Foundations of Map-based Web Applications

A Survey of the Use, Limits and Opportunities Offered by Digital Maps

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Abstract: Traditional maps are one of the oldest way to express relevant information on a locality base, as synthetic representations of reality. The traditional visualization theory of maps and the related principles used to structure spatial information can inspire the modelling of new solutions in the field of information management in web application. But, the fast and generalized spreading of digital maps, and the related production of geo-localized social media is not followed by a deep integration of map in web applications, preventing the effectiveness of digital maps in solving pressing issues like aggregation, retrieval, recommendation and presentation of spatial media. Through the analysis of key concepts of maps, this contribution addresses the foundations of map-based applications, discussing the limits of current approaches and introducing new opportunities based on deep integration between maps and applications.

1 INTRODUCTION

Traditional maps are one of the oldest way to express relevant information on a locality base (Shahaf, 2013), combining and defining different semantics using visual signs (MacEachren, 1995), in order to present a synthetic representation of reality at different scales and organizing data in a structure defined by the purpose of the map (Keates, 2014) (Okada, 2014). The traditional visualization theory of maps and the related principles used to structure geographical information can inspire the modelling of new recommender systems for online tools, based on the integration between data structure and interaction of applications and digital maps.

Nowadays, the fast and generalized spreading of digital maps, and the related production of geo-localized social media, is due to the intuitiveness of maps in representing reality. Digital maps often complement web applications, even thoes applications not specifically related to geographical purposes such as social networks, public platforms or thematic portals. Digital maps provide a spatial context, an alternative query system and a visualisation tool to spatial media.

Nevertheless apart from web geographical information systems (Web GIS), digital maps are not "fully" integrated in web applications, in terms of features, interaction and information management. The decoupling of maps and applications generates ambiguities and counter intuitive behaviuor in web applications, leading to segregating digital maps to be uneffective "add-ons".

Maps are used as "canvas" to present spatial media, and to help users in selecting an area of intereset – a bounding box is a section of the canvas- and therefore a subset of application entries. The main use of digital maps is to let users interact with the system to navigate a surface (a world map), changing scale and area of interest, and visualizing at the same time extra sources of information as points of interests (POIs) or other geometrical features.

A light-weighted use of digital maps does not require any understanding of maps as knowledge theory, because limited to the visualization of spatial features mostly collected automatically (implicitilly) through mobile devices. Current web applications including maps cannot be considered "map-based" since not exploiting map features in the information management: representation, retrieval, recommendation and visualisation.

This contribution enquiryies how the theory about of maps can be reflected in web applications, how a map-based application should integrate maps

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extensivelly, which are the limits of common approaches and new opportunities. Specifically, maps are analysed from multiple perspectives: data visualisation, filtering, aggregation and recommendation:

- How to extend visualization mechanisms used to create maps from data sets of geographical features to “points of interest” (POIs)
- How to extend map scale theory to the management of POIs
- How to use geographical entities in data aggregation
- How to take in account users’ interaction with a map in data collection
- How to build a geographical recommender

The theoretical concepts behind the definition of maps are demonstrated to be relevant to provide a meaningful and coherent context for spatial media. The relevance theory within the implementation of scales in cartography is presented as solution of the issues about ambiguities of spatial feature of social media and filtering, leading to the revision of the current mataphor behind the interaction and information management with digital maps.

The solution to the ambiguities in POIs collection open the path to overcoming the current solutions in data aggregation and filtering, defining suitable alterntive to popularity ranking, and spatial clustering. Moreover, the strong connection between POIs and geographical entities a identification of the connection between POIs and geographical entitie open the possibility to new multiple solutions.

The rest of the paper will discuss the theoretical and technical steps needed after a state of the art and followed by a discussion of open issues, further research topics and conclusions.

2 DIGITAL MAPS

In web applications, digital maps provide the geographical context of spatial media: the visualisation as POIs of their position (spatial feature) on a cartography. Also, digital maps support exploring POIs with dialogue popups - clicking on markers – and interacting with the map viewer changing viewer bounding box and scale to change the retrieved data.

Digital maps can be used to entry geographical features such as positions, in alternative to using addresses or GPS. But, the decoupling between map status and the data leads to ambiguous entries, hard to process automatically and to present to users (Figure 1).

