Generation of Virtual Reality Environments using Expert Systems

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ABSTRACT

This paper describes a system for generating virtual reality environments and, more specifically, three-dimensional geometric models of large-scale urban areas for driving instruction simulators. These models include roads, buildings, road signs and road markings. Such models also find application in other training simulators, virtual reality environments and games.

1. Introduction

Training simulators are used for a wide range of application including airline and sea piloting and road driving [Vinc93]. The present work relates to the latter. These systems are concerned with the real-time visualisation of, and interaction with, a computer model of an environment. The creation of these models, typically polygon- based, has traditionally been a time-consuming task requiring much effort from a database modeller [Dave94]. The models contain a large number of two- and three-dimensional features, such as roads, rivers, forests and urban areas, all of which are modelled by polygons.

In the technique to be described, a given area is divided into land-use zones including residential, commercial, industrial, and park land. A road network is constructed and buildings, trees and road signs are placed under the control of expert system rules.

Overall Structure of the Technique

The generation of the model of an urban area has been implemented as three main tasks: the zoning of the area, the selection and positioning of roads, buildings and other features, and the geometrical construction of the model [McNe94a, McNe94b, McNe94b, McNe94c].

The first task, zoning, is concerned with the layout of the urban area. Each urban area, whether town, city or village, will consist of a number of different zones: domestic, commercial, industrial and park land. The size, shape and distribution of these zones are based on a theory of land-use incorporated in the rules of a knowledge-based system.

The second task, that of populating the urban area with the roads, buildings and road signs of the correct type in appropriate locations, is further divided into three sub-tasks: the generation of a road network, the addition of buildings and the placement of road signs, road markings and other "road furniture".

The generation of a road network is achieved, firstly by determining their style: their length and width, and the colouring and texturing of their surfaces, appropriate to each of the zones.

Buildings are added as the road network grows. The selection of buildings is controlled by a second knowledge-based system, which produces an agenda of building types for each zone, with constraints concerning the adjacency of similar buildings. The placement of road signs and other road markings, is controlled by further production rules, which examine the structure of the completed road network section-by-section, placing signs by the sides of the road as they are required.

2. Land Use

This section describes the method of dividing the urban area into zones according to land usage based on the "Multiple Nuclei Model" [Harr45]. This takes into account the size of the urban area, its location and a few large-scale features. Such as a major road or a river which might be given as initial conditions. The zones are produced from a number of nuclei, which grow in an analogous way to the historical development of a real area. The rate of growth and land usage of the zones is controlled by a rule-based system. This model has been chosen because it is simple to implement and permits a wide variety of land-use patterns to be created. There are four basic types of zones: Commercial, Industrial, Park land and Suburban with the following basic characteristics:

CATEGORY	BUILDINGS FOUND
Commercial	offices, shops, small businesses
Industrial	large businesses, factories, docks
Park land	parks, commons, greens
Suburban	housing, small shops, churches

The allocation rules for the nuclei depend on a number of factors:

- the country in which it is located
- its size
- its elevation
- its surroundings

Urban areas are classified according to size: LARGE (> 1,000,000 sqm), MEDIUM (100,000 to 1,000,000 sqm), and SMALL (10,000 to 100,000 sqm). Details of the land usage depend on the size as follows:

SIZE	LAND USES
LARGE	All types of Housing use (single houses, terraced rows, apartment blocks) All types of Commercial use (offices, shops, supermarkets, shopping malls) Park land (parks, natural areas) All types of Industrial use
MEDIUM	Most types of Housing Some types of Commercial use Some types of Park land use A few types of Industrial land use
SMALL	Some types of Housing use A few types of Commercial (shops)

	Park land Industrial use

Other factors that influence the nature of the development are:

- The elevation of the urban area will have an impact on the styles of buildings, and on the species of trees and other vegetation in the park land regions. Four classifications have been employed: COASTAL (less than 300m), LOWLAND (between 300m and 1000m), HIGHLAND (between 100m and 2000m) and MOUNTAINOUS (above 2000m).

- The climate of the urban area will, together with the elevation, have an effect on the types of buildings and vegetation.

- Different rules are used according to the country (e.g. for England and America). Rules also govern the characteristics of the different types of zones. Commercial regions contain offices and shopping areas. Industrial regions will contain factories and warehouses. Suburban areas have rules to choose types of housing from single dwellings, terraced housing to high-rise flats. The rules for park land regions decide the species of vegetation and whether the area is natural or planned. Additional rules apply to mountainous regions:

- A rule is provided to assign traffic direction according to the country, as `LEFTSIDE` or `RIGHTSIDE`.

After the distribution of the types, numbers and initial locations of the nuclei has been determined, the next task is to cause the nuclei to grow according to a further section of the rule-base.

