ARCS Architectural Chameleon Skin

A swarm-based architectural installation

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Abstract. *Traditionally, interactivity in architecture has been suppressed by its materiality. Building structures that can transform and change themselves have been the dream of many architects for centuries. With the continuous advancements in technology and the paradigm shift from mechanics to electronics, this dream is becoming reality. Today, it is possible to have building facades that can visually animate themselves, change their appearance, or even interact with their surroundings. In this paper, we introduce Architectural Chameleon Skin (ARCS), an installation that has the ability to transform static, motionless architectural surfaces into interactive and engaging skins. Swarm algorithms drive the interactivity and responsiveness of this "virtual skin". In particular, the virtual skin responds to colour, movements, and distance of surrounding objects. We provide a comprehensive description and analysis of the ARCS installation.*
Keywords. *Interactive architecture; responsive facade; swarm-based projection; virtual skin; interactive installation.*

INTRODUCTION

The digital age has blended the built environment with "hybrid", dynamic, and interactive architecture (Flachbart and Weibel, 2005). In today's world "signs and labels are becoming dynamic, text is jumping off the page into three-dimensional space, murals are being set in motion, and the immaterial is blending seamlessly with the material" (Mitchell, 1999). Active pixels are essential to the architecture of the digital age "as static tesserae were to the Romans" (Mitchell, 1999). As a result, architecture as "a container of human activity" (Roth, 2007) is being superseded by architecture of "interaction of space and events" (Tschumi, 1996). At the same time, advanced technologies such as smart surfaces, video-projected displays, and virtual and augmented reality support augmentation of building surfaces and facades with "luminous digital information" (Mitchell, 1999). All of these advancements have opened new horizons for generating interactivity in architecture.

Inspired by the distinctive ability of the chameleon skin to frequently and rapidly change colour, and motivated by the on-going attempts to create interactive architectural skins (Boyd et al., 2004), we developed Architectural Chameleon Skin (ARCS), an installation that projects a virtual skin onto the facade of a building or a wall. ARCS installation is composed of the following main components: an interactive virtual skin (a computer-based responsive swarm system), a computer, a camera, and a projector. In ARCS, the simulated swarm system is projected onto a facade of a building or a wall in an interior space. The swarm integrates and interacts to contextual entities and events around the facade or wall, including movements and colours, even people.

In analogy to the biological inspiration, the swarm system can be seen as the Chameleon skin and the swarm agents as the skin cells. This is mainly due to ARCS's ability to change colour based on its surrounding conditions (environment). ARCS offers unprecedented opportunities for not only acknowledging and visualizing the presence of people in an architectural space but also using their appearances and movements to generate infinite numbers of responsive patterns on walls and facades. ARCS aims at creating interactive architectural skins and increasing interaction between people and architecture.

In our paper, we provide an overview for the first ARCS installation prototype, designed for a small exhibition setting, with emphasis on the design and development of the ARCS swarm system. In the related works section, we highlight some of the work that inspired ARCS. In the subsequent section, we explain the algorithmic details that make ARCS acknowledge and interact with the presence, appearance, and activities of people in an architectural space. We describe our findings in the result section and then provide a discussion about the ARCS system behaviour. We conclude the paper with a conclusion section and an outlook of possible future works.

RELATED WORKS

With the growing desire to increase complexity and interactivity in architectural projects in response to the zeitgeist, installing smart facades, interactive installations, and media walls on buildings has been expanding significantly for the last decades. Many signature buildings across Europe, North America, and Asia are distinguished with their facades' abilities to frequently change their drawn surface.

The BIX light and media installation at the Kunsthaus Graz in Austria, the transparent metallic grilles skin of the Maison Folie in Lille, France, GreenPix – a Zero Energy Media Wall projected onto the Xicui entertainment complex in Beijing – to name only a few – all give evidence to the growing trend of incorporating interactive systems with architecture. Interestingly, these interactive skins have transformed the buildings into architectural landmarks and have drawn much attention to them within the architecture community and beyond.

Another example is the facade of the Galleria Department Store in Seoul, South Korea, which was retrofitted with 4330 glass discs that are "mounted on the existing concrete skin of the building" [1]. The glass discs "include special dicroic foil generating a mother-of-pearl effect during the day, whilst during the night each glass disc is lit by LED lights which are able to be programmed to create a multitude of effects" [1]. A computer program displays fading patterns and colours on this facade, creating an effect not unlike chameleon adapting to its environment [2].

