Reducing the Split-Attention Effect in Assembly based Instruction by Merging Physical Parts with Holograms in Mixed Reality

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Abstract: Split attention in instructional materials is a recognised problem known to cause an increase in cognitive load. Instructional designers often try to resolve this by using a variety of methods that do not account for the spatial disconnect between diagrams being matched up with physical parts during an assembly task. The emergence of Mixed Reality offers a solution, using "holograms" which can project 3d images into the physical environment around the user. This paper reports on a project that proposes the creation of a software prototype that simultaneously enables part identification and tracking of parts for assembly. It conceives a new way of providing instructions when assembling flat pack furniture by endeavouring to facilitate working memory constrains. The software prototype will assist the user by showing where parts should be placed and by providing real-time feedback based on interaction.

1 INTRODUCTION AND BACKGROUND

Split attention in instructional materials is a recognised problem known to cause an increase in cognitive load. Instructional designers often resolve this by placing text and diagrams close together to reduce working memory constraints. While this method is effective in solving split attention within the diagram itself it does not account for the spatial disconnect between looking at the diagram and matching up the physical parts required during assembly. Flat pack instruction manuals often show diagrams from an optimal viewing angle to make it easy to understand but this representation is still only two dimensional leaving the user to interpret it into three dimensions or from a different angle, which is not ideal. The emergence of Mixed Reality (MR) offers a solution, using "holograms" which can project 3d images into the physical environment around the user. These 3d images can act as an animated guide which can be looked at from all angles at any scale. While using "holograms" as a reference may improve user perception, it does not solve the split attention effect to aid the user.

Holographic computing is an emerging technology that allows "holograms" to be perceived within the users' physical environment and treated as if they are there. Holographic displays are referred to as "mixed reality" which incorporates the best parts of virtual and augmented reality (a technology that superimposes a computer-generated image on a users' view of the real world, therefore providing a composite view) using a clear head mounted display.

In assembly and instructional design for example computer based manuals or augmented reality experiences via mobile devices provide little to no positive or negative feedback. This is due to training systems having inadequate built in perception based artificial intelligence (computer vision) or no "intelligent tutoring" within the software (Westerfield et al., 2015, p. 169).

It is up to the user or external observer to make sure a task is being done correctly. While the full capabilities of mixed reality technology are yet to be explored, the author intends to investigate the possibilities of computer vision integration on a headset such as the HoloLens™ as a tool to help assembling a piece of flat pack furniture.

The problem that has been identified is a visual disconnect between instructional assembly diagrams and the physical parts of the assembly such as in flat

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pack furniture, this is known to cause split attention. Ayres and Cierniak, (2012, p. 3172) explain that "Split-attention occurs when learners are required to split their attention between two or more mutually dependent sources of information (e.g. text and diagram), which have been separated either spatially or temporally".

Split attention is known to negatively impact on the capacity and duration of working memory, (Cooper, 1998) leading to reduced learning efficiency and comprehension (Kalyuga et al., 1999, p. 351).

A prototype software application could be devised that provides users with immediate feedback on their correct and incorrect actions during assembly tasks and progress. The design would help to integrate the instruction into the users' physical environment by overlaying diagrams onto the physical parts via the head mounted display instead of a separate diagram as a point of reference. Integration is based on the split attention design principle in multi-media instruction. This principle stipulates that instruction should be designed so that users do not have to mentally integrate multiple sources of information as it requires processing to be decided between the sources leading to split-attention (Mayer & Moreno, 1998, pp. 318-319).

A gap in knowledge was identified as there is no research on overlaying "holograms" on physical objects to substitute the use of separate 3d model reference or a diagram on an augmented display.
When using existing technology such as augmented reality or a head mounted display attention could be split in different ways depending on the solution. When using an augmented device, attention is split between identifying the physical parts needed for the assembly and the device itself. This attention split also occurs when a 3d model is displayed through the headset as a reference only, this is because it still requires comparison to be made with the parts. While this method does integrate the 3d model into the users' environment it is still spatially a separate diagram.

A review of the literature raised the questions: Can a prototype application be designed that uses a holographic guide to lessen the impact of split attention in assembly based tasks by reducing the amount of working memory used?

In what ways is the use of computer vision to identify, track and place physical parts using holograms different to using a holographic instructional reference guide?

