Soundscape: Sensing and Visualizing Acoustic Landscape on Campus

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Abstract
Soundscape or acoustic landscape is an important spatial characteristic that can influence real estate development and urban economics. Understanding of soundscape is thus essential for urban design and planning. This paper presents the development and implementation of our Soundscape system that senses and visualizes soundscape in an area on campus, as a case study. Unlike other soundscape sensing approaches that can only capture instance sound levels of the area, our system can collect and visualize longitudinal soundscape information that better reflects aggregate spatial characteristics.

Author Keywords
Soundscape; acoustic landscape; sound sensing; sound visualization.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

Introduction
Today, more than half of the global population now living in cities [10]. Urbanization is quickly transforming places globally. Improving urban environments for the well-being of the increasing number of urban citizens is becoming one of the most important challenges of the

21st century. Maps are the traditional tools for urban planners to figure out plans on how to maintain and improve urban environment, e.g., routing traffic and managing commercial and residential development. So, city planners' visions are customarily limited to visual esthetics. The qualitative perspective of sound, which includes sonic diversity and acoustic ecology, is often a neglected area of urban design. Sound is an invisible yet highly affecting and socially relevant area of urban enquiry and design [7].

Soundscape is an acoustic landscape, which is a combination of the physical environment represented in terms of acoustical characteristics of sound waves, and a social environment dimension represented by human perception of sound. Soundscape occurs when one perceives the surrounding sonic environment with his/her hearing, where a sound is a basic element in the scape [8]. Sound level also poses a multitude of health and safety concerns on such aspects as productivity, comfort, and functionality [4][6].

Unlike landscape, soundscape changes periodically over time, typically depending on the area type and spatial characteristics. An area in a commercial zone may be characterized by different soundscape patterns (i.e., daily, weekly, etc.) than a residential zone's. Being able to understand soundscape is thus very important to better inform urban design and planning. Capturing sound level data is a challenging task. Previous investigations in soundscape understanding used sound level data based on surveys [5], voice recorders [1], and mobile phones [9], which can only capture instant sound levels but not the complete temporal characteristics of soundscape that can be used to form longitudinal patterns. Therefore, this study attempts to

fill in this gap by developing a system for soundscape data sensing and visualization. This paper thus presents our system development and implementation composed of a wireless soundscape sensor network and visualization tool, demonstrating through a case study of sensing and visualizing soundscape on campus.

System Overview

In this prototype system, we first deployed and implemented the concept of the Soundscape on a small and manageable area on campus, which was the 4th floor of the main Engineering building at Chiang Mai University where Department of Computer Engineering is situated. The implementation was run for two months (April – May 2018). The system overview is shown in Fig. 1 where the core system consists of three main components; sensor network, online database, and visualizer (i.e., Soundscape user interface).
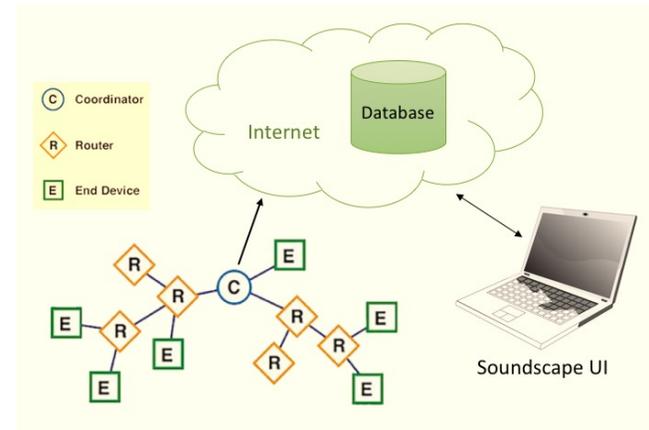

Figure 1: System overview of the soundscape system that consists of three main components; sensor network, online database, and user interface (UI) or visualizer.