The integration of digital maps in web applications opens issues related to the heterogeneity of crowd-data and design tools able to support unexperienced users without a common ground. The web domain forces toward intuitive and pragmatic tools that can be used by everyone without any training or guidance, and at the same time archiving an overall good quality of the result.

Following, we are going to analyse current uses, limitation and constraints of digital maps, outlining alternative solutions and new approaches.

2.1 Information Management Systems

Nowadays, the importance of user-generated contents (UGC) is continuously arising in many fields, and crowdsourced unstructured and/or incomplete dynamic data with spatial attributes need to be organized and analysed in order to leverage their immense value.

Web-GIS (web geographical information systems) are a class of applications focused on working with geographical information, providing tools to define geometries (paths, polygons, lines, multi polygons, points). Web-GIS are often supported by volunteering and crowd-based geography movements, and used to build big datasets of geographical information where there is a lack of official sources. The major project in this regards is OpenStreetMap (OSM). Web-GIS specific focus are geographical data, thus they cannot be bended to social media where the geographical aspects are important but marginal and with they do not share the same efforts in terms of correctness of entries, methodology, features, required training, etc.

Social media such as Facebook and Twitter, make use of spatial features as fundamental part of their strategies to handle crowdsourced big data. A crucial part of the success of those applications is their effort on usability: intuitive interactions, smart defaults, action feedbacks, personalised interfaces, etc. The result is archived combining any means like user profiling, reasoners and domain specific recommenders. Geographical profiling is the natural consequences of adding geographical features to social media.

2.1.1 Limitations

The concept of scale remains implicit in digital maps and in location based social media. In general, what you see on a map the application is not aware of and therefore is not what you get interacting with the application. Without considering the scale, the organization of information does not reflect the user experience, mostly oriented to search for different sets of information at a neighbourhood, urban scale or territorial scale.

Scale is a broad concept investing technical schemas, urban plans, public strategies programmes and many other fields, and it is referred to the need of visualising different cluster of data in different scales for specific purposes. This concept translated in digital maps leads to do not aggregate information considering the geometrical proximity of POIs based on their coordinates, but their relevance at each scale.

Another aspect to consider in current digital maps is that the spatial features of social media are mostly ambiguous and under specified. For instance, what is the meaning of a media position? A user is visiting something or it is just passing by? Is the posted content related to where a user is or from somewhere else? In case of complex environment like shopping malls, where the user actually is? There is a huge effort in disambiguating this information but a major contribution can come directly on less ambiguous interfaces enabling users to specify where and what they are doing and the scale of reference. In Figure 1 for instance, the same input (position) may have different meaning according to the view scale, problem that does not rise using address as reference system.

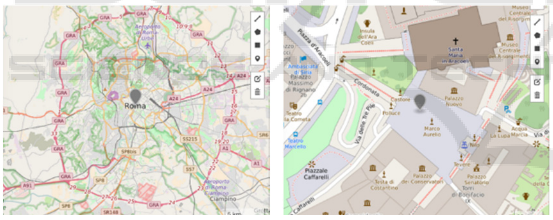


Figure 1: A position changes meaning at different scale: the marker is referring to Campidoglio square (a) and to the city of Rome (b).

Furthermore, a disconnection between the visualization state of the map and the application status heightens the ambiguity of scale in user interactions with digital maps. In other words, the change of scale associated to a change of zoom level is limited to the cartographic base, but it does not change the status of the application in terms of retrieval and visualization mechanisms.

2.1.2 Alternatives

Which aspects of the concept of scale should be considered for web applications? In general, it is possible to consider three kind of scales: cartographic scale, geographic scale, and operational scale. The cartographic scale address the relationship between a distance on a map and a distance on the ground. The geographic scale reflects the geographical structure of social interactions and size, level and relations define it. Operational scale corresponds to the level at which relevant processes operates and include the traces of actions belonging to the same chain of activities (Lam, 1992) (Smith, 1992) (Howitt, 1998). OpenStreetMap (OSM) is currently the biggest open geographical data source available, and OSM's definitions of spatial entities are mostly focused on space functions and uses (Marston, 2000). Therefore, applications features relying on geographical data should consider what is available beforehand (operational and geographical scales).

