Schematization of Clutter Reduction Techniques in Geographic Node-link Diagrams using Task-based Criteria

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Keywords: Visual Clutter, Geographic Node-link Diagram, Edge Congestion, Geo-referenced Networks.

Abstract: Visual clutter is a hot topic in the domain of node-link diagrams as it negatively affects usability, aesthetics and data interpretation. The organization of items, i.e. the way nodes and links are positioned in the display, is one problem among many that leads to visual clutter. In previous work, different techniques were proposed to reduce the clutter that depends on the organization of nodes and links. However, a schematization of such techniques by task was never considered. Approaching the problem by task would be more efficient since visual clutter, by definition, depends on the task to be performed. In this paper, we propose a solution to visual clutter driven by the type of task. In particular, the aim of our work is to provide an answer to the following question: Given a task and a geographic node-link diagram, which are the appropriated techniques to reduce the visual clutter that depends on the spatial organization of nodes and links. In our solution, we have classified tasks into a limited number of task groups. For each tasks group, we have identified and analyzed issues leading to a performance degradation. The final outcome consists on a list of good candidate techniques for each task group. The selected techniques are the results of a survey that selects only approaches that act on the position of nodes and links.

1 INTRODUCTION

The node-link diagram is a powerful tool for the visualization of relationships between entities. However, such visualization often suffer from visual clutter (Liu et al., 2014; Sun et al., 2013; Ellis and Dix, 2007) affecting usability, aesthetics and data interpretation.

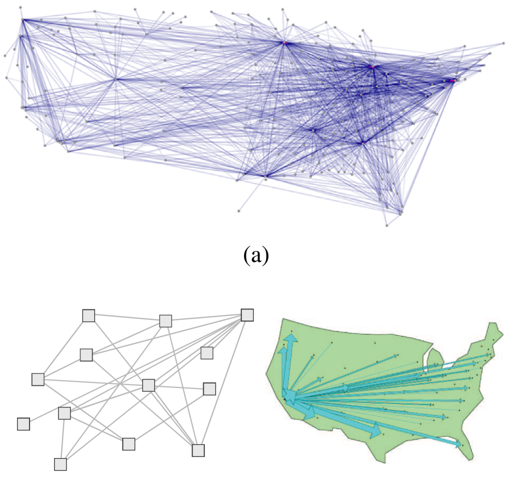
In previous studies visual clutter is defined as: "the state in which excess items, or their representation or organization, lead to a degradation of performance at some task" (Rosenholtz et al., 2005). Hence, visual clutter depends on the task, as shown in Figure 1. If the task is "find a node", only the diagram in Figure 1(a) should be considered cluttered (Holten and Van Wijk, 2009; Ersoy et al., 2011; Hurter et al., 2012) because many nodes are occluded. If the task is "given a node, find the connected nodes", also the diagram in Figure 1(b) should be considered cluttered (Wong et al., 2003; Wong and Carpendale, 2007; Schmidt et al., 2010) because ambiguities are present. If the task is considered of high-level, such as "understand the story described by the data", then the diagram in Figure 1(c) should also be considered cluttered (Phan et al., 2005; Verbeek et al., 2011; Debiasi et al., 2014) as it is not aesthetically pleasing.

In this work we focus on the problem of organization of items, i.e. the way nodes and links are positioned in the display, for which we propose a solution that is driven by task group. In geographic node-link diagrams, this aspect is critical because the position of nodes is fixed accordingly to geographical information. As opposite, we do not examine clutter that depends on the graphical representation of items, for example when the color of the nodes is the same of the background map, or when size of nodes is too small or too large taking into account the display size and the number of items.

Our work answers to the following research question: Given a task and a geographic node-link diagram, which are the appropriated techniques to reduce the visual clutter that depends on the spatial organization of nodes and links.

We start identifying and analyzing the main problems that lead to a degradation of tasks performance, i.e. uninterpretable representation, occlusion, ambiguity, and unaesthetic representation. Then, we divide the tasks into task groups, and for each group we associate the problems that characterize it. We use the task taxonomy for graph visualization (Lee et al., 2006) that covers exploratory and analytical tasks. We include a tasks group related to the aesthetic of the visualization, i.e. explanatory tasks. Finally, we pro-

Debiasi, A., Simões, B. and Amicis, R.
Schematization of Clutter Reduction Techniques in Geographic Node-link Diagrams using Task-based Criteria.
DOI: 10.5220/0005674801070114
In *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016) - Volume 2: IVAPP*, pages 109-116
ISBN: 978-989-758-175-5



(a) (b) (c)

Figure 1: Examples of different visual clutter in geographic node-link diagrams.

vide a list of good candidate techniques for each problem.