Sound Sensor Network

Sound sensor network consists of end devices (E), router (R), and coordinator (C), as shown in Fig. 1. Each end device is a sound sensor, for which we used KY-037 High Sensitivity Sound Microphone Sensor Detection Module (shown in Fig. 2) that takes 5v DC power supply and produces analog output with a threshold level output flip. Since the sound sensor produces analog output, we needed to convert it into decibels (dB), so we conducted an experiment by examining analog output values at various distances from the sensor with different sound levels in dB measured with a standard sound level meter. We obtained a mathematical relationship (curve-fitting equation) between the analog output values and dB values of sound level from our sensor, as shown in Fig. 3. We used this equation for our analog-to-dB conversion.
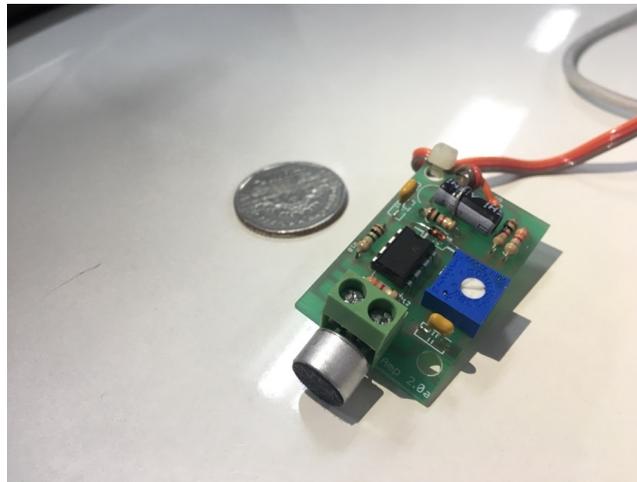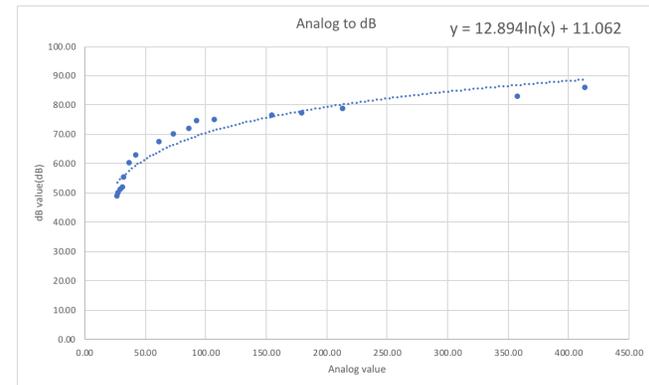

Figure 2: Sound sensor.

Figure 3: Mathematical relationship for sound level conversion from analog output value to dB.

As we developed the sensor network using the mesh network topology (Fig. 1), our sound sensors needed to be able to send the sensed sound level data to the router while some sensors needed to be able to route the sensed data streams (its own sensed data and other nearby routed data) to the coordinator that will then forward all routed data streams to our online database. So each sound sensor was attached to an Arduino[1] board, which acts as a data sender and router using Zigbee[2], as shown in Fig. 4. Arduino is an inexpensive open source single-board microcontroller, which was quite suitable for our sensor development.
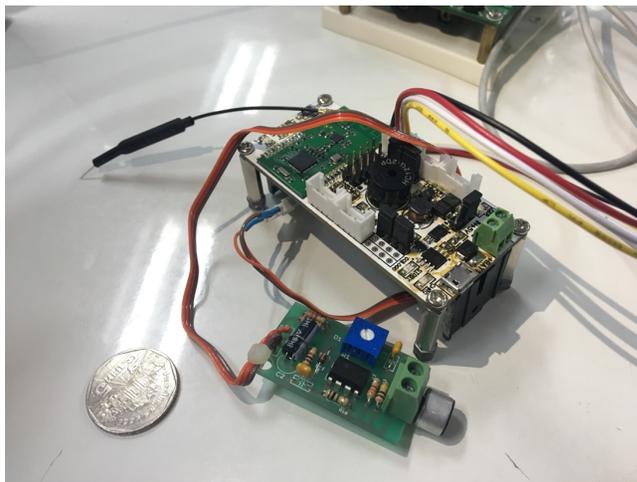
[1] https://www.arduino.cc
[2] http://www.zigbee.org

