THE REALIZATION OF A MEGACITY ENVIRONMENT IN THE DRIVING SIMULATION OF BMW GROUP RESEARCH AND TECHNOLOGY

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Abstract – *For many emerging advanced driver assistance systems and driver information systems investigations in the area of megacities are required. Therefore, a project was set up for implementing this new and challenging environment in the driving simulation of BMW Group Research and Technology. This paper describes the different phases of definition and realization of the megacity. Aspects like the identification of typical complex crossings and the type and density of surrounding buildings are covered as well as an extensive performance tuning. Beside the graphical part, the behaviour and the control of traffic in the megacity is discussed. Different adaptations and extensions had to be done to get a realistic behaviour in this environment and to improve the setup possibilities for achieving a huge number of cars in the close surrounding. Finally, the advantage of the new megacity environment is shown in the context of a driving simulation study about contact analogue navigation.*

Key words: *Database Modelling, Megacity, Traffic Simulation, Contact Analogue Navigation, Head-Up Display.*

Introduction

Driving simulators are used in the automotive industry to develop and test new car systems such as advanced driver assistance systems or driver information systems [Hue1]. Due to the worldwide launch of these systems they also need to be investigated in the area of megacities. On the one hand the behaviour of the driver in such an environment must be considered. On the other hand the systems must be compatible with these big cities or are even designed for this highly complex area. For these reasons BMW Group decided to develop a megacity environment for its driving simulators.

The reproduction of a megacity in a driving simulator comprises many challenging aspects. At first a 3D database with a complex road network and many high buildings is required. In addition to this static environment traffic plays a very important role. High amounts of cars, bikes and pedestrians occur in the streets. These static and dynamics contents of the megacity have very high demands on the performance of the computer hardware in the area of number crunching and visualization. But not only vision, also sound from the engines of the cars and bikes, talking people, construction sites and horns account for a holistic impression. To complete this list even the smell of the city area would have to be considered.

At a first step BMW Group concentrated on the development of the 3D database and traffic for the megacity. An experienced supplier in the field of databases was chosen for cooperation to enter this new demanding area. Due to existing very advanced solutions for cars and pedestrians the main focus in the field of traffic was put on these road users.

Megacity Database

The development and modeling of the 3D database was split into different parts. First of all basic issues and requirements had to be defined to ensure that the aims from the application point of view would be achieved. Then realization was done with a lot of testing and performance tuning. Additionally, an optimization of the rendering software was necessary to process this very complex content in high frequency.

Definition Part

What is a megacity or, to be more precise, what are the typical characteristics of a megacity? Actually, each city is unique and there are as many types of megacities as there are megacities in the world. A megacity in the driving simulation should therefore be representative for all of them in terms of road types, surrounding buildings and traffic. It should provide a generic test environment for new car systems regardless of the location and the specific attributes of the different real cities.

What is the challenging part of these cities' road networks? First, a large number of lanes leading to varying destinations and ending at sometimes very complex intersections. Second, a large number of different intersections within small areas. And third, long roads with moderate deflections providing a far viewing plane.

Complementing the road infrastructure the overall appearance of the 3D environment had to be consistent. Characteristic buildings (i.e. skyscrapers) in high density, accompanying infrastructure (e.g. parking areas, pedestrian areas and advertising billboards) and vegetation were further features to be considered.

In the road network, special emphasis was put on the design of the intersections. If you look at aerial imagery, you will clearly see that there are typically few very large intersections within megacities, many major ones and an almost uncountable number of small ones. Each of these types demands varying (usually high) numbers of driving lanes in complex sequence – within the intersection and on the adjacent roads – many traffic lights and even more traffic signs (many of them lane-specific).

The 3D environment envisaged for the driving simulation was supposed to reflect all of these characteristics. Additionally, the proven tile-based-concept for databases was applied which means that actual databases are composed on the basis of tiles according to a specific study's requirements. In this way, high flexibility and reusability of database tiles is guaranteed.