3. Road Generation

The distribution of road features, which is controlled by an expert system, involves the following: the average length, curvature, width, and frequency of types of junctions. The overall process incrementally adds small sections of road thereby increasing the extent of the network until the boundary of the urban area has been reached. The land usage of the zones of the urban area affects the choice of road style. The generation of buildings accompanies the generation of roads; the selection and placement of buildings are described in the next section. At the outset, starting points are required from which sections of road network can be developed. Two methods are used to provide these initial points: the first allocates points in relation to pre-defined large-scale features, such as inter-city highways and rivers that cross the area, and the second uses points generated at suitably placed points within the zone.

Road Sections

The road network is constructed in a piecemeal fashion, new sections being added to the existing road network where the starting points allow. Each new section is generated from a pattern that dictates its overall size and shape, colour and texture. The style of the road network, which depends on rules based on the type of zone, takes into account the relative proportion of simple straight or curved road sections to the more complicated branching pieces such as T-junctions and cross-roads. Each new section of road is selected according to some criteria as described below.

Road Styles

Patterns of road sections are organised as sets, each set representing a certain style of road, and stored in a central list. This list of sets, `road_patterns`, contains one or more sets, each holding a number of control attributes, followed by one or more patterns.
Each set has a `road_set_name`, such as `commercial` or `industrial`. The `road_set_class` is the class of the road, for example `MOTORWAY` or `A-ROAD`, that the patterns in this set represent. A procedure is used to extract a set, which uses the total list of patterns and the `road_set_name` and returns the subset of patterns required. Below is an example of part of the `suburban` road pattern set:

```
[ 'suburban' ^URBAN
 [ culdesac 1
  [
   [main 0 FRONT 0 0 10 5 4 1 0 [^LEFT ^RIGHT ^FRONT] INTERN 'Road-Suburban']
  ]
 ]
 [crossroad 80
  [
   [start  0 FRONT 0  0   10 5 4 1 0 [^LEFT ^RIGHT] INTERN 'Road-Suburban']
   [centre 1 FRONT 0  0   4  0 4 0 0 []             INTERN 'Road-Suburban']
   [left   2 LEFT  20 -40 10 5 4 1 1 [^LEFT ^RIGHT] EXTERN 'Road-Suburban']
   [right  2 RIGHT 20 -40 10 5 4 1 2 [^LEFT ^RIGHT] EXTERN 'Road-Suburban']
   [end    2 FRONT 0  0   10 5 4 1 0 [^LEFT ^RIGHT] EXTERN 'Road-Suburban']
  ]
 ]
]
```

Building a Road Section from a Pattern

The patterns describe the shape and the layout of the section, but in order to add the section to the road network, a set of polygons must be generated to represent the actual physical shape of the section.
Figure 1(i) shows the specification of the new piece of road, and (ii) and (iii) show how a filler piece is inserted to join the new piece to an existing one.

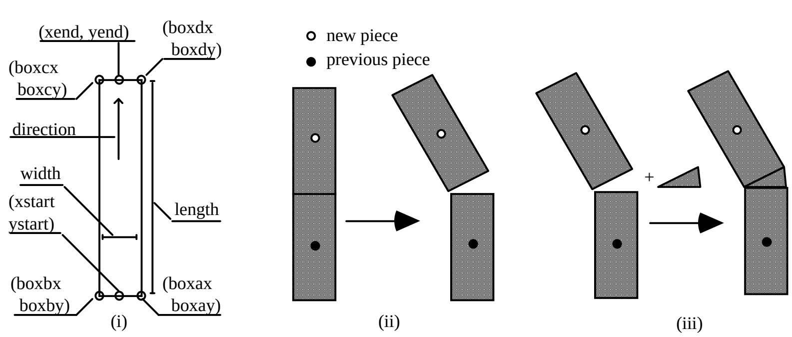

Figure 1: Creation of road pieces

An example of a basic definition of a cross-road pattern is:

```
[crossroad
  [
    [start  0 FRONT 0  0   10 5 4 1 0 [^LEFT ^RIGHT] INTERN 'Road-Suburban']
    [centre 1 FRONT 0  0   4  0 4 0 0 []             INTERN 'Road-Suburban']
    [left   2 LEFT  20 -40 10 5 4 1 1 [^LEFT ^RIGHT] EXTERN 'Road-Suburban']
    [right  2 RIGHT 20 -40 10 5 4 1 2 [^LEFT ^RIGHT] EXTERN 'Road-Suburban']
    [end    2 FRONT 0  0   10 5 4 1 0 [^LEFT ^RIGHT] EXTERN 'Road-Suburban']
  ]
 ]
```

Figure 2 shows the default shape created from this pattern and variations (i) to (vii) when the directions of the horizontal members are modified.

