The "Helpful Environment": Geographically Dispersed Intelligent Agents That Collaborate

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A future network of sophisticated sensors, protection, and repair systems could be integral to clothing, communications devices, transportation systems, buildings, and the environment. These would form the basis for a distributed, adaptable, and resilient "helpful environment."

AI's first 50 years have given us powerful techniques and tools, some which have found significant and valuable application. AI technology helps many people on a regular basis, both directly and indirectly, through the goods they use, through the services they receive, and in the course of their work. The promise of ubiquitous computing, sensor grids, home robots, and Web services is an exciting new driver for AI that should see its reach extend still further into our everyday lives. AI's role in underpinning much of the emerging Semantic Web is one example already of how widely we'll use the methods in the future.

Imagine an environment where sophisticated sensors and autonomous or semiautonomous diagnosis, protection, and repair systems are integral to clothing, communications devices, vehicles, transportation systems, buildings, and the environment. These would form the basis for a distributed, adaptable, and resilient "safety net" for every individual and organization at personal, family, business, regional, national, and international levels.[1] In natural-disaster-prone areas, government legislation, building codes, and insurance requirements would ensure that all future PDAs, communication devices, vehicles, and buildings include appropriate sensor and actuator systems to assist both their users and others nearby. Systems would adapt and respond to emergencies whether or not communication were possible. Where feasible, local help would be used, with appropriate calls on shared services facilitated, whenever this is both possible and necessary. Through this framework, requests for assistance could be validated and brokered to available and appropriate services in a highly distributed market fashion. Services would be provided to individuals or communities through this network to add value and give all sorts of assistance beyond the emergency response aspects. In emergency situations, the local infrastructure would be augmented by the facilities of the responder teams at any level from local police, ambulance, and fire response, all the way up to international response. An emergency zone's own infrastructure could be augmented on demand by laying down temporary low-cost sensor grids and placing specialized devices and robotic responders into the disaster area.

Emergency response challenges

The United Nations Office for the Coordination of Humanitarian Affairs (http://ochaonline.un.org) is one of the international bodies that are charged with assisting in international crises. OHCA's primary functions are to

* develop common strategies for response,
* assess situations and needs,
* convene coordination forums,
* mobilize resources,
* address common problems, and
* administer coordination mechanisms.

These challenges face any group or organization that intends to help in a crisis.

Local or regional governments are often responsible for the event handling, planning, coordination, and status reporting involved in emergency response. They must harness local response capabilities to augment their own by calling on other resources. Figure 1 shows the Tokyo Metropolitan Government's emergency response center, which, in the event of an emergency, will provide information and support to the public (through emergency phone lines), responders, and decision-making authorities.

Figure 1. A typical emergency response coordination center (at the Tokyo Metropolitan Government).

Across a range of emergency response scenarios, there is a common set of requirements that intelligent computer systems might address. Such requirements include

* sensor data management and fusion,
* accurate information gathering,
* correlation and validation,
* relevant and understandable communication,
* contact making,
* requests for assistance and matching to available capabilities,
* use of standard operating procedures and alarms,
* planning and coordination, and
* scalability and robustness.

AI challenges

To give such support and make the vision a reality, we must address many AI challenges. Hiroaki Kitano and Satoshi Tadokoro outlined some of these challenges in a 50-year program of work for future rescue robotics in Japan.[2] They also introduced the annual RoboCup Rescue Simulation competition, which tests systems in a simulation of the 1995 Kobe earthquake. Several other proposals for "grand challenges" in computing and AI take the theme of emergency response.[1] For example, the UK Advanced Knowledge Technologies (AKT) program (http://aktors.org) addresses emergency response challenge problems, and a European program called OpenKnowledge (http://openk.org) has chosen emergency response as one of its core challenge problems. The UK FireGrid project (http://firegrid.org) seeks to link sophisticated, large-scale sensor grids and faster-than-real-time simulations to emergency response coordination systems.

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We can outline several core technologies, many with essential AI components, that must develop, mature, and be integrated with other systems to make this vision of a connected world a reality. Such technologies include

* sensors and information gathering (such as sensor facilities and large-scale sensor grids, human and

photographic intelligence gathering, information and knowledge validation and error reduction, the Semantic Web and metaknowledge, simulation and prediction, data interpretation, and identification of "need"),

* emergency response capabilities and availability (such as matching needs, brokering, and "trading" systems; agent technology for enactment, monitoring, and control; and provision of robust multimodal communications;),
* hierarchical, distributed, large-scale systems (such as local versus centralized decision making and control, mobile and survivable systems, human and automated mixed-initiative decision making, and trust and security),
* common operating methods (such as shared information and knowledge bases, shared standards and interlingua, shared human-scale self-help Web sites and collaboration aids, shared standard operating procedures at local to international levels, and standards for signs, warnings, and so forth), and
* public education (such as publicity materials, self-help aids, training courses, and simulations and exercises).

