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Enhancing Cloud Services through Multitier Workload Analysis

Ling Liu, Georgia Tech

This installment highlighting the work published in IEEE Computer Society journals comes from IEEE Transactions on Services Computing.

Services computing is penetrating IT and computing technology at every level, encompassing the Web, the cloud, big data, business process modeling, and more. One feature that distinguishes cloud computing from conventional distributed computing is its hierarchical organization of computing capabilities as services, represented by infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS).


IaaS promises considerable economic benefit because applications can be encapsulated in their own virtual machines and “run anywhere.” This application portability across many clouds theoretically enables users to choose the most cost-effective IaaS service provider. Several production cloud environments can achieve portability very quickly, with typical whole system setup times on the order of hours instead of the days required in nonvirtualized environments.

Although typical applications can be brought up quickly in computing clouds, the complexity of modern n-tier applications can’t be completely masked by a single virtualization layer. Several macro-level indicators reveal serious challenges in making large-scale, mission-critical applications run equally well in different clouds. First, average datacenter utilization has been reported at very low levels over the years, with a Gartner survey reporting 18 percent average utilization; Google reports about 30 percent for a mixed workload combining long-running batch jobs with Web-facing applications. Second, unexpectedly long response-time requests (several seconds), at a relatively low average of five to six percent CPU utilization, have been associated with very short bottlenecks that last only a fraction of a second.

Based on extensive experimental analysis, the authors report on the differences they’ve found among six IaaS virtualized cloud environments by running standard benchmark applications—such as RUBBoS and CloudStone—with similar or the same configuration settings. They compared performance and scalability variations in three representative public cloud infrastructures: EC2, Open Cirrus, and Emulab. An interesting discovery from large-scale experiments is that for the RUBBoS n-tier application benchmark, the best-performing configuration in Emulab can become the worst-performing configuration in EC2 due to a combination of hardware and software component differences, even though the RUBBoS implementation has been ported with minimized changes. The authors also compared the nontrivial differences among three mainstream hypervisors—Xen, VMware, and KVM—in a controlled environment. Their discoveries show significant differences among six modern IaaS cloud infrastructures and providers. Specifically, functional portability—which is routinely demonstrated—doesn’t necessarily imply performance portability; the latter requires careful study, measurement, and analysis.

This work is just one effort in experimental analysis toward providing more efficient and effective cloud services. The differences it reveals in IaaS for six cloud computing environments demonstrate the value of such experimental measurements in gaining an in-depth understanding of cloud services and cloud service provisioning. Furthermore, it suggests that concrete measurement of standard benchmarks is necessary to help both cloud service providers and consumers better understand the performance impact of configuration settings in their clouds. [c]

LING LIU is a professor in the School of Computer Science at Georgia Tech, and directs the research programs in the Distributed Data Intensive Systems Lab (DiSL). Contact her at lingliu@cc.gatech.edu.
The IEEE Computer Society’s lineup of 13 digital magazines covers cutting-edge computing topics ranging from software design and computer graphics to Internet computing and security, from scientific applications and machine intelligence to cloud migration and microchip manufacturing. Here are some highlights from recent issues.

**Computer**

**Manipulating a product’s online ratings** might influence market performance but might not maximize profits, according to “Online Product Rating Manipulation and Market Performance” in Computer’s May 2015 issue.

**IEEE Software**

Software companies frequently must create multiple versions of products for different customers. However, the number of changes necessary for each version and the dependencies between variation points can skyrocket and create problems. Facing these challenges is the topic of a special section—“Trends in Systems and Software Variability”—in IEEE Software’s May/June 2015 issue.

**IEEE Internet Computing**

**Physical-cyber-social (PCS) computing** is the subject of IEEE Internet Computing’s May/June 2015 special section. PCS computing integrates data and knowledge from the physical, cyber, and social worlds for analysis. It is becoming increasingly important as mobile technology, social media, and the Internet of Things become more popular and connect physical and social elements with traditional cyber entities.

**Computing in Science & Engineering**

The US National Energy Research Scientific Computing Center (NERSC)—a state-of-the-art facility that serves government, industry, and academic users—celebrated its 40th anniversary in 2014. CiSE’s May/June 2015 special issue includes articles that document NERSC’s history and discuss some of its major contributions.

**IEEE Security & Privacy**

Policymakers are focusing on informed consent as a way to defend privacy. However, behavioral studies cast doubt on this approach’s effectiveness, as many people tend to agree with
almost any request they see on their screens. A related technique that promises improvement is addressed in “Informed Consent: We Can Do Better to Defend Privacy,” in IEEE S&P’s March/April 2015 issue.

**IEEE Cloud Computing**

Much of the huge and growing amount of data produced daily will be generated from Internet of Things devices and sensors, and will be stored in cloud-accessible datacenters. The article “Processing Distributed Internet of Things Data in Clouds,” from IEEE Cloud Computing’s January/February 2015 issue, discusses the capabilities and limitations of big data technologies for collecting and analyzing distributed big datasets across multiple datacenters.

**IEEE Computer Graphics and Applications**

Historically, most attention in visual analytics (VA) has been given to developing machine capabilities. But it is also essential to develop the abilities of the visual analysts themselves. The University of British Columbia has experimented with ways to do this. Details are in “Preparing Undergraduates for Visual Analytics,” in IEEE CG&A’s March/April 2015 issue.

**IEEE Intelligent Systems**

Researchers have tried to use footsteps as a basis for biometric systems. However, constructing an identity-verification system based on footsteps remains challenging. “Footstep-Identification System Based on Walking Interval,” which appears in IEEE Intelligent Systems’ March/April 2015 issue, describes a novel system.

**IEEE MultiMedia**

Traditionally, multimedia has been associated with video, audio, or other media content. Recently, however, its definition has expanded to include media-related context such as video motion features or time stamps, and media connectivity features such as the degree of friendship between two social-media participants. This is the basis of IEEE MultiMedia’s April–June 2015 special issue titled “Multimedia Goes beyond Content.”

**IEEE Annals of the History of Computing**

In “The Production and Interpretation of ARPANET Maps” from IEEE Annals’ January–March 2015 issue, the University of California, Los Angeles’ Bradley Fidler and Morgan Currie explore a series of network topology maps that the firm Bolt Beranek and Newman (now BBN Technologies) produced in the 1960s, 1970s, and 1980s. These maps were a way to represent ARPANET, a precursor of today’s Internet, to engineers.

Pervasive computing has yet to be widely exploited in physical spaces. According to the guest editors of IEEE Pervasive Computing’s April–June 2015 special issue on smart spaces, pervasive computing in physical spaces could provide many business and social opportunities that are currently being missed. The articles in this special issue consider new technologies and approaches for developing pervasive smart spaces.

**IT Professional**

“Could What Happened to Sony Happen to Us?” from IT Pro’s March/April 2015 issue says that until there are cybersecurity standards of practice, Internet commerce will experience problems like 2014’s Sony exploit.

**IEEE Micro**

IEEE Micro’s March/April 2015 special issue contains articles about a set of processors presented at 2014’s Hot Chips 26 conference. Over the years, Hot Chips has consistently provided an early look at trends in the processor industry.

**Computing Now**

The Computing Now website (http://computingnow.computer.org) features up-to-the-minute computing news and blogs, along with articles ranging from peer-reviewed research to opinion pieces by industry leaders.
One constant when it comes to technology has been change. Computing and communications have consistently experienced new developments at all levels, including hardware, software, networking, and security.

This issue of *ComputingEdge* features articles on various important and interesting technology trends. A piece from *IEEE Security & Privacy* discusses an increasingly popular and dangerous cyberattack trend: malware that uses various techniques to hide some of its elements, commands, and communications. This makes it difficult for security software to recognize the threat.

Also included is an *IT Professional* article on the promise of healthcare analytics. The healthcare system is undergoing tremendous changes, including the ability to collect huge amounts of patient data. Analytics appears ready to play a central role in improving patient outcomes while helping to control costs.

An article from *IEEE Intelligent Systems* ponders the challenge that researchers face because the timeframe for both proving a new intelligent technology’s usefulness and publishing R&D reports is often outstripped by fast changes in the approach itself.

A piece in *IEEE Internet Computing* looks at bringing location technology online. Until recently, rich geographical information was a highly specialized corner of the Web. Now, though, the overall Web is beginning to understand geographical concepts, which will make it much more useful to consumers and application developers, as well as provide valuable context for the Internet of Things.

The topic of technology trends is also represented by articles from

- *IEEE Pervasive Computing* on approximate computing, which lets computers become faster and more efficient by being less than perfect for tasks that don’t require great precision;
- *IEEE Cloud Computing* about the processing of distributed Internet of Things data in the cloud; and
- *Computer* on flexible displays.

Other interesting topics are also covered. For example, an *IEEE Software* piece by Grady Booch examines parallels between the Industrial Revolution and the current computing revolution regarding risk, transparency, and responsibility.

This issue will give readers a look at technology trends already under way and those waiting in the wings, including the promise they hold and the challenges they face.
This essay focuses on a fundamental disconnect brought about by the rapid pace of change in intelligent technology. A previous essay in this department referred to this as a critical challenge to human-centered computing: the time frame for experimentation to firmly establish the understandability, usefulness, and usability of intelligent systems (and software, in general) is too long to keep up with the pace of change in the core technology. Robust controlled experimentation takes time, and by the time it has reached its conclusion, the capacities and capabilities afforded by technology will have changed. In this essay, we focus on a derivative disconnect: the time frame for publishing reports on significant results of research and development activities—the time it takes to garner influential publications—is also vastly outstripped by the pace of change in the technology. At a recent government-sponsored workshop on prospects for new technologies, a mantram was: in a rapidly changing world, the “quickest studies” will win. This is both arguably true and troubling. This fundamental disconnect has negative consequences for the agenda of human-centered computing HCC, but it also jeopardizes the realization of the promise of intelligent systems. Even more broadly, it calls into question the notion that science is in the driver’s seat, that science is cumulative, and that the peer review process is viable.

We start with two stories. Within reason, we try to refer to these examples independent of any specific identification because we want to make clear that these observations are totally unrelated to individuals or any particular deliberations, decisions, or specific journals.

A First Story: Technology Begs for Experimental Evaluation

In the late 1980s, virtual reality (VR) became hot. At the cutting edge of visualization and simulation, VR offered a degree of presence and immersion that was unparalleled and unmatched by the residual and approaching passé capacities of 2D screens. One of us (P.A.H.) was fortunate enough to secure one of the first commercial “eyephones” (VPL-003) systems. The empirical question for science was of course: is this offered technology a true “quantum leap” forward, or is it just another overhyped technical gizmo? This technology just begged for controlled experimentation to evaluate this proposition, and this was precisely what we proceeded to do. The protocol for the first experiment was really quite simple and represented an extension of the standard “transfer of training” approaches used in classic experimental psychology research. The experiment promised to provide a fair test of VR’s utility compared to other methods of training.

We need not recount the results of that experiment here. Suffice it to say that the results were interesting, informative, and to a degree positive: VR did offer some advantages at least in the realm of movement skills training. A report was submitted to a leading relevant journal under a rubric labeled “rapid communications.” We were therefore hopeful for prompt publication of the findings. The data were collected in late 1990, the submission was in early 1991, and the accepted revision was accepted some few weeks later. The eventual publication date? 1993! By that time, VR had become just warm. Despite the fact that our results were among the first published in an archival journal, two years was a long time to wait for a “rapid” communication. Like the world, the lead graduate student on the research had by then moved on. It has been gratifying that the work has often been cited, but we still believe it could have had a greater, broader, and more meaningful impact.

Another Story: Drive at Your Own Risk

A recent event has served to recapitulate that VR experience. The technology is Google Glass, and the...
realm is driving. There is little doubt that distracted driving places lives in peril.2,3 Furthermore, the propensity for drivers to use handheld, carried-in devices in their vehicles is clearly snowballing. This combination threatens to radically increase the number of driving-related injuries and fatalities.4 As a result, many innovation design and technology firms are looking for ways to reduce such distraction, and this is part of a wider effort in the area of wearable computers. Such is the innovation of Google Glass. Quite rightly, we looked to evaluate the use of Google Glass while driving, and compare it to certain alternative technologies.

In this effort we were not alone, and the race was on to reach the pages of a leading journal first—with the caveat that proper experiments had to be conducted and meaningful and useful results had to accrue. The research of others is just now emerging in the form of conference proceedings. That counts as a publication in deciding which computer science faculty members get tenure, because (so it is argued) proceedings submissions are said to be heavily reviewed. In experimental psychology, only publications in peer-reviewed journals count. One wonders how a five-page paper buried in the morass of unobtainable proceedings from meetings such as the Fourteenth Somewhat International Meeting on Highly Specialized Things for Use in Specific Widgets (FSIMHSTUSW, Timbuktu 2001) will have any profound impact.

By dint of one journal editor’s heroic efforts, we managed to get our own results published in what must be close to record time. Although we are more than grateful for this special effort, the fact that it was special actually emphasizes our main point about the fundamental disconnect and extraordinary efforts that individuals must undertake in order to keep up. We wish to make clear these two stories of ours are neither cases of blame nor sour grapes, since both efforts culminated in useful contributions. Currently, the overall process is what it is. But our two stories are tales of responsibility, heroism, and the systemic abrogation of same. The central question is this: must the process of archival publication remain like this, or will such a lag eventually challenge the very foundation of peer-reviewed science by preventing any genuine cumulation of knowledge? It is upon this superordinate issue that we focus.

Implications for HCC

The problem of publication priority and relevance has, in a sense, always been with us. From the time of Darwin and Wallace’s contemporaneous publication of the ideas of evolution in the organ of the Linnean Society, to the angst expressed by Watson and Crick over the prospect of being beaten to the structure of DNA by Linus Pauling, scientists have always been aware of the importance of time and precedence. But now the intrinsic competition among individual scientists and/or groups has been augmented by the accelerating rate of technological innovation. We all know that technology is cycling at an ever-faster frequency. It is almost an axiomatic cliché of our business that we now illustrate this by referring to a defunct system such as “eight-tracks” or “reel-to-reel” tapes. But the very rate of this replacement has reached such a precipitate level that the cycle time of technology is now faster than the publication cycle of almost any mainstream refereed journal. And here is our professional problem: our primary archival journals cannot now keep pace. By the time that such work appears in our primary archival journals, it is already essentially out of date.

We have heard it said, going back some years now, that the real purpose of journal publications is not to change the “now” but to inform the next generation. Whether science writ large is succeeding at this is open for discussion. It is arguably true that perhaps the most common means by which published work is utilized is in the production of a never-ending stream of literature reviews. This seems to be a mandatory “Task 1” in most grants and contracts. But owing to time and resource constraints, 60 percent of these reviews are too selective to be of much use, and the other 40 percent languish in the proprietary and dust-covered shelving of contractors.

What all this means for a scientific discipline devoted to human-technology interaction is that we stand in danger of being permanently behind the use curve. And what that means—since research is needed to determine that technology is usable, useful, and understandable—is a never-ending stream of user-hostile systems based solely on designer-centered design and weak usability analysis.5

Individual researchers or groups of researchers have reacted to this current situation in several ways. One obvious response is to publish work in faster turnaround outlets such as conference proceedings or nonrefereed communications, or even self-publish online in order to get the word out. One can even present results in popular books or via the press that, as the cold-fusion debacle showed, promises to be a rather dysfunctional process for science. But quo vadis science in such situations? Evading time delays by evading peer review might be a pragmatic solution, but eventually such a solution will erode a critical element of the very raison d’etre of science. Down this road lies the dissolution of our unique value, to the detriment of all concerned.
So, if we cannot step around the issue, can we shrink the cycle time of refereed journals? Some sort of cycle time metric is the flavor of the week in many discussions of journal editorial policy. Such departments as “rapid communications” propose to circumvent the impasse by shortening the journal’s side of the problem, but as we ourselves experienced, this strategy is fighting uphill. Especially vexing is the introduction of software systems to support journal editing and manuscript processing. In our experience, these have the consequence of turning editors into spreadsheet monitors. Indeed, editors often no longer actually edit at all. The upshot is the actual burdens of editing get shifted over to the reviewers, who themselves must feed the beast by placing sanitized, isolated statements into webpage templates and checklists rather than actually digging in and annotating manuscripts.

As Gandhi might say, “perhaps there is a way out of (this) hell,” which is contingent upon theory. Here theory represents our proactive stance with respect to each generation of technical development and innovation. It is predicated upon our direct understanding of human physical and cognitive capacities, and here we can provide technological pronouncements about what technologies should do (prospective prognostications) as opposed to how we might approach potential solutions. A theme of HCC is that human factors considerations and research should lead the parade. A theme of HCC is that human factors engineering, as either a science or profession, is doomed to just “clean up after the parade” versus “having its own parade.” A theme of HCC is that human factors engineering, as either a science or profession, is doomed to just “clean up after the parade” versus “having its own parade.”

This question brings us to a critical impasse. If HCC and human factors engineering are to lead the parade, they must be based on a “science of technical design.” It is salutary to note that, at the present time, design is much more an art than a science (when it should be strongly both), and we have no unequivocal rational, scientific basis upon which is found our “device advice” other than some nebulous “user acceptance.” Whether a true, quantitative ratio-based science of design is a feasible proposition remains a debatable yet critical question. With such a scientific yardstick it could then be possible to deal with ever shorter cycle times by being permanently ahead of the curve—an extension of the “envisioned worlds” approach. Thus in theory and by theory, this could solve the impasse we have noted. However, it leaves the present pragmatic public problem still very much in place.

Founded on the envisioned worlds strategy, we have our own notions as to how we might approach potential solutions. However, we solicit the thoughts of others. If we do not solve the issue and if our archival sources become simply superfluous to the modern technological world, it will not simply affect the revenue stream of our professional societies but rather, promises to undermine the nature of science itself.

It has generally taken a month or two from the time an essay for this department is in final draft, undergoes peer review, and then appears in print. The only software we need is Microsoft Word. HCC essays do not undergo traditional time-consuming peer review, but this is not to say that there is no review. At least one of the HCC department editors is an author on each essay, with the other editors serving as these peers, providing genuine and challenging editorial comments. Indeed, some draft essays have been trash-canned and never saw the light of day. We leave it to others to judge the value and quality of the HCC essays.

The HCC essays present ideas, methods, and principles and are not research reports. Thus, it is an apples-to-oranges contrast with time-to-publication of research in major journals. That being said, we could easily form an essay around a brief report of methods and results of research studies. It’s just that such offerings have not appeared (yet).

As the saying goes, if you toot your own horn, it will play a single note. Would that everyone who has reached a certain level of accomplishment had access to rapid publication. Would that anyone at any level of accomplishment could quickly publish hot results and ideas. Would that all of us actually had the time to read all the resulting material.

We welcome your suggestions of topics and possibilities of collaboration on these issues and others in future HCC essays.

References


Peter A. Hancock is Provost Distinguished Research Professor, University Trustee Chair, and Pegasus Professor at the University of Central Florida. Contact him at peter.hancock@ucf.edu.

Robert R. Hoffman is senior research scientist at the Florida Institute for Human and Machine Cognition. Contact him at rhoffman@ihmc.us.

Recent studies by Cisco and IBM show that we generate 2.5 quintillion bytes of data per day, and this is set to explode to 40 yottabytes by 2020—that’s 5,200 gigabytes for every person on earth.\textsuperscript{1,2} Much of this data is and will be generated from Internet of Things (IoT) devices and sensors. IoT comprises billions of Internet-connected devices (ICDs) or “things,” each of which can sense, communicate, compute, and potentially actuate, and can have intelligence, multimodal interfaces, physical/virtual identities, and attributes. ICDs can be sensors, RFIDs, social media, clickstreams, business transactions, actuators (such as machines/equipment fitted with sensors and deployed for mining, oil exploration, or manufacturing operations), lab instruments (such as a high energy physics synchrotron), and smart consumer appliances (TV, phone, and so on).

