Agile Emergency Responses Using Collaborative Planning HTN

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ABSTRACT

Emergency response planning is a complex task due to multiple organizations involved, different planning considerations, etc. Using artificial intelligence collaborative planning helps in the automatic planning for complex situations. Analyzing all impacting factors along with plans that are executable can facilitate the decision making in Emergency Operations Centers for an agile emergency response. A main component of a planner is a knowledge base. Although many systems are developed to support decision making in emergency response or recovery, they either focus on specific or small organizations, or rely on simulations. To the best of our knowledge, there is a gap that there is no common knowledge base for provincial level mass emergencies for automatic planners. The multiplicity of the emergency response documents and their structure makes the knowledge acquisition complex. In this paper, we explain the process of extracting knowledge based on hierarchical task networks and how it speeds up the reactivity to a disaster.

Keywords

Collaborative emergency response planning, emergency operations center, emergency response knowledge base, decision support systems, hierarchical task network.

INTRODUCTION

Managing emergencies often require the cooperation of many agencies. Emergency Operations Center (EOC) provide a collaborative environment to facilitate information sharing, resource management, and plan development to respond to an emergency. The main objectives of each organization are defined in EOC by a person associated with that agency, and then is communicated to EOC personnel. The decision makers in EOC work on these objectives, as well as the ones developed by EOC personnel, coordinate all communications, and collaborate on making decisions.

Multiple factors such as information sharing and communication between different organizations (Ley et al., 2014) and managing emergency logistics (Choi et al., 2016) make the decision making and managing of an emergency a complex task. In provincial level or mass disasters, where number of involved organizations and information resources increases, emergency response planning becomes even more complex. Many information systems are developed to facilitate the communication or collaboration between multiple organizations (details can be found in related work section). However, the problem of resource allocation and making sure that a plan is executable regarding the current situation, timing, and available resources cannot be solved with information sharing systems. As a result, these factors should be integrated in order to provide an effective information system that supports planning emergencies.

Different approaches are developed to facilitate the planning. Banuls et al. developed a method for modeling the scenarios, assessing impacts, and planning collaboratively for emergency management (Banuls et al., 2013). In (Diirr et al., 2015), an approach is presented that uses states and unforeseen situations, mapping between these two, and defining the states' dependencies to monitor, suggest, and adapt a plan. Hofmann et al. (Hofmann et al., 2015) present the use of precedence diagram to manage and schedule the activities based on the resources

and execution times. However, there is no support tool for the above mentioned methods.

Consider a flood event in which multiple buildings from various zones should be evacuated. The number of people to evacuate, their age, available responders and vehicles, their distance to the buildings, and the transportation route are some of the factors that should be considered in the planning. The actions to be taken and the required resources depend on many factors such as whether the evacuees are seniors, school aged children, or patients of a hospital.

According to Flachberger and Eduard, the information centric paradigm is needed for crisis management (Flachberger and Eduard, 2016). Focusing on the provided information, automatic planning techniques can address the above-mentioned issues while automating complex tasks such as task tracking, impact assessments of each action, and resource management. They can provide different sequences of actions (plans) that satisfy a goal with given constraints such as task prerequisites and available resources. By considering all the impacting information and factors, and making sure that a plan can be executed, automatic planners facilitate agile emergency response management.

Among various planning techniques, we focus on an artificial intelligence (AI) planning technique called Hierarchical Task Network (HTN) and developing a knowledge base for HTN in provincial level emergency management. HTN is used due to its specific features to solve a problem by abstracting the tasks in a hierarchy and then defining an executable plan. The hierarchy of tasks in HTN is similar to the cognitive concept of problem solving by humans and in EOCs. Figure 1 demonstrates a schematic view of an HTN planner. By receiving information from the user about the event and the current situation such as available responders on site, blocked or clear routes, requests of emergency logistics, and etc. it generates a plan – sequence of actions – that is executable with respect to the given and predefined conditions. Other than the planning algorithm, the main component of an automatic planning engines is a knowledge base that is used to analyze different tasks and the conditions that must be satisfied in order to have an executable plan. This knowledge base should be defined for each specific domain based on various actions, conditions, and causalities between the tasks.

