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Implementing a Hybrid Space Discretisation Within An Agent Based Evacuation Model

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Abstract Egress models typically use one of three methods to represent the physical space in which the agents move, namely: coarse network, fine network or continuous. In this work, we present a novel approach to represent space, which we call the 'Hybrid Spatial Discretisation' (HSD), in which all three spatial representations can be utilised to represent the physical space of the geometry within a single integrated software tool. The aim of the HSD approach is to encompass the benefits of the three spatial representation methods and maximise computational efficiency while providing an optimal environment to represent the movement and interaction of agents.

Introduction

Within all evacuation and pedestrian dynamics models, the physical space in which the agents move and interact is discretised in some way [1,2]. Models typically use one of three basic approaches to represent space [1], a continuous representation of space e.g. SIMULEX [3], a fine network of nodes e.g. buildingEXODUS V4.07 [4] or a coarse network of nodes e.g. PEDROUTE [5]. Each approach has its benefits and limitations, the continuous approach allows for an accurate representation of the building space and the movement and interaction of individual agents but suffers from relative poor computational performance, the coarse nodal approach allows for very rapid computation but suffers from an inability to accurately represent the interaction of individual agents with each other and with the structure. The fine nodal approach represents a compromise between the two extremes providing an ability to represent the interaction of agents while providing good computational performance.

In this paper, we present a novel approach to represent space, which we call the ‘Hybrid Spatial Discretisation’ or HSD. In the HSD approach all three spatial representations can be utilised to represent the physical space of the geometry within a single integrated software tool. The aim of the HSD approach is to encompass the benefits of the three spatial representation methods and maximise computational efficiency while providing an optimal environment to represent the movement and interaction of agents. Using the HSD approach, the fine nodal approach is used to map the majority of the geometry, providing reasonable speed and an ability to model agent interaction. In parts of the geometry where greater precision is required to model detailed interaction between agents, the continuous approach is used and in regions where knowledge of detailed agent interaction is not required the coarse nodal approach can be used, providing improvements in speed and computational efficiency. This approach is particularly useful in modelling very large complex spaces and urban environments.

In this paper, we examine where the various spatial representations are appropriate for use and we briefly describe the key algorithms developed for the bEX-H implementation, in particular those required to model the continuous and coarse nodal regions. In addition, we provide a demonstration example of how the technique can be applied and discuss related accuracy and performance issues. In the work presented here, the HSD approach is implemented within the buildingEXODUS V4.07 software and is identified as the buildingEXODUS-Hybrid prototype or bEX-H. The buildingEXODUS (bEX) model has been frequently described in other publications [4, 6] and will therefore not be described here.

Software Architecture

The bEX-H makes use of the core architecture of the buildingEXODUS software. The buildingEXODUS software has been modified to allow plug-in modules to be included into the core software using a component oriented engineering approach. This architecture provides a platform whereby new functionalities can be independently developed and incorporated into the model as required. The coarse network and continuous region are examples of two components which have been developed as plug-in modules for the bEX-H model.

Continuous Region Component

When using a continuous approach for the discretisation of space, it is possible to take into consideration a larger number of agent attributes allowing for a wider range of agent behaviours to be modelled. In this section, we describe the planning approach of the agents and some of their advanced behaviours. bEX is based on a multi-agent system whereby each agent is modelled as an autonomous agent which exhibits some forms of adaptive behaviour. In other words, the agent has the ability to navigate in a life-like manner and react to stimuli in its environment. The agent will at some point in its trajectory encounter obstacles. The obstacles can be static such as walls or tables or dynamic, for instance, other agents navigating in the same environment. In this respect, the agent is able to detect these obstructions and react to them accordingly. Some of the additional attributes of the continuous agents are as shown in Table 1 below.

