ARK Team Description: A Change-based Approach to Urban Rescue

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Abstract

In a dynamic environment like RoboCup Rescue Simulation System, agents can benefit from a change-based representation and reasoning framework. As agents sense and discover properties in the world, these discoveries are confined to a limited space surrounding the agent at any point in time. As the agents move and communicate, a more complete world model emerges. A theory of change can help the agents in progressing and updating their beliefs about the world over time. The change framework that we explore in this work uses clustering to abstract uniform spatial regions. These abstractions seem useful in assigning tasks to agents, and in estimating the size of fires. Moreover, a messaging technique is used to reduce overall traffic while keeping agents informed.

1. Introduction

The RoboCup rescue simulation environment is a dynamic multi-agent environment that simulates urban rescue operations following an earthquake. The environment changes continuously and significantly following the earthquake as buildings crumble, fires erupt and roads become blocked with debris. Search and rescue agents representing of police brigades, fire fighters, and ambulance teams have to navigate their way around the city trying to save life and limiting the further spread of fires and damages to property.

Some properties remain unchanged throughout the simulation like the location of the roads and the unique identifiers assigned to individual agents. However, many other properties change during the simulation. The rate of change of properties differs from some sudden changes to more gradual ones. A building may suddenly collapse following the earthquake or an aftershock whereas a building next to a fire might heat up at first and then start burning, before gradually becoming severely burned or totally burnt out.

Therefore, it is important that fire fighters attend to fires as soon as possible. However, movement around the city is difficult as roads are blocked with debris and the police cruisers are assigned the duty of clearing the roads. Agents can move on clear or partly clear roads. As they move around, agents can collect information about injured civilians trapped in broken buildings, fires erupting in the agent's vicinity and the state of the roads. Each agent has a map to record states and can communicate its findings to a central office or co-workers.

The fundamental notion in our approach is that agents can be more effective if they can take into consideration possible changes in the world as they make their decisions and act in the environment. The importance of representing time and reasoning about change has propelled research in this area over the last two decades. The surveys by Chittaro and Montanari (2000) and Vila (1994) present important trends in this area. More recently, a new focus on representing change over space and time has emerged (Cohn and Hazarika, 2001). McCarthy (2003) considers the representation of change, in particular continuous change, one of the challenges for computer science in the next decades.

In this paper, we discuss some aspects of change in the urban rescue environment and present some initial results. Section 2 presents some aspects of change in the RoboCup rescue simulation environment. Section 3 discusses the impact of change on agent behavior. Section 4 presents agent belief update and the messaging protocol used. Initial results are reported in Section 5 followed by the conclusion in Section 6.

2. Aspects of Change in the Urban Rescue Environment

The RoboCup Rescue Simulation System (RCRSS) incorporates discrete change as well as continuous change. Some changes are persistent and others are transient. Some changes are controlled while others are spontaneous. The following list details some aspects of change in RCRSS.

- Building collapses: The collapse simulator module simulates the damage to buildings following the earthquake or aftershocks. Damages are persistent and their time of occurrence is discrete.
- Fires: Fires erupt following the earthquake at a number of points throughout the city. Fires spread gradually. The spread of fires from one building to adjacent building depends on the size of the fire, the properties of the buildings and the number of fire brigades fighting the fire. If the fire is small, one fire brigade may be able to extinguish it. For bigger fires, a number of fire brigades may be necessary to control it or put it out. Here we assume a continuous time spreading rate for any reported fire. We also assume that fires persist until the fire brigades extinguish them.
- Blockades: Roads are blocked by the debris after the earthquake. Police agents can clear the roads. A road does not have to be completely clean to be passable. A blocked road remains blocked until it is cleared by police.

- Agent parameters: Agents possess some parameters that are also changing. The ability of an agent to move around depends on the state of surrounding roads and should improve with time as police crews clear the roads. Moreover, the traveling distance/time between two points may become shorter as more roads are cleared. The health state of injured civilians can deteriorate with time. This steady deterioration may lead to the death of a civilian if not rescued promptly by an ambulance team.

