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Human augmentation: re-inventing embodiment

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Introduction

Human augmentation technology for physical abilities via robotic systems is no longer a dream for a future age.¹ It is happening now and it seems promising on many respects. For instance, a number of exoskeletons are already on the market. They increase the strength of the person wearing it by a factor of twenty and reduce the effects of gravity and inertia. With an exoskeleton, it thus becomes possible to lift important weights or to run for a long time without getting tired. They only have to become light enough so that it seems natural for everyone to put them on every morning like a coat. Extra robotic limbs are also under development, enabling several objects to be simultaneously held and manipulated. In the experimental domain, for instance, researchers have designed an extra finger (i.e. third thumb) with two degrees of freedom, which allows its user to open a jar with only one hand by stabilizing the grip, among many other things (Kieliba et al. 2021). Some of the artificial devices are controlled by muscle activity (e.g. the two toes for the third thumb), while others can be directly interfaced with peripheral nerves, or even with the brain.

In the face of these technological advances, one might worry that they have larger implications than just acquiring the new skill of opening a water bottle with one hand only. What are the consequences if our body becomes partly biological, partly artificial? Andy Clark (2007, p. 263) claims that thanks to human augmentation, we shall become “brand new

¹ I shall focus here exclusively on the augmentation of physical abilities, leaving aside cognitive enhancement.

integrated agents”, both mind and body being extended. Within the framework of embodied cognition, it may seem indeed that by altering the body and its sensorimotor abilities, one alters the mind itself. However, in what sense is the augmented body *an intrinsically different body*? Can the artificial device become a proper part of the body? At stake is the ontological, but possibly also legal and moral, status of the artificial device. As Aas (2021) phrases it, if someone were to voluntarily damage it, would it be a situation of vandalism or of assault? I shall leave this fascinating question aside, and focus rather on the way the brain processes the device. The question then becomes whether information about the artificial system is processed in the same manner as information about one’s own biological body part. Embodiment has often been suggested as the ideal for an amputee to achieve if she is to be satisfied with her prosthetic limb, and to regularly wear it (e.g. Scarry, 1994; Engdahl et al., 2020; Page et al., 2018; Graczyk et al. 2018). But is this ideal feasible in the case of augmentation technologies? And is it even desirable?

The difficulty here is that the term ‘embodiment’ may refer to different notions (Vignemont, 2011). For the sake of this chapter, I shall simply distinguish between two interpretations. According to a strong interpretation, the question is whether an artificial system can be experienced as a proper part of the body. This phenomenological objective can be reached if the processing of the artificial system is similar enough to the processing of biological body parts (*strong embodiment*). According to a weak interpretation, the question is whether an artificial system can be integrated within the body schema (*weak embodiment*). The body schema is defined here as the representation that carries information about the effector(s) in a format directly exploitable by the motor system to guide action planning and control (Vignemont et al., 2021). We shall see that this objective is easier to achieve, but possibly too easy, and that many objects may then qualify as weakly embodied without us becoming ‘brand new agents’.

1. Rubber bodies

Cognitive research on human augmentation is still relatively recent (e.g. Di Pino et al., 2014; Dominijanni et al., 2021; Kieliba et al., 2021). It is thus sensible to look at domains in which the use of artificial limbs has been more extensively investigated, namely, the field of restorative technology in patients. There are actually some conditions in which the border between restoration and augmentation is unclear, as in the case of ageing. Many devices used to enhance physical abilities in able-bodied individuals are often originally designed with the prospect to substitute a missing or impaired body function. One might then assume that restoration and augmentation are like two sides of the same coin. On this view, adding a sixth finger involves the same mechanisms as replacing a fifth finger. The principles governing the integration of artificial limbs are the same whether it is to replace a missing limb after amputation or to add a supplementary one in addition to the healthy biological limbs. These principles, one may further argue, may be borrowed from the way one normally processes one's own body parts. One should then expect the artificial limb to be represented and experienced as a proper part of the body, to be *strongly embodied*. This seems to match the amputees' own wishes. They often explicitly express satisfaction when their prosthesis subjectively appears to them exactly like their biological limbs:

