Enabling Citizen Science in Rural Environments with IoT and Mobile Technologies

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ABSTRACT

Citizen Science focuses on engaging and incentivising individuals to collect, categorise and sometimes analyse scientific data. Over the last few years, many of these projects have contributed to relevant scientific discoveries, but bringing them to successful completion is often full of challenges and complexities. In this paper we present our progress in the creation and deployment of a Citizen Science project in Guapiruvu, a village located in the Atlantic Forest in Brazil. We propose an IoT communications platform based on LoRa-enabled Raspberry Pis, which act as network hubs, and which can communicate directly with smartphone hosted applications. This platform is used to run a messaging app that allows two or more smartphones to exchange text over a LoRa network. We tested the platform in the village and results show that communication was possible up to 220 meters, even if one of the hubs was located in an area densely populated with trees. We also discuss how Sapelli Collector, a popular Citizen Science-enabler app, can be used over our developed infrastructure, and mechanisms that can used to increase adoption.

KEYWORDS

Citizen Science, IoT, LoRa, Mobile Computation

1 INTRODUCTION

Supporting 'citizen science' projects with personally owned systems and devices has seen significant growth in recent years [4]. This includes the use of smart phones that enable data capture with geo-referencing. This data is subsequently delivered to a cloud service for storage and analysis. A number of citizen science appli-cations have been proposed in recent years, ranging from pollution monitoring in cities to monitoring of local habitats [1].

A key premise of citizen science projects is to engage volunteers to gather or process data, and subsequently to use this data (as part of a bigger data collection effort), to address scientific question(s) of interest to a community. Data generated through a citizen science project is combined/co-referenced to curated data obtained from more *official* sources, e.g. government agencies.

Understanding how participants involved in such an effort can be incentivised to engage actively remains a challenge for a successful project. Citizen science projects are closely aligned with efforts in 'cyber-physical-social' systems, whereby the social dynamics and incentive mechanisms within the group of (usually) volunteers are key to the successful delivery of its outcomes.

Understanding how human users, who are often not technical experts in the systems they use, can use mobile technologies to support data capture and *sense-making* is particularly useful when dealing with global challenges – e.g. climate change, sustainable development, etc. Citizen science therefore provides a good example of how cyber-physical-social systems (CPSS) can be utilized in a particular context. Studying the potential impact that CPSS have on humans and how they use these systems to undertake problem solving, and vice versa, remain important challenges.

The capability available through sensors embedded in smart phones (accelerometer, microphone, camera), associated apps, and externally hosted infrastructure (e.g. internet of things & edge devices) has significantly altered the range of possible applications that can be realised. Many of these systems however rely on the existence of a backbone communications network to transmit the data from the user device to a cloud system. Where such network is only available intermittently (or not at all), understanding how a data transmission infrastructure can be provisioned, supported through 'citizen' effort, remains a challenge.

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Efforts range from the use of “relays” or mesh networks, where devices of individuals are used as routers to forward data from a source to a destination (assuming that the final node in the path has a connection to the cloud hosted server), to variable speed local area networks (e.g. LoRaWan, SIGFox etc) to enable development of a long distance low-bit rate communications network.

In this paper we present the progress towards developing a Citizen Science project in the Guapiruvu village, in the rainforest of Brazil. Our final goal is to create a platform that enables the citizens of the village to develop their own network and data capture infrastructure. The key premise is that citizens should not only be collecting data, but also contributing to infrastructure that is used to support this data collection. To this end, we rely on low cost hardware, such as Raspberry Pi devices, to develop a data exchange environment that can connect to apps hosted on mobile devices.

The remainder of this paper is structured as follows: a description of the overall aims of the project and the Guapiruvu village is provided in Section 2. Section 3 describes our proposed IoT platform and Section 4 the tests we conducted with it in the village. Section 5 presents the work with a mobile data collection app and some related work is reviewed in Section 6. Finally, we draw some conclusions and describe lines of future work in Section 7

2 GUAPIRUVU VILLAGE IN BRAZIL

The final aim of this work is to address the knowledge and infrastructure deficits that have hampered the sustainable development aspirations of the Guapiruvu tropical forestry community in the Sete Barras region of Brazil[1]. Our research focuses on addressing the challenges of climate change, which for this community of 300 households, has been exacerbated by political inaction, geographic isolation and educational deficits. For those living in Guapiruvu, climate change has accelerated environmental destruction, which has resulted in socio-economic deprivation as traditional farming and foraging practices are compromised[3]. Without co-ordinated engagement and suitable education, members of this community will continue to be disenfranchised. Our aim is to enable the broad cross-section of the community (farmers and children alike) to better understand the value and relevance of biodiversity.