Three main tiles in the style of a megacity were designed, each consisting of a road network with a very large intersection, partially accompanied by major and smaller ones. The large intersections reflect three different basic types: one roundabout (derived from an aerial image of Sao Paolo, Brazil), one inner-city motorway interchange (derived from a situation in Shanghai, China) and a complex crossing (derived from Potsdamer Platz in Berlin, Germany).

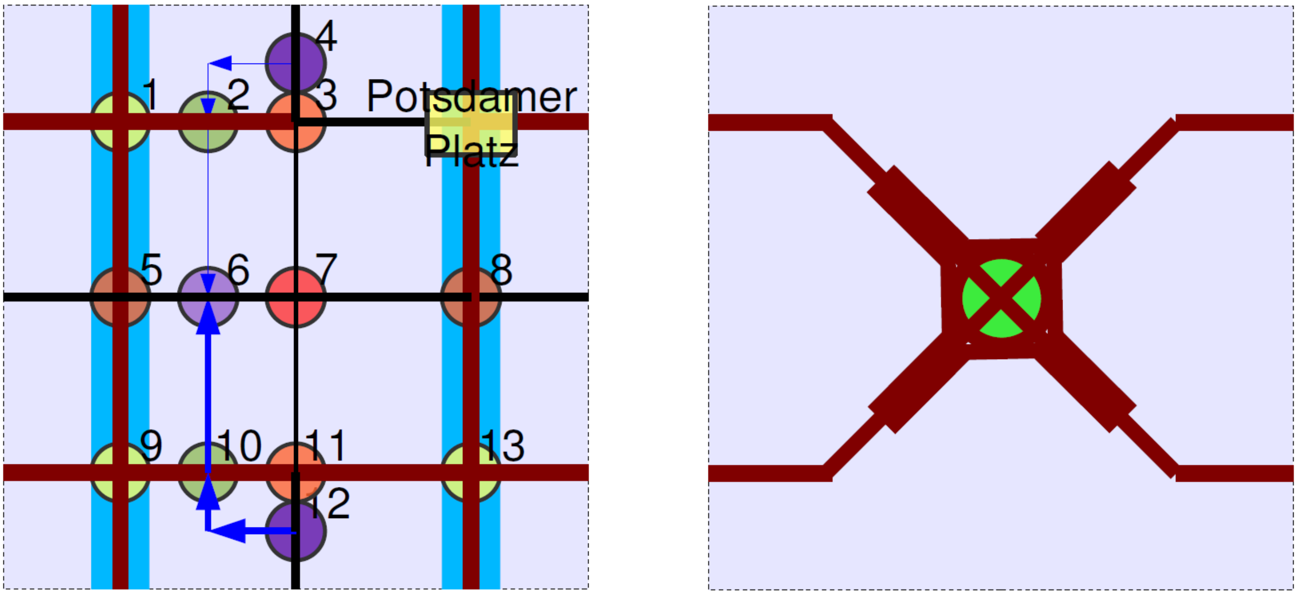

Fig. 1: Tiles with crossings and interchanges derived from real constructions (Potsdamer Platz in Berlin, Germany and interchange in Shanghai, China)

Complementing the three main tiles, a series of further tiles was designed to provide various connections and transitions to smaller road networks. Road and landscape cross-sections had to be harmonized at the interfaces so that the tiles could be arranged as flexible as possible.

Software Optimizations

Modeling database tiles with the mentioned complexity has to go along with performance considerations if they are intended for real-time driving simulation. Achieving the desired visual complexity requires that the image generation software provides a large polygon, material and object count budget.

Previous profiling results showed that the performance depends heavily on the number of distinct objects to be rendered and that the dependence on the number of polygons is weaker. This observation led to specific optimization techniques that reduce the number of objects without decreasing the perceived visual quality.

Occlusion culling is one of these techniques and a city environment is a very good candidate for its application because buildings in a street hide everything behind them. Therefore, performance can be improved without any loss of visual quality. There are two main possibilities for occlusion culling: hardware occlusion culling or using manually placed occlusion planes. The definition of these planes tells the render software not to draw any objects that are fully masked by them from the current point of view. Early tests showed that manually placed occlusion planes provide a better performance so that the database creation and rendering tool-chain was adapted accordingly.