Well, to me it is as if, though I have not got my lower arm, it is as though I have got it and it is [the prosthesis] part of me now. It is as though I have got two hands, two arms. (Murray, 2010, p. 85)

However, such an incorporation is rarely reported. Up to 45% of individuals missing a limb do not regularly wear their prosthesis, especially for upper limb replacements (Biddiss, 2010). The issue may be partly technological, most prostheses still being relatively uncomfortable,

but one may wonder about the existence of more fundamental obstacles to represent an artificial limb as a proper part of one's body.

The rubber hand illusion (RHI) is often taken as the proof of concept in this context (e.g. Bekrater-Bodmann, 2020; Zbinden et al., 2022). In the classic set-up of the illusion, participants sit with their arm hidden behind a screen, while fixating on a rubber hand presented in their bodily alignment; both the rubber hand and the real hand are then stroked in synchrony or not (Botvinick and Cohen, 1998). It has been found that after synchronous stimulations, some participants (a) feel tactile sensations to be located in the rubber hand, (b) experience the rubber hand as part of their body, (c) mislocalize their hand in the direction of the location of the rubber hand (i.e. proprioceptive drift), and (d) display an increase in arousal when the rubber hand is under threat. In brief, the rubber hand is strongly embodied. One might then hope that by analyzing the conditions under which one can elicit the RHI, one might be able to increase the amputees' satisfaction with their prosthesis.

The problem, however, is that the RHI cannot provide clear guidelines for strong embodiment of artificial limbs. To start with, one should note that it is far from being a systematic illusion, unlike classic visual illusions. It has been reported that at least 25% of the participants never experience it (Lush et al., 2020).² One may then investigate what explains this variability and various options have been recently proposed, but the fact is that the RHI shows not only that it is possible to incorporate an external hand, but also that in many cases we do not incorporate it and we do not know why.

Notwithstanding intersubjective variability, one may also question the relevance of an illusion that is primarily *sensory* to understand the acquisition of new skills through human augmentation. The RHI is generally induced thanks to visuo-tactile congruency, and rarely

² I myself have never succeeded.

involves motoric aspects. It has been found that subjects report no sense of control over the rubber hand and that action can remain immune to the effect of the proprioceptive drift (Longo et al., 2008; Kammers et al., 2009). This is at odds with the primary motor purpose of artificial limbs, which is to increase one's motor repertoire and to allow for fluid interactions with the world. On the basis of the RHI, it has been argued that multisensory integration is essential for bodily self-awareness (e.g. Blanke, 2012). However, this cannot be the primary path for the appropriation of artificial limbs given the general lack of somatosensory feedback in most current prostheses. Amputees generally do not feel from the inside the location of their prosthesis and what it touches. Their only access is visual. Hence, unlike the RHI, there cannot be any visuo-somatosensory congruence that could ground the appropriation of the artificial limb. As long as it lacks sensory feedback, it may seem that there is little hope for prosthesis strong embodiment.

2. Deafferented bodies

There is considerable research on the sensory dimension of artificial limbs (e.g. Bensmaia et al., 2020; Graczyk et al. 2019). So far, it mainly involves providing information about contact between the device and objects, either by providing tactile stimulation on a displaced skin surface, or by directly activating the neural pathways originally supporting the sensory function. This research is motivated by the assumption that somatosensory feedback could improve motor control and the experience that users have of their prosthesis. For instance, two amputees described that their artificial limb felt as being more natural and their control more intuitive and less attention-demanding when their prosthesis was sensory-enabled through neural interface than when it was not. Interestingly, when the phase trial of sensory restoration stopped, one patient noted that his prosthesis: “does not feel like me—went back to

being an attachment.” (Graczyk et al. 2019, p. 8). Evidence on the actual role of somatosensory feedback remains, however, anecdotal and its absence in most cases is not rated as the factor with the highest priority in survey studies inquiring about prosthesis abandonment (Zbinden et al., 2022). One may then ask how crucial somatosensory sensations are for embodiment by considering another case in which they lack such sensations, namely, after *peripheral deafferentation*.