The IoT vision is to allow things to be connected anytime, anywhere, with anything and anyone, ideally using any path, network, and service. This vision has recently given rise to the notion of IoT big data applications that are capable of producing billions of datastreams and tens of years of historical data to provide the knowledge required to support timely decision making. These applications need to process and manage streaming and multidimensional data from geographically distributed data sources that can be available in different formats, present in different locations, and reliable at different levels of confidence.

IoT Big Data Application Requirements

The current generation of IoT big data applications (such as smart supply chain management, syndromic surveillance, and smart energy grids) combines multiple independent data analytics models, historical data repositories, and real-time datastreams that are likely to be available across geographically distributed datacenters (both private and public). For example, in a smart supply chain management IoT application, advanced analytics provides the next frontier of supply chain innovation. However, data management in supply chains is challenging because:
- datasets span multiple continents and are independently managed by hundreds of suppliers and distributors;
- datasets are updated in real time based on feeds from sensors attached to manufacturing devices and delivery vehicles; and
- customers express their sentiments regarding products via a mix of venues such as social media, product review portals, and blogs.

Companies must combine and analyze this distributed data along with contextual factors such as weather forecasts and pricing positions to establish which factors strongly influence the demand of particular products and then quickly take action to adapt to competitive and evolving environments. Similarly, syndromic surveillance IoT applications require churning through massive amounts of heterogeneous, real-time information available from social media, emergency rooms, health departments, hospitals, and ambulatory care sites to detect outbreaks of deadly diseases such as SARS, avian flu, cholera, and dengue fever.

Clearly, these IoT applications produce big datasets that can’t be transferred over the Internet to be processed by a centralized public or private datacenter. The main reasons for this state of affairs are:

- the datasets have strict privacy, security, and regulatory constraints that prohibit their transfer outside the parent domain;
- the datasets flow at a volume and velocity too large and too fast to be processed by a single centralized datacenter as it could lead to high network communication overhead; and
- the analytics models and intelligence required to process the datasets are available across geographically distributed locations.

Despite the requirements posed by IoT big data applications, the capability of existing big data processing technologies and datacenter computing infrastructure is limited. For example, they can only process data on compute and storage resources within a centralized local area network, such as a single cluster within a datacenter. In addition, they don’t provide mechanisms to seamlessly integrate data spread across multiple distributed heterogeneous data sources.

Finally, they can’t ensure security and privacy-preserving processing of heterogeneous data governed by heterogeneous policies and access control rules.

**State of the Art in Distributed IoT Data Processing**

Existing big data processing technologies and datacenter infrastructures have varied capabilities with respect to meeting the distributed IoT data processing challenges.

**Datacenter Cloud Computing Infrastructure Service Stack**

Commercial and public datacenters such as Amazon Web Services and Microsoft Azure provide computing, storage, and software resources as cloud services, which are enabled by virtualized software/middleware stacks. Examples include virtual machine management systems such as Eucalyptus and Amazon Elastic Compute Cloud (EC2); image management tools such as the Future-Grid image repository; massive data storage/file systems such as Google File System (GFS), the Hadoop distributed file system (HDFS), and Amazon Simple Storage Service (S3); and data-intensive execution frameworks such as Amazon Elastic MapReduce. In addition, Future-Grid (http://FutureGrid.org) and OpenStack provide software stack definitions for cloud datacenters.

On the other hand, private datacenters typically build basic infrastructure services by combining available software tools and services. This software includes cluster management systems such as Torque, Oscar, and Simple Linux Utility for Resource Management (Slurm); parallel file/storage systems such as storage area network/network-attached storage (SAN/NAS) and Lustre (http://wiki.lustre.org); as well as data management systems such as the Berkeley Storage Manager (BeST-Man, https://sdm.lbl.gov/bestman) and dCache (www.dcache.org). In addition, some private datacenters are enabled for resource sharing with grid computing middleware, such as Globus toolkits, Uniform Interface to Computing Resources (Unicore, wwwunicore.eu),

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The IoT vision is to allow things to be connected anytime, anywhere, with anything and anyone, ideally using any path, network, and service.
and Lightweight Middleware for Grid Computing (gLite).

**Massive Data Processing Models and Framework**
The MapReduce paradigm has been widely used for large-scale data-intensive computing within datacenters due to its low cost, massive data parallelism, and fault-tolerant processing. The most popular implementation, Hadoop framework allows applications to run on large clusters and provides transparent reliability and data transfer. Other implementations include Compute Unified Device Architecture (CUDA),\textsuperscript{5} field programmable gate array (FPGA),\textsuperscript{6} virtual machines,\textsuperscript{7} as well as streaming runtime,\textsuperscript{8} grid,\textsuperscript{9} and opportunistic environment.\textsuperscript{9} Apache Hadoop on Demand (HOD) provides virtual Hadoop clusters over a large physical cluster based on Torque. MyHadoop provides on-demand Hadoop instances on high-performance computing (HPC) resources via traditional schedulers.\textsuperscript{10} Other MapReduce-like projects include Twister (www.iterativemapreduce.org), Sector/Spear (http://sector.sourceforge.net), and All-pairs.\textsuperscript{11}

**Data Management Service across Datacenters**
The following four storage service abstractions supported by cloud providers differ in how they store, index, and execute queries:

- Binary Large Object (Blob) for unstructured data such as Amazon S3 and Azure Blob;
- key-value storage such as HBase, MongoDB, and BigTable;
- message queuing systems such as SQS and Apache Kafka; and
- relational database management systems such as Oracle and MySQL, which support ACID (atomicity, consistency, isolation, durability) transactional properties.

Accordingly, several research efforts have integrated different cloud data storage services by providing a transparent interface. Examples are Simple Cloud API (http://simplecloud.com), Simple API for Grid Applications (SAGA) with an SRM interface, and some uniform services such as PDC@KTH’s proxy service\textsuperscript{12} and Open Grid Services Architecture Data Access and Integration (OGSA-DAI, www.ogsadai.org.uk) Web services. In addition, a number of third-party providers (DropBox, Mozy, and so on) simplify online cloud storage access.

**Data-Intensive Workflow Computing**
Typical data-intensive scientific workflow models include Pegasus, Kepler, Taverna, Triana, Swift, and Trident. Various business workflow technologies have also been applied to data-intensive workflow systems. Examples include service orchestration with Business Process Execution Language (BPEL) and YAWL (Yet Another Workflow Language),\textsuperscript{13} service choreography with Web Services Choreography Description Language (WS-CDL, www.w3.org/TR/ws-ccd-10), and service-oriented architectures.\textsuperscript{14}

**Research Issues**
Big IoT data processing across multiple distributed datacenters remains challenging, mainly because of technical issues related to basic service stacks for datacenter computing infrastructures, massive data processing models, trusted data management services, data-intensive workflow computing, and benchmarks.

**Service Stacks in a Multidatacenter Computing Infrastructure**
Despite significant advances, public cloud computing technologies are still technically challenging for serving large-scale IoT applications across data-
centers. First, cloud technologies must be integrated into the resource management and file systems of existing private datacenter infrastructures to provision cloud services.

Massive Data Processing Models for Datacenters
There are several limitations in using MapReduce and Hadoop for large-scale distributed massive data processing. First, this framework is limited to compute infrastructures within a local area network or datacenter, and can't be directly used for large-scale IoT applications across geographically distributed datacenters. Second, MapReduce suffers from performance degradation due to the absence of a high-performance parallel and distributed file system that can seamlessly operate across multiple datacenters. Third, MapReduce uses a task “fork” mechanism that can't be directly deployed in traditional private datacenters with local task managers such as Torque and Globus, not to mention the lack of security models. Fourth, the limited semantics of MapReduce can't easily present the diverse parallel patterns of large-scale scientific applications. In addition, MapReduce and Hadoop aren't currently widely supported by data-intensive workflow systems, although there are some preliminary efforts.16

Optimized Data Management across Datacenters
Several research efforts have integrated heterogeneous types of cloud storage services by providing a transparent interface. However, these services and interfaces can't guarantee that data is secured both in motion and at rest, don't support automated ranking of competing storage services, and cannot handle uncertainties regarding cloud storage services and network routes.

To process and store massive datasets across geographically distributed storage services while providing required quality of service (QoS) guarantees raises several concerns.

First, current cloud storage services aren't secure by nature because of the inherent risk of data exposure, tempering, and denial of data access. Ensuring data confidentiality, integrity, and availability is a great concern.

Another issue concerns the intelligence to automate the choice of the best storage services and network routes for optimal application QoS. Existing quantitative criteria approaches applied optimization17 and performance measurement techniques18 for selecting cloud services. Other research focuses on static XML schema matching methods.19

The uncertainty of cloud storage services and network routes in a multiple datacenter environment is another major concern. Several reactive techniques rely on service state monitoring and action triggering to ensure QoS while adapting to run-time variation in resource loading and failures.20,21 Some QoS prediction methods such as the Network Weather Service use both monitoring and forecasting. Another proposed network QoS-aware approach uses QoS profiling, modelling, and prediction.22

Data-Intensive Workflow Computing
IoT applications typically require distributed processing of data as a workflow that spans across multiple data processing services and repositories. Several open source products exist for running data-intensive workflows. However, current systems suffer from some limitations. For example, there's limited support for workflow walk across heterogeneous file systems, such as Lustre, HDFS, and GFarm. There's also limited support for MapReduce task and sub-workflow in data-intensive workflows across distributed datacenters. Finally, data storage and management services aren't incorporated in the service-oriented framework for data-intensive workflow systems.

Benchmark and Application Kernels
Currently, there's no agreement on available performance for executing large-scale IoT applications in distributed datacenters. Even worse, there are currently no intercenter benchmark and application kernels or standards for running large-scale IoT applications on distributed datacenters.

Large-scale IoT applications need to process and manage massive datasets across geographically distributed datacenters. These applications need to be provisioned across multiple datacenters to exploit independent and geographically distributed data sources and IT infrastructure. The capability of existing data processing computing tools (for example, file systems, MapReduce, and workflow technologies), however, is optimized for single datacenter. Future research efforts will need to tackle the challenge of provisioning IoT applications across multiple datacenters by extending existing big data processing tools with the ability to process data across geographic locations; developing techniques for ensuring security and privacy of sensitive data; and developing intelligent techniques for application provisioning based on cost, performance, and other QoS requirements.3,4,5

References


LIZHE WANG is a professor at the Institute for Remote Sensing and Digital Earth, Chinese Academy of Sciences, and at the School of Computer at the China University of Geosciences. Wang has a PhD in computer science from Karlsruhe University. He is a senior member of IEEE. Contact him at lizhe@wang@icloud.com.

RAJIV RANJAN is a senior research scientist, Julius Fellow, and project leader at the Commonwealth Scientific and Industrial Research Organization. At CSIRO, he leads research projects related to cloud computing, content delivery networks, and big data analytics for Internet of Things (IoT) and multimedia applications. Ranjan has a PhD in computer science and software engineering from the University of Melbourne. Contact him at rajiv.ranjan@csiro.au.

Information Hiding as a Challenge for Malware Detection

Wojciech Mazurczyk | Warsaw University of Technology
Luca Caviglione | National Research Council of Italy

We’re experiencing an exponential growth in malicious software. According to the antivirus research firm AV-TEST, 2014 saw approximately 130 million new forms of malware, compared to just over 80 million in 2013 and about 30 million in 2012 (www.av-test.org/en/statistics/malware). Although the influx of malware has drawn the attention of security experts worldwide, the countermeasures that are currently available are progressively showing their limitations. For example, Symantec, one of the largest antivirus vendors, recently admitted that its products are able to detect only approximately 45 percent of new threats.1 As a result, we should expect a relevant increase in the number of undiscovered types of malware.

Consider the case of the Regin Trojan, called a “top-tier espionage tool” by Symantec and other security companies. The sophistication of Regin and other malware such as Flame, Duqu, and Stuxnet leads industry experts to believe that they weren’t created by “typical” cybercriminals for profit. Instead, they’re thought to have been created by nation-states to spy on a wide range of international targets and eventually launch attacks if necessary. Regin has been used since at least 2008 to spy on several international targets including government and business organizations, infrastructure operators, researchers, and private individuals. Its six-year period of hidden activity raises the question: How can malware developers avoid detection for long periods of time?

Information Hiding

Providing a clear answer is difficult, but the most common arguments consider the increasing degree of sophistication of new threats, such as modular design to enable customization (seen in Regin, Flamer, and Weevil) or multistage loading architectures in which each stage is hidden and encrypted (seen in Regin, Stuxnet, and Duqu). In this article, we highlight the importance of understanding information-hiding techniques in malware. These techniques have often been neglected by the security community, but are widely used to exfiltrate data and make security threats stealthier by postponing their detection for as long as possible.

Information hiding is part of a wide spectrum of methods that are used to make data difficult to notice. This practice shouldn’t be confused with encryption, in which the content is unreadable, as it is instead overt. Such mechanisms are often used jointly to ensure that a conversation remains unreadable. Steganography is one of the most well-known subfields of information hiding and aims to cloak secret data in a suitable carrier. Historical examples include the use of tattoos or invisible ink to hide a conversation from unauthorized observers.2

Typically, to exchange secrets, the involved parties must agree on a preshared scheme and embed the secrets in a carrier: the greater the carrier’s popularity, the better its masking capacity. Too many alterations would reveal the presence of hidden information, thus limiting the amount of data that can be covertly transmitted. For example, using too many least significant bits (LSBs) of an image’s pixels as the carrier can reveal the secret data due to visible artifacts. Onkar Dabeer and his colleagues’ “Detection of Hiding in the Least Significant Bit” shows a representative method of detecting this scheme.3

Networks play an important role in modern malware, making network steganography a crucial tool: in this case, the secret is injected into network traffic. For example, the data can be cloaked by
manipulating the content of unused flags within headers or by modulating the inter-packet time (IPT) of network flow datagrams. In the latter case, a sender can encode bits of information in previously agreed-on IPT values. Similar to the LSB example, overly aggressive deviations would make it possible to differentiate the hiding process from normal jitter events. Therefore, hidden channels are typically characterized by a low bandwidth, often ranging from a few to a few hundred bits per second.

Today, many other methods enable covert communications among desktops or digital devices, including generating inaudible sounds or utilizing a smartphone’s sensors to receive a sequence that activates a threat. Malware can use information-hiding techniques to cloak its existence, making it harder to detect. Having a better understanding of these types of malware will help security professionals detect, mitigate, and prevent attacks.

**Roots of the New Trend**

Advancements in security systems over the past 15 years have forced malware developers to investigate new possibilities to make their “products” stealthier. Although it’s difficult to determine the origin of information-hiding techniques, the first massive usage of these techniques can be traced back to 2006, when Operation Shady RAT led to attacks against numerous institutions worldwide and inflicted damage for months.4 Years later, security experts agreed that the main program responsible for this attack was the phishing virus Trojan.Downbot.5 This virus created a back door and then downloaded files appearing as real HTML pages or JPEG images. These files were encoded with commands that would allow remote servers to gain access to local files on the infected host computer.

Other notable examples of information hiding–capable malware include Regin and Linux. Fokirtor, which use network traffic to covertly leak data, and Alureon, Duqu, Lurk, and Trojan.Zbot, which use digital images as hidden data carriers. Even when rudimentary, new threats exploiting some form of information hiding continue to be discovered, as seen in Soundcomber and AirHopper, which modify the status of shared hardware/software resources to exfiltrate confidential data, and in Feederbot, W32.Morto, and Smuggler, which manipulate network traffic for this purpose.

Smartphones are better suited than desktops to exploit information hiding because they natively incorporate cameras, GPS, WLAN, Bluetooth, cellular networks, and other various sensors.6 Even when using legacy general packet radio service or connectivity with bandwidth scarcity—in which case, data leaking could be very slow or impracticable—the availability of different carriers could provide an effective workaround. Furthermore, after their success with desktops, malware developers turned a significant portion of their attention to mobile devices, leading to a 1,800 percent increase in mobile malware over the past two years, as reported by McAfee.7 Threats using information hiding on mobile platforms could be the next great challenge for security researchers.

**Information-Hiding Malware: A Classification**

Nearly all information hiding–capable malware was discovered between 2011 and 2014, with a peak in 2014. Table 1 shows the most popular types and proof-of-concept implementations proposed by the research community. However, we consider only examples that are sufficiently mature to be deployed in real scenarios. A convenient way to organize existing hiding-capable malware is according to the methodology used to implement covert communications. As such, we introduce three major groups:

- **group 1**—methods that hide information by modulating the status of shared hardware/software resources,
- **group 2**—methods that inject secret data into network traffic, and
- **group 3**—methods that embed secret data by modifying a digital file’s structure or using digital media steganography, for example, by manipulating image pixels or sound samples.

Groups 2 and 3 contain techniques that are primarily used to increase the stealthiness of communications carrying commands or leaked data that are mainly observed in malware-targeting desktops. Group 1 includes mechanisms that bypass a security perimeter, such as a sandbox, or enable communications from or to an isolated source or destination, for example, two disconnected devices located on the same workbench. In this case, the prime targets are smartphones and mobile devices. In Table 1, desktop and mobile refer to the malware format. Real-life malware refers to actual malware that’s been discovered, and academic malware refers to proof-of-concept malware proposed by the academic community.

Next, we describe what we consider the three most meaningful examples for each group.

**Group 1**

Researchers’ increasing attention combined with Android’s open source nature has allowed the development of many instances of proof-of-concept information hiding–capable mobile malware. A prime example is Soundcomber,8 which covertly transmits the buttons pressed during a call, for example, when entering a PIN for
a bank service. Notably, it uses information hiding to bypass the security framework of mobile OSs. In fact, the malware could have insufficient privileges to access the network to exfiltrate data, so it can use a “colluding” application to leak data outside the device.

Soundcomber utilizes several information-hiding methods to form four local covert channels whose range is limited to the single device. The covert techniques exploit the most popular smartphone functionalities such as vibration or volume settings (one process differentiates vibration or volume status, and another infers secret data bits from this event), screen state (secret bits are transferred by acquiring and releasing the wake-lock permission that controls the screen state), and file locks (secret data is exchanged between the processes by competing for a file lock).

As we mentioned, another relevant field in which information hiding can be used is the covert transmission of data from and to devices that are physically isolated from other peers. For instance, Luke Deshotels uses standard smartphone speakers to transmit data via ultrasonic sounds. This technique can cover distances up to 30 meters with a rate of 9 bits per second. Similarly, AirHopper enables infected devices to communicate by modulating the graphics processing unit load to emit electromagnetic signals. In this case, the coverage is reduced to 7 meters, but the rate is in the range of 100 to 500 bits per second.

Table 1. The most popular and recent information hiding–capable malware.