The 555 KUBIK projections onto Hamburg's Kunsthalle in Germany significantly transformed the "sterile facade" of the building into a dynamic and performing sculpture. The idea behind this projection was: "How it would be, if a house was dreaming" [3]. The projected animations considered and expanded on the physical structure of the building. Supported by the rapid advancement of technology, 555 KUBIK and similar installations open new horizons for building unique architectural facades and skins that perform as art works in an urban context or interior space. Also, with integrating means of interactivity into digital facade technology, one can achieve real adaptivity and engaging dynamics.

D-Tower installation in Doetinchem in the Netherlands is a good example for such interactive engaging installations. The installation is composed of a 12 m tower with a biomorphic form (made of epoxy panels and located in the center of the city), a website, and a questionnaire (Kolarevic, 2005). All the three components of this installation are interac-

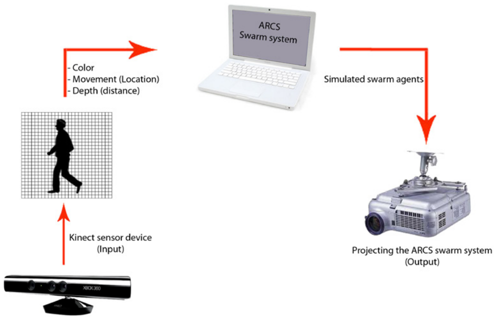


Figure 1
A conceptual diagram showing the relationship between the main components of ARCS installation.

tively related to another. D-Tower is a hybrid installation "where the intensive (feelings, qualities) and the extensive (space, quantities) start exchanging roles, where human action, colour, money, value, feelings all become networked entities" [4].

This art installation measures and maps four emotions (happiness, love, fear and hate) of the Doetinchem inhabitants in the art piece [5]. It uses the questionnaire to record emotions of the participants. The information from the questionnaire then used and translated into hand-drawn graphs that are presented on the website. Since the zipcodes of the participants are known to D-tower system, "the emotions of the participants can be placed on the map of Doetinchem" [5]. The system then calculates the most prominent emotion in the city based on the answers received from the participants, and then uses this information to light up the translucent tower in one of the four symbolic colours specified to each emotion (red for love, blue for happiness, yellow for fear, and green for hate) [6]. Thus the city's "state of mind" can be seen by looking at the tower and/or the corresponding website (Kolarevic, 2005).

ARCS
The digital facade projects and installations mentioned in the previous section conceptually inspired ARCS. However, ARCS puts forward a unique computational approach that deploys large numbers of reactive swarm agents and supports the emergence of context-aware patterns in real-time rather than pre-set projected patterns and colours. At the same time, since interactivity in architecture can be achieved by building components' ability to respond to the surrounding changes, therefore, ARCS is a true interactive system. This is because ARCS uses people's inputs in a direct way and engage them in generating colours and patterns on building surfaces around them.

ARCS HARDWARE SETUP
Figure 1 shows the apparatus for ARCS. Information about the environment is fed from a camera into a computer whose reactive renderings are projected onto a screen. ARCS works with a Microsoft Kinect camera that provides colour, movement, and depth information.

ARCS AT OPERATION
When the ARCS system is not perceiving any changes in its environment, it is idling, i.e. the swarm agents ignore the camera input and spread across the projection surface. As soon as the camera picks up passing or approaching objects or colour changes, the swarm agents become aware of these stimuli and start reacting to them. After five minutes without incoming stimuli, the ARCS system returns to the idle state.

ARCS VIRTUAL SKIN
The ARCS swarm system deploys three type of swarm agents, A, B, and C, that react to the perceived stimuli and which are rendered onto the projection surface. The agents have different behavioural and visual attributes. Their behaviours let them change their states in accordance with the stimuli provided by the camera system and with their local (virtual) environment on the projection surface. The actions of the agents are regulated by the behavioural rules developed for them. For the implementation of ARCS swarm system, we used the Processing programing framework.

