Automated Procedural Generation of Urban Environments Using Open Data for City Visualisation

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Abstract. Ever increasing populations are putting considerable strain on the critical infrastructures of our towns, cities, and countries. The interconnecting and interdependent components of these man-made living procedures and protocols give-way in unforeseen, unplanned situations. Having the ability to visualise these interconnecting entities and the interaction they have on one another is critical for future city planners. We propose a novel framework called Project Vision Support that provides an automated visualisation of real world open data maps for the creation of procedurally generated urban environments. This framework can then be used to implement planning and scheduling algorithms for the orchestrated task of emergency services for crisis management response.

Keywords: Critical infrastructure protection · Games technology · Visualisation · Open data · Procedural content generation

1 Introduction

The term *Critical Infrastructure* (CI) is primarily associated with facilities which are critical for the functioning of our society and economy. Examples of such facilities are electrical power systems, gas distribution systems, financial services, telecommunication systems, emergency services, etc. These universal services power and support practically every activity that modern society does. We, both as individuals or organisations, intrinsically rely on these universal services in our daily lives. Such services are implicitly assumed on a day-to-day basis and are therefore required to be both reliable and trustworthy. In times of crisis the resilience and reliability of these services becomes even more crucial.

According to the latest report that we are aware of, in the US alone there are 560,104 critical infrastructures. This consists of 28,600 networked Federal Deposit Insurance Corporation institutions, 2 million miles of gas pipeline, 2,800 power plants (with

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300,000 production sites providing assets), 104 nuclear power plants, 80,000 dams, 60,000 chemical plants, 87,000 food-processing plants, and 1,600 water-treatment plants [1]. These figures are expected to have increased in the last decade since that report was published. These infrastructures have interconnections and interdependencies towards one another. For example, if resources are not delivered to power plants then electricity cannot be generated. These cascading effects can have devastating consequences if not planned for. If the electricity is not generated, the supply of power to water processing and pumping stations will stop, thusly major communities will be without power and without clean drinking water. Power outages caused by unforeseen cascading effects has struck the USA spanning many decades. In 1965, 30 million people went without power for half a day. In 1971, 1977, and 2003 there were widespread power outages throughout parts of the northeast and Midwestern areas of the USA and spanning into parts of southern Canada. In 2012, hurricane Sandy disabled power supplies from high winds and flooding.

In the UK, on March 29th 2004, a fire broke out in a tunnel 30 feet under the streets of Manchester. This tunnel was designed and built in the cold war era and are housing multiple telecommunication cables. Approximately 130,000 fixed telephone lines were affected by the fire. This caused a more devastating cascading effect as communications to emergency services were completely halted. The incident was estimated to have cost the local business, community and government £22 million pounds worth of damaged over the 5-day disaster [2].

The ability to visualise and predict cascading effects in modern urban environments, especially big cities such as London and New York will not only be extremely helpful to crisis managers but also to city planners for accurate decision making. Early work on disaster support frameworks for disaster management has been created by Michalowski et al. called *NEGOPLAN,* a rule-based model of sequential decision-making [3]. Michalowski states that there are four phases in disaster support decision making. The first is mitigation phase, which aims to reduce the risk to property, assets, and human life. The second is preparedness phase which contains a set of actions closest to the onset of a disaster aimed at minimising the damage and enhancing disaster response operations. The third is response phase, a coordinated response to contain disasters to prevent further fallout and finally the recovery and reconstruction phase – planned actions to minimise further fallout and reconstructing a normal functioning system.

In this paper we propose a framework called *Project Vision Support* (PVS) to model and visualise cascading effects resulting from the interconnections, interdependencies, and interactions between critical infrastructures. This framework can provide more detailed decision making criteria for crisis managers and be used for accurate automated planning and scheduling of emergency services in the event of a disaster. An initial prototype of this framework has been developed and used to visualise urban environments of an area on OpenStreetMap (OSM) [4] website and it has received many positive feedbacks from professionals and academics.

