Planning Operation: An extension of a Geographical Information System

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Abstract. The paper proposes to use CR-prolog to add planning capabilities to a Geographical Information System. Cr-rules can restore the consistency of a program giving the diagnosis of possible causes of failure in a plan. In this paper we give an additional use for cr-rules: we propose to use cr-rules to obtain an alternative plan in case of the ideal plan fails. They not only restore consistency and give the diagnosis they also give support to define an alternative plan. In particular, we show the use of cr-rules in a situation related to the risk zone of volcano Popocatepetl. We show, by means of an example, how to obtain alternative evacuation routes using cr-rules.
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1 Introduction

Government is responsible for the long-term health, safety, and welfare of citizens. We know that people could be at risk from different types of disaster such as terrorist attacks, extreme weather events such as hurricanes, earthquakes and volcano eruptions. Having a plan seems to be the best response to the threat of such events [J00]. Nowadays, Plan Operativo Popocatpetl office in Mexico has the responsibility of coordinating the actions to put in safe people distributed in 50 towns living next to the risk zone of volcano Popocatepetl in case of an eruption occurs. This office uses printed maps and printed reports to decide the best plan in case of danger. Usually it is difficult to justify the decisions because they do not have enough information [SR01]. Moreover, the UNESCO has published in [UU85] a handbook to help those involved in pre-disaster planning. In it is remarked the importance of having a plan before an emergency occurs.

We have discussed about evacuation plans in volcano Popocatepetl with researchers in volcanology of Laboratoire de Geophysique Interne et Tectonophysique of Université de Savoie in France. They had remarked that in order to define effective evacuation routes it is necessary to consider the different scenarios at moment of volcanic eruption and consider the different hazards that can

accompany volcanoes, such as: mudflows and flash floods, landslides and rockfalls, earthquakes, ashfall and acid rain or tsunamis occur. They recommend to take into account the hazard map at Popocatepetl [MCND$^+$95]. Hence, our goal is related to add planning capabilities to a Geographical Information System (GIS) in order to give support in definition of evacuation plans. With this aim, we consider to explore the use of Answer Sets [GL88] as a formalism to represent and obtain plans. Answer Sets is a logic programming language for declarative knowledge representation, well suited for planning, with strong theoretical work and with inference engines implemented. However, nowadays there are only few real applications using Answer Sets.

We consider to explore the use of the Answer Set approach presented in [Bar03] since it is focused on planning in dynamic domains. One important characteristic of these domains is that they allow considering a main agent and other agents doing actions, referred to as exogenous actions. Exogenous actions are beyond the control of the main agent and may modify its environment. For instance, explosive volcanoes blast hot solid and molten rock fragments and gases into the air. Then if a road becomes blocked this is an exogenous action. The architecture of agents in dynamic worlds consists of repeated execution of the following steps [Bar03]:

1. Observe the world and add the observations (about agent's actions and exogenous actions) to the agent's set of observations (O).
2. Construct a plan (sequence of actions) from the current moment of time to achieve the goal.
3. Execute the first action of the plan and add this execution as an observation to the set (O).

We propose a GIS extension where an agent should be able to find the set of possible evacuation plans or the best one (using a criterion of preference). This agent should be able to take information such as towns, roads, number of people and safe zones from a GIS database, and at the same time it should consider the traffic flow capacity of roads and critical danger points. It should also be able to take the specification of a scenario given by the user. This scenario should describe the hazard or set of hazards (mudflows, rockfalls, etc.) when a volcano eruption occurs.

We think that we can take advantage of declarative knowledge representation of Answer Sets when the scenario is described. Hence the users do not have to be expert programmers because they only have to describe the scenario in a declarative way and wait for the answer.

Normally, planning in GIS is made with geometric operations and it is supposed that data describing the environment are completely know and static [BCCW96]. Therefore, another advantage of this approach is to allow reasoning with both incomplete and dynamic knowledge. For example, if we do not know anything about a segment of road we can assume that this segment of road can be used in an evacuation unless we have the specific information that this segment is blocked.