<table>
<thead>
<tr>
<th>Malware name or developers</th>
<th>Group</th>
<th>Discovery/proposal date</th>
<th>Desktop (D) or mobile (M)</th>
<th>Real-life (R) or academic (A) malware</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soundcomber</td>
<td>1, 2</td>
<td>Feb. 2011</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>Trojan:Downbot</td>
<td>3</td>
<td>May 2011</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Feederbot</td>
<td>2</td>
<td>Aug. 2011</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Alureon</td>
<td>3</td>
<td>Sept. 2011</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Duqu</td>
<td>3</td>
<td>Sept. 2011</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Trojan:Android/FakeRegSMS.B</td>
<td>3</td>
<td>Jan. 2012</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>Marforio and his colleagues^{16}</td>
<td>1</td>
<td>Dec. 2012</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>Sensor-based malware</td>
<td>1</td>
<td>May 2013</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>KINS Trojan (variant of Zeus)</td>
<td>3</td>
<td>June 2013</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Linux.Fokirtor</td>
<td>2</td>
<td>Sept. 2013</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Lalande and Wendzel^{17}</td>
<td>1</td>
<td>Sept. 2013</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>Inaudible sound-based malware</td>
<td>1</td>
<td>Nov. 2013/Aug. 2014</td>
<td>D/M</td>
<td>A</td>
</tr>
<tr>
<td>Lurk</td>
<td>3</td>
<td>Feb. 2014</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Trojan.Zbot</td>
<td>3</td>
<td>Mar. 2014</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Oldboot.B</td>
<td>3</td>
<td>Apr. 2014</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>AirHopper</td>
<td>1</td>
<td>Oct. 2014</td>
<td>D/M</td>
<td>A</td>
</tr>
<tr>
<td>Smuggler^{18}</td>
<td>2</td>
<td>Nov. 2014</td>
<td>D/M</td>
<td>A</td>
</tr>
<tr>
<td>Multilayer .NET malware</td>
<td>3</td>
<td>Nov. 2014</td>
<td>D</td>
<td>R</td>
</tr>
<tr>
<td>Regin</td>
<td>2</td>
<td>Nov. 2014</td>
<td>D</td>
<td>R</td>
</tr>
</tbody>
</table>

Group 2
In 2011, Symantec announced the discovery of the worm W32.Morto, which propagates using a
vulnerability in the remote desktop protocol. To communicate with command and control (C&C), it uses domain name system (DNS) records. Specifically, W32.Morto exploits the TXT record, which was originally introduced to contain text readable by humans. W32.Morto queries for a DNS TXT record (not for a domain to IP lookup), and then validates and decrypts the returned data. The obtained information typically yields a binary signature and an IP address where the worm can retrieve another malware to execute.

The recently identified Linux.Fokirtor is a Trojan virus that opens a back door and allows attackers to remotely compromise a host. Symantec reported that the malware was utilized in May 2013 to attack one of the largest hosting providers and focused on stealing confidential customer information such as credentials and emails. As cybercriminals realized that their target network was generally well protected, they hid malware communications in an innocent secure shell and other server process network traffic. In addition to this information-hiding technique, Linux.Fokirtor used the Blowfish encryption algorithm to cipher stolen data or other communications with its C&C server.

In November 2014, Regin took malware stealthiness a step further. It utilized many sophisticated mechanisms, including antiforensics capabilities, a custom-built encrypted virtual file system, and an alternative encryption (RCS variant). It also exploited information hiding in network traffic to covertly communicate with its C&C server by tunneling secrets in Internet Control Message Protocol/ping traffic and embedding commands in HTTP cookies or in custom TCP segments and UDP datagrams.

**Future Trends**

Due to the rich availability of options and the masking features offered by the massive utilization of the Internet, malware developers could find the highest potential in network steganography. Although early steganographic techniques focused only on modifying unused fields of TCP/IP headers (such as the type of service field of IPv4, which is rarely set by routers), more recent and sophisticated methods include, but aren’t limited to, the exploitation of flows produced by popular services such as Skype and BitTorrent. Furthermore, network traffic produced by popular online games can be used to covertly exchange data, even in devices with limited capabilities, such as gaming consoles. In fact, the signaling used to locate players in a first-person shooter game can be an effective carrier. To this end, some bits of the set of coordinates and angles can be used to hide data.

In addition, because smartphones are complete computing platforms, they can leverage all the techniques presented in this article and combine them with a rich set of sensors, offering essentially unlimited options for covertly communicating with the surrounding environment. From this perspective, we can envision the following future trends:

- New information-hiding techniques will be continually introduced, and their degree of sophistication will increase. Hence, future malware-related traffic could be harder to detect.
- Information hiding offers a decoupled design. Therefore, it can be easily incorporated into every type of malware to provide stealthy communication of both control commands and the exfiltration of confidential user data as well as communication from isolated environments or networks.

**Group 3**

In the second half of 2011, the Laboratory of Cryptography and System Security in Budapest, Hungary, discovered malware generating strange files with the prefix “-DQ” as a result, it was named Duqu. It bears many resemblances to the famous Stuxnet worm, which was likely developed to attack Iran’s nuclear infrastructure. Duqu is generally considered the precursor to a future Stuxnet-like attack. Duqu’s main aim is to gather information about industrial control systems. To exfiltrate secrets, it encrypted data, which was appended at the end of innocent digital images and then sent over the Internet to a C&C server. This approach postponed the worm’s detection because the images containing leaked information were hidden in the bulk of actual digital pictures. In the same period, a variant of Alureon used a comparable technique.

In February 2014, malware called Lurk was found spreading via websites using <iframe> or an Adobe Flash exploit. A thorough analysis revealed the use of steganography to embed encrypted URLs in an image by manipulating pixels. Such information is then used to retrieve an additional payload.

Another approach uses a variant of the Trojan.Zbot malware, which was first detected in 2014. This version downloaded innocent-looking JPEG images depicting sunsets or cats that contained a list of IP addresses to be inspected, mainly pointing at financial institutions. Once users visit any of the listed destinations, the malware proceeds to steal their confidential information, such as access credentials.

Regin, Duqu, and Lurk are real-life examples of what security experts should expect to see daily in the future. In fact, even if the information-hiding methods utilized in current and future malware aren’t yet very sophisticated, they could become dangerous in the next few years if state-of-the-art academic solutions are considered.
Information hiding–capable malware can remain cloaked for a long period of time while slowly but continuously leaking sensitive user data. Thus, this type of malware must be considered a new advanced persistent threat and must be addressed properly.

A long-term solution to these trends is to consider the potential vulnerabilities enabling covert communications from the very early design phases of desktop and mobile platforms, services, and protocols. For existing devices, especially smartphones, a short-term approach would require some form of ad hoc mitigation, at least for the most hazardous threats. However, this a posteriori approach must be addressed properly.

We hope that raising awareness and understanding of these information-hiding techniques will help researchers and security experts develop the necessary countermeasures.

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Wojciech Mazurczyk is an associate professor at the Institute of Telecommunications in the Faculty of Electronics and Information Technology at the Warsaw University of Technology. He’s also an associate technical editor for IEEE Communications Magazine. Contact him at w.mazurczyk@tele.pw.edu.pl.

Luca Caviglione is a researcher at the National Research Council of Italy. He holds several patents and is an associate editor of Wiley’s Transactions on Emerging Communications Technologies. Contact him at luca .caviglione@ge.issa.cnr.it.

Flexible Displays, Rigid Designs?

Kasper Hornbæk, University of Copenhagen

Rapid technological progress has enabled a wide range of flexible displays for computing devices, but the user experience—which we’re only beginning to understand—will be the key driver for successful designs.

Display technology has undergone significant change over the years. However, despite major improvements in image resolution, color rendering, energy efficiency, interactivity, and other features, the rigid form factor of traditional displays continues to limit the portability and use of computing and communication devices.

Emerging flexible displays promise to mitigate these limitations. In contrast to CRT and LCD displays, flexible displays are thin and pliable, enabling them to be bent, folded, stretched, crumbled, twisted, rolled up, and even cut. With a flexible display, you could physically expand it to see an entire document. Your large-screen phone would always fit in your pocket, and you could change its shape to wrap around your arm when exercising.

Academic and commercial researchers have recently made substantial progress in meeting some of the technical challenges of flexible displays. Equally important, but less well understood, are the technology’s benefits to users, as human–computer interaction (HCI) experts have produced few user studies of flexible displays. Beyond some obvious applications, the question therefore remains: how might people employ flexible displays?

TYPES OF FLEXIBLE DISPLAYS
Flexible displays became technically feasible in the 1980s with the development of e-paper using organic light-emitting diodes (OLEDs), but it wasn’t until a decade ago that researchers developed cost-effective prototypes. Since then, research has rapidly progressed. Currently, three types of flexible displays—passive, sensing, and actuated—have either hit the market or are under development in commercial or academic labs.
Passive

Passive flexible displays allow only simple deformations. These deformations are fixed at the time of manufacture in existing consumer products, such as curved Samsung 4K UHD (ultra high definition) TVs (www.samsung.com/us/video/uhd-tv) and the LG G Flex phone (www.lg.com/us/mobile-phones/gflex). Concepts like the Nokia Morph (http://research.nokia.com/morph) will also let users bend and reshape the display to make the device wearable. However, none of these devices senses deformations or manipulations.

The key challenge of passive flexible displays is scalability to enable wall-size displays and devices whose entire surface is a display. Startups like Canatu (www.canatu.com) and Kateeva (http://kateeva.com) are exploring this challenge.

Sensing

Sensing flexible displays can be bent, stretched, and otherwise deformed by the user, and those deformations can be sensed and used as input. The PaperPhone, shown in Figure 1a, has an e-paper display and an array of bend sensors on the back that allows users to bend the corner of the phone to take calls or answer messages. Another example is Gummi, a prototype computer that lets users supplement touch input with bending and stretching.

A major challenge in realizing these types of displays is combining pliability with sensing, even for simple touch input. FlexSense is a transparent surface that can sense complex deformations on or above a display. Another challenge is making displays that can stretch and be worn directly on the skin. Recent progress toward this goal has been made with iSkin, a thin, touch-sensitive, stretchable sensor that can be affixed to the skin. Combining such sensors with displays will enable a range of novel on-body user interfaces.

Actuated

Actuated flexible displays can bend, fold, or otherwise deform on their own. MIT researchers have developed inFORM, shown in Figure 1b, a surface comprised of 900 motorized rods that can move up and down to create a display that is part projected, part physical. Commercially, an Apple 2010 patent describes “a shape-changeable surface that can selectively alter according to an input so as to provide changeable topography of the user interface” (www.google.com/patents/US20100162109).

“INDISTINGUISHABLE FROM MAGIC”: EXPLORING EMERGING INTERACTIVE TECHNOLOGIES

Antti Oulasvirta, Aalto University

Arthur C. Clarke stated that “any sufficiently advanced technology is indistinguishable from magic.” This oft-repeated “third law of technology” alludes to the fantastical ways we expect computers to work for and with us—with the flick of a wand.

The motivation for this new bimonthly Computer column is an inconvenient truth: despite enormous investments and high public expectations, many—too many—long-awaited technological breakthroughs haven’t yet occurred. One need look no further than the interfaces of everyday computing devices: some, like menus, hypertext, and buttons, have been around for decades, while others, such as the qwerty keyboard, are centuries old.

Why have the promising visions of virtual reality, speech control, and smart homes not yet been realized? Should we have been able to predict which technologies didn’t even have a chance of becoming indistinguishable from magic?

Sometimes the reasons for a slow start are technological, like low recognition accuracy in the case of speech interfaces. Often, however, the reasons have deeper social and psychological roots, as the problems with Google Glass show. Indeed, interactive design problems can’t be solved by traditional computer science and engineering alone.

The goal of this column is to create a forum that goes beyond the hype of emerging interactive technologies to explore both technical and human-related challenges. If you’re interested in contributing to this discussion, please send column submissions or suggestions for future topics to me at antti.oulasvirta@aalto.fi.

ANTTI OULASVIRTA is an associate professor in the Department of Communications and Networking at Aalto University, Finland. His research interests include user interfaces, human–computer interaction, human performance, and using predictive models and optimization methods to design interactive tasks. Contact him at antti.oulasvirta@aalto.fi.
and Tactus Technology (http://tactustechnology.com) has demonstrated how to make physical buttons appear and disappear on touch displays. Not only will actuation allow new forms of physical display, it will also enable symmetric displays that can both be deformed and also deform themselves: input can become output and vice versa.

Combining display technology with actuation presents many technical challenges. Promising directions include very small mechanically actuated displays such as Morphees and using programmable matter such as claytronics. The long-term goal is to create displays that can morph themselves into particular shapes while allowing users to manipulate them.

**USING FLEXIBLE DISPLAYS**

Technology is only one of the challenges in realizing a successful flexible display. Just as important, but less familiar to developers, is the value such a display offers to users. Such value isn’t always obvious, as one CNET reporter lamented in a review of the Samsung Galaxy Round: “A curved display itself is not really a benefit to consumers.”

HCI researchers often employ user studies to determine what prospective technologies would best match consumer needs and expectations. The EU-funded GHOST project (www.ghost-fet.com) brings together teams from the University of Copenhagen in Denmark, the University of Bristol and Lancaster University in the UK, and Eindhoven University of Technology in the Netherlands to explore “generic, highly organic shape-changing technology” (hence the project acronym) with a focus on how users interact with such technology, including flexible displays.

Two example user studies from the project highlight the importance of user research. In one study, user experiences with simulated elastic displays inspired novel design ideas. The other study revealed that conventional design parameters might be too rigid for actuated displays.


**Figure 2.** A simulated elastic display from a study examining what gestures users would perform on the display in response to a set of common computing tasks. One promising use of this technology is 3D object manipulation (right).

**ELASTIC DISPLAYS ALLOW EASY 3D MANIPULATION**

Touch screens are now widely deployed, but what if you could also poke, pinch, twist, or slap a display? Elastic displays aren’t yet technically possible, but a GHOST team led by Giovanni Troiano obtained interesting data by simulating an elastic display using Lycra and a commodity projector and then studying users’ reactions to it.

Troiano asked 17 participants to show gestures they would perform on the display in response to a set of common tasks, as Figure 2 illustrates. The tasks included selecting an object, navigating among views on a map, changing the view of a 3D drawing, and other common interactions. In HCI research, such guessability or elicitation studies can help identify preferred modes of interaction that would be good candidates for implementing in actual interfaces.

The study produced 493 gestures, and the researchers observed many common uses of depth in the tasks. For instance, when asked to rotate, displace, and deform 3D objects, participants treated the objects as if they were physical by grabbing, pushing, pulling, and twisting the display.

and Tactus Technology (http://tactustechnology.com) has demonstrated how to make physical buttons appear and disappear on touch displays. Not only will actuation allow new forms of physical display, it will also enable symmetric displays that can both be deformed and also deform themselves: input can become output and vice versa.

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Two example user studies from the project highlight the importance of user research. In one study, user experiences with simulated elastic displays inspired novel design ideas. The other study revealed that conventional design parameters might be too rigid for actuated displays.

**ELASTIC DISPLAYS ALLOW EASY 3D MANIPULATION**

Touch screens are now widely deployed, but what if you could also poke, pinch, twist, or slap a display? Elastic displays aren’t yet technically possible, but a GHOST team led by Giovanni Troiano obtained interesting data by simulating an elastic display using Lycra and a commodity projector and then studying users’ reactions to it.

Troiano asked 17 participants to show gestures they would perform on the display in response to a set of common tasks, as Figure 2 illustrates. The tasks included selecting an object, navigating among views on a map, changing the view of a 3D drawing, and other common interactions. In HCI research, such guessability or elicitation studies can help identify preferred modes of interaction that would be good candidates for implementing in actual interfaces.

The study produced 493 gestures, and the researchers observed many common uses of depth in the tasks. For instance, when asked to rotate, displace, and deform 3D objects, participants treated the objects as if they were physical by grabbing, pushing, pulling, and twisting the display. The
researchers also observed a few imaginative interactions that could be implemented in future displays: some participants pinched a map to zoom in on it, used the display’s elasticity to simulate a slingshot, or reached behind the display and pulled a virtual object to move it farther away.

Overall, the study revealed that an elastic display would enable a variety of novel interaction techniques, including gesture recognition on both sides of a display and pushing/pulling as an alternative to tapping. It also suggested several natural gestures for changing a display’s depth.

SHAPE CHANGE PREFERENCES ARE TASK-DEPENDENT

There has been little research on the experience of interacting with actuated displays, and the data available are based on simple prototypes that cover only a fraction of the actuation possibilities. To address this deficiency, Esben W. Pedersen and his GHOST colleagues created 51 videos of a shape-changing phone by systematically varying seven design parameters, including area, curvature, and amplitude. They asked 187 participants to watch these videos and respond using both rating scales and free text. The rating scales made it possible to assess participants’ emotional reactions to and perceptions of the device, while the free-text descriptions allowed open-ended analysis of the participants’ experiences across the many design variations.

The participants’ experience of shape change was surprisingly complex. There were large and significant differences in ratings of the design parameters—for example, users preferred curvature to amplitude variability. In addition, hedonic quality (for example, stylish or inspiring) was inversely related to urgency, and some shapes were perceived as ugly yet useful. These findings suggest that shape-change preferences for a phone are highly task-dependent.

Curiously, the speed of shape changes had minimal impact on the study participants’ experiences. This was unexpected, as previous flexible display studies found that users favored some technologies (for example, pneumatics and motors) over others (for example, smart-memory alloys) because of their faster response rates.

The free-text descriptions yielded many important insights. One participant was particularly enthusiastic about a phone display whose area automatically expanded and retracted: “If a phone could grow that big and then go back I would pay crazy amounts of money for it!” Actuated curvature, shown in Figure 3, invited both positive interpretations (“standing on two legs waiting to be picked up”) and negative ones (“seeming to bite at the hand”).

Although seeing videos of a device isn’t the same as actually holding and interacting with one, the study showed the promise of actuated flexible displays: participants were uniformly positive about adding the third dimension to otherwise flat phones. Actuated displays could give rise to novel and varied forms of interaction, such as phones that adapt their shape to the app being used or, say, in the case of text notifications, the sender’s identity.

Rapid technological progress in recent years has made flexible displays possible, enabling a wide range of new forms of interaction. However, it’s the user experience that will ultimately be the selling point and key driver for successful designs.

Researchers must expend as much time and effort understanding these experiences as they now spend exploring the technology itself. Only in this way will they be able to identify which features—such as 3D modeling through deformation, and display shape changes actuated by particular application or user needs—developers should focus on as well as to discover novel interaction capabilities that can be the basis for future research. 

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Kasper Hornbæk is a professor in the Department of Computer Science at the University of Copenhagen, Denmark. Contact him at kash@diku.dk.

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The Promise of Healthcare Analytics

Seth Earley, Earley & Associates

In the next ten years, data sciences and software will do more for medicine than all of the biological sciences together.” That’s quite an assertion by venture capitalist Vinod Khosla.1 The venture capitalists of the world and Silicon Valley entrepreneurs might all be excited about the promise of wearable technologies with biophysical interfaces, physiological sensors, and embedded diagnostic tools to measure “the quantified self,” which will then empower individuals to take control of their healthcare, improve the effectiveness of treatments, and “replace 80% of what doctors do.”2

However, it’s one thing to have information, and it’s another to act on it. Patients are notorious for not following through on “doctor’s orders,” and many of the diseases caused by lifestyle choices are due to them avoiding what they should be doing (quitting smoking, exercising regularly, eating healthy foods, and so on). Following through on treatment regimens requires the missing discipline that contributed to the condition that the treatment is meant to remediate.

What Works in Treatment Adherence

Behavioral changes and adherence to medical treatment are better addressed through patient-provider communication than they are through an application.3 “Patient non-adherence is a physician-patient communication challenge—not a health information technology challenge,” according to Stephen Wilkins, a consumer health behavior researcher.4 He goes on to say that when doctors prescribe a new medication, they typically spend less than a minute explaining it to the patient: why it needs to be taken, how to take it, when to stop, and so forth.