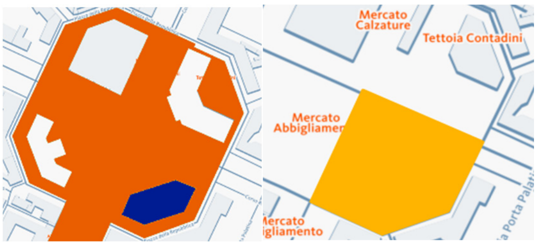
In digital maps:

- The size is controlled by users through zoom controls
- The level of focus - local, national, regional – is bounded to what is considered relevant at each scale, from buildings to the city level, and usually is related to a bounding box, defined by two points, the South-West North-East extremes of the map window
- OSM entities are rendered as geometries according with their size and vertical ordering
- Names are rendered as labels over geometries

The connection between the state of the map and the state of the application can be archived reflecting the change of scale within the application. Changing the zoom level changes the cartography but not the data on the map. There is not an explicit mapping between the zoom levels and scales which can be used to create a dynamic visualisation system.

The status of a map is not limited to the bounding box but also to geographical units currently visible, ranging from administrative entities as for instance cities or districts, to informal boundaries as neighbourhoods, to spatial units as building blocks, public spaces or buildings (Figure 2). The concept of geographical unit is connected again to the scale, as the scale change the relevant units change. This mechanism unveils the existence of a "focus layer" of entities which are significant - and highlighted in the cartography at - changing as the map status changes. Connecting POIs and geographical unites is therefore possible to filter the information as the users interact with the map, in a more comprehensive way.

Furthermore, key concepts of a map implemented with the map theming, symbols and legends can be extended to information management and vice versa. A map legend can be effectively reflected in the data organisation and for instance, a category system can be used to generate map theming dynamically.



(a) (b)

Figure 2: Example of geographical units considered for the indexing system: building (a) and square section (b).

In digital maps, theming and scales are implemented into styling rules defining what should be rendered and how - colours, labels, hatches, lines, symbols, vertical order - during the map generation process. Following an example of styling rule about how to fill the buildings polygons from CartoCSS in Mapbox (https://github.com/mapbox/carto/):

```
[class='street’][zoom>=9]{

  line-pattern: @small;
    [zoom>=13]{
     line-pattern: @medium;
    }
    [zoom>=16]{
     line-pattern: @big;
   }
}
```

In this example, the CSS rules {…} are valid for the interval between 9 and 22 (max zoom possible), from the city to the indoor level. Following the previous example, streets do not have a style for levels higher than 9 and consequently not rendered (even if the information is still there). The inner rules override the styling of streets accordingly to the zoom level. At 13 and 16 there is an increment of the size of streets. For instance, the vertical ordering - a street overlapping a river – is also encoded by styling rules.

Rules are applied to labelled spatial entities at rendering time, but with current vector maps it is possible to change them dynamically. The logic within styling rules can effectively extracted and generated, enabling a two-way connection between cartography and application.

Summarising, as the map changes POIs can be filtered, and as users exclude/include contents with other tools the map theming can also change. Moreover, the theming can be connected to application organisation system such as categories and vice versa.

2.2 Data Viewers

Technically speaking, digital maps are web viewers for pyramid images (cartography). The cartographic bases are images (raster, svg) or data sources organised as “tiles” in layers. A tile is a bounding box of fixed dimension, identified and retrieved by a triple: z for the layer, and x and y for the area. A map viewer is a tool to identify and retrieve tiles, converting the bounding box and zoom level in triples and to present tiles and layers of geographical features on a spatial canvas. POIs are represented by their geographical feature (point) in overlay layers above the tile layer.

2.2.1 Limitations

One of the most common limit of digital maps is the lack of control over the visualized information. The visualisation of data is done pushing data in overlay layers, which are implemented as arrays. The map viewers usually provide control over the visualisation of layers but not about the contents of layers beside the bounding box. For instance, dynamic information can make maps overcrowded and impossible to be used, which is in contrast with the very purpose of maps in general: synthetic representations based on hierarchical representation of information and selection.

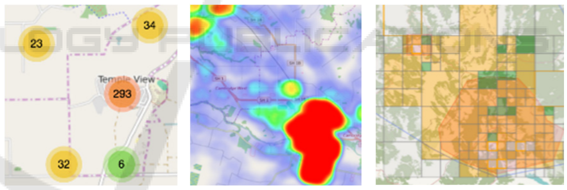


Figure 3: Aggregation approaches: (left) marker clustering, (centre) heat map, (right) grid-based aggregation.