After acute neuropathy, some patients can lose all proprioceptive and tactile signals from their damaged nerves. The most studied of these patients have almost their whole body (except the head) affected, though their motor nerves are spared. Hence, with their eyes closed, they do not know the location of their limbs and they may even report feeling as though they were “nothing but a head” (Gallagher and Cole, 1995). At the beginning, they are unable to control their limbs, but with time, they learn how to guide their bodily movements on the only basis of visual information. Yet, many have argued that the deafferented limbs are not fully re-embodied, even in the weak sense (Brewer, 1995; Gallagher and Cole, 1995; Paillard, 1999; Wong, 2015).

There are strong commonalities here with artificial limbs. Users have to control their devices in the absence of somatosensory feedback and on the basis of vision only. The difference is that deafferented patients can still feel pain, heat and cold in their body, whereas prosthetic users have no sensations whatsoever. If the deafferented limbs remained disembodied despite those preserved sensations, how could fully insensitive rubber and metal devices claim to be embodied, even weakly?

However, one should not too hastily conclude that there could be no embodiment without somatosensory feedback. Let us first examine the reasons for which some deny weak embodiment in deafferentation. The patients have to rely exclusively on visual control, and,

according to Gallagher and Cole (1995), this involves reflexive use of the visuo-spatial body image, instead of the body schema. It is not clear, however, why visual control could not be based on the body schema as well. The extensive use of vision in both deafferented and artificial cases does not fundamentally depart from what normally happens. Vision is the primary source of information about the world in which we act and it is pervasive in bodily control, no matter whether one is deafferented or not (Vignemont, 2018). Furthermore, with training there is no longer the need to pay attention to what one is doing. Consider how good we become at driving though it is mainly based on visual control. New skills, such as moving only on the basis of visual information, are cognitively demanding and effortful at the beginning but they become automatized with practice. After a learning phase, deafferented patients no longer need to reflexively think about what they are doing. The same is true for amputees with artificial limbs. Visual control requires less and less attention, until it becomes almost natural. For instance, patients with lower limb prostheses describe that they still need to consciously think about the position of their legs to start with but once in movement, they could “just walk” (Murray, 2010, p. 85). Even after only five days of training with their third thumb, participants had no difficulty performing new actions with it, even with simultaneous heavy cognitive load (Kieliba et al., 2021). Hence, contrary to what has been said, the body schema might not be missing in deafferentation, and, as a consequence, the current lack of somatosensory feedback might not be a fatal obstacle for prosthesis weak embodiment.

What about strong embodiment? Descartes famously said in his *Sixth Meditation*, “I am not only lodged in my body as a pilot in a vessel but that I am besides so intimately conjoined, and as it were intermixed with it, that my mind and body compose a certain unity”. Even if the deafferented limbs are integrated in the body schema, it might seem that at the phenomenological level, the unity that Descartes describes is broken and that the deafferented patients experience their body as an external object that they pilot from the outside because

they no longer feel it moving from the inside (Brewer, 1995; Wong, 2015).³ Somatosensory feedback may thus be important for strong embodiment. However, it is time to determine whether strong embodiment should be an objective for human augmentation **because if augmentation technologies aim to truly expand the body, why should they try to merely replicate the way the body works?**

3. Beyond what the body can afford

The type of plasticity that is required in human augmentation differs from what has been commonly described in the literature on restorative technology. At the neural level, the amputation leaves space in the primary somatosensory and motor cortex that can be co-opted by the new artificial limb. At the phenomenological level, amputees often feel the presence of the amputated limb, which can help the integration of the prosthesis, as if it were the material incarnation of their phantom (Murray, 2010). By contrast, in the augmentation case, there is no body part missing, no phantom to materialize, no neural resources unused. Processing the artificial device as a body part will thus come at a price (Makin et al., 2020). In the domestic economy of the brain, developing one's abilities further can be associated with a decrease of other abilities. This is what has been called the 'neural resource allocation problem' (Dominijanni et al., 2021): how to channel motor commands and sensory information to and from the augmentative device without hindering the sensorimotor control of biological limbs. We may possibly gain a new body part, but we do not want to lose our own in the process.

