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RoboCup Rescue
A Grand Challenge for Multiagent and Intelligent Systems

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■ Disaster rescue is one of the most serious social issues that involves very large numbers of heterogeneous agents in the hostile environment. The intention of the RoboCup Rescue project is to promote research and development in this socially significant domain at various levels, involving multiagent teamwork coordination, physical agents for search and rescue, information infrastructures, personal digital assistants, a standard simulator and decision-support systems, evaluation benchmarks for rescue strategies, and robotic systems that are all integrated into a comprehensive system in the future. For this effort, which was built on the success of the RoboCup Soccer project, we will provide forums of technical discussions and competitive evaluations for researchers and practitioners. Although the rescue domain is intuitively appealing as a large-scale multiagent and intelligent system domain, analysis has not yet revealed its domain characteristics. The first research evaluation meeting will be held at RoboCup-2001, in conjunction with the Seventeenth International Joint Conference on Artificial Intelligence (IJCAI-2001), as part of the RoboCup Rescue Simulation League and RoboCup/AAAI Rescue Robot Competition. In this article, we present a detailed analysis of the task domain and elucidate characteristics necessary for multiagent and intelligent systems for this domain. Then, we present an overview of the RoboCup Rescue project.

At 5:47 AM on 17 January 1995, an earthquake of magnitude 7.2 hit Kobe City, Japan, killing over 6,432 people; injuring at least 43,800 (recorded in hospitals); and crushing houses belonging to one-fifth of the city's 1.5 million people. Some 104,906 buildings completely collapsed, and only 20 percent of the city's buildings were usable after the earthquake. The damage area concentrated on a strip of land within 13 miles by 0.6 miles, and over 2,300,000 people were seriously affected. The cost for repair of the basic infrastructure damage exceeded $100 billion, and total property damage, including private properties, well exceeded $1 trillion. The devastation was at least ten times larger than that of the 1994 Northridge earthquake that hit that southern California area. Similar tragedies have also taken place in Turkey, Taiwan, and other places on the globe.

With the first hit of the earthquake, houses, buildings, and other facilities collapsed, and road, railways, and other public transportation systems were totally disrupted. Basic urban infrastructures, such as electricity, gas, water supply, and sewage systems, were severely damaged. Although the earthquake was devastating, information on the scale of damage was not immediately transmitted to other parts of the country because information infrastructures and personnel to transmit damage reports were catastrophically damaged so that they were incapable of sending precise information.

Many victims were under collapsed structures. Immediately after the earthquake, 285 fires were reported, with 14 large-scale fires, and many were starting to spread into wider areas. Firefighting was not effective because water supply was disrupted, and local reservoirs were cracked so that water leaked out within hours. To make the situation worse, roads and open areas that were supposed to stop the spread of fires turned into combustion pathways because debris from the collapsed wood homes was exposed to air.

Paramedic and rescue teams had a hard time trying to get to the disaster site because of the disruption caused by damaged roadways, collapsed buildings, and the flood of refugees. Also, there was insufficient and inaccurate information about where these teams should be. Aerial surveillance finally provided a view of the overall situation, but there was no detailed information about the specifics of the situation on the ground. The problem with the helicopters and the other aircraft is that the noise they create hampers ground operations in locating victims under the collapsed houses because the faint sounds that victims create is their only source of location information.

The lesson that we learned from the Kobe, Turkey, and Taiwan earthquakes was the serious need for a robust, dynamic, intelligent planning system for search-and-rescue operations and for powerful human-machine systems, including robots and digital assistants, to cope with the changing situation and to best save people. The scale of the disaster and the speed at which the system must change according to the situation is far beyond human-based mission planning and results in an extremely hostile condition that to this point has made human search and rescue ineffective.

The aim of RoboCup Rescue is to develop a series of technologies that can actually save people in the case of large-scale disasters and to actually operate such systems worldwide.

A Grand Challenge

In this article, we describe RoboCup Rescue (Kitano 2000; Tadokoro et al. 2000; Kitano et al. 1999) as a grand challenge project for the AI, multiagent systems, and robotics communities. The aim of RoboCup Rescue is to develop a series of technologies that can actually save people in the case of large-scale disasters and to actually operate such systems worldwide. Although RoboCup Soccer was claimed to be the landmark project (Kitano et al. 1997), RoboCup Rescue is designed as a grand challenge project to directly attack a socially significant problem. Once accomplished, it will be the one of the largest contributions that the AI and robotics communities can make for mankind.

We launched RoboCup Rescue within the context of RoboCup activities for several reasons: First, RoboCup itself was originally designed to contribute to the next-generation social and industrial infrastructure by providing innovative technologies. Soccer was chosen because it involves many issues (such as multiagent collaboration, real-time planning, and integrated sensing) that are essential for technologies in future industries and social infrastructures. Transfer of some of these technologies to the disaster-rescue domain at some point had been our initial plan. Second, disaster rescue and soccer have some similar characteristics, such as teamwork, uncertainty of information, and real-time decision, as well as some largely different characteristics, such as the number of agents involved, heterogeneity, logistic planning, and emergent collaboration. Thus, investigation of the two domains provides a deeper understanding of the essence of multiagent collaboration and autonomous real-time systems. Third, disaster rescue alone is serious enough to justify initiation of the large-scale project, and we believe that the community and project-management approach that has been successful in RoboCup Soccer can bring about rapid progress in research in this new field.

AI and robotics research can already make immediate contributions within the reach of current technologies and a number of long-range contributions with future technologies: First, there is a potential need for simulating and understanding the optimal or near-optimal search-and-rescue strategy for a large-scale disaster. The astonishing fact is that there is no simulator that can carry out comprehensive simulation of large-scale disasters. Therefore, development of the simulator itself can be a major contribution. However, more advanced simulation with autonomous agents in the simulated environments might make a far larger contribution. As illustrated in the previous section, the numbers of incidents and the uncertainty in making confident decisions is far beyond current human capability. Providing simulators and a decision-assistance system would significantly improve the quality of decisions and the understanding of the possible simulation about to unfold. Such a simulator and decision-assistance system should be an integrated simulation of properties and infrastructure damage, fire proliferation, refugee movement, and other factors involved, and a group of agents should be deployed to examine the efficacy of specific search-and-rescue strategies. In the future, such a simulator should be linked to mobile communication and data-acquisition systems in the field. This simulation possibly involves 1,000 to 10,000 agents and events.

Second, there are immediate needs and opportunities for researchers to contribute search-and-rescue strategies by building a group of robots that work as a team, each of which is specialized in specific sensing and mobility, as well as information systems that can gather, transmit, and receive information

	Rescue	Soccer	Chess
Number of Agents	100 or more	11 per team	—
Agents in the Team	Heterogeneous	Homogeneous	—
Logistics	Major Issue	No	No
Long-Term Planning	Major Issue	Less Emphasized	Involved
Emergent Collaboration	Major Issue	No	No
Hostility	Environment	Opponent Players	Opponent
Real Time	Seconds-Minutes	Milliseconds	No
Information Access	Very Bad	Reasonably Good	Perfect
Representation	Hybrid	Nonsymbolic	Symbolic
Control	Distributed, Semicentral	Distributed	Central

Table 1. Features of Rescue, Soccer, and Chess.

on the situation and the proper course of action. For example, to find victims under the debris, one robot might have hexapot legs and walk over the debris and insert a rod with a microphone and a micro-CCD camera in between debris. Another robot might be small enough to go into the debris with a CCD and an infrared camera. These robots would collaboratively cover the space under the debris. To efficiently and completely cover the space, teamwork would be an essential factor. The number of agents involved in this scenario could perhaps be less than 20, although it depends on the size of the single site.