The Agents' Visualization
Each agent has a shape, a size, a colour, and a location on the projection surface. For instance, an

agent can be represented by a blue circle with a radius of 20 pixels and be located at the center of the projection surface. These attributes may change depending on the agents' states, e.g. active or idling states. All the agents have a circular shape but are displayed according to the state of the agents. The agents of type A are displayed when they are idling and when they are active, whereas agents of types B and C are only rendered on the surface when activated.

When idling, the agents of type A have a fixed size. When active, their sizes correspond to the distance values captured by the depth-sensing camera. In order to achieve a reasonable agent size, the raw depth value (distance value) is divided by a constant before it is used as the agents' diameter. The size of the agents of type B and C do not change with changes in depth.

When idling, agents of type A are rendered in shades of grey (from white to black), depending on the projected background colour (Figure 2). When active, they adopt the colour provided by the Kinect camera. Thus, the agents change their colour and match it with the colour input from the Kinect, mimicking what chameleon skin cells do in nature. Agents B and C are always rendered white and grey, respectively. All the agents are first rendered completely transparently slowly turning opaque as time passes by in the active state.

The locations of the agents also change according to the behavioural rules. The initial locations of the agents (when idling and activated) are assigned randomly within the projection surface. The changes in agents' locations occur according to the movement behaviours of each state.

Finally, in addition to the agents of type A, B, and C, in active state a representing circle appears on the projection surface. The circle is coloured with the colour provided from the camera, thus the colour of the agents of type A. The center of the circle represents the center of activities (movements) of a moving object/person passes by the installation (calculated from the Kinect). For example, if a person moves by the projection surface the center of his/her movement is mapped on the virtual skin and visualized as a moving circle on the surface (Figure 3).

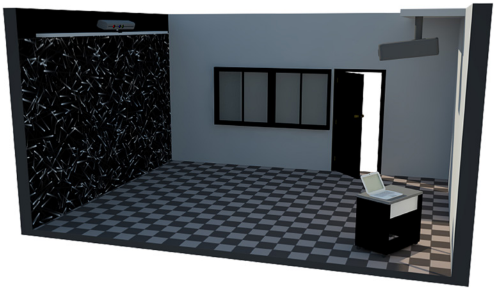


Figure 2
A visualization for ARCS installation in idling phase.

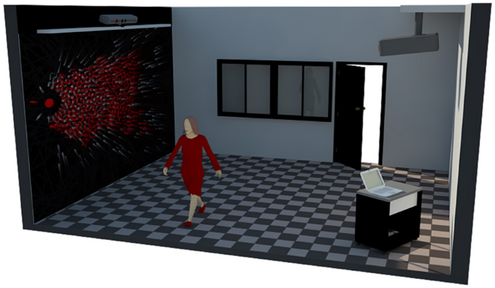


Figure 3
A visualization for ARCS installation in active phase.

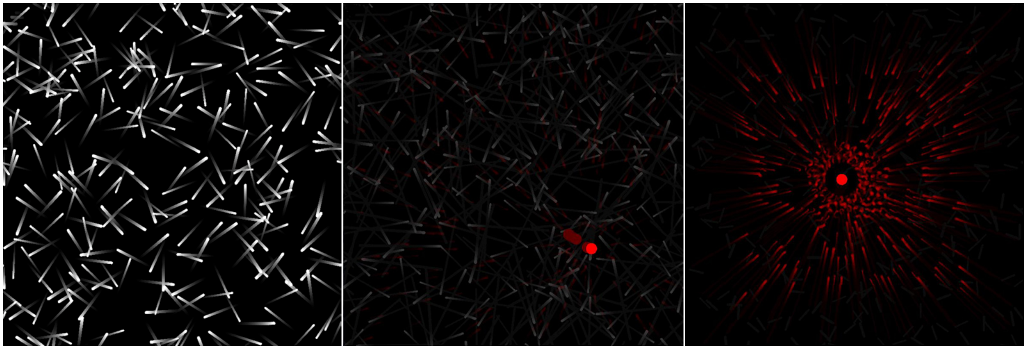
In summary, when there is no movement detected around the installation there is only one element, agents of type A, rendered on the virtual skin. When a movement is detected (active state), however, there are four elements rendered on the virtual skin which are: the agents of type A, B, and C and also a representative circle.