We focus on supporting citizen science as part of the curriculum of rural schools in Guapiruvu, with the insertion of content focused on environmental issues, and the valorization of the rural and the forest as a source of work and income opportunities. In addition to income opportunities through local agriculture, the production of environmental services through rural tourism and the conservation of forests and river sources could be strengthened as a viable career pathway for young people. Consequently, the project focuses on supporting school children in the community capture data about biodiversity in their local area. The school also acts as a ‘hub’ for implementing and supporting a bottom-up communications infrastructure.

2.1 Stakeholders & Incentive Models

Figure 1 identifies the members of the community involved and the potential incentive models that we can use to engage them. Stakeholders can include: (i) the school children – the most important participants who need to be incentivised to engage and contribute; (ii) school teachers – who are responsible for coordinating the overall activities undertaken by the children, and to manage the clubs (technology and bio-diversity tracking); (iii) government agencies – such as Instituto de Pesquisas Ecologicas (IPE)[2] in Brazil, who are responsible for conducting bio-diversity studies in the region. It is important to involve these agencies, as they remain important beneficiaries of the data collection supported through the citizen science efforts, and (iv) other community members who see a benefit in school children carrying out these activities – these include local farmers and “elder” promoting economic and environmentally sustainable practices to be developed in their community.

An incentive model can be both short term, e.g. giving immediate recognition to the child who has made the greatest number of observations (referred to as "Fame/Recognition" in Figure 1), and long-term, e.g. articulating the benefit of sustainable agricultural practices for the community and its impact on the bio-diversity of the area. Based on discussions with the community, it is important that these incentive models must also include economic benefit, such as potential revenue that can be generated through tourism.

3 IOT COMMUNICATIONS PLATFORM

The lack of a communication infrastructure in the Guapiruvu village led us to the development of a system that could enable long range communication in the area. To this end, we designed a platform with the following hardware:

- Raspberry Pi 3 B+, as a portable communication hub with a built-in Wi-Fi antenna[3].
- LoRa modules: We used a solution provided by Cooking Hacks with a Semtech SX1272 chipset and an Arduino-to-Raspberry Pi connection bridge[4].

This platform was conceived as a standalone solution using LoRa-enabled Raspberry Pis, with additional wireless-enabled devices as interface (e.g. laptop, tablet or smartphone). This design decision was motivated by the limited resources available in the deployment environment, the village (e.g. lack of a backbone network), as we did not want to rely on external screens/input devices or internet connectivity to manage the LoRa connections.

Figure 2 depicts a sample scenario with 2 Raspberry Pis that communicate using LoRa and with smartphones running an application that displays a user interface. Each Raspberry Pi runs a software stack as depicted in Figure 3, formed of the following blocks:

- Hostapd and dnsmasq: used to create a wireless hotspot and a DNS+DHCP server in the Raspberry Pi. A user of the platform connects a device (e.g. smartphone) to the hotspot and, then he/she is redirected to a web page served by the Raspberry Pi.
- A Python-based web stack: used to serve the web page that acts as interface with the LoRa module. The web front-end uses Bootstrap[5] for the visual elements, like the fonts and the

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[1] Sete Barras region (in Portuguese) http://www.setebarras.sp.gov.br

[2] IPE: https://www.ipe.org.br/en

[3] Raspberry Pi 3 B+: https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus

[4] LoRa SX1272 Shield: https://www.cooking-hacks.com/sx1272-lora-shield-for-raspberry-pi-900-mhz