Third, personal digital assistants (PDAs) can significantly empower search-and-rescue operations. Such a system must be robust enough so that it is operational in various disaster situations. When a certain intelligence is to be added to each such device, it has the potential to change the way a rescue operation might be carried out. Not only personal devices but also certain information infrastructures embedded in the environment can significantly improve the efficiency of the operation. For example, distributing passive data tags on building floors with respective floor numbers can assist in locating possible victims after a building collapse by using probes to find the distribution of floor numbers in the debris. A number of technologies can be used and invented within AI, as well as in more general technologies, for saving people

The RoboCup Rescue Project

The RoboCup Rescue project is designed to maximize the contribution to the society and attain high throughput in research. From the research perspective, RoboCup Rescue is designed to (1) ensure smooth transfer of technologies invented through RoboCup activity to a socially significant real-world domain, (2) establish a domain that complements features that are missing in soccer, and (3) examine fundamental principles of teamwork and real-time multiagent systems by having multiple domains with certain commonalities. Domain characteristics of soccer, rescue, and chess are illustrated in table 1.

RoboCup Rescue consists of four major projects (figure 1): (1) simulation, (2) robotics and infrastructure, (3) integration, and (4) operation. The *simulation project* involves developing comprehensive disaster- rescue simulation systems that can evolve into deployable real-time decision-support systems and investigating the best search-and-rescue strategies using the simulator with autonomous and nonautonomous rescue agents. The *robotics and infrastructure project* involves developing deployable robotics, digital assistants, and information infrastructures that can significantly improve search-and-rescue operations in real disasters. The *integration project* involves integrating the comprehensive simulation system, robotics, and digital assistant systems for eventual full-scale deployment. The *operation project* involves stepwise deployment of the system in the real world.

It is important that both the simulation project and the robotics and infrastructure project are carried out in parallel. There are a number of issues that each project can independently work on and contribute to society. Although our final goal is to bring such technologies into reality and actually save people, we need built-in mechanisms to ensure the sustainable progress of quality research and deployable sys-

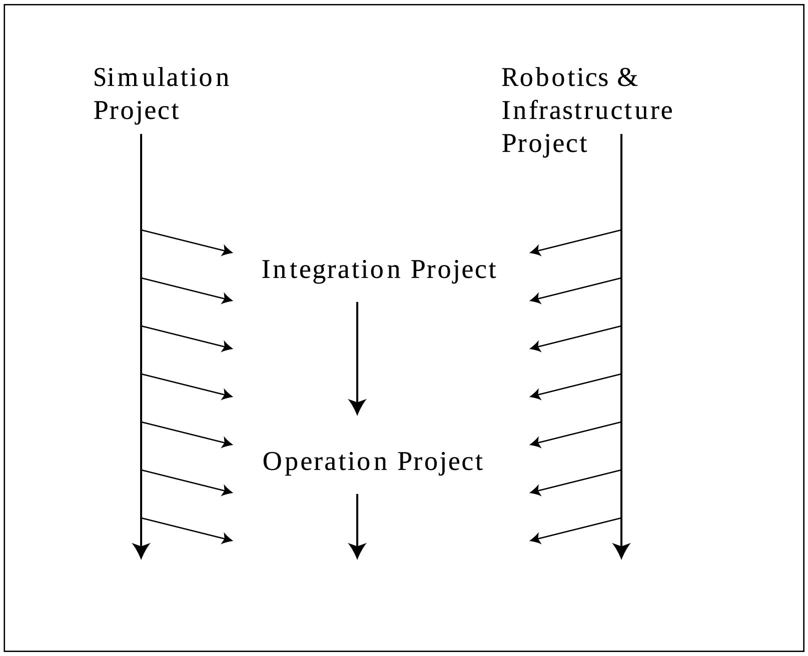

Figure 1. Projects in RoboCup Rescue.

tems. Three basic principles guide the research and development of the projects: (1) interoperability, (2) open-endedness, and (3) best practice.

Interoperability: Software, robots, and other equipment that comply with RoboCup Rescue standards should have a guaranteed level of interoperability, ensuring that robots in one region of the world can be deployed to save people in other regions most effectively.

Open-ended system: The entire system will be open ended, so that any new module and technologies can be plugged in easily, and the system can be scalable.

Best-practice configuration: The system should be the collection of the best-available modules and technologies. The selection of each module and technology will be made competitively.

These principles ensure that the results of the research and development are always up to date and that we have a consistent collection of the best-available technologies. At the same time, successful standard formation guarantees a competitive evolution of the overall system as well as world-wide operational capabilities.

Simulation Project

Disaster simulation requires the integration of the various aspects of disaster, including fire; housing and building damage; disruption of roads, electricity, water supply, gas, and other infrastructures; movement of refugees; status of victims; and hospital operations (figure 2).

Surprisingly, there is no comprehensive simulator for disaster and rescue operations. We consider that the development of a comprehensive simulator that enables the simulation of a multiagent rescue operation contributes to the quality and effectiveness of an actual rescue operation in the long run. By developing an integrated and comprehensive simulator for large-scale disaster rescue, a number of different strategies and tactics can be compared to best save people and property. With the progress of multiagent systems research, technologies and methodologies invented can actually be applied to a real search-and-rescue system that commands fielded personnel and robots.

Simulator Architecture

The simulator should be able to combine various domain-specific simulations, such as fire, building collapse, refugee movement, and traffic and present them as a coherent scene. The current version of the simulator architecture is shown in figure 3.

A kernel of the simulator combines all information and updates the status. Several domain-specific simulators are connected to the kernel. Information on an entire disaster field is stored in a geographic information system. A number of agents are deployed in this simulation environment to test the strengths and weaknesses of the search-and-rescue strategies.

Presenting complex disaster information is a major challenge in such a simulation system. The current version of the simulator is equipped with a two-dimensional situation monitor (figure 4), a three-dimensional view of collapsed houses (figure 5), a three-dimensional monitor (figure 6), and a sophisticated layered presentation system (figure 7).

The building and housing damage simulator simulates the degree of damage to buildings and houses. When detailed simulation is to be performed, this simulation needs to be made block by block, with increased detail for specific landmarks.

The fire simulator simulates the occurrence of fires and how they might spread over time. The composition types of buildings and weather factors will be incorporated. The spreading patterns of fires need to reflect the collapse of buildings and the effectiveness of fire fighting. Existing simulators model this process as a stochastic process of propagating heat and catching fire with thresholded functions over static terrain. They do not incorporate damage to buildings and related fire-fighting efforts.

