Crisis Management

Distributed Coordination of First Responders

In a disaster scenario, first responders must be able to perform multiple functions in a coordinated way. At all levels of the task — from integrating heterogeneous systems to addressing response tasks and allocating resources — responders must be able to make decisions in a globally optimal fashion. Automated coordination mechanisms can help, but they still face several challenges that researchers must address to make them effective and useful. This article discusses the application of distributed constraint optimization in disaster management coordination.

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Coordination among emergency personnel and organizations is a critical factor in the successful management of any natural or man-made disaster – tasks must be assigned, food, medical, shelter space, and other resources distributed, shared radio frequencies negotiated, and so on. Effective coordination ensures that these efforts aren't duplicated and that all available resources, including time, are used well. Unfortunately, accomplishing this at a large scale in the heat of the moment is difficult at best, meaning that first responders generally rely on manual problem solving and communication over unreliable and limited analog voice radios. Automated, networked systems could offer a much needed capability to augment human decision making and enable better coordination in managing disaster scenarios.

Most of the decision making in a disaster scenario involves the fundamental problem of propagating and then solving systems of constraints. Figure 1 shows an example scenario, in which groups of evacuees seek shelter during a crisis. These different-sized groups require either basic first aid or advanced trauma care, yet the shelters in the area have finite capacities and might not provide all the necessary medical services. Thus, the constraints in this example include size, capacity, medical requirements and capabilities, and location.

Even in this simple setting, we can

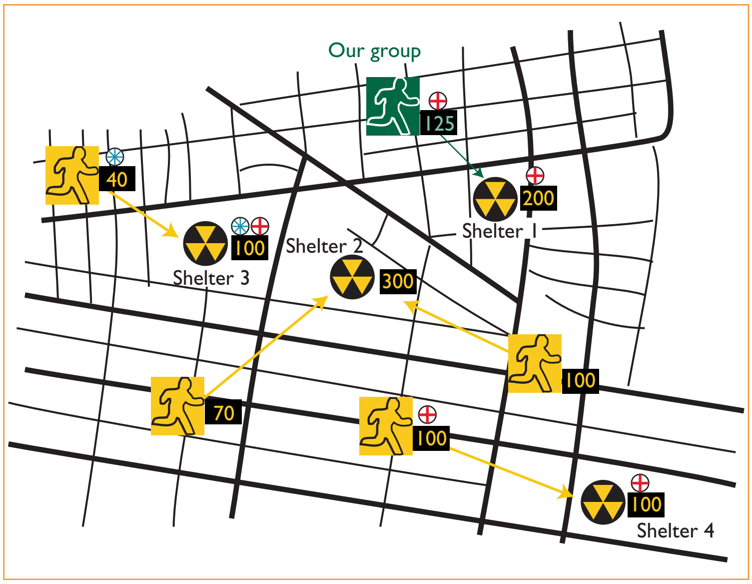

Figure 1. Disaster scenario. Each walking figure represents a group of evacuees seeking shelter, with icons indicating their required basic first aid or advanced trauma care and the corresponding shelter-provided capabilities.

see a great need to coordinate decisions and avoid wasting medical resources while getting the groups to shelters (without overcrowding them) as quickly as possible. This task is difficult for human decision makers to manage, especially if they act independently, but we could easily and naturally represent it as a constraint-optimization problem and solve it with computerized techniques. In this scenario, area wardens and first responders would use handheld wireless devices to report their requirements, such as group size and medical needs. An automated constraint solver would then use this input to guide each group to the appropriate shelter. These shelter assignments would provide an optimal, coordinated plan for the entire scenario, rather than requiring evacuees to rely on decisions made based on locally available information.

In a disaster setting, however, many of the standard assumptions in constraint optimization simply don't apply. In particular, it's unlikely that first responders could deploy high-performance centralized servers to conduct this optimization in a timely fashion, given their other responsibilities. Similarly, network infrastructure is unlikely to be sufficient to collect all inputs at one location, solve the problem, and then disseminate the results. Fortunately, distributed constraint optimization (DCOP) addresses these problems, among others.[1–3] Under the DCOP approach, agents exchange portions of their constraints or preferences and go through rounds of determining, sharing, and refining partial solutions in a completely decentralized fashion. Eventually, the agents' partial solutions converge into a globally optimal solution.

To experiment with this approach, we implemented Evac-Op,[4] a notional application for the sheltering scenario. The software runs on tablet and handheld computers over an ad hoc, wireless network and is deployed to the first responders leading evacuation groups. Evac-Op provides a dynamic map displaying the area and any available updates, minimal text messaging functionality, and an interface to input group size and medical requirements. A software agent uses this information to represent the group in the DCOP process. Once a solution is determined, the agent informs its group leader of the assigned shelter and general direction of travel.

Evac-Op's DCOP solving is performed by DCOPOLIS, a framework we developed for benchmarking and comparing DCOP algorithms. DCOPOLIS is publicly available at http://dcopolis.sourceforge.net and has been used to conduct some of the first uniform tests analyzing DCOP algorithms in practice.[5] Evac-Op is also the first implementation of DCOP algorithms on live wireless networks, as well as one of few real-world DCOP applications in development. Using this application and framework, we've begun to explore the edges of current DCOP research and investigate the future research necessary for applying DCOP to real problems.

Due to its decentralization, efficient utilization of cheap mobile computational resources, and limited bandwidth consumption, the DCOP approach fits naturally with the coordinated decision making required in disaster management. Deploying such systems will require further research on applying DCOP to dynamic environments, adapting it to network topology and characteristics, and increasing its robustness. However, promising applications such as those that improve coordination among first responders are certain to continue driving this work.

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Pragnesh J. Modi passed away earlier this year after making several contributions to artificial intelligence, especially in the field of distributed constraint optimization. He was a much loved professor, mentor, and friend.

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