Another optimization technique is based on the fact that there are many objects in the viewing frustum that cover only a very little amount of pixels in the screen area. Detecting such objects and preventing their rendering is called "Small Feature Culling". This technique was applied successfully in this project since the complex city environment contains many small or distant objects.

An easy method to reduce the object and polygon count is limiting the far plane distance. Objects behind the far plane aren't regarded by the rendering software. There are two problems with this technique:

- Objects that enter the visible area become suddenly visible which is easily detected by the human eye.
- There is a visually empty area after the visibility distance, covered by sky instead of buildings and street.

Traditionally, far planes are positioned far from the observer to solve these problems. However, addressing these problems with other techniques allows reducing the far plane distance, which means a significant amount of reduction in rendered object count.

A distance based fade-in method was used to prevent the sudden appearance of objects when they enter the visibility region. First, they are rendered completely transparent (i.e. invisible) but as their distance to the eye becomes smaller, they gradually get visible. To alleviate the problem with the empty area, a 2D background image showing buildings was placed behind the actual 3D world. These two methods helped to reduce the far plane improving performance.

Realization of Database

With the target content and structure of the databases being as complex as laid out in the definition part of the project, the realization was a demanding task: large roads providing room for a vast number of vehicles, large intersections with many individually controlled traffic lights, a populated environment and high buildings along straight, wide roads.

In order to minimize the expected effort of performance tuning a gradual approach was chosen: the layout of the intersections and lanes was designed first and in accordance with the requirements of future studies. All other features were introduced step by step and recurring tests were performed on the actual simulator hardware (IG and projection system). This approach helped to identify basic performance killers (e.g. occluded geometry) early and develop appropriate solutions.

Extensive tests of the scenarios in all driving directions and from the respective eye-points were very time-consuming. The performance analysis led to further optimizations of the static database (e.g. by introducing additional occlusion planes) and with regard to dynamic elements like vehicles and pedestrians. Especially dynamic entities were crucial since the clear aim was to simulate a traffic environment as dense as possible.

The following images will give an impression of the database complexity that was achieved:

Fig. 2: Complexity of road network and graphical content

Traffic Simulation

The simulation of traffic is one of the main aspects if you aim to reproduce a megacity in your simulation. In a first step the major focus was put on three components, each of them emerging in high numbers and used in a complex context: traffic lights, pedestrians and in particular, vehicles.

Configuration of Traffic

In order to reduce the time and effort to configure huge traffic scenarios, appropriate parts can be implemented as re-usable template configurations for single tiles. A transformation mechanism transforms a template definition to a certain instance of the associated tile within a bigger road network. The transformation is done for positions and directions, and also for object names. The transformation of names guarantees unique names if the same tile with the same traffic template is used twice.

The switching of traffic lights is implemented separately for each tile. Each intersection with all corresponding traffic lights is configured considering the individual aspects of turn lanes. Furthermore, the traffic lights of consecutive intersections on main roads are phase-shifted to get long road sequences of green lights (green wave).

In addition to individuals for graphical decoration pedestrians are also used for specific test situations. Therefore, it is possible to define for each pedestrian route, type of movement and speed. The interaction with other road users is part of the simulation software.

Vehicles are the most important road users in driving simulation because they interact with the driver of the simulator at most. From configuration point of view there are three different groups of vehicles in the simulation to consider:

- Vehicles on parking lanes: Parked vehicles are necessary to get a realistic appearance of urban traffic.
- Moving vehicles for heavy traffic: It is important and quite tricky to control vehicles in a way to get heavy traffic around the viewer but not to use as many instances that performance drops.
- Vehicles with special reproducible behavior: These individually programmed vehicles are used for the special situations that a simulator experiment requires.

