

## Urban Fusion

### Visualizing urban data fused with social feeds via a game engine

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**Abstract**— This paper presents a framework which allows urban planners to navigate and interact with large datasets fused with social feeds in real-time, enhanced by a virtual reality (VR) capability, which further promotes the knowledge discovery process and allows to interact with urban data in natural yet immersive way. A challenge in urban planning is making decisions based on datasets which are many times ambiguous, together with effective use of newly available yet unstructured sources of information like social media. Providing expert users with novel ways of representing knowledge can be beneficial for decision making. Game engines have evolved into capable testbeds for novel visualization and interaction techniques. We therefore explore the possibility of using a modern game engine as a platform for knowledge representation in urban planning and how it can be used to model ambiguity. We also investigate how urban planners can benefit from immersion when it comes to data exploration and knowledge discovery. We apply the concept of using primitives to publicly available transportation datasets and social feeds of New York city, we discuss a gesture-based VR extension of our framework and lastly, we conclude the paper with feedback from expert users in urban planning and with an outlook of future challenges.

**Keywords**- urban planning; transportation planning; Big Data; visualization; game engine; virtual reality; Unity

#### I. INTRODUCTION

Increasing population, urbanization, and motorization growth continues to pressure urban systems. Data mining and data analytics deliver information about critical urban phenomena. The combination of static data sources (e.g., geographic maps, point-of-interest (POI), etc.) with dynamic data streams (e.g., sensors data, social media, etc.) improves the quality of new knowledge that can be deduced. Decision makers prefer to use models based on high resolution spatial and temporal datasets to become more realistic about uncertainties related to different urban planning scenarios. Though modeling ambiguity is still a challenge [18, 7].

Visual representation of data from multiple sources adds a layer of complexity in urban science [8, 19]. To bridge the complexity with user friendliness, some attempts use game engines as a tool to tell a narrative within the context of urban modeling [2, 3]. Other attempts fuse static data sources and POIs with dynamic streams from social media [13, 11, 1, 12, 22]. Studies related with transportation and social media use were elaborated in [4, 15, 10, 16]. These contributions

are targeting specific problems and are developed for 2D desktop screens. This makes them not easily applicable for other domains within urban planning and they do not support immersive visualization techniques like virtual reality, which could be beneficial for data exploration and knowledge discovery.

Therefore, we investigate the possibility of using a modern game engine as a multi-domain visualization platform for knowledge representation in urban planning and how they can be used to model ambiguity. We also investigate how virtual reality can further promote the knowledge discovery process by allowing users to interact with urban data in natural yet immersive way.

Our motivation is that game engines have evolved over the years into capable software tools not only for interactive simulations (games), but also into a testbed for novel visualization and interaction techniques. Their latest iterations support rendering techniques like geometry instancing, which allows rendering large number of identical meshes (106 and more) without compromising refresh rate. They also have a build-in support for VR headsets. Game engines can be therefore seen as a possible interactive and real-time tool for Big Data visualization in urban planning and other areas.

For the purpose of this paper, we use publicly available transportation data and Twitter-based social media feeds. We look into concepts of visualizing ambiguous urban data and we identify the types of primitives that are suitable for this purpose. We then discuss more thoroughly how our framework was implemented and how we deal with VR-support and gesture-based navigating and controls.

We then evaluate our approach, discuss outcomes and describe future challenges.

#### II. VISUALIZATION CONCEPTS

Urban data from sensors or citizens tends to be ambiguous and noisy and requires several processing steps such as filtering, applying of several aggregation steps and spatial mapping to turn it into useful information for urban planners. Unfortunately, this point cloud type of information overlaid with urban terrain is still less informative than simple statistical data shown in simple empirical graphs [6].

For a better readability in 2D graphs, curves are often fitted to scatter plots with an approximation function to capture key patterns in the data, while leaving out noise or other fine-scale structures. This approach can also be applied

on 3D map scenarios by converting surface and point information into density and volumetric forms that can be much easier understood by the audience. In 2D multimodal time series data, graph correlations play a huge role to identify potential causal relationships between them e.g. traffic conditions and perceptions of the public transport systems raised through social media. Whereas graph correlations are easier to spot, correlations between volumetric forms are not, as their forms can be embedded in one of the other and become easily invisible. For this reason, we experiment with using game engines for see-through, color mixing and immersive virtual reality approaches in 3D space specific to urban data. We found that see-through approaches may become quite complex due to their 3D character, whereas color mixing seems to be quite intuitive. The resulting color depends hereby on the source colors applied in the volumetric components and the density with the degree of overlapping. The majority of urban phenomena evolve over time and thus require a temporal aspect in their graphical representation. One way of doing this is to show animations that illustrate repetitive behavior patterns.