Table 1. Additional agent attributes within bEX-H

Attributes	Description	Quantity
2-D Position	The location of the person in continuous space	Vector
Velocity	Rate of change of displacement	Vector
Acceleration	Rate of change of velocity	Vector
Max Acceleration	Maximum acceleration of a continuous person	Scalar
Orientation	The possible movement directions (headings)	N basis vectors
Body Frame Width	The width of the person excluding the size of the shoulders	Scalar
Body Shoulder Width	The width of the person's shoulders	Scalar

The agent navigates around its environment using two levels of navigation comprising of local and global strategies each influencing different aspects of the individual's movements. Local navigation relates to low level reactive behaviours which are required for collision avoidance. Whereas the global strategy relates to navigation and high level decision making processes for example an agent deciding which route to adopt from their current location to their target.

The path of an agent within continuous space from a start location to an end location can be described as a continuous map [7]. However, the complexity of this map can increase significantly in large geometries for example, buildings with multiple internal rooms and floors. Moreover, the presence of static obstacles within the enclosure makes the path planning process of the agents even more complex. In order to reduce the complexity of the continuous map, the continuous region in bEX-H uses a Navigational Graph. This is a network of waypoints and path segments which is automatically generated in the pre-processing phase. Each waypoint is assigned a potential value which represents the shortest visible arc distance from the external door. Illustrated in Figure 1 is a geometry with multiple compartments and its corresponding navigational graph. However, unlike other roadmap methods such as the visibility graph [7] where the links (path segments) are connected to each and every visible vertex, in the navigational graph, the waypoints are generated only at locations where the internal angles are concave.

The behaviour of the agents is modelled as simple components which can serve as building blocks for simulating more complex behavioural routines. Moreover, this approach allows behaviours to be implemented and tested individually, followed by an incremental integration. Examples of behaviours in bEX-H include:

- Seek - used to steer a person towards a specific goal, which takes into account the agents speed and turning rate,
- Wall Avoidance – ability to detect collisions which could happen in the future given the current trajectory,
- Agent Avoidance and Lane Formation - enables the agents to maintain a desired interpersonal space from each other which is proportional to the agents velocity and the body width of neighbouring agents.

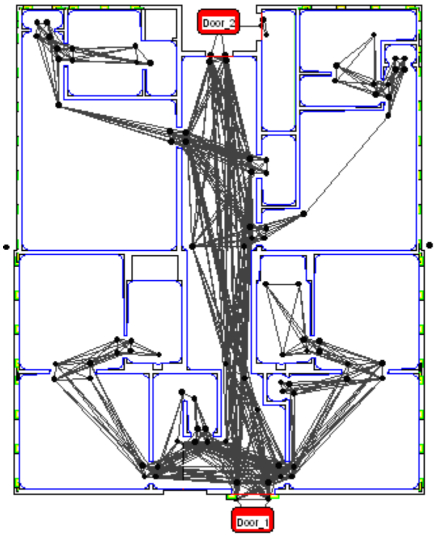


Fig. 1. The Underlying Navigational Graph

The Continuous Region component includes both an adaptive and prescriptive setting for agent travel speeds. In the adaptive setting, the agent considers each neighbouring agent within its perception box (see Agent Avoidance) in turn, and computes a repulsive force. This force is normalised and scaled to be inversely proportional to the squared of the inter-person distance so that distant neighbours have a negligible effect on the assessing agent. The sum of the vectors has a decelerating effect on the agents thereby reducing the travel speed of the agent. In other words, the agents adapt their travel speeds according to population density in their surroundings. In the prescriptive setting, the travel speed of each agent is dictated by a speed density relationship such as, S = k – akD [8], where S is the speed, D is the population density and a and k are constants. As the population density within a room or compartment may be non-uniform, bEX-H uses a localised density calculation approach.