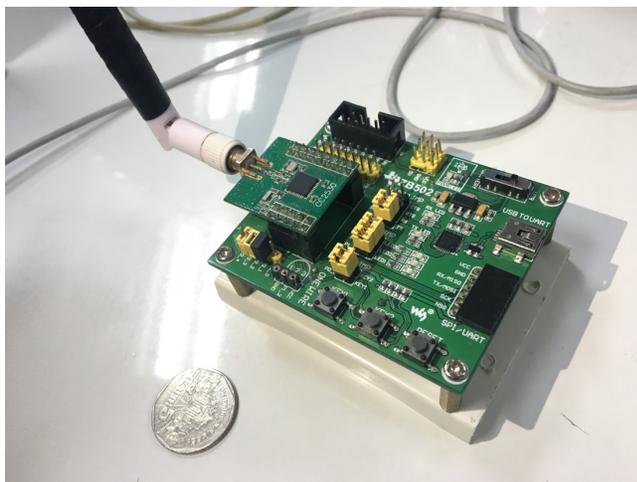**Figure 4**: Arduino-based router and sound sensor.

Figure 5: Raspberry Pi-based coordinator.

Our sensor network needed one coordinator to read the data passed through the network from all routers and forward them into our online database (Google Firebase[3]). So, we built the coordinator using a Raspberry Pi[4] as it has been widely used as an effective coordinator for a wireless sensor network [2]. Our Raspberry Pi-based coordinator is shown in Fig. 5.

For our soundscape deployment, was used 11 sound sensor/router nodes and one coordinator. The locations of sensor nodes are shown in Fig. 6 on a floor plan of study area (approx. 1,600 m^2). All sensors were deployed in the hallways and corridors.
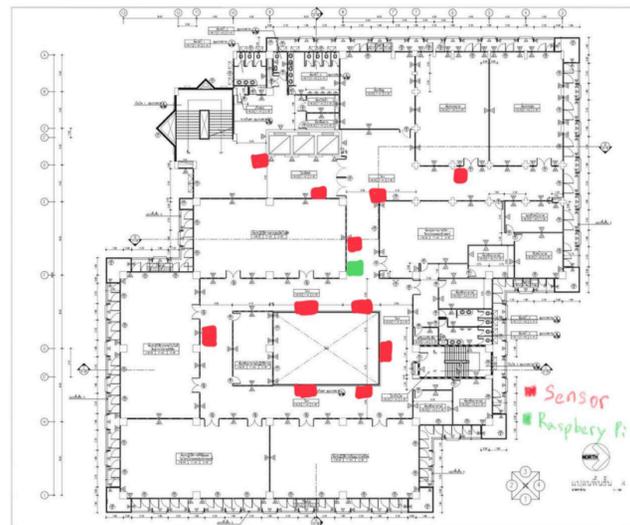

Figure 6: Floor plan and locations of the soundscape sensors and coordinator.

To protect the sensor nodes from people and other unwanted incidents that might interfere them, we covered each one of them using plastic material and taped it into a fixed position, as shown in Figs. 7 and 8.
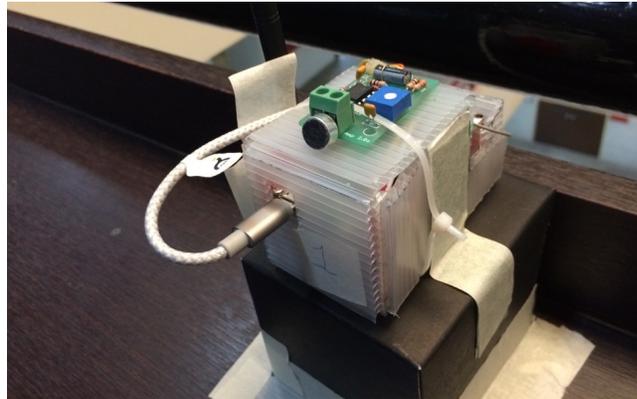

Figure 7: Deployed sound sensor/router with cover protection.

Figure 8: Deployed coordinator with cover protection and internet connector.

