Technological Challenges in Emergency Response

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Effective management of disastrous events, whether due to natural causes or manmade, is a vital challenge for modern society. Emergency response refers to all phases of disaster relief operations, including planning and preparing for disasters, actions taken in the immediate aftermath of a crisis to minimize impact, and recovery actions taken to bring the societal infrastructure back to normalcy.

Each of the emergency response phases consists of a number of activities aimed at mitigating the impact of disasters to human lives and property. For instance, the response phase immediately after the event includes multiple functions, such as damage assessment, response-needs assessment, response prioritization, coordination and mobilization of rescue operations, resource and logistic planning, evacuation planning, situation monitoring, and timely information dissemination to citizens and organizations.

The complexity of actions taken during emergencies depends upon the severity of the crisis and the entities involved. Depending upon the disaster's magnitude and scope, response might involve multiple levels of the government (city, county, state, and

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federal agencies), national and international partners, public authorities, commercial entities, hospitals and health organizations, volunteer organizations, media organizations, and the public. For example, if a disaster in the Greater Los Angeles region requires coordination among the 87 cities in the LA County jurisdiction, then multiple disaster management area coordinators and several public/private agencies must provide operational views for both crisis and consequence management. In a crisis, such organizations form a loosely coupled and dynamically evolving virtual organization to perform tasks such as medical triaging, evacuation, sheltering, and dissemination of food, water, and other supplies to the impacted population, as well as inspection of damage.

Each of the emergency response tasks are, in general, information driven—they require governmental leaders, response personnel, and other actors to interpret information and interact with one another to make rapid decisions. The quality of these decisions and the speed at which the process transitions through the phases depends upon the speed with which accurate information enters into the system. As the response proceeds and as more accurate information becomes available, new problems are identified, decisions are reassessed, and response activities may be reprioritized and sometimes even reversed.

The key operative concept in emergency response is that of situational awareness—that is, enabling awareness of the resources, incidents, and needs before, during, and after an incident. Accurate and timely assessment of the situation can empower decision makers during a crisis to make more informed decisions, take appropriate actions, and better manage the response process and associated risks. Situational awareness is traditionally defined at three increasing levels of understanding:

- *perception*, where elements of the current situation are observed,
- *comprehension*, where information obtained through observation is combined and interpreted, and
- *projection*, where sufficient information and understanding exists to make predictions about impending events.

Fueled by the advances in sensing, networking, and communication, the past decade has witnessed significant advances in emergency response from both the research and practice perspectives. A variety of new technologies for rapid capture of an evolving situation use

- sensors (such as robotic vision systems for monitoring incident sites, localization, and other personal sensing technologies to track the state of responders during rescue operations, as well as satellite imagery for damage assessment);
- better tools that support seamless information flow among organizations for coordination and collaboration between diverse entities;
- improved geographic information system (GIS) tools for evacuation modeling;
- Web-based technologies for resource management (including coordinating donations and relief operations as well as portals that support family reunification); and
- social media as a major tool to disseminate emergency information and as a collaboration platform, to crowd source for rapid interpretation of data for tasks such as damage and need assessment.

These new opportunities have also created new challenges, the solutions to which have the potential to bring transformational improvements to the response process. Some of these challenges include a diversity of information and information sources, as well as a diversity of information users.

Diversity of Information and Information Sources

Information relevant to decision making might be dispersed across a hierarchy of storage, communication, and processing units. Although a few sensor technologies have been incorporated in field-level response, the potential that such technologies offer remains a futuristic goal.

For instance, social media such as blogs, Twitter, and information portals have emerged as society's dominant communication mechanism. Exploiting such input to gain awareness of an incident, how it's impacting society, and what the emerging needs are is a critical direction for research in effective emergency response. A related challenge is to build tools and technologies to rapidly identify and find the right information.

Diversity of Information Users

Response personnel might need to share information across diverse, loosely coupled, emergent multiorganizational networks that lack centralized control, in which different entities play different roles in response activities, have different needs and urgencies, different cultures, and potentially vastly different capabilities with respect to technology use. Disaster response networks are characterized by heterogeneity in their network relationships (for example, direction and control versus voluntary coordination, or formal or contractual versus informal relationships) and a shifting composition as new organizational entities join the network in response to changing conditions and disaster-related demand. These organizations might have policies in place regarding data sharing and collaboration.