The workflow of using game engines within the context of urban modeling is no different from other visualization tools, though some specifics arise from the need for visualization types, which respects internal optimization of those engines when it comes to handling objects in 3D space [5]. Visualization belongs to the Data Exploitation part of the Big Data chain [14] and therefore it deals with similar 3 “Vs” (volume, velocity, variety) as described in [8, 9].

*Volume* in visualization represents the amount of objects / record that need to be shown in a 3D scene at the same time. More objects mean better models, but it comes at a cost. Game engines operate / update their state at several frames per second (FPS) and generally, the higher the number the better. Optimization methods (grouping, offloading CPU intensive tasks to GPU) or alternate graphical representations need to be explored to maintain desirable FPS counts, because dealing with very high number of objects is taxing.

*Velocity* in visualization refers to the creation speed of object / records. This requires consideration and potential trade-offs as all objects do not have an identical lifespan. Another aspect of velocity is how and at what moment in time data are fed to the renderer. Different strategies need to be applied for data stored in local / remote storages.

*Variety* in visualization means using different types of objects to promote knowledge and learning. While game engines can display virtually any object of any shape, picking the right type for data visualization is essential. There are several visualization types that are suitable for different data visualization purposes and most of them are offered by a game engine as primitives:

- Planes – 2D maps and cartography
- Terrain – 3D density maps
- Particles - 3D dot maps; per record movements
- Cubes – 3D histograms
- Spheres – 3D scatter plots

Fig. 1 shows some of the available primitives and how they could be utilized for data visualization and analysis.

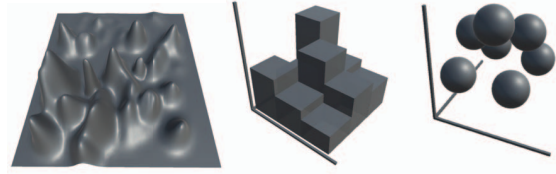


Figure 1. Primitives for data visualization

### III. IMPLEMENTATION

Since our goal is to provide expert users with a tool that visualizes urban data fused with social network feeds, we use publicly available transportation data of New York taxis [17] and Twitter-based social media feeds [20] as the input data to be processed by our visualization tool. We deliberately select the period from 1.6.2016 till 30.6.2016 for analysis. The transportation data consists of approximately 16 million records of individual taxi events, stored in a CSV format. Every record contains 21 different parameters, including information about pickup time and location, dropoff time and location, passenger count, fare and others. The social media data specifically pre-selected for the area of New York city is stored in a JSON format. Each day of the tested dataset consists of around 15000 tweets, each tweet containing 22 parameters, including its ID, time, content, latitude and longitude. Our approach uses the Unity game engine [21] as the underlying technology for processing and rendering. The decision to use Unity as the main development platform is due to its build-in support for primitives (cubes, spheres, terrain, planes, particles) that are beneficial for data visualization and analysis, which could lead to reduced development time. Its straight-forward scene editor and scripting support allow rapid prototyping too. Moreover, it supports VR and has an extensive support for plugins which makes it more versatile. For the purpose of finding an optimal blend between complexity of input data and user friendliness, several mockups are designed by a graphic designer (Fig. 2).

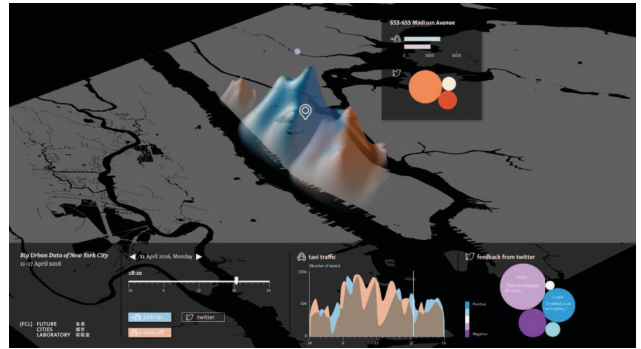


Figure 2. One of several mockups designed as a reference for the tool

Since this research work was conducted through a transdisciplinary research program, the mockups were presented to a pool of expert users in urban planning at FCL and their feedback led us to the following design decisions:

- to show the trends and progression of transportation data in a form of animated, see-through 3D density maps to spot repetitive patterns more easily
- to broaden the visualization with corresponding 3D histograms to accompany the density maps for sake of perceiving numerical values of events
- to represent every social media feed as a separate entity, with tweets relevant to public transport distinguished from others by a different color
- to use minimalistic user interface which focuses more on the actual content, while having the power to change parameters of visualization easily
- to support VR for more immersive visualizations

#### A. Hardware Setup

The workstation used for the purposes of the presented paper is a PC desktop computer running Microsoft Windows 10 64bit operating system and equipped with an Intel Core i7-6800K CPU clocked at 3.40GHz with 6x2 cores available for the OS, 32 GB DDR3 RAM and 1TB SSD + 3TB hard drive. The workstation is also equipped with an NVIDIA GeForce GTX 1080 GPU with 2560 CUDA cores and 8GB GDDR5 RAM.