While critical infrastructure protection research has received a healthy attention from researchers in the past decade, to the best of our knowledge, there are not many research proposals in this field that make use of a combination of visualisation, planning, scheduling, artificial learning, prediction, and games technology. We believe the combination of these areas can greatly improve the quality of the decisions made by crisis managers. We will start our discussion with a review on related projects.

2 Review of Related Projects

The SAVE (Sustainability Assessment Visualisation and Enhancement) project visualises the interactions between society, environment, and economics, as well as the future possible consequences of the current behaviours through mathematical modelling of materials used in construction [5]. The simulation uses the analytic network process (ANP) methodology, a network built of elements, each having individual attributes (numerical interaction values with the world), and creates a *super matrix* containing initial judgements of these attribute values, and then using a pair-wise comparison against a *fundamental scale* (basically a table of judgments of the priority of the elements) to create a *comparison matrix* which is used to create the *eigenvectors* of each element. The *eigenvectors* are combined with the *super matrix* to create an *unweighted super matrix* which is then calculated with a final pair-wise matrix representing the interactions of the clusters of elements and the *eigenvectors* to give the final *weighted matrix*. This becomes the measurable priorities of the sustainability factors corresponding to objects in a real world. This matrix can be applied to objects in a virtual world through shader programs to visualise the colour changes. We would like to create something similar to this mathematical matrix representation of vulnerabilities in our framework to show areas which are subject to flooding or potential fire hazards.

ALLADIN (Autonomous Learning Agents for Decentralised Data and Information) is a project for the automated decision making of agents, particularly emergency service representations. The project has 3 main subcategories: Situational Awareness; RoboCup Rescue; and Evacuation. We would like to build upon the 2D representations of the project by applying the concepts and algorithms into the 3rd dimension.

3 Project Vision Support Framework

The Project Vision Support framework that we are developing combines the role of visualisation, planning, scheduling, artificial learning, prediction, and games technology in the critical infrastructure protection. The rationale of our approach is as follows:

Visualisation is an important factor in understanding the interdependencies between critical infrastructures. As detailed in [6], there are four types of interdependencies between infrastructures namely Physical, Geographical, Cyber and Logical. The first two are particularly important. Physical interdependencies consist of one infrastructures input being the output of another. If upset is caused to the output of an infrastructure which is used by other infrastructures, the cascading effects can ripple through the interconnections, snow-balling and causing unforeseen issues and further upsets. Geographical interdependencies relates to the locations of assets; be it personnel, server farms, access points etc. For example, a water mill is reliant on the flowing water of a river. If the water flow stops, then the internal infrastructure of the water mill will stall. Knowing the information of the surrounding geographical details will be critical for the accurate modelling and decision making of evacuation plans, also, supply and demand constraints between infrastructures. These interdependencies can be represented as a 3D visualisation of an area.

Furthermore, 3D visualisation can also be used to represent Population Mobility. Population Mobility models are especially interesting to our research and framework because it is the modelling of how entities move and interact within urban environments. This model has been used for the modelling electric power grids and wireless communications. We can use this model for traffic flow modelling and evacuation modelling with multiple transportation systems. Osogami et al. of IBM, model transportation systems in two categories: ***microscopic*** modelling tracks the individual details of vehicles such as location, and is often the most detailed description of traffic modelling but this addition of parameters means more computations; ***macroscopic*** is concerned with tracking the speed and flow of traffic but does not allow the study of minute changes in the traffic model [7]. We can apply these modelling types to all entities and parameters of our virtual world, to the fire resistance of materials for buildings, to the evacuation of humans in transport systems.