This paper outlines the proposed creation of a software prototype that simultaneously enables part identification and tracking of parts for assembly. Endeavouring to reduce working memory the software will show where parts should be placed and provide real-time feedback based on interaction when assembling flat pack furniture.

2 INSTRUCTIONAL DESIGN

According to Smith and Ragan, (1999, p. 2), the term instructional design refers to "the systematic and reflective process of translating principles of learning and instruction into plans for instructional materials, activities, information resources and evaluation". It is important for instructional designers to be able to explain the philosophical foundations and theory of their field because they are a key source for design principles. Contrary to this many designers have a limited theoretical background which has implications when constructing instructional material and selecting a suitable learning position (Ertmer & Newby, 2013, p. 43).

This research draws upon the cognitivist learning theory approach because it emphasises how internal mental processes (memory) can affect problem solving and attention (Spector, 2014, p. 5). Cognitive teaching strategies can be applied to the features of the software prototype to appraise its effectiveness in instruction and subsequent performance.

While cognitivism has many facets, the following concepts mentioned below were the most appropriate for this study seeing it is taking place outside of the classroom environment with no assistance from a teacher.

Cognitive theorists contend that environmental (external) influences and instructional components alone cannot account for all the learning that results from an instructional task (Ertmer & Newby, 2013, p. 51). Memory and internal mental processes needs to be equally weighted with instructional materials as it has consequences as to how the visual design and information layout is deployed. If instruction is poorly designed it will have a negative memory function leading to poor comprehension.

Part of the cognitivist learning approach is the implementation of feedback to give awareness of results that guide and support accurate mental connections (Thompson et al., 1992 cited in Ertmer and Newby, 2013, p. 53).When designing, instruction emphasis is placed on structuring, organising, and sequencing information to facilitate optimal processing. The use of instructional explanations, demonstrations and illustrative examples are all considered useful tools to aid understanding (Ertmer & Newby, 2013, p. 52). A software application that gives users feedback will help to chaperone them through the task in a supportive manner and provide guidance to move forward.

Cognitivism takes the stance that individuals acquire and store new information that is combined with old information in order to learn. Preceding changes in "behaviour" are identified to show what is happening in the learners' mind (Petri & Mishkin, 1994, p. 30).

Learning is said to happen when information is stored in memory in a structured and meaningful way. The transfer of information to long term memory is said to occur when a learner understands how to apply knowledge in different contexts. Prior knowledge is used to identify the similarities and differences of new information. Not only must the knowledge itself be stored but also how to use it (Ertmer & Newby, 2013).

The aim of the proposed software is to make sure the user knows the assembly process by keeping it similar to an instructional manual. In this way, the working concepts and functionality will have an air of familiarly, to form correct correlations in the users' mind. Once the assembly process is learned it could be used to assemble a multitude of items in the same manner.

Based on the concepts mentioned cognitive architecture will be further explored using cognitive load theory, to investigate the influence of instructional materials on memory to make accurate considerations in the design process.

3 COGNITIVE LOAD THEORY

Cognitive load can be defined as a multidimensional concept representing the load that performing a task inflicts on a learners' cognitive system (Paas & Van Merriënboer, 1994, p. 122). Cognitive load is amplified when learning requires the mental integration of multiple sources of information (Ayres & Sweller, 2014, p. 206).

Cognitive load is divided into three main frameworks namely Intrinsic, Extraneous and Germane.

Intrinsic cognitive load is the level of difficulty associated with an instructional topic. It is determined by an interaction between the characteristics of the material being learned and the ability of the learners. It cannot be modified by instructional designers because it comes from an individual's existing knowledge (Paas et al., 2003b, p. 65).

Extraneous or ineffective cognitive load is produced by the way information is presented to learners and is under the control of instructional designers (Chandler & Sweller, 1991). It is defined as the extra load beyond the intrinsic cognitive load and its main cause is poorly designed instructional materials (Paas et al., 2003a).

Germane or effective cognitive load is the amount of mental effort devoted to handling the construction and automation of schemas (Sweller, 1988). This theory is part of cognitivism and prescribes that knowledge is stored in long-term memory in the form of schemas. A schema categorises elements of information according to how they associate with existing information to provide solutions to potential problems (Chi et al., 1981). By reducing extraneous load, germane load can be upheld which positively facilitates the creation of schemas.