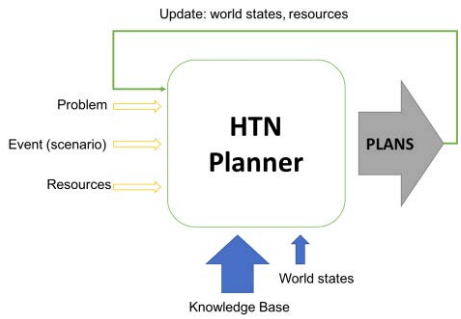

Figure 1. HTN Planner

One of the main challenges of developing such a knowledge base is the multiplicity of the documents and their high-level explanation of the actions for emergency responses. These are the documents that are open to public, and can be found on the government websites. On the other hand, although some actions are specific to each type of event (for example flood, earthquake, etc.), there are a lot of response actions that are shared among these documents; but there are specific emergency response actions developed for each type of event. The emergency response plan documents are long booklets with different sections developed for specific organizations or specific tasks such as logistics, and is intended to be used within its own authority/province.

We believe that developing a knowledge base, independent of a location or organization, can benefit the emergency management in developing countries as well, where information systems are not used widely for emergency management. Such a knowledge base used in an HTN planner, suggest specific set of actions that might be taken at certain times, regarding the event and the states of the situation provided for the planner.

In this paper, we explain the process we used to develop a knowledge base that includes the networks of actions, their dependencies, tasks' hierarchies, and pre- and post- conditions of each task from emergency response documents.

We will review multiple approaches and systems that support emergency management or emergency decision making in next section. Although there are libraries in some works that is referred to as a reference/guidance in specific situations (such as information on specific chemical in a chemical leak event), the others provide restricted information on the use of an actual knowledge base or provide small examples on specific domains

which contain only a few actions or tasks, as an experimental study. To the best of our knowledge, a provincial level emergency management knowledge base for HTN is lacking in this field. We address this problem by giving examples of the process that we are using to extract such a knowledge base.

RELATED WORK

In this section, we provide background review in three main classes: Collaborative Planning (CP), Decision Support Systems (DSS), and Hierarchical Task Networks (HTN).

CP and DSS are reviewed to make sure that we include information systems that might use a knowledge base for emergency management. CP in general is used to facilitate collaboration. EOC personnel collaboratively plan for an emergency. We studied the set of works that facilitate collaborative planning or include features that should be included in the system designs for CP in emergency management. DSS is used to support decision making and commercialized version of DSS are available for emergency management. We review DSS to categorized the works that work on emergency knowledge management and to identify systems that suggest plans as part of decision making. In the third sub-section, we present HTN systems and HTNs that are developed for emergency management. Most approaches mainly focus on the software system or architecture of the system to access various knowledge. Other than (Alvear et al., 2013) working on the road tunnels, the reviewed DSS or HTN systems use small applications with a few tasks or only provide information to facilitate decision making. The actual knowledge repository used in these systems are not provided or are specific to small and specific domains. Even in works that develop HTN based planners for emergency management, the focus is on adding properties to the knowledge representation or HTN to adapt emergency management requirements.

Collaborative Planning

Collaborative planning is a process that is used in EOCs, in which multiple agencies collaborate to define a plan for emergency response. The collaboration and interaction methods between people in the emergency management are studied in different works and multiple systems are developed for this collaboration. Fischer et al. (Fischer et al., 2015) study the ways people collaborate to manage an uncertainty situation while working around a table. They propose an augmented bird table and the principles for system designs in disaster management. Qin et al. developed a collaborative system using tabletops for emergency management. They analyze how people can manipulate objects, analyze situations, and collaborate to deal with an emergency while using their system (Qin et al., 2012). In (Doeweling et al., 2013) authors provide a tool that support situation analysis and planning for crisis management with interactive tabletops. They mainly focus on the role specific interactions while sharing the information.

Pedro et al. studied the collaborative features required for the development of software products for fire fighters and implemented and evaluated two applications based on their study (Pedro et al., 2016). Collaborative features of decision making in emergency management are also studied in Wu et al. work (Wu, et al. 2013). They research on system designs to support team work and developed a role based prototype for analyzing and visualizing geo-spatial maps and sharing information. Ley et al. also studied and developed a system porotype for sharing information and expertise between various organization involved in an emergency (Ley et al. 2014). Shatte et al. present a web based tool for collaborative document writing in emergencies (Shatte et al. 2016).

Decision Support Systems

The primary component of the decision support systems is developing a knowledge base or knowledge repository. Zhang et al. suggest a knowledge management framework for the assistance in decision making process in disaster relief (Zhang et. al., 2002). This framework is for the integration of distributed knowledge and information from different resources. The main part of the framework is a knowledge base which acts as a repository and should provide action recommendations for decision makers. Another theoretical approach is developed in (Arain, 2015) for the post-disaster response and a DSS shell. The main components are the knowledge base and the DSS to support the actions.

