A Reservation-based Smart Parking System

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***Abstract*—Finding a parking space in most metropolitan areas, especially during the rush hours, is difficult for drivers. The difficulty arises from not knowing where the available spaces may be at that time; even if known, many vehicles may pursue very limited parking spaces to cause serious traffic congestion. In this paper, we design and implement a prototype of Reservation-based Smart Parking System (RSPS) that allows drivers to effectively find and reserve the vacant parking spaces. By periodically learning the parking status from the sensor networks deployed in parking lots, the reservation service is affected by the change of physical parking status. The drivers are allowed to access this cyber-physical system with their personal communication devices. Furthermore, we study state-of-the-art parking policies in smart parking systems and compare their performance. The experiment results show that the proposed reservation-based parking policy has the potential to simplify the operations of parking systems, as well as alleviate traffic congestion caused by parking searching.**

***Index Terms*—smart parking; modeling; simulation;**

I. Introduction

Searching for a vacant parking space in a metropolitan area is the daily concern for most drivers, and it is time-comsuming. It commonly results more traffic congestion and air pollution by constantly cruising in certain area only for an available parking space. For instance, a recent survey [1] shows that during rush hours in most big cities, the traffic generated by cars searching for parking spaces takes up to 40% of the total traffic. To alleviate such traffic congestion and improve the convenience for drivers, many smart parking systems aiming to satisfy the involved parties (e.g., parking service providers and drivers) have been deployed. The current smart parking or parking guidance systems only obtain the availability information of parking spaces from deployed sensor networks, and simply publish the parking information to direct drivers. However, since these systems cannot guide the drivers to their desired parking destinations, even sometimes make the situation worse, they are not "smart" enough. For instance, when the number of vacant spaces in an area is limited, more drivers, who obtain the parking information, are heading for these spaces. It will cause severer congestion. It is, therefore, strongly desired to provide an effective strategy to address these concerns.

In this paper, we design and implement the prototype of a Reservation-based Smart Parking System (RSPS) not only to broadcast real-time parking information to the drivers as part of a communal application, but also to provide reservation service as part of user-targeted service. Built on advanced sensing and mobile communication techniques, RSPS processes streams of timestamped sensing data from sensor network in parking lot and published parking availability information. The drivers can retrieve parking information and reserve their desired vacant spaces via Wi-Fi or Internet.

The rest of this paper is organized as follows. In Section II, we set the background of the proposed research by introducing several existing approaches and challenges for smart parking systems. In Section III, we present the detailed architecture of proposed reservation-based smart parking system. In Section IV, we evaluate the proposed RSPS through extensive simulation. In Section V, we summarize the related work. Finally, we conclude this paper in Section VI.

II. Background

In this paper, we mainly focus on designing a new smart parking system that assists drivers to find parking spaces in a specific parking district. In addition, an important goal of the system is to reduce the traffic searching for parking, hence reduce energy consumption and air pollution.

A. State-of-the-art Parking Management

Many parking guidance systems have been developed over the past decade [3][4]. In this subsection, we study several existing parking guidance approaches and explain their limitations. Furthermore, we simulate these different parking management strategies under realistic traffic and parking conditions, compare their performance, and show results in section IV.

- *Blind Search*: Blind searching is the simple strategy applied by users when there is no parking information. In this case, the drivers keep cruising for parking spaces within a certain distance to their destination. The drivers will stop searching until finding any available space. Otherwise, the drivers will extend the searching area and continuously look for vacant spaces in the neighboring parking lots.
- *Parking Information Sharing (PIS)*: This mechanism is commonly adopted by the current state of the smart parking system design [7]. After the smart parking system publishes the parking availability information to the drivers in certain area, the driver will decide their desired parking destination where the parking lot has available spaces, according to the obtained parking availability information. However, if the number of vacant spaces in a parking lot is very limited in busy hours, it is likely that the number of drivers in demand for these parking spaces

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would increase, which is based on parking information. This phenomenon is called "multiple-car-chasing-single-space", which may cause severe congestion.