The actual locations of all 12 deployed sensor nodes and coordinator are shown in Fig. 9. All nodes were deployed in the hallways and corridors where people normally walk by to go to lectures, labs, and offices. Sensor network was deployed over two months during which students, staff, academics, and visitors were carrying out their daily activities. To protect people touching them, we put up a warning sign at each sensor. For Zigbee communication between sensors to work, we placed each sensor within 10 meters of range from the nearest one where nothing blocked the sight between them.
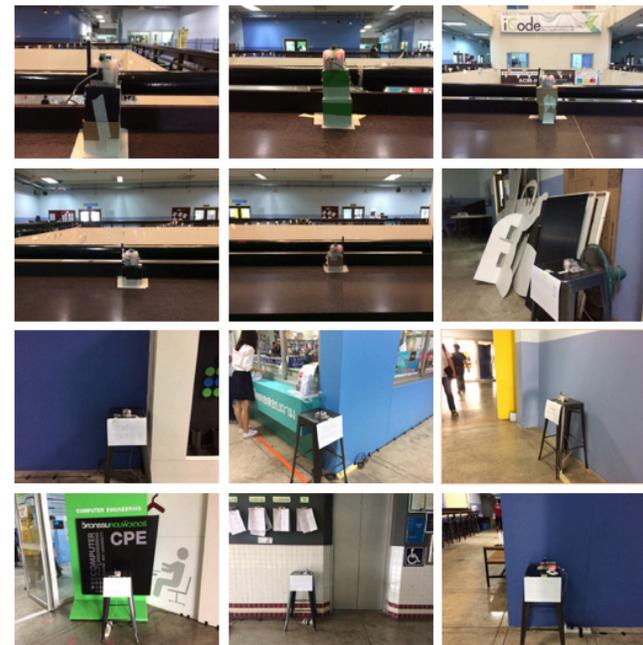

Figure 9: Deployed locations of sensors/routers and coordinator around the area of study.

Soundscape Visualizer

Once the sound data streams have been collected and forwarded into our online database, our soundscape visualizer can then connect and query the data from the database to transform the numerical data into interactive graphics. Our visualizer was built with the Processing Development Environment (PDE)[5] as it's been an effective environment and programming language for creating interactive media. The main user interface of the soundscape visualizer is shown in Fig. 10. Sound level is visualized using heatmap – showing variation of sound level in reddish shading on the floor plan. Corresponding date and time are displayed. The user can view all sensor locations by clicking on SHOW SENSORS button (left-hand side). On the top of the visualizer, the user can observe the overall soundscape of the entire area as time series bar charts separated by 24 hours. The user can also select one or more sensors to view their soundscape data by clicking on the sensor location(s). The time series bar charts would change according the selected sensors' readings. To select all sensors, the user clicks on SELECT ALL button (on the right-hand side). On the right side of the visualizer, there are two radar charts each showing the overall soundscape characteristics daily and weekly. The daily radar chart shows average values across each hour of the day. Likewise, the weekly radar chart shows average values across each day of the week. These radar charts can reflect aggregate characteristics of the monitored area (i.e., selected sensor locations).

By simply comparing the observed soundscape pattern with the lecturing schedule, they are intuitively coherent. There were lectures with the same schedules

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arranged on Monday and Thursday, and another same schedule for Tuesday and Friday. The soundscape pattern of each day pairs (Mon-Thu and Tue-Fri) are similar (captured from the two selected sensors near to the lecture rooms, as shown in Fig. 10), which reflect on this actual scheduling.

Understanding the soundscape pattern at different locations and its distribution can be useful for spatial design, particularly where sound level is one of the influential factors. Implementing the concept of soundscape in the urban space is still our ultimate goal in this investigation, therefore this prototype will serve as our baseline as we move forward with our study.
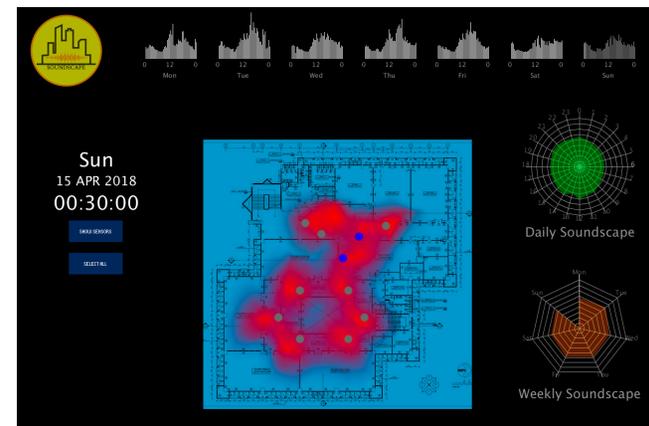

Figure 10: A snapshot of the soundscape visualizer.