Running through all these technologies is the need for flexible, extendible representations of knowledge with rapidly altering scope and with changing versions and refinements. We can't monolithically agree on a single representation of all the knowledge that will be involved. The science and technology of ontologies and their management will be vital to sustain this knowledge.

FireGrid

The technologies outlined in the previous section come from a number of fields—some more mature than others, each with its own philosophy and assumptions. However, the technological and research advances necessary to realize this vision are starting to be made. One project that's helping to develop such an integrated, interdisciplinary approach is FireGrid (http://firegrid.org).[3] This UK project addresses emergency response in the built environment, where sensor grids in large-scale buildings are linked to faster-than-real-time grid-based simulations and help fire responders work with the building's internal response systems and occupants to form a team to deal with the emergency.

FireGrid will integrate several core technologies, extending them where necessary (see figure 3). These include

* high-performance computing involving fire models and structural models;
* wireless sensors in extreme conditions with adaptive routing algorithms, including input validation and filtering;
* grid computing, including sensor-guided computations, mining data streams for key events, and reactive priority-based scheduling; and
* command and control using knowledge-based planning techniques with user guidance.

Figure 3. Integration of FireGrid technologies.[3]

I-Rescue

This project (http://i-rescue.org) explores AI planning and collaboration methods in rapidly developing emergency response and rescue situations. The overall aim is the creation and use of task-centric virtual organizations involving people, government and nongovernmental organizations, automated systems, the Grid, and Web services working alongside intelligent robotic, vehicle, building, and environmental systems to respond to very dynamic events on local to global scales.

The I-X system and I-Plan planner provide a framework for representing, reasoning about, and using plans and processes in collaborative contexts.[4] An underlying ontology, <I-N-C-A>, is the basis of a flexible and extendible representation for the issues and questions to address, nodes and activities to perform, constraints to maintain, and annotations to keep.[5] The I-X approach to plan representation and use relates activities to their underlying "goal structure" using rich (and enrichable) constraint descriptions that include the activities' intended impact on the environment. This allows for more precise and useful monitoring of plan execution, allowing plans to be adjusted or repaired as

circumstances change. It can exploit information about the dynamically changing context and status of the agents and products involved (for example, through emerging geolocation services for people and products). It also provides for the real-time communication of activities and tasks between human and automated resources.

I-X agents and the underpinning <I-N-C-A> ontology can be used in a range of systems including supportive interfaces for humans and organizations, and potentially in intelligent sensors and robotic devices. The I-X agents and <I-N-C-A> ontology can thus act as a shared mechanism for coordinating these systems, sensors, and devices and giving them intelligent planning and process support (see figure 4).

Figure 4. An I-X Process Panel and its accompanying tools, engaged in coordinating the response to a simulated environmental emergency.

I-Rescue and I-X systems aim to be part of a future environment that has

* multilevel emergency response and aid systems;
* a backbone for progressively more comprehensive aid and emergency response;
* applications for aid-orientated commercial services;
* a robust, secure, resilient, and distributed system of systems;
* advanced knowledge and collaboration technologies;
* low-cost pervasive sensors, computing, and communications; and
* changes in building codes, regulations, and practices.

Advanced Knowledge Technologies e-Response

The Collaborative Advanced Knowledge Technologies in the Grid (CoAKTinG) project used technologies from the AKT program to support distributed scientific collaboration in an emergency response situation—in particular, a scenario involving managing an oil spill.[6] Focusing on the interchange between humans in the scenario, CoAKTinG provided tools to assist scientific collaboration by integrating intelligent meeting spaces, ontologically annotated media streams from online meetings, decision rationale and group memory capture, meeting facilitation, planning and coordination support, argumentation, and instant messaging and presence.

AKT focuses on the provision of next generation knowledge technologies, particularly in the context of the Semantic Web as both a medium and a target domain for these technologies. Work on the AKT project focuses on a challenge problem dealing with the aftermath of a civil cargo aircraft crashing into a large city—an actual scenario for which contingency plans are in place. This research looks at how to use the Semantic Web to help make sense of the situation, both to guide emergency responders and to find appropriate specialized rescue and medical capabilities.

OpenKnowledge e-Response

OpenKnowledge is a European Union project involving the Edinburgh, Southampton, and the Open Universities in the UK, along with Amsterdam, Trento, and Barcelona. The project aims to provide an open framework for agent interaction and coordination in knowledge-rich environments. It focuses on two challenge problems, one of which is emergency monitoring and management. The project chose this domain as a test bed because it demands a combination of geographical and geopresence knowledge alongside active support for collaboration and planning in multiagent, dynamic situations.