Coarse Network Component

In this section we describe the coarse network approach for representation of physical space, and its implementation within bEX-H. Using this approach, the available physical space can be segmented into partitions whereby each partition can represent a section of the geometry such as a room or corridor. Each partition is a node which is connected via arcs or links to represent doorways or other forms of connectivity in the structure. Each node has a limit on the number of agents it can contain (maximum capacity) while the arcs have a maximum flow capacity, that is, the maximum number of agents that can traverse the arc per time period. There are seven types of coarse node implemented within bEX-H, these are; compartment (general region in which agents exit or enter), intersection (complex region in which flows from different directions merge), interchange (larger version of intersection), gates (narrow metered passage such as turnstiles), stairs, escalators and travelators. The agents within coarse networks transit from one segment to another while the physical movement within the segment itself is not represented. The flow rate through a coarse node in bEX-H is a function of travel speed, travel distance and population density in the region. The travel distance is defined as the distance the agent has to travel, within the node, from their entry point to their exit point. This is implemented using a "Flow to Density Equation" also known as the F-D Model **[5]**. The rate of flow, in a coarse node, is also subject to two other limitations, the maximum capacity of the coarse node and the connecting arcs. When an agent enters a coarse node, their path, travel distance and speed is fixed based on the Flow to Density Equation. The only dynamic events which can affect their dwell time in the node are the capacity of the arcs out and congestion in adjacent nodes.

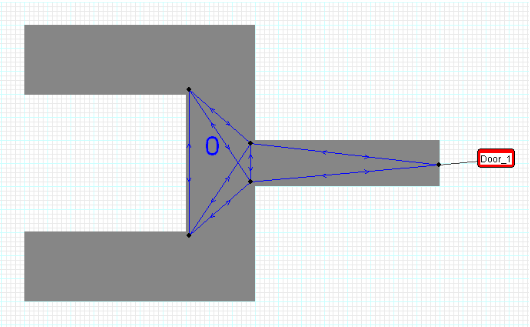


Fig. 2. Coarse Node Implementation of non-convex geometry in bEX-H

The nature of the coarse network approach restricts the modelling of a region with simple geometrical shapes such as rectangles. However, these simple shapes might not be sufficient to accurately model all the complex segments within an enclosure. Unlike other coarse node models, the coarse node implementation in bEX-H allows the creation of non-convex regions as shown in Figure 2. The key data structure behind a coarse node is a mesh which is based on the same principle as the Navigational Graph.

The coarse node model in bEX-H features a behavioural mechanism which enables agents entering a coarse node to adjust their paths depending on the evolving conditions of population density within the coarse node. This feature is implemented through a load balancing algorithm. This algorithm dynamically adjusts the potential value of the waypoints to account for the number of agents heading towards them.

The HSD approach involves the mixing of macroscopic (coarse node) and microscopic (continuous and fine) modelling methodologies which in itself presents several challenges. In the continuous and fine node models, the agents are modelled from an individual perspective whereby their movements, exact locations and behaviours can be tracked. However, in the coarse network approach, the agents are modelled from a global perspective whereby the population is treated as a homogenous ensemble, such that the locations and physical space occupancy of the agents are not represented. bEX-H incorporates some behavioural and movement mechanisms to facilitate the transition of agents across the transition regions. The current implementation of bEX-H features the representation of all six possible interface transition regions namely: Coarse Node ↔ Fine Node; Fine Node ↔ Continuous and Coarse Node ↔ Continuous. The mechanisms for some of the key transitions are briefly described below.

Coarse Node/Continuous Region Transition: This transition represents the two extremes on the scale of granularity. When an agent traverses from the coarse node to the continuous region, its starting location in the continuous region is set equal to the coordinates of the waypoints from which it emerges. This may result in a narrow stream of agents emerging from the coarse node, which may appear unrealistic. bEX-H incorporates a behaviour called Separation which is invoked temporarily by the agents upon entering the continuous region. This generates a repulsive force between agents which is inversely proportional to their inter-person distance. This allows the agents to spread out and make a more realistic use of the available continuous space.