“In healthcare, the actionability and effectiveness of data science hinge on communication between providers and patients, and on patients’ ability to act on those insights. There are a few methods of provider-to-patient communication and actionability” that are effective at getting patients to change behaviors, according to Kyle Samani, a veteran of the electronic medical records industry.5 These mechanisms for encouraging change represent the virtual embodiment of things that help people make the day-to-day decisions that lead to long-term changes in unhealthy behaviors and habits—communication, education, reminders, and, in some cases, nagging spouses. Point-of-care information from physician to patient is delivered in a very small window of time. This information needs to be reinforced with ongoing education from just-in-time sources such as portals, mobile tips, and daily motivators.

A most interesting idea is for mobile sensors to detect behaviors in real time and offer alternatives, interventions, or, in an extreme example, an alert to a health coach or spouse to intervene and discourage a poor choice. (Google Glass identifying a cigarette about to be lit. “Leave me alone, Glass.”) The key is understanding context and offering the correct messaging and mechanisms when the patient is receptive and in need of the information, encouragement, motivation, or admonition. Context is determined and enabled by text analytics by correlating unstructured content consumption with measured outcomes through...
DATA ANALYTICS

Another source of rich historical data across large patient populations is that captured by healthcare payers—the insurance companies and public health agencies that mine millions of claims each year for trends in service delivery, quality, efficacy, abuse, waste, fraud, and errors. The data holds great promise for outlier detection in healthcare services. The US Center for Medicare and Medicaid has just enacted policies to release claims data that until recently wasn’t publicly available. (The American Medical Association received an injunction in 1979 that prevented the public from knowing how much taxpayer money individual doctors received from the Medicare program, which effectively closed this data off from analysis.) This data will allow for greater scrutiny of costs and provide visibility into unusual claim patterns that could be indicative of fraud. In 2011, more than US$4 billion in fraudulent healthcare payments was recovered, but that amount is a small fraction of the estimated total for fraudulent payments. Therefore, the incentive is high for such analyses.

In addition, data analysis could identify the most effective treatments for specific subpopulations at a more granular level than has been possible before. Evidence-based medicine is a broad concept that applies descriptive, statistical, and analytical approaches to evaluating the efficacy of treatment through review of experimental (structured clinical trials) as well as analysis of unstructured observational data (typically, electronic health records) (see www.cebm.net/study-designs). To a layperson, all healthcare might seem to be “evidence-based.” Isn’t medical science based on evidence?

The challenge is that though medicine is founded in science, the practice of medicine is considered an art based on science. Evidence-based medicine combines research approaches with clinical observations of treatments and outcomes. It also combines a variety of approaches for developing, disseminating, and implementing practices that are clinically appropriate and cost effective.

Analytics and big data approaches for dealing with large amounts of structured and unstructured heterogeneous data will help support evidence-based medicine by providing another analytical tool in the researcher’s and clinician’s toolkit. Other efforts hold great promise in helping to identify low-frequency adverse drug events through the analysis of observational medical data (see www.fnih.org/work/past-programs/omop).

Personalized medicine is an important, emerging area of healthcare. The ability to personalize medical treatment is based on the data-intensive fields of pharmacogenomics, nutrigenomics, and pharmacoproteomics, all of which use the understanding of the molecular behavior of bioactive molecules to develop advanced medical treatments.

Biological systems are variable, dynamic, complex chemical systems in which slight variations in an individual’s genomic makeup have significant implications with regard to a therapy’s effectiveness. Analysis of the data could identify the most effective treatments for specific subpopulations at a more granular level than has been possible before. Decoding the mechanisms of action of compounds and biologicals in this environment depends on researchers’ ability to model interactions with thousands of potential variables and millions of possible data points.
Tailoring treatment to individual needs based on genetic makeup will require highly sophisticated analyses—personalized medicine is mind bogglingly data- and analytics-intensive.

The healthcare system is undergoing tremendous change, and analytics plays a central role in improving outcomes and quality of life while helping to control costs. The next several years will see many new mechanisms and tools making significant contributions in all of these areas.

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Seth Earley is CEO of Earley & Associates (www.early.com). He’s an expert in knowledge processes and customer experience management strategies. His interests include customer experience design, knowledge management, content management systems and strategy, and taxonomy development. Contact him at seth@early.com.
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You will often hear geographers claiming that everything is geolocated, even abstract concepts like Einstein’s Theory of Relativity, or peace, but you don’t have to accept that claim of universality to recognize that geolocation is important. Since the release of GPS technology beyond the military in 1996, government, scientists, entrepreneurs, and consumers alike have gone wild publishing and consuming spatial data in popular applications, for finding a way through a traffic snarl, keeping a watchful eye on kids, or alerting us to heavy rain within the hour.

There are at least three reasons for the importance of spatial data. One is that, to a first approximation, it’s easy to integrate independent, heterogeneous data that includes a reference to a location on the earth’s surface. Everybody knows that all you need is the latitude and longitude and you can plot the data on a visually appealing and conceptually familiar map. Well, okay, you do need to know which coordinate is latitude and which is longitude, but that isn’t asking for much. The ability to create data “mash-ups” using Web mapping APIs such as those of Google and Bing was a defining feature of many Web startups in the early 2000s.

Another reason for spatial data’s importance is that this data, whether observed or simulated, underlies solutions to some of the most compelling issues of the modern world: discovering and efficiently utilizing scarce resources such as fertile land, minerals, water, energy, and biodiversity; forecasting and adapting to global climate change; and reducing human conflict and epidemiological disease, while at the same time ameliorating everyday consumer discomforts like the craving for a good coffee or the shame of forgetting where the car was parked.

A third reason is driven by hardware technology advances coupled with mass-market consumer demand for physically small, sensory-rich, and delightfully mobile electronic devices of all kinds. These devices are learning to passively observe their physical environments and to actively interact with their (often) human vehicles. Commonly called the Internet of Things, we’re seeing the development of a complex interplay of location-aware sensing and social or economic impact, with a desperate need for loosely-coupled data exchange just as we see in the Web of linked data.

So what can we do to maximize the value from these emerging demands and opportunities? The Open Geospatial Consortium (OGC) has been working for two decades to develop and standardize solutions for publishing and interoperating over geospatial data and services. The work of the OGC has been adopted by Government Agencies and National Mapping Agencies to publish and share their data, often in the form of a National
or Regional Spatial Data Infrastructure (SDI). While successful for this use case, the OGC Web services are an example of the Deep Web, with much of the valuable information published behind specialized Web services in databases that are inaccessible to most Web users, human or automated.

On the other hand, for nearly 15 years the World Wide Web Consortium (W3C), the standards consortium for the Web, has been developing and standardizing solutions for the Web of Linked Data (an application of the Semantic Web). This describes an architecture for interoperability and integration relying on formalized vocabularies, a graph data model, and RESTful http machine-to-machine communication. There's a cultural emphasis within the Linked Data community to support small consumers — to develop methods that can be rapidly taken up by application software developers without special expertise. To date, geospatial data has been only lightly touched within the W3C community. It has been powering along, however, in Linked Data developments outside the standards sphere: the GeoNames Linked Open Data (LOD) resource is second only to DBPedia in inward-linking in the LOD Cloud and the geonames and geo (WGS84_pos) vocabularies follow only foaf and dc in the prefix.cc account of "what knowledgeable RDF hackers are interested in" (excluding rdf, rdfs, and owl).

The OGC and the W3C have decided to combine their efforts; to bring the might of the two together for the first time to co-develop a suite of Linked Data technologies and best practice guidelines for spatial data on the Web. The Working Group will assess practice in both the Linked Data community and the OGC community to recommend best practices for the growth of the Geospatial Semantic Web. A persistent theme across all the work of the group will be to ensure that the expert knowledge of the geographers, as demonstrated through existing OGC standards, is employed for spatial representation. On the other hand, the Group will be relying on the expertise of the computer scientists of the Web’s W3C to recommend methods and tools that will be of most use for rapid uptake by the fast-and-furious Linked Data developer community. Let's look a little deeper at the problems to be tackled.

### Geography Is More Than a Point in Space

While at its most basic a location may be expressed as a coordinate in some agreed reference system such as the well-used World Geodetic System (WGS84), we need to be able to describe more complex geographic features that may or may not have well-defined point locations or shapes and to be able to model the relationships between them. This has become known as the conflict between the well-defined idea of "space" and the less-defined concept so important to geography, "place." Think of the urban villages common in many western cities, such as New York’s Meatpacking District or London’s Little Venice, which have no formal boundaries. Are such locations contained within the larger cities, or are they independent? Think also of ephemeral lakes like Lake Lefroy in Western Australia, famous for land yacht sailing. These places can’t, in a sense of geometric encoding, “touch” a boundary with other neighborhoods; and whether a road “crosses” them may be quite subjective and time-dependent. Nevertheless, as abstract objects they need identifiers so that they can be talked about.

URIs as identifiers for anything at all, both real-world objects and information resources, are a critical concept for the Web of Linked Data and are supported by well-developed practices for associating the identifiers for the objects with the identified information about them. This practice is not so well understood in the Geospatial community, where objects like Lake Lefroy may not be identified independently of some (time-varying, context-dependent) geometric representation, a practice likely to have been driven by the data modeling of traditional GIS tools. We hope that the Working Group’s advice on this topic will have impact beyond Linked Data publishing, into the practices of developing linkable SDIs that also need to share interoperable information about real-world objects at a large scale.

There are a number of well-known spatial relationship vocabularies embedded in spatial databases, in OGC standards, and in Linked Data practice; these often include encodings for geometry and geometric literals in RDF. Probably the GeoSPARQL vocabulary is best known, including not one but three families of topological relations among pairs of georeferenced geometric objects (OGC Standards and associated documents are available from www.opengeospatial.org/standards). While all three are well-defined by geometric algorithms, in the spirit of the Web there may be some weaker notions required, such as “sdw:samePlaceAs,” “sdw:near” (like foaf:based_near) and “sdw:in” that would be useful irrespective of geometry. Clearly the very imprecision of these makes them context-dependent, and so open to inappropriate interpretation, but does that matter? On the other hand, are the well-defined topological relations too strong for the laissez-faire Web, where dynamic spatial joins over distributed data sources are unlikely to perform well anyway?

NeoGeo suggests a convenient design for handling alternative encodings of geometry, Linked Data style, using Multipurpose Internet Mail Extensions (MIME) types and content negotiation. GeoJSON (JSON stands for JavaScript Object
Notation), with its variant TopoJSON, has become a particularly popular JSON encoding, and it’s being developed to comply with the new Linked Data standards JSON-LD and the JSON-LD API (W3C standards and reports are available from www.w3.org/TR). Although primarily concerned with administrative notions of location, the European Commission (EC) developed the Interoperability Solutions for European Public Administrations (ISA) Core Location vocabulary that also addresses geographic identifiers and geometry. It’s easy to see why both publishers and consumers of spatial data on the Web are looking for advice on which way to jump.

The Spatial Data Infrastructure movement has invested heavily in the capture and formalized representation of metadata implemented in, for example, the ISO 19115 standards. There, metadata is conceived as a standardized description of a substantial chunk of data, itself commonly identified as a file or archived package of files. Instead, metadata as linked Data can be intrinsically connected to the data, being represented in the same RDF graph model as the data itself, and indeed in the same connected graph as the data. Metadata can be associated with resources at any level of granularity. The Working Group will articulate some principles for multigranularity metadata applicable to spatial objects.

Time Is Everywhere, Too

Confoundingly, things have an unfortunate tendency to move, so as soon as we talk about place we have to talk about time, too. Even observations made at fixed locations change over time because everything in the space is moving. The Linked Data community has a very popular vocabulary for time, OWL-Time (OWL stands for Web Ontology Language), a working draft in the W3C since 2006. The time has come to promote that vocabulary, or something very like it, to the status of a formal standard for interoperability. While the vocabulary may be too committed to the Gregorian calendar, it covers both the representation of instants and intervals in time and important temporal relationship concepts. It may be recommended with little change, although extension points for alternative calendars may be needed, as may updating to account for the XML Schema datatypes revision of 2012.

Sensors Measure Things in Space and Time

In 2012, a W3C incubator group published an ontology for sensor networks that’s usually known as the Semantic Sensor Networks (SSN) ontology. It has been highly cited in the research literature, and is known to be used or trialed in industrial applications for smart agriculture, satellite configuration, building management, and Internet of Things services. It’s very commonly used in association with research efforts to build a Web of linked streaming data and complex events, for example.

The SSN design deliberately remained agnostic to encodings for measurement locations, times, and values, and this has frustrated some adopters. Now we have the opportunity to closely align SSN with the standard representations for location and time being developed in the Group. The W3C RDF Data Cube vocabulary, developed since SSN, offers a highly successful platform for Linked Data publishing of time series values, a common style of data arising from sensors, and alignment with the Data Cube would be beneficial to Linked Data publishers and consumers.

We need to keep an eye on other recent developments for representing dynamic data on the Web, too, such as Robert Sanderson and Herbert Van de Sompel’s work. There are also plans to improve SSN usability through modularity and documentation in the Working Group.

Remote Sensors Measure the Earth

We’re also witnessing an explosion in geolocated data that’s sensed remotely by satellites. Traditionally, this kind of rather large and technically difficult-to-interprets data has been locked inside the computer rooms of military, government, or academic research labs, but both commercial and public-good objectives could be better served by high availability.

For remote sensing data, the Working Group will be looking again at the RDF Data Cube vocabulary. While raw sensed data is likely to be considered too raw for widespread consumption, once georeferenced tiles are obtained it seems conceptually sensible to use a Data Cube model to represent observations of geophysical properties such as sea surface temperature and ocean wave height (see Figure 1). The Linked Data design should work well for small addressable geolocated images, but almost certainly the underlying scale of Earth Observation (EO) datasets will create challenges. The OGC standard Geography Markup Language Application Schema-Coverages (GMLCOV) defines a comprehensive XML Schema model for coverages that has been known to work well for data queried from 130-Tbyte coverage databases, so this gives us confidence that a Linked Data interface will be feasible, too. The SSN ontology should be useful here for sensor description. However, coverage is not always sensor-observed and the Working Group aims to deliver at least a Linked Data recommendation for the simple case where a time-varying property is associated with a fixed point location, such as in OGC’s WaterML.

What Will the Geolocated Web Look Like?

If the Working Group is a success, what could we expect to see?
Imagine running for the airport and realizing that you left your laptop on the bus. Your favorite search engine would be able to tell you that the bus is currently “Outside the Queen Elizabeth Conference Centre,” its final destination and expected time of arrival, the telephone number of the lost property office of the bus operator and its opening hours today, and how long it will take you to get there by taxi from your current location. Already, much of the information to locate objects in the real world and information about them exists online, somewhere, but not in a format that would allow you to search for your lost laptop!

Governments are publishing spatial data in interoperable ways to promote reuse of high-quality fundamental datasets. In Europe, their SDI is mandated as a European Union (EU) directive called Infrastructure for Spatial Information in Europe (INSPIRE). To date, SDIs have developed as information silos disconnected from the rest of the Web. While such data may have a stronger sense of authoritativeness and careful quality-oriented custodianship than typical Linked Data (trawled, for example, from citizen-contributed sources such as Wikipedia), publishing it in a form that’s easy to consume has got to be “A Good Thing.” Surely this will contribute to the objectives of SDIs that relate to realizing the economic and social value tied up in spatial data assets. A good question for providers of such data will be to ask what Linked Data principles can be properly used in that more controlled context. For example, should a provider of high-precision roads or vertical obstructions data, suitable for autonomous vehicle navigation, be encouraged to use something like our hypothetical sdw:samePlaceAs links to connect to locations like Little Venice that might be rather less controlled? We propose that the Working Group will not only influence the development of SDIs, improving inter-connectivity and provenance of data, but will also magnify the benefits of SDIs by making them citizen-accessible.

Often, data provenance is important to spatial data. Data may be sourced from SDIs and manipulated and integrated through simulation or visualization tools to underpin strategic and sensitive government decisions. The Australian Government BioRegional Assessment process is an exemplar (see www.bioregional-assessments.gov.au), where decisions to permit coal seam gas mining must balance economic gains against the risks of long term damage to water resources and other environmental assets. Good provenance records are not only important for assessing suitability for input to such processes, but also for association with process outputs to back up transparent and scientifically-contestable decisions. Fortunately, the recent W3C PROV Recommendation provides an ideal technical solution that aligns well with the plans for the Working Group. As the group Recommendations are adopted for government information published as Linked Data, we should expect to see rich provenance attached in a way not previously possible, progressing liberal social principles for both transparent science and transparent government.

The Working Group is just starting (see the related sidebar). This article only represents the knowledge and opinions of the authors and shouldn’t be interpreted as representing the collective opinions and wisdom of the

Figure 1. NOAA polar orbiting satellites obtain the data for sea surface temperature. This is a composite 15-day image showing the extension of the Leeuwin Current around Tasmania. (This image by CSIRO is licensed CC-BY 3.0.)
Group. We look forward to developing a consensus among the participants and we hope you can join us to help bring location, in all its richness, to the Web of Linked Data.

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Kerry Taylor is a principal research scientist at CSIRO, Canberra, Australia, an adjunct associate professor at the Australian National University, a principal fellow at the University of Melbourne, and a visiting reader at the University of Surrey, UK. Her research interests include the Semantic Web and e-research. Taylor has a PhD in computer science from the Australian National University. Contact her at kerry.taylor@acm.org.

Ed Parsons is the Geospatial Technologist of Google Research, London, UK. His work focuses on evangelizing Google’s mission to organize the world’s information using geography and tools, including Google Earth and Google Maps. Parsons has an MS in Applied Remote Sensing from Cranfield Institute of Technology and holds an honorary doctorate in science from Kingston University, London. He’s a fellow of the Royal Geographical Society. Contact him at eparsons@google.com.
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Mobile devices run at the limits of what is possible in computer system designs, with performance and battery life both paramount. Unfortunately, battery technology is advancing slowly. Making mobile devices truly better from generation to generation will necessitate new, creative ways to extract more from each joule of a battery’s capacity.

Approximate computing is an emerging research area that promises to offer drastic energy savings. It exploits the fact that many applications don’t require perfect correctness. Many important mobile applications use “soft” error-tolerant computations, including computer vision, sensor data analysis, machine learning, augmented reality, signal processing, and search. A few small errors while detecting faces or displaying game graphics, for example, might be acceptable or even unnoticeable, yet today’s systems faithfully compute precise outputs even when the inputs are imprecise.

Approximate computing builds software and hardware that are allowed to make mistakes when applications are willing to tolerate them. Approximate systems can reclaim energy that’s currently lost to the “correctness tax” imposed by traditional safety margins designed to prevent worst-case scenarios. In particular, research at the University of Washington is exploring programming language extensions, a compiler, and a hardware co-processor to support approximate acceleration.

**APPROXIMATE COMPUTING CHALLENGES**

There are two key challenges to realizing approximate computing’s full potential: we need ways to safely program approximate computers, and we need hardware technologies that can smoothly trade off energy for accuracy.

Regarding programmability, an approximate system must make it table for programmers to write correct software even when the hardware can be incorrect. Programmers need to isolate parts of the program that must be precise from those that can be approximated so that a program functions correctly even as quality degrades. For example, an image renderer can tolerate errors in the pixel data it outputs; a small number of erroneous pixels might be acceptable or even undetectable. However, an error in a jump table could lead to a crash, and even small errors in the image file format might make the output unreadable.