- *Buffered PIS (BPIS)* To address the problematic "multiple-car-chase-single-slot" phenomenon, some designers of smart parking systems modify the PIS mechanism. They intentionally reduce the number of vacant spaces, when publishing the live availability information, to keep a buffer. Therefore, though there may be more drivers pursuing the limited available spaces, the system has some extra spaces to avoid the conflict. But it is difficult to determine the number of the buffer spaces. If the buffer is too small, the problem of "multiple-car-chase-single-space" will not be eliminated. If it is too large, the utilization of parking spaces will be low.

As alluded to above, the blind search system is an open loop system, where users make decision without looking at the state of the system. The PIS and BPIS strategies allow drivers to make decisions based on the system state (e.g., parking availability information). However, the phenomena of multiple-car-chase-single-space cannot be fully eliminated. To reduce the traffic searching for parking, we suggest a reservation-based system, where drivers make reservations through the parking management system. If a driver makes the reservation successfully, it guarantees an available parking space for him, and the driver can park at the reserved space without searching. The reservation-based system allows drivers to select the most convenient parking space under their budget constraints.

B. Performance Metrics

In order to evaluate the performance of the strategies implemented in smart parking systems, we introduce the following metrics, which reflect the willingness of drivers, and our concerns on traffic congestion and environmental protection.

- *Walking Distance*: Walking distance is defined as the distance from a driver's selected parking space to the destination. This important factor reflects the willingness of drivers when selecting parking spaces. The driver commonly wants to choose the most convenient parking space where it is closest to his destination. In the proposed model of RSPS, the drivers select the parking spaces depending on this factor, which indicates their satisfaction.
- *Traffic Volume*: In our proposed model, traffic volume is specifically defined as the amount of traffic generated by parking searching. This factor is not negligible and associated with the traffic congestion and air pollution. The proposed reservation-based smart parking system is design to reduce the traffic volume caused by parking searching, as well as satisfy the need of drivers.

We investigate performance of the proposed smart parking system using these performance metrics.

C. Challenges

Given the design objectives of smart parking systems that requires the coordination among multiple parties, we summarize the main design considerations as follows:

- *Reservation Performance*: The PSPS utilizes both the Internet and Wi-Fi, whereby drivers can check the real-time parking information and complete their reservation. However, there is a bottleneck to the system when many drivers are simultaneously making reservation. In this case, the system has to synchronize the parking information and handle each reservation request, which significantly reduce the system performance, and even cause some conflicts. In order to address this challenge, we design a distributed reservation strategy implemented in the proposed smart parking system. When a drivers selects desired parking lot, the system will reconnect the driver to the subsystem in related parking lot, the driver can complete the reservation without communicating with the central system. Therefore, the central system no longer needs to maintain the reservation service.
- *Data Collection and Local Presentation*: The system collects and stores the data about the performance metrics, including the status of parking space, reservation time, parking location, driver's identity. All data stored by the system is at least stamped with time metadata. Furthermore, the system allows the driver to check the parking information, including the location of parking spaces, the vacancy time of parking spaces and reservation information. In order to protect the security of the system, we separately design a repository of sensing data and a mirror database of reservation. The repository is the sink of the sensing data, and the mirror database is synchronized with the repository and stores the reservation information. In this way, the drivers are only able to check and update the information in the mirror database.
- *Drivers' Identity Verification* Once the reserved space is detected to be occupied by a vehicle, the system should verify the driver's identity. If he/she did not reserve the space, the system will alarm the driver this space is reserved. In our proposed system, the drivers can visit the website and verify their identity via Internet. If they cannot access Internet, the drivers are able to communicate with the sensors by Bluetooth wireless connection.

III. System Architecture and Design

In this section, we present the architecture and design of proposed reservation-based smart parking system, which implements a reservation service to reduce the traffic volume caused parking cruise.

A. Overview

Fig. 1 shows three components in the smart parking model, including parking lots, users and the smart parking system. The management system determines the parking prices, and broadcast live parking availability information to users (also drivers). Upon receiving parking information, the user selects a desired parking lot and reserves a space in the parking lot. As a result, the state of parking resources is changed by

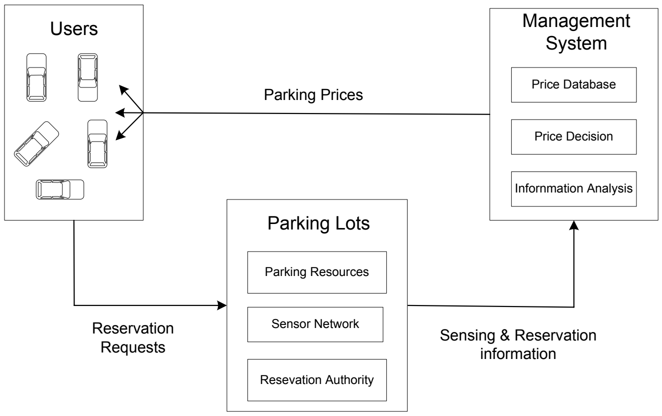

Fig. 1. System architecture

users' parking decisions.