The selected techniques are the results of a survey that selects only approaches that act on the position of nodes and links. We restrict the analysis to this subset mainly because the position is the most used variable in the context of geographical node-link diagram to reduce clutter. We do not consider force-directed techniques on nodes because they do not preserve spatial information.

This paper is structured as follows. First we summarize, in Section 2, previous works on visual clutter in geographic node-link diagrams. In Section 3, we identify the visual clutter problems. Then we define in Section 4 our classification of tasks by groups. Lastly, in Section 5 we itemize the main clutter reduction techniques according to the defined criteria. An overview of the results obtained and of future work is presented in Section 6.

2 EXISTING SURVEYS

In literature different surveys on clutter reduction techniques are presented. However, they do not consider the different problems related to visual clutter (e.g. occlusion and ambiguity), nor they take into account the task.

In (Sun et al., 2013; Liu et al., 2014) visual analytics techniques were presented and a section was dedicated to the clutter reduction methods in large graph layouts. However, no hints are made with respect to the aforementioned aspects. The clutter problem and the related solutions are also mentioned in different categorizations of node-link diagrams (Hadlak et al., 2015; Debiasi et al., 2015a), but not as main challenge.

Zhou et al. (Zhou et al., 2013) provide a survey on edge bundling techniques. They described the algorithms accordingly with the way they generate the final graph layout, i.e. they distinguished cost-based, geometry based and image-based techniques. As opposite, we classify the different approaches accordingly with the criteria they fulfill, by looking at the final layout they generate. In the survey (Tominski et al., 2014), lens techniques in the context of visualization are categorized according to data types and tasks. Although many clutter reduction techniques are included, they are classified according with the proprieties of the solutions.

A previous survey (Ellis and Dix, 2007) focused on cluttered visualizations caused by huge amounts of data. The authors classified clutter reduction methods defining eight criteria based on their experience and on the study of the related literature. The main difference between our work and theirs is that their criteria focus on the techniques. We provide criteria derived from an analysis of cluttered layouts and tasks. Moreover, our work focus specifically on inappropriate organization of nodes and links in node-link diagrams and not on clutter caused by huge data.

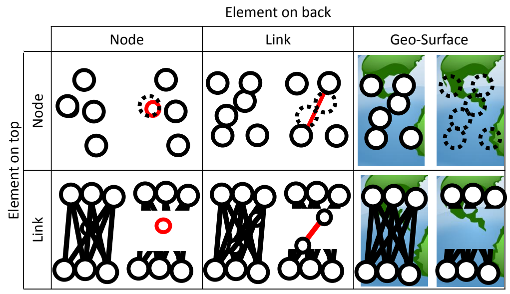
3 VISUAL CLUTTER PROBLEMS

Focusing on the organization of items, clutter is mainly the result of the overlapping (overplotting or overdrawing) of those items, i.e. items rendered on top (on near) of each other. In this work, the considered items are nodes, links (straight lines or curves), and the geographical surface (background map). We define the symbology *(element1, element2)* to indicate that *"element1 is rendered on top of element2"*. We describe four problems associated to clutter: uninterpretable representation, occlusion, ambiguity, and unaesthetic representation.

3.1 Problem of Uninterpretability

The readability of node-link diagrams deteriorates when items are badly located or when the size of the graph and its link density increase (Ghoniem et al., 2004). The problem of uninterpretable representation occurs when items become impossible to identify, making the visualization useless.

Table 1: Occlusion of elements (in red) results in loss of information. For each scenario, we apply an approach that acts on elements opacity to solve the problem.



3.2 Problem of Occlusion

Table 1 shows information loss of geographic node-link diagram taking into account all possible combinations between elements.