3.1 Memory

How memory works is central to this research because it can impact a users' ability to interact with instructional material effectively. It is widely established that the mind uses three types of memory set apart by the Atkinson–Shiffrin memory model (1968). These memory components are referred to as sensory memory, working memory and long term memory (Atkinson & Shiffrin, 1968).

Sensory memory processes stimuli that is received from the senses including touch, smell, taste, sight and sound. A separate division of sensory memory exists for each one of these senses. Sensory memories are not retained for long, nearly half a second for visual and three seconds for auditory information (Cooper, 1998). Within the small amount of elapsed time the brain must allocate meaning to the new information to be able to recall it and use it at a later date.

Working memory is the portion of the mind that provides consciousness and allows both logical and creative thinking. Working memory is associated with "where and how" attention is directed to think or to process information. Working memory can be increased through the presentation of information visually and auditorily in comparison to just using a single sense (Baddeley, 1992). The main limitation of working memory is its capacity to process no more than approximately seven elements of information consecutively (Miller, 1956). Working memory is used for problem solving, this makes it the most important out of the three types of memory for the purposes of this research.

Studies have observed how differences in Working Memory Capacity impact the efficiency of design principles in multimedia learning, including the Modality Principle, which recommends using information in both visual and auditory presentations instead of using text and images (Seufert et al., 2009). The approach of combining these two senses will be applied to the software design in an attempt to aid the working memory of the user. WMC is a limited capacity cognitive paradigm that differs between people and plays a key role in learning. It is shown to reveals individual differences in the capability to actively sustain information relevant to the task and relate it to information from long-term memory when faced with diversions (Cowan, 2005; Engle & Kane, 2003).

Using the proposed software, the amount of extraneous cognitive load and the need for substantial amounts of information to process in memory may decrease. Therefore, this should lead to an increased completion speed because the task will require less problem solving leading to lower cognitive load and expenditure of working memory.

The assembly task given to the participants as part of this study does not require mastery therefore there is little reason for it to be stored in long term memory. Long term memory denotes the vast collection of information made up of schemas and expertise that is held in a close to permanently accessible form (Albers & Mazur, 2014, p. 106). This assumes that it is unlikely that the assembly of a piece of furniture (flat pack) will need to be repeated in a real-world context without the assistance of the software. With the software aiding the user there is no need to spend time or effort memorising the intricacies of the entire task in order to assembly it.

Many people to which this software is targeted will have used an instructional manual at some point in the past and possess an associated schema. All the participant needs to learn is the new process of how the software instruction works and associate it with their existing schema as part of their long-term memory. The software will also reduce the number of elements being processed at any one time by displaying only what is needed at the time, showing no more than seven elements of information.

3.2 Measuring Cognitive Load

There are three separate ways of measuring cognitive load; physiological responses, subjective techniques and task based. The intensity of mental effort can be considered as an index of mental workload (Paas, 1992). Mental effort may be defined as the total amount of controlled cognitive processing in which a subject is engaged. Measures of mental effort can provide evidence on performance and the costs associated with cognitive learning (Paas & Merriënboer, 1993, p. 738). Performance is perceived by the success in undertaking a task; regularly measured by speed, accuracy or scores. This study will employ task based and subjective techniques which are described below along with physiological responses.

3.2.1 Physiological Response

The use of cardiological (heart rate) measurements have been established as part of an empirical study into measurement techniques within the cognitive load framework (Paas et al., 1994). They measured heart rate variability to estimate the level of cognitive load. It was found to be un-intrusive but also invalid because it could not detect minor changes in cognitive load. Pupillary responses were measured over time in multiplication tasks that ranged in different levels of difficulty to measure cognitive load during a study by Hossain and Yeasin, (2014). The findings reported that the pupil diameter increased in relation to the difficulty of the equation presented. Change in pupil size during a cognitive task interaction can suggest that the subject is in cognitive control, attentive or potentially overloaded.