We suppose that adding to a GIS these characteristics would offer to experts a better approach to specification and possible solutions of this kind of problems.

We propose to use an answer set approach to model how an agent can get an evacuation route in the risk zone of volcano Popocatepetl. This volcano is rounded by towns in risk and roads. We have information about towns and roads in this zone [SR01]. At the moment, the evacuation routes have been defined by Mexican government. Nevertheless, in an emergency situation some of the segments of these routes can become blocked by some exogenous actions. Then it is necessary to obtain alternative evacuation plans depending on the effects of different kinds of exogenous actions. Hence, in this paper we show by means of an example, how to obtain alternative evacuation plans. In order to obtain these alternative plans, we propose an additional application to consistency restoring rules (cr-rules) [BG03]. Originally, cr-rules have been proposed for restoring consistency of a program and to make a diagnosis of the reasons of this inconsistency. An initial version of this work appears in the technical report [ZOS04].

The paper is structured as follows. We introduce a GIS example related to the risk zone of volcano Popocatepetl. Next, we show how to obtain an alternative evacuation route, using cr-rules. Finally, we present conclusions and future work.

2 Evacuation Plans using Answer Sets.

We think that if our goal is related to add planning capabilities to a GIS in order to give support in definition of evacuation plans then we need a description of Popocatepetl scenery as close as possible to the real problem. We need a correct representation of the network of roads related to towns in the different risk zones to develop evacuation plans. This representation should be created from information about the real evacuation routes and towns from [SR01]. Hence we represent the network of roads as a directed graph where an evacuation route is a path in this graph. We remark that Mexican government has defined the ten evacuation routes in Puebla state. At the same time, in order to obtain the evacuation plans we explore the use of the Answer Set approach presented in [Bar03] since it is focused on planning in dynamic domains. We take advantage of one important characteristic of these domains: the exogenous actions. Exogenous actions can describe the effects of a hazard or set of hazards when a volcano eruption occurs. Now we are going to describe how we represent Popocatepetl scenery to develop evacuation plans and how we can obtain evacuation plans.

We consider that towns are connected with other towns by roads, each road is made up by segments, and each segment is represented by $road(P, Q)$ where P and Q are nodes. Some segments can belong to an evacuation route. There is an exogenous action $block(Q)$, which causes node Q become blocked. If one segment of road is unblocked and belongs to the evacuation route, it is possible to travel by this segment when the zone is in risk. We consider an agent capable of performing the action, $travel(P, Q)$. We assume that actions take one unit of time. The *action* is defined by the rule:

$$action(travel(P, Q)) \leftarrow road(P, Q), route(P, X), route(Q, X).$$

This rule says that it is possible to travel from P to Q if there is a segment of road from P to Q and if the edge between P and Q belongs to the evacuation route. Exactly as Plan Operativo Popocatpetl office in Mexico indicates. The *effects of this action* are expressed by the following rules:

$$caused(position(Q), travel(P,Q)) \leftarrow edge(P), edge(Q).$$
$$caused(neg(position(P)), travel(P,Q)) \leftarrow edge(P), edge(Q).$$

The first rule says that if the agent travels from P to Q then the new position is Q, and the second rule says that if the agent travels from P to Q then the agent is not in position P. Normally, the action travel is executed. However, there are two exceptions to this action expressed as follows:

$$noaction\_if(travel(P,Q), neg(position(P))) \leftarrow edge(P), edge(Q).$$
$$noaction\_if(travel(P,Q), blocked(Q)) \leftarrow edge(P), edge(Q).$$

The first rule states that it is impossible to travel from P to Q when the agent is not at position P. The second rule states that it is impossible to travel from P to Q if edge Q is blocked. Here $position(P)$ and $blocked(Q)$ are *fluents* which define the possible domain states [Bar03].

In order to show how this program works, we give some specific values for the background knowledge. We take only some segments of roads from two towns in Huejotzingo from our GIS database referred in [SR01]. Huejotzingo is part of the Popocatepetl risk zone.