Planning, scheduling, artificial learning and prediction play an important role in critical infrastructure protection. They can be thought of as being completely separate or comprehensively entwined. Planning concerns itself with finding a sequence of actions for an initial state to a goal state. With planning, a difficulty is solving general purpose planning problems because of the complexity of inferring what a general problem is, and how it can be broken down into smaller problems and then converting these to commands to be executed. It is much easier to develop ad hoc techniques to solve particular problems [8]. Multiple algorithms and descriptive languages have been created to encapsulate planning: STRIPS, planning domain definition language (PDDL), action description language (ADL), a behaviour language (ABL) [9], Finite State Machines (FSM), Rule Based Systems (RBS), and many others. El-Rhalibi et al. evaluate the performance of multiple planning algorithms for use for digital interactive storytelling (DIS): Graphplan; SatPlan; Heuristic Search Planner (HSP); LPG-TD; Fast-Forward (FF); Metric-FF; Marvin; JSHOP2 [10]. They conclude that JSHOP2 produced the fastest solution in their test bed of a small story of medium complexity, in 0.021 s, with FF (0.023 s), Metric-FF (0.036 s) and Marvin (0.040 s) being very close in terms of speed. We believe a crisis situation is a story, a start, middle, and an end. We intend to build on top of the PDDL for more accurate descriptions of our specific domain of emergency services interactions. Scheduling is similar to planning but is concerned with creating a time dependent sequence, and this is where we feel the constraint satisfaction entwines with scheduling. For an action to trigger, pre checks must be done (will that calculation finish on time?). Orkin [11] states the benefits of goal oriented action planning (GOAP), and presents his modular regressive GOAP, built from the structure of PDDL, and has given great results for the automated planning of non-player characters (NPC) in commercial multi-million dollar games. He states regressive GOAP maps well to NPCs of games and also maps prioritisation of actions if multiple solutions are found to problems. The decoupling of the goals and actions allows for sharing of behaviours, thusly designers only need to write an action once and it is available for all types of agents. Orkin states their planner calculates accurate plans in real-time which is particularly interesting because the simulation we plan to create will be within a highly dynamic scene. We intend to include this type of hierarchical approach to planning in our framework for agents representing emergency services.

We have developed a prototype of the Project Vision Support framework to show the potentials of our approach. The prototype runs on Windows based machines and is programmed using the C# language utilising the Microsoft XNA framework with additional extension methods and classes. Addition libraries such as Awesomium [12] which allows integration of web platforms into.Net applications such as: Javascript, PHP, SQL, HTML5, and web access, and the Nuclex framework [13], an open source set assemble libraries which take care of low level code features such as multithreading and 3D text rendering, have been added, resulting in a procedurally generated 3D world harvesting real-world map data obtained from OSM website. Although the integration of map data is not streamlined, and multiple steps must be taken to include the files into the project solution in Visual Studio 2013, we believe the use of the Awesomium libraries will alleviate this pre-compiled multi-step process.

OSM is an open licensed world mapping project using local volunteers to map their surrounding areas, as well as input from GPS data and other donated services and sources. This community driven project can be kept up to date with their already implemented web and desktop mapping programs by anyone with a web connection and a supporting computer. To counter act the use of amateur mappers, OSM has created quality assurance tools to help created a better quality of OSM data. OSM has been used in academic and commercial projects in hundreds of websites and mobile applications and other devices.

Data from OSM is in XML format. It has four main elements: *Node* (a point on the Earth's surface using longitude and latitude values); *Way* (an order list of *nodes*, if the first *node* if the same as the last *node* in the list then this creates a boundary, such as the edges of a house); *Relations*; and *Tag* (extra information describing the node or way such as *Tag* = *Home*). The OSM XML document is serialised into class objects using the XSD tool. The loaded XML document is sorted and stored in lists of separate types obtained from the *Tag* attribute: buildings; government buildings; hospital boundaries; police boundaries; amenities; and roads of varying types (highways, residential, paths etc.).

