Mind-Prosthesis Metaphor for Design of Human-Computer Interfaces That Support Better Attention Management

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Abstract

In this paper we investigate the issues of user attention management in the context of the changes of underlying metaphors in human-computer interface design. After the introductory part, we discuss the problems of staying focused as well as reconstructing the context of an interrupted task while working in some computer environment. We highlight the problems with current interfaces and the desktop metaphor in particular, we propose that the mind-prosthesis metaphor may be better suited for the design of future, attention aware systems, and we put forward some guidelines for interface design that follow from our analysis. [1]

0. Introduction

The work presented here builds upon our previous research on metaphors in interface design [Stojanov & Stojanoski, 2001] and attention aware systems [Roda & Thomas 2006, Roda & Nabeth 2006]. In [Stojanov & Stojanoski, 2001], we have investigated the changes of the underlying metaphors in the evolution of human-computer interfaces (HCI): from the first command prompt, text based ones, to the modern dominating WIMP (Windows Icons Menus Pointing) interfaces. We have argued that when talking about human-computer interaction people implicitly assume linguistic interactivity, without necessarily being aware of that. In [Roda & Thomas 2006, Roda & Nabeth 2006] we highlight that human attention is strained by the information overload generated by the fast and continuous access to information and people, multi-tasking, and interruption typical of modern, digitally-enabled environments, and we have identified *human attentional processes* as key processes to be supported by digital technologies.

Here, after highlighting the problems with current interfaces and the desktop metaphor in particular, we propose that the mind-prosthesis metaphor may serve as a guide for the design of future, attention aware, systems.

The paper is structured as follows. We first elaborate on the (implicit and explicit) use of metaphors in interface design (section 1), and we argue for the need for a radically different approach to systems design by highlighting the major problems associated to the desktop metaphor: task fragmentation and the consequent load on attention allocation processes (section 2). In section 3 we introduce some current research that, we believe, has tried to address the same problems we are concerned with. We then give a detailed description of the mind-prosthesis metaphor (section 4).

1. Metaphors and analogies in HCI design

Modern theories of metaphor and analogy [Lakoff and Johnson, 1980; Lakoff, 1993; Hofstadter, 1995] ascribe central role in cognition to these mechanisms. Although the use of metaphors in interface design is advised in many HCI design textbooks [e.g. Thimbleby, 1990; Nielsen, 1993] the issue seems not to have received a systematic analysis. For example, as noticed by Blackwell [1998], studies of quantitative evaluation of one metaphor over another are indeed very rare. In this paper we present a first qualitative comparison between different approaches to set the basis for a quantitative evaluation of two types of interfaces: the widely accepted *desktop interface*, and a new type of interface that, we propose, would better serve the needs of nowadays users: the *mind-prosthesis* interface. Following the qualitative/theoretical research work described in this paper, we have started experimenting and collecting quantitative data with a first prototype interface of which we give a preliminary description in [Clauzel, Roda, & Stojanov 2006].

In what follows, by way of summarizing [Stojanov & Stojanoski 2001] we discuss the underlying assumptions in the two widely adopted HCI metaphors: conversational and desktop.

Since their appearance, computers have been construed as *conversational partners*. Therefore, by extrapolation we can describe HCI in terms of Reddy's conduit metaphor [Reddy, 1993]: the information that the user wants to transmit to the computer is *packed* in a command (plus maybe some optional command switches) and via the linguistic *channel* (the command prompt) it is sent to the *recipient* (the computer). The computer is supposed to *unpack* the command and perform the actions required. The delay of execution only supports the implicit linguistic interaction (e.g. while the user waits to see the result of the command just issued, their reasoning might go like this: *now it's thinking what to do*…)

To see in what way we think of human-computer interaction as linguistic or conversational, we can contrast this interaction to the one that we have with our cars. Human-car interaction has been, so far, inherently non-conversational, and people don't expect their cars to talk back to them (even if sometimes we *do* talk to them). Indeed, we are not even comfortable with that concept. It is for this reason that, although the technology is available, cars that talk (to warn you to fasten your seat belt, for example) are not very common. Instead, various visual or auditory cues for that purpose are provided. It should be noted however that the field of speech/audio interfaces for various in-car activities (not directly related to the control of the vehicle) is very active [Burnett, 2001; Buhler et al, 2003; Fu et al. 2004; Lai & Cheng, 2001]. Most of this research deals with speech/audio interfaces for operating mobile phones, navigation systems, or entertainment centers during driving, and mainly involves automatic speech recognition (ASR).