It is important to make notice that the basic data for a GIS database has two components [LGMR01]. The first component is spatial data: consisting of maps and which have been prepared either by field surveys or by the interpretation of Remotely Sensed (RS) data. The second component is non-spatial data: attributes as complementary to the spatial data and describe what is at a point, along a line or in a polygon and as socio-economic characteristics from census and other sources. For instance, the socio-economic characteristics could be the demographic data, occupation data for a village or traffic volume data for roads in towns. Hence, we use non-spatial data about segments of roads and towns in order to define the background knowledge. Using a GIS tool it is possible to save the descriptive information in a text file. Each line of this file corresponds among other information to the identifiers of initial and final nodes of a segment of road. Nevertheless, when we analyzed this information we have realized that some identifiers repeat several times or do not take the sequential order that corresponds to the map that they describe. These problems do not allow us to define a directed graph from the text file. Therefore we have had to order the segments and later to rename each one of their nodes. Figure 1 shows the segments of road used in our example. The segments of road are the following:

$road(507, 508)$. $road(508, 1096)$.
$road(1096, 1102)$. $road(1102, 1113)$. $road(1113, 1116)$.
$road(1096, 1105)$. $road(1105, 1131)$. $road(1131, 1109)$. $road(1109, 1113)$.

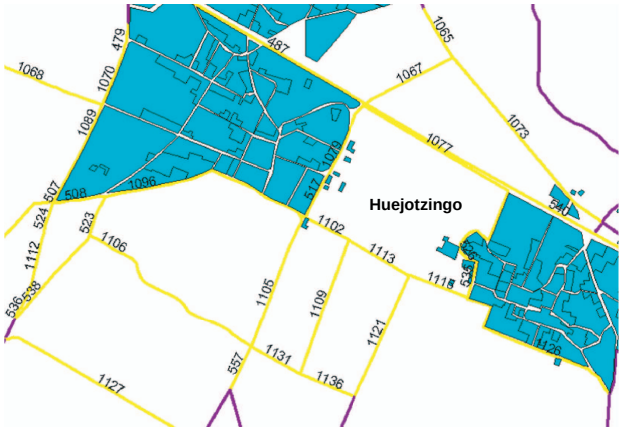

Fig. 1. A zoom in between two towns from Huejotzingo

We also have the following two rules to represent that we need an evacuation route from node 507 to node 1116.

$$initially(position(507)). \quad finally(position(1116)).$$

Also, we assume that only nodes 507, 508, 1096, 1102, 1113 and 1116 belong to the evacuation route. The result is the following plan:

$$travel((507, 508), 1). \quad travel((508, 1096), 2). \quad travel((1096, 1102), 3).$$
$$travel((1102, 1113), 4). \; travel((1113, 1116), 5).$$

The plan reads as follows: the agent should travel from 507 to 508 at *time* 1, from 508 to 1096 at *time* 2, from 1096 to 1102 at *time* 3, etc. All the edges in this plan belong to the evacuation route. Now, if an exogenous action occurs. For instance, a mudflow blocks part of the road, we add to the background knowledge the following rule:

$$initially(blocked(1102)).$$

This rule says that the node 1102, which belongs to the evacuation route, is blocked. The result is that the program is inconsistent and the agent is not able to find an evacuation route because of the fact that action travel only works if all the edges belong to the same route. Hence, now the problem is to find an alternative evacuation route. In the following section, we propose the use of *cr-rules* [BG03] to solve this problem.

3 Cr-rules and planning in GIS

In [BG03] each rule of a CR-Prolog program is referred as a regular rule. However, if an agent has no way to obtain a consistent set of beliefs using regular rules it

is possible to restore consistency using cr-rules and some exogenous actions that may have occurred in the past. Then, using cr-rules we can obtain a diagnosis of the reason for the inconsistency. The example presented in [BG03] illustrates the use of cr-rules. Let P be the following program:

$a \leftarrow \text{not } b.$
$\neg a.$
$r_1 : b \leftarrow^+ .$ % r_1 is the name of the cr-rule

The first two rules are regular rules and the third rule is a cr-rule. Cr-rule r_1 says that the agent is allowed to believe in b if the agent has no way to obtain a consistent set of beliefs using regular rules only. We can see that the program P is inconsistent without the use of r_1. Consistency can be restored using r_1, leading to the answer set $\{\neg a, b\}$.