The parking lot consists of a group of parking spaces. The on-street parking can also be considered as a virtual parking lot. The state of a parking lot is the number of occupied spaces versus total spaces. Every parking lot has access to the Internet to communicate with the management system and users, and share parking information with other parking lots. In each parking lot, the reservation authority is deployed for authenticating the individual user's identity and reservation request. In this case, the reservation authority in the parking lot communicates with the specific user individually. Once the reservation order is confirmed, the reservation authority updates reservation information to hold the related space for the user. The sensor system deployed in parking lot is responsible for monitoring the real-time condition of parking lots and delivers the live aggregated sensing information (the number of available spaces or occupancy rate) to the smart parking system. The sensing information is updated on demand. Upon retrieving the parking information, the system updates the state of the parking lot. Based on the state of parking lots, the system (1) analyzes their occupancy status and congestion level, (2) determines the parking prices according to their pricing scheme, (3) broadcasts the prices to all users periodically, and (4) stores the parking information and prices for further analysis. The system serves as the centralized decision-making body in a planned economy. It makes all pricing decisions regarding the state of parking lots and user demands [18]. This system is a closed-loop system to dynamically adjust parking price, balance the benefits between users, and service providers and reduce traffic searching for parking.

By placing the reservation authority in individual parking lots, we simplify a lot of issues related to the implementation, including communication overhead, reservation synchronization and load balancing. Since each user only has to communicate with his desired parking lot to make his reservation, rather than the centralized system, the communication overhead of reservation is highly reduced. Also, since each parking lot manages its own reservation information, it makes the reservation requests from users easily to be synchronized, comparing with reservation synchronization in the system.

B. Hardware

The system hardware is organized into three main components, the sensor network, the central server and the mobile device, as shown in Fig 2. In the following, we discuss the detailed design and implementation of each component, along with the specification of communication between them.

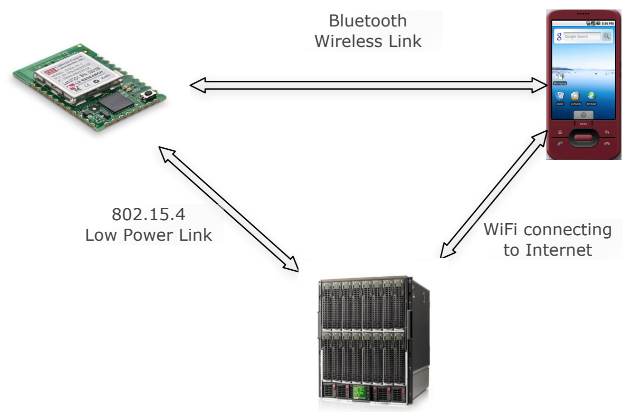

Fig. 2. System hardware components

In our project, we developed a number of functions on Zigbee sensors that provide a continuous measure of parking status for each space. Each sensor is integrated with two wireless mote. The wireless mote platform provides a 250 kpps 802.15.4 wireless radio, 8 channel A/D and an 8 MHz microcontroller for on board digital signal processing. Mote 1 hosts light and vibration sensors, which is used to detect the vehicles. In reality, the light sensor is easily interfered by light sources. So we use highly directional beam to strengthen light and reduce the interference. Mote 2 hosts the communication module of Bluetooth. As a result, the sensor bridges the communication between the Zigbee on mote and the Bluetooth module on smartphone (e.g., Android G1). In this case, the sensor confirm the identity of users when vehicle is detected in reserved parking lot.

The mobile phone is used to assess Internet, over Wi-Fi or a GSM cellular network, to obtain the information of parking availability and make parking reservation from the Internet server. The mobile phone also provides the Bluetooth module to communicate with sensors when verifying the driver's identity.

