Workshop on End-to-End, Sense-and-Respond Systems, Applications, and Services (EESR '05)

Seattle, WA
June 5, 2005

OPENING REMARKS

Chatschik Bisdikian, of IBM Research, the co-chair of the EESR workshop, explained that the motivation behind the workshop is the context-aware middleware work for pervasive applications. The goal is to examine the role of sensor and actuators and to apply the technology in Internet-scale systems.

Advances in sensor technology and increased intelligence in actuators have provided a rich set of applications. Businesses want to use these Sensor and Actuator Networks (SANETS) to make better decisions and to form true sense-and-respond (S&R) systems. An S&R system has not only sensors and actuators but decision analysis or control components. S&R systems evolve from SANET applications by taking an end-to-end view, where data is sensed, interpreted by the decision-making components, and then acted upon. An example of such a system is the context-aware electricity grid, part of the GridWise project, the subject of the keynote address. In addition to the keynote address, the workshop hosted eight papers, with half covering S&R technologies and half covering applications. The workshop closed with a lively panel discussion.

KEYNOTE ADDRESS

Summarized by Himanshu Raj

■ *The GridWise Project*

Rob Pratt, Pacific Northwest National Laboratory

Rob Pratt presented several problems in existing power grid design. The infrastructure consists of three layers: the generation, the transport (physical wires), and the substations for distribution to end users and businesses. Because the transport layer is exposed to the elements, the whole system is vulnerable to disruptions, with serious consequences to the economy. In addition, the distribution system, from big generation plants to users, does not support third-party, small-scale power producers. One objective of the GridWise project, whose overall goal is to apply sense-and-respond research to the power grid of the future, is to build the "nervous system" for the electric power grid by making a ubiquitous communication infrastructure. This will allow intelligent distribution of power via facilitating cross-level communication.

What causes blackouts? Generally, complete blackouts are caused by a ripple effect in which part of the electric grid goes down and the rest of the system tries to keep up with the load. When the system cannot meet the demand, more of the system shuts down, creating a vicious cycle and eventually resulting in a complete blackout. To address this problem, we need intelligence built into end-user appliances. Such appliances will be able to take actions that are largely unnoticeable to the user and can help the overall system adjust to load shedding. Building such a system, however, requires collaboration between the Grid operators and device manufacturers.

In conclusion, markets and control systems are ultimately going to merge. The ability to optimize at lower granularities than the ones available today will drive future business processes. More information on the GridWise project is available from http://www.gridwise.org.

Most of the questions related to the basic electrical engineering behind power generation, such as how multiple generators are kept in

sync in terms of frequency (one generator starts up and works as the heartbeat while others synchronize to it) and whether we can packetize power and treat it like data on the Internet to store and forward (no, but there are some taps in the making that can maintain the flow of power on different lines).

SENSE 'N' RESPOND TECHNOLOGIES

Summarized by Jonathan Munson and Apratim Purakayastha

- ***A File System Abstraction for Sense and Respond Systems***

  Sameer Tilak, Kenneth Chiu, and Nael Abu-Ghazaleh, State University of New York (SUNY) at Binghamton; Bhanu Pisupati and Geoffrey Brown, Indiana University

  Challenges for wireless sensor networks (WSNs) include heterogeneity in hardware and software, communication models between system elements, the scale of the system, and resource constraints. Previous approaches have examined DB abstractions, but these are too close to the application level. Current abstractions are programming-language– and OS–based. In this presentation, Sameer Tilak proposed a filesystem abstraction. With this approach, the WSN is presented as a distributed file system. The interface is well understood, hides heterogeneity, enables application-specific namespaces, offers structured namespaces, and allows fine-grained control over resources. Tilak then introduced an extended example, a Smart Zoo. The research challenges they face include supporting resource-efficient operation and in-network application-specific processing, the consistency model, and tolerating network unreliability.