3. Change-Aware Agents

To make the agents change-aware, it is necessary that agents receive frequent updates reflecting changes that take place in their environment. However, it is impossible to acquire information about changes in the system every cycle. In fact, the communications and mobility constraints imposed on agents make it difficult to acquire the sensory data necessary to monitor any significant subset of entities in the system. For this reason, we adopt belief-based change method that allows agents to progress available information over time until updated sensory reading is available to agent by sensing the environment or through communications. In particular, changes about the spreading of fires, the health state of injured civilians, and the clearing of roads are crucial to effective operation of rescue agents.

- Spreading fire: To model the spread of fires, agents receive some initial information about the location of a fire (its center) and its size (radius or boundaries). The agents progress this information by assuming that the fire is spreading over time. The assumed radius of the fire is increased at regular intervals. The rate of spreading of the fire takes into account the average number of fire brigade per reported fire. The fire center is responsible for assessing the center and size of all fires. The center uses k-means clustering to assess these quantities. The problem with the k-means clustering algorithm is that it is too slow. Pelleg and Moore (1999) propose a faster algorithm for exact k-means clustering. However, as the number of clusters is not known before hand, it is necessary to test different values of k (the number of clusters) to determine an optimal clustering. This is time consuming even with a faster algorithm. Alternatively, we can use a clustering algorithm that does not depend on a predetermined number of clusters like hierarchical clustering. Regardless of the choice of the clustering algorithm, clustering has to be performed infrequently to maintain the system responsiveness.
- Deteriorating health: An injured civilian agent reports its health status to the rescue agent that finds it. If the agent is not in position to rescue it, the location of the injured civilian and the health status are reported to a central office. Agents responsible for rescuing the civilian will account for the deterioration of the health of the injured civilian over time as they prioritize the rescue efforts.

- Changing road conditions: The priority function the police officers follow is dependant upon the attributes of the roads to be cleared. Roads leading to a refuge are important to make it possible for civilians to reach the refuge. Since blockades on route to buildings on fire can prevent the fire brigades from reaching their destination, these roads must be given some priority. Also, roads leading to areas where injured civilians are located have a high priority. In addition, fire trucks run out of water and it is important to clear the roads leading to water supplies. Knowing the priority roads will allow other agents to guess the status of some roads over time. This may help them with their route planning.

4. Belief update

Each agent receives a message from its center that summarizes the important new information about the world for the agent. The agent uses the new information to update its beliefs and fills in missing data using default change assumptions like the ones introduced in the previous section. The agent sends to its central office information about new fires, previously unknown blockades and newly discovered injured civilians. For example, a police force agent on its way to clear a road hears a civilian cry. Instead of completely ignoring what it heard, it would increase the efficiency of the ambulance teams if the police force can somehow transmit what it heard to them.

The following messaging protocol is adopted:

- An injured civilian asks for help by saying help followed by its ID, position, health point, damage, and buriedness.
- Similarly, information about small fires and discovered road blockades can be reported to center agents.
- Large fires can be sensed from a far distance and need not be reported as most agents can figure this out. In general, information that the agents can sense is not sent.
- Central offices exchange information with one another and then prepare and send a broadcast message containing information relevant to their affiliated agents.

Agents merge their sensory information and information received from their central office to update their maps (or world model). This update procedure is nonmonotonic. Agents will retract assumption based assertions if they conflict with sensory or communicated observations. This process of continuous belief update will help agents act in a sensible way in this complex environment.

5. Implementation and Results

The rescue agents are implemented in Java using the YabAPI package (Morimoto 2002). The agents as implemented at the time of this writing are not fully change aware. Ambulance agents are aware that the health of injured civilians deteriorates with time. However, the clustering of fires necessary to abstract fire representation and make it possible for agent to estimate its spreading is not integrated in the current implementation. We have tested a straight forward implementation of the k-means clustering algorithms and the results are good yet the algorithm is too slow. In the current implementation central offices dispatch agents to specific tasks. However, free agents maintain a prioritized task list that they try to accomplish when they are not assigned a different task. Ambulance agents maintain a list of injured civilians, fire agents maintain a list of fires, and police agents maintain a list of priority roads.