#### B. Software Platform

The developed software tool is based on the Unity game engine. The version used was Unity Professional Edition version 5.5.0f.

#### C. Visualization Implementation

The developed tool uses terrain-based 3D density maps and cube-based 3D histograms as a mean to represent trends in transportation data on a plane-based map of New York City. Furthermore, it uses sphere-based 3D scatter plots for relevant user tweets (Fig. 3).

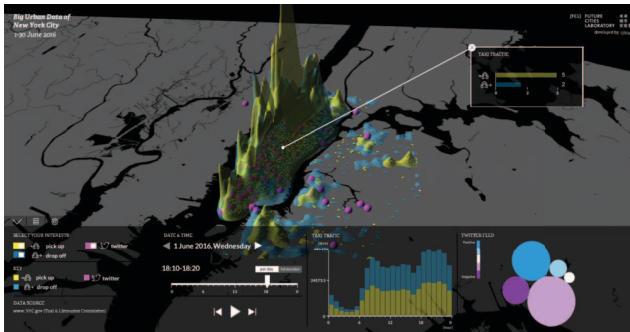


Figure 3. The complete visualization with pickup and dropoff 3D density maps, 3D histograms, Social Media data, dashboard and details panel

Initial analysis of the publicly available transportation data of New York taxis has shown that the number of record

per day is around 350000. Because the input datasets are spatial and temporal in their nature, we use spatial dividing based on record's latitude and longitude and temporal grouping of records into 10 minutes long time groups based on pickup and dropoff times to have the input information for the chosen visualization types.

First limitations of the visualization are exposed by the need to use pre-fixed sizes of terrain objects in Unity. The available terrain heightmap resolution sizes are one of the following: 33×33, 65×65, 129×129, 257×257, 513×513, 1025×1025, 2049×2049 and 4097×4097. These sizes are in Unity's own 3D world units. This limitation has set the resolution for accommodating 3D histograms as well. To provide users with different levels of detail based on camera positions, 3 heightmap resolutions are supported. Each smallest cell in 65×65 resolution corresponded to 180×180m<sup>2</sup> in real world metric units. For resolution 129×129 it is 90×90m<sup>2</sup> and 257×257 corresponded to 45×45m<sup>2</sup>.

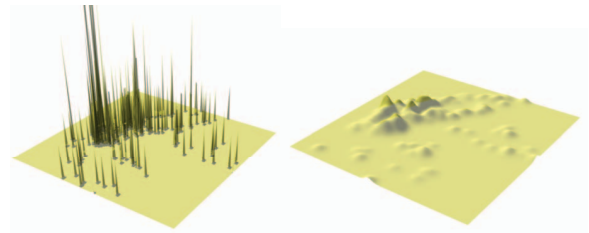


Figure 4. The non-smooth (left) and smoothed (right) form of a pickup 3D density map

The input information for each 3D density map is a two-dimensional height matrix. The matrix is filled by spatial division of every taxi record. Separate 3D density maps were developed for visualization of pickup and dropoff taxi events. Fig. 4 shows the non-smooth and smooth representations of pickup events happening in New York, US on the 6th of June 2016 in pre-selected area with the smallest cell representing 90×90m<sup>2</sup> in real world. Animation of density maps is performed by feeding the appropriate terrain object with interpolated data between two defined points of time. The terrain smoothing is realized by a modified smoothing function from Terrain Toolkit v1.0.2. Different color mixing is used for pickup and dropoff density maps.

