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Key Technologies of Urban Computing in Big Data Era

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***Abstract*—In Big Data era, it is difficult to build effecive intelligent analysis and decision support system as urban computing information resources are incomplete and the horizontal integration and contribution of information is seriously inadequate. Intelligent analysis and decision support system largely depends on the seamless connection of data fusion analysis and information presentation with real scenes. This paper presents the major issues that urban computing is facing. It analyzes three key technologies of urban computing in big data era, namely, the 3D spatial-temporal expression and establishment of urban scenes, the semantic computing and fusion of urban multi-modal data, and the on-the-spot analysis and decision-making of urban events.**

Keywords- big data; urban computing; smart city; intelligent decision making

I. Introduction

With the continuous progress of urbanization, China's population and resources have been rapidly concentrated in cities, and the proportion of urbanization has exceeded 50%, becoming the most populous country in the world. Although urbanization improves the living standards of people, but also makes the city's social environment become increasingly complex. The main results are: complex spatial structure, high population density, large mobility, huge and complicated social relations, severe traffic congestion, and frequently happening accidents and malignant events, etc. The complex social environment has become the obstacle of urban development, which brings great challenges to urban management and public security protection. In addition to management consciousness and policy factors, more lies in the management decision makers' lack of timely, comprehensive and accurate understanding of the key elements such as object, behavior and status, time, place, origin involved in urban complex events. As time goes on, these factors tend to have high dynamics. The existing information technology lacks mechanism and means to timely capture and perceive these elements, which results in inaccrate and tardy decision-making, inadequate and inconvenient service. These problems have become the bottleneck of the healthy and sustainable development of cities. How to solve them effectively is extremely urgent.

"Urban computing" thus came into being. With the coming of the big data era, diverse and social information perception model makes the information space, the physical world and human society gradually merge, deeply relate and interact under the urban environment, forming an organic whole with closed loop feedback loop, namely an "information-physic-society" ternary space. The ternary space fusion system under urban environments is extremely complex and highly dynamic, involving not only information acquisition, processing, transmission, analysis, understanding, feedback and other links, but also the human's reasoning and decision-making control in the loop , as shown in figure 1.

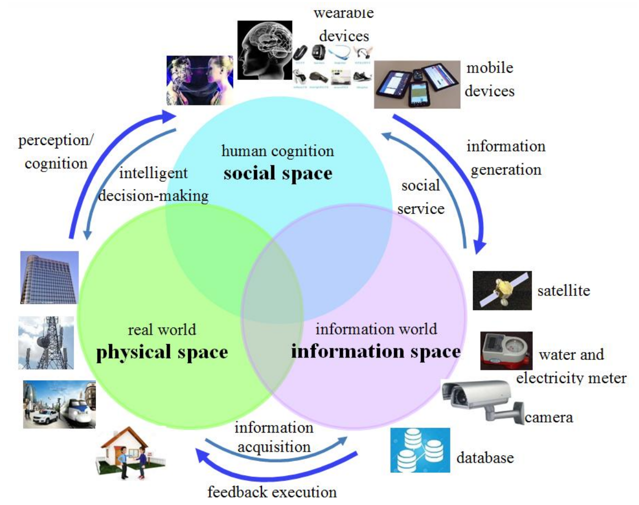

FIGURE I "INFORMATION-PHYSIC-SOCIETY" TERNARY SPACE

Urban computing is an interdiscipline subject, which realizes the intelligent fusion of the ternary space under urban environments through the integration, analysis and mining of huge unban heterogeneous data and provides computing model for the comprehensive perception, analysis and understanding, and decision-making service of modern urban complex events. In 2009, IBM proposed the concept of "smart earth", and the research of urban digitization and intellectualization related theory and technology has attracted much attention from international academic circles. In 2012, "How Smart is Your Home?"[1] and "How Smart is Your City?"[2] was published in succession in Science. which states the importance of the intellectualization of cities, and points out that, although data of urban environment can be acquired through various information collecting devices, but to achieve family or city intellectualization, the key is to establish a unified intelligent supporting environment, and integrate all kinds of information together seamlessly to form an organic whole. In recent years, urban computing has received extensive attention in our country and has been strongly supported by the government. The 12th five-year science and technology plan puts forward the fusion of urbanization, industrialization and informatization, striving to develop science and technology for a new generation of information technology, modern services, and smart cities to promote the sustainable development of cities and urbanization. “National Medium and Long-term Science and Technology Development Plan Outline”(2006-2020) emphatically points out the future reseach must be focused on the acquisition and update technology of urban basic data, the integration and mining technology of urban multivariate data, the urban multidimensional modeling and simulation technology, the urban dynamic monitoring and application technology, and the urban emergency and linkage service technology, etc.