The life-line damage simulator simulates

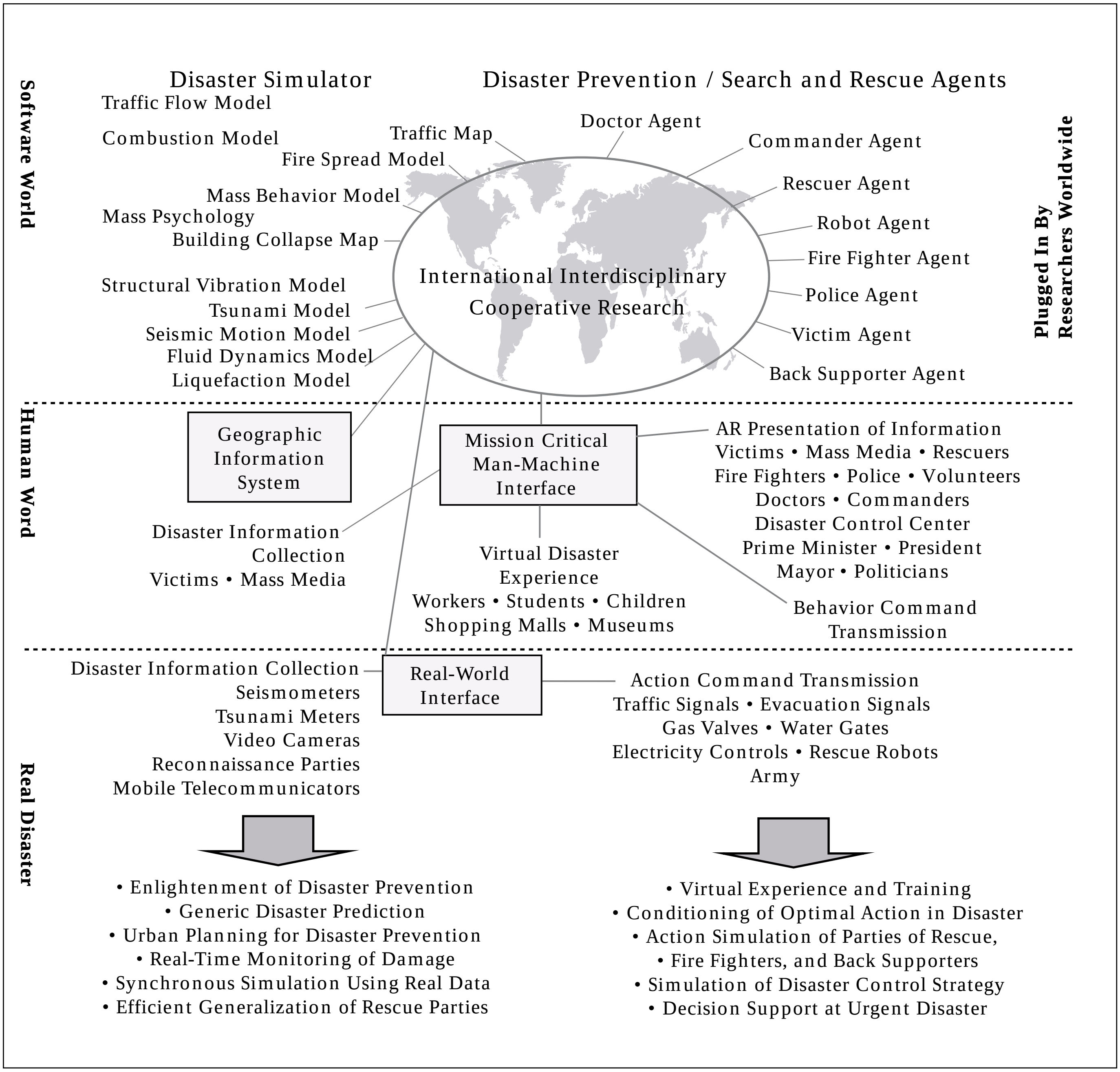

Figure 2. The Overall Concept for the Simulation Project.

damage to roads, electricity, water supply, gas, and other infrastructures. These damage simulations need to be tightly coupled with the building and housing damage simulator. Currently, a few simulators can predict road blockage with 70- to 80-percent accuracy (Takahashi et al. 1998); these simulators, however, are not yet coupled with other simulators.

The victim modeling simulator represents victims and refugees, critical components of a simulation. Depending on the type of disaster, the location of victims, and the magnitude of the disaster, the physical and mental damage that victims suffer differs drastically. Such a simulator needs to reflect what the changing difference and urgency of the victims is as well as how to rescue them. Factors to consider include the time frame of the operation, the kind of paramedic first aids, hospitals that victims can be transported to, and the types of equipment and the expertise of the paramedic teams.

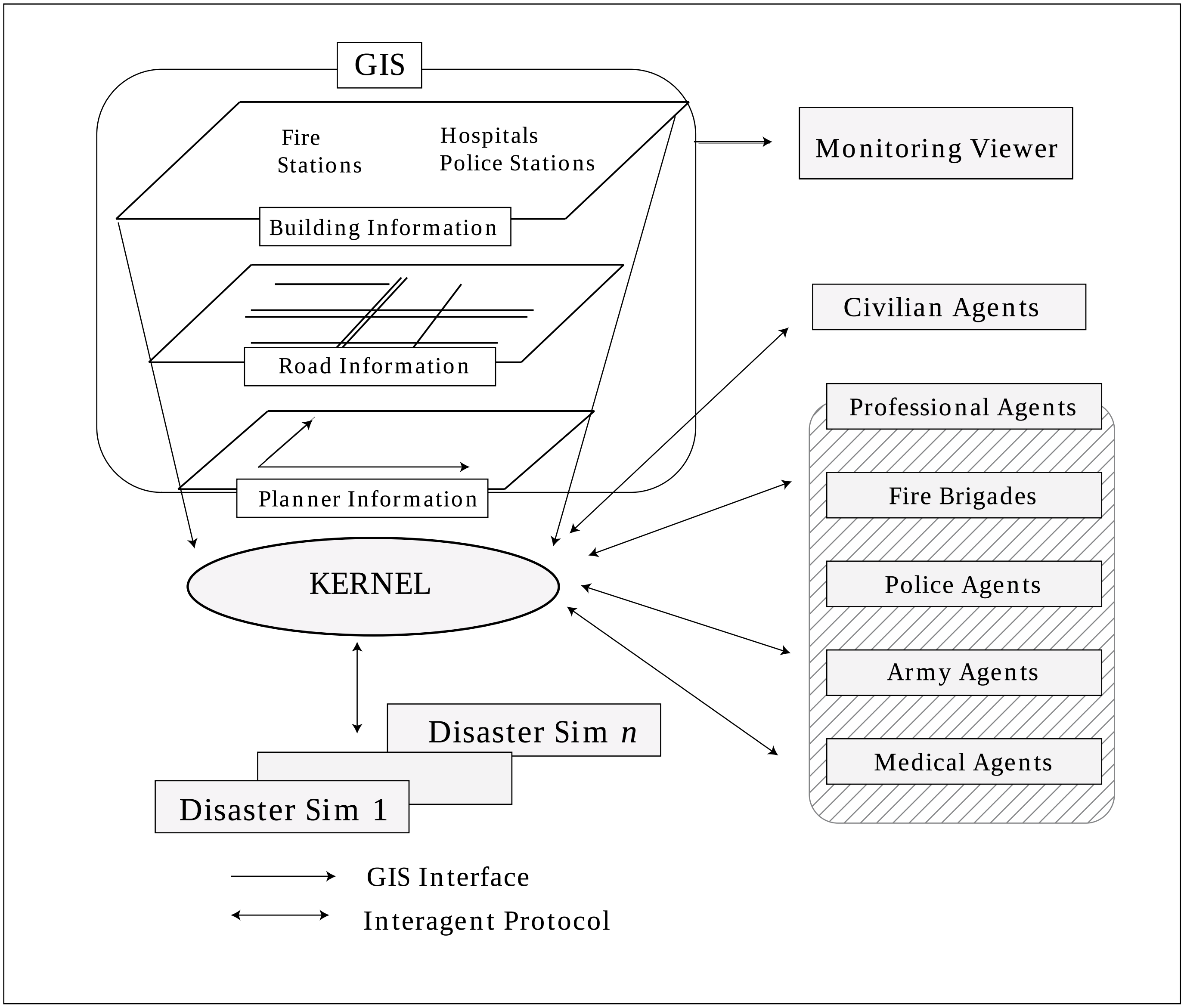

Figure 3. An Architecture of the Simulator.