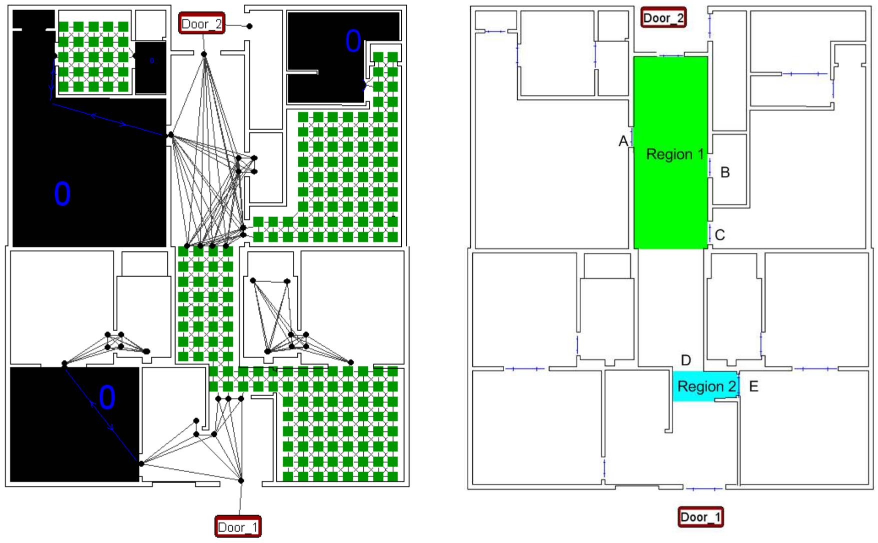
Coarse Node/Fine Node Transition: When agents traverse from coarse nodes to fine nodes, they are re-positioned on the available fine nodes which are connected by arcs to the coarse node region.

Fine Node/Continuous Region Transition: The transition of agents from the fine nodes to the continuous regions is based on the same approach as for the Coarse Node/Continuous Region.

Demonstration Case using HSD approach

In this section we demonstrate the application of the HSD approach to the complex geometry depicted in Figure 3a. In this example a multi-compartment geometry is modelled using all three spatial representations. The building population initially occupies every compartment, thus the scenario investigated demonstrates all six possible interface transition regions: Coarse Node ↔ Fine Node; Fine Node ↔ Continuous and Coarse Node ↔ Continuous. The simulations were performed using a PC with Intel E8600 Core 2 Duo CPU, 3.3 GHz and 8GB of RAM with a 512 MB GeForce GTS 250 graphics card. The experimental set up in bEX-H was as follows:

- 300 agents in total with average density of 2 persons/m^2 in each compartment.
- Free-Flow conditions were imposed on the exits i.e. no flow rate limitations were imposed.
- Fast Walk (Unimpeded walking speed) : 1.5 m/s
- Response Time: 0 s
- Both external exits available and all internal exits are 1.0 m wide.



(a) Geometry modelled using bEX-H involving 40% Continuous (white regions),

(b) Location of Intersection Nodes (shaded regions 1 and 2) in the geometry. All the other

30% Coarse (dark regions) and 30% Fine node regions (grid of nodes).

areas modelled using Compartment Nodes.

Fig. 3. Complex geometry used in demonstration example

In order to demonstrate the differences and similarities between the various approaches, the demonstration case is repeated using; all Coarse Nodes, all Fine Nodes and all Continuous Regions. Ten simulation runs were conducted for each case. In the all Coarse Nodes case, the geometry was modelled by using a combination of compartment and intersection blocks as shown in Figure 3b.