II. Urban Computing and Its Main Problems in Big Data Era

At present, urban computing in our country still has problems such as incomplete information resources, insufficient information horizontal integration and contribution, and difficulties in establishing effective intelligent analysis and decision support system. The establishment of intelligent analysis and decision support system largely depends on the seamless connection of data fusion analysis and information presentation with real scenes, providing high quality support for urban management analysis and decision-making through the enhancement and presentation of spatio-temporal cities.

Based on the above idea, we conclude that urban computing faces four major challenges: (1) lack of spatio-temporal precision coupling between urban data.Urban data often involve different fields (such as the telecommunications industry, power industry, urban regulation, etc.), collected in different ways (such as surveillance video, laser scanning, image transmission, etc.), complex and diverse, and extremely disperse. The content is mixed, uncertain, incomplete, and even contradictary with each other. (2) lack of intelligent analysis of urban data. Urban data exists in the form of multimodal states, with the characteristics of large spatio-temporal span, lack of content relevance, globally sparse and local redundancy. For example, the same vehicle may be monitored by multiple intersections at different times, but because the monitoring only covers one local area, the global information is scattered. (3) lack of timeliness processing of urban data. As urban activities are highly dynamic, and the evolution process is fast and complex, the managers are unable to give timely decisions, responses and services. (4) lack of urban situation-relevant decision support. As the event object in the urban environment is unpredictable, to realize accurate decision support, the computational model is required to have a strong on-the-spot adaptibility.

The increasing processing power of computing devices and the intersection as well as the fusion of different computer disciplines in big data era provides feasible conditions for coping with the above challenges. Establishing a unified expression for the spatio-temporal coupling of urban unstructured information (such as 3D spatio-temporal model of the scene) can provide data basis for urban computing. Further analysis of the semantic association between scenes and spatio-temporal objects in urban environment, establishing the connection between the information space and physical space, through the seamless integration of visual analysis, augmented reality technology and the real scene, can present data analysis results based on urban scenes, realize the reasoning and decision-making of urban computing, and thus implement the organic combination of human-machine intelligence.

III. Key Technologies of Urban Computing In Big Data Era

A. *Three Dimensional Spatio-temporal Expression and Construction Of Urban Scenes*

Urban unstructured information spatio-temporal coupling depends on 3D spatio-temporal information under urban environment, namely 3D spatio-temporal model of urban objects and scenes. Urban 3D scene data provide space carrier for urban computing to integrate other multi-source information. With the development of image sensing technology, the urban 3D space has become an integrated mode of air, sky and earth. Especially in recent years with the rapid development of laser measurement technology as well as the use of vehicle-borne or airborne laser radar, combined with the traditional visual technology, urban spatial information can be quickly acquired, and a large scale 3D modeling of urban scenes can be realized[3]. American government funded several scientific research projects focused on city-level 3D modeling of big scenes, such as the project named “Rapid 3D Modeling of Large-scale Urban Scene” in University of California, Berkeley, and the project “Urban Scan” in Massachusetts Institute of Technology. Companies such as Google and Apple have launched internet-based 3D maps and applications. Domestic companies such as Tencent and Baidu have started developing similar platforms too. With the popularity of mobile devices and the miniaturization of sensors, the industry has begun to consider how to combine big data and crowdsourcing to build smart city, such as using 3 million photos on the Internet to realize 3D reconstruction of Roman[4]. At the university of Heidelberg, Germany, in “Open Architecture Model” project, through an online platform, the user labels a location on the map and upload the 3D model of the building on the location, then gradully builds the architectural model of the whole city[5].