The problem of overcrowded maps is addressed directly by applications through filtering, recommendations, and ranking (ordering solution) in conjunction with specific solutions for digital maps, like spatial clustering (Figure 3). Spatial clustering creates dynamic clusters of markers accordingly to their distance, ignoring geography of their location like physical barriers and administrative boundaries (Figure 4), and other distances like street routes. Ordering solutions are used in combination with limits on the results, e.g. top 100. The limit that can be global (in a bounding box) or local to each section of the map (tiles). It can be implemented hiding marker or using marker of different dimensions.

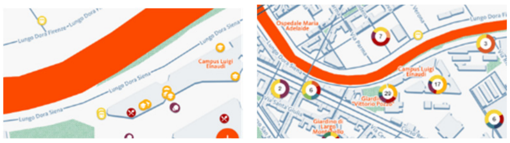


Figure 4: Marker clusters take in account the distance (left) despite any physical obstacles like a river (right).

2.2.2 Alternatives

Again, the limits of the mentioned approaches are due to not considering maps as knowledge systems. Considering data structures of maps, the projection of a subset of geographical features should be done coherently with a synthetic theory implemented in theming and scales. In other word, the data visualisation can be based on accordingly to the hierarchy implemented in the current scale and on what is currently visible in the cartography. To bridge maps and applications views it is required to use the same rules in generating maps within the application.

Alternative solutions to overcrowded maps can be built on top of the visualisation of geographical entities on maps, in terms of type like buildings, administrative areas, parks. The connection between POIs and geographical entities can be used to transfer properties from geographical entities to POIs and vice versa. For instance, the hierarchical organisation and vertical alignment of geographical entities can be reflected on data overlay layers in alternative to highlighting popular contents.

2.3 Recommender Systems

Digital maps are currently used as location-based filtering systems, instead recommendation is mostly based on users' spatial profile or their current location. But current web technologies allow to generate maps almost runtime, applying dynamic themes and even manipulating map data sources. Can dynamic maps support recommendation?

POIs recommendation is still a major issue in location-based social networks. POIs have spatial and temporal dimensions, making this domain hard for common recommender (Griesner, 2015). The recommendation of POIs should also be user-based, location-aware, and context dependent (Liu, 2013). There are several possible approaches to build a geographical recommender system:

- to combine temporal and spatial dimension of POIs (Griesner, 2015) (Lu, 2015) and to use time/location data of users;
- to exploit POIs content, considering associated textual and context information (Liu, 2013);
- to collect data about the interactions of users with digital maps and update their profile with category preferences and locations (Oku, 2010).
- to extend the friendship-based approach to locations (Ye, 2010), considering the emerging correlations between friendship and favourite places.

2.3.1 Limitations

Users' geographical profile is not always a reliable source of information, in particular where users can access the same platform for very different purposes, like in case of public portals and civic platforms. The users' current goal is unknown and it cannot be inferred especially in multi-thematic and multipurpose platforms. For instance, the reasons behind selecting a place, planning an activity, enquiring for a service or trading a good is commonly implicit and overlooked, and not reflected on map views.

In this context, users have a passive role – without control - in determining which contents are displayed, and recommended contents based on users' geographic profile is just the result of an aggregation of preferences associated to spatial features.

2.3.2 Alternatives

Map theory again can support the definition of new geographical recommender system, which do not require users' geographical profile, but can exploit the geographical types in combination with users' activities, giving control to users on what they want to see case by case.

Traditional maps are "a priory" recommender systems, where readers could see only a specific set of information, accordingly to what they need, selecting the right kind of map, in terms of scope, scale, purpose/theming.

Currently, digital maps open a wide range of approaches, providing the possibility to create multiple maps from the same data source in term of theming and scales. For instance, it is possible to settle a general goal "traveling" and different approach at each scale "walk", "bike & car", "bus & train", "airplane & boat", generating very different vires.

The introduction of an indexing system for POIs, using geographical units connected to the zooming system results in: 1) providing a tool to users to explicitly control the results and 2) extending the recommendation aspect from maps to geographical units and then to contents.