Furthermore, the networks must rapidly reconfigure (frequent structural and functional changes resulting in expansion or extensions, for example) to adapt to the changing communication and control demands present during crisis events. Finally, different people or organizations have different needs and urgency levels regarding the same information. For instance, although a field worker might require detailed information about the specific location of hazardous materials in a burning building, the monitoring and response team at a nearby command center might only need to know how many hazardous-material locations exist within a catastrophe's vicinity.

State of the Infrastructure

Driven by factors such as economics, communities usually design and deploy IT and communication infrastructures for expected usage scenarios, and not necessarily for extreme situations. During a crisis, the very infrastructure that we expect to serve as an enabling technology for effective and timely response might itself be prone to failures and vulnerable to malicious attacks. Dependence on an IT infrasctructure might thus introduce new additional vulnerabilities to an already fragile process.

For example, if emergency organizations start depending solely on technologies such as reverse 911 (a communication solution that combines databases and GIS mapping to deliver outbound notifications to targeted geographical areas via voice and text messages) to communicate alerts and evacuation plans with the public (instead of exploiting citizen networks, as is done currently), telephony's failure under extreme loads could have devastating consequences. The challenge is to design IT solutions that are robust and predictable even in extreme situations, but that aren't cost-prohibitive at the same time.

About This Issue

Creating the next generation of emergency response technologies requires a variety of innovations in intelligent system technologies, ranging from new models for data fusion, semantic understanding of data, modeling emergent events and actions in the environment, human-computer interaction (HCI), group behavior and dynamics, "Big Data" analytics, social media analytics, and scenario-based adaptive decision making, to multiobjective resource allocation. Intelligent systems to support emergency response is a broad topic, and no single special issue can do justice to all aspects of the evolving technologies. Here, we focus on opportunities and technologies to leverage new types of data and knowledge representation frameworks for emergency response.

In the first article in this special issue, "Using Shared Procedural Knowledge for Virtual Collaboration Support in Emergency Response," Gerhard Wickler and his colleagues propose a collaborative knowledge creation and representation framework based on AI plan representations and built using MediaWiki, the open source and scalable collaborative document-editing facility that powers Wikipedia. The framework represents procedural knowledge in a wiki using an informal textual description marked up with formal tags based on a hierarchical task network used for AI planning. The tool can significantly reduce procedural uncertainty by making procedural knowledge explicitly available during disaster events in a familiar form via a Wiki.

For the next article, "Heterogeneous and Stochastic Agent-Based Models for Analyzing Infectious Diseases' Super Spreaders," Wei Duan and his colleagues develop stochastic agent-based models to explore the spread of super spreaders—a small number of people who account for a large part of the population becoming infected. Identifying super spreaders has clear implications in preventing disease outbreak. The authors built an agent society, including models of severe acute respiratory syndrome epidemic progress, human contact patterns, weighted scale-free networks, and infection probabilities. Through computational experiments, they determine some key factors in what will make people super spreaders—these factors include a delayed amount of time before hospital admission, active contact patterns, and a high pathogen load and shedding rates.

Next, using mobility data acquired from more than a million users Teerayut Horanont and his colleagues analyze human mobility and behavior during a large-scale crisis in the article "Large Scale Auto-GPS Analysis for Discerning Behavior Change during Crisis." This research has implications for understanding how humans react to catastrophic situations, revealing new avenues of research in crisis management.

Finally, in "Intelligent System for Large-scale Disaster Behavior Analysis and Reasoning," Xuan Song and his colleagues introduce an intelligent system for analyzing and simulating of human evacuation behaviors during large-scale disasters. Disaster Behavior Analysis and Probabilistic Reasoning System (DBAPRS) stores and manages daily GPS records from mobile devices used by more than one million people. By mining the large dataset of auto-GPS mobile sensor data, DBAPRS is able to automatically discover and analyze the short-term and long-term evacuation behaviors of people during large-scale disasters. The system is even able to simulate or predict population mobility in various cities impacted by the disasters. DBAPRS was successfully applied to the 2011 Great East Japan Earthquake and the Fukushima nuclear plant accident.

We hope you find the articles in this special issue of *IEEE Intelligent Systems* to be a useful introduction to ongoing work in the important application area of emergency response.

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