Demo

For demonstration purposes, a video clip showing how our Soundscape system works is available on YouTube at https://www.youtube.com/watch?v=2_-WM_EeK6s.

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[5] https://processing.org

Figure 11: Questionnaire for the user experience study.

User Experience Study

We conducted a user experience study to assess our Soundscape system for usability and future improvement. A total of 40 subjects participated voluntarily in our study. Each subject was asked to try out the system and afterwards completed a questionnaire (as shown in Fig. 11). We designed our questionnaire based on the theory of four elements of user experience [3], which askes to the user to rate their agreement with four different statements concerning the user experience with the system that include:

1. It is useful.
2. It is easy to use.
3. It is easy to start using.
4. It is fun and engaging.

Each participant was asked to give a rating of agreement level to the four statement where the rating score is a 5-likert scale where 1 means the lowest level of agreement and 5 means the highest level of agreement.

Overall, the aspects of being useful and easy to use were rated the highest at 4.00 for both, followed by being easy to start using at 3.70, and then being fun and engaging at 3.33.

When the subjects were grouped by genders, there were 21 male and 19 female participating users. The result is shown in Fig. 13. Female users gave a slightly higher rating than males in all aspects. The trends are the same for both genders with the overall ratings. One of the comments from male users was "*The concept is interesting, but the tool still needs improvement to be attractive. I think the sensors are too clustered together, which makes it difficult to see the variation in soundscape in the area.*" A female user commented that "*It's interesting. I like graphics. It can be useful for monitoring a space usage and sensing crowd level.*" This suggests that we need to improve on the appearance of the visualizer.

Figure 12: Overall result of the user experience study.
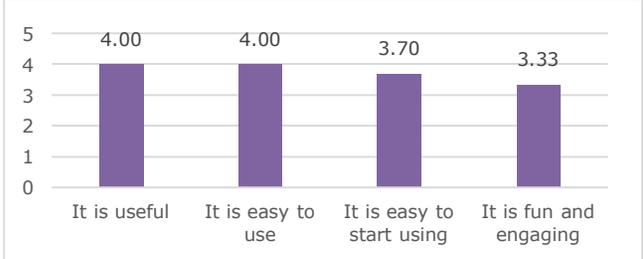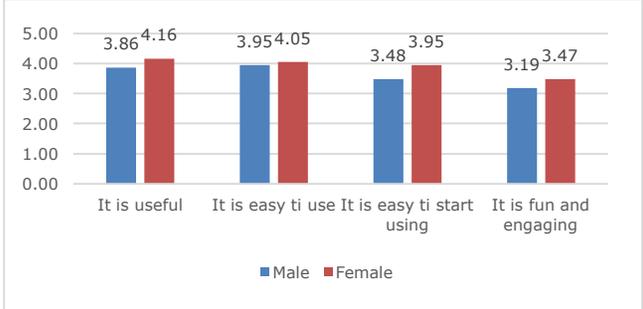

Figure 13: Overall result of the user experience study.

When separated by age, there were four users who were under 20 years old, 23 users between 20-29 years old, 8 users between 30-39 years old, 4 users between 40-49 years old, and one user between 50-59 years old. The result is shown in Figure 8. The users who were from the age groups of less than 20 and 40-

49 years old gave the highest ratings overall when compared with other age groups. A 41-year old user commented that "*This is a very interesting concept. I can see that it can be used along with other sensing infrastructures to get a more detailed information of space usage and characteristics*." A 35-year old user commented that "*It looks useful, but I think its graphics need to be more attractive. There should be more interesting features to make people want to use it. Perhaps you can add some more tools for soundscape analysis.*" This suggests that we may improve the visualizer by including more sophisticated features for soundscape analysis.
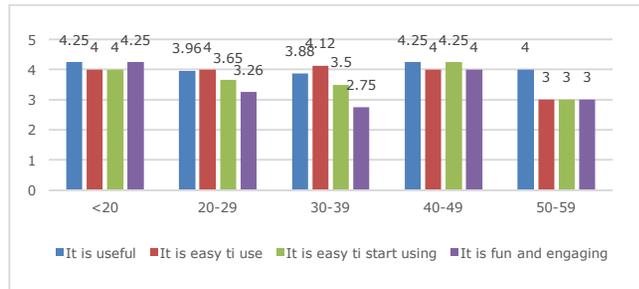

Figure 14: Overall result of the user experience study.