[5] Bootstrap library: https://getbootstrap.com

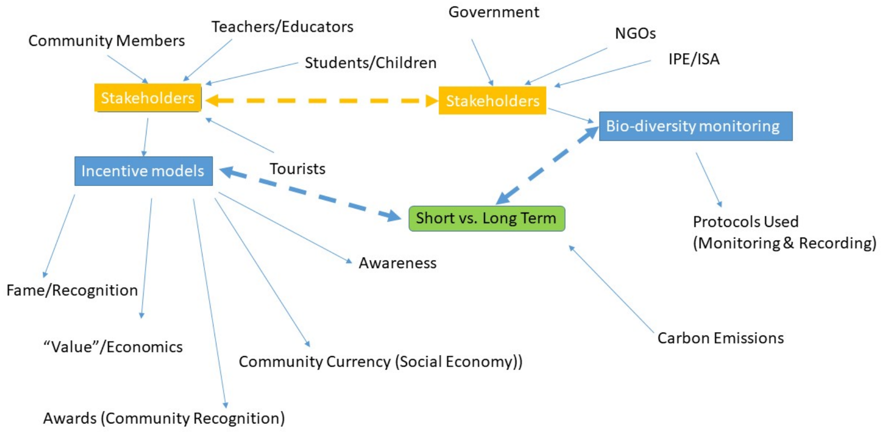

Figure 1: Stakeholders involved

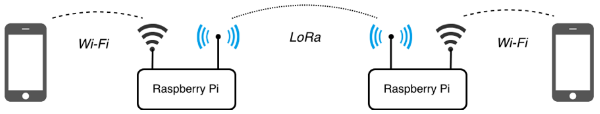

Figure 2: Connectivy scheme

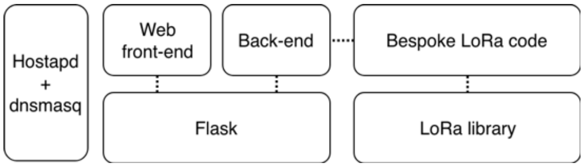

Figure 3: Software stack

- buttons. This front-end calls a set of REST APIs in the Back-end, which act as proxy for several LoRa functions in charge of sending and receiving messages through LoRa. These web modules are built on top of Flask, a Python framework for web development.
- A LoRa module: on top of the LoRa library and APIs provided by the manufacturer, we developed several functions in charge of setting up the LoRa module at start-up, and of sending and receiving messages through the LoRa devices when they are called from the web back-end.

In order to test long range communication with a realistic application, we developed a simple messaging app that enabled a user to send a text message (140 characters long at maximum) to any other device found in range. The web page is self-refreshed every 5 seconds to check if there is any new message received from other devices. Figure 4 shows a screenshot of the web page.

The software we developed is publicly available in an open repository[6].

Mensagem de longa distância

Você está conectado ao Raspberry Pi 1

Digite sua mensagem abaixo (máx. 140 caracteres):

Mensagem recebida (atualizado a cada 5 segundos):

Hello from the other side

Última verificação de recebimento:

20:32:5

Figure 4: Screenshot of the web front-end

4 LONG RANGE COMMUNICATION TESTS

We conducted a set of tests with the IoT platform in Guapiruvu on the 5th of November 2018, between 10:00 and 12:00 local time. The weather was sunny, with no rain but high humidity.

The LoRa devices were configured in Broadcast mode, so any device could send and receive messages to/from any other device. Table 1 shows the main parameters of the LoRa configuration we used.

In order to provide mobility to the prototype, an Anker PowerCore 26800 external battery[7] was attached to each Raspberry Pi. This 26800 mAh battery provided sufficient charge to run all the tests with less than a 25% of its charge.

Figure 5 shows a representation of the test area as a map – please note that it is not made at scale. Also note 3 icons of a photographic

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[6] LoRa Messenger: https://github.com/ulopeznovoa/lora-messenger

[7] Anker PC 26800: https://www.anker.com/products/variant/powercore-26800/A1277011