Regarding the technology, approximate hardware must offer appealing quality-performance tradeoffs that can be exposed to the compiler. For example, an approximate adder implemented using power gating can rely on ISA (instruction set architecture, or hardware/software interface) extensions to specify the amount of error allowed in an addition operation. The challenge with most approximate hardware techniques is that they require modifications to existing processor designs, making their near-term adoption difficult, and they often present little energy reduction over their precise counterparts.

To address these challenges, our end-to-end system includes two building blocks. First, a new programmer-guided compiler framework transforms programs to use approximation in a controlled way. An Approximate C Compiler for Energy and Performance Tradeoffs (Accept) uses programmer annotations, static analysis, and dynamic profiling to find parts of a program that are amenable to approximation.

Second, the compiler targets a system on a chip (SoC) augmented with a co-processor that can efficiently evaluate coarse regions of approximate code. A Systolic Neural Network Accelerator in Programmable logic (Snnap) is a hardware accelerator prototype that can efficiently evaluate approximate regions of code in a general-purpose program. The prototype is implemented on the FPGA fabric of an off-the-shelf ARM SoC, which makes its near-term adoption possible. Hardware acceleration with Snnap is enabled by neural acceleration, an algorithmic transformation that substitutes regions of code in a program with approximate versions that can be efficiently evaluated on a specialized accelerator. Using Accept and Snnap, a software programmer can leverage the benefits of approximate acceleration with minimal effort by...
annotating legacy software with intuitive approximate datatype annotations.

**AN APPROXIMATE COMPILER**

The Accept compiler framework combines programmer annotations, code analysis, optimizations, and profiling feedback to make approximation safe and keep control in the hands of programmers. Its front end, built atop the LLVM compiler infrastructure, extends the syntax of C and C++ to incorporate an APPROX keyword that programmers use to annotate datatypes. Accept’s analysis identifies code that can affect only variables marked as APPROX. Optimizations use these analysis results to avoid transforming the precise parts of the program. An autotuner component measures program executions and uses heuristics to identify program variants that maximize performance and output quality. The final output is a set of Pareto-optimal versions of the input program that reflect its efficiency-quality tradeoff space.

**Safety Constraints and Feedback**

Because program relaxations can have significant effects on program behavior, programmers need visibility into—and control over—the transformations the compiler applies. To give the programmer fine-grained control over relaxations, Accept extends an existing lightweight annotation system for approximate computing based on type qualifiers. Accept gives programmers visibility into the relaxation process via feedback that identifies which transformations can be applied and which annotations are constraining it. Through annotation and feedback, the programmer iterates toward an annotation set that unlocks new performance benefits while relying on an assurance that critical computations are unaffected.

**Automatic Program Transformations**

Based on programmer annotations, Accept’s compiler passes can apply program transformations that involve only approximate data. To this end, Accept provides a compiler analysis library that finds regions of code that are amenable to transformations. An ensemble of optimization strategies transform these regions. One critical optimization targets Snnap, our neural accelerator (described in more detail later).

**Autotuning**

Although a set of annotations might permit many different safe program relaxations, not all of them are beneficial in the quality-performance tradeoff they offer. A practical approximation mechanism must help programmers choose from among many candidate relaxations for a given program to strike an optimal balance between performance and quality. Accept’s autotuner heuristically explores the space of possible relaxed programs to identify Pareto-optimal variants.

**NEURAL ACCELERATION**

Neural acceleration is a powerful approach to approximate computing that works by substituting entire regions of code in a program with machine-learning models. Neural acceleration trains neural networks to mimic and replace regions of approximate imperative code. Once the neural network is trained, the system no longer executes the original code and instead invokes the neural network model on a neural processing unit (NPU) accelerator. Neural networks have efficient hardware implementations, so this workflow can offer significant energy savings over traditional execution.

Neural acceleration consists of three phases: programming, compilation, and execution.

**Programming**

To use neural acceleration in Accept, the programmer uses profiling information and type annotations to mark code that’s amenable to approximation. For many applications, it’s easy to identify the “core” approximate data that dominates the program’s execution—such as the pixel array in an image-filter algorithm. The programmer also provides a quality metric that measures the accuracy of the program’s overall output.

**Compilation**

The compiler implements neural acceleration in four phases: region selection, execution observation, training, and code generation. Accept first identifies large regions of code that are safe to approximate and nominates them as candidates for neural acceleration.

Next, it executes the program with test cases and records the inputs and outputs to each target code region. It then uses this input-output data to train a neural network that mimics the original code. Training can use standard techniques for neural networks—we use the standard backpropagation algorithm.

Finally, the compiler generates an executable that replaces the original code with invocations of a special accelerator (the NPU), which implements the trained neural network.

**Execution**

During deployment, the transformed program begins execution on the main core and configures the NPU. Throughout execution, the program invokes the NPU to perform a neural network evaluation in lieu of executing the code region it replaced. Invoking the NPU is faster and more energy-efficient than executing the original code region on the CPU, so the program as a whole runs faster.

**HARDWARE SUPPORT FOR APPROXIMATE ACCELERATION**

Our NPU implementation, Snnap, runs on off-the-shelf FPGAs. Using existing, affordable hardware means that Snnap can provide benefits today, without waiting for new silicon. Snnap uses an emerging class of heterogeneous computing devices called programmable system-on-chips (PSoCs). These devices combine a set of hard processor cores with programmable logic on the same die.
Compared to conventional FPGAs, this integration provides a higher-bandwidth and lower-latency interface between the main CPU and the programmable logic. However, the latency is still higher than in previous proposals for neural acceleration with special-purpose hardware.

Our design covers this additional latency by exploiting parallelism.

Implementation on the Zynq
We’ve implemented Snnap on a commercially available PSoC: the Xilinx Zynq-7020 on the ZC702 evaluation platform. The Zynq includes a Dual Core ARM Cortex-A9 and an FPGA fabric. The CPU-NPU interface composes three communication mechanisms on the Zynq PSoC for high bandwidth and low latency.

First, when the program starts, it configures Snnap using the medium-throughput general-purpose I/Os (GPIOs) interface. Then, to use Snnap during execution, the program sends inputs using the high-throughput ARM Accelerator Coherency Port (ACP). The processor then uses the ARMv7 SEV/WFE signaling instructions to invoke Snnap and enter sleep mode. Finally, the accelerator writes outputs back to the processor’s cache via the ACP interface and, when finished, signals the processor to wake up.

Micro-Architecture
Our design, shown in Figure 1, consists of a cluster of processing units (PUs) connected through a bus. Each PU is composed of a control block, a chain of processing elements (PEs), and a sigmoid unit, denoted by the SIG block. The PEs form a one-dimensional systolic array that feeds into the sigmoid unit. Systolic arrays excel at exploiting the regular data-parallelism found in neural networks, and they’re amenable to efficient implementation on modern FPGAs.

When evaluating a layer of a neural network, PEs read the neuron weights from a local scratchpad memory where temporary results can also be stored. The sigmoid unit implements a nonlinear neuron-activation function using a lookup table. The PU control block contains a configurable sequencer that orchestrates communication between the PEs and the sigmoid unit. The PUs can be programmed to operate independently, so different PUs can be used to either parallelize the invocations of a single neural network or evaluate different neural networks concurrently.

EXPERIENCE AND RESULTS
We applied Accept and Snnap to a set of approximable benchmarks. Our goal was to show that programmers can unlock significant efficiency gains at a small accuracy cost with minimal effort.

Writing Approximate Programs
To evaluate the effort required to apply approximation, we annotated a set of benchmarks for Accept’s language. The programmers included three undergraduate researchers, all of whom were beginners with the C and C++ languages and new to approximate computing, as well as graduate students more familiar with the field.

Programmers tended to approach annotation by finding the central approximable data in the program—for example, the vector coordinates in a clustering algorithm, or pixels in imaging code. Accept’s type errors guided programmers toward other parts of the code that needed annotation. Programmers needed to balance effort with potential reward during annotation, so auxiliary tools, such as profilers and call graph generators, were useful to find hot spots.

Snnap Acceleration Efficiency
Our evaluation targeted seven benchmarks from many application domains: option pricing, signal processing, robotics (the inverse kinematics for 2-joint arm—inversek2j), lossy image compression, machine learning (k-means), and image processing. We compared...
each program’s performance, power, and energy consumption when using Snnap versus running the original software on the ARM processor. We limited each application’s output error to 10 percent. Snnap incorporates eight processing units and runs at one quarter of the CPU’s core frequency.

Performance and energy efficiency. Figure 2 shows the geometric mean for the whole-application speedup, which was 3.78 times faster across our benchmark suite. As shown, the speedup ranged from 1.30 times faster for k-means to 38.12 times for inversek2j. Inverse kinematics saw the largest speedup, because the bulk of its execution was offloaded to Snnap. The target code for that benchmark includes trigonometric function calls that are expensive to evaluate on an ARM CPU. Neural acceleration approximates these expensive functions with a compact neural network that can be quickly evaluated on Snnap. Conversely, the benchmark that had the smallest speedup couldn’t offload most of its execution to Snnap, and the neural network that was trained to approximate the target region was relatively complex and didn’t present a significant advantage over executing the original target region on the CPU.

The energy efficiency results were similar: energy use was reduced 2.77 times on the SoC+DRAM subsystem, ranging from 0.87 times for k-means to 28.01 times for inversek2j. The primary energy benefit of Snnap comes from racing to completion: faster execution times must compensate for Snnap’s fixed power overhead.

Comparing Snnap with application-specific datapaths. Specialized hardware accelerators are another way to improve applications’ energy efficiency using FPGAs. We compared Snnap’s performance to specialized FPGA designs generated by a commercial high-level synthesis (HLS) tool, Vivado HLS 2014.2. For each benchmark, we generated a specialized datapath by compiling through HLS the same region of code that we offload to Snnap via neural acceleration.

For a fair comparison, we normalized performance of each approach by its resource usage on the FPGA. To our surprise, neural acceleration offered better resource-normalized throughput on four out of seven benchmarks. In particular, when HLS couldn’t fit a fully pipelined datapath on the available resources, the resulting throughput was affected.

In addition to competitive performance, Snnap and Accept also offer programmability and generality advantages over specialized datapaths. Neural acceleration doesn’t require hardware design knowledge which was often required to debug or optimize the performance of HLS kernels. Also, all seven benchmarks we compiled through HLS generated a different specialized datapath, whereas Snnap provides a fabric for accelerating all seven benchmarks, making virtualization and context-switching possible.

Accept and Snnap represent the first steps toward near-term approximate computing on PSoCs, but compilation and neural acceleration aren’t the only challenges in approximate computing. We’re also developing high-level tools to help programmers better navigate and understand performance-quality tradeoffs, including special-purpose debuggers for approximate programs. We also wish to explore the rich design space for approximate acceleration; neural acceleration is just one coarse-grained technique among others. Future work will establish better error guarantees for neural acceleration using robust training.

Approximate computing research is in its infancy and needs more tools for prototyping and evaluating ideas. The Accept framework and Snnap prototype—both of which we plan to make open source—demonstrate a practical and efficient implementation of approximate transformation.

Approximate computing is especially relevant in mobile environments for two important reasons. First, mobile devices are energy-constrained. Second, most of the applications we run in mobile devices

Figure 2. Whole-application speedup rates across the benchmark suite. The geometric mean was 3.78.
are inherently approximable—including video chatting, games, video creation and consumption, sensor data collection and summarization. If we can make approximate computing a reality on smartphones, it could significantly increase performance while simultaneously decreasing energy consumption, thereby potentially enabling new, more demanding applications.

**ACKNOWLEDGMENTS**

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Although cloud technologies have been advanced and adopted at an astonishing pace, much work remains. IEEE Cloud Computing seeks to foster the evolution of cloud computing and provide a forum for reporting original research, exchanging experiences, and developing best practices.

IEEE Cloud Computing magazine seeks accessible, useful papers on the latest peer-reviewed developments in cloud computing. Topics include, but aren’t limited to:

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- Cloud experiences and adoption (deployment scenarios and consumer expectations),
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Submissions will be subject to IEEE Cloud Computing magazine’s peer-review process. Articles should be at most 6,000 words, with a maximum of 15 references, and should be understandable to a broad audience of people interested in cloud computing, big data, and related application areas. The writing style should be down to earth, practical, and original.

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If you have any questions, feel free to email lead editor Brian Kirk at bkirk@computer.org.
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From the Editor in Chief

The Importance of Being... Bored

Maria R. Ebling, IBM T.J. Watson Research Center

On my ride to work in the morning, I’m usually listening to NPR. Recently, NPR’s New Tech City ran a program called “Bored and Brilliant.” I found the series fascinating and enjoyed their challenges. I’d like to share parts of it here and issue my own challenge for our readers.

INNOVATIVE DAYDREAMING

Neuroscientists have been studying what the brain does when it isn’t doing anything in particular. Neuroimaging studies have found that the brain is surprisingly busy. In addition, the body is putting quite a bit of effort into that activity, as measured by a drop in blood flow of just 5–10 percent during periods of “rest.” Functional magnetic resonance imaging suggests that daydreaming is the default mental state of the human mind.

Meanwhile, Sandi Mann from the University of Central Lancashire wondered what could possibly be the evolutionary point of boredom. Mann performed a study in which she got participants as bored as possible—having them copy phone numbers from a telephone book for 20 minutes—after which point she asked them to think of as many uses as possible for two paper cups. In the next experiment, she had them do something even more boring—simply read the phone book. Yet the participants who read the phone book were much more creative in their answers about those two paper cups. Participants who copied out the phone book came up with ideas such as using the cups as holders or planters. Participants who read the phone book came up with ideas for turning those cups into earrings, musical instruments, and more.

In considering this burst of creativity, the belief is that boredom gets you to start daydreaming and allows your mind to wander. It moves you beyond the conscious mind to the subconscious, which is where your imagination is most active. Consequently, “missing out” on boredom could be a major problem from the perspective of inventing creative solutions to important problems.

What does this have to do with pervasive computing? Consider the last time you were bored and what you did. Did you pull out your smartphone and check your email? Play a game? Watch a video? Smartphones provide an endless stream of entertainment (as long as your battery is charged). We never have to be bored! And if we never have to be bored, are we losing the potential time to daydream and find creative, imaginative solutions to important problems?

This brings me to NPR’s “Bored and Brilliant” series. The series, which walks you through the science behind the importance of being bored, challenges you with different ways of bringing boredom back into your day. See the “NPR: New Tech City’s ‘Bored and Brilliant’ Challenges” sidebar for a description of each day’s challenge.

ACCEPTING THE CHALLENGE

Here, I examine my own experiences with the six-day “Bored and Brilliant” challenges.

Pocket Your Phone

I couldn’t complete this challenge because it wasn’t realistic for me. Women’s clothing generally either doesn’t have pockets or has pockets too small to be of any use, so I carry my phone in my purse or my hand (at work). This past week, I carried my phone and my laptop in a bag all day. I found that it became a conscious decision to check my phone rather than a habit when my mind began to wander. I was concerned that I would miss important texts or calls, but that turned out not to be a problem (and, yes, I did catch an important text message even though my phone was in my tote bag). I am undecided about whether I will continue to carry my phone and laptop in a bag every day, but it’s something I’m considering.
Here are the daily changes issued as part of the “Bored and Brilliant” series. For more information, see www.wnyc.org/series/bored-and-brilliant.

**Day 1: Keep Your Phone in Your Pocket**
Keep your phone in your bag when you are in motion. By not carrying your phone, you ease your sense that part of your attention must be on your phone. It will also open up some time to daydream. To learn more, read *The Distraction Addiction*, by Alex Soojung-Kim Pang (Little, Brown and Company, 2013).

**Day 2: Photo-Free Day**
See the world through your eyes—not your screen. Don’t take any photo! A study done at Fairfield University in Connecticut showed that taking a photo in an art museum impacts your ability to remember what you see.1 By outsourcing your memories to your camera, your brain doesn’t bother storing the information.

**Day 3: Delete That App**
We all have that one app that we spend too much time on. Find the app that is wasting your time... and then delete it. For more information about how these games can be addicting, check out *Hooked: How to Build Habit-Forming Products* by Nir Eyal (2013).

**Day 4: Take a Fauxcation**
Disconnect from the digital world for a day. Set an out-of-office message as if you were on vacation. Set an “away” message on instant messaging and social media. Disconnect at work and take some time to just think.

**Day 5: One Small Observation**
Go somewhere public, anywhere, and hang out. Observe the world around you and let your mind wander. Just notice something—anything. This is the type of situation in which humans are most creative and imaginative.

**Day 6: Dream House**
Put your phone away. Get bored (by watching a generous pot of water come to a boil or writing 0s and 1s on a small piece of paper in small font). Then, empty the contents of your wallet onto the table and use the items to create your dream house. Give the house a name, take a photo, and then send it in.

**Put Down the Camera**
The “no photos” day was probably the least appropriate challenge for me. Because I normally don’t take photos except during touristy activities and because this challenge occurred on a workday, this was trivial for me. I did find the discussion about how taking photos can hurt our ability to remember the experience very interesting and will need to consider this during our next vacation.

**Stop Playing Useless Apps**
This was my favorite challenge. I deleted two time-wasting apps: Two Dots and Bonza. And I don’t miss them! I don’t turn to them at every “boring” moment. I also don’t accidentally stay up late playing them. They both stayed deleted on Day 4 and beyond.

**Disconnect**
This was another favorite challenge—taking a fauxcation from the digital world. In fact, I do this regularly when I need quiet time when thoughtfulness is required. For example, as I write this message, I am not connected to email, nor to instant messaging, nor to Facebook. My laptop is open and I am using a computer, but it is a tool to support me and not a tool that can demand anything from me.

**Observe**
For this challenge, I went to a large bookstore in New York City, with “miles” of bookshelves. The interesting thing is that people were not, by and large, using their phones. They were looking at books. My child sat on the floor reading a book that a friend had just purchased. No texting. No videos. No games. Just reading... *paper* books!

**Embrace Boredom**
I must admit that I didn’t bore myself and then try to build a dream house out of items in my wallet. I just couldn’t bring myself to watch a pot of water come to a boil! That seems a bit too much like watching the grass grow! But those who did complete the challenge produced some pretty creative work (see www.wnyc.org/story/winning-wallet-dream-houses-artist-nina-katchadourians-picks).

**Lessons Learned**
The biggest lesson I took away from the “Bored and Brilliant” series was to remember to be purposeful about when to use technology. Another lesson was that being bored is good because our brains might do critically important work during exactly that sort of “down time.” And finally, I took away the lesson that I need to make sure that my use of technology does not take away 100 percent of my boredom.

The conclusion of the series got me to thinking about other challenges, ones appropriate to pervasive computing users. My plan is to issue my own challenge to you each issue to help you evaluate your use of pervasive technologies and help you find more time to be bored! You’ll find the first challenge in the “Pervasive ‘Bored and Brilliant’ Challenge” sidebar.

**REFERENCE**
and fade into the background. Might they someday also support boredom? Perhaps we could check our phones at the door, knowing that the room would inform us if an important call or notification arrived. Of course, there are many challenges that the designers of such smart spaces face, ranging from the question of where to process captured data to that of how to know who is located where within the space. I thank Helal and Tarkoma for the excellent work they have done to bring you this issue, which explores many of these challenges.

I’d also like to take this opportunity to thank IEEE Pervasive Computing reviewers. For a list of the 2014 reviewers, please see www.computer.org/cms/Computer.org/dl/mags/pc/2015/02/extras/mpc2015020005s.pdf.