The need to harness electronic communication networks in emergency situations has been recognized as a European research priority. The EU Emergency Response Grid program (www.cordis.lu/ist/grids/emergencey_response_grid.htm) says

In times of crisis—be it a natural disaster, terrorist attack, or infrastructure failure—mobile workers need to work together in time-critical and dangerous situations. Real-time access to information and knowledge, powered by Grids, will help save lives. Crises are complex situations, with large numbers and varieties of mobile workers—medical and rescue teams, police, fire fighters, and other security personnel— appearing on the spot at short notice. These different teams come from different organizations, and

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generally have incomplete or even contradictory knowledge of the crisis situation.

Emergency response coalitions are often highly dynamic and opportunistic "communities of practice." In this context, the OpenKnowledge e-Response test bed involves the exploration of the following peer-to-peer services:

* *Network data sources*. Sensor data flows must be coordinated in the large. These data will be classified locally and must be made available to different "experts or peers" on the basis of contextual classification schema.
* *Collaborative services*. These support planning, communication, and coordination within the expert peers community.
* *Mitigation assessment services*. As potential emergency situations are identified, mitigation needs can be determined and prioritized.
* *Preparedness services*. Such services support those activities that prepare for actual emergencies.

Collaborative operations for personnel recovery

Personnel recovery (search and rescue) teams must operate under intense pressure, taking into account not only hard logistics but also "messy" factors such as a decision's social or political implications. The Collaborative Operations for Personnel Recovery (Co-OPR) project has developed decision support for sense-making in such scenarios, seeking to exploit human and machine reasoning's complementary strengths. Co-OPR integrates the Compendium sense-making support tool for real time information and argument mapping[7] with the I-X artificial intelligence planning and execution framework[8] to support group activity and collaboration. Both share a common model for dealing with issues, the refinement of options for the activities to be performed, handling constraints, and recording other information. The tools span a spectrum from Compendium (which is very flexible, with few constraints on terminology and content) to I-X (with its knowledge-based reliance on rich domain models and formal conceptual models, or ontologies). In a simulated exercise involving personnel recovery during a UN peacekeeping operation, with roles played by military planning staff, external evaluators judged the Co-OPR tools to be very effective.

International systems and organizations

The infrastructure and organizations that would be required to make the vision of the helpful environment possible are being put in place. The Galileo European Satellite Navigation System (http://europa.eu.int/comm/dgs/energy_transport/galileo) and its mobile geolocation and emergency response services program will be another to spur development. Both commercial and freely provided emergency response facilities are being interwoven to ensure active development and support over a long period.

Examples of the type of "helpful organization" that will enact this vision are already starting to emerge. The Multinational Planning Augmentation Team (www2.apan-info.net/mpat), an organization consisting of 33 Pacific Rim nations, has been developing shared knowledge and procedures to assist in responses to regional crises.[9] MPAT used computer collaboration aids and a simple brokering system during the December 2004–February 2005 Indian Ocean tsunami response to help affected countries access the specialized capabilities of response organizations more effectively. MPAT is an excellent example of people training and working together to ensure emergency response readiness. MPAT would be a prime beneficiary and exploiter of any future helpful environment.

On a smaller scale, the Washington, D.C. area is conducting the Capital Wireless Integrated Network (http://capwin.org), led by IBM and the University of Maryland. This program works with local services to support responses by all agencies to incidents occurring on a stretch of freeway in the Washington D.C. area. It aims to show coordinated wireless-computing services' potential value for integrated and cohesive response across police units, ambulance services, emergency support teams, fire brigades, hazardous-material units, and the military.

In the not-too-distant future, every citizen, vehicle, in-transit package, and other "active device" might be treated as a potential sensor or responder. Individuals or vehicles that need help, as well as local, regional, national, and international emergency agencies, could look up specialized capabilities or find local assistance through a much more responsive and effective environment. Systems could interoperate to enable preventative measures to be taken so that those in imminent danger could be forewarned by their own systems, and by the people, vehicles, and buildings around them.

These would support a diverse range of uses, such as

* disaster response and evacuation,
* terrorism incident response,
* civil accidents,
* disease control,
* business continuity,
* family emergencies,
* transportation aids,
* help desks, and
* procedural assistance.

We could create a truly *helpful environment* that everyone can access. In the second 50 years of AI, let's make it happen!

Acknowledgments

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Index terms—AI, emergency response, safety net, ubiquitous computing, sensor grids, intelligent agents