Interactivity is the main features of digital maps, enhancing the value of users' inputs on maps enhance the effectiveness of the map as tool without raising the overall complexity of a web application.

Users' needs play a central role to understand what connects their favourite locations and their activities (Guy, 2015). In this perspective, we propose to start considering users' actions, in alternative to systems based on users' spatial profiles. Allowing users to control the outcomes and introducing a concept of users' contingent goal/task consent to provide a tailored support to their current activities. A goal is something that can be handled by users directly and explicitly reducing the premises to how best support specific user activities rather than guessing users' interests.

As result, maps can be shaped dynamically accordingly to users' tasks, for instance removing useless entities and highlighting a work area like a district or neighbourhood.

3 MAP-BASED APPLICATIONS

What are the features of a map-based application? An application can be considered map-based if it exploits the core mechanisms of maps in such a way that interacting with a map is interacting with the applications' entries and as the map status changes the application status changes and vice versa. Thus, the fully integration between map and application is a requisite to provide an intuitive tool, improving the overall capability to manage complex scenarios such as social networks, or any big data, relying on the geographical features of data.

A map-based application should implement the principle "*what you see is what you get"* (WYSIWYG), solving the ambiguity of data input, and the decoupling between map view and application data. In this regards, not all web applications using maps should be map-based. For instance, hotel web applications do not need to provide any other information aside hotels, therefore there is no need to consider scales or implementing dynamic theming.

Summarizing, a map-based application should support the following mechanisms:

- The connection between application contents and map entities, that each spatial media is linked to a geographical entity;
- The connection between map status and application status, or rather actions in the application should be aware of the current status of the map in term of scale, area and available entities for users.

3.1 Information Management

What does it mean to connect map and contents? As general principle, connecting a map to its content means to show, hide and highlight accordingly to the map goal. For instance, a political atlas shows nations despite their size, population or political influence, and nations are usually coloured to highlights their boundaries, but there are no orographic references or any other element describing their morphology. A political atlas is not meant to describe orography nor morphology of countries, but to show the physical relations among them. Conversely, in physical atlas countries with similar territory can be easily confused – there is not a neat distinction of national borders - because the aim of this kind of representation is to highlight natural element characterizing the territory. Maps produced for different goals contain and show different elements.

Considering another perspective, road guides are books for traveling by car, usually organized in local and national tables. National tables show main roads such as highways and main dorsal railways. Local tables contained also secondary and local streets. Even if local and national tables are intended to show similar entities (streets, railways, paths) and they looked very similar, their content is different. Even in this case, maps select information for the user, considering different goals: travel by car to reach a place or to explore and find a specific address of a place. The representation theory about scales is directly linked to theories of relevance about map contents.

Digital maps allow users to change the map zoom to observe different portions of space, but this kind of interaction does not necessarily affect the map scale. In fact, there is not an explicitly connection between zooming and scale because scales are usually outside the scope of applications, encoded in "tile servers" (map providers). Even if a map switches from a zoom level to another does not mean that map contents change accordingly, this leads to overcrowded maps.

Making explicit the connection between map and content management will reproduce the same use of physical maps, the choice of the right map for the current use but seamlessly. This requires to build a data structure based on the data source of maps, which can be possible only with crowd-based and volunteering geographical data sources.

3.2 Connecting Maps with Applications

Why are POIs cannot be connected to geographical entities in current applications? Digital maps are considered "flat" even those they are not. The data layers and POIs are "pinpointed" on maps, without any regard to what lies behind. The current metaphor is using maps as pincushions, without any connection between map and markers (pinpoints).

Pinpointing a marker on a map is maybe the easiest method to add the spatial dimension to contents, and the practice demonstrates that so far is a solid metaphor when comes data collection. In fact, very few non-geographic systems support anything more than markers.

But in terms of other tasks we may find a more suitable metaphor considering again the data structure behind maps and how users interact with them. Rather than pinpointing the action of placing POIs is "dropping" them on geographical entities. What is the difference between pinpointing and dropping? Even if technically raster maps are flat, we can assume users placing POIs considering a structure of ordered elements they saw: streets are above rivers, buildings are above parks, etc.