Victim modeling also has a serious time-sensitive element. Certain casualties need to be taken care of within a short period of time, and if a paramedic team arrives late to the scene, the nature of the operation could be very different. If certain casualties are less serious, their priority would be lower, and rescue would be directed toward victims with more urgent needs. Saving such victims can become time critical as victim attrition gets serious, and other urgent factors are revealed.

The refugee behavior simulator simulates a large number of people who are trying to escape from a disaster site, trying to find a secure place, and searching for family and friends. The movement of a refugee is critically important because massive refugee marching to escape from a disaster site seriously blocks rescue traffic. It is possible that some artificial life type of approach can provide reasonable simulation of this aspect. The simulation, however, needs to be interactive because of changing terrain. Collapsed buildings and roads and police road blockades can continuously change the terrain, and the effects of these changes on refugees need to be simulated.

The data-collection and -visualization simulator simulates the data collection of a situation in a disaster site; the visualization of complex information is a major issue for such systems to have practical value. Data collection is not a major problem if we use the simulator for offline simulation during training and research. However, if we want to use the simulation system as a decision-support tool and assist decision makers, the method of appropriately collecting and consolidating information is a major issue. No such effort is underway at the moment, and the number of research opportunities is vast.

Visualization aspects are also important. The amount of information that needs to be displayed and conveyed to decision makers and people in the field is tremendous. It would not be useful for the systems to display all the information that would be available. People would be unable to quickly comprehend all this information. There is a need for selective display and a new method of providing meaningful information that is suited to commanders, rescue personnel, and civilians. The research on this area has just started (Shinjoh et al. 1999).

Open Evolution of Simulator

The simulator is designed to be scalable in terms of functions and the size of simulation events. New simulator functions can be added by specialized plug-in simulation modules with an interface protocol that complies with the defined standard. If anyone provides a specific simulation module that has a higher perfor-

Figure 4. A Two-Dimensional Situation Monitor View.

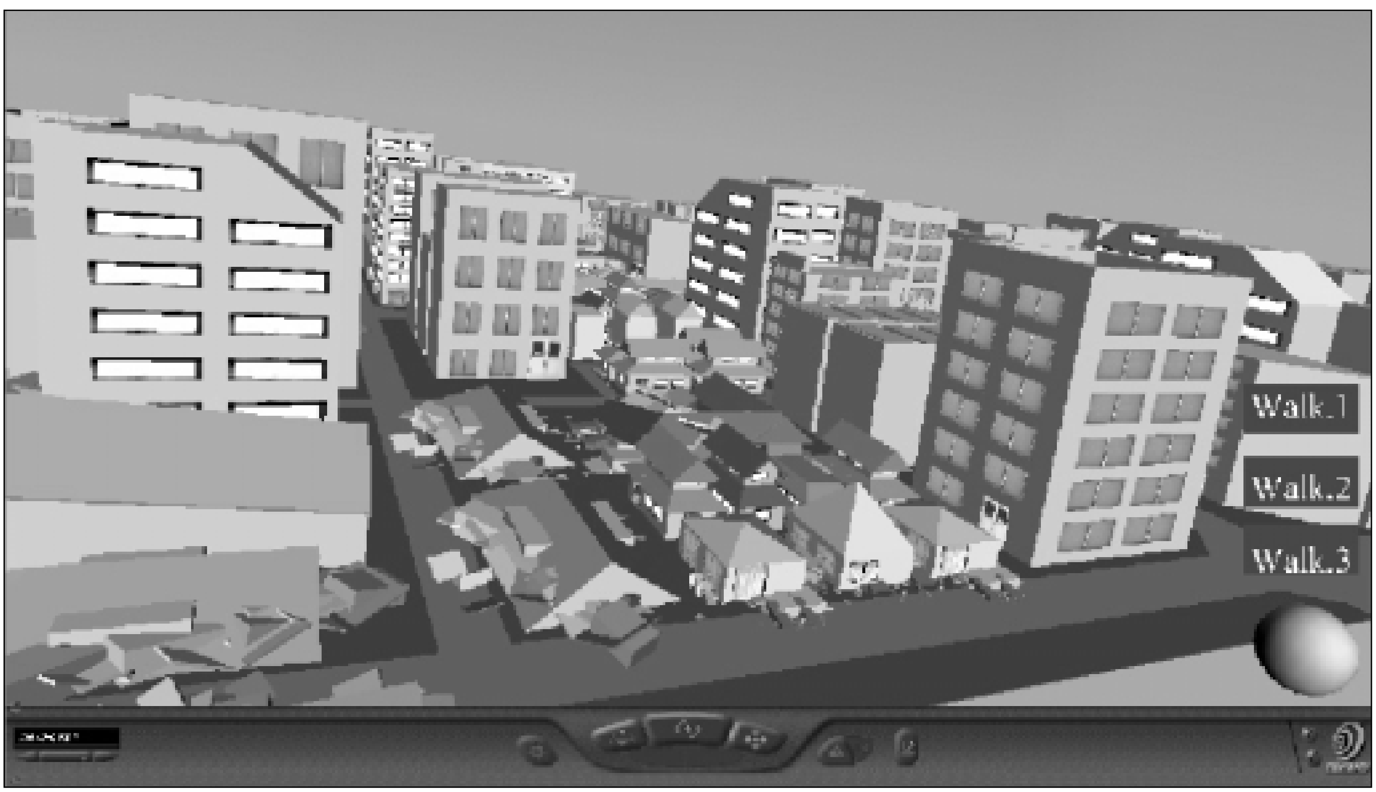

Figure 5. A Simulator View of Collapsed Houses.

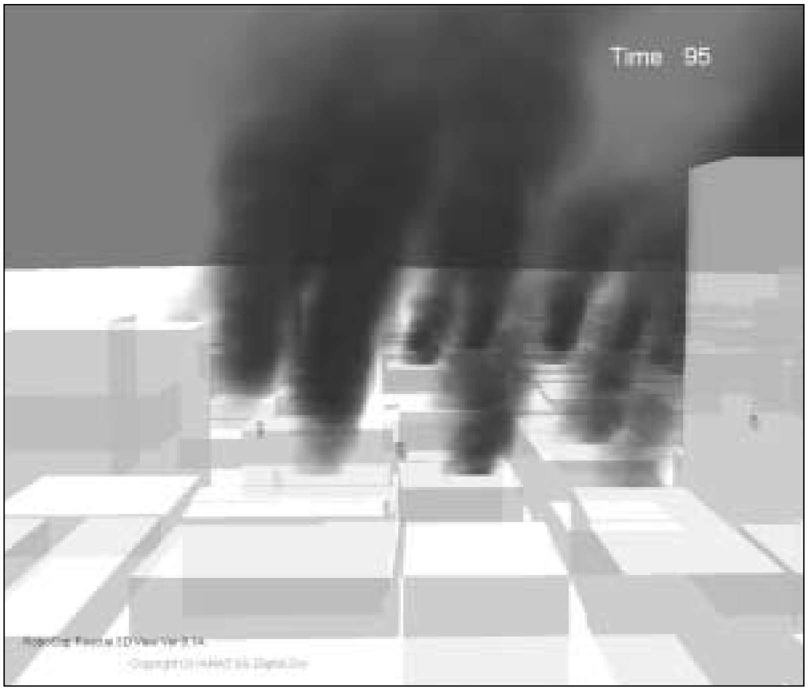

Figure 6. A Three-Dimensional Situation Monitor View.