Here some elements are hidden behind other elements:

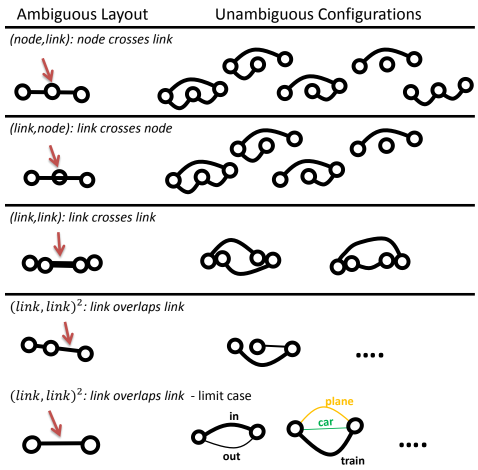
- *(node,node);(node,link);(node,geo-surface)*: Nodes located is the same spatial location or near with each other may cause their occlusion. In the same way, nodes can occlude also links or background map.
- *(link,node);(link,link);(link,geo-surface)*: Links obscure nodes, links, information in the background, map labels or map features. This problem is accentuated with thick links, or with a large number of links.

3.3 Problem of Ambiguity

Table 2 shows the ambiguity problem of node-link diagram taking into account different cases of ambiguity:

- *(node,link);(link,node)*: It can be difficult to assess, when a link crosses a node, or vice-versa, whether this link is incident to this node or it is merely crossing it. This makes it difficult to identify the actual sources and destinations of links. If nodes are rendered on bottom of links, links may obscure the content of the nodes. In the opposite case, the unambiguous layout candidates are more in numbers.
- *(link,link)*: Link crossings are an important factor in readability (Purchase et al., 2004). We consider colliding links also when they are very close to each other and are almost parallel. When eyes try to follow a link to its destination, small crossing angles between this link and other links create multiple paths along the direction of the eye movement, either taking eyes to the wrong path, or slowing down the eye movement. However, if two links share one node, this ambiguity does not occur.

Table 2: Ambiguity cases and their possible unambiguous configurations.



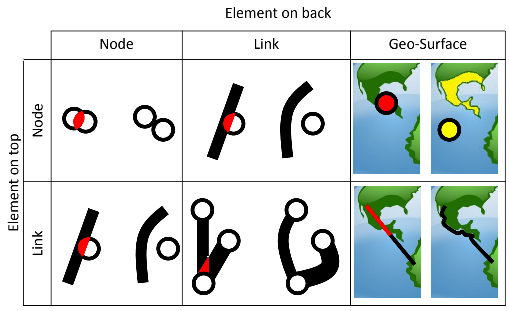
- *(link,link)*^{2}: In this case links overlap each other. Hence, it can be considered an occlusion criteria. This happen if they have one or both incident nodes in common. For example if links represent path segments, two or more links completely overlaps if they have same origin and destination but different time period.

3.4 Problem of Unaesthetic

The problem of unaesthetic representation differs from the occlusion problem, because we do not necessarily have loss of information. As shown in Table 3, partial overlapping causes a decrement in visual quality of the layout. Thus, for the aesthetic of the representation, the following cases are relevant to describe the effect of clutter:

- *(node,node)*: Nodes located is the same spatial location or near with each other may cause partial overlapping of nodes.
- *(link,node);(node,link)*: Links can cut directly across a node (or vice-versa) interfering with the visual quality of the layout.
- *(link,link)*: It is possible to have links that are close to or actually overlapping each other.
- *(link,geo-surface);(node,geo-surface)*: When links or nodes overlap a region, they may decrease the layout aesthetic.

Table 3: Partial overlapping of elements (colored in red) causes a decrement of layout aesthetic. For each case an approach acting on elements position is applied to solve the problem.



3.5 Criteria Fulfillment

We use the criteria mentioned below, to valuate the candidate solutions for the identified problems.

The problems of uninterpretable representation and occlusion, are analyzed by applying each technique to example in Figure 1(a). Although such diagram does not present a background image, we enrich the visualization with the appropriate map. For ambiguity problems in Table 2, each technique is applied to example in Figure 1(b). For the problem in Table 3, each technique is applied to example in Figure 1(c). Although such diagram does not present overlapping nodes, we enrich the visualization increasing the size of the nodes.