Collaborative knowledge as a service (CKaaS) for disaster management is used in (Grolinger et al., 2015). The authors explain a case study where the cloud consumer and cloud broker use two KaaS providers to make a right decision about turning off the gas. The KaaS providers include the information about critical infrastructure and best practices and recommendations based on related disaster management decisions. They mention how the simulation knowledge is integrated and used in this case to provide the information. The CKaaS architecture proposed in this paper explains how different KaaS entities containing various information can be integrated together to be used for decision making.

Mendis et al. developed a framework to model the commonsense knowledge in a three phases process (Mendis et al., 2007). The application of their work in disaster management is provided by mentioning the spatial data that is used in disaster management.

Multiple decision support systems (DSS) are developed for disaster management. In (Rolland et al., 2010), authors use resource-constrained project scheduling models (MRCPSP) and adapt it along with an algorithm for disaster management. They provide mappings from the MRCPSP criteria to disaster response scheduling problems such as mapping of late and setup costs to loss of life and personnel moving.

Cioca and Lucian-Ionel studied the DSS and its application in disaster management, specifying a case study on a fast flood warning system (Cioca and Lucian-Ionel, 2010). In (Gadomski et al., 2001) IDA approach is used to make an intelligent DSS for emergency managers. The prototype uses an oil port as the test case. In (Alvear et al., 2013), a DSS for road tunnels emergency management is developed. This DSS uses the decision, incidents, and evacuation models for road tunnels.

In (INDIGO, 2010) multiple information systems for disaster management are represented. They mostly focus on large scale systems or projects funded by governments. For example, RIB (2012) is an Integrated DSS that provides information access for multiple organizations, alerting and sending information, and supporting decision making by providing related information from the libraries, e.g. chemical types and properties in a chemical leak event.

HAC-ER is a prototype disaster management system (Ramchurn et al., 2015). This system provides situation awareness from crowdsourcing and is able to allocate tasks to first responders on the ground and Unmanned Aerial Vehicles (UAVs) and showing the paths. A planner agent that uses Multi-Agent Markov Decision Process (MMDP) to solve the planning process is part of the system.

Hierarchical Task Network

Hierarchical task network (HTN) is an artificial intelligence technique to solve a problem which is close to how human solves a problem or plan. These techniques consist of a set of higher level (more abstract) and lower level actions, such that each high-level task can consist of a set of a more abstract task. A plan is a solution of these tasks when the conditions are satisfied for each action. Each action changes the states of the world and its conditions also can be considered as a set of states that must be true in order that to be an executable task. A plan is changing the world states step by step until it reaches a final state which is the goal or the final solution. An example of an HTN task network is provided in next sections. HTN approaches require a knowledge representation for the domain and a planning process (Castillo et al., 2014).

HTN planners are used in various applications such as web service decomposition (Georgievski and Marco, 2015), robotics (Lallement et al., 2014), and crisis action plans (Castillo et al., 2005). Domain configurable planners can speed up planning by many orders of magnitude (Nau, 2012). HTN planner can solve problems by reducing the search space and is suitable for emergency management. HTN is similar to the process of developing action plans for an incident and provides an effective approach to generate action plans for emergency management. In (Tang et al., 2012) specific characteristics of HTN are named that make it a good candidate for emergency management domain: expressing the real-world problems which is provided by the form of knowledge used in HTN, the hierarchical nature of the task network which represent the goals/sub-goals and provide details for decision makers, similarity of the HTN and the decision making process in emergency management, and its ability to scale up for complex problems where there are thousands/ hundreds of thousands of objects and actions. The final characteristic of HTN is related to its procedural domain knowledge (Tang et al., 2012).

Specific forms of HTN are developed for emergency management. TPHTN is a temporal HTN developed for emergency management (Li et al., 2016). Specific networks named Simple Temporal Network with Preferences (STNP) is used to represent the information of temporal preferences. The temporal expression is also used in the operators and methods of TPHTN. The results of this work are compared against the HTN regarding planning quality and time. The problem designed for this comparison is a small set of operations on the logistics domain and considers only timings. Other than this experiment, there is no information about the use of any knowledge base for emergency management. This is part of a primary work where the authors developed a heuristic search in temporal HTN planning for developing incident action plans (Tang et al., 2012). Similarly, other than its domain, there is no information about the knowledge base used for developing the problem that is used in the planner.