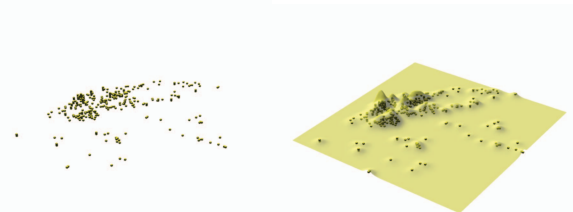


Figure 5. 3D pickup histogram (left) and its alignment with 3D density map (right)

Each 3D histogram is constructed using the same height matrix as its appropriate 3D density map. The height of every cube is corresponding to number of pickup/dropoff events happening at particular location and each cube has the same real-world dimensions as corresponding smallest cell of 3D density map. Because every element of the histogram contains the same mesh, we use GPU instancing to draw the cubes with only a few draw calls. Fig. 5 shows the spatial alignment of pickup histogram and pickup density map in pre-selected range area both of which having the resolution of  $90 \times 90 \text{m}^2$  in real world. The corresponding 3D density maps and 3D histograms are spatially aligned with an outline-based map of New York (plane object). Transparency is used to visualize the alignment as a see-through. The spatial alignment is realized by matching real-world latitude and longitude of every game object with Unity's own 3D world units.



Figure 6. Tweets in 3D space (left) and their alignment to the map object (right)

A lexical analysis is performed on every tweet instance, by analyzing its content value (actual tweet text) to detect keywords relevant to traffic data. Afterwards, using its latitude, longitude and time parameter, every tweet is spatially and temporally represented in the scene respecting the same space and time conventions as 3D density maps, histograms and map objects (Fig. 6). To reduce the number of draw calls, we again use GPU instancing to draw the tweet objects more efficiently, because they contain identical meshes. The co-relevance of transport data and social media feed is achieved by visualizing every tweet with the same conventions as for pickup and dropoff taxis (Fig. 7).

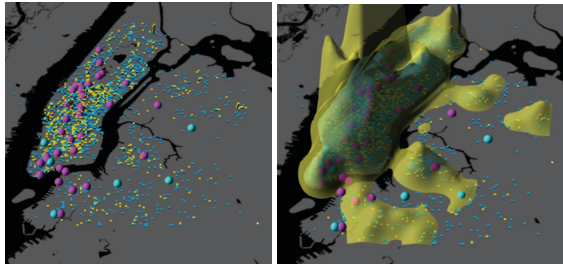


Figure 7. Spatial and temporal co-relevance of transportation and social media data

The co-relevance plays a huge role in ability to perceive correlation between different modalities of visualized data.

#### D. User Interface

One of our focuses is to evaluate possibilities how to empower users with the ability to analyze urban data in a simple and user-friendly way. After several user interface (UI) mockups are presented to experts, the concept of a fully dynamic Dashboard is introduced. The dashboard (Fig. 8), divided into 4 sections, allows to change visualization parameters (section 1), navigate through data in time (section 2), quickly perceive overview information of transport data per active day via a stacked bar graph (section 3) and also to see the results of linguistic analysis of social media per active day via a multi-colored bubble graph. To get visualization values, user use the mouse to click the objects of their interest. After clicking, a Details Panel is shown (Fig. 3) with appropriate values of the clicked objects.

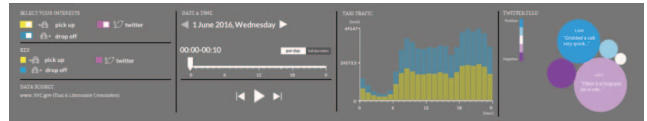


Figure 8. Dashboard

A size-reduced version of the dashboard (Fig. 9) is implemented as well.



Figure 9. Mini Dashboard

The Mini Dashboard provides users with an overview of visible transportation and social media data per every time group (representing 10 minutes).

#### E. VR-Support and Hand-Based Controls

Using Unity's VR and plugins support, we provide users with a more immersive version of the visualization. We use HTC Vive as the VR headset with room-scale tracking and LeapMotion for hands tracking. We opt for natural, gesture-based controls over using external controller and provide users with two types of head-up-displays (HUD). By default, no HUDs are visible so the users have an unobscured view on the visualization. To change visualization parameters, users have to raise their left hand and an opaque Dashboard HUD will be presented to them (Fig. 10) with all the functionalities of the 2D dashboard (as mentioned in 3.4). To get values of the visualization, users have to use their right hand to touch the objects of their interest. After touching, a transparent Details HUD is shown with appropriate values of the touched objects.





Figure 10. Dashboard HUD (left) and details HUD (right) in VR

#### IV. RENDERING PERFORMANCE

We use Unity's Profiler tool to measure performance of the visualization for a regular FullHD (1080p) representation and for the VR version.

Fig. 11 shows the profiler's graphs (green represents rendering times, blue represents pre-processing time, orange represents VR device overhead) for a case when all the objects (3D density maps, 3D histograms and tweets) are visible on the HD screen or on the VR headset, with the density maps resolution set to  $129 \times 129$ . In both cases, the game engine provides a stable visualization with the framerate above 60 FPS.