3.2.2 Subjective Response

When using the subjective method participants are asked to self-report their invested mental effort by translating their perceived amount of mental effort into a linear numerical value. It is a modified form of a rating scale for measuring perceived task difficulty established by Bratfisch et al., (1972). This method works under the assumption that people can report their own mental effort. Values are reported on a visual analogue scale from very, very low mental effort (1) to very, very high mental effort (9). This value needs to be combined with an effectiveness measure, as it does not indicate performance on its own. Depending on the task the given efficiency measure could be a percentage of correct answers in a data set or how many tasks were completed within a set time.

While self-assessments to measure cognitive load are subjective they are well established. The rating scale has been tested through empirical studies (Paas, 1992; Paas & Van Merriënboer, 1994) for sensitivity and reliability to construct validity and intrusiveness. This evaluation indicated that the subjective rating scale is sensitive to relatively minor differences in cognitive load, valid and nonintrusive (Sweller et al., 1998). While there are several measures available the method using rating scales continues to be the most popular because of its easy implementation and accuracy.

Having participants rate their invested mental effort completing a task versus how difficult they perceived a task to be should be separated into different questions to avoid potential ambiguity of just using one or the other. Hypothetically, invested mental effort may contain more interpretations than only the task, such as individual enthusiasm while perceived task difficulty concerns mainly to the task itself (Van Gog & Paas, 2008). Applying both measures may provide some motivational indicators rather than just experienced load. While the interpretation of invested mental effort and task difficulty ratings are still highly subjective they provide a clear advantage over just using one or the other. Providing set definitions to the participants prior to the commencement of the task will help minimise ambiguity.

3.2.3 Task based Response

Task based techniques include two subclasses: primary task measurement and secondary task methodology. The primary task is based on performance while the secondary task is conducted simultaneously (Paas et al., 2003b). Typical performance variables are reaction time, accuracy and error rate. A secondary task was deemed as inappropriate for this study as it would not represent a realistic setting and scenario in which the assembly is trying to emulate. All the measurements will be focused on the primary task.

4 IMPLEMENTATION

Using the Vuforia™ SDK markerless object tracking, the dimensions of a 3d model can be specified and stored in the database. An image of any design can then be authored in an external application to be printed out and wrapped around the physical object. Currently the technology is limited to cuboid and cylindrical shapes but this is sufficient for testing the assembly task concept. The textures used must be the same aspect ratio to the corresponding 3d surface. In this instance, the pattern chosen will be a texture that could be made unique for each surface. For aesthetic purposes, the pattern could easily be changed to replicate different finishes commonly found for furniture. Custom software can be developed inside the Unity 3d game engine to incorporate the target model data into a Universal Windows Platform (UWP) application.

The Time of Flight camera sensors in the HoloLens™ headset facilitate "spatial mapping" allows for placement of virtual objects, occlusion, physics and navigation to provide real-world behaviours (Microsoft, 2017). This research is focusing on the placement aspect to enable virtual objects to interact with the physical environment, keeping their position even when out of the camera frame.

Due to the limited Field of View (FOV) on the HoloLens it is possible to track where the user is looking at any time in relation to the holograms and the users' relative position in the room. The HoloLens FOV is approximately 30 x 17.5 a 16:9 aspect ratio (Doc-Ok.org, 2015) which means the user must look around to view any holograms outside. That ability can be taken as an advantage for recording and recreating the environment inside unity 3d as another method for observation. This observation aims to uncover split attention, based on where the user is gazing to see if it correlates with their cognitive load.

4.1 Human Computer Interaction

Multimodal interfaces are interactive systems that are designed to enhance natural human capabilities to communicate though speech, gestures, touch and facial expression. (Turk, 2014, p. 189). Multimodal interfaces are growing in importance due to advances in hardware and software. These interfaces are unlikely to replace traditional desktop computing and graphical user interface but offer an alternative. Multimodal interfaces are a more natural way of communicating. Combining several ways of interacting is well suited to the saturation of the mobile computing platforms (Cutugno et al., 2012, p. 197). Given multiple options users can pick an interaction method that is more suited to them, a particular task or to reduce repetitive physical motions. Obrenovic and Starcevic, (2004, p. 65) express that people naturally communicate with the world multimodally through consecutive use of multiple senses. In other words, people use all their senses to interact with their environments and that has shifted to technology. In this case of this research users will be able to interact with the HoloLens™ using the software by using gestures, speech recognition and by moving physical objects in the real world through marker less tracking.