We also have two feature articles this issue. The first is “Proximity Detection with RFID,” by Miodrag Bolić, Majed Rostamian, and Petar M. Djurić. They show how their Sense-a-Tag system can facilitate the Internet of Things. One key feature of the IoT is the ability for things to know about other things in their immediate vicinity—which isn’t possible with UHF-based RFID systems. However, using their approach, the authors show how to perform fine-grain localization in a few different scenarios using a traditional RFID system enhanced with a network of Sense-a-Tags.

The second feature article is “Predicting Reduced Driver Alertness on Monotonous Highways,” by Gégoire S. Laure, Andry Rakotonirainy, and Anthony N. Pettitt. The authors evaluate a range of machine-learning algorithms for their ability to detect reduced driver alertness. They use EEG signals as the gold standard and examine a number of surrogate measures that are easier to collect in a vehicle, including heart rate and eye activity. Their findings show that neural networks can detect a substantial number of periods of inattention with a low rate of false alarms in plenty of time to support in-vehicle interventions. These exciting results do have some limitations, which are discussed in detail in the article. The question in my mind is whether these ideas can be implemented in vehicles before driverless cars become available.

For our department lineup this issue, I’m afraid we begin by saying goodbye to a dear friend and colleague, Gaetano Borriello. Gaetano was a founding member of the Editorial Board of IEEE Pervasive Computing until stepping down from our Advisory Committee in late 2014. We will deeply miss his kind heart, generous spirit, and wise counsel. Please be sure to read the In Memoriam department—my tribute, honoring his legacy.

Another tribute for Borriello occurred at the Sixteenth Workshop on Mobile Computing Systems and Applications (ACM HotMobile 2015), which is covered in our Conferences department. Brad Campbell, Thomas Zachariah, and Noah Klugman from the University of Michigan report on the workshop, which began with a keynote by Mark Corner, CTO of Fiksu and associate professor at the University of Massachusetts, Amherst. Corner shared his views of the academic and start-up worlds and discussed both their similarities and differences. Campbell, Zachariah, and Klugman then summarize the papers and topics and discuss the tribute at the conference banquet. Participants toasted the memory of Borriello and his many contributions to the field. I think he would have liked that.

Furthermore, we’ve done something different this issue and are covering two recent events in our Conferences department. In addition to the HotMobile report, Nicola Dell and Trevor Perrier from the University of Washington report on the 2014 ACM Annual Symposium on Computing for Development. They provide a nice overview of each of the keynotes and each of the papers presented during the conference. I was impressed by the variety of work being done to address the significant challenges experienced in developing areas. They also observe that one of DEV’s strengths is the diversity of its participants, with researchers coming together from many different communities, allowing for cross-pollination and seeding interesting collaborations.

Our Innovations in Ubicomp Products department highlights the role of tooling in the IoT. Christian Weichel, Jason Alexander, Abhijit Karnik and Hans Gellersen describe two IoT tools and the ways they are used in digital fabrication to reduce the number of context shifts makers typically experience. Each context shift disrupts the flow of design, and these tools have shown a significant reduction in context shifts. This work highlights the intersection between IoT technologies and digital fabrication!

This issue’s Health department looks at “Living Labs for Pervasive Healthcare Research.” Jesus Favela, Jeffrey Kaye, Marjorie Skubic, Marilyn Rantz, and Monica Tentori look at three different living laboratories: the Oregon Center for Aging and Technology, the TigerPlace senior housing center in Missouri, and the Pasitos smart school for children with autism. They consider the utility of these living labs in terms of both user-centered design and evaluating pervasive...
FROM THE EDITOR IN CHIEF

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In closing, one of the things I like most about IEEE Pervasive Computing is learning about the many ways people are using technology to serve our communities, whether that’s serving people in the developing world or figuring out how to make better use of precious joules. However, I challenge you to be mindful about your use of technology. Use it to serve you and the rest of humanity; don’t allow it to waste your time and reduce your creativity.

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Maria R. Ebling is a director at the IBM T.J. Watson Research Center. She manages a team building systems capable of supporting a Smarter Planet while not forgetting about the people who use such systems. Ebling received her PhD in computer science from Carnegie Mellon University. She’s a member of the IBM Academy of Technology, a distinguished member of the ACM, and a senior member of IEEE. Contact her at ebling@us.ibm.com.

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technologies in the field. They also highlight the challenges living labs face in terms of funding, maintenance, and data overload. If you are considering building a living lab, this article is a good overview of the costs and benefits such a lab provides and gives good pointers to a number of examples.

In our Smartphones department, Thierry Moreau, Adrian Sampson, and Luis Ceze bring approximate computing and its relevance to pervasive computing practitioners to our attention. They highlight work done to build programming language extensions, a compiler that makes energy/performance trade-offs, and a hardware co-processor that supports approximate computing. Applications of this technology to image recognition or sensor data analysis might come to a smartphone near you in the (not-too-distant) future. This is certainly a technology worth following!

This issue’s Notes from the Community discusses a number of interesting topics. One discussion examines some of the ethical issues of monitoring our children. Another takes a look at a 3D printed exoskeleton to defend a woman’s personal space. A third summarizes some of the very real issues around drones flown by inexperienced pilots. This third topic hit a nerve with me because, during a tour I took at Olana, a historic property in New York State, I observed first-hand the concern of the staff when two teenagers showed up with remote-controlled aircraft. One wrong “turn” could cause untold damage to the historic property—and apparently has in the past. I encourage you to join our subreddit community and participate in the discussions.

In closing, one of the things I like most about IEEE Pervasive Computing is learning about the many ways people are using technology to serve our communities, whether that’s serving people in the developing world or figuring out how to make better use of precious joules. However, I challenge you to be mindful about your use of technology. Use it to serve you and the rest of humanity; don’t allow it to waste your time and reduce your creativity.

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ON COMPUTING

Of Boilers, Bit, and Bots

Grady Booch

ONCE UPON A TIME, boilers used to blow up quite often, killing many people.
This was generally not seen as a good thing.
Despite the comforts that boilers brought to life—trains and steamships that could transport people and goods faster than a horse, central heating for buildings previously warmed by individual fireplaces, power for innumerable manufacturing industries from milling to weaving to machining—the social transformation and human cost couldn’t be neglected. In the second half of the 1800s, professional engineering organizations formed, best practices were codified into law, and the ethos of living with these noisy, smelly, and sometimes explosive boilers slowly entered the daily life of everyone dwelling in an industrialized city. It took much longer to regulate the pollution associated with coal-burning boilers, but that too mostly came back into balance (only to be subsumed by other kinds of energy-related pollution).
But, by going back in time, I get ahead of myself. Let’s begin again with three contemporary stories.

On Privacy, Regulation, and Encryption
There’s a site that lets you watch tens of thousands of unsecured Internet connected cameras (www.insecam.com). The public outrage over this site has been rather vociferous, especially by those who have found their home or office on the list. Their reaction is quite understandable. For the most part, we all have some expectation of privacy in our personal spaces, and we rightfully assume that what happens behind closed doors will remain hidden from public view.
On the other hand, the reaction by the technical community has been far less sympathetic. As many have noted, putting an unsecured IP camera on the Internet is akin to placing your home or office on a busy public street, installing large glass windows, and leaving the drapes open. Of course—as the digerati point out—you have abrogated your right to privacy by being so careless.
Amazon just announced the Echo, an intentionally unobtrusive physical artifact that embodies Alexa, an ever-present digital personal assistant. Alexa joins a growing family of personal digital assistants, including Apple’s Siri, Microsoft’s Cortana, and Google’s Now.
We aren’t by any means even close to a really personal digital assistant such as Samantha, as found in the universe of Spike Jonze’s Her, but it’s not hard to trace the trajectory of such technology. Human as we are, we often desire an uncomplicated and compliant companion to
assist us with the tedious and cruft of life. Even today, the wealthy and the famous might have the means to hire a flesh-and-blood personal assistant; technologies such as Alexa, Siri, Cortana, and Now bring some of that ease to the masses.

That being said, there are certainly issues worth debating publicly. As one observer wryly noted regarding Echo’s product features, the “NSA, CIA, and FBI would like to personally thank Amazon for installing spy mics in every home” (http://techcrunch.com/2014/11/06/amazon-echo/#comments). While I don’t exactly share that level of cynicism or paranoia, the observer does make a valid point: In a digital world, what’s the meaning of trust?

There are any number of legal battles going on whose front lines are at the confluence of the digital and the social. The FCC is at the center of the debate about network neutrality. Many ISPs are against it, driven by economic needs that prefer an unregulated Internet (just as long as the playing field still tilts unnoticeably in their direction), whereas many of those representing consumer rights are against it. FBI Director James Comey has come out against the efforts by Apple and Google to encrypt their phones in ways that increase consumer privacy at the expense of law enforcement having easy access the data behind such encryption. Taylor Swift’s latest album 1989 went platinum—the first such album of 2014, in a year in which music sales were deeply reduced—in spite of explicitly withdrawing her tracks from the digital streaming service Spotify.

What can we make of these contemporary stories?

Now and Then
Let’s return to the age of boilers, the age of the great Industrial Revolution that transformed nations and lives. This was also the age of Charles Babbage and Charles Dickens (who, by the way, died only about a year apart). In his marvelous book Charles Dickens in Cyberspace (Oxford Univ. Press, 2006), Jay Clayton speaks of the societal transformation that took place in that era, a time that I also spoke of in my earlier column, “To Code or Not to Code” (IEEE Software, vol. 31, no. 5, 2014, pp. 9–11). Referring to Jane Austen’s novel Mansfield Park, Clayton observes that part of the plot hinges on “the consequence of complex interactions among varied communications media”—in short, the juxtaposition of the pen and paper against the telegraph. Clayton notes, “we live in an undisciplined culture again,” so our challenges in adapting to a digital culture are born out of the same human dynamics that people in the time of Babbage and Dickens faced in adapting to an industrialized culture.

Boilers used to blow up, but science and industry were compelled to mitigate the underlying causes, and society and the law eventually metabolized their use. Cameras, digital assistants, and encryption sometimes yield terrible results, yet the art and science of computing is similarly compelled to mitigate their negative aspects. Furthermore, we have a generation being born who doesn’t know that these things once didn’t exist.

Let’s return to each of my contemporary stories one last time.

Evolving Doors
The problem with unprotected cameras is just one visible manifestation of a much larger issue: the growth of the Internet of Things. Who in his or her right mind would have imagined a world in which doorknobs and light bulbs would have unique IP addresses, much less each of us carrying around mobile network device (our phones) and driving around in our cars (which themselves are networked)? Well, actually, a few prescient folks did predict such a thing, but the basic undercarriage of the original Internet was never crafted for such circumstances (thus the recent move from the IPV4 address to IPV6).

In the early days of the Industrial Revolution, who would have thought of putting a boiler in every home? Well, we do now, in the form of water heaters. These things are still capable of explosion and damage, but we’ve largely engineered the risk out of them. Also, their user interface is so simple that we mostly don’t even think about them, they have so faded so completely out of sight.

So it will be with these cameras and other connected devices, but with one big difference. By their nature, they’re connected in ways beyond our choice—their meaning is materially different from the water heaters we place in our homes. How then do we cope? The general public must adjust; they must accept the additional risk that these things might blow up in unintended digital ways.

At the same time, we who develop, deploy, and deliver such technology must engineer the risk out of them and make them so simple we don’t even think about them. As we engineers know, making things simple is terribly hard, but the human use of our software-intensive artifacts demands it.

The rise of cognitive assistants brings us to exactly the same perspective. Whereas the Internet of Things connects us to one another, Siri, Cor-
tana, Now, and Alexa have the potential to give us something much more intimate: ways to connect to ourselves, to reduce the friction of life. We engineers still must drive the risk out of these artifacts and make them part of the atmosphere. This too is very hard, made even more so because we’re talking about software-intensive systems that can become extremely personal. Not only do we need good software engineers and cognitive scientists building such things, we also need psychologists, cultural anthropologists, and artists to be a part of the journey.

As for the vibrant legal morass that we now see at the intersection of computing and humanity, let me offer the positive spin on it that the presence of such noise might actually be a good thing. Science and technology always precede the rule of law. The fact that we see public debate suggests that the time has finally come for society to codify best practices into law, just as in the age of boilers. The thing we nonlawyer software types must get used to is that the business of making laws is incredibly messy, often muddled and inconsistent, and rarely ever stable or settled. To that end, as computer scientists we must both accept the rule of law and not be silent in its making.

The story is often told of Steve Job’s maniacal focus to shave milliseconds from seemingly trivial parts of the Mac OS. Under his point of view, even milliseconds—when multiplied by trillions of times of execution—add up to human cost. Early boilers were incredibly sloppy and wasteful, but we engineered efficiencies into them. Most of our Web-centric systems are equally sloppy and wasteful, but because we live in an abundance of computational resources, the energy costs of a simple RESTful interaction are often ignored. And yet, when multiplied by trillions of times of execution, they do add up to cycles spent on a server, electricity consumed, and some fuel—fossil, hydroelectric, nuclear, or solar—expended.

We, who have the privilege to develop, deploy, and deliver software-intensive systems that matter, shouldn’t expect the general public to grok the intimate technology with which we live and breathe and in which we delight. We must design these artifacts as if our children’s lives depended on them (and, in many cases, they do). We’re the builders of these modern-day digital boilers that entertain us, feed us, care for us, and serve us. It’s our responsibility to ensure that we do our work with the utmost professionalism and care for the human spirit, to which our work is ultimately directed.

GRADY BOOCCH is an IBM Fellow and one of UML’s original authors. He’s currently developing Computing: The Human Experience, a major transmedia project for public broadcast. Contact him at grady@computingthehumanexperience.com.
Email Address Internationalization: 例子 @ 例子.中国

Arnt Gulbrandsen

Jiankang Yao • China Internet Network Information Center

For 30 years, Internet email addresses have used the format user@example.com, with the character set A–Z, 0–9, ., and -. Gradually mail has been extended to support bæ, löffel, and 中国 in most places, but not in addresses. Now Email Address Internationalization (EAI) work has added support for unicode in addresses, simplifying syntax simultaneously.

As the use of email widened around 2000, a new audience appeared: people who spoke only one language — not English — and wanted email addresses they could understand. For someone who has no friends or associates in Boston, and who perhaps can’t read Latin letters anyway, an ASCII address is more an impediment than a help.

Thus, in 2003, the Internet Engineering Task Force (IETF) introduced the first proposals to support non-ASCII email addresses. Around 2007 or 2008, they tested a set of experimental extensions and found them wanting. They reworked those experimental extensions, and in 2012 the IETF published a set of workable standards and developers began implementing them.

Email Address Internationalization (EAI) Extensions

Internet email is stored and transmitted mostly using a handful of protocols and standards. The message format used universally is that defined by RFC 5322, which is, in turn, largely compatible with the one defined in 1982 by RFC 822. RFC 5322 may be regarded as a clarification of RFC 822 (that isn’t strictly true, but it’s close).

Various extensions were added to the message format over the decades. Most importantly, RFCs 2045–2047, part of the suite of Multipurpose Internet Mail Extensions (MIME), defined Content-Type, multipart mail, attachments (such
Email Address Internationalization: 例子@例子.中国

as images), and the like, and RFC 6376 defined DomainKeys Identified Mail (DKIM) signatures, a mechanism used to confirm that the signing domain was, in fact, involved in sending the message.

Messages are sent from the user-agent to the user’s server using an authenticated “submission” variant of the Simple Mail Transfer Protocol (SMTP; see RFC 5874), then onwards to the recipients’ servers using regular SMTP (RFC 5321), and are finally accessed by the recipients using the Internet Message Access Protocol (IMAP; see RFC 3501) or POP3, allowing the use of UTF-8 (the Universal Character Set Transformation Format — 8-bit) to encode unicode characters in addresses. Each EAI extension is similar: there’s a flag to indicate UTF-8 support; it becomes legal to use unicode strings (encoded as UTF-8) in most circumstances, provided that both ends support that; and no character encodings other than ASCII and UTF-8 are allowed.

The EAI extensions are simpler than most previous mail extensions, but we pay for that simplicity with one big limitation: they require everyone to support EAI and unicode addresses in order for the extensions to be useful.

Today, for example, Gmail supports EAI and Yahoo mail doesn’t. That means that an EAI message can be sent to a Gmail address, but not to a Yahoo mail address. Yahoo users can’t send email to 例子@例子.中国, receive email from 例子@例子.中国, or even receive email that’s copied to 例子@例子.中国. Users of an email system that supports EAI can exchange email with both ASCII and UTF-8 addresses (including a mixture of the two), while users of an email system that doesn’t support EAI can only deal with ASCII email addresses.

Similarly, a mail reader from 1986 can’t be used to send mail to 例子@

When EAI is used, email addresses are almost entirely case-insensitive. In classic email, the domain is case-insensitive and the localpart (to the left of the “@”) may or may not be. Formally speaking, in an address such as Fred@example.com, “example.com” is case-insensitive and example.com decides whether “Fred” is case-sensitive.

Everyone outside the example.com domain is supposed to treat “Fred” as case-sensitive, because it might be. Many users simply expect “Fred” to be case-insensitive, and will read addresses over the phone without specifying case, but the RFCs specify that the domain owner decides whether “localparts” are case-sensitive.

EAI changes that. If there’s at least one non-ASCII character in a localpart, then that localpart is entirely case-insensitive. In Féodor@gmail.com, both localpart and domain are case-insensitive, and “Féodor” and “féodor” are both assured to be valid and the same. (This change could be pointed out more prominently in the RFCs.)
Apart from these changes, EAI is exactly like the classic email in use since the 1980s. One of the authors was able to update one program in about an hour, and another (23-year-old) program needed no changes at all: it just had to be tested. (Not everything is that simple, however: a third program needed weeks of steady work.)

For a more complex message, with attachments, the simplifications are a little greater. However, Delivery Status Notifications (DSNs, as defined in RFC 6533 and older RFCs) are somewhat more complex, because it can be necessary to send new unicode addresses even to unicode-ignorant senders.

For instance, if x@yahoo.com sends mail to example@example.net.cn, which is forwarded to 例子@例子.中国 and is rejected by the spam filter there, it’s formally necessary to report this to x@yahoo.com, even though yahoo.com can’t really handle the failing address. Because of this, DSNs exist in two varieties now.

### SMTP and IMAP

SMTP, IMAP, and POP3 all needed to be extended by EAI, and RFCs 6531–6533 and 6855–6858 define those extensions.

SMTP, like most of the really old Internet standards, is based on “lines” of text, which each line ends with a specified line-end character or sequence. Clients send lines of text to servers, and servers send lines of text back.

The SMTP extensions are plain: The server declares that, in addition to ASCII, the client may use unicode with UTF-8 encoding, the client uses that, and all is well. Here’s an example (lines written by the client start with C, ones with the server start with S):

C: ECHO mta.example.com
S: 250-mta.beispiel.de
S: 250 2.1.0 Ok

In the example, the client sends the usual EHLO command (extended hello), and the server’s response indicates that it supports unicode addresses (the SMTPUTF8 extension). Note that the EHLO can’t use unicode: the client doesn’t know yet whether the server supports it.

The source address in this example uses only ASCII, but the client specifies the SMTPUTF8 extension on the MAIL FROM command because it knows that something else about the message needs unicode. The server responds with OK, agreeing that it will accept unicode addresses. From that point, everything is similar to classic email, except that it can use unicode addresses and the simpler message format that includes unicode characters.

If the SMTP server doesn’t support the SMTPUTF8 extension, things grow more complicated. In general, it ends up being returned to the sender ("bounced") if it requires that support.