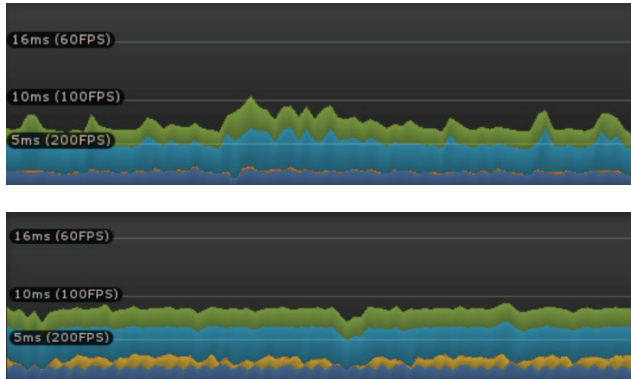


Figure 11. LCD (Up) and VR (Down) Representation with All Objects Visible and No Density Maps Animation

The performance test shows that our framework and the game engine itself is able to provide users with optimal refresh rates for both 2D and VR versions when the parameters of visualized objects are set accordingly. This enables users to perceive the visualization, exploration and interaction in real-time and allows to avoid motion sickness in virtual reality as well.

#### V. EVALUATION

For evaluation, we focused on data exploration and manipulation. We conducted interviews with five experts in urban planning at FCL. During the interviews, we first explained the workflow of manipulation with urban data and social feed specific to our work, then we showed the differences between interacting with 2D and VR version of the tool. Then we asked the experts to work with both

versions themselves and to provide us with their feedback. Each interview lasted for around 20 minutes and their feedbacks are summarized as follows.

In general, all experts agreed that the user interface is intuitive and well designed for both versions and that it supports the analytical task. They also agreed that the input response, taking into account the large number of object dynamically visualized on the 2D screen or in the VR headset is real-time or near it. They especially liked the animation of both 3D density maps in time, which allowed them to perceive repetitive behavior patterns more easily compared to 3D histograms. Abilities to get numerical values of every visualized element (taxi records and social media) at any moment and being able to manipulate time in a continuous and smooth way were evaluated highly. The VR version was preferable over the 2D version for exploration and knowledge discovery purposes. The experts acknowledged that the immersive visualization allowed them to focus more on spatial and temporal aspects of the presented datasets. They also appreciated no visual clutter while working with the VR version. We did not receive any feedback regarding motion sickness while wearing the VR headset.

The experts provided us with comments on how to further improve the user interface and interactions related to both versions.

#### VI. DISCUSSION

Unity is able to handle very high number of objects filled with information from external sources like transportation traffic or social media feeds when spatial and temporal grouping of data is applied. Using optimization methods like GPU instancing can further improve rendering performance and the game engine is ultimately limited only by the workstation's available memory. But filling objects with data is a time-consuming task. This is when streaming data from external servers can be highly beneficial. Maintaining a stable FPS is needed to provide users with the sense of real-time input and interaction. Unity's build-in UI support makes creating visual interfaces easy and straight forward. Unity's build-in VR support is beneficial in cases when users are interested in more immerse visualizations and Unity's plugin system provides a possibility to experiment with novel ways of interacting with objects and interfaces.

Our experiences are that natural variations in time and place occur frequently in large scale urban systems and often leave a confusing impression when viewed by the user. To deal with this uncertain conditions mean-variance evaluation based on historic data could be applied to separate frequent from random behavior. A corresponding visual metaphor for uncertainty could be the degree of opacity / fogginess of the respective volumetric form for a better behavior pattern identification. We believe that game engines have the rendering capabilities to allow visualizations to deal with these conditions too.

## VII. CONCLUSION

In this paper, we present a framework based on Unity game engine which allows urban planners to navigate and interact with large ambiguous data sets in real-time, enhanced by a VR capability.

Other frameworks / game engines were considered too, but Unity has proven itself as highly capable for (multi-modal) data visualization and analysis.

By utilizing build-in terrain, cubes and spheres objects and by spatial and temporal grouping of them, we are able to visualize publicly available transportation data of New York taxi and fuse it with social media feeds while maintaining desired refresh rates. Moreover, we provide urban planners with an immersive version of our framework as well and we use intuitive yet natural gesture-based controls for it.

We plan to further extend the visualization capabilities of the framework to support even more input modalities like noise, pollution, weather data and other. We also plan to extend our framework to deal with uncertain conditions in data by utilizing volumetric fog or similar rendering techniques.

The paper is a joint work of authors from computer science, architecture, graphic design, communication, and urban development and contributes to the ongoing problematics of visualizing information and knowledge.

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