The Agents' Movements

ARCS virtual skin is not solely determined by the agents' attributes but also by their behaviours and interactions with the system. In ARCS's swarm system, the following movement behaviours have been implemented:

1. Brownian motion with a confined area,
2. movement toward a specified target location,
3. aggregation and keeping a certain distance from an identified, possibly moving target, and
4. Brownian motion with collision avoidance.

Figure 4
Left to right: (a) The random movement of the agents in idling state. (b) The gradual transition of the agents from transparent to opaque. (c) The appearance of the aggregation and following of the agents together.



When idling, the rendered agents (type A) move randomly on the projection surface at a given speed (assigned in the code) ignoring their neighbours. When activated, thus the camera detects a moving object, all the agents (type A, B, and C) move toward the representing circle (center of activity) on the virtual skin. Thus, the agents follow the moving object on the projection surface. When the agents get close enough to the circle, they start to aggregate around it within a given distance. As the distance between an agent and its neighbours reach a specified limit they start to avoid colliding with each other in a wandering visual effect.

The display of the three types of agents in the active state doesn't start together. Upon the activation of the active state, the agents of type A first appear on the projection surface. After sometime, the second group of agents (type B) with a slower speed appears on the virtual skin while moving toward the circle and aggregate around it as well.

Finally, the appearance of the second group of agents is then followed by the appearance of a third group of agents (type C) that moves and aggregates around the circle at an even slower speed. The agents continue to follow and aggregate around the moving object, generating infinite pattern on the projection surface. As the agents move around, they leave fading traces, adding a visual richness to the virtual skin.

RESULTS

The visual outcomes from the virtual skin vary according to the condition around the installation. When no moving object is detected (the agents idling) the colour of the agents remain the same and variations occur in the agents' random movement only (Figure 4a). Thus, not much interesting visual diversity appears on the projection surface and the virtual skin is not interactive at this state. This effect, however, changes as soon as a moving object is detected in the scene. In this case, the influence of the real-time interaction between the object and the virtual skin soon become visible. Many appealing visual effects emerge on the virtual skin.

The accumulation of time in the simulation appears in a number of effects such as the agents' gradual transition from transparent to opaque (Figure 4b). The emphasis on the moving object's location in relation to the projection surface is well depicted in both the aggregation and following of the agents around the representing circle. These two movement patterns appear individually and/or together, generating dynamic visual effects on the virtual skin. If the moving object stops rapidly or move in a slower speed both of the patterns emerge together as it is shown in (Figure 4c).

The number of the agents and the dominant colour on the virtual skin remain the same until the appearance of the agents of type B and C in the ac-

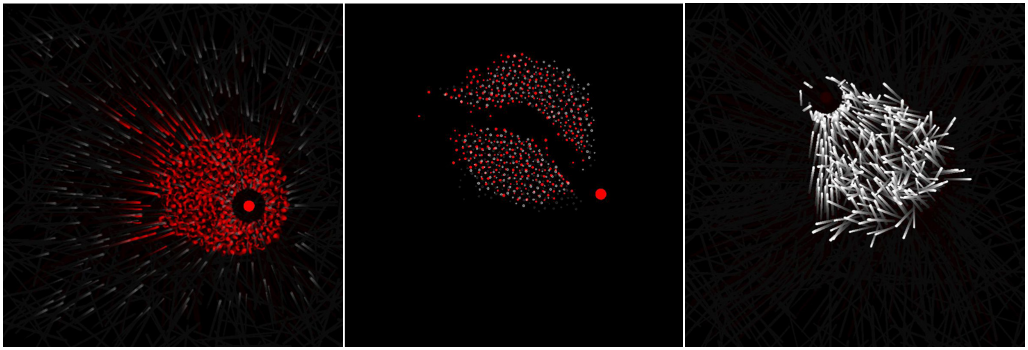


Figure 5
Left to right: (a) The appearance of the 2nd group of agents and moving toward the circle as the agents become less transparent. (b) The interruption of the agents' aggregation when the object starts moving again after a few minutes of pause. (c) Returning back to the idling from active state.

tive state. This effect enables observers to estimate time of interaction between the moving object and the virtual skin. At the same time, the time difference between the appearance of the agents of type A, B, and C generates interesting visual effects from the combination of more transparent agents with more opaque ones (Figure 5a). As the moving object stays in a location for a period less than 5 minutes, the aggregation of the agents around the representing circle become more regular. If the object then starts to move again, the circle moves across the agents interrupting the agents' aggregation (Figure 5b). Consequently, some interesting segregation effects of the agents appear on the virtual skin.

