Large-Scale Mapping and Navigation in Virtual Worlds
Thesis Summary

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The prevalence of virtual worlds presents a challenge for intelligent mobile agents. Online, large, persistent virtual worlds such as Second Life and massively multi-player on-line games are becoming more popular. There is a challenge to provide intelligent agents for these environments that are able to generate and use maps to navigate the world without long delays or a large amount of map pre-processing required. The problem we are investigating is how to enable these virtual agents to represent, generate and use maps in large scale, dynamic and potentially unstructured two dimensional environments. Usually, generating and using maps is addressed on a small scale in a controlled, office-based environment due to hardware issues, sensor noise and localisation problems. By looking at virtual agents we can side-step the problems faced by physical agents and focus on how to represent and build maps of increasingly large, complex environments. Looking at dynamic and populated environments means the agent is faced with a realistic setting, where objects move, the layout changes, and the agent is able to observe the movement of other avatars in the area. Localisation in virtual worlds is provided by the server.

We propose to investigate map representation using hybrid, multi-level maps, giving the agent new methods for building and improving on these. Hybrid maps consist of several layers, each giving different levels of abstraction for the environment. The low level map is usually a metric representation, containing geometric information about the environment which is used to identify free and blocked space. From this we can build probabilistic roadmaps (PRMs) which give a graph of connected regions of free space, allowing the agent to plan routes between individual spots in the environment. From these representations the agent can build a topological map, segmenting space into distinct regions and allowing the agent to handle increasingly large environments.

We split this problem into smaller sections to investigate it fully. First we looked at generating PRMs for small scale, static environments and how to improve on these using trails. After this we started to look at methods of segmenting space and generating maps of large scale environments. Finally, we extend this to generating and updating maps in dynamic environments.

Related work

A lot of research has been done on representing maps for agents. These mostly fall into two categories, metric and topological maps. Metric maps are the simplest form of map, formed by examining and interpreting sensor data. They give geometric information about the environment and are generally considered to be robust and accurate (Kuipers and Levitt 1988; Filliat 2003; Thrun 1998; 2002). The most commonly used metric map is the occupancy grid (Elfes 1989). Another type of metric map is the object map (Thrun 2002), which reduces the environment to geometric primitives and use these represent free or blocked space. Object maps are a more compact representation than occupancy grids and lend themselves well to virtual environments where the environment already consists of geometric objects within a coordinate frame. However, as the size of the world increases the size of all metric maps also increase unsustainably. To solve this problem abstract representations such as topological maps are often built.

Topological maps are usually built from metric maps, though some can be generated from sensor information. They consist of two elements, nodes and arcs. Nodes are specific locations in the environment, such as a room or an individual coordinate. Arcs are the routes between nodes; they store how to travel between one node and another (Huang, Rad, and Wong 2008). They are built by segmenting the space into individual regions, with the arcs showing connectivity between these regions. Topological maps are a more compact representation as they hold only key information about the environment. One form of topological map that we look at is the PRM.

PRMs can be generated in any environment and give a graph of interconnected points of free space (Kavraki et al. 1996). They are especially useful for large environments as they can descretise the space, however, generation time can be a problem for PRMs, especially in large environments. PRMs consist of two phases, the construction and query phase. In the construction phase points are selected and if the point is in free space it is added to the map. Each point is then connected to its neighbours where there is a free path between them. The method for point generation in PRMs affects the type of map created. One method for point generation is to observe and copy the movement of other agents in the environment.

Trails are from a concept used in urban architecture; they show the routes taken by agents in an environment, rather than the paths intended for use. Trails have been used in virtual environments to aid human navigation (Ruddle 2005) and also as a starting point for a robot's map building process (Yuan, Twardon, and Hanheide 2010). A digital trail is defined as the list of points an agent has been observed at over time.

Progress to date

The first step in solving our problem was resolving how to represent and generate a map of the environment. We used PRMs to allow an agent to plan a route between two points. Our hypothesis was that we could improve PRM generation by using trail information to build the map both to indicate popular routes and decide if a point lies in free space. A good PRM will allow the agent to plan a route between any two points in space, plan relatively short routes and be generated in a short amount of time. Trail points can be used as the selected points in a PRM and the routes taken used to form arcs. After investigation, we have shown that the combination of using trails and randomly selected points in PRMs enables the agent to generate maps which are more successful at finding routes and generating shorter paths. However, the use of trails increases the generation time of the map.

The second step is addressing how to segment space, allowing an agent to build topological maps and maps of very large-scale environments. It is important that the agent segment the space intelligently, so that areas that relate to one another are kept within a single region else the map will require more upkeep long term. There are numerous methods for doing this, but the best approach will take into account any structure in the world. Following on from trail points, we can look at where large groups of people congregate in the world. These cluster-points show important places in the environment and how places relate to one another. One method of segmenting space is to use the cluster points as Voronoi seed points (Thrun 1998), giving a map that attempts to keep important places in the center of each node. This work we expect to have finished by July.

Future plans

The final stage in solving our problem is to look at how to generate and update maps of dynamic environments. The construction cost of changing virtual worlds is low, so they tend to change rapidly. This requires the agent to update its map, and recognise when changes occur both gradually and without warning. An interesting problem is detecting new cluster points as they emerge, which potentially causes the topological map to change. We could also use trails to show where free space may have altered. If someone is observed moving through previously blocked areas the agent knows the map requires an update. It may be possible for the agent to use knowledge gained from generating maps of previous environments to augment this process. We plan to have this section complete by October 2012.

The anticipated contribution of this thesis is a new method for representing and generating maps of large scale, dynamic and unstructured environments. We have shown that trails can be used to generate more successful PRMs which allow for shorter routes to be planned. We expect that by using cluster points we can segment space allowing the agent to generate maps for any size of environment. Learning how to build better maps is an interesting problem and one which requires investigation. If the agent is able to generate better starting maps based on previous information then it will have an advantage in updating these maps over time.

Timeline

This section covers a brief timeline of my expected activities over the rest of my degree.

- February-March: Investigate clustering and segmenting space. Write up results
- April-May: Investigate topological maps and segmenting large-scale environments
- June-July: Dynamism in maps, how to keep the map up to date and know what needs changing
- August-October: Learning maps based on previous knowledge and movements
- October-November: Start writing up thesis. Skeletal outline of most chapters
- December-January 2013: Literature review
- February: Improving probabilistic roadmaps using trails
- March: Segmenting space for large scale maps
- April: Dynamic large scale maps
- May: Conclusion and Introduction
- June-August: Proof reading and submission

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