IMAP is similarly extended: the server advertises unicode support, and the client enables it using the IMAP ENABLE command. Once that’s done, both the client and server may send UTF-8 in any strings where they previously used ASCII. The following is an example (one line has been wrapped for layout reasons):

S: * OK [CAPABILITY ...] Hi!
C: a login arnt p1lls
S: a OK [CAPABILITY IMAP4rev1 ENABLE UTF8=ACCEPT] done
C: b enable utf8=accept
S: * ENABLED UTF8=ACCEPT
S: b OK done
C: c select inbox
S: * FLAGS ([\Answered ...])
S: * 73897 EXISTS
S: * 0 RECENT
S: * OK [UIDNEXT 252246]
S: * OK [UIDVALIDITY 2]
S: * OK [UNSEEN 68666]
S: c OK [READ-WRITE] done

The server advertises that it supports unicode addresses.

Command “a” is the client login. (In the wild, this should properly use AUTHENTICATE, but LOGIN is so much nicer in print than AUTHENTICATE, with the latter’s long base64 strings.)

Command “b” enables unicode support, command “c” opens the inbox, and command “d” creates a mailbox called maßkrug (containing the German “eszett” character). IMAP aficionados will appreciate that words such as “maßkrug” require no encoding contortions.

When an unextended IMAP client accesses an extended server, the server has three options. First, it can deny the client’s SELECT commands if the user tries to open a mailbox containing unicode addresses (because the client hasn’t enabled support for those addresses, and wouldn’t be able to handle the UTF-8 in the server’s responses).

Second, it can implement either RFC 6857 or RFC 6858, both of which specify ways to present “downgraded” extended messages that unextended clients can read (RFC 6857 is more ambitious, while RFC 6858 is simpler to implement). Both of these approaches render messages well enough that the user can read mail, download attachments, and so on. Replying isn’t possible, though, because there are no valid email addresses to replace the unicode addresses that the client doesn’t support.

Last, it can simply present the client with unicode-extended email messages. This is, strictly speaking, forbidden, but if a server should do this it would hardly be the first time a client is exposed to syntactically invalid mail. A survey by the Gmail development team shows that this approach works fairly well in practice. But again, the client won’t be able to reply.

The situation regarding POP3 is entirely similar; however, POP3 implementers appear to be either uninterested
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or extinct. We don’t know of any POP3 implementations of the EAI extensions.

W
hile this article provides examples using both European and Chinese unicode characters, the main interest in EAI is from countries using CJK (Chinese–Japanese–Korean) characters. EAI support is reportedly growing in those countries, because it satisfies a very strong need, and the vast majority of their users mostly use email within their own country.

As EAI-enabled email increases there and makes its way out to the rest of the world, we expect EAI support in both SMTP servers and infrastructure, and webmail and IMAP (and, possibly, POP3) clients to increase as well, in a manner similar to how MIME support grew. Today, essentially every email user can send and receive message bodies in other character sets, which also contain attachments.

Perhaps in a few years, every email user will be able to receive mail from addresses like jør@blåbærøysytøy. example and from 原子@原子.中国.

Arnt Gulbrandsen is a long-haired Unix hacker who interrupted his CS/mathematics studies to join a startup, and has been working mostly in startups since. His interests include computer communication, such as email, and software documentation. Contact him at arnt@gulbrandsen.priv.no.

Jiankang Yao is a senior engineer at China Internet Network Information Center (CNNIC). His research interests include internationalized domain names, email address internationalization, and DNS technology. Yao has a DE in computer software and theories. Contact him at yaojk@cnnic.cn.

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Multiple job openings are available for each of these categories. To view detailed job descriptions and minimum requirements, and to apply, visit the website address listed. EOE.
MOUNTAIN VIEW, CA


Systems Engineer – Devices Group or Other: Work with team members to implement hardware and embedded software across a variety of products and technologies. http://bit.ly/MSJobs_1406

Technology Solutions Professional- EPG Core Solution Specialist - CnE or Other: Drive product win rates by proving the value of products to customers and partners. http://bit.ly/MSJobs_1672

SAN FRANCISCO, CA
Sr. Technical Evangelist-DX Evangelist SpecCorp SMSG (S&T) or Other: Drive future growth of the Microsoft platform by engaging a community of customers, partners, and academics. Telecommuting from home office permitted. Travel required up to 35% to underutilized client sites throughout the U.S. http://bit.ly/MSJobs_1177

SUNNYVALE, CA


Design Researchers:Develop user interface and user interaction designs, prototypes and/or concepts for business productivity, entertainment or other software or hardware applications. http://bit.ly/MSJobs_1502

SAN DIEGO, CA
Hardware Dev. or Design Engineers, Hardware Engineers, Electrical Engineers, and Design Engineers (all levels, including Leads and Managers): Design, implement and test computer hardware. http://bit.ly/MSJobs_HardwareDevEng


GM, Hardware- Surface or Other: Lead the overall Strategy and Planning Team for the Surface organization within Microsoft. Requires domestic and international travel up to 25%. http://bit.ly/MSJobs_2068

FORT LAUDERDALE, FL


Account Executive-Field Global Sales or Other: Responsible for selling online advertising solutions. http://bit.ly/MSJobs_1394

Account Executive, Advertising & Online New Markets LATAM - Field Global Sales or Other: Develop business, grow revenue and increase overall sales partner satisfaction and loyalty. Requires local travel up to 50%. Telecommuting permitted. http://bit.ly/MSJobs_1429


DOWNERS GROVE, IL

CAMBRIDGE, MA


Design Researchers:Develop user interface and user interaction designs, prototypes and/or concepts for business productivity, entertainment or other software or hardware applications. http://bit.ly/MSJobs_1502


CHARLOTTE, NC

WASHINGTON DC

Multiple job openings are available for each of these categories. To view detailed job descriptions and minimum requirements, and to apply, visit the website address listed. EOE.
Microsoft Corporation currently has the following openings:

**NEW YORK, NY**

Support Engineers / Escalation Engineers: Provide technical support on issues experienced with Microsoft technologies. [Visit here](http://bit.ly/MSJobs_Support_Eng)

Solution Specialist DC-EPG Core Account Coverage or Other: Enhance the Microsoft customer relationship from a capability development perspective. Requires travel up to 25% with work to be performed at various unanticipated worksites throughout the U.S. [Visit here](http://bit.ly/MSJobs_1283)

Premier Field Engineer-Global Business Support or Other: Provide technical support on mission critical issues experienced with Microsoft technologies. Requires travel up to 50% with work to be performed at various unknown worksites throughout the U.S. Telecommuting permitted. [Visit here](http://bit.ly/MSJobs_1349)

Solutions Sales Specialist – EPG Core Account Coverage or Other: Enhance the Microsoft customer relationship from a capability development perspective. Telecommuting permitted. [Visit here](http://bit.ly/MSJobs_1653)

**FARGO, ND**

Technical Account Managers: Assure productive use of Microsoft technologies, focusing on delivery quality through planning and governance. [Visit here](http://bit.ly/MSJobs_Delivery_Relationship_Mgmt)

**IRVING, TX**

Support Engineers / Escalation Engineers: Provide technical support on issues experienced with Microsoft technologies. [Visit here](http://bit.ly/MSJobs_Support_Eng)

**HOUSTON, TX**

Technical Account Manager: Assure productive use of Microsoft technologies, focusing on delivery quality through planning and governance. Requires travel throughout the U.S. up to 75%; telecommuting permitted. [Visit here](http://bit.ly/MSJobs_1668)

**LOS ANGELES, CA**

Technical Account Manager: Assure productive use of Microsoft technologies, focusing on delivery quality through planning and governance. Requires travel throughout the U.S. up to 25%. [Visit here](http://bit.ly/MSJobs_1540)

**EDINA, MN**

Technical Account Manager – Premier COGS or Other: Assure productive use of Microsoft technologies, focusing on delivery quality through planning and governance. Requires travel up to 75% to various client sites in the Minneapolis region. Telecommuting permitted. [Visit here](http://bit.ly/MSJobs_1630)

**BENTONVILLE, AR**

Senior Premier Field Engineer - Global Business Support or Other: Provide technical support to enterprise customers, partners, internal staff or others on mission critical issues. Requires travel up to 50% with work to be performed at various unknown worksites throughout the U.S. [Visit here](http://bit.ly/MSJobs_1301)

**ISELIN, NJ**

Premier Field Engineer-Global Business Support or Other: Provide technical support to enterprise customers, partners, internal staff or others on mission critical issues. Requires travel up to 75% with work to be performed at various unknown worksites throughout the U.S. [Visit here](http://bit.ly/MSJobs_1251)

**Solution Sales Professional, PDW-EPG Core Account Coverage or Other:** Enhance the Microsoft customer relationship from a capability development perspective. Requires travel to various unanticipated locations up to 50% of the time. Telecommuting permitted. [Visit here](http://bit.ly/MSJobs_1752)

**AUSTIN, TX**

Account Technology Strategist-EPG Core Account Coverage or Other: Provide pre-sales technical and architectural support for sales of software, solutions, and related products. [Visit here](http://bit.ly/MSJobs_1483)

Multiple job openings are available for each of these categories. To view detailed job descriptions and minimum requirements, and to apply, visit the website address listed. EOE.

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**SOFTWARE DEVELOPER** - Assist in development of software for cloud based scheduling systems and desktop management suites for multiple industries. Consult with clients to determine business requirements. Design and execute tests to ensure control. Must have a degree in Computer Science, Systems Eng., or related field, or foreign equivalent. Must be proficient in C#/.Net; ASP.Net; SQL Server; Java script; Visual Studio; Win Forms; Visual Basic; testing frameworks such as Selenium, Sikuli, and HP Quality Center; Hudson Continuous Integration Server; and GIT. Resumes to: Elite Software Inc., 4001 W. Newberry Rd, Gainesville, FL 32607.

**SIEMENS PLM SOFTWARE INC.** has an opening in Troy, MI for Sr. Application Engineer to support technical sales, determine customer specs & demo related LMS ImagineLab software to customer. Requires 25% domestic/international travel. Email resumes to PLMCareers@ugs.com & refer to Req#143906. EOE

**SPLUNK INC.** has the following job opportunities in San Francisco, CA:

Senior Software Engineer in Test (REQ#9ASSS8). Test, design & develop automated testing framework for distributed sys upgrades. Senior UI Software Engineer (REQ#9CXTSZ). Design & implement new front end for Co’s Mobile Intelligence product. Refer to Req#9ASSS8 & mail resume to Splunk Inc., ATTN: J. Aldax, 250 Brannan Street, San Francisco CA 94107.


**SYSTEMS ENGINEER** (Mult. Openings) Allen, TX, Nexus Insight, Inc. W/ a BS in Comp Info Sys. or rtd 30 mos exp as ITO Service Delivery Consultant or rtd. Dsgns & dvlpms solutions to complex apps prgms, syst. admin. issues, or network concerns. Dsgns, modifies, dvlp, writes, & implets s/w prgms. Mail resumes to Nexus Insight, Inc., 1301 Central Expressway S., Ste 200, Allen, TX 75013. Attn: HR

**CLOUDERA, INC.** is recruiting for our Palo Alto, CA office: Software Engineer: Architect, design, develop and test large distributed systems based on the Hadoop ecosystem capable of processing multiple petabytes of data. Mail resumes w/job code #36215 to: Cloudera, Attn: HR, 1001 Page Mill Rd., Bldg. 2, Palo Alto, CA 94304.

www.computer.org/computingedge
NEW YORK UNIVERSITY ABU DHABI POSTDOCTORAL RESEARCHER established the Center for Interdisciplinary Studies in Security and Privacy (CRISSP-AD) to meet the growing challenges that are faced in securing networked information technology systems that have become pervasive and address broader political, economic and policy issues that help understand and mitigate cyber risk. CRISSP-AD is seeking outstanding postdoctoral candidates to join our team to further support its research activities. The areas of expertise aimed at, but not limited to, are: cyber threat intelligence and network analytics; hardware and critical-infrastructure security; and user-centric security. Candidates must hold (or be close to completing) a Ph.D. in Computer Science, Electrical and Computer Engineering or quantitative social sciences. Ph.D. holders with a strong publication record and hands-on skills are encouraged to apply. Applicants with a M.S. in the same fields may apply for a Research Assistant or Research Engineer position. To be considered submit a cover letter, curriculum vitae, and a statement of research interests online at: http://nyuad.nyu.edu/en/about/careers/faculty-positions.html

SENIOR SIEBEL CRM CONSULTANT -Cambridge MA. Design, develop, test and deploy Siebel CRM technology solutions. Analyze customer requirements to design technical architecture for business process solutions. Translate business requirements into Siebel CRM functional and configuration requirements. Work on Siebel Tools, Siebel Workflows, Siebel Reports, OATS, Selenium, EAI, Siebel Integration and Siebel upgrade. Required a Master’s Degree in Computer Science, Engineering, Math, CIS or MIS and 1 year of work experience. A Bachelor’s degree in a related field and 5 years of work experience would be acceptable in lieu of Master’s degree in related field. Any suitable combination of education, training or experience would be acceptable. Resume to Dipali Trivedi, Director, CLOUDFOUNTAIN, INC., 125 Cambridge Park Drive, Suite 333, Cambridge, MA 02140.

PROGRAMMER ANALYST: Analyze, develop, implement, migrate and test software applications utilizing knowledge of C,C++, PL/SQL, Java, .NET, Oracle Applications(11i/R12), reports & form builder (6i/10g), SDLC, OA Framework, SQL * Loader, Unix. AIM. Knowledge in Microsoft Windows, Visual Basic .NET, Linux, SOA, System administration and Web Methods req'd. Must be willing to travel & reloc. Reqs MS in comp sci, eng, bus or rel. Mail resumes to Nitya Software Solutions Inc. 9690 South 300, Ste 319, Salt Lake City, Utah 84070.

BUCKNELL UNIVERSITY, GIS/WEB APPLICATION SPECIALIST: DUTIES: LEWISBURG, PA. Develop, integrate, implement GIS/digital scholarship applications that will advance the University’s academic mission. Research & recommend infrastructure solutions.

INFOSYS LIMITED is in need of individuals to work full-time in Plano,Texas and various unanticipated locations throughout the U.S. Must be willing to work anywhere in the U.S.as all job opportunities may involve relocation to various and unanticipated client site locations; any relocation to be paid by employer pursuant to internal policy. We have multiple openings for each job opportunity, and are an Equal Opportunity Employer M/F/D/V. Please apply online at: http://www.infosys.com/careers/apply-now/apply.asp. Select ‘Americas’ under ‘Job Opportunities’ and follow the link for ‘Experienced Professionals.’ Once a user account has been created, please follow the link for ‘Search Openings’ and enter reference ID(s) for the position(s) of interest in the ‘Auto Req ID’ box.

ASSOCIATE ENGAGEMENT MANAGER(S) needed to contribute to competitor analysis and prospect identification; provide ground intelligence to pursuit teams, as well as account context and client introductions required for opening diverse service offerings in account(s). Travel required. (REF ID 88808BR).

CONSULTANT(S) (DOMAIN) - US needed to help conduct IT requirements gathering, define problems, provide solution alternatives, create detailed computer system design documentation, implement deployment plan and help conduct knowledge transfer with the objective of providing high-quality IT consulting solutions. (REF ID 88788BR).

CONSULTANT(S) (PRODUCTS AND PACKAGES) - US needed to help conduct IT requirements gathering, define problems, provide solution alternatives, create detailed computer system design documentation, implement deployment plan, and help conduct knowledge transfer with the objective of providing high-quality IT consulting solutions. (REF ID 88798BR).

LEAD CONSULTANT(S) (PRODUCTS AND PACKAGES) - US needed to help conduct IT requirements gathering, define problems, provide solution alternatives, create detailed computer system design documentation, implement deployment plan, and help conduct knowledge transfer with the objective of providing high-quality IT consulting solutions. (REF ID 88778BR).

LEAD CONSULTANT(S) (DOMAIN) – US needed to anchor different phases of IT engagement including business process consulting, problem definition, discovery, solution generation, design, development, deployment and validation. (REF ID 88518BR).

LEAD CONSULTANT(S) (PRODUCTS AND PACKAGES) – US needed to anchor different phases of the IT engagement including business process consulting, problem definition, discovery, solution generation, design, development, deployment and validation. (REF ID 88528BR).

PRINCIPAL(S) - Business Consulting needed to lead small proposals and multiple streams on complex proposals. Develop best in class proposals that present Infosys Point of View, approach and IT solutions. Help identify clients and opportunities for the practice, present preliminary ideas and proposals to clients, lead engagements from launch to closure. Travel Required. (REF ID 88548BR).

PRINCIPAL CONSULTANT(S) (DOMAIN) US needed to lead the engagement effort for IT assignments, from business process consulting and problem definition to solution design, development and deployment. Lead proposal development. Travel required. (REF ID 88558BR).

SENIOR TECHNOLOGY ARCHITECT(S) – US needed to provide IT architectural solutions for one or more projects. Provide input to create technology and architectural frameworks. Understand and analyze client business & IT problems, technology landscape, IT standards, and enterprise roadmaps. (REF ID 88768BR).

TECHNOLOGY ARCHITECT(S) - US needed to provide inputs on IT solution architecture based on evaluation/understanding of solution alternatives, frameworks and products. Will interact with clients to elicit architectural and non-functional requirements like performance, scalability, reliability, availability, maintainability. (REF ID 88778BR).
for GIS use on campus and upgrade of GIS software. Provide technical support for GIS use across campus.

REQUIREMENTS, Must have Bachelor’s Degree or foreign equivalent in Geomatics Engineering or related field and 6 months post-baccalaureate experience in GIS System development & support in an academic or professional setting. Experience must include 6 months experience using ArcGIS desktop and Image processing software to conduct applied spatial analysis in academic research projects; building GIS systems or modules using Python, C#, SOL, and C/C++/Delphi; using ArcGIS Server, Google Maps API, Java Script, HTML, and CSS to build GIS web applications; and knowledge of software algorithms on both vector and raster data. Please send cover letter and resume including job history to Alison Epting Razet, Bucknell University, One Dent Drive, Lewisburg, PA 17837; ae015@bucknell.edu. Equal Opportunity Employer.

MPHASIS CORP. has multi openings at various levels for the following positions at its office in NY, NY & unexpected client sites thr/o the US 1. Info. Sys. Anyst* - Ana. & provide sys req & spec. 2. SW Dvlpers* - Design, dvlp & modify SW sys. 3. Sys. Architect Dvlpers* - Dvlp IT architecture 4. Graphic UI Design* - Design UI & perform UAT 5. N/W Infra Eng* - Maintain & TRBL n/w, design, dvlp, install n/w infrappl. 6. Business Operation Anyst* - Ana bus process thru app of s/w sol. 7. IT Mgrs* - Plan & manage the delivery of IT proj. 8. Enterprise Svc Enaggmt Mgr* - E2E sale of IT svc/prod. 9. Eng Engaggmt Mgr* - Manage & direct business integration of proj activities. 10. Mkt Dvlp Mgr* - Promote IT svc/prod. & impl bus plans. Must have a Bachelor/equiv and prior rel. exp, Master/equiv, or Master/equiv and prior rel. exp. Edu/exp req vary depending on position level/type. "Lead positions in this occupation must have Master/equiv+2yr or Bachelor/equiv+5yr progressive exp. Travel/reloc exp req. Send resume & applied position to: recruitmentm@mphasis.com or 460 Park Ave S., Ste# 1101, New York, NY 10016 Attn: Recruit.

SAMSUNG SEMICONDUCTOR INC. has a Director, Software Engineering (job code: 5CJ2512) job opportunity in Menlo Park, CA: Define, consult and contribute to the software architecture of SSIC mHealth Simband platform. Mail resume to 2440 Sand Hill Rd., Ste 302, Menlo Park, CA 94025, Attn: S. Tan. Must reference job code to be considered. EOE.