The continuous in-depth application puts forward higher requirements on urban 3D modeling. Accordingly, the scale of scenes becomes larger and larger, the particle degree is more and more fine, and the update frequency is higher and higher. Therefore, using the existing urban semantic information for rapid modeling, realizing on-demand multi-scale modeling of urban objects and scenes, using mass multi-source heterogeneous data for incremental modeling, etc., have become new ways for 3D spatio-temporal modeling in urban computing. The multi-source data under urban environment such as geometry, images, graphics, text, etc. are complementary, which can avoid the incompleteness of the single source data such as laser scanning data so as to obtain more comprehensive information of the scene and generate high precision of 3D geometric model. Geometric or textured features of 3D scenes (such as continuity, symmetry, repeatability, style, consistency, etc.) often contain semantic information such as structure, function and domain. Semantic samples as well as priori knowledge plays a very important role for the progressive modeling of urban scenes. For example, based on the symmetry and regularity of local objects, the hierarchy structures of buildings can be iteratively optimized to achieve the diversification of building modeling[6]. Besides, using robots to scan scenes actively and progressively can eliminate 3D scanning bottleneck caused by objects' self-occlusion and mutual-occlusion or other factors, thus build detailed 3D models of urban scenes[7]. Traditional vehicle-borne scanning and detailed scanning carried out by robots are able to implement closed-loop collection processing, which provides the basis for the coarse and fine granularity automatic scanning of urban scenes.

B. Semantic Computing and Fusion of Urban Multi-Modal Data

Although the urban 3D scene provides a basis for the integration of non-structural information for urban computing model, there is still a problem of semantic fusion of multi-modal data in information space. In order to describe the complete semantic and the interaction relationship between urban objects, urban objects need effective correlation and semantic fusion of multi-modal information.

The semantic computing and integration of urban data involves 3D space positioning, attribute extraction and attribute correlation analysis of urban objects. The existing research on 3D positioning method of urban objects mainly focuses on single mode or low dimensional data used to position urban public facilities, landmarks, green coverage area and downtown locations, such as the urban traffic navigation and positioning using global satellite navigation system and image processing technology[8]. At present, the extraction of attribute information of urban objects also mainly focused on single modal data, and the extracted attributes (such as the shape, texture, or spectrum characteristics extracted from aviation or remote sensing images) are relatively simple[9]. In recent years, the emergence of fine-grained object recognition[10] provides the basis for detailed annotation of urban objects. For the correlation between the attributes of urban objects, transfer learning across data attributes gradually aroused people's interest in recent years. The most typical example is that the word, bag-of-word, theme model and other concepts in text analysis have counterparts in image and video analysis, such as visual words, visual bag-of-word, visual theme model, etc., which greatly pushes the research of the classification and recognition of objects and scenes in images and videos[11]. However, the current transfer learning only considers knowledge transfer between two attributes, the data attributes of the source space and target space is relatively single, and collaborative learning theory and methods based on a variety of different properties is lacking.

The difficulty of the semantic computing and fusion of multi-modal data is that existing urban data have the characteristics of cross spatio-temporal correlation, mass heterogeneity and troubles in extracting attributes. It is regarded that the cognitive mechanism of human vision should be fullly utilized, the multi-scale coding mechanism model based on perception neuron should be combined with multi-modal data analysis and understanding, and the principle of human visual perception cognitive should be extended to the general multi-modal data using the idea of transfer learning. For image data with the characteristics of high dispersion, poor correlation and local redundancy, target detection and tracking methods of multiple camera image data can be used to establish across spatio-temporal correlation between target groups to explore the characteristics of the interaction between across spatio-temporal image objects, especially the cognitive rules of group effect and emergencies under complex environment. For urban big data with the characteristics of mass redundancy, heterogeneous multi-source and dynamic change, multi-level data reduction and nonlinear dimension reduction algorithm can be used for simplification. Besides, keywords extraction, salient region detection, geometric measurement, motion analysis and object recognition are also beneficial to the extraction of attribute characteristics of urban objects.

C. On-the-Spot Analysis And Decision-making of Urban Events

The main goal of on-the-spot analysis and reasoning of complex events is to find the correlation between interested things in ternary space, and predict the development trend of events using data mining technology to help analysis and decision-making.