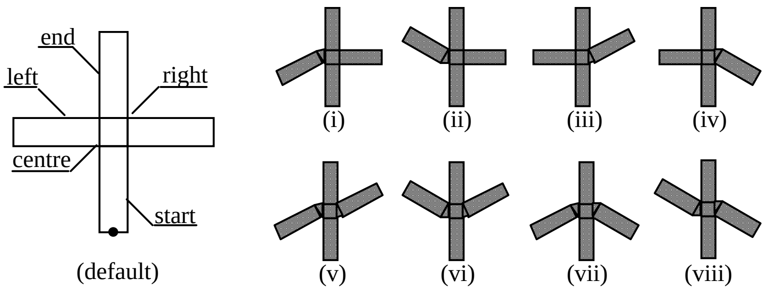

Figure 2: Variation of the Crossroad Pattern

Linking Road Sections into Streets

As road sections are created, it is important to assign them identity and street number codes, for subsequent use. Each piece of road has four lists that denote the pieces that lie to its sides, and these are updated when new pieces (or buildings) are added.
The maintenance of a record of interconnections is important for road-sign placement to identify junctions where road signs will be required.
As an example, consider a starting point with some arbitrary values: a North-facing direction (0û), a street number of 1 and a piece numbered 1, for a crossroad section. When realised, this results in the shape seen in part (i) of Figure 3, with the street and piece numbers shown in part (ii) and the connections between the pieces shown in part (iii).

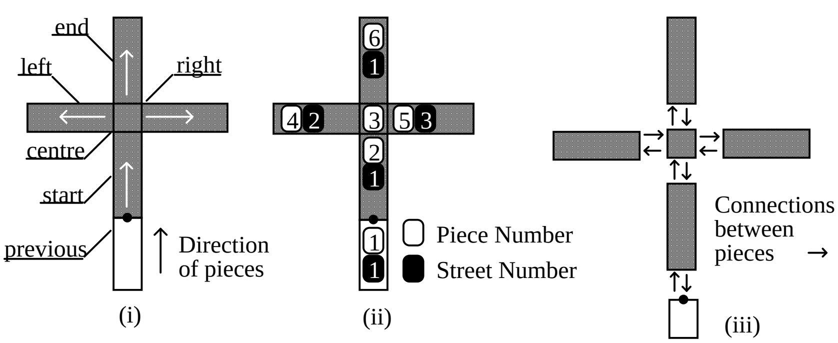

Figure 3: Linking Pieces in a Section

Space Allocation in the Urban Area

When a new piece is placed in the urban area, it is important to test whether the space required is unoccupied, and possibly to alter shape or location of the new piece to avoid a conflict with an existing piece. A mechanism for noting space occupancy is required. This consists of an array of cells. The contents of the cells are checked before placing buildings or new pieces of road. Figure 4 shows some examples of plans of road networks that have been created using these techniques.

Figure 4: Example 2D Road Networks

4. Buildings

Buildings are added to the road network as road building proceeds. The determination of the position and type of the buildings to be placed on each section of road is controlled by a rule-base. The rule-base encapsulates the knowledge concerning the type and number of buildings to be placed within the zones of the urban area, and the constraints on the placement of the buildings with respect to their neighbours. Procedural processes then use this information to select the particular buildings to be placed on a section of road, satisfying the constraints imposed by the rule-base. Each building has a pre-defined size and shape, and is placed within a rectangular plot of land. Plots can be modified in size and shape to allow buildings to be placed within them.

Building Pattern Descriptions

The rules used to decide which buildings to use depend on the size of the urban area and the size and type of the region. Rules in this project use the NEWPSYS toolkit [Slom91]. Examples of rules, from the `buildings_ruleset` for the `suburban` regions of a small urban area are shown below:

```
define :rule hospital_small_urban_area in buildings_ruleset
        [urbanarea size small]
        [region ?ID1 type suburban]
        [region ?ID1 agenda ?A1]
        [NOT region ?ID1 agenda [ == [ surgery == ] == ]];
    [DEL 3]
    [POP11 psys_add([region ^ID1 agenda [^^A1
      [surgery 1 special nonadjacent]]]])]
enddefine;

define :rule house_small_ua in buildings_ruleset
        [urbanarea size small]
        [region ?ID1 type suburban]
        [region ?ID1 agenda ?A1] [region ?ID1 area ?A2]
```

```
          [NOT region ?ID1 agenda [ == [house == ] == ]];
      [DEL 3]
      [POP11 psys_add([region ^ID1 agenda [^^A1
        [house -1 nonspecial adjacent]
        [terrace -1 nonspecial adjacent]
        [smallflat -1 nonspecial adjacent] ]])]
  enddefine;

  define :rule church_small_ua in buildings_ruleset
          [urbanarea size small]
          [region ?ID1 type suburban]
          [region ?ID1 agenda ?A1]
          [region ?ID1 area ?A2]
          [NOT region ?ID1 agenda [ == [church == ] == ]];
      [DEL 3]
      [POP11 psys_add([region ^ID1 agenda [^^A1
        [church 2 special nonadjacent] ]])]
  enddefine;
```