SIADEX is another HTN based planner developed for forest fire fighting. It uses an ontology based knowledge base for the planner and stores the information about the objects, worlds, tasks, and temporal constraints as various ontologies. It has a separate module to translate these ontologies to the SHOP task formation (an HTN-

based popular planner) and PDDL (Planning Domain Definition Language) (Asunción et al., 2004; Asunción et al., 2005). To the best of our knowledge, this is one of the works that specifies the knowledge it used and its knowledge base architecture in detail. There is no information on whether the knowledge base used in SIADEX is publicly available and how complete it is. However, the domain is specified for the forest fire fighting.

State based partial order causal link and state abstraction combined with HTN planning are represented in (Bernd and Biundo, 2002) and (Biundo and Bernd, 2014) respectively. In each work, a combination of HTN planning is used and its application on the crisis management is represented.

DEVELOPING EMERGENCY RESPONSE KNOWLEDGE BASE

There are multiple documents on government websites that include information about emergency response and plans for different provinces (Emergency Response Plans, www.emergencymanagementontario.ca). These documents, are high level documents including various information such as: stating different emergency response plan activations, response actions, roles of various authorities and organizations in responding to an emergency, communication channels and information flow, powers of ministers in activation of some tasks or ordering tasks to response, reduce or prevent damage or lose in mass emergencies, different considerations for various actions, situational understanding, logistics, coordination of human resources, facilities, and equipment, access controls and transportation, agencies' communications, and assistance requests.

Extracting a knowledge base that can be used in a software tool is not possible by only using this information as it is. To make the knowledge base, we use the following process, which is shown in Figure 2: Acquiring various documents that contain information on emergency response planning; Extracting information from these documents and making task networks on higher level tasks; Adding the conditions and effects of each action in the task networks and using the considerations for each action; Connecting various task networks and making the highest level task network; And modifying or completing the task networks based on higher level connections, pre-conditions and effects, and other response documents. This is an iterative process to make the knowledge base and update it from time to time. In the following sections, the process in each step is explained in detail.

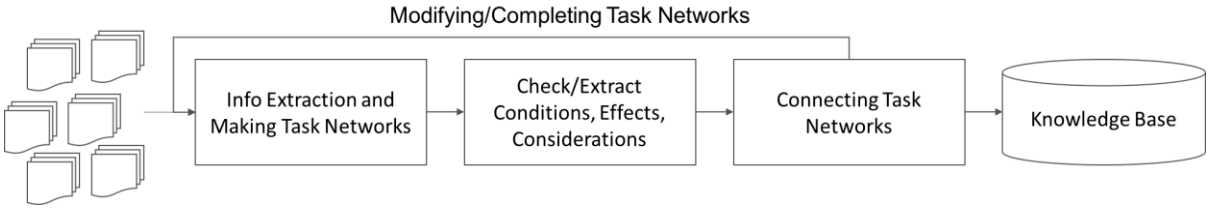

Figure 2. Developing Emergency Response Knowledge Base

Extracting Information

Other than relying on the online and publicly available resources, we have requested emergency response plan documents for different levels of operations (provincial, township, or organization) from experts in this area and from our industry partner C4i Consultants Inc. (http://c4ic.com). These documents are in various response domains, including earthquake, flood, oil and gas, and etc. The goal however, is developing a usable knowledge base for all levels, which is not location specific and can be used in different locations.

Making the Networks

Based on the information in an emergency response plan document, we can identify the main high level actions and responsibilities for different organizations in responding to an emergency. When constructing the networks, the primitive tasks can be found under the required response actions for each organization or authority, the required resources, the various response actions in different conditions, in an explanation of an action, or list of possible responses. There are two approaches to translate each sentence or response action to a task:

- Breaking a sentence or response action down into two or more tasks
- Combining sentences or response actions to a higher-level task

Examples of the former is *DIRECT AND PRIORITIZE RESOURCES* sentence, which includes two separate actions of *RESOURCE PRIORITIZATION* and *RESOURCE DIRECTION*. Also, the actions can be combined together to make a higher-level task in the network. For example, *HIRING DRIVERS* and *HIRING EMERGENCY RESPONDERS* actions should be determined under a higher-level task, *HIRING HUMAN*

RESOURCES, in the network. An important aspect of this creation involves the data management of these tasks; Thus the network is created using the principles of a Metamodel where the data gets classified into efficient structures (Bénaben et al. 2016).