4.2 Assembly

The underlying concept for the experimental software prototype is demonstrated in Figure 1. The diagram shows a physical part being placed inside the holographic template which can be set up anywhere in the users' room for convenience. Ideally the hologram would be positioned in the location the furniture item would situate upon completion of the assembly to make sure it can fit before commencement. To indicate the current step of the assembly the physical parts required will be highlighted when the user looks at the set of parts to distinguish them from those that are not needed for the present step.

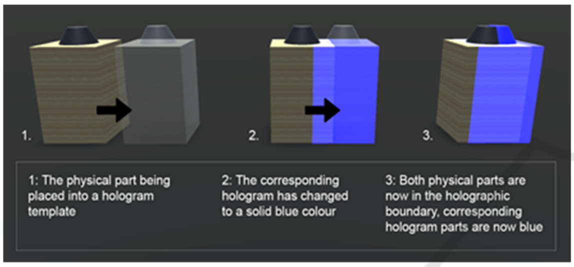

Figure: 1 Holographic assembly workflow concept.

To further assist with assembly, the corresponding holographic part will pulse a blue colour on the template to match with the physical part, this is intended to capture the users' attention. When the physical part is placed into the holographic template the part will stop pulsing blue and stay solid, showing that the part is in the correct position and orientation. These visual cues will be complemented with text and audio prompts. Jeung et al., (1997, p. 342) support this notion of including graphic indicators such as flashing, colour changes or simple animation. They agree that it is necessary for audio-visual instruction to be an effective instructional technique in situations where visual searching is prevalent.

The use of holograms negates redundancy found in step by step diagrams by combining all the steps into an interactive diagram. This is because there is no need to look at several diagrams for comparison over multiple steps. Interactivity also makes the assembly system more coherent to users because there is no irrelevant information displayed, this is known as the coherence principle (Fenesi et al., 2016, p. 691). That is, only showing what is needed to make the task comprehensible at any one time.

4.3 Scaffolding

Educational instructional scaffolding refers to the process in which teachers show how to solve a problem and then offer support as needed, which traditionally takes place within a classroom environment. Jerome Bruner a Psychologist and instructional designer first used the term 'scaffolding' in the field of pedagogy between teachers and children as cited in Wood et al., (1976, p. 90). McLoughlin, (2004) argues that "the concept of scaffolding needs to be redefined ... into contexts where the teacher is not present".
With technology now commonplace in both the workplace and at home it makes sense that the use of scaffolding concepts be extended outside of the classroom (Jumaat & Tasir, 2014, p. 74). Interest for such integration has been expanding in teaching (Reiser, 2004, p. 275) and further into commercialised applications.

When demonstrating instruction in the context of assembling flat pack furniture for example it typically would be constructed in the home or office. Scaffolding needs to be structured in such a way that is both self-explanatory and self-directing. The benefit of computer based scaffolding is that it provides infinite patience and is highly scalable. A clear downside of computer based scaffolding is flexibility. In comparison to one on one interactions the software has to base its response on pre-defined behaviours (Belland, 2017, p. 24).

In place of the teacher the following scaffolding examples will be used in the prototype application to facilitate the user in a way that is responsive and supports their needs: There is no general consensus on the underling concepts of scaffolding although Van de Pol et al., (2010) review revealed some commonly used strategies such as fading, contingency and transfer.

4.3.1 Fading

The idea behind this concept is to provide support to a novice learner which is gradually removed over time to develop independent learning strategies (Collins, 1987, p. 19). This is employed by having the software display a tutorial that explains how the assembly system works on the first couple of steps of the assembly. By instructing the user through a worked example it will provide a frame of reference for the future steps.

4.3.2 Contingency

Contingency is an aid mechanism that is responsive to the users' needs through tailored, differentiated, or calibrated support (Van de Pol et al., 2014, p. 604). It can be thought to be similar to a backup plan when a user gets stuck on a task. It will be designed in a way that offers support throughout the entire assembly task. If users reach an impasse and need to be reminded on the way then the software steps in and the tutorial section at the start can be viewed again at any time. Hints will be presented by highlighting where the part should be placed and what parts are currently needed to avoid any potential confusion.