There are a central Ethernet-connected server deployed with storage and computational power. These servers provide hardware support for the software services, which are described in section III.C. In particular, it is for system users to request the services of parking information and parking reservation. Once user's reservation is authorized, the server will update the state of related parking sensor by wireless low power link, IEEE 802.15.4.

C. Software

Fig. 3 shows the design of software architecture, primarily defining the *iRev*, which is the central location of the system to host applications and functions as the point of control and configuration for the distributed system. Primary software elements are discussed in the following.

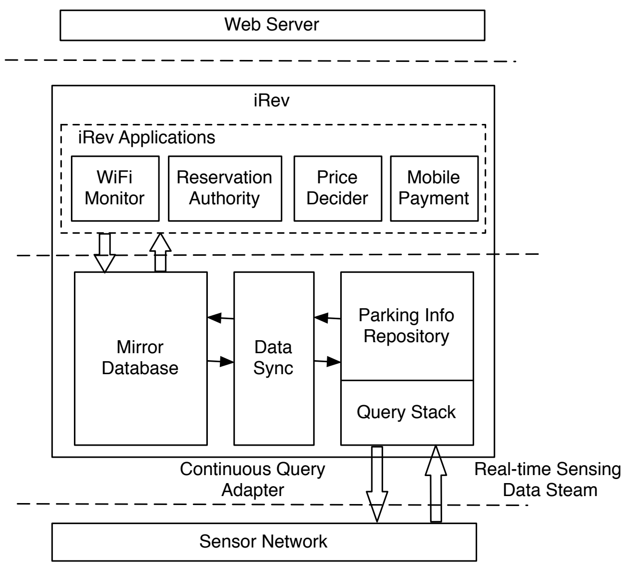

Fig. 3. System software architecture

RSPS has a subsystem of sensor network in the parking lots. The sensor networks provide the real-time parking information to the upper layer. Here we categorize sensor nodes to detecting nodes and collecting nodes. Specifically, the detecting nodes take the responsibility to monitor the status of parking spaces, as well as communicate with mobile phones. Moreover, the collecting nodes advertise itself as the root node and are responsible to collect and deliver the detected event and data from detecting nodes.The sensor nodes are able to achieve end-to-end connectivity across a set of nodes and access points by implementing collection tree protocol.

As the middle layer between the sensor network and web server, the iRev is the sink for all data sent from the lower sensor nodes. To simplify application development, we have developed query stack for delay-tolerant continuous query processing. Meanwhile, the parking information repository can retrieve real-time sensing data stream. To transfer data efficiently and reduce the complexity of the system, we have developed data synchronization processor that can connect and synchronize the data between parking information repository and mirror database. The user can check the parking price and make their reservation via mirror database, and data synchronization processor takes the responsibility to transfer related data to repository. In this case, the security of parking information is protected, as well as the information redundancy is reduced. Based on the real-time parking data, there are four specific applications in the iRev, including Wi-Fi monitor, reservation authority, price decider and smart payment. (1) Wi-Fi monitor is designed to monitor and report on Wi-Fi Access Points. It monitors and reports on performance, availability and problems. (2) Reservation authority is responsible for verifying the reservation process and driver's identity. (3) Price decider is to determine the parking price based the parking state. (4) Mobile payment allows drivers to use their mobile phones to pay parking fee.

Fig. 4. Reservation service

RSPS provides the web service to the drivers, as shown in Fig. 4. The system dynamically updates the parking and reservation information on the website according to the data stored in mirror database. The driver is able to obtain the real-time parking information and complete the reservation from the web server.

IV. Evaluation

In this section, we simulate the proposed Reservation-based Smart Parking system (RSPS) based on real traffic traces and real-world parking map, and demonstrate the performance of the RSPS in terms of the metrics shown in Section II.

A. Simulator Design

In order to investigate the parking guidance policies and the proposed RSPS, we have to develop a simulator to import the real-world map and traffic traces, simulate users' parking behaviors and implement related parking strategies.

1) Import From Real Map: This simulator allows us to import a real-world map as the target area, and acquires the information from the map, e.g., distance and paths. Given the map, let $G = (N, A)$ be traffic network defined by a set N of nodes and a set A of edges, where N and A represent the set of blocks and the set of roads connecting blocks. With the parking map, we aggregate the parking lots in one block as a virtual parking lot. Therefore, each node has a (virtual) parking lot attached, and an edge has a specific value assigned to represent the distance between two blocks.