If no activity detected for more than 5 minutes in the active state, the agents then go back to their idling state. At this stage, the representing circle and the agents of type B and C disappear immediately, and the agents of type A no longer respond to any inputs from the Kinect. Consequently, the random movement of the agents starts from the regular aggregation from the active state, generating an interesting visual effect as it is shown in (Figure 5c).

The variation in colour and equality in number of agents in each of group of agents (type A, B, and C) results in a colour balance on the projection surface when all the groups of agents are rendered. However, an imbalance in colour soon appears as the moving object gets closer to the projection surface. This is mainly because the agents of type A become larger in size and their colour (which corresponds to the circle's colour) dominates the virtual skin. Also, this change in agents' size (type A) provides a visual clue about the distance of the moving object from the projection surface because the more the object is closer to the surface the larger the size of the agents become.

DISCUSSION

ARCS installation aims at enriching people's experience in or around architectural spaces. It is designed as an interactive installation that engages people in generating countless and emerging visual effects on architectural surfaces around them and, thus, increases their interaction with architectural spaces. ARCS makes an effective medium for connecting people with architecture; the visual outcomes resulted from passer-by's intentional or unintentional interaction with the system encourages more active interaction and engagement with a space.

ARCS swarm agents' attributes, behavioural rules, and interactions with the system inputs are defined in the swarm algorithm that is responsible for generating the visual outcome of the ARCS virtual skin. The swarm algorithm is designed to be a flexible algorithm that generates emergent visual effects from the system inputs. Small changes in the system inputs can create significant changes in the visual outcome.

The visual effects from ARCS swarm algorithm are designed to embrace interactivity in the system and convey some visual meanings. The followings