4.3.3 Transfer

In a teaching situation, the notion of transfer was traditionally a "relationship" that shifts between teacher and student when a student takes increasing learner control (Van de Pol et al., 2010, p. 275). Based on the context of this study, transfer can be thought to be the changing of the responsibility from the software developer to the user once they have learned how to use it (usually after fading has taken place). Transfer is never fully shifted to the user in this instance because the software is always fully active. Instead the relationship is one of constant back and forward as the user is prompted to make their next move. When a part is placed in the right place the user is presented with visual or audio cues (response) to keep them on track and moving forward. At any time during a task the shift of responsibility may need to change between the user and the software which will fall back to the contingency responses.

5 FUTURE DIRECTIONS

The next step in the research process is to prototype a simple version of the assembly application in Unity for deployment of the HoloLens. 3d printed parts will be devised to make up a scaled down cabinet using Computer Aided Design and Drafting (CADD) software. This needs to be done because the dimensions of the printed parts have to match those entered into the object recognition data base in order to be tracked. Further investigation needs to take place into the method of wrapping the 3d printed parts with patterned paper to see if making holes in the parts has a negative effect on the tracking.

Testing will take place using the purpose built prototype as there is no off the shelf solutions available that offer suitable feature sets for control groups. Three control groups will be asked to complete the same assembly task using the HoloLens. Every iteration will be facilitated by an animated guide to act like an instruction manual. The amount of assistance provided will vary with feature sets building on previous iterations.

The first prototype iteration provides a baseline and will use a holographic reference positioned next to the assembly location. This iteration provides no feedback to the user and they are left to make their own decisions.

The second iteration offers feedback in the form of part identification and tracking for each step of the assembly. This aims to reduce split attention by assisting the user with finding parts.

The third iteration has the most comprehensive scaffolding and feedback. It uses the part identification and tracking found in test two with one change, physical parts can be placed inside a holographic template. This approach removes the separate reference hologram and shifts the task into a single point of focus. This is in contrast to the previous two tests which rely on the user to use a hologram as a diagrammatic reference and carry out the assembly next to it.

The Visual Analogue Scale will be employed to measure task difficulty and perceived cognitive load at set times during the assembly task. Following this a survey will be administered to gather feedback on what could be improved based on user experience. Performance measures will correspondingly be captured based on completion times of each step, in order to calculate the relative condition efficiency of each prototype iteration.

Data analysis will take place using Analysis of Variance (ANOVA) to examine if there is any statistical significance between the test groups. Consulting with a statistician will provide advice on the correct classes of model to be employed before any testing takes place. This will uncover correlations between the prototype design iterations and their efficiency when compared to each other. The use of instantaneous load over time shown in in Paas et al., (2003b) will also be explored to identify and define trends in the pattern of cognitive workload.

Comparing the efficiency of the prototype iterations will conclude if user performance has increased when cognitive load has reduced and how it is impacted by memory. By doing this analysis the proposed research questions will be addressed.

6 CONCLUSIONS

A review of the literature informs the proposal of a software prototype that seeks to use the cognitive memory architecture to assist users in processing information. The prototype uses holographic templates to address split attention and redundancy by eliminating the use of a reference manual or separate diagram. Merging the physical parts with holograms aims to free up users to focus their attention on the assembly task instead of constantly referring to a separate 3d diagram or a visually disconnected augmented device. Furthermore, the part identification will avoid constantly searching for the set of parts needed to complete a particular step by highlighting them when in the users view. Reducing visual searches has been shown as an effective way to eliminate split attention and facilitate learning (Cerpa et al., 1996, p. 2).

The software will employ scaffolding that fades out over time while still offering contingency if the user gets stuck or forgets where they are up to. The scaffolding provisions first introducing how the assembly system works with a demonstration consisting of step by step worked example through the initial stage of the assembly. While the scaffolding may be pre-defined leveraging the software with a form of built-in intelligence removes the frustration commonly found in static instructional materials.

The responsibility of how to progress through a task is never transferred entirely to the user making the experience feel balanced and much more enjoyable. Users have no need to learn the intricacies of the assembly task, but rather understand how to interact with the elements on the holographic system to guide them. In this way working memory is freed and the assembly system associations are stored in long term memory as a schema.

This proposal of merging holograms and physical parts in mixed reality has emphasised the critical importance of considering the characteristics of human cognition and cognitive load when devising instructional materials.

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