Why are we not comfortable with the talking cars then? Here's our hypothesis: whenever during the interaction with some entity there is a hint of conversational competence, human beings immediately span a huge web of specific expectations regarding the abilities of that particular entity [Weizenbaum, 1966; Huhtamo, 1993]. We tend to anthropomorphize those entities and consequently loose the sense of direct control over them. The control, as it is indeed the case with other human beings, can be exercised only *indirectly* via linguistic means. And if you are driving a car, you certainly want to be in direct control. Therefore all the cues on the control table of a car tend to be non-intrusive and supportive of your main attention focus: driving the car and paying close attention to what's in front of you.

When the evolution towards "windows, icons, menus, pointing devices" (WIMP) interfaces happened, the conversational metaphor from the prompt based HCIs remained in a sort of conceptual blending [Fauconnier & Turner, 2002] with the explicit *desktop metaphor* usually adopted in the implementations of the WIMP interfaces. (In fact, to be more precise we should add that the acronym "WIMP" does not fully describe these interfaces, as elements of linguistic interactivity like labels and fill-in forms, radio-buttons, options tick boxes, system messages… are omitted. WIMP-L, which includes these Linguistics aspects, might be a better acronym.)

The desktop metaphor invites users to apply their knowledge from the physical world by directly manipulating the items on the virtual desktop using the virtual continuation of their limbs (the mouse pointer). At the same time, the conversational metaphor is still nurtured via the text elements mentioned above. The end effect is that while we are directly manipulating objects on the desktop there is also some entity (agent?) which occasionally prompts us with linguistic messages, and sometimes asks for linguistic input from us.

Nowadays WIMP-L interfaces are most widely used, mainly because of Microsoft Windows and Apple's Mac OS.

2. The need for a different metaphor

Current desktop interfaces are strongly based on two fundamental concepts: the *applications*, and the *file system* They have been carefully designed and conceptualized to resemble - as closely as possible - the many tools that one might have had on a desktop in the pre-digital era (e.g. the typewriter, the calculator, the pencil, and more recently, the telephone, the tape-player). In principle, there is an association between *one* application and *one* tool, *one* document and *one* file. The widespread use of the digital version of the tools (the applications) and the advent of the Internet have allowed an increased productivity whilst making easier for people to communicate and exchange the documents produced. This in turns has generated a greater demand on peoples' activities: people are often expected to be able to access and elaborate a much wider range of documents, whilst selecting amongst a wider range of tasks that must be completed in a shorter amount of time.

We assist at a double layer of fragmentation of work (see figure 1): on the one hand the fragmentation generated by multi-tasking and interruptions (level 1); on the other hand the fragmentation generated by applications and files (level 2). Each of these two types of fragmentations imposes a new load on humans' limited cognitive abilities. Switching between tasks, contexts, applications, documents, etc. requires the activation of processes that involve our perception, and memory (both prospective, and retrospective [Marsh, Hicks, & Bryan, 1999; Meacham & Leiman, 1982; Sellen, Louie, Harris & Wilkins, 1996]), and overall reduces our capacity to appropriately allocate attention.

Level 1 fragmentation was minimal during the work on the first prompt-based interfaces in the pre-Internet era. Imagine working as a user on a Unix terminal of a mainframe non-networked machine. The few things that could distract you included: system messages ("a process has finished its execution"), a *write* message, or a *talk* attempt from another user, and that was, more or less, everything. Digitally available information was a scarce resource while the user terminal had virtually all of the user attention. On a par with HCI evolution, what also happened is the ubiquity of internet, and the convergence of communication devices (Instant Messengers, cell phones, chat programs…).