When separated by occupation, there were five students, 18 academics, seven researchers, two university staff members, and eight others. The result is shown in Fig. 15. Students generally gave the highest ratings among other occupations. They even gave the highest rating for the aspect of the system being fun and engaging. One female commented that "*I like it. We should have this running in our department. It would be great if I can also access the data for my project.*" This suggests that another potential improvement of our system is to develop an API for

other people to access the soundscape data to enable open-data innovations. Academics found the system useful and easy to use, but not so fun and engaging. One of the comments from academics was "*Nice concept and implementation. It would be interesting to see how this concept can be implemented in the urban space. A user manual can be useful. Real picture of how each sensor is deployed in space could be displayed for better understanding of the system.*" A comment from one of the researchers was "*Interesting. It would be very useful system if it also allows the user to access the actual collected data.*"
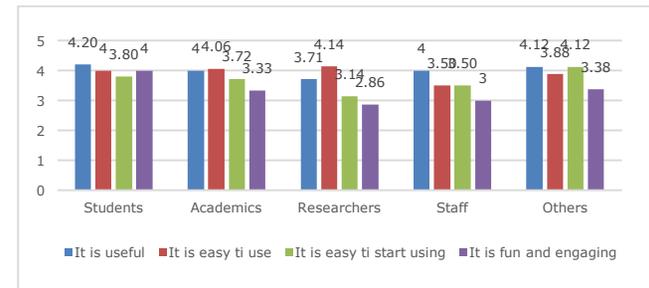

Figure 15: Overall result of the user experience study.

These results along with the users' comments and suggestions are valuable for our future improvement of the Soundscape system. They serve as a guideline for our future design and development.

Conclusion

Sound is another important aspect of spatial characteristics. Soundscape or acoustic landscape can play an important role in land valuation, area classification, and spatial planning. Capturing the soundscape is a challenging task due to its spatiotemporal dynamism. Previous investigations used

surveys, voice recorders, and smartphones to capture soundscape, which can only obtain instant sound levels but not the complete temporal characteristics of soundscape. This study thus fulfills this gap by introducing a system that captures and visualizes longitudinal soundscape. Our prototype was developed and deployed to capture soundscape on campus. An area of approximately 1,600 m^2 was used as our case study area. Two months of soundscape data was collected. Our soundscape system consisted of three main components; wireless sound sensor network, online database, and visualizer (user interface). The sensor network was built as a mesh network in which the collected sound data was forwarded to the nearest sensor node and all eventually to coordinator that reads all data streams into our online database. Our visualizer then connects and queries the data to create interactive graphics showing soundscape in action. Visualizer illustrates the soundscape data in forms of heatmap, graphs, and radar charts from which the soundscape patterns can be observed and analyzed. To assess our system, a user experience study was conducted. The system was well received overall. The results of the user experience study along with comments and suggestions from the real users are constructive and beneficial to our future design and development of the system.

There are nonetheless some issues that we have encountered during our system development that need to be properly addressed in the future. The first issue was the communication between sensor nodes that were limited to 10-meter range and there required no obstacle blocking the signal. Second issue was the sensor power supply. We first tried 18650 Li-ion battery (3,000 mAh) to power each sensor. However, it only lasted about 20 hours. So, we solved this by using direct power supply from the wall outlet, using USB connection. Although it solved issue in our case, it may not work when deployment is done outdoor or at a city-wide level. Solar cell can be considered as an option here. Thirdly, there was some delay in routing the data from some sensor nodes, which caused some lost data as the sensor wouldn't collect new data if the collected data was not sent. Lastly, internet connection lost (at the coordinator) caused some missing data in the online database. We used a pocket Wi-Fi (with SIM card). These are the issues that should be considered in our future system design and development.

Although this is still a prototype of our soundscape system, we still believe its concept and first implementation experience reported here is valuable and it adds to the body of literature, which can be useful for researchers in the field.

Acknowledgements

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