For each problem, a technique is marked as:

- ✓: if the technique removes the problem.
- ✓*: if the technique may removes the problem, however, this condition is not guaranteed for all the cases.
- -: if the technique does not provide any evidence that it reduces or removes the problem.
- ✗: if the technique increase the problem. In such cases, the goal of the technique is another.

4 TASKS GROUPS FOR GEOGRAPHIC NODE-LINK DIAGRAMS

We distinguish different tasks groups in the context of geo-referenced networks, to better understand visual clutter. At high level of abstraction, we apply the general division for information visualization tasks (Keim et al., 2006):

- Exploratory and Analytical tasks: Visual exploration allows the possibility to get new insight. In case of analytical scenario, the user knows always the task, being it implicit or explicit. We classify the tasks identified in (Lee et al., 2006) as follows:
  - Graph-specific tasks: The tasks are related to the topology of the graph, i.e. "given a node, find adjacent nodes" and "given a link, find incident nodes".
  - General low-level tasks: The user examines each item of the network to make new discoveries. The tasks are: "find item", "retrieve value", "filter item", etc.
  - Overview tasks: Some high-level tasks require only an overview of the graph such as finding clusters of related nodes, finding patterns and outliers.
- Explanatory tasks: The main goal is to make sense (i.e. associative thinking) of a story visually described by the data. In literature, common examples of node-link diagram for such tasks are flow maps: geographical maps where straight or curved lines represent the movement of groups of objects from one location to another. The thickness of the line identifies the number of moving objects, see Figure 1(c).

4.1 Analysis of Tasks Groups and Clutter Problems

In this section we identify the problems that characterize each tasks group, as shown in Figure 2.

In the task group "Overview Tasks", visual clutter is interconnected to the interpretation of the representation. In these tasks it is not essential to solve the problem of occlusion, ambiguity and unaesthetic.

In the task group "General low-level tasks", visual clutter involve also the occlusion of items. It becomes difficult to understand information encoded in visual variables of occluded elements.

In the task group "Graph specific tasks" ambiguity is an important aspect to take care of. In this task group, we are not only searching for hidden elements, but also we are trying to have a clearer (unambiguous) layout.

In the task group "Associative Visualization Tasks" there is the problem of unaesthetic representation. Due to the layout, some partial overlap between elements may occurs, which cause a decrement in visual quality of the layout. The aesthetic is not a priority in exploratory and analytical tasks.

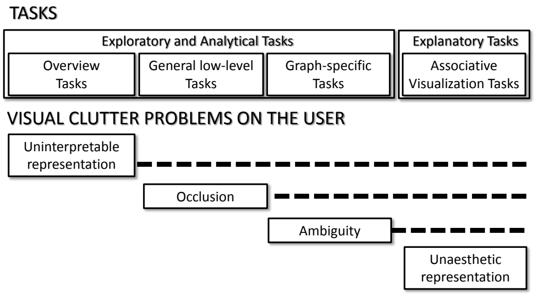


Figure 2: Task groups are affected by different types of visual clutter.

5 APPLIED SCHEMATIZATION

Each technique surveyed in this work is compared with respect to our criteria, see Table 4. For each task group, analyzing the table, we propose the following candidate solutions.

5.1 Overview Tasks

Edge bundling is one of the main techniques that makes a layout more easy to interpret. In edge bundling, links of a graph are bundled together according to defined conditions. In the first generation of such algorithms (Qu et al., 2007; Zhou et al., 2008; Telea and Ersoy, 2010; Holten, 2006; Cui et al., 2008; Holten and Van Wijk, 2009; Gansner et al., 2011; Lambert et al., 2010a), without considering the combination with other techniques, the main benefit is the reduction of the number of visible items.

5.2 General Low-level Tasks

Winding Roads (Lambert et al., 2010b), KDEEB (Hurter et al., 2012), and ADEB (Peysakhovich et al., 2015), when compared to previous Edge Bundling approaches, are able to avoid overlapping of links with nodes and map portions. Edge Bundling techniques are also designed to manage multivariate networks. DEB (Selassie et al., 2011) is able to separate opposite-direction bundles, emphasizing the graph structure. SBEB (Ersoy et al., 2011) bundled similar links according to directions and also further variables associated to links.