Spatial entities work as castle of *"buckets"* one inside another, in respect to their size and vertical ordering. POIs are falls inside these buckets because users can *"see"* where they place them. Applications not aware of what users are interacting with are disregarding partially the meaning of users' actions with the consequence of losing the essential information and failing in representing correctly users' contributions.

Considering what users interact with saves a lot of issues and computation, and it enables to build a reliable connection among users' contents and geographical data by design.

3.3 Applicative Solutions

The requisite is the connection between POIs and geographical entities instance. It can be archived introducing a specific geographical index recording the relations as users generate contents (Antonini, 2017). The indexing system requires the definition of focus layers, a coverage made of geographical units, for each defined level of the index.

As users change scale the application can load the relative focus layer, to build features based on the understanding of what users can see and can interact with. It enables to:

- Dynamically change the map theming
- Filter POIs which are not related to the geographical unites in the current focus layer
- Enhance the entry of data on maps, from points to "deep" points referring to a specific scale
- Aggregating information accordingly to the geographical entities they belong to (Figure 5)
- Rank POIs accordingly to the focus layer

The WYSIWYG principles can be archived. For instance, a POI about a building is retrieved if the building is retrieved, not only in terms of bounding box but in terms scale.

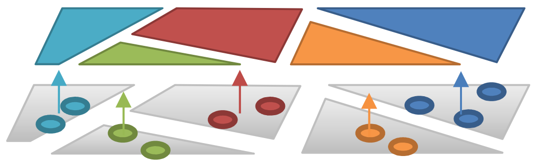


Figure 5: POIs connected to geographical units can be used to generate area-based aggregates, preserving the coherence with the geographical data as users see them on the map.

The system provides support to synthetic representations, saving computational costs and relative approximations. It can have great impact on performances, readability and intuitiveness, even with critical issues in web applications related to crowd sourced big data.

In terms of recommendation, it is possible to exploit the "type: of geographical entities to build users' "focus area" within the bounding box.

In Figure 6 the results of a first experiment. Using a simple flooding algorithm, the users' position is expanded on a weighted visibility graph connecting the visible geographical units. At users is given the control of a "task" selector, where to express their current activity. Tasks correspond to weights array indicating the cost of expanding the area accordingly to the "relevance" of the type of geographical units. For instance, during "sport" crossing a street "costs" much more than traversing a long park. The expansion of the focus area was bounded to two criteria, a maximum size of 50% of the bounding box or the inclusion of 50% of POIs within the focus area.

In Figure 6 the shape outline of three areas generated for the three tasks, starting from the same dataset of geographical entities and POIs.

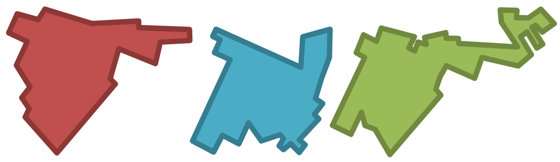


Figure 6: The outline of three focus area corresponding to: (left) shopping, (center) education and (right) sport, generated from the same setup: user position, POIs and geographical data.

The use of focus area to select geographical entities and therefore POIs, is an alternative solution to other recommenders not requiring user profiling.

4 CONCLUSIONS

This contribution addressed how the theory about maps can be applied to web applications to archive deep connection between data and interactions from maps to applications and vice versa.

The revision of current approaches and their limits were presented to introduce new opportunities offered by the foundation of maps from multiple perspectives: information management, data visualisation, data filtering and recommendation.

It was addressed the issue of connecting application data and geographical entities, discussing a geographical indexing system able to provide to applications the insight about what users “see” interacting with a map. Based on the geographical index, it was introduced the concept of focus layer a coverage of geographical units relevant within a given scale. Combining the connection between POIs and geographical entities in focus layers it was introduced the solution of area-based aggregation to overcome the limitation of current clustering-based approaches. Finally, it was presented the preliminary result of a geographical recommender, which select contents accordingly to users’ “focus area”.

Currently the presented ideas are being developed in solutions to support civic platforms such as FirstLife (http://firstlife.org/) and WeGovNow (http://wegovnow.org/). The necessity to address challenges issues such as aggregation, quality of crowdsourced data, spatial filtering in a public platform without relying on user profiling, was the stimulus to pursue alternative solutions to main stream approaches of social networks and thematic web portals.

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