  A member of the audience asked about the rate of change of the directory structure. Tilak responded that most changes are localized even though the system is dynamic. Weak consistency is good enough. Another member of the audience asked about using a content-driven approach rather than a directory-driven one. He offered TinyDB as an example of a content-driven approach. Tilak responded that a content-driven approach can be realized by application-specific namespaces. The next question was about how you can generate that organization automatically, to which Tilak responded that file systems easily support a dynamic scheme—unlike databases, whose schemas are generally fixed.

- ***Transversal Issues in Real-Time Sense-and-Respond Systems***

  Ahmad T. Al-Hammouri, Vincenzo Liberatore, and Huthaifa A. Al-Omari, Case Western Reserve University; Stephen M. Phillips, Arizona State University

  Ahmad Al-Hammouri defined real-time sense-and-respond systems as remote control of a physical environment via an S&R system. The contribution of this work is formulating a conceptual framework for real-time S&R issues for networks.

  Transversal issues in S&R systems arise because of the necessity of providing quality of service in real-time S&R systems. One issue is adaptability and tolerance to round-trip delays and jitter. They decompose delay into predictable delay and jitter. Jitter is dealt with via playback buffers. Dealing with playback delay is challenging because existing schemes (e.g., from multimedia systems) do not apply since the performance metrics are different. The delays in S&R systems are round-trip rather than one-way, and delays are determined by the controller. The scheme they used in this work is a combination strategy, in which the controller determines the playback delay based on the round-trip time. Al-Hammouri also discussed congestion control and enabling a choice of utility functions for different S&R systems.

  During the discussion that followed, the similarities between this work and that of multimedia systems were explored. Al-Hammouri explained that multimedia is concerned about jitter. He also explained that they had examined queue lengths as well as packet-receive rates and output lengths. He presented fixed playback delay, but pointed out that you could focus on avoiding packet losses.

  More information is available at http://vorlon.case.edu/~vxl11/NetBots.

- ***M-ECho: A Middleware for Morphable Data-Streaming in Pervasive Systems***

  Himanshu Raj, Karsten Schwan, and Ripal Nathuji, Georgia Institute of Technology

  Himanshu Raj presented M-ECho, a middleware for system morphing (the continuous and dynamic adaptation of services and systems). The objective is to extend the application's longevity by optimizing power consumption. The application area of interest is robotics.

  M-ECho uses an event-driven, pub/sub architecture. Dynamically deployable codelets serve as event handlers and filters. It uses both dynamic code generation and static code repositories. To evaluate the system, the authors integrated it with the Player/Stage robotics framework and measured the power performance of two different mechanisms: code parameterization/substitution and code migration. In the future, Raj expects to examine robotics applications, the use of compiler-assisted techniques, and quantifying the energy cost of dynamic compilation of codelets versus using a static code repository server.

  A member of the audience asked whether the optimization is done on each node or across the entire system. Raj responded that the optimization happens across the entire system. Another question was whether the optimization algorithm was centralized. Raj respond-

ed that it is currently centralized, but that they plan to use a clustered approach in the future.

- ***The Abstract Task Graph: A Methodology for Architecture-Independent Programming of Networked Sensor Systems***

  Amol Bakshi and Viktor K. Prasanna, University of Southern California; Jim Reich and Daniel Larner, Palo Alto Research Center

  Sensor networks involve three roles: the end user (usually a domain expert such as a scientist), the application developer, and the system programmer. In his talk, Amol Bakshi presented the Abstract Task Graph (ATaG), a macro-programming model that involves specification of aggregate behavior, not simply node-level programming. ATaG is an application-neutral approach and tries to support reuse. ATaG uses data-driven flow, in which events carry information about the phenomenon. It also uses mixed imperative/declarative specifications in order to separate "what" from "where" from "when."

  Feng Shao asked when the binding of abstract tasks occurs. Bakshi responded that some are bound at runtime and others at compile time. Another member of the audience asked about the use of channels. Bakshi responded that the channel is not a communication link but is input/output plus a zone of interest. It is a way to associate a task to a data item.