Nowadays, information overload and constant interruptions have become commonplace. At any given moment a user has 8 windows opened on the average, and they spend about 11 minutes on a given task before being interrupted [Mark, Gonzales, & Harris 2005]. Although interruptions may bring to one's attention information possibly useful for the primary (current) task, or even, in the case of simple primary tasks, facilitate task performance [Speier, Vessey & Valacich, 2003]; it has been widely reported that interruptions increase the load on attention and memory [Gillie and Broadbent, 1989], may generate stress [Bailey, Konstan & Carlis, 2001;

Zijlstra, Roe, Leonova & Krediet, 1999), and compromise the performance of the primary task [Franke, Daniels & McFarlane, 2002; McFarlane and Latorella, 2002; Nagata, 2003; Speier et al., 2003] especially when the user is working on handheld devices in mobile environments [Nagata, 2003]. Information inflow increases, cognitive load augments, and attention becomes a scarce resource. Researchers are dealing with new phenomena of notification overload (as a specific example of the information overload) [Van Dantzich et al, 2002] and attention fragmentation [King et al, 2005]. Generally, the issue of attention management in HCI is getting much attention lately as testified by the publication of special issues in academic journals [e.g. Vertegaal 2003; McCrickard, Czerwinski and Bartram 2003, Roda and Thomas 2006a], and by the organization of specialized fora of discussion [e.g. Roda and Thomas, 2004] and research projects [Roda and Nabeth 2006].

We argue in this paper, that whilst level 1 fragmentation is intrinsic in nowadays activities, level 2 fragmentation could be removed by moving away from the desktop metaphor that has no longer reason to exist in a digital environment which is free of desks, calculators, tape writers, and the likes. The new mind-prosthesis metaphor interface would not only allow removing level 2 fragmentation, but also enable the management of level 1 fragmentation and consequently support human attention allocation processes.

3. Current attempts to address fragmentation and facilitate attention allocation

One avenue taken by some researchers in trying to address the issues related to attention allocation, has been to augment WIMP-L interfaces. The dominant WIMP-L metaphor blend, however, does not facilitate improvements and extensions that would account for attention in a natural manner. In order to be useful a new metaphor should have natural extensions to be able to justly serve technological advances and increasing underlying system complexity. Technological advances made modern CPUs, RAM, and hard-disk memories, hundreds of thousands times faster and as many times bigger in their capacity. Monitors, on the other hand, increased their size by a factor of about 1.5 to 2 (on the average). The current situation is that a computer systems can internally represent much more complex entities while having (almost) the same display capacity. A study from Microsoft Research group [Czerwinski et al, 2003] showed that people using large (42 inches) monitors or even dual or triple monitors can finish their tasks in 10% to 44% less time. The problem with this approach (i.e. keeping the WIMP-L interface and having bigger monitors) has its apparent limits (how much can we extend the monitor size?). Moreover, as noted by the same group of researchers [Czerwinski et al, 2006] bigger screens bring more usability problems (pp 71-72, emphasis added):

1. **Losing track of the cursor**. As screen size increases, users change mouse acceleration to compensate and it becomes hard to keep track of where the cursor is.
2. **Distal access to information**. As screen size increases, it becomes increasingly more difficult and time-consuming to access icons, windows, and the Start Menu across large distances.
3. **Window management problems**. Large displays lead to notification and window creation problems, as windows and dialog boxes pop up in unexpected places. Window management is made more complex on multimon displays because users wish to avoid having windows placed so that they cross bezels (because of the resultant distortion).
4. **Task management problems**. As screen size increases, the number of windows that are open increases and users engage in more complex multitasking behavior – better task management mechanisms become a necessity.
5. **Configuration problems**. The user interface for configuring multimon displays is overly complex and hard to use. When a monitor is removed from the display configuration, it is possible to lose windows offscreen.
6. **Failure to leverage the periphery**. With larger displays a true periphery is available and could be leveraged for better, peripheral awareness in support of user activities.

Therefore despite the fact that users loved working with large screens, reportedly the situation with attention management had worsened.

In an attempt to adequately answer to the trend toward pervasive computing Maglio and his colleagues [Maglio et al, 2000] rightfully point to the central notion that attention should have in the future interfaces (pp. 1):

> If point-and-click graphical user interfaces (GUI) have enabled wide use of PCs, what will be the paradigm for interaction with pervasive computers? One possible approach is attentive user interfaces (AUI), that is user interfaces to computational systems that attend to user actions—monitoring users through sensing mechanisms, such as computer vision and speech recognition —so that they can attend to user needs— anticipating users by delivering appropriate information before it is explicitly requested[…]

Their experimental setup is designed within a framework where the AUI is supposed to be a pro-active mediator and interpreter of the user's intentions