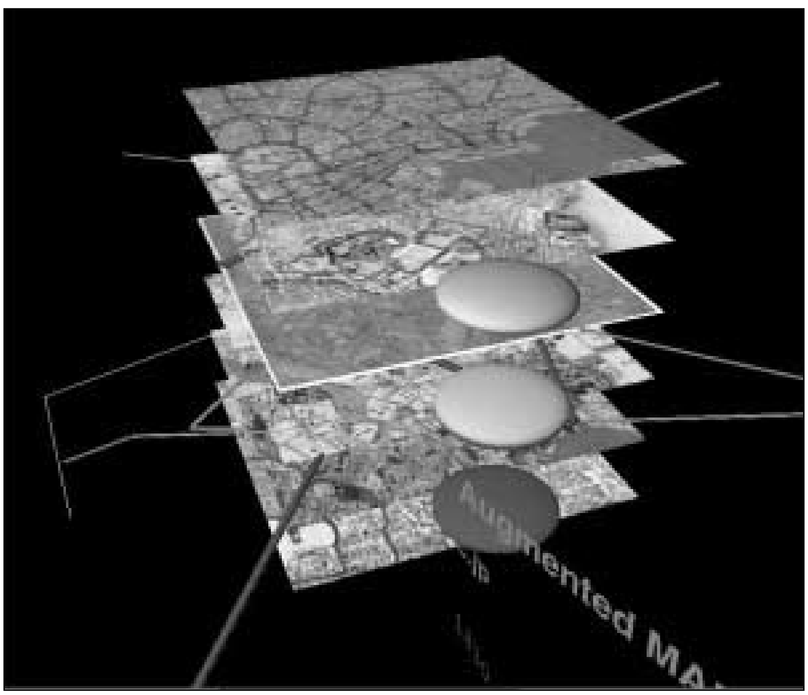

Figure 7. A Layered Display of Complex Disaster Information.

mance rating than the existing module, it will be possible for a better module to replace an existing module, so that the simulator systems are always at their best configuration.

The important issue is to make resources open and available to researchers, so that anyone who wants to participate can make their contribution from any of a number of aspects. Thus, it is important that protocols and the overall architecture are well agreed on at the start and improved on based on ongoing discussions and the developmental progress of the technologies.

Industrial sectors can contribute by providing the way in which their systems can be connected to the simulator, as well as making their codes available, so that the RoboCup Rescue simulator can be the hub of all rescue-related modules. In the long term, companies will be able to make sure that their products are consistent with the de facto open standard for all the disaster-rescue simulation and decision-support systems. Already, there are local governments (mostly in Japan for now) that are working on rescue strategy and urban planning using the RoboCup Rescue simulator.

Search-and-Rescue Strategy

Finding out the best search-and-rescue strategies for large-scale disasters involves state-of-the-art planning and multiagent research, such as teamwork (Tambe and Zhang 1998), planning under uncertainty (Pollack and Zhang 1998), resource boundedness (Russel 1995), hierarchical planning (Kambhampati et al. 1998), and real-time planning.

Just like the RoboCup Soccer simulation league, the RoboCup Rescue simulation project provides a simulator and a set of scenario so that researchers interested in rescue strategy will be able to investigate and evaluate their approach. In conjunction with several government sectors, researchers who are interested in disaster simulation efforts will provide realistic scenarios of disasters for a few cities in the world to those who are interested in rescue operations. Any number of researchers can work on the same scenario to compare the advantages and disadvantages of each rescue strategy.

There are a number of issues to be investigated. Although we cannot possibly create an exhaustive list of research issues, the following major issues can be addressed.

Multiagent Planning

This domain can involve planning and execution monitoring for more than 10,000 agents with different physical and informational capabilities under a dynamically changing hostile environment. Planners can work in several ways: First, they can coordinate global strategy with several subordinate planners. Flexible hierarchical planning is essential to achieving large-scale planning. Second, planning is done in a distributed manner because disaster sites are typically spread over wide areas, and communication between them is limited. Each local planning system, however, must communicate with the other planners, and the global planner must synchronize activities and update the status to achieve an optimal strategy. Third, contrary to the notion of a global planning system, there is a need to establish technologies that effect totally distributed and asynchronous planning when no clear global planning center exists, or the expected global planning site is destroyed. Whether the most efficient strategy planning can be achieved by global planning with subordinate planners or totally distributed planning is a major research issue. The entire planning system needs to be flexible enough to dynamically reformulate the planning strategy from distributed planning to hierarchical planning and vice versa.

In addition, the agents involved are heterogeneous. There are rescue people and robots, helicopters and airplanes, ground-based vehicles, and other autonomous and nonautonomous agents.

Real-Time–Anytime Planning

Quite obviously, the need for planning under real-time constraints is critical in this domain, given that the situation can change quickly and often for the worse. Coming up with a good plan as quickly as possible might not be good enough—in this case, a plan agent should be able to provide a plan on demand.

Heterogeneous Agent

The planner should be able to recognize the capability of each agent and coordinate them to accomplish certain tasks. It might often be the case that the capability necessary is missing in the agents available on site. The planner should be able to access the potential availability of missing features and request that the capability be added to the agent or that new agents be added to the team.

Robust Planning

Much of the information available to agents and decision makers during a disaster can be incorrect, partial, and essentially unreliable. Planning systems should be able to assess the reliability of information and cope with possible errors. A feature that enables the planner to actively request information gathering would be critical. Not only information but also actual agents can be involved in accidents or disabled for various reasons. In addition, because of unexpected hardships at the site of a disaster, it is not always guaranteed that plans dispatched to agents will be executed. There must be ways of coping with the range of uncertainty and be able to replan and execute in real time.

Mixed-Initiative Planning

Many times, the human rescuers will make their own decisions and execute a search-and-rescue plan that is not necessarily consistent with that of the planner. The planner must cope with such a complex situation and negotiate to find the best solution. At the same time, if actions taken by human rescue personnel that are inconsistent with the planner worked well, certain learning and archival capabilities can transfer such successful actions to other sites.

Execution Monitoring

In such a hostile environment, it is not at all guaranteed that commands and operators dispatched from the planner will be executed as expected. The major questions to address are (1) how to gather information on the status of plan execution, (2) how to cope with the disruption of communication, and (3) how to deal with misinformation when personnel on site are given incorrect information. This issue of execution monitoring is tightly coupled with robust planning.

Scenario-Based Planning

It is totally inconceivable that we would be completely prepared for disasters. There are a number of search-and-rescue scenarios and doctrines, just like in military planning. There are political and social decisions that are not easily incorporated into automated planning, and rescue strategies devised by responsible officers need to be accommodated. Thus, planners must be able to use a given set of plan scenarios as well as create their own plan.

Resource-Bounded Planning

Search-and-rescue operations are always constrained by resources, such as materials, personnel, and time. For example, the number of robots and personnel that can arrive at a specific site within a given time limit, is seriously limited by traffic, fatigue, and available agents. The planner must be able to take into account such constraints and possibly propose plans to mitigate such constraints and still maintain long-range strategies.