Behaviour of Vehicles

Multi-lane urban roads with large intersections require some special strategies for driving behaviour to achieve a realistic traffic flow. With regard to megacities, some mechanisms were added and optimized in the driving simulation software [Str1]:

- Approaching a large intersection with red traffic lights, vehicles should decide only once which lane to use to line up and perform this single lane change maneuver.
- Because of small distances between intersections, several driving lanes and heavy traffic it is necessary to change early to a suitable lane for a future left or right turn. Already some intersections before, this has to be concerned with regard to lane change decisions (see fig. 3).

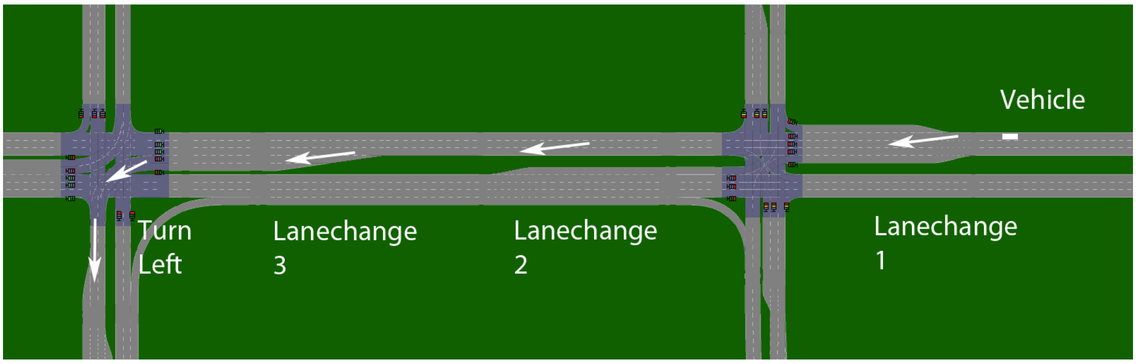

Fig. 3: Multiple lane changes in short distance

- If vehicles turn left while traffic lights are green, in a first step they should drive into the intersection until short before the conflict area with oncoming traffic starts. Then they should recognize when the oncoming traffic stops, and afterwards finish the left turn maneuver immediately.
- Park and unpark maneuvers occur very often in city environments and are an important factor for traffic flow. These maneuvers must work with all parking lanes in the megacity database.

Traffic Control

To create the impression of dense traffic around the driver of the simulator – what he expects from a megacity – and not to run into any performance penalties, vehicles must be activated and deactivated in a tricky way. The aim is to get a certain amount of vehicles at the right time and position.

With the definition of single individually controlled vehicles this would be too much effort. A traffic bubble in which vehicles are created at a certain distance in front or behind the driver of the simulator works well at linear courses like highways or country roads, but is not suitable for megacities with dense road network layout. For this reason two new features were implemented in the driving simulation software:

- The activation or deactivation of vehicles on basis of occlusion conditions. In this way vehicles can be activated e.g. in a crossing road very close to the intersection, while they can't be seen by the viewer. The advantage of this approach is that activated vehicles get very close to the viewer in a short time and cannot be delayed e.g. by red traffic lights on their way to him. An ideal approach to test the visibility is the usage of occlusion planes which are created mainly for the rendering system.
- The introduction of "traffic sources". A traffic source has a defined location, e.g. close to an intersection, and one or more routes starting from it, e.g. leading straight, left and right over the intersection area. Detailed parameters can be specified, e.g. the total number of vehicles per traffic source or the percentage of vehicles per route. With these parameters the traffic can be trimmed easily.