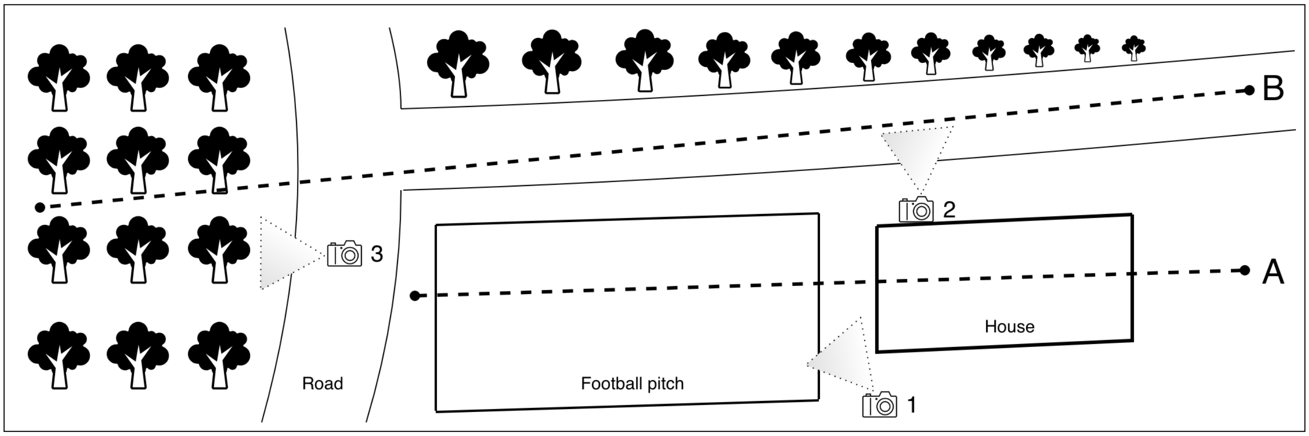

Figure 5: Testing area - Map

Table 1: LoRa configuration

Parameter	Value
Frequency	900 Mhz
Channel	10
Output power (Low/High/Max)	High
CRC	On

camera with a number next to them: these correspond to several pictures taken in the area and shown in this manuscript (Figures 6, 7 and 8). This link[8] provides a 360 degree view of the test area in Google Maps uploaded by user Gabriel Aoki.

The main objective of the test was to find the limits of LoRa in the area and in particular, to find places where the Raspberry Pis could communicate not being in line of sight. We used two Raspberry Pis, each with an external battery, and a smartphone per Raspberry as interface. We report below the most relevant scenarios where communication was possible, which are depicted in Figure 5 as dashed lines:

- Test A: Approximately 100 meters with a house of bricks in between.
- Test B: Approximately 220 meters, 100 of them in a dense area full of trees (as in Figure 8).

These tests show that it would be possible to set several distributed LoRa-enabled Raspberry Pis scattered across the village to act as hubs for the exchange of information.

5 USING SAPELLI COLLECTOR

To engage the citizens of Guapiruvu further in Citizen Science, we plan to introduce a data collection activity such as counting sightings of local wildlife. Using hand-held mobile devices such as smartphones, the children will use a mobile app to record each time they see a particular type of animal. The sightings from each child will then be collated to produce a survey of the local wildlife.

Repeating this activity over weeks, months or even years will illustrate any changes to wildlife patterns that may be seasonal or due to local development in the region that affect wildlife habitats. Through this data collection activity, the children will learn the value of data for monitoring their local environment and how they can be instrumental in that monitoring. In fact, they will likely be the only citizens monitoring the wildlife in their local region.

To collect data on animal sightings we plan to use Sapelli Collector[9], an open source citizen science mobile app. Sapelli Collector has three compelling features that match the requirements of our data collection activity for children:

- An icon-driven rather than language-driven user interface that enables children with a variety of ages and correspondingly varied levels of literacy development to participate.
- A decision-tree interaction style that leads users quickly though the app to record their observations.
- Functionality to record photographs, video and geographical coordinates of the observations.

Figure 9 shows an example user interface from a Sapelli Collector application for observing wildlife crimes. The user interface of Sapelli Collector can be configured to show icons specific to each data collection application. We will work collaboratively with the children to design the icons of the animals to further engage them in the data collection activity.

Each Sapelli Collector app transmits the observations made with the app to a GeoKey[10] data collection server. GeoKey is a Django server application that provides a REST API for receiving geographic data collected by citizen science applications. Sapelli Collector sends the geotagged photo and video data to GeoKey through the REST API.