SENSE 'N' RESPOND SOLUTIONS

Summarized by Ahmad T. Al-Hammouri

- ***A Sensor-Based, Web Service–Enabled, Emergency Medical Response System***

  Nada Hashmi and Dan Myung, 10Blade, Inc.; Mark Gaynor and Steve Moulton, Boston University

  Steve Moulton, a surgeon at Boston University, presented a scalable emergency response system that combines sensors, mobile databases, Web services, and wireless infrastructure technologies. Steve described current emergency medical services (EMS) problems: patient care reporting is paper-based, poorly captured, untimely, incomplete, and not searchable. The problem is exacerbated in mass casualty events, where there is a need to identify and distinguish each patient's condition so that patients with severe conditions receive immediate care. Also, there is a need for patients to be directed to the care center that can best treat the patient's condition. Consequently, there is a need for an emergency service system with improved communication, documentation, and exchange of information between the pre-hospital and hospital phases of emergency care.

  Steve introduced a system that meets the above requirements. He explained the system's components and how data flows between these components. Emergency medical technicians (EMTs) enter patient information on PDAs and tablet PCs equipped with wireless connectivity. A sensor is attached to each patient to keep track of the patient's vital signs and the patient's location (via GPS). Patient sensors in one location form a sensor network. Data from each sensor network, along with data from PDAs and tablet PCs, used by EMTs, is aggregated at a local command center (an ambulance). All such communication occurs over a wireless network, e.g., 802.15.4. Data from different local command centers is then transferred via the Internet and aggregated at a central command center where resources can be managed. Decisions then propagate back to local command centers. The first prototype is built upon several technologies such as TinyOS, 802.15.4 and Zigbee, C# and Java, and Web Services and Grid.

- ***A Rule-Based System for Sense and Respond Telematics Services***

  Jonathan Munson, David Wood, Gerry Thompson, and Alan Cole, IBM T. J. Watson Research Center; Sang Woo Lee and DaeRyung Lee, IBM Ubiquitous Computing Laboratory, Korea

  Jonathan Munson defined telematics as vehicle-based computers and communication systems. Potential applications include traffic navigation, weather detection, congestion detection, safety vehicles, and distributed multimedia and gaming. Programming challenges arise when developing such applications because of the heterogeneities in data acquisition, data processing, data collection, event detection, and response processing.

  Munson presented the Telematics Event Detection Service (TEDS), which offers a rule-based programming model that enables developers to more easily develop a wide range of event-driven telematics services. This project was done in the Ubiquitous Computing Laboratory in Seoul, Korea, jointly created by the government of Korea and IBM.

  Rules present low-level events in terms of Boolean expressions or programs with different states. Rule inputs, such as position, velocity, or pressure, are fed from data acquisition devices. Functions defined on rules include spatial functions, temporal functions, and logical functions. A higher-level program can be constructed using the ABLE rule language, a low-level yet flexible language.

  In the most recent TEDS prototype, a developer defines a set of rules and the actions for responding to events from the rules; it represents a sense-and-respond framework similar to the Struts framework for developing Web Services applications.

- ***Meteorological Command and Control: An End-to-End Architecture for a Hazardous Weather Detection Sensor Network***

  Michael Zink, David Westbrook, Sherief Abdallah, Bryan Horling, Vijay Lakamraju, Eric Lyons, Victoria Manfredi, and Jim Kurose, University of Massachusetts; Kurt Hondl, National Severe Storms Laboratory

  Michael Zink presented the software architecture of the meteorological command and control (MC&C) component of a NetRad prototype. The goal of NetRad is to detect a tornado within 60 seconds of formation and to track its centroid with a temporal error no greater than 60 seconds. The MC&C component forms a closed control loop starting from ingesting data from remote radars (sensors), identifying meteorological features in the data, reporting features to end users, and determining each radar's future scan strategy based on detected features and end-user requirements. All of these steps need to complete within 30 seconds before another cycle starts.

  A benchmark based on Nexrad radar data is used to determine whether the total processing time of all steps can fulfill the 30-second deadline. The results show that all these steps have sub-second execution times that make them well-suited for the NetRad system.