Microsoft Corporation currently has the following openings (job opportunities available at all levels, including Principal, Senior and Lead levels):

REDMOND, WA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

Research Software Development Engineers (all levels): Responsible for conducting applied research into new products and services through software engineering techniques. (http://bit.ly/MSJobs_Research_Software_Engineer)

MOUNTAIN VIEW, CA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

PALO ALTO, CA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

SAN FRANCISCO, CA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

SUNNYVALE, CA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

SAN DIEGO, CA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

CHICAGO & DOWNERS GROVE, IL
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

CAMBRIDGE, MA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

DURHAM, NC
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

ALISO VIEJO, CA
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

RE MACHINES
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

NEW YORK, NY
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

HUMACAO, PUERTO RICO
Software Engineer, Principal IT-Ops Services or Other: Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_1930)

FARGO, ND
Software Engineers and Software Development Engineers in Test (all levels, including Leads and Managers): Responsible for developing or testing computer software applications, systems or services. (http://bit.ly/MSJobs_SDE) (http://bit.ly/MSJobs_IT_SDE)

Multiple job openings are available for each of these categories. To view detailed job descriptions and minimum requirements, and to apply, visit the website address listed. EOE.
COMPUTER PROFESSIONALS. Central NJ IT Consulting company requires candidates for following positions at their primary New Brunswick, NJ location 1) Biztalk Developer: design & implement EAI & SOA business solutions using Biztalk App Integration Bus, Web Services, Real Time Messaging, Data Virtualization Layer, etc. Candidates must have min 1yr exp in SOA, Biztalk ESB, SAP/PeopleSoft Adapters, HIPPA/EDI, .NET,BAM, SRE, etc. 2) Java Developer: To Design, develop & implement business software apps using Java & J2EE, Candidates must have 1yr. of mandatory exp in Java Flex, Blaze Server, Web Services, UI Development, integration w/legacy systems, Hadoop, etc. All positions require: MS in CS/Engineering/Info systems/Business or related. BS degree + 5yrs exp can be substituted for the MS reqirmt Any combination of foreign edu + related exp equivalent to a US Masters, or any combination of foreign edu +related exp equivalent to a BS Degree will be accepted. Travel to several unanticipated locations all over US & might involve relocation consistent w/client reqirmts & State & Local reqirmts. Mail your resume to: eVantage Solutions Inc., Inc, Attn: HR, 317 George St., Ste # 205, New Brunswick, NJ 08901.ttn: HR, 317 George St., Ste # 205, New Brunswick, NJ 08901.

EVENTBRITE, INC. is looking Sr. Software Engineers – Front End in San Francisco, CA to build software solutions & application features. Resume to HR. Job #EB05, Eventbrite, Inc., 155 5th St. Fl 7, San Francisco, CA 94103.

Samsung Research America, Inc. has the following opportunities (various levels) available in Mountain View, CA:

- Staff Software Engineer (Ref# MTV15C01)
- Software Engineer, Staff 1 (Ref# MTV15C02)
- Sr. Engineer (Ref# MTV15C03)
- Sr. Software Engineer (Ref# MTV15C04)
- Sr. Research Engineer (Ref# MTV15D01)
- Software Engineer, Sr. Staff 1 (Ref# MTV15E01)
- Software Engineer (Ref# MTV15E02)
- Interaction Designer, Staff 1 (Ref# MTV15E03)
- Interaction Designer, Staff 2 (Ref# MTV15E04)
- Sr. Product Manager (Ref# MTV15E05)
- Staff Engineer (Ref# MTV15E06)
- Sr. Graphics Driver Engineer (Ref# MTV15E07)
- Sr. UX Researcher (Ref# MTV15E08)

Specific requirements apply. All of these positions will involve developing technologies for company’s computer, digital television, mobile telephone, printer, or other electronic products. Mail your resume referencing job title and Ref to farhat.k@samsung.com.
Microsoft Corporation currently has the following openings (job opportunities available at all levels, including Principal, Senior and Lead levels):

REDMOND, WA
Program Managers: Coordinate program development of computer software applications, systems or services. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_HW_ProgMgr)

Program Managers: Coordinate program development of computer software applications, systems or services. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_ProdQlty_Supp)

Business/Operations Program Managers: Responsible for the design, implementation, and release of programs or projects. Telecommuting permitted when not required at factory sites. (http://bit.ly/MSJobs_1869)

MOUNTAIN VIEW, CA
Program Managers: Coordinate program development of computer software applications, systems or services. Requires international travel up to 50%. Telecommuting permitted when not required at factory sites. (http://bit.ly/MSJobs_1967)

PALO ALTO, CA
Senior Program Manager - Skype Engineering or Other: Coordinate program development of computer software applications, systems or services. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_1411)

SAN FRANCISCO, CA
Program Managers: Coordinate program development of computer software applications, systems or services. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_1364)

NPI/SCC Engineering Program Manager - Devices Group or Other: Coordinate program development of hardware products / systems. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_1587)

Director, Program Manager - Product Marketing or Other: Manages program development of computer software applications. Requires domestic and international travel up to 25%. (http://bit.ly/MSJobs_1380)

BUSINESS PROFESSIONALS
Business Program Manager (Learning & Development Specialist MPP) - SMSP Partner Coverage or Other: Responsible for the design, implementation, and release of programs or projects. Requires Domestic and International travel up to 25%. (http://bit.ly/MSJobs_1489)

Senior Hardware Program Manager - Large Screen Devices (LSD) or Other: Responsible for leading a cross-functional team from initial conception to high volume production. Requires Domestic and International travel up to 25%. (http://bit.ly/MSJobs_1589)

Multiple job openings are available for each of these categories. To view detailed job descriptions and minimum requirements, and to apply, visit the website address listed. EOE.
Apple Inc. has the following job opportunities in Cupertino, CA:

**Systems Design Engineer (Req# 9JQNT9)** Eval latest iPad, iPhone, & iPod HW systems in field. Travel Req 30%

**ASIC Design Engineer (Req# 9D82KR)** Work w/ SoC design, system group & OSAIs to define & execute the state-of-art assembly technology roadmap including PoP, SiP, CSP, wirebond & flip chip BGA.

**Engineering Project/Program Manager (Req#9ML2Y6)** Plan & execute Apple Power Eng Programs through building strategic vision, implementing processes, & providing precise guidance to team while leveraging eng & operation partners to meet & exceed programs’ critical milestones. Travel Req 25%

**Senior Software Engineer (Req# 9QZTQV)** Dsgn & dvlp software for web apps.

**Software Engineer Applications (Req#9L5TEK)** Des & imple user friendly, highly function & secure PTS sys that meet global req of reg, zero down, reliable & scal.

**Software Engineer Systems (Req# 9HDBNF)**. Resp for writing sw to develop & maintain mission critical portal app including writing code for new feats & sup existing svcs.

**Software Development Engineer (Req#9FTNYV)**. Respon for design & development of algorithms & sw for comp vision sys.

**Software Engineer Applications (Req#9KXSB3)**. Respon for design & develop of web/mobile based sols for Apple Retail Bus.

**Software Engineer, Applications (Req#9M2RLX)**. Des & dev SW sys based on machine learning & algorithms.

**IST Technical Project Lead (Req# 9LZVCC)**. Anlyz bus users’ reqs to provide conceptual & detailed des to meet bus users’ needs by combining SAP stand. config & custom dev.

**Information Systems Manager (Req# 9BGQ73)**. Admin, install, config, trblshst & write sprrt doc for IBM/AIX & act as lead for team of AIX sys engs.

**Hardware Development Engineer (Req# 9F4T6X)** Dsgn, intgrt & validate analog & mixed signl hrdwre subsys for prtdle dvc.

**Software Engineer Applications (Req#9NBSC4)**. Respon for develop, design & debug of sw for iOS retail sys.

**Information Systems Engineer (Req#9H3UX6)**. Respon for design, implement & deploy for the Apple communities used to sup prod questions & issues.

**Engineering Program Specialist (Req#9CYVHL)**. Assist hw eng teams to coordinate key areas of hw eng progs w/ exposure to cross-func teams & overseas vendors.

**Technical Content Analyst (REQ# 9HBVRY)**. Resp for diagnosing, troubleshooting, analyzing CMS/ data processing problems to imple & imprv comp systems.

**User Interface Designer & Prototyper (REQ#9BVW2D)**. Des & prototyp user interf for new compn prod

**Software Development Engineer (REQ#9JU2T)**. Create test plans for new & ex’ting 1st-party apps & OS funct’n’lity.

**Software Development Engineer (REQ#9LDP6)**. Des & impl large-scale, high vol, high avail, queue-based backend pipeline SW using Java.

**Software Development Engineer (REQ#9KHB3)**. Res for validat. of WiFi SW stack on iOS & OS X platforms.

**ASIC Design Engineer (REQ# 9AAUUK)**. Dev tests & test envrnmnts for GPU designs.

**Software Engineer Applications (REQ#9D2W4)**. Des & dev large scale machine learning platform w/ mission critical perform req.

**Technical Project Coordinator (Req# 9Q3S2W)**. Coord & drive build deliver & cross function’l dependencies.

**Software Engineer, Applications (REQ#9XXPXE)**. Des & dev web/ mobile based soltns for Apple Retl Busns.

**Software Engineer Applications (Req#9UXPWL)**. Des & dev SW for Apple internet servers.

**Software QA Test Engineer (Req# 9QEU6)**. Test iOS device integ & compatib w/Apple CarPlay & non-CarPlay auto head units.

**Hardware Development Engineer (Req#9FD2D)**. Support the des, constrctn, & validation of board/ sys level electronics for consumer electronic devices.

**Software Development Engineer (Req#9NYVDS)**. Des & dev sys SW apps & frameworks for Apple Watch prod w/ well-designed soltns.

**Software Engineer, Applications (Req#9H6THF)**. Spprt lg-scale retail POS sys utlzng exp in comp apps sftwre dsgn, dvlpmnt, implmntn & maintnnc.

**Software Quality Assurance Engineer (Req#9LG3YS)**. Responsible for testing code for iTunes products and services.

**ASIC Design Engineer (Req# 9FQ3Y)**. Respon for design verification of complex SOCs. Create direct & random test for hw design.

**Hardware Development Engineer (Req#9K4Q7D)**. Lead proj from concept phase prod in colab de-

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**June 2015**
Apple Inc. has the following job opportunity in Newark, CA:

**Systems Programmer (Req# 9CZPUX)** Define, create & implement custom development, user interfaces & large scale internal tool sets.

Apple Inc. has the following job opportunity in Austin, TX:

**ASIC Design Engineer (Req# 9GX2FB)** Implement complex, high performance & low power units of a CPU involving logic design, HDL synthesis & place-and-route.

Refer to Req# & mail resume to Apple Inc., ATTN: L.M. 1 Infinite Loop 104-1GM Cupertino, CA 95014.

Apple is an EOE/AA m/f/disability/vets.
The Department of Computer Science and Engineering at the University of Notre Dame seeks candidates for a teaching faculty position to teach courses primarily in the CS&E undergraduate curricula. This is a full-time, continuing position in the Special Professional Faculty track. Competitive candidates will have the training and experience necessary to teach effectively in a range of courses in accredited degree programs in Computer Science and Computer Engineering. Candidates with backgrounds in all areas of Computer Science and Computer Engineering will be considered. Relevant industry experience is also valued.

The University of Notre Dame is a private, Catholic university with a doctoral research extensive Carnegie classification, and consistently ranks in USNWR as a top-twenty national university. The South Bend area has a vibrant and diverse economy with affordable housing and excellent school systems, and is within easy driving distance of Chicago and Lake Michigan.

Qualified candidates should have at least a Masters degree, and preferably a doctoral degree, in Computer Science, Computer Engineering, or a related area.

Applications should include a cover letter, curriculum vitae, statement of teaching experience and philosophy, and names of at least three professional references, at least two of whom must be able to comment on the applicant's teaching experience. Review of applications will begin on June 1 and continue until the position is filled.

Applications should be submitted at http://apply.interfolio.com/29569.
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San Francisco, CA: Software Engineer (Ref#: SF3): Responsible for the definition, design, development, test, debugging, release, enhancement or maintenance of networking software.

San Jose/Milpitas/Santa Clara, CA: Technical Marketing Engineer (Ref#: SJ15): Responsible for enlarging company’s market and increasing revenue by marketing, supporting, and promoting company’s technology to customers. Network Consulting Engineer (Ref#: SJ9): Responsible for the support and delivery of Advanced Services to company’s major accounts. User Experience Designer (Ref#: SJ587): Identify user interaction requirements and develop user experience interface specifications and guidelines. Scrum Master (Ref#: SJ129): Coordinate and develop large engineering programs from concept to delivery. Deploy technical solutions to large cross functional groups. Consulting Systems Engineer (Ref#: SJ812): Provide specific end-to-end solutions and architecture consulting, technical and sales support for major account opportunities at the theater, area, or operation level. Telecommuting permitted and travel may be required to various unanticipated locations throughout the United States. Software Engineer (Ref#: SJ10): Responsible for the definition, design, development, test, debugging, release, enhancement or maintenance of networking software. Systems Engineer (Ref#: SJ143): Provide business-level guidance to the account team or operation on technology trends and competitive threats, both at a technical and business level. Telecommuting permitted. Software/QA Engineer (Ref#: SJ11): Debug software products through the use of systematic tests to develop, apply, and maintain quality standards for company products.

Tewksbury, MA: Software Engineer (Ref#: TEW7): Responsible for the definition, design, development, test, debugging, release, enhancement or maintenance of networking software.

Whippany, NJ: Software Engineer (Ref#: WH1): Responsible for the definition, design, development, test, debugging, release, enhancement or maintenance of networking software. Test Engineer (Ref#: WH32): Build test equipment and test diagnostics for new products based on manufacturing designs.

Please mail resumes with reference number to Cisco Systems, Inc., Attn: M51H, 170 W. Tasman Drive, Mail Stop: SJC 5/1/4, San Jose, CA 95134. No phone calls please. Must be legally authorized to work in the U.S. without sponsorship. EOE.

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Application Deadline: August 20, 2015
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COMPSAC 2015 will also feature a workshops program for topics closely related to the conference theme, *Mobile and Cloud Systems - Challenges and Applications*. Special sessions such as Fast Abstract and Industry Papers will be applicable especially for researchers and engineers who would like to present a new, early and work-in-progress ideas, method, and analysis. The Doctoral Symposium will provide a forum for doctoral students to interact with other students, faculty mentors, industry and government. Students will have the opportunity to present and discuss their research goals, methodology, and preliminary results within a constructive and international atmosphere.

**Important Dates for Authors:**
- January 17, 2015: Paper submissions due
- March 15, 2015: Paper notifications
- April 28, 2015: Camera ready and registration due

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Computer Users:
The Next Generation

Evan Butterfield

People go on and on about “the next generation” of computers or “the next generation” of technology or “the next generation” of publishing. I’m as guilty as anyone. (For the record, I will also go on and on about Star Trek: The Next Generation.)

Last month, IEEE Computer Society staff confronted “the next generation” of ... generations. For Bring Your Child to Work Day, three CS staffers brought their kids to our Los Alamitos, California, office for a day of organized activities dedicated to learning about Computer Society products, services, activities, and fields of interest. One of the activities was designing a mock cover for Computer magazine. The covers they drew reflected different views of what computation means to today’s young people.

To Samuel Sims, 11, his cover represented computations determining that the Los Angeles Clippers professional basketball team makes 53 percent of its three-point shots. Jayden Thompson, 10, drew a 3D representation of a PC. And Saoirse Walsh, 10, sketched a magnifying glass demonstrating the Internet’s ability to bring the world into focus.

For their generation, computers aren’t something separate and distinct—an us-versus-them thing—but rather a natural part of everyday life. It was a delight to have these young people at our office; maybe someday they’ll be Computer society members!

Evan Butterfield is the IEEE Computer Society’s director of products and services. Contact him at ebutterfield@computer.org.
Not long ago, my books competed with one another on my shelf: it was Philip K. Dick versus Jorge Luis Borges. The volumes would peer at each other over the paperbacks between them, just waiting for me to grab one some rainy Saturday morning. That seemed like good competition: words versus words.

Now, however, the bookshelf is digital, and when Philip looks at Jorge, he might see only my email app or Angry Birds. For some people, it might not even be a fair fight any more. E-books have remained simply a collection of words. The reading experience hasn’t necessarily been enhanced by this digital medium; it’s merely a new type of paper.

The Impact of Apps

Now that I work in publishing, it’s interesting to see how apps—and digital technology in general—have impacted a publication’s readership and our ability to communicate with an audience. By and large, I feel that many of us are still re-creating words on paper and this might not be enough to draw people away from interactive apps.

Also, since the early 20th century, the publishing industry picked up some habits that haven’t inspired either efficiency or economic effectiveness, such as a bookseller’s right to return unsold copies to the publisher and the practice of pulping unsold books.

Nonetheless, I was still optimistic that stories would find a way to people, regardless of whether the words are printed or displayed on a screen. Now, though, I must admit that apps’ ubiquity has made me a bit concerned.

It’s an interesting time, to be sure. And if we look at words and the containers that carry them, we can see that the times indeed are a changin’.

Today’s books are zeros and ones lost in a sea of apps, and the competition is fierce. Is the answer to make words more like apps, bringing in social-media connectivity, interactive minigames between chapters, or hidden expositions that are unlocked based on a reader’s location as detected by GPS technology? Or must publishers, who have been in the paper game, get into the hardware game?

There is still a place for words, and there will probably be more apps before it’s all said and done. I just hope that the next generation can recognize the difference, appreciate both, and not think that e-books are simply boring apps.

Brian Kirk is IEEE Computer Society’s associate manager for editorial project development. Contact him at bkirk@computer.org.

Selected CS articles and columns are also available for free at http://ComputingNow.computer.org.

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The Word on Apps

Brian Kirk

Between Google Play and Apple’s App Store, there are almost 3 million apps. For users, the process of accessing apps is easy and straightforward: find the app and click. We can then bask in the glow of the innovative things that our apps can accomplish. We can view the night sky, find the planets’ locations, and see the number of steps we’ve taken during a period of time. We can read the news, videochat with friends, find a house for rent, and play games.

However, apps—and digital technology in general—also pose a challenge to the publishing industry. And for those who value the written word, it’s important to understand the nature of this challenge.

Medium Well

As a college student, I was drawn to the digital revolution and its effect on the written word. I felt like the idea of a story was somehow limited to its medium. I love stories, and certain stories work better in certain media. I would rather watch The Avengers on a big screen than read it in a book, and I never need to see a movie on The Chicago Manual of Style. In the same vein, I’ve never directly compared books to movies and games because they are different media.

I figured printing words on paper allowed for only certain types of stories. Regardless of genre, the reader follows the trail of words as they’re presented, basically without choice or interaction. For me, reading was a passive experience, one in which a narrator in your brain used the words on the page to tell you a story and paint you a picture or two. (My narrator spoke in a British accent and could do some excellent impressions.)

I thought the digital future would be somehow different, allowing us more options in a narrative experience by enabling multimedia, tangential expositions, and potentially other readers’ comments presented within or alongside the text.

Digital Challenge

I love my tablet. It’s a wonderful device, albeit a tad outdated as it’s almost two years old. It’s got a fair amount of music, some games, a few movies and television shows, and a growing collection of e-books. Now when I fly somewhere, I don’t have to schlep my current reading list in printed form.

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