MoleView (Hurter et al., 2011) is a semantic lens that selects a set of data elements located within the lens' radius and having an attribute value defined by the user. In case of graph layout the lens moves the control points that compose links around the lens. EdgeAnalyzer (Panagiotidis et al., 2011) is able to select specific sub-groups of links on dense areas. Those techniques are able to reveal nodes, links and map occluded by the links.

5.3 Graph-specific Tasks

Edge bundling techniques can be designed to reduce ambiguities. SideKnot (Peng et al., 2012) focused on *(link,link)* ambiguity. Although it does not reduce the ambiguity, with respect to the aforementioned bundling techniques, it does not even increase that problem. Stub Bundling (Nocaj and Brandes, 2013) made a step forward. It uses parallel routing of links to facilitate the display of additional data attributes by varying width or color. Hence, it solves the *(link,link)*^{2} ambiguity problem. Ambiguity-Free Edge-Bundling (Luo et al., 2012) is an approach that bundles only links which share a common node. In this way the *(link,link)* ambiguity in not increased during the bundling procedure. Moreover, this method reroutes links that pass over nodes reducing the *(node,link)* ambiguity. Finally, Edge Routing with Ordered Bundles (Pupyrev et al., 2012) is able to fulfill most of our criteria. Here, links are placed in parallel channels to avoid overlaps. This approach could theoretically be used to create flow maps, however, the result has to be evaluated in terms of aesthetic.

Links can be drawn as curves in a 3D space to reduce *(link,link)* and *(node,link)* ambiguities, and nodes are snapped over a geographical surface to preserve the spatial context (Cox et al., 1996; Munzner et al., 1996). Curved links allow more display space compared to their straight counterparts and potentially reduce visual clutter (Xu et al., 2012).

Interactive Bundling (Riche et al., 2012) is an interactive technique that generates crossing-minimal bundles that are routed to distinguish them. Wong et al. (Wong et al., 2003) proposed *EdgeLens*; a technique that iteratively curves graph links away from the point of focus. This consents to disambiguate the relationship between nodes and links without losing information. An analogous multi-touch technique is PushLens (Schmidt et al., 2010). 3DArcLens (Debiasi et al., 2015b) extends the functionalities of EdgeLens, distinguishing the distorted links around the lens. As drawback, the distorted links may cross with the surrounding lines causing further ambiguity. With Edge Plucking the user can drag groups of links away to clarify cluttered zones and specify links or nodes to be left unmoved (Wong and Carpendale, 2007). However, Edge Plucking requires a certain amount of manual effort. Bearing this in mind, Schmidt et al. (Schmidt et al., 2010) designed (but not implemented) multi-touch interaction techniques based on

Table 4: Techniques to reduce unaesthetic representation/ambiguity/occlusion/uninterpretable in geographic node-link diagram. From top to bottom, the color identifies the task group: Overview Tasks, General Low-level Tasks, Graph-specific Tasks, and Associative Visualization Tasks.

Clutter Reduction Techniques	Unaesthetic Representation					Ambiguity			Occlusion				Uninterpretable Representation
	(link, link)	(node, link) (link, node)	(link, map)	(node, node)	(node, map)	(link, link)	$(link, link)^2$	(node, link) (link, node)	(link, link)	(node, link) (link, node)	(link, map)	(node, node) (node, map)	
Edge Bundlings (1° Generation)	-	-	-	-	-	×	×	×	×	✓*	✓*	-	✓
SBEB, DEB	-	-	-	-	-	×	✓*	×	-	✓*	✓*	-	✓
Winding Road, KDEEB, ADEB	-	✓	-	-	-	×	×	✓	×	✓	✓	-	✓
SideKnot	-	-	-	-	-	-	×	×	-	✓*	✓*	-	✓
MoleView, EdgeAnalyzer						-	✓*	-	✓	✓	✓	-	-
3DArcLens						✓*	✓*	✓	✓	✓	✓	-	-
3D curving edges						✓*	-	✓	✓*	✓*	✓*	-	-
Interactive Bundling						✓	-	-	-	✓	✓	-	-
Interactive Link Fanning						-	✓	-	-	-	-	-	-
Link Magnet, Interactive Link Legend						-	✓*	-	-	-	-	-	-
EdgeLens, PushLens						-	-	✓	✓	✓	✓	-	-
MultiTouch Techniques						✓	-	✓	✓	✓	✓	-	-
Stub Bundling	✓*	-	-	-	-	-	✓	×	-	✓*	✓*	-	-
Ambiguity-Free Edge-Bundling	-	✓	-	-	-	-	-	✓	-	✓	✓*	-	-
Edge Routing with Ordered Bundles	✓	✓	✓	-	-	✓	✓	✓	-	✓	✓	-	-
Flow Map Layout	✓*	✓*	-	-	-	-	-	-	-	-	-	-	-
Supervised Flow Map Layout	✓	✓	-	-	-	-	-	-	-	-	-	-	-
Conuent Spiral Drawings, Flow Map Layout via Spiral Trees	✓	✓	✓	-	-	-	-	-	-	-	-	-	-
Necklace Maps	-	✓*	-	✓	✓*	-	-	-	-	-	-	-	-

