustainable Datacenter research in two key facilities—the HP Labs Datacenter (Palo Alto, California) and the new, state-of-the-art HP Fort Collins (Colorado) Research Lab datacenter, a collaboration between HP Labs and HP ESSN.

The Palo Alto datacenter houses the Net-Zero Energy testbed where a new generation of datacenter management solutions are being created. It includes a temperature sensor network used to control supply temperature and cooling units, and uses outside air for cooling. Alongside the cooling microgrid, the datacenter also contains a solar-powered microgrid.

The team is combining the use of alternative energy sources with dynamic IT workload scheduling and integrated management techniques to improve overall datacenter utilization while allowing demand 'shaping' based on resource availability. They have also designed an innovative net-zero energy architecture for operating a datacenter in a manner that consumes zero net energy from the public utility grid. The net-zero energy

HP's Fort Collins Research Lab datacenter

solution has been implemented in the Palo Alto testbed, and has demonstrated energy and cost savings when compared to other common workload scheduling algorithms.

In March 2011, HP celebrated the grand opening of the 50,000-square-foot Fort Collins facility, showcasing the datacenter's cutting-edge sustainability features including thermal sensors, cooling unit fan speed and set point control, and Adaptive Vent Tiles (AVTs) developed by HP Labs. Using temperature, pressure, and flow data, HP Labs' algorithms initiate real-time control of the AVTs to deliver chilled air exactly where it is needed. The research Sandbox, an environmentally separate space, adds 350-watt-per-square-foot power density, outside-air cooling, and humidity control.

The Fort Collins datacenter provides a demand-side testbed at scale for HP Labs researchers. The entire facility has been instrumented with nearly 10,000 networked environmental sensors collecting data on air and water temperature, humidity, airflow, and power usage. HP servers also ship with HP's "sea of sensors": thermal sensors providing component-level measurements that are used to control and optimize server cooling and power usage. Researchers are developing advanced analytics models to process, analyze, and visualize sensor data, and then optimize datacenter operations.

As HP Labs continues its sustainable datacenter research in domains such as integrated control, advanced analytics and visualization, pervasive cross-layer sensing, datacenter lifecycle design, and power and cooling microgrids, the team plans to showcase new breakthroughs at both state-of-the-art datacenters.

Kiara Corrigan

Ph.D., Agricultural and Resource Economics, University of California, Davis

Research Scientist, Sustainable Ecosystems Research Group

Research Interests

Corrigan was recently hired as a full-time HP Labs researcher after working as a post-doc for two and a half years. An Environmental Economist, she is now part of the new Resource Management as a Service (RMaaS) project team. Her work and research interests focus on the modeling of environmental externalities and resource markets, with an emphasis on quantifying the fiscal risks associated with enterprise-scale worldwide consumption of resources like energy, water, and waste.

Spotlight

Corrigan's research has focused on estimating the economic cost of environmental and regulatory trends from agriculture to IT. Most recently, she led the development of Supply Chain Assessment Tool for Tracking Environmental Risk (SCATTER), a multi-scale environmental assessment tool—currently used within HP's Energy and Sustainability Management business—that generates an environmental profile of a company's balance sheet. Corrigan has also taught courses in microeconomics and macroeconomics at the University of California, Davis, and at Sonoma State University.

Appendix:
Selected 2011 Technology Transfers

Cloud and Security

BOCK

BOCK is a high-performing, scalable, and secure elastic block service that represents a critical component of HP Labs' cloud services development effort. Contributions this year include work focused on copy-on-write, volume encryption, caching, block realization, management and metadata handling, and thin provisioning and access control.

Situational Awareness for HP Software

HP Labs is working closely with a team from ArcSight, a company that was recently acquired by HP and is a leader in security event and incident management software. Together, these teams are playing a central role in shaping HP's security strategy and developing next-generation security solutions. HP Labs completed initial transfers for an improved expression matching capability and development of a visualization tool for log data.

Trusted Virtualized Clients

Confidence is needed that devices can and will enforce appropriate separation of security concerns, and this is the focus of the Trusted Virtualized Clients (TVC) effort. In 2011, HP Labs developed product specifications and continued work on strategy, key partner relationships, and architecture design.