Sapelli Collector has a flexible data transmission system that makes it ideal for use in Guapiruvu with its limited internet connectivity, as described above. In the best case, where internet connectivity is available, Sapelli Collection can transmit directly to a GeoKey server. When an internet connection cannot be established but there is a mobile phone signal, Sapelli Collector can transmit

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[8] Test area in Google Maps: https://goo.gl/maps/F64su7oZPc82

[9] Sapelli: http://www.sapelli.org

[10] GeoKey: https://geokey.org.uk

Figure 6: Testing area - Picture 1

Figure 7: Testing area - Picture 2

limited observation data via SMS to a phone that does have an internet connection with a GeoKey server. In the worst case, where no internet connection or mobile phone signal is available, Sapelli Collector can store observations locally on the mobile device and transmit them later when an internet connection to a GeoKey server becomes available. Figure 10 shows Sapelli Collector's flexible data transmission system.

As a feasibility test, we have successfully deployed the GeoKey server on a Raspberry Pi 3 B+, which included installing a Django stack, PostgreSql and PostGIS, a geographic extension to PostgreSql. This way, the main hardware requirements for our data collection activity would be smartphones and a set of Raspberry Pis.

6 RELATED WORK

The Citizen Science community has been active in deploying information exchange and communication systems to enable data collection in rural environments. This section presents some of the most relevant proposals found in the literature.

In 2011, Rohokale et al. [9] proposed a cooperative IoT platform to monitor the health status of a community of people. To that end, each monitored individual should wear an active RFID sensor to measure parameters like blood pressure or hemoglobin levels. Each of these RFID sensors would submit the collected information to a network of nodes called Opportunistic Large Array, in charge of sending the data via internet to a doctor that can assess the health of the individual. Authors set a theoretical experimental scenario and evaluate the energy, latency, and throughput tradeoffs in the network using simulation.

In 2015, Dlodlo and Kalezhi [2] presented a literature analysis and review about the ways that IoT technologies could be used to reduce poverty in rural areas of South Africa and Zambia. They first present an analysis of the state of agriculture in those regions and after that, an exploration of potential uses of IoT in agriculture, e.g., to use sensors to monitor and control temperature, humidity and light.

Figure 8: Testing area - Picture 3

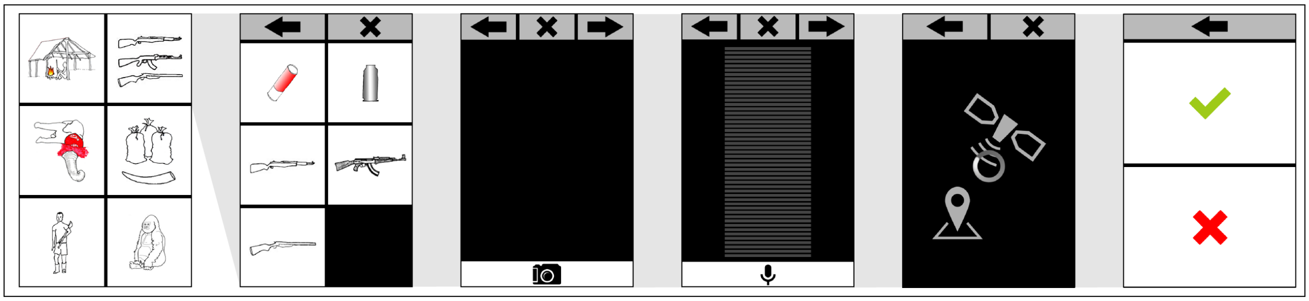

Figure 9: An example icon-driven Sapelli Collector user interface. Source: http://www.sapelli.org/reporting-wildlife-crime/ under Creative Commons (CC BY 4.0)

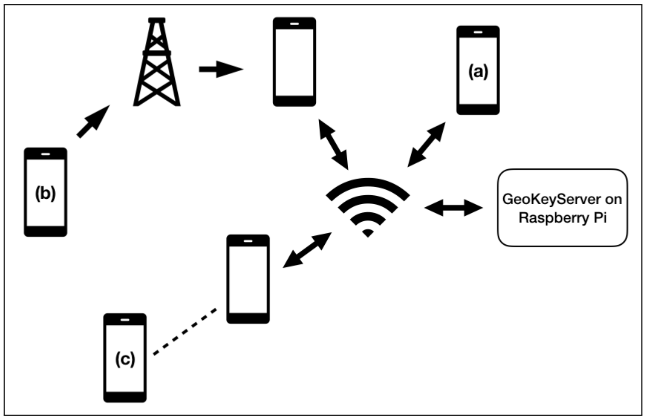

Figure 10: Sapelli collector can transmit data to a GeoKey server in a variery of network connectivity scenarios: (a) Direct transmission via WiFi; (b) Indirect transmission via SMS to a device connected to WiFi; (c) Delayed transmission until the divice can connect to WiFi.