link displacement.

Other interactive lenses were designed to reduce clutter accordingly to the multivariate encoding of links (Riche et al., 2012). For example, Interactive Link Fanning creates space between links incident to a selected node, to show labels or arrowheads for individual links. With Link Magnet, when a visual object representing a data attribute is dragged, data items are attracted by an amount depending on the attribute value of the item. Finally, with Interactive Link Legends, link curvature encodes semantic information such as different types of links in heterogeneous graphs.

5.4 Associative Visualization Tasks

In Necklace Map (Speckmann and Verbeek, 2010), nodes are rearranged in circular layouts to remove the overlapping between them. However, the spatial context of nodes is preserved for two reasons: the nodes are moved not too far from their original position and the color of nodes is used to associate them with their original location on the background map.

Phan, et al. (Phan et al., 2005) developed a method to generate a flow map layout in a recursive and simple manner. The overlapping between links and nodes is only partially solved because undesired crossings may occur. However, in a post processing phase, user has the possibility to modify flow lines by moving their control points. Debiasi et al. (Debiasi et al., 2014) presented a method to generate flow map layouts using a force directed approach to remove the *(link-node),(node-node)* overlapping.

A second generation of flow map algorithms was developed to satisfy all the criteria related to the partial overlapping of links. Verbeek, et al. (Verbeek et al., 2011) introduced a method using spiral trees, i.e. links are logarithmic spirals, implemented as cubic Hermite splines. A different approach called Confluent Spirals (Nocaj and Brandes, 2013) consists of smooth drawings in which link direction are represented by increasing curvature.

6 CONCLUSIONS

This work provides a list of criteria to classify the effects of the visual clutter on geographic node-link diagrams on different scenarios. The scope of this work is not the creation of a rank of techniques, but a classification that helps the reader to decide, given a task, on the list of candidate solutions that help to reduce the clutter in a geographical node-link diagram. Moreover, it provides guidelines to the design of novel techniques, helping the researchers to focus on a well-defined list of criteria to fulfill. As shown in Table 4, among the techniques we surveyed there are no solution that are capable of satisfying all criteria.

Regarding edge bundling techniques, the fulfillment of criteria depends on the information used. Starting from unambiguous layout, aggregating links with no information about nodes increase all the ambiguity cases. Information about their incident nodes is needed to solve the ambiguity of overlapping links. As opposite, information about crossing links is needed to avoid completely the link-link ambiguity. Finally, information about nodes positions is needed to avoid crossing among links and nodes.

It is possible that some techniques that remove or reduce the occlusion of items affect negatively the graph-based tasks. The combined use of techniques that act on position of nodes and links with techniques that act on other visual variables can further improve the final result. From the proposed classification only one approach (Necklace Map) satisfies the partial overlapping criteria related to occluding nodes. The reason is the difficulties in rearranging the nodes without losing their geographic information.

As future work we plan to extend this schematization into a classification of techniques, based on their intent, e.g. “put in parallel”, “aggregate”, “push away”. Furthermore, we could include techniques that act on other visual variables such as color, final image rendering, etc. Finally, the task classification has to be improved. No group takes into account the background map in their tasks.

ACKNOWLEDGEMENTS

This research has been supported by the European Commission under the c-Space (G.A. 611040) and the LIFE+IMAGINE (LIFE12/ENV/IT/001054) projects. It has been carried on in the context of the National Geoportal project for the Italian Ministry of Environment.The authors are solely responsible this work.

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