The priorities assigned to different tasks change over time. For example, roads leading to the water supply for fire trucks gains priority when the police agent estimates that fire trucks will soon need water. Similarly, an ambulance agent will assign a lower priority to an injured civilian in a far location that is not likely to be reached before the civilian dies.

The results reported here for the "improved" implementation are based on a version that allows the police agents to use a different cost function when calculating a route to a certain destination to ensure that the police clears the shortest route to a destination. This, together with the frequent belief updates, enable the police to clear the roads with greater efficiency. Combined with the messaging system between the police and the fire brigades, the police can clear the route that fire brigades path with high speed.

For comparison purpose, we are reporting here the performance of our agents before and after the improvement described above. Also reported are the results for the sample agents provided with the simulation environment. The sample agents are based on the YabAI team agents (Morimoto, Kono and Takeuchi 2001). Each curve shown in Figures 1 to 6 represents the average of five simulation runs for each of the three sets of agents. Figures 1-3 report results for the map of Kobe and Figures 4-6 report results for the map of the Virtual City.

Figures 1 and 4 show that the sample agents did slightly better than our improved agents in terms of agent survival. Figure 2 shows that our improved agents have been more successful in fighting fire in Kobe while Figure 5 indicates that the sample agents outperformed them by a small margin in the Virtual City.

Throughout the simulation, our agents kept more roads 100% clear in Kobe than the sample agents (Figure 3). This is not necessarily of great advantage because roads that are 50% clear or 25% clear are usable. For the Virtual City, Figure 6 shows the change in the number of roads that are 25% cleared over time. From the figure, it is clear that the sample agents focused on making as many roads as possible clear resulting in a continuous increase of roads that are 25% blocked. Our initial implementation tried to clear the roads that are 25% blocked resulting in their decrease. Meanwhile, our improved agents focused on clearing roads that are 100% blocked leaving the number of roads that are 25% blocked nearly constant.

From the figures, it is clear that the performance of the improved agents is comparable to that of the sample agents. These initial results are encouraging and we expect to implement fully change aware agents along with other improvements for the 2004 competition.

While the reported results do not include statistics on messages exchanged, we believe that a high degree of coordination can be achieved with limited communications if the agents can reason about the goals and needs of other agents. Under similar conditions Fenster at al. (1995) shows successful coordination without any communication. Arkin (1992) demonstrates the efficiency of multi-agent schema-based navigation for object retrieval without communication