2) Parking Demand Modeling: In the simulation, we use the real-world traffic traces to generate the parking demand. Here the parking demand is the number of drivers who need parking spaces in the target area. However, in reality, it is difficult to collect the traffic traces for parking in the target area. Although the sensor network is deployed to monitor the incoming and outgoing traffic for parking in individual parking lot [7], [9], the traffic data from individual parking lot cannot represent the total traffic traces for parking in the whole area. Fortunately, we can employ the highway traffic traces to estimate traffic for parking, which are available from the Performance Measurement System (PeMS) at the University of California, Berkeley. Here we make a general assumption that real total traffic for parking is proportional to the highway traffic. Although not all of traffic pursuing parking spaces in target area are from highways, and not all highway traffic need to park in the target area, the highway case can simulate the state of total traffic for parking. We classify the total highway traffic into incoming traffic and outgoing traffic, which represent the traffic approaching to and leaving from the target area. The incoming traffic serves as the reference of parking demand. We use the driving distance within the target area to measure the traffic for parking. For calculating the driving distance, the vehicles begin to run the distance meters, once they enter the area, until reaching the selected parking lot. Moreover, as we discuss in Section III, we use congestion factor l to represent the level of congestion condition. In the simulation, we use the traffic load to simulate the congestion condition. For instance, if $l = 1$, the traffic load is under normal condition. If $l = 2$, the traffic load is double the normal condition.

3) Simulator Implementation: In order to implement different parking policies in the simulation environment, we use object-oriented design to realize the interactions between objects (e.g., users and parking lots). Although there are thousands of autonomous drivers who behave differently, they have the same common concerns about the parking selection, including convenience degree and parking price. So the object-oriented design provides us a cost-effective way to implement different behaviors and common concerns of objects through structures within the program. Meanwhile, by providing the interface of the objects, it is easy to extend the simulator to other applications. Therefore, the simulator is developed not only for reservation policy and dynamic pricing scheme, but to simulate general strategies of parking selections.

B. Simulation Setup

In our simulation, we use the map of Los Angels Downtown as the target area, as shown in Fig. 5, which is surrounded by the interstate highways, I-101, I-110, I-10 and I-5. In this area, there are multiple typical districts including central business district, residential district, entertainment venues, which is one of busy areas in Los Angeles. This area is very representative in big cities. Furthermore, Fig. 6 illustrates the incoming and

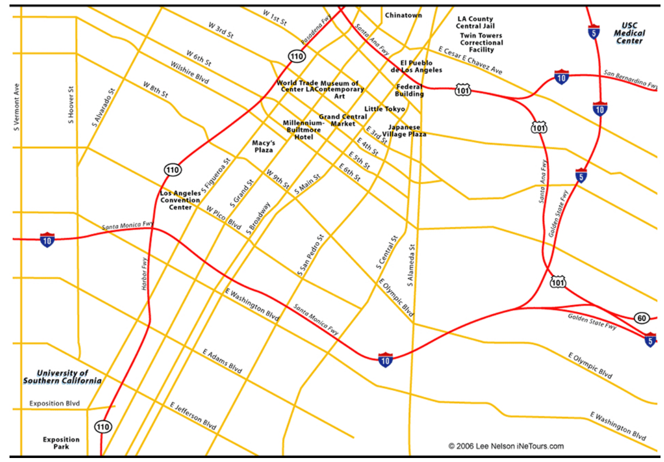

Fig. 5. Map of Los Angeles Downtown

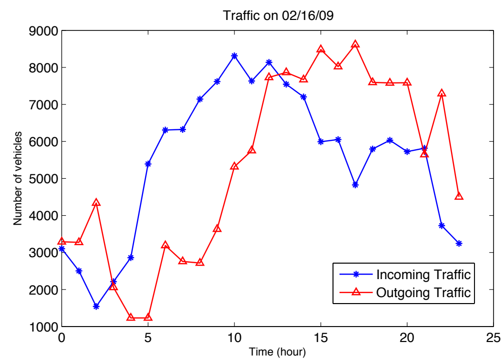

Fig. 6. Incoming and Outgoing Traffic

outgoing traffic in two different days. As we see, the peak time of incoming traffic is from 6am to 10am, and the rush hours of outgoing traffic is during 5pm to 8pm. It matches people's regular schedule, in the morning most people drive to work and go back home after 5pm. Therefore, the traffic trace is reasonable to generate the parking demand in the simulation.