- ***Reducing Business Surprises Through Proactive, Real-Time Sensing and Alert Management***

  Mitch Cohen, Jakka Sairamesh, and Mao Chen, IBM T. J. Watson Research Center

  This paper describes the system design of a unified semantic event-stream system that continuously monitors diverse data sources and generates alerts based on domain-specific rules. Such a system can enable manufacturers to closely monitor critical business events (reducing surprises) and gather business failures, warranty intelligence, field events, sales transactions, and asset performance. Jakka Sairamesh noted the factors motivating the need for such a system: lack of visibility in current business operations, rising costs for business management, and late reaction to critical events.

  The system needed to address several challenges such as real-time sensing and monitoring, complex event management, domain-specific analytic, multi-format streams, and multi-rate streams. Jakka Sairamesh presented the high-level architecture for this system, which is primarily composed of the Event Stream Processor. The Event Stream Processor uses the Event Transformation Service to convert into the standard format, the Event Correlation Service to retrieve a list of metrics that need to get calculated, and the Session Update Service to ensure that the current event is included in future metrics calculations. The Metric Evaluation Service determines what, if any, actions need to be taken based on the newly calculated metrics. These actions are taken with calls to the Action Instantiation Service.

PANEL SESSION

Summarized by J. Sairamesh

- ***Research Challenges of End-to-End Sense 'n' Respond Solutions***

  Panelists: Ron Ambrosio, IBM T. J. Watson Research Center; Malena Mesarina, HP Labs; Vincenzo Liberatore, Case Western Reserve University; Feng Zhao, Microsoft Research

  The panel session began with short presentations from each panelist. Feng Zhao focused on challenges in planet-scale S&R systems. He considered application domains such as autonomous vehicle tracking, health care, networked transportation, ubiquitous appliances, and motion sensing for security. He also talked about the role of sensor subnets, protocols for sensor subnet communication, and storage issues in S&R systems, and he considered issues pertaining to two applications in particular: a marine center for air-ground combat sensors and a system for monitoring space in parking lots. He demonstrated the challenge of tracking vehicles using ground-based sensors and the issues in real-time communication and coordination.

  Malena Mesarina focused on the role of standards and return on investment (ROI) for sensor-based applications in the industry and physical environment. She talked about applications such as combat field tracking and habitat monitoring, and the role of motes in sensing. She also talked about RFID- and EPC-based sensor applications for the industry as being important and timely. She argued that the ROI is critical to enabling real deployments and that pilots are needed to validate such deployments. She has found that the technology is expensive, hard to program, and requires deep knowledge about the events.

  Ron Ambrosio talked about a better closed-loop operations control between the sensor systems at the edge of the network and the operational enterprise systems at the core. He discussed the traditional model of computing, which had a separation between this core and the edge systems. He focused on architectural principles and programming models for scalable Internet control systems that have seamless integration between the edge nodes and the core enterprise nodes. He enumerated many architectural principles. He also defined "real-time" processing as not being simply handling a higher rate of information through sensors but a notion of determinism of the process and events.

  Vincenzo Liberatore supported the desire to provide deterministic performance, even at the expense of latency. He supported the definition of "real-time" processing that Ambrosio described. He said that measurement, validation, and metrics for validation are critical in understanding scalable S&R systems.

He talked about a tele-epistemology application and the value of networked S&R in such applications. He argued that almost all of the S&R applications fall into the area of control theory models and that these models need to be applied and validated. He strongly argued the need for real-time S&R benchmarks, simulation, evaluation, metrics, emulation, autonomous operation, determinism in operation, and handling failure situations.

A fundamental question was raised by the audience on whether we were reproducing control theory work. The panel responded that, to some extent, S&R systems are already in the field (e.g., home control systems). However, these systems do not scale up. They also believe that existing control theory is being applied. Questions were raised about event management. The panel talked about event handling, event bus architecture, and standards for handling events.

The panel discussed standards in depth and agreed that standards should focus on accessing information and representing the data to abstractions provided by the sensors. As for what would enable S&R to succeed, the panel felt that the entire community has a role to play. Academia can contribute to application, methodology, and metrics for evaluation. In fact, the NSF has a $40 million program in this area. Business can also contribute, especially focusing on the ROI question.