Finding out the best search-and-rescue strategies for large-scale disasters involves state-of-the-art planning and multiagent research, such as teamwork, planning under uncertainty, resource boundedness, hierarchical planning, and real-time planning.

Data-Collection Agents and Planning

One of the major problems in a disaster is, as repeated many times already, the difficulty in getting accurate information in a reasonable amount of time. There is a need for explicit planning and a specific agent for data collection, which is tied to other agents and planners, so that the necessary information can be obtained faster and more reliably. This issue is totally open and has not yet been investigated.

Robotics and Infrastructure Project

The robotics and infrastructure project focuses on the development of robots, digital assistants, and infrastructures to enhance search-and-rescue operations with AI, robotics, and information technologies.

The most important task in search and rescue is to find victims under the debris. Unless we identify the location of victims, rescue operations cannot take place. Thus, the initial emphasis of the project might focus on, although not exclusively, establishing the technologies for highly effective and practical systems for victim search. Concurrently, effort will be made to achieve robotic systems that work with human rescue personnel to rescue victims at the disaster site.

The most important task in search and rescue is to find victims under the debris.

In either situation, robots need to work together as a multiagent robotics team as well as with human rescue personnel and commanders. Assuming that robots, digital devices, and human rescue personnel are all treated as agents, we have a massive multiagent robotics problem. Various kinds of robot can be used and form teams at various levels. Some robots might be very small, and hundreds of them will be deployed to go into small spaces within the debris to find victims. Other robots might be big, with a human on board to remove debris so that victims can be rescued.

At the time of a disaster, person-power is at an absolute shortage. It is not feasible that two or more persons are needed to operate one robot at the disaster site unless the robot is extremely efficient for victim search. It is preferred that multiple robots be operated by one person; thus, robots must have an adjustable level of autonomy. Robots should have autonomy because they can search for victims without human help. However, it should be realized that a disaster site is very complex, and it would be difficult to build fully autonomous systems that can accomplish a task without any human intervention. Also, rescue officials would generally resist technologies that were not battle proven. Although efforts to improve the level of autonomy will continue, it would be better if we provided technologies with an adjustable level of autonomy, so that systems can be used as teleoperation systems when autonomous systems are yet technically infeasible. With the advancement of technologies, the system can gradually increase the level of autonomy when judged appropriate.

Another issue for rescue robots is that in many cases, they will have to be used for other purposes as well. Disasters do not always take place. Having dedicated robots and intelligent systems only for disasters that might happen only once in 30 years is not practical from an engineering or an economic point of view. Of course, certain numbers of robots can be specially designed for rescue and used for fire and other small-scale disasters that happen more frequently. The system has to be used in daily life so that it is justified economically, and we can be sure that it will be functional at the time of the disaster.

AI and robotics can contribute to the search-and-rescue problem in a number of different areas. With reference to actual robots and PDAs, rather than high-level planning, mechanical aspects of robots, the robots' physical performance, and concrete multirobot collaboration must be investigated. The following issues, among many, need to be addressed:

First are robust robot systems that can go into disaster sites, which means moving around on an uneven surface and in a hostile environment.

Second are multiple sensing systems with flexible configurations, so that sensors can be placed and extended into debris to capture signs of victims. This task can be accomplished not only by single robots but also by multirobot teams. Intelligent systems are also needed to automatically, or semiautomatically, carry out sensor placements and self-positioning.

Third are multiple-robot systems that can collaborate as a team with human personnel to rescue victims. Such robots should work together to remove debris, so that elaborate planning and communication are unnecessary.

Fourth is a human-robot interface that enables rescue personnel to control a team of robots for more effective operations.

Fifth is an interface with strategic planning systems to coordinate local operations with global operations.

Most of these issues are still open problems for AI and robotics; thus, this domain is a rich source of inspiration that can promote not only rescue-related robotics and AI but also more general technologies. Already, there is

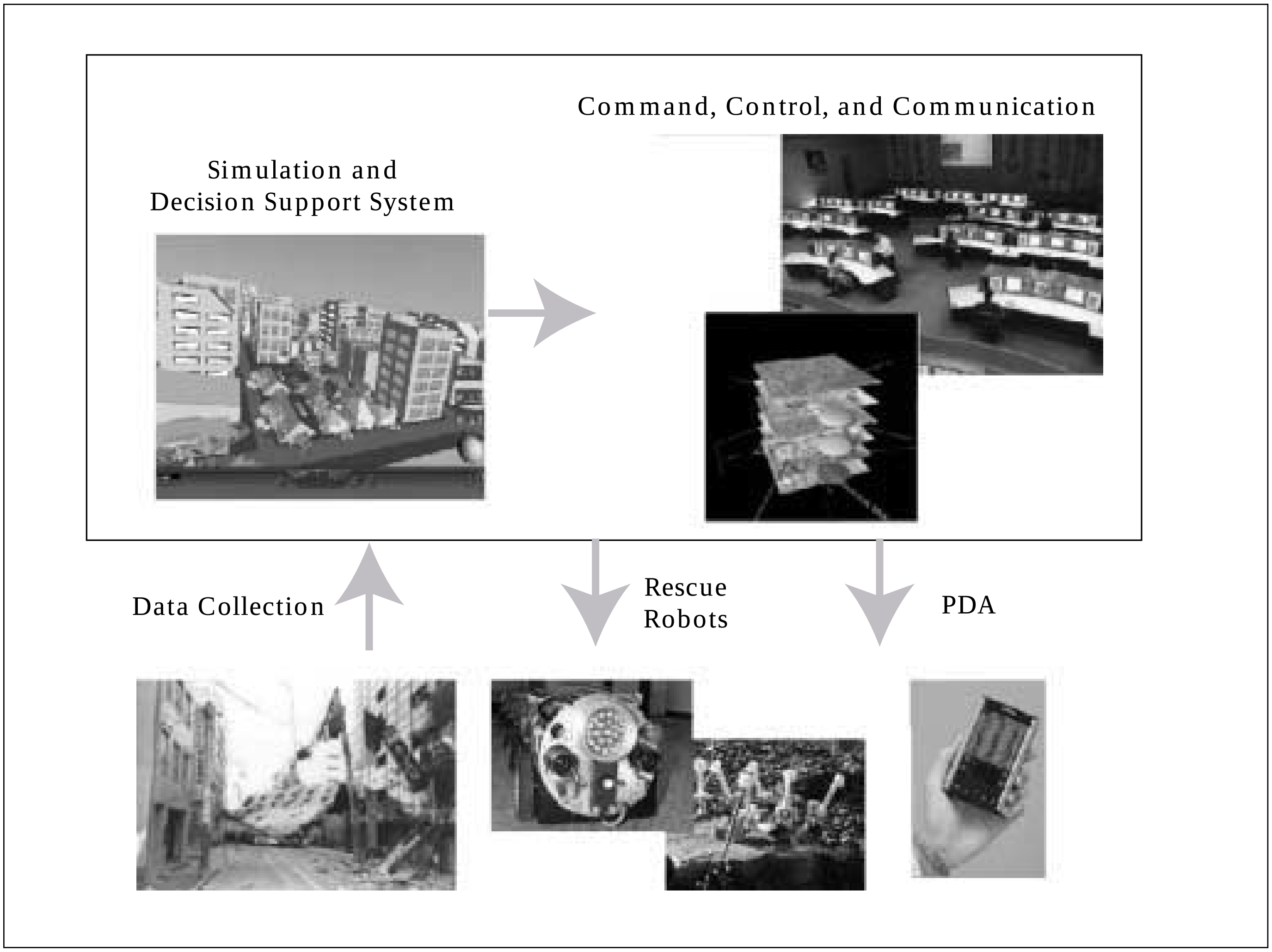

Figure 8. Integrated System.

some pioneering research in this area (Murphy et al. 2000). Some robots and multiple-robot teams that have been developed for other purposes, including multisegment robots for pipe inspections at GMD (Scholl et al. 1999), can be applied for rescue purposes.