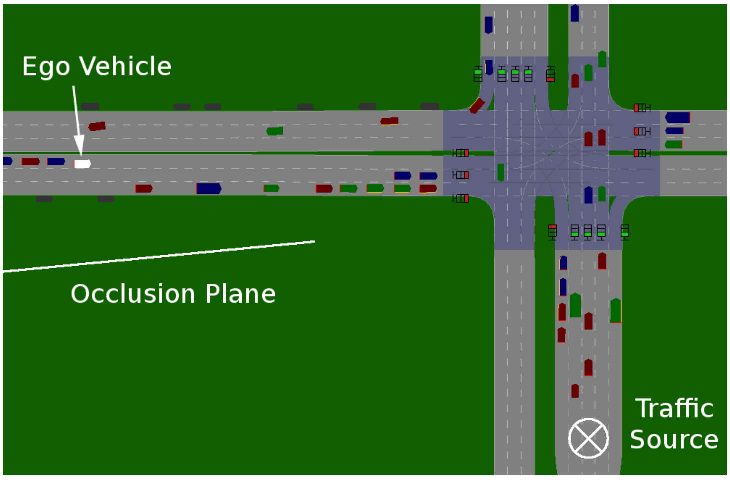

Fig. 4: Occlusion plane to check visibility of traffic source

Result

With the realization of the discussed extensions in vehicle behaviour and traffic control the traffic flow and density could be improved a lot and the aim to provide realistic vehicle traffic for studies was achieved. The traffic density can be easily adjusted and the scenarios are well reproducible even if the drivers of the simulator behave differently. The efficient setup method for vehicles and the overall performance tuning allow simulating traffic on a level that provides a good megacity impression. In fig. 5 a scenario is shown where 200 vehicles in the close surrounding of the viewer are computed.


Fig. 5: Complexity of traffic. Left: Driver's view.
Right: Observer's view; driver is in white BMW X1 close to the middle of the picture.

Application: Contact Analogue Navigation in Head-Up Display

The new possibilities emerging from the developed megacity environment could be proven in first driving simulation applications. One of these was a study about a new navigation concept in the head-up display of cars. In contrast to the classic approach with symbols, lane based navigation information was displayed contact analogue. This means, that the information is positioned and formed so that it appears to be attached to real objects in the scene from the driver's perspective (fig. 6). By means of the study the potential of such a contact analogue navigation should be tested.

Fig. 6: Contact analogue lane marking and realization of head-up display in driving simulation

A special setup in the simulator was necessary to realize a head-up display with big horizontal (20°) and vertical (5°) field of view. As shown in fig. 6 a combiner screen was installed in front of the driver which reflected the image of a 50”-Monitor on the roof of the cabin to the driver’s eyes. With this setup the driver had the impression that the information shown on the monitor was located at a specific position in front of him. In comparison to directly render the head-up information in the driving scene the shown setup provided a much more realistic impression of a head-up display due to the separated display technique.

The new navigation concept in this study consists of sequences with symbolic and contact analogue information to mark the lanes which should be used to drive in the recommended direction at intersections ahead. Details can be read in [Jan1]. A database with multiple lanes per driving direction and complex intersections in short sequence is an important requirement for such a kind of study. Therefore, the developed megacity was an ideal environment for testing the navigation system.

Additionally, the requirements on the visualization were very high in terms of field of view as well as spatial and temporal resolution. On the one hand the driver had to be able to look into crossing roads and be aware of the exact position of the own car in the street. On the other hand, traffic signs, road markings and other important contents had to be displayed clear and sharp even if they were small due to the distance. For these reasons, the study was conducted in a simulator with 220° horizontal (120° left and 100° right) and 45° vertical field of view and a resolution of 4’ / OLP [Hue2].

Rendering the megacity in such a high resolution configuration with 60Hz was one of the big challenges of performance tuning.

The result of the conducted study can also be read in [Jan1]. In general, the new contact analogue concept for lane based navigation was preferred in many aspects in comparison to a classic solution.

Conclusion and Outlook

The reproduction of a megacity environment in the driving simulation needed a lot of effort, but the results are convincing. The envisaged aims of BMW Group Research and Technology were achieved and first studies already have been conducted on basis of this new environment. Still not all aspects of a megacity are realized. Among others two major key aspects can be identified for further development.

First, traffic simulation must be enhanced with the typical behaviour and density of motor bikes and bicycles. They play an important role to reproduce the high dynamics of traffic in an urban area and to provide a further type of road users with specific properties.

And second, an extension of the sound simulation is necessary. Not only sound from the own or other vehicles can be heard in cities, also walking and shouting people, construction sites and music from open stores generate noise, which is characteristic for megacities.

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