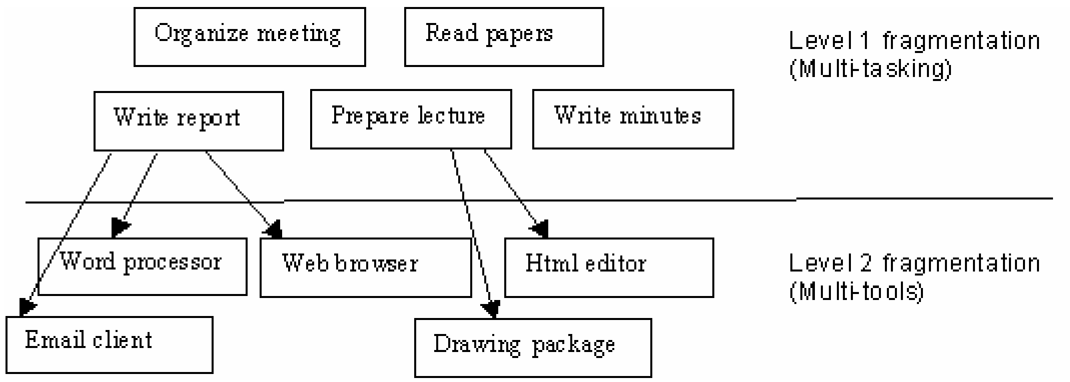

Figure 1 Double layer fragmentation in current digital environments.

. The questions of accessing user attention and interpreting user intentions are indeed very complex. Horvitz et al. in [Horvitz et al, 2003] report the fruits of more than 5 years of research in models of attention in "computing and communication". In the context of non-intrusiveness of interfaces they say (pp. 52):

> We consider attention as a rare commodity -- and critical currency -- in reasoning about the information awareness versus disruption of users […]

It is interesting that in the same article, when talking about attention cues, authors quote an example of linguistic interaction in humans (pp. 52):

> Attentional cues are central in decisions about when to initiate or to make an effective contribution to a conversation or project. Beyond knowing when to speak or listen in a conversation, attention is critical in detecting that a conversation is progressing. More generally, detecting or inferring attention is an essential component of the overall process of grounding—converging in a shared manner on a mutual understanding of a communication […]

Their *Notification Platform* is a cross-device messaging system that balances the cost of disruption of the user with the value of information from multiple message sources. The platform maintains a probabilistic model of user attention and performs ongoing decision analyses about "ideal alerting, fidelity, and routing." In an attempt to come to the point where the AUI will be able to infer where the user attention is, there has to be an "[…] overall process of grounding—converging in a shared manner on a mutual understanding of a communication […]"In other words in this approach, researchers reinforce the entity (mediator) component within the WIMP-L interfaces. We want to argue that given the best results from Artificial Intelligence research we are far from being able to construct an artifact capable of developing shared understanding of situations. The consequence is that AUI built within the above approach will necessarily be very complex, frequently wrong in guessing user's attention state, inherently unpredictable, and consequently they risk being more often a nuisance instead of help.

One alternative proposed with the aim of overcoming the aforementioned problems with WIMP-L interfaces was the so called Anti-Mac approach, where Mac stays for the WIMP-L interfaces in general.

Gentner & Nielsen in [Gentner & Nielsen, 1996] explore the possibilities of building better interfaces by violating the main principles of Mac or any other WIMP interface. Among the principles they propose are:

-The central role of language

In WIMP-L interfaces users directly manipulate objects. But this manipulation is rather limited, (compared, say, to numerous switches in a Unix command). Therefore we should head back for something like a command prompt.

-A richer internal representation of objects

Currently, only a limited number of attributes are known about a file, say: name, size, type, author and the like. The interface has access to only limited information and even less possibilities to add/change some. In an Anti-Mac interface it would be possible to include additional information at interface level: importance, keywords, related documents etc.

-A more expressive interface

As the technology certainly enables more, why keeping the same icon for all the text documents? We have books on the bookshelves but by looking at them we can guess which one is which without opening them.

-Expert users

WIMP-L interfaces may be good for beginners but experts would prefer trading inflexible direct manipulations with more complex operations which can be expressed via command line.