Integration

The integration of simulation, information infrastructure, and robotics systems is the ultimate technical goal of the project. Figure 8 gives an abstract view of how this integration will take place. The challenges are to (1) interface with real-world sensors and reports to determine the situation at the disaster site, (2) represent such information in the simulation, (3) transmit information to PDAs and other devices in the appropriate way for persons on site, and (4) produce commands and instructions for robots and their operators at an adjustable level of autonomy.

Although it is too early to discuss full-scale deployment, many interesting research issues involve man-machine interaction at various levels as well as information representation and sensing.

Evaluation Sessions

A series of evaluation sessions can be organized to measure the performance of various approaches. Although the theme of the research is life and death, it is not appropriate to organize evaluation sessions as entertainment events, as with RoboCup Soccer. Nevertheless, certain forms of competition would be useful to evaluate overall characteristics of the various approaches and promote technological development.

In the simulation project, evaluations for rescue strategies can be made on the basis of the number of lives saved and the amount of property damage prevented. Figures 9 and 10 show evaluation results for two teams (TRIDENT

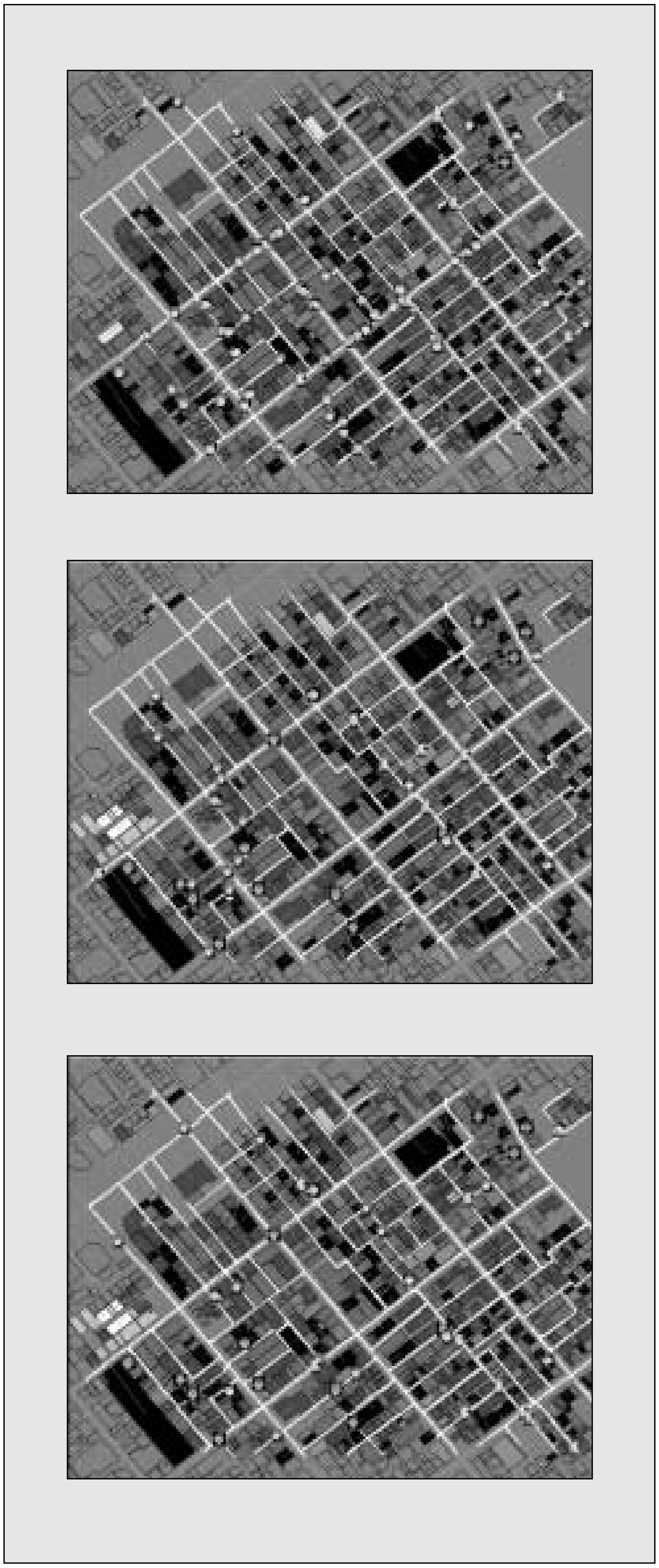

Figure 9. Snapshot from a RoboCup-2000 Rescue Simulator Demonstration—Successful Fire Fighting Rescue Operation.

Top: Onset. *Middle:* 160 min. *Bottom:* 300 min.
(Courtesy of Milind Tambe, ISI/USC)