It may be worth noting that in [BG03] a set of examples about the use of cr-rules are given. Among these examples there are two that show how cr-rules can be used to generate plans of minimal length. In this paper, we propose to give an additional use to cr-rules.

We realized that using only regular rules it is not possible to obtain an alternative evacuation route when an exogenous action occurs. Hence we propose to use cr-rules to restore consistency and to obtain alternative plans to achieve the main agent goal. In this case, if an agent has no way to obtain an evacuation plan using only regular rules it is possible to obtain an alternative plan using cr-rules. The following example shows how we can use cr-rules to obtain an alternative evacuation route.

Let us suppose that it is not possible to obtain an evacuation route from node 507 to node 1116 because an exogenous action has occurred. The exogenous action indicates that the node 1102 which belongs to the evacuation route is blocked. As we mentioned before, it is not possible to obtain an evacuation plan using only regular rules. Then, in order to restore consistency and obtain an alternative plan we propose to add to the program the following cr-rule:

$$r_2 : action(travel(P, Q)) \leftarrow^+ road(P, Q).$$

This rule says that it is possible to travel from P to Q if there is a segment of road from P to Q. This cr-rule does not check if the edge between P and Q belongs to an evacuation route or not, as the regular action *travel* defined previously. As we described before, this cr-rule should be used only if the agent has no way to obtain a plan when an exogenous action occurred.

The result of adding this cr-rule when the exogenous action $blocked(r1102)$ occurs is the following plan:

$travel((507, 508), 1)$. $travel((508, 1096), 2)$. $travel((1096, 1105), 3)$.
$travel((1105, 1131), 4)$. $travel((1131, 1109), 5)$. $travel((1109, 1113), 5)$.
$travel((1113, 1116), 6)$.

We can see that the plan indicates the agent should travel from 1096 to 1105 at *time* 3 in spite of node 1105 not belonging to the evacuation route.

The same occurs for nodes 1105, 1131 and 1109, hence the agent has found an alternative evacuation route. The implementation of this example was inspired by an example from [Bar03] and we have used Smodels [Sim95].

4 Conclusions and future work

Today, the GIS analysis technology is very complex and specifically implemented for unique applications only. It seems to be very useful to have a planning operation as part of a GIS system in order to give decision support. We think that an Answer Set approach seems to be appropriated to explore in order to add planning operation as an extension of a Geographical Information System. In this paper we present only the initial work tin order to achieve this extension. We have defined a representation of the network of roads related to towns in the different risk zones to develop evacuation plans from non-spatial data of our GIS database. We represent the network of roads as a *directed graph*. We also proposed to give an additional use to cr-rules, using them to restore consistency and to obtain alternative plans, however we need to continue working. We plan to consider a description of a scenery as close as possible to the real problem. In particular, it should take into account the place where people are located with respect to the time and capacities of roads. It should identify "priorities" or "preferences" among the different possibilities: we should find the plan that minimizes the time needed to evacuate everybody, or the safer plan that uses as many safe roads as possible, or all possible plans. For this step, we are considering the relationship between the real problem to solve and some similar existing problems such as the maximum flow problem [HWH01]. The goal of maximum flow problem is to maximize the flow that can be transported from a given node to another given node within a network such that each edge is associated with a capacity.

It would be also necessary to compare the capabilities of Answer Set Programming to represent incomplete knowledge and planning problems within dynamic real-world environments with other dynamic planning approaches, such as [MT00]. We can consider the work in [CDN04] which is directly related to evacuation plans using an Answer Sets approach. In this work the flow of lava in volcanic eruptions is modeled and in order to show its feasibility they use data from Etna volcano.

Finally, we think that this idea could be useful to compare the different ways of expressing preferences, costs, and other methods or algorithms to optimize within the answer set programming framework. In particular, we could compare Answer Set Optimization of [BNT03] with Answer Set Planning under Action Costs of [EFL$^+$02].

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