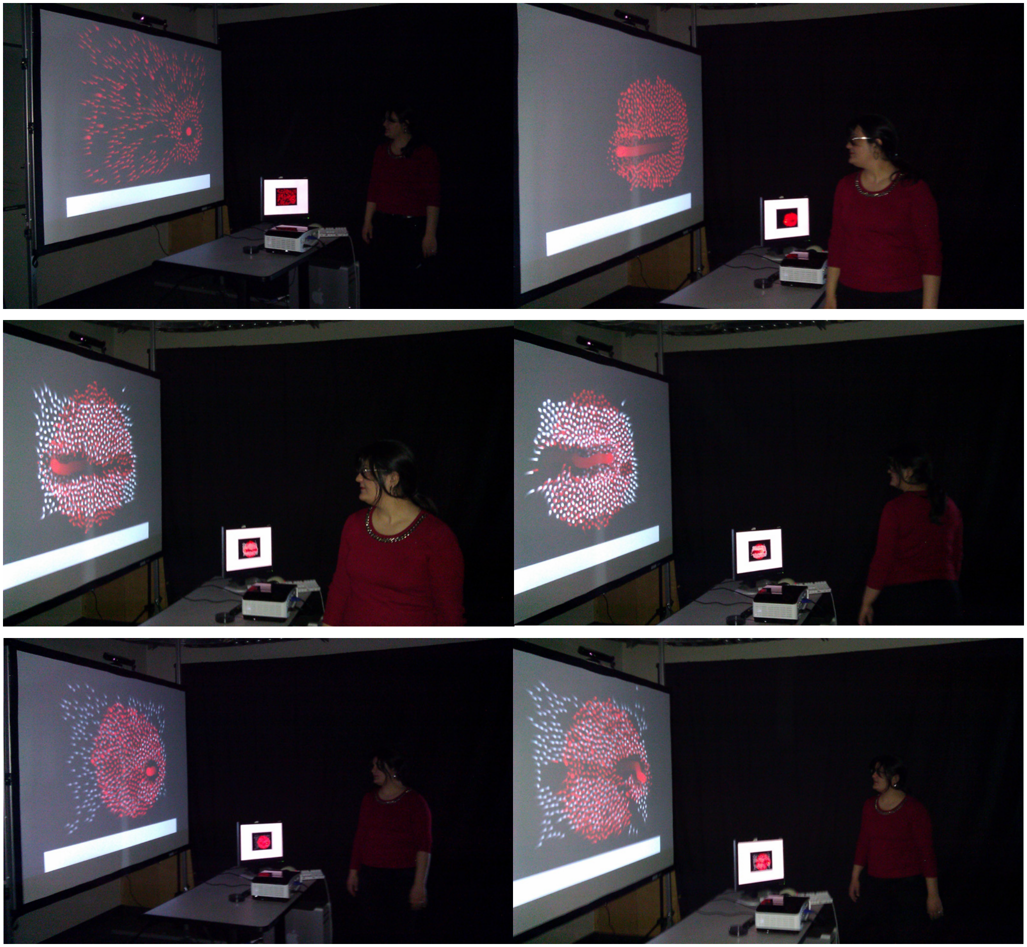


Figure 6
Top to bottom: (a) The agents (type A) adjust their colour to the colour of the moving person (detected from the camera) and move towards her. (b) Agents (type A and B) track the user's movement by following the representing circle. (c) The agents had aggregated around their target (moving person) and are dispersed upon sudden movements from her.

are some explanation for the visual effects generated by the ARCS swarm system on the virtual skin.

1. *Colour adoption*: The colour adoption of the agents from type A to the colour provided by the Kinect camera from a moving object (a passer-by) is an attempt to replicate Chameleon skin's colour adoption to a surrounding environment and create Chameleon like architectural surfaces and facades (Figure 6a). Adopting colour awareness behaviour based on people's colour inputs in ARCS systems will not only introduces instantaneous colour adoptivity into architecture, but also engages people and makes them active participants in creating events in their surrounding architectural surfaces.
2. *Number of agents and their aggregation*: The number and aggregation of the agents around the representative circle for a passer-by in active state aims at adding time dimension to

the system and visualizing level of movement around ARCS installation (Figure 6b). Larger number of agents with more regular aggregation around the representative circle indicates that a passer-by was not moving for a period of time. This system behaviour enables visualizing and mapping level of activity around an architectural surface or facade, adding an interesting time-based interaction into architectural spaces and activities in and around them.

3. *Size changes*: The use of the depth input from the Kinect camera to update agents' size (type A) aims at representing a passer-by's proximity in relation to the projected architectural surface or facade; the larger the size of the agents the closer the passer-by is to the virtual skin. In addition to increasing interactivity in ARCS system and mapping more attributes from the people and their interaction with an architectural space, this behaviour enables intensifying or reducing colour impact from the passer-bys and further diversifying the visual outcomes of the virtual skin.
4. *Speed and colour differences*: The difference in speed and colour among the agents from type A, B, and C aims at creating variations in the agents' attribute and behaviour in the swarm system. Our goal was to explore variation within ARCS virtual skin components and demonstrate the countless opportunities ARCS supports for creating interactivity and diversity in the swarm system and its visual outcomes.

In addition to the individual visual effects and their impacts on the visual outcomes, the combination of these effects together in ARCS swarm system makes ARCS installation a unique one.

Finally, ARCS installation combines a number of technologies together. As a result, technological limitations related to these technologies affect the performance of the installation. For example, the Kinect camera's field of view, capabilities in detecting the required parameters and inputs for the system, and position in relation to an augmented wall or facade, the projector's specifications, and other technological and logistical related factors impose some limitations on the installation and its performance.

CONCLUSIONS

The use of swarm agents for generating visual effects in ARCS paves the road for exploring interactive emergent virtual skins for facades. Simple changes of the swarm agents' behaviours and representation can have significant visual impact on the virtual skin. In contrast to other existing facade projections and installations, ARCS engages people both visually and kinetically. ARCS maps the passers-by's activities and appearance on the virtual skin in real-time, and uses these parameters for updating the swarm system. In doing this, ARCS aims at creating events in and/or around architectural spaces, which enables people to experience these spaces in different ways overtime.

ARCS virtual skin can be viewed as an augmentation of architectural surfaces; thus expanding their capabilities of what they can do. ARCS allows emerging physical properties of a real facade (or any other architectural surface) with properties of virtual objects (swarm agents) in real world. Thus, with the use of ARCS it is possible to convert a static wall/facade into an animated one (i.e. retrofitting uninteresting surfaces). This new property of architectural surfaces will uncover a new realm for creativity and innovation in architectural spaces.

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