To analyze, understand, and build correlation model for visual elements associated with complex events in ternary space is the core and key to understand the situation of urban complex events, analyze the cause of complex events, and make countermeasures. "Single-viewpoint Behavioral Recognition"[12], a study of the university of southern California, is designed to effectively identify human behavior through collaborative analysis of multiple camera information. However, the existing methods are often limited to the analysis of single spatial data, which is a bottleneck difficult to break through. And, more importantly, most of the existing research makes an analysis of the behavior of a small amount of objects from local data. How to use mass data in ternary space to collaboratively analyze the behavioral pattern of group objects is also a problem to be solved.

Data mining is the core technology of understanding and analyzing complex events in big data era[13], but it has serious limitations in some situations and conditions. The best application of data mining techniques is that the attributes and integration of the processing data do not change over time, data is complete and clean, and the analysis targets are recognized. However, the analysis of complex events in smart cities faces a lot of problems, such as different data sources, incompleteness, disunity, dynamic changes, and unpredictation in advance. Urban complex event analysis is related to social public security and life property security, and the potential risk is high, which puts high requirements on the ability of improvisation. Data analysis and mining technology can only provide the basis for decision making, and the understanding and analysis of complex events that machine intelligence cannot complete must be jointly completed with the help of human intelligence.

For urban complex objects and events, visual analysis can help to analyze massive data, provide a complete information visualization analysis environment for decision makers, and is useful for the deep coupling of human intelligence and machine intelligence. Sandbox[14], a representative visual analysis system, provides a man-machine interactive information based, flexible, expressive reasoning environment, supports visual thinking and provides analysis process template, and helps users achieve visual analysis and reasoning. In 2005, the National Visual Analysis Center (NVAC) published a report "The Research and Development Program of Visual Analysis"[15] summarized the method and application prospect of visual analysis, pointed out that the core of visual analysis is to adopt visualization and user interaction methods to assist users to rapidly excavate useful information from large-scale, complicated, contradictory, and even incomplete data in order to make effective decisions.

Therefore, visual perception should be taken as the basic channel of the on-the-spot analysis and decision-making of urban events. Through visual interface and interaction, some aspects of human intelligence, such as knowledge, personal experience,intuition,and those "perciptible but inexpressible", can be combined into the correlation analysis, reasoning and decision-making process of complex urban data. In short, the analysis and processing of on-the-spot complex events must be the organic combination of human, data and analysis technology. During the process, data mining and interactive visual analysis method each performs its own functions, they are mutually complementary and iteratively progressive to realize efficient reasoning and decision-making.

IV. CONCLUSIONS

Urban computing in big data era involves computer graphics, computer vision, data visual analysis, data mining and other related domain knowledge. The research results laid the theretical and practical foundation for urban computing. According to the status quo and challenges of areas such as urban spatio-temporal data acquisition, multi-modal data semantic computing and complex event on-the-spot analysis, the trend of future urban computing has the following two aspects.

First, the active agent in social space, that's, the human, will participate in the whole process of urban spatio-temporal data acquisition, analysis and processing. The mechanism analysis and research of crowdsourcing strategy is worth the focus of attention in the future. Using crowdsourcing mechanism to make labels and semantic analysis of data will help to obtain geometrical, material and behavioral attribute information of urban objects and scenes to realize consistent 3D reconstruction and dynamic update of urban scenes. In addition, using deep learning to explore urban scenario understanding mechanism from human understanding will also provide solutions for spatio-temporal coupling of urban unstructured data.

Second, gradually convert the current understanding and analysis of facts in urban computing to the origin analysis of events, making the coupling of the analysis and simulation inversion of real data much closer for better inference and decision-making. Take the calculation of pollutants as an example, urban 3D spatio-temporal model is taken as a data base, through the analysis of the mathematical model of pollutant diffusion and migration, the existing computer technology is used to do inversion of detected pollution data. Urban computing can not only present the current information such as the pollutant concentration, influence scope, but also can get key information such as the number of pollution sources, location, and intensity so as to provide references for the government management staff and environmental management personnel to analyze the reasons of pollution and guide emergency isolation measures.

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