During run time, a procedural content generation (PCG) technique is used to create 3D models from the information extracted from OSM. The technique is algorithmic and requires minimal or zero manual input. It works by extruding the 2D GPS data to create 3D models that represent the different buildings in the area. PCG has been used for making every aspect of a complete scene in a 3D game with varying accuracy. Figure 1 shows the prototype of the procedurally generated scene around the Liverpool Women Hospital. The visualisation runs at 47.78 frames per second on average and use 822,000 Kb of system memory. The image shows the hospital highlighted in red and educational areas highlighted in green. The buildings are created by extruding planes from the points within a *way* list, one by one, and used a triangulation algorithm for the creation of the rooftops. The roads are generated in a similar fashion, but needs to be extended with interpolation algorithms to create smooth curving roads.

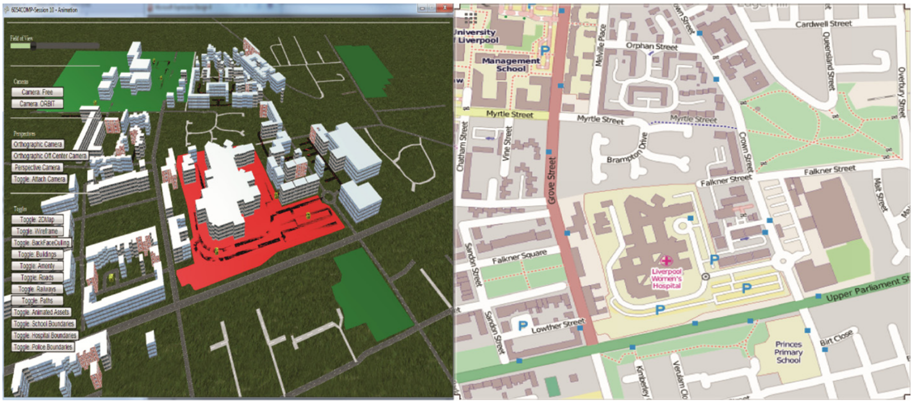

Fig. 1. (Left) Highlighted procedurally generated Liverpool's women's hospital and (Right) the 2D image obtained from OSM web portal of the same scene

4 Summary and Future Work

We have presented initial components which we intended to combine into a consolidated framework for helping and advising correct decision making for crisis managers. We have also presented an initial prototype capable of generating relatively realistic user selected environment from the global mapping service OSM. Further improvements to the prototype are planned as the research progresses.

On the user interface side, we intend to improve the frame rate and reduce the memory usage by means of culling techniques and advanced shaders. We plan to visualise the heuristic pathfinding solutions coupled with constraints such as road width, direction, and traffic density for accurate and realistic pathfinding plans for emergency services. This is made possible because the road network is built of nodes and they are compatible with the A-star pathfinding method.

Modelling the interconnections between entities and infrastructures and representing the visualisation with games technology has been accomplished with the GlassBox Engine [14]. The data-driven simulation integrates simulation units which act as representations of input/output infrastructures such as factories. Each unit has resources such as coal and when active produces power and pollution. The simulation rules trigger animation effect presenting a one to one representation of cause and effect. Addition modular components can be added to extend the functionality of the simulation unit. The units are tailoring to representing: economic loops, residential environments, industrial units, and commercial outlets. The engine is designed to contain tens of thousands of agents which carry the resources used and produced by the simulation units along directed paths. The agents trigger simulation rules when they arrive at their destination, manipulating data and visualising cause and effect. From observations of the simulations, the direction the agent takes is random choice, and the resource allocations are on a first come first serve basis. A issue with the simulation is the size of the map and the cube like nature of the resource and road network layout. We would like to build upon: the resource allocation techniques of agents for the prioritisation of constrained assets; the details of the map using real-world data as well as the scale of map representation.

The Project Vision Support framework that we are proposing is unique in a sense that there are not many existing work in critical infrastructure protection field that make use of a combination of visualisation, planning, scheduling, artificial learning, prediction, and games technology. Thus by doing so, we can greatly improve the quality of the decisions made by crisis managers.

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