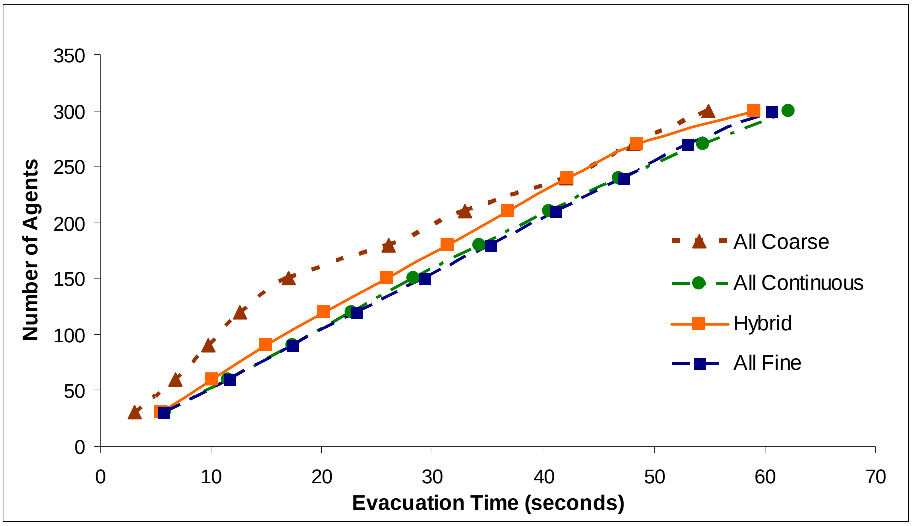


Fig. 4. Time taken for a specific percentage of people to evacuate using All-Fine, All-Continuous, All-Coarse and Hybrid spatial representations

Table 2. Summary of results averaged over 10 simulations

Spatial Representation	Average Total Evacuation Time (sec)
All-Fine	60.6
Continuous	62.2
All-Coarse	54.9
Hybrid	59.1

The evacuation time curves for each case are shown in Figure 4. As can be seen, the evacuation curves for the All-Coarse, All-Fine and Continuous cases are similar, with the All-Coarse case consistently underestimating the egress times throughout the evacuation. The All-Fine and Continuous simulations produce virtually identical evacuation histories up to the final part of the evacuation. During the last 10% of the evacuation, the exit flow rate in the Continuous model tails off at a slightly greater rate than in the All-Fine model. This produces a slightly longer total evacuation time for the Continuous model as shown in Table 2. The average total evacuation time for the Continuous model is some 2.6% slower than the All-Fine model while the average total evacuation time for the All-Coarse model is some 9.4% faster than the All-Fine model.

As can be seen the Hybrid simulation curve falls between the curves for the All-Coarse simulation and the All-Continuous simulation (see Figure 4). The average total evacuation time falls between the two extremes produced by the All-Coarse and the All-Continuous models and is marginally (2.5%) smaller than that produced by the All-Fine model (see Table 2).

More effort is required to determine the impact of using different combinations of the three discretisation approaches on both the accuracy of predictions and the speed of performance. These factors are also expected to be influenced by the type of discretisation that is used to represent specific regions of the geometry and the size and location of the simulated population. However, two primary applications are anticipated for bEX-H, the first are large complex structures such as airport terminals and high-rise buildings or systems of structures such as long tunnels with complex interchanges. In these types of applications, the majority of the structure would primarily consist of a combination of Fine and Coarse nodes. The Fine node structure would be used throughout the bulk of the structure where detailed analysis was required while the Coarse nodes would be used in the far field to represent parts of the structure which are not central to the analysis. The Continuous approach would only be utilised in special areas to represent regions such as pinch points or exits.

The second type of application involves urban environments such as a town or city. In applications involving urban scale geometries, the bulk of the geometry would be represented using the Coarse node approach with key areas such as assembly points or interchanges represented using the Fine node approach. It is unlikely that the Continuous approach would be utilised in such large scale applications.

In addition to the performance enhancements offered by the hybrid version of buildingEXODUS, the software can also be run in parallel using multiple computers [9]. This capability will also be expanded to include the hybrid version of the software.

Conclusions

In this paper we have presented a novel approach, known as the HSD to represent the discretisation of space in circulation and evacuation models. The HSD approach allows enclosures to be modelled using a mixture of the three basic techniques for space discretisation, coarse networks, fine networks and continuous. In the example presented, in which 30% of the domain was represented by the coarse discretisation, 30% by the fine discretisation and 40% by the continuous discretisation, the HSD approach was shown to produce results of similar accuracy to that produced by the All-Fine and All-Continuous approach. While further testing is required, the HSD approach appears to provide flexibility in defining the mix of approaches used in discretising the circulation space within the geometry. Further work is also required to optimise the numerical efficiency of the various plug-in components so that numerical efficiencies offered by using a mix of discretisation schemes can be fully exploited. In addition, the HSD approach will be extended so that it works efficiently within the parallel computing environment currently offered by buildingEXODUS.

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