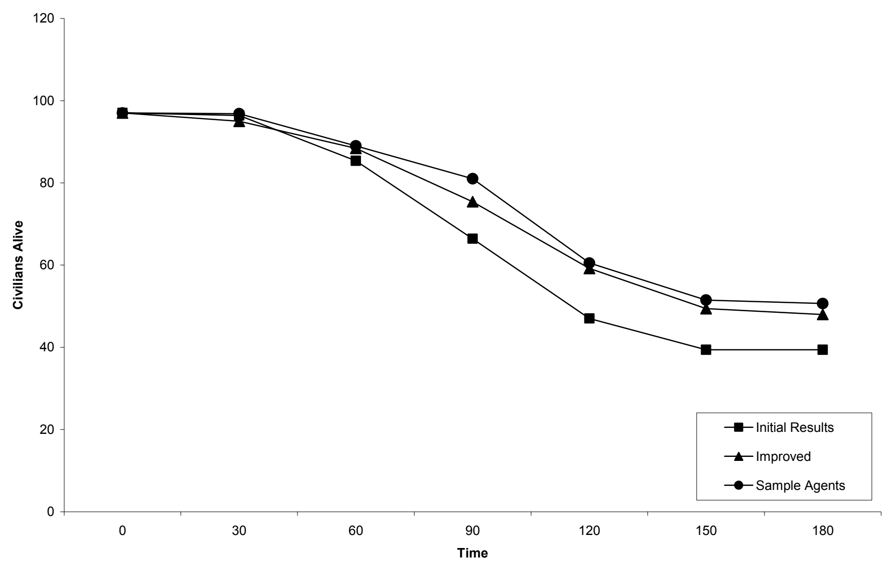

Figure. Civilians Alive in Kobe

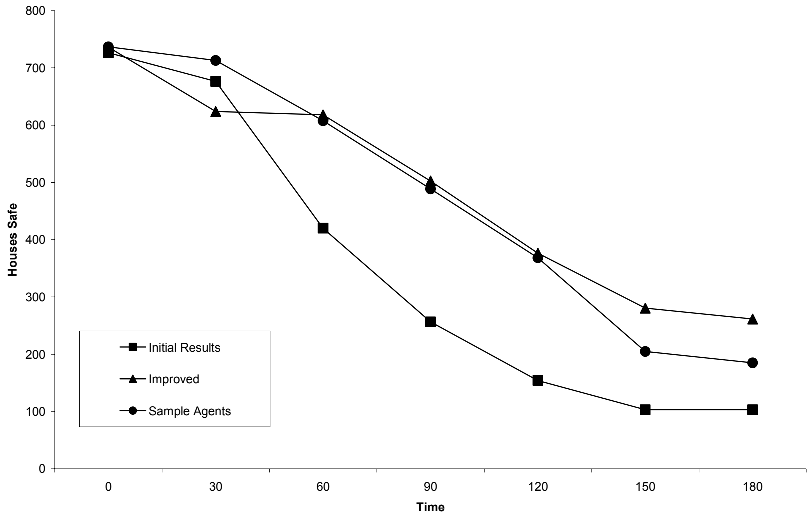

Figure 1. Safe Buildings in Kobe

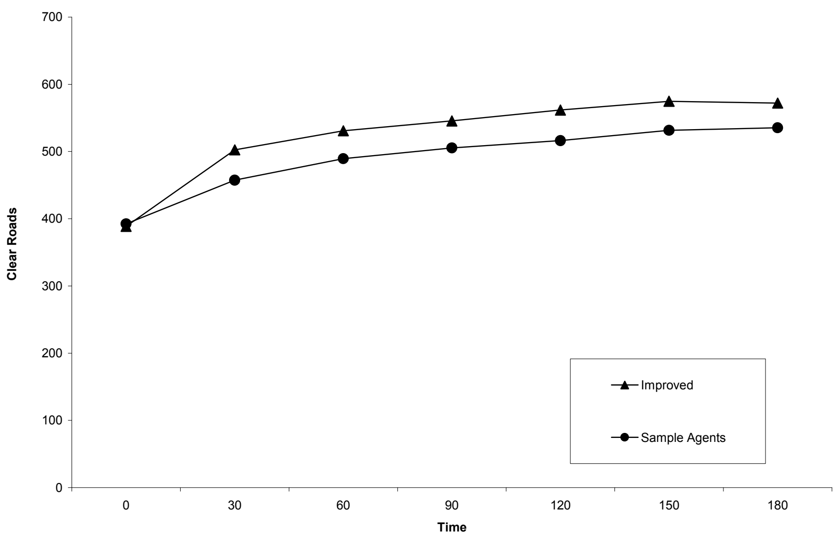

Figure 2. Clear Roads in Kobe

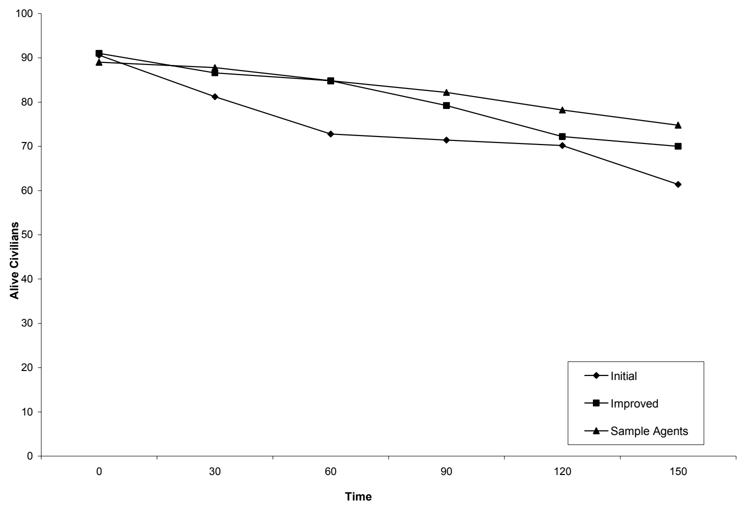

Figure 3. Civilians Alive in Virtual City

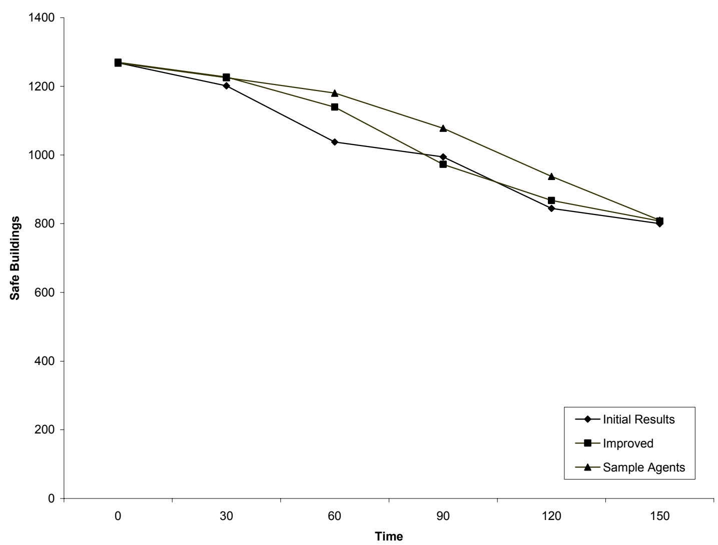

Figure 4. Safe Buildings in Virtual City

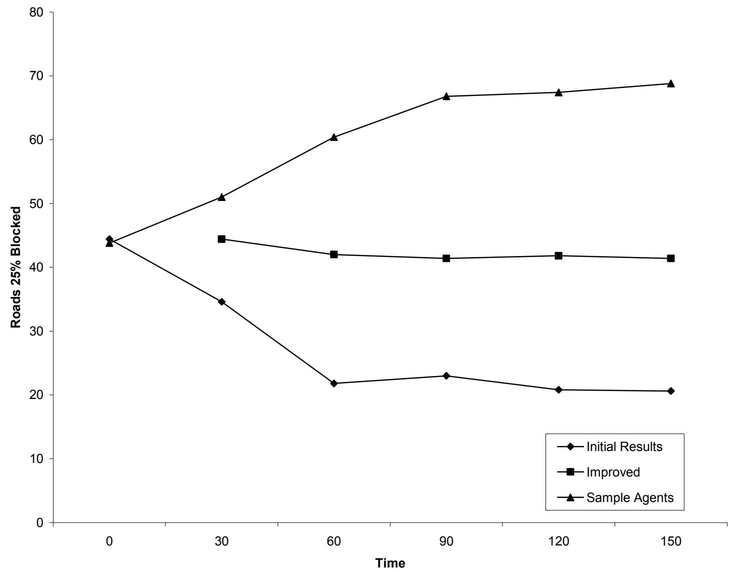

Figure 5. Roads 25% Blocked in Virtual City

6. Conclusions

A careful analysis of the change in the RoboCup Rescue Simulation environment reveals that it is useful to integrate a temporal reasoning capability within the agents. This capability enables them to adjust their activities to the needs of other agents and to cope with changes in the environment thus reducing the reliance on inter-agent communication as a mean of coordination. The results obtained so far are promising. However, there are many aspects that can be improved.

Acknowledgements

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