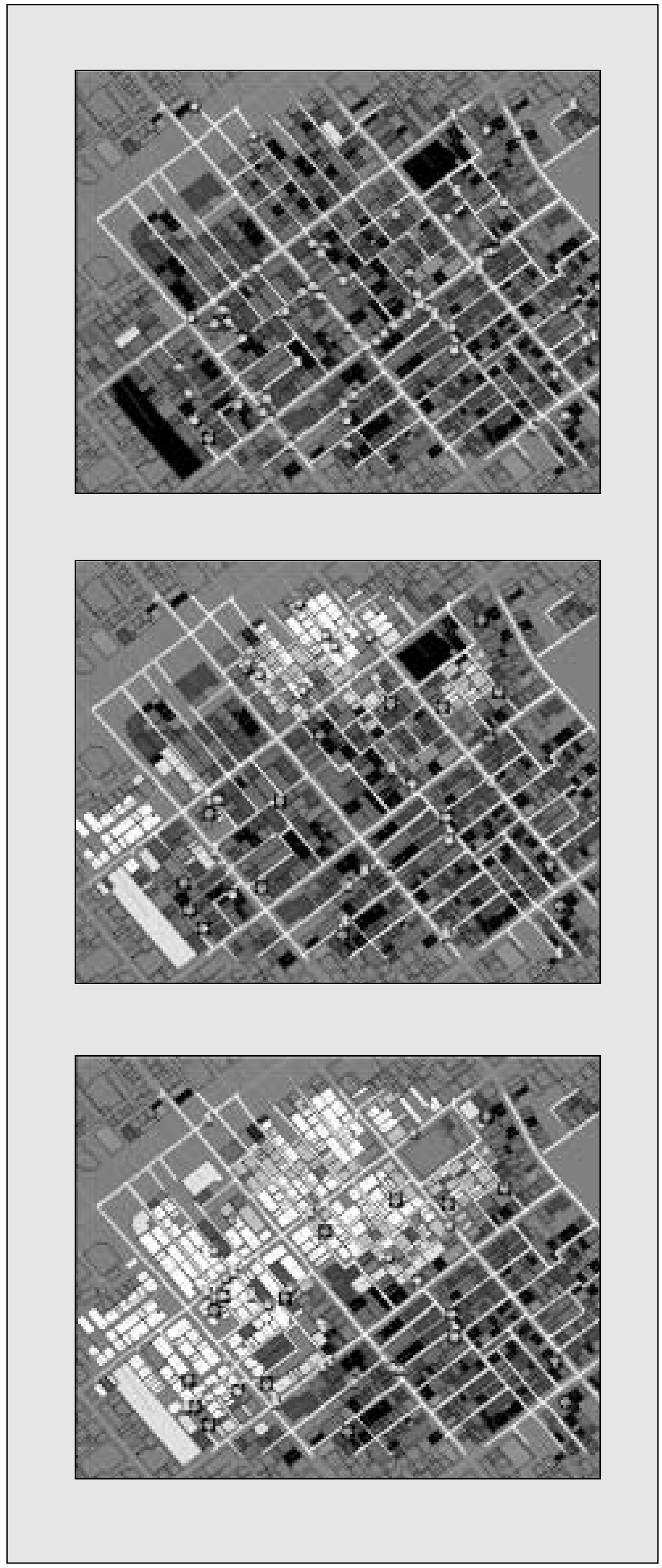

Figure 10. Snapshot from a RoboCup-2000 Rescue Simulator Demonstration—Unsuccessful Fire Fighting Rescue Operation.

Top: Onset. *Middle:* 160 min. *Bottom:* 300 min.
(Courtesy of Milind Tambe, ISI/USC)

team from University of Southern California Information Sciences Institute and the team from the Nagoya Institute of Technology) for small-scale fire-fighting simulation using actual data from the Kobe earthquake (Nair et al. 2000). In addition, the accuracy of specific simulation submodules can be evaluated and always upgraded to the best-available module.

In the robotics and infrastructure project, evaluation for search-and-rescue systems can be done by locating numbers of victims (faked or actual human) under the simulated debris and measuring the accuracy and speed of finding these victims under the debris with no or minimum visual contact. The evaluation can be extended to measure the speed of pulling victims from the debris and sending them to a designated first-aid station. This time, the level of physical damage to the victims can be evaluated using sensors attached to the simulated victims. Currently, the RoboCup Rescue technical committee is working with the National Institute of Standards and the American Association for Artificial Intelligence (AAAI) to define the simulated debris field used in the competitive evaluation at the RoboCup/AAAI Rescue Robot Competition to take place at RoboCup-2001 in Seattle, Washington, in conjunction with the Seventeenth International Joint Conference on Artificial Intelligence (Murphy, Casper, and Micire 2000). This field was already used at the Twelfth National Conference on Artificial Intelligence (AAAI-2000) rescue robot competition (figure 11).

Conclusion

In this article, we described RoboCup Rescue as the grand challenge project for RoboCup. The basic motivation behind the project is the sense of obligation as scientists and engineering researchers in AI and robotics to help mitigate the suffering of people from disasters. It is also consistent with RoboCup's initial intention to apply technologies developed through RoboCup Soccer to serious social problems. It is designed to ensure the smooth transfer of technologies developed in RoboCup Soccer as well as promote innovation as it complements features missing in soccer. RoboCup Rescue has both simulation and real robot aspects, each of which initially focus on different areas of the overall activity. As was clearly illustrated, RoboCup Rescue is a rich source of research, and direct contribution to society is expected. For further information, please visit www.robocup.org/rescue/ as well as the mailing list r-resc@isi.edu.

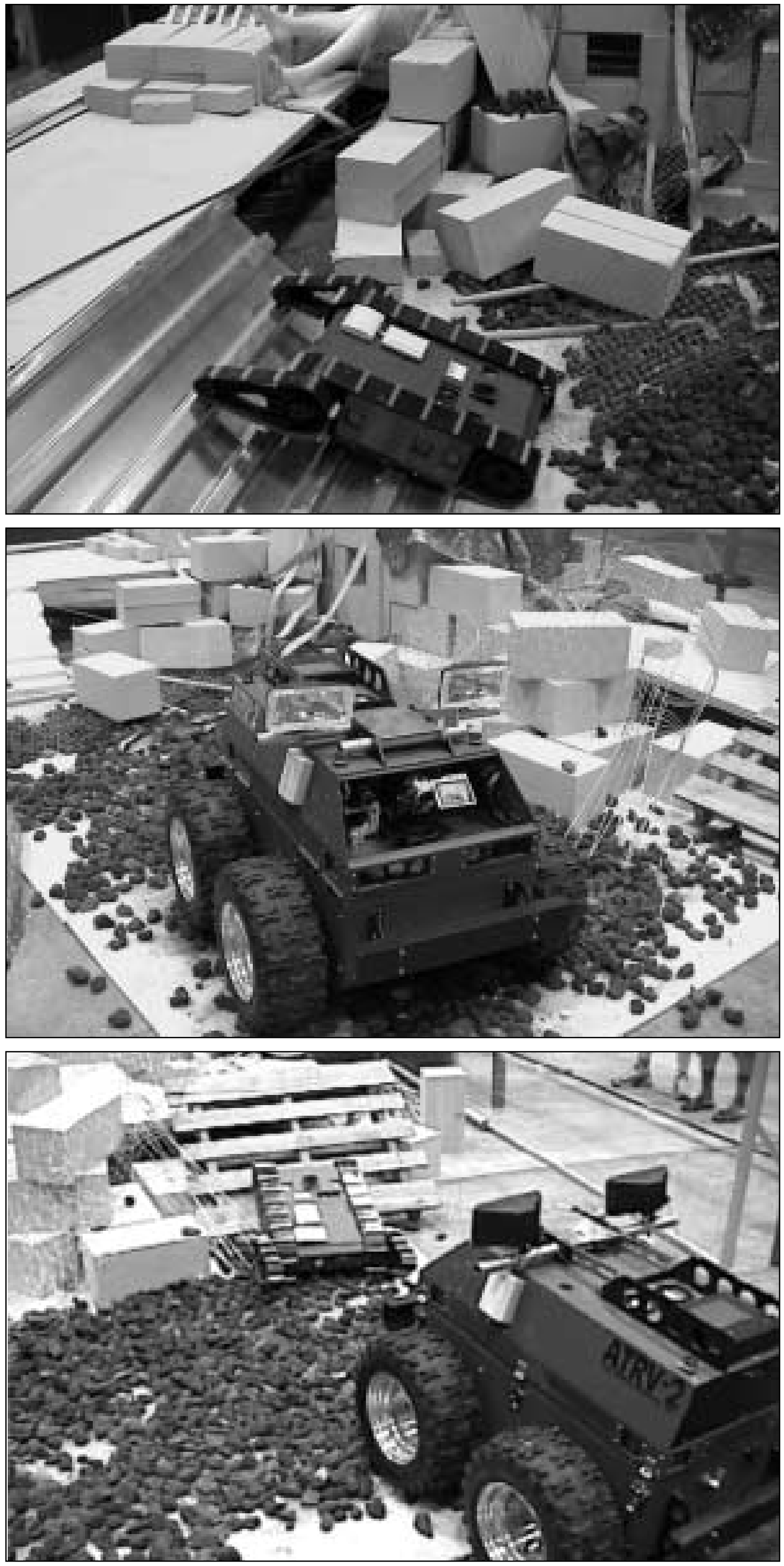

Figure 11. Rescue Robot Evaluation.

National Institute of Standards test-bed red zone: Scenes from AAAI-2000 rescue robot competition. *Photo courtesy of William Adams (NRL), Alan Schultz (NRL), and Robin Murphy (USF).*

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