Trusted Virtualized Client Management

This effort leverages Trusted Virtualized Client (TVC) technology developed for HP's devices for a broader enterprise-level client virtualization service business. In 2011, HP Labs designed and developed an early adopter program for TVC-based enterprise pilots in collaboration with HP's Personal Systems Group and software business. Initial prototypes were developed for client automation-based infrastructure for enterprise deployment and management of TVCs.

Vnet

Vnet is a solution using standard network protocols that provide scalable network virtualization in the cloud. This is particularly useful in big datacenters that host cloud services where the physical network is shared between multiple users. Source code, documentation, and support were provided in 2011.

Information Analytics

Application Lifecycle Automation

HP Labs is introducing a revolutionary approach to the IT automation problem. Leveraging a simple, common interface for all IT applications enables the creation of novel IT automation technologies that have the potential to revolutionize the application management world with implications for mobility and computer accessibility. In 2011, HP Labs built a prototype image-based automation application including the segmentation engine, classification engine, semantic engine, temporal engine, and supporting infrastructure.

Context-Aware Search for IT Service Management (ITSM) Knowledge Base Search

Current business technology optimization solutions include search engines based on keyword queries; due to the ambiguity of keyword searches, however, results are often unsatisfactory. Hence, HP Labs is developing a search system that exploits a rich set of query contacts, such as user profiles, semantics, and user interactions with the system to locate relevant documents and other structured data. In 2011, HP Labs developed a proof of concept for ITSM knowledge base context-aware search.

Live Customer Intelligence and Sentiment Analysis

Harnessing the explosion of unstructured and external content is a key component of HP Labs' LiveBI research efforts. Live Customer Intelligence and Sentiment Analysis is an application for demonstration that, if successful, creates opportunities for new service offerings in a fast-growing market. 2011 contributions include demonstrations for HP's social intelligence practice. The team also focused on customer intelligence platform development for HP's Communications and Media Solutions business, Vertica offerings, and HP's home shopping website.

Metabox (IBRIX Archive)

As customers try to cope with the information explosion of unstructured data, there are substantial business opportunities in IT management, business governance, compliance, and risk management. This year, HP Labs developed file metadata database technology that was largely incorporated into a new HP "IBRIX" file system product with an initial focus on large-scale content archives.

Scalable Storage

HP Labs' scalable storage research results in leading cloud storage solutions addressing challenges related to capacity, reliability, cost, performance, and geographic scale. In 2011, work from this project represented a key contribution to HP's new Cloud Services business.

Intelligent Infrastructure

Optical Backplane

HP Labs' advances in optical interconnects will allow HP to utilize low-cost optical components to create leadership datacenter switching systems. This year, HP Labs completed a significant demonstrator of an optically connected datacenter switch that was officially introduced at InterOp 2011. The team also drove improvements on electrically pumped hybrid lasers and thermal performance of CMOS-compatible photonic components.

Mobile and Immersive Experience

Immersive Ops Center

This research focuses on the vast and growing universe of enterprise information, 95 percent of which is unstructured, and rising expectations for actionable business intelligence. We often hear that a person just didn't "see it" at the time, which can result in serious consequences. The team is working on immersive technologies to present and manipulate large numbers of data sources, and the data itself, to drive insight and effective decision-making. In 2011, HP Labs created an Ops Center test facility with large 2D and 3D data walls, workstations, and multi-touch devices for integrating multiple live data streams and facilitating group interactions. The team also created software platforms and utilities to simplify creation of usage scenario-based demonstrations.

SAIL technology licensing

HP Labs is working on next-generation displays including roll-to-roll manufacturing technology for flexible electronics. This year, the team began licensing technology based on self-aligned imprint lithography (SAIL).

SocialTouch

SocialTouch is a multi-touch, multiparty social collaboration interface that supports multiple sites and large-form-factor displays. Working with HP's Personal Systems Group, the technology was developed for integration in HP's large display walls, new desktop products, and other collaboration solutions. This year, new features including multisite session management and an initial user experience layer for HP social collaboration solutions were developed.

Vayu Experience Platform and Dock

HP Labs aims to enable rich and intuitive user experiences that deliver the value of computing and the Internet for non-tech-savvy users. Driven by the fact that cell phone users in emerging markets outnumber PC users by an order of magnitude, the team developed a Vayu User Experience (VUE) with intuitive user interfaces and non-keyboard/mouse interaction metaphors (gestures, speech, etc.) for application with existing home device ecosystems and mobile phones. In 2011, HP Labs developed the Vayu Internet Dock (VInD), a home appliance to bring computing and Web experiences into the living room. The Vayu Experience Platform was also created; it includes new applications and a toolkit for rapid authoring of interactions with existing applications.