In 2016, Pham et al. [8] developed a low-cost communication platform based on LoRa for rural environments with the aim of improving the productivity of applications like agriculture or fish farming. Similar to the work we have presented, they built a LoRa gateway using a Raspberry Pi and a SX1272/76 communications board. However, in their case, they forward the collected information to servers out of rural environments for further data analysis. Their LoRa gateways were deployed outdoors with appropriate casing and left running for several months with no technical issues.

In the same year, O'Grady et al. [5] presented a discussion on the issues of setting a distributed platform to enable Citizen Science. They presented their SIXTH Middleware as a layer for ubiquitous sensing, in charge of collecting sensor data through mobile phones, and the way the developed an extension to enable P2P communication. In their tests, they use Libelium Waspmote sensors and Apache Cordova to implement a multi-platform mobile app. Based on this infrastructure, the authors describe the key challenges they encountered to enable a Citizen Science project, like task management and implementing gamification.

Also in 2016, Petrić et al [7] conducted a performance assessment of a LoRa communications network arranged as a star topology in the city of Rennes, France. They built several types of IoT nodes for their network, ones called *IoT objects*, with Arduino boards and LoRa shields, in charge of data collection and forwarding, and others called *IoT stations* using a Kerlink solution to acts as a LoRa hub with Ethernet or 3G internet connection for data forwarding. Authors generated synthetic traffic that represented a real-world application like sensor monitoring and used it to benchmark the capacity of the network. They chose 7 spots across the city to place their IoT nodes and they present a study of the sensitivity of the system to the position of the nodes and the performance in each of the scenarios.

In 2017, Oliveira et al. [6] measured the coverage distance of LoRa in a rural and two urban scenarios in Portugal. For each scenario, they present the covered range, details about signal quality and performance of the solution delivering information. In their tests, authors achieve communication in a distance of 5 km in the urban scenario and close to 2 km in urban scenarios.

Finally, in 2018, Sanchez-Iborra et al. [10] presented a performance evaluation of LoRaWAN network under different environmental conditions. They chose an urban, a suburban and a rural environments, all three in the region of Murcia, Spain. Authors placed a LoraWAN end-node in the roof of a car and a base station in different locations of the described environments. They drove the car through the test scenarios while the end-node kept transmitting data to the base station and performed an analysis of the robustness of the network and the data transmission. Authors conclude that, based on their results, wave propagation has a significant effect in the performance of a Long Range WAN.

7 CONCLUSIONS

This paper has described the progress in the deployment of a Citizen Science project in Guapiruvu, a village in the Sete Barras region, Brazil. To this end, we have built an IoT platform using Raspberry Pis and LoRa communication hardware, and developed a messenger app as a case study. In November 2018, we conducted some tests with the IoT platform in the village and proved that communication was possible up to 220 meters, including an area densely populated with trees, and up to 100 meters in a area with a house in between. We have also tested Sapelli and GeoKey, two pieces of software that would enable out-of-the-box data collection by the citizens of the village on top of the IoT platform.

The future work on the technical side will head in two directions: First, to further test and improve the deployment of the LoRa-enabled Raspberry Pis in the village. These devices will need to be able to respond to operational constraints (such as humidity, rain fall, etc), and need to be positioned to ensure that there is good coverage of a given area. Second, to deploy and test Sapelli and GeoKey in the Guapiruvu village with end users. We will introduce Sapelli to the citizens of the village and set it up so they find interesting and amenable to use.

After this, the project will focus on using the technological deployment to address the deficits of knowledge of the community and to foster the collaborative collection of nature data for further analysis, as described in depth in Section 2.

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