Each rule adds buildings to the agenda for a particular zone. As a result of the rules shown above, five buildings are added to the agenda for the `suburban` region:

```
  [house     -1 nonspecial adjacent]
  [terrace   -1 nonspecial adjacent]
  [smallflat -1 nonspecial adjacent]
  [surgery    1 special nonadjacent]
  [church     2 special nonadjacent]
```

After the new buildings and plots have been added to the network, the interconnection lists of the roads are updated. Each new building is given a unique identification number that is added to the relevant list. Figure 5(i) shows the street and piece numbers, and figure 5(ii) the connections between pieces.

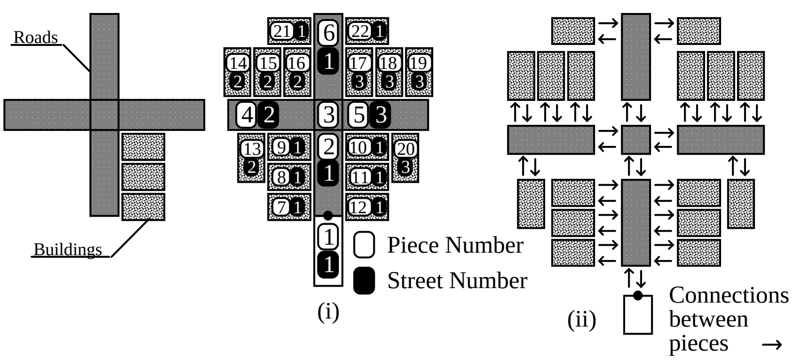

Figure 5: Linking Buildings to a Section of Road Network

5. Road Markings

Road signs are added after the buildings have been placed, to give warning of road features, such as junctions and bends in the road, and buildings, e.g. hospitals and schools. There are four main classes: Road Signs, On-Road Marks, Street Lighting, and Miscellaneous Objects.

- Road signs are the primary class of objects that are placed, and include all fixed, post-mounted signs typically found by the road side. These signs are further categorised by function: warning signs and signs that give information.
- On-Road Marks include lane division and directional lines, no-waiting and no-parking lines, and give-way markings.
- Street lighting and traffic lights are treated as road markings and are included in this category.
- The final case of Miscellaneous Objects includes trees that line the sides of streets.

The addition of road markings is driven by a rule-base that determines, given a certain set of road conditions at a given point, if a particular sign is required. This rule-base is assisted by procedures that examine the road network and place signs at the required positions. The first procedure examines the road network, and re-interprets it into a form more easily used by the rule-base. For the rule base to make a decision, it must have a set of initial facts or conditions, and these are obtained by searching the road network to a given depth and noting the objects and features that exist within a certain distance of the current point. The information must be interpreted to identify road features such as turns and junctions. The final stage is to add the road signs to the road network at appropriate locations and correct orientations, such a s shown in Figure 6.

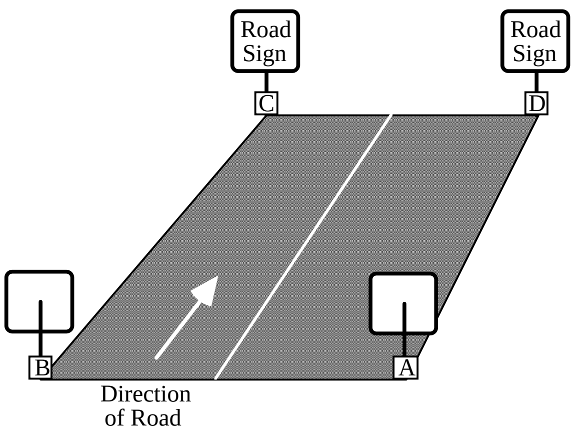

Figure 6: Examples of Road Sign Locations

6. Conclusions

It has been shown that it is possible to automate the tedious manual task of generating three-dimensional model databases for simulator visual systems. The use of knowledge-based tools allows concepts, facts and rules to be coded within an environment which supports facilities to store, manipulate and arrange high-level information. However, such tools do not support many of the complex numerical and graphical processes required to manipulate 3D models. The inference engine has therefore benn integrated with a procedural language, Pop-11 [Barr83]. However, this layer of software can remain hidden from the modellers who need only interact with the system at a high level by extending the rule-set.

7. References

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