Many of the elements mentioned above were incorporated in different contemporary interfaces. For example, nowadays it is possible to associate metadata to a file via the file system. Those metadata can be used to define, for instance, collections (personal, work, holidays, a project, etc.), priorities (urgent, later...), and relevance dates (this file is only useful the 1st Monday of the month, this file have to be kept until the end of the year, etc.). The file browser can process those metadata and propose custom views to the user. Furthermore, when displaying a list of file, some systems provide more information than a simple icon (see Figure 2). Linux desktop GUI display files with document's thumbnail instead of using generic icons. So, when browsing the disks the user can actually have a look at what is inside the document and is not restricted to information as file name or size. In a similar manner, file metadata can be provided for the user as small simple icons added on the thumbnail. For example, the file browser displays a key lock if the file is locked, an arrow if the file is a shortcut, gears if the file is important system file, etc. To those automatic metadata icons users can add custom elements: it can be an eye if the user wants to remember to read this file or a heart for a document that they like. Users also have the possibility to define rules for automatically displaying custom icons overlay, based on the files' metadata.

The interest of smart icons is to convey to the user as much as possible information about the objects they represent, in a clear and non-intrusive way.

Figure 2 Two documents with smart icons

The main problem with the Anti-Mac approach is that it does not offer an umbrella metaphor that will guide the introduction of new elements to the interface. This is so because of its negative definition (*Anti*-Mac).

In what follows, we describe the mind prosthesis metaphor for HCI design. We describe how a systematic application of this approach facilitates extensions of the interface towards better attention management.

4. The mind prosthesis approach (MPA)

The fundamental philosophy behind the mind prosthesis approach is to treat the interface as an *augmentation* of human cognitive/perceptual capabilities. Much like the hearing aids, spectacles, binoculars, pace-makers etc. are restoring/augmenting our existing capabilities, or like spell-checkers or search engines are adding new ones. The point of departure here should be human users' limited perceptual, working memory, and overall attentional abilities. What we mean by augmentation (prosthesis) can be interpreted as a set of functional organs in the sense of Vygotsky [1978] and Leont'ev Activity Theory [1978]; as adding diverse possibilities for structural couplings [Maturana and Varela, 1987], between the user and their environment; or adding diverse possibilities for repetitive interactivity [Bickhard, 1993]. These functional organs (or diverse structural coupling) should act towards surpassing human limitations mentioned above. For example, being aware of my working memory limited capacity the interface should provide a way to store and quickly retrieve any sort of object that I may need. I should have the certainty that I can easily and quickly retrieve them at any moment.

This ability to *retrieve* is related to the ability to *bring into focus* the desired information. Focus, and attention in general, should not be seen as static (as done in most HCI research so far) but rather, as suggested in the work of Arvidson [Arvidson, 2003, 2004], attention should be seen as "a process, [which] is dynamic and often tense; it can involve significant transformations of content and relationships." [Arvidson 2004, p. 2[2]]. Arvidson advocates that we may *attend* at three different levels: thematic (focus), contextual, and marginal. Attending thematically corresponds to focusing. Attending contextually allows one to distinguish content that is relevant to the theme. Attending marginally allows one to distinguish content which is co-present but irrelevant to both the theme and the context. This model of attention, which although not the main-stream one in cognitive psychology is supported by experimental results [Arvidson, 2004], seems to allow us to address two important issues in system design. On the one hand, it becomes obvious that the context is just as important as the theme when it comes to information representation, it should blend with it allowing the user to define where the theme ends and the context starts. On the other hand the dynamic processes that, in Arvidson's model, allow elements of the context or the margin to become thematic suggest that interfaces should make the best possible use of these three levels. For example, in order to attenuate the intrusiveness of events or incoming information one could represent them in a contextual or marginal area. There, users can still be aware of them while not disturbed in what they are doing. This seems also Mark Weiser's and John Seely Brown's suggestion when they say that

> Calm technology engages both the center and the periphery of our attention, and in fact moves back and forth between the two. [Weiser & Brown 1996]

The idea of MPA is to stress the fact the user should feel always in control. In that sense, the periphery of attention can contain vague indices allowing one to initiate particular interactions (e.g. launching a particular program; surveying the state of the system, etc.) which are at hand. When the user decides, they can proceed and engage in a particular activity. One example of this principle is MAC program bar at the bottom of the screen which displays barely distinguishable icons for different applications. Because of their position, and because of the fact that the

[2] Page number refers to manuscript

user can always drag the mouse pointer over them which results in a nice zooming effect, the user will be assured that they will launch the application they wanted. The net effect of this is a de facto gain in the size of the display, without having physically bigger screen.