C. Experimental Results

The following experimental results illustrate the efficacy and feasibility of the proposed Reservation-based Smart Parking System (RSPS) in a cost-effective way. We evaluate the effectiveness of reservation policy in terms of following perspectives:

1) Traffic Searching for Parking: As we discuss in section II, Fig. 7 shows that the driving distance under blind search is the worst, especially during the peak hours; PIS and BPIS are better than blind search when traffic flows increase; and the reservation policy is the best compared with others. Note that, in this simulation, there is no pricing scheme implemented in reservation policy. An interesting observation of reservation-based policy is that the average driving distance is decreasing at peak time, rather than increasing. That is because, after users learn the states of parking lots, they tend to reserve the nearest parking lot to their destination.

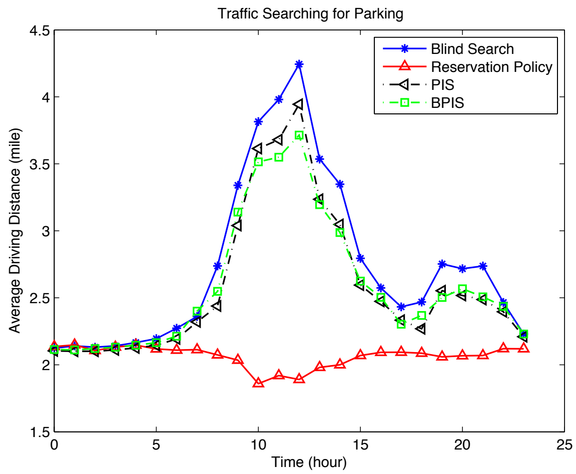

Fig. 7. Traffic searching for parking comparison under different parking guidance strategies

During the peak hours, most parking lots are almost fully occupied in central area. Consequently, users have to select the parking lots in surrounding area, which are near to their start points. Therefore, it results in the reduction of average driving distance during the peak hours.

V. Related Work

Currently, most research work on smart parking is from the perspective of system design, which focus on implementing a wireless sensor network to detect parking information and provide real-time parking service. In addition, we introduce the pricing-related topics in networks, which provide us a powerful tool to manage parking lots.

In [9], the authors present a smart parking management system based on wireless sensor network technology, which provides remote parking monitoring, automated guidance and parking reservation service. They demonstrate this system architecture can help commuters to find vacant parking spaces. Rongxing Lu *et al* [7] introduce a new Smart PARKing (SPARK) scheme, which is based on Vehicle Ad Hoc Networks (VANET), provides drivers with accurate and convenient parking services in large parking lots, including real-time parking navigation, intelligent antitheft protection, and friendly parking information dissemination. In [11], authors proposed a scalable information dissemination algorithm for discovery of free parking spaces via VANET.

Furthermore, appropriate parking control to motivate drivers to balance their parking demands is another goal for smart parking system. Pricing policy, as an important economic tool, is effective to allocate resource in network. In [13], Kelly *et al* show that, when selfish users seek to maximize their benefits, the system can provide incentives to reach the optimization of global network. In [14], authors proposed a reasonably complete DiffServ pricing model integrated a pricing structure for different service class and the demand behavior of users. They show that, when different service classes operate at different target utilization, they provide different levels of service, and users see a stable service price and maintain stable. Moreover, Feldman *et al* in [15] formulate the fixed budget resource allocation game and study the existence and performance of a distributed market-based resource allocation system.

VI. Conclusions

In this paper, we have developed a new prototype of Reservation-based Smart Parking System (RSPS) to optimize parking management. In this system, we implement parking reservation policy to balance the benefit of service providers and requirements from the users. Moreover, we have presented the detailed design, implementation and evaluation of the prototype. Based on the obtained results from our simulation study, we conclude that the proposed reservation-based smart parking system can alleviate traffic congestion caused parking searching and reduce the amount of traffic volume searching for parking.

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