Checking Conditions/Effects

When making a planner, each executable task requires some conditions to be satisfied. Without these conditions – considered as the prerequisites of the action – the action cannot be complete, and therefore, the plan including that action cannot be executed. There are various considerations in the provincial level emergency response plan documents that also should be taken care of for each action. Examples of the conditions and the considerations are explained in the following:

To evacuate a building, we should have enough personnel, either emergency responders or volunteers to help in the evacuation process. Moreover, sheltering areas should be available with vacancies for the number of people evacuated. The transportation available, the distances' considerations, and many other factors should also be considered. Furthermore, the evacuation order should be issued first, and must be done by the person in power. These orders and some of the conditions are only stated as considerations or in the powers and responsibilities of ministers, etc. Therefore, when defining the tasks and pre-conditions for each one, all of these considerations should be included, in addition to rational and explicitly stated pre-conditions such as available personnel.

When an action is performed, it has some effects on its environment. Having a list of what are the effects of each action that affect other tasks in the planning process is an important part of developing a knowledge base. One example of such an effect can be impact assessments. When the damage is assessed for an impact area, the effect of this action is having the list of damaged building, routes, etc. available. As a result, it can be used for other tasks later on, since the states of our world are changed.

Connecting Networks

When making the task networks, we build a network for highly relevant tasks at once. For example, including all the actions for procurement coordination. As a result, at the end there are several task networks, but they are separate islands that should be bridged together. These networks are connected together by defining higher level tasks that can be linked to the highest task in each network. In Figure 3 three task networks are represented for controlling access to/in the impacted area, increase human resources to support emergency response, and providing essential supplies.

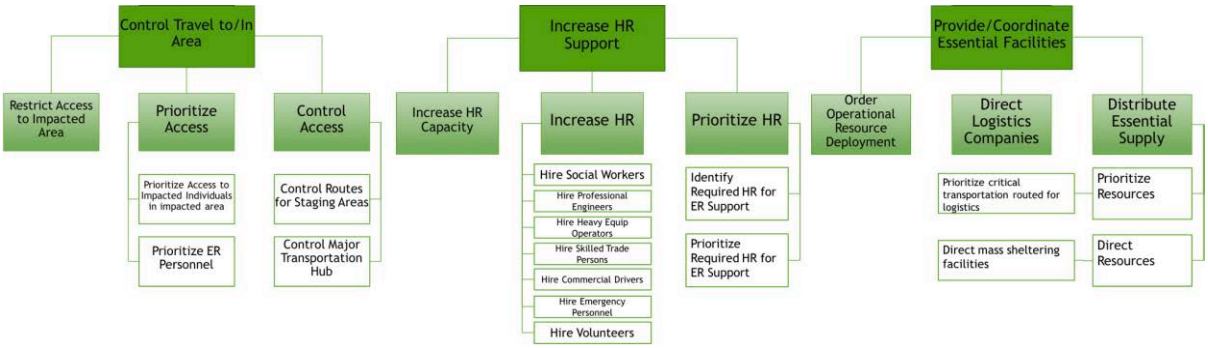

Figure 3. Three task networks

Modifying/Completing Networks

To complete a network, we should consider the following points, which affect completion or modification of a task network:

- Pre-conditions of each action (primitive task)
- Effects of each action (primitive task)
- Connection of two or more networks
- Effects of each action (primitive task) on the tasks of other networks

In the previous step, multiple networks are connected together to make the whole task network for the planner. In this process, and also in the step that we determine pre-conditions and effects of each action, some missing

actions are identified. For example, one condition for evacuation is availability of personnel. However, identifying the available personnel and their expertise is not defined previously. Therefore, we also require a task network for acquiring information about the personnel, their information and expertise, locations, numbers, updating all this information, and etc. The same applies when connecting multiple networks together. One such example is increasing the support for human resources and available personnel. We should also take care that this task will affect in other networks such as logistics, sheltering, transportation, essential supplies, and etc. Again, for each of the task networks that are connected together, we might notice that some actions should be added to each network based on the ones it is connected to, or it can have an effect on.

Completing and modifying networks is an iterative process and requires a lot of attention. Each time a task is updated, new connections are made between the networks, or new information is received, an update can be applied to the whole or a portion of each task network.