We believe that the possibility action of zooming on any object on the screen may be the crucial one in the MPA. [Raskin, 2000; Bederson & Hollan, 1994]. Having the zooming feature enables the users to have a quick and holistic overview of the whole system and quick adjustment to the level of detail needed at any given moment. As argued in [Raskin, 2000] ideally, zooming would eliminate the need of many intermediary levels (or concepts) seen in WIMP-L interfaces like file names, the notion of different applications, etc.

Another crucial feature is that the user should get immediate (if minimal) feedback for any action they choose to perform. This feature again, increases the feel of being in control.

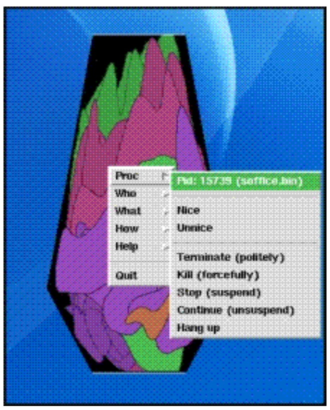

Figure 3 LavaPS application. (see text for explanation)

Another example of effective use of peripheral attention is LavaPS [Heidemann, 1998] program. Instead of presenting a lot of detailed information about the status of usage of system resources by the active processes (like *ps* command in Unix) some of the most important information about system status is represented in an analog form. A process is represented with a blob whose color is a combination of the process name (for the hue) and the last time it has run (for the saturation). The CPU usage by that particular process affects blob's movement and the more memory it uses the bigger the blob is. In such a way, without paying much attention to it, to user has a summary info of the system status: the blobs that are bright, big, and are moving fast represent processes that use most of the system's resources.

We conclude by briefly proposing some practical guidelines for the design of interfaces as mind-prosthesis supporting human attentional processes.

-generalized zooming facility: by this we describe a possibility provided to the user to change the level of presentations of any part of the system. For example a quick *not-too-detailed* view of the whole system should be available at any moment. On the other hand, zooming on a particular object (e.g. a text file) should provide the user with further information about the file and, if the user so decides, in that file being opened in the appropriate application in a manner transparent for the user.

-possibility of building different organizational patterns (for example, additional visual representations of the same internal elements);

-continuous navigation (the user should have clear orientation within the abstract space topology - the user could thus make use of their spatial intelligence in dealing with the interface);

-tracking the history of the user actions (as much as is possible in detail on a system level); this feature will enable UNDO of any action, as well as generation of historical context for interrupted activities;

-redundancy in the audio-visual cues in the peripheral zone (e.g. the feedback for the user actions or system messages);

-screening out (e.g. minimization) of the data not relevant for the task at hand;

-complying to the capacity of the human short term memory,

-managing elements that interrupt the on-going user activity, allowing the user to make informed decisions on whether they want to bring elements of the periphery in the focus of attention;

- **customization** should be given as an option to the users;

The success of Google search engine interface as well as Apple's iPod control interface shows that users are willing to give up on many powerful (and complex to use) features for the sake of simplicity, predictability, repeatability, intuitive and meaningful operation.

We are aware that full blown implementation of the MPA metaphor based interface would require drastic departure of current design of Operating Systems even at a conceptual level. Besides, sheer inertia in using WIMP-L based computer systems would prevent the spread of MPA based interfaces unless they indeed offer something immediately usable.

5. Conclusions

In this paper we have tried to briefly make explicit the underlying metaphors in the history of human-computer interfaces design starting from the prompt based to modern WIMP-L interfaces. We have outlined the main problems of attention management and speculated that the dominating WIMP-L based metaphors do not offer natural extension which would deal with these problems. We also argued that the Anti Mac approach does not offer a unified underlying metaphor for effective HCI design. We have identified several issues that must be addressed in modern system design including: the problem of work fragmentation, and consequent dynamic attention allocation. In the final part of the article we presented the mind-prosthesis approach as a possible new metaphor for interface design that addresses the issue previously raised.

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