Houdini

Houdini is a desktop collaboration appliance that provides easy content sharing. As part of this project, an HP Labs-developed media processing framework designed to simplify the building of real-time media applications was adopted by HP's Imaging and Printing Group as its real-time media engine in 2011.

Networking and Communications

CeNSE

HP Labs is developing sensing solutions that are positioned to provide a new level of environmental awareness through a wireless, cloud-based network—one with trillions of inexpensive sensors, data storage, and analysis tools that monitor the environment, assets, and health and safety. Key technologies are enabling a leading-edge partnership with Shell to develop an ultra-high-resolution seismic sensing solution for the oil and gas industry. 2011 technology contributions include a handheld spectrometer sensing platform, surface-enhanced substrate techniques, algorithms for multi-radio network resource allocation, low-cost differential GPS (D-GPS) post-processing, network coordination control, energy-saving point coordination function (PCF) polling, and energy-efficient data compression.

Flexible, Programmable Networks

HP Labs is focused on network platform programmability and management technologies building HP leadership in enterprise and datacenter networking. Key technology contributions in 2011 are tied to network energy efficiency, transmission control protocol (TCP) acceleration in moderate- to long-latency networks, programmable optical cabling, ensemble routing, and Smart Path Assignment in Networks (SPAIN).

Printing and Content Delivery

Photo Creative Technologies and Cloud Services

HP Labs is combining novel technologies for photo tagging, selection, and page layout to build streamlined, integrated authoring platforms that adapt to a user's photos and the desired output format. Project results are creating a wealth of new opportunities in photo merchandise generation for HP Snapfish and other HP Imaging and Printing businesses. In 2011, HP Labs' key contributions include development of applications for iPhotobook, STArt Designer, Photodither, and ImageRank. HP Labs also completed a social storytelling demo for retail fulfillment and enhancements to autogreetingcard.com and autophotobook.com sites.

Printing and Imaging Forensics

HP Labs is providing printing and imaging forensic solutions, including capabilities for functional printing, supply chain counterfeiting assessment, mass serialization analytics, and document content analysis. Contributions this year include a contact-based Dyson Relay CMOS Imaging Device (Dr. CID) for printed character capture, a secure coupon solution, a red-eye removal module, mass serialization and analytics code and integration support, a forensic imaging demo, content typing OCR testing and qualification, and a progressive 4D barcode demonstration.

Document Imaging Services

This effort focuses on enabling the monetization of scan services by hosting document imaging services in the cloud. These services can be accessed from multiple client devices including All-in-Ones, scan-only devices, mobile cameras, and document capture cameras. Major 2011 contributions include the development of services including document identification and field extraction, and functionality for skew correction and document and field registration.

ePrint

ePrint uses the cloud to connect people who want to print to available printers in their vicinity, enabling them to print wherever and however they choose. The technology capitalizes on emerging models of communications and collaboration, and the need for mobile-aware context services to provide service-based mobile solutions. Deployed in 2010, the innovative technology surpassed one million registrations in early 2011 and continues to gain strong support in the market.

Services

Authorization-Based Access Control

The authorization-based access control mechanism developed by HP Labs manages data sharing across multiple organizations in a service-oriented environment. Data sharing policies can be managed and enforced in a much simpler and more scalable manner by this approach, compared to the existing Federated Identity Management (FIM)–based products in the market today. The technology is currently under evaluation by HP Enterprise Services for implementation in a number of verticals including transportation and healthcare.

Labor Strategy for HP Technology Services

HP Labs is developing data-driven advanced analytics services that address HP's key strategic and operational challenges in labor and procurement. This year, the team completed an initial-phase prototype of a labor strategy optimizer—a labor-mix model for optimizing HP's field support and consulting workforce. HP Labs also made significant progress on implementing the tool in seven country pilots.

Sustainability

Sustainable Datacenters

HP Labs' work in Sustainable Datacenters addresses cradle-to-cradle design and management of datacenters. It also focuses on the development of technologies allowing the Net-Zero Energy Datacenter to achieve total cost of ownership targets enabling applications in growth economies and in management of resources in other ecosystems. Key 2011 transfers include development of data analytics tools for optimizing datacenter cooling infrastructures and automated estimation of thermal zones.

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