One example of completing a task network is shown in Figure 4. This is a modification that is required when considering the actions of two networks

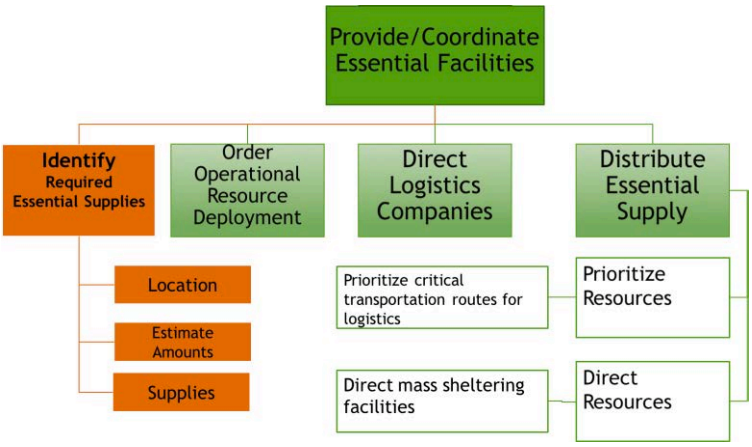

Figure 4. Completing/Modifying a task network

DISCUSSION AND IN PROGRESS WORK

Interview

We have set up interviews with people in this field. We interviewed two persons, one directly working in an EOC and involving in setting the objectives and make them available to the EOC manager, coordinating, and etc. These interviews are done concurrently to the process of knowledge extraction to make sure about some features of the planner we are working on are useful and gain more insights about the process of emergency management in EOCs. Other than interviews, we discussed the process of HTN knowledge base with an industry partner, C4i Consultants Inc. (http://c4ic.com/), which is a software development and training service company for emergency responders. Based on our discussions, such a knowledge base and planner can benefit the emergency management EOCs. There were also concerns about the information that should be included in the system and specific processes. Obviously, no evaluation or direct feedback is received since the system is not developed yet.

Work In Progress

The development of the automatic planner in this work is a part of a bigger project for the development of Emergency Operations Center of Future (EOCF). EOCF is intended to bring new technologies to EOCs in order to make emergency response more efficient (Chan et al. 2016; Marbouti and Maurer, 2016).

Currently, we have extracted a big portion of the higher level knowledge base from provincial level emergency response documents. Part of this knowledge is translated to a format that is useable for an HTN planner. We intend to require higher level documents to complete the network, and also include detailed knowledge to complete the task networks in lower levels of actions. Working on the planner and making the list of states that should be included as a world state is in progress.

Metamodel Implementation

After having iterated through the previous steps, a concrete, implementable Knowledge Base is able to be produced. The implementation of this Knowledge Base can be taken from a specific form, to a more general context by creating a Domain to represent the Knowledge Base. This Domain is then able to be parsed through the HTN planner to produce a world state.

As shown by Benaben et al., Domains can be represented by the operators of the Knowledge Base (Benaben et al. 2016). As previously mentioned, we have developed a working, sample study to demonstrate the applicability of the HTN Planner. The sample was designed to mimic the evacuation of a hospital, but at the most High-level abstraction available, as shown in Figure 5. In this case only a few operators are needed, which allows for ease of not only study, but also replication.

Figure 5. An example of a created Knowledge Base

In this example, the operators are shown in a concrete hierarchy, with their relationships extending downward until the world state is affected. A Knowledge Base can be defined where;

WorldState = [Entities]
Entities = (name, [attributes])
Operator = (WorldState, [methods], [Operator])

Comparing this to diagram 5, we demonstrate that an abstract Metamodel can be used to build a non-primitive syntax for a Knowledge Base.

Note that additional methods are required to be performed within operators, and that these methods do not require to be classified as operators themselves. With this representation the world state is able to be affected by an outside influence, allowing for the ability to re-evaluate the hierarchy during run-time, as the operators use the world state within the external methods to determine the proper assignments of sub-tasks. This is an implementation the idea of agility noted in Barthe-Delanoë et al. which allows for a dynamic world (Barthe-Delanoë et al., 2012).

Discussions

Additionally it is also worth mentioning that knowledge acquisition is not a new field. Multiple algorithms based on natural language process and text mining exist to extract knowledge from different resources. While this is a valuable approach, many of the knowledge extraction systems for emergency management are developed ontologies, knowledge models, or information extractions from social media. One example of a

knowledge acquisition in emergency management is an ontology developed for mass emergency medical services to be used an intelligent DSS (Haghighi et al., 2013). Many works rely on crowdsourcing and knowledge extraction from social media (García-Santa et al. 2015; Xu et al., 2016). In emergency response planning, we need to rely on a concrete and reliable knowledge base. The tasks networks that we are developing can be used as a base knowledge to build upon or update with automatic knowledge extraction later. We are developing prototype knowledge base and in order to be used in real world, these networks should be validated by experts in emergency management.

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