One may then propose to apply a principle of time sharing. In this scenario, one would use one biological hand and one extra hand or the two biological hands together depending on the

³ One may still question whether the other sensations that they experience may not preserve this experiential unity (Vignemont, forthcoming). What is clear, however, is that artificial limbs feel no pain, heat, or cold, and that it is not even part of the research program to make these sensations possible.

task. This solution is relatively parsimonious: it takes advantage of what already exists without requiring much adaptation. However, it closes the door to the possibility of simultaneously using all the biological and extra limbs together. Furthermore, it is not clear that it would work for artificial systems whose designs and functions can have little in common with the human body. Arguably, there are biological factors - and possibly also social ones - that shape the template of what counts as a body. We have priors, according to which the body has two arms, two legs, and five fingers for each hand, for instance. Given these priors, it should be more difficult, if not impossible, to experience devices that do not follow a standard body template as proper parts of one's body. Hence, only augmentation technologies sufficiently consistent with body priors could be strongly embodied. Seeking strong embodiment thus reduces the scope of human augmentation. It almost seems paradoxical to expect new devices to be processed as proper parts of the body when their objective is to afford for more than what the body affords.⁴ On the other hand, if the goal is not to fit with a prior body template, one is not restricted to take the human body as a model.

Human augmentation should not be reduced to the mere reproduction of artificial counterparts of body segments. It precisely aims to go beyond the standard body, to supplement it with abilities that it was not hard-wired for, and this cannot be achieved solely on the basis of an artificial ersatz of the body. For instance, a plausible example of human augmentation is the ability to fly. One must then look beyond human anatomy and enlarge the study to other animals' bodies and their abilities. Even then, one should not necessarily stick too closely to what biology teaches us. Consider Leonardo da Vinci's attempts to design a flying machine. He first analyzed birds and tried to reproduce their wings but adhering too

⁴ One may reply that one can experience supernumerary limbs, as shown by some neurological syndromes and by versions of the RHI with two rubber hands simultaneously stroked (e.g. Ehrsson, 2009; Folegatti et al., 2009). However, one may question whether all the hands, biological and artificial, are simultaneously embodied (Vignemont and Farnè, 2010). Furthermore, these extra limbs still look and function like biological limbs, whereas augmentation devices may work on completely different principles.

closely to the original model led to failure. Later more successful attempts still involve wings but no longer directly in contact with the body. Now, if one considers SpaceX, the wings are reduced to their minima. At the individual level, jetpacks seem the most optimal solution. We are far from biological templates.

4. Just a new tool?

I have just argued that if human augmentation really aims at adding new abilities, and not only expanding those we already have, it should not stick to the model of the body and it should give up on the ideal of strong embodiment. One may then reply that if the artificial device is not processed as a proper body part, then it is nothing more than a tool. For instance, Andy Clark (2007) imagines a critic challenging him to show that human augmentation does extend the agent:

“You are making quite a song and a dance out of this, what with talk of brand new systemic wholes and so on. But we all know we can use tools, and that we can sometimes learn to use them fluently and transparently. Why talk of new systemic wholes, of extended bodies and reconfigured users, rather than just the same old user in command of a new tool?” (Clark, 2007, p. 271)

Augmented devices and tools have many features in common. First, they enhance one’s motor capabilities. Secondly, they do not need to bear any bodily resemblance. Thirdly, they involve sensorimotor integration that allows for fluid interactions with the world. Could it be that an extra artificial arm is no different from a basic rake?

Clark replies that one should be careful not to confuse mere use with what he calls ‘true incorporation’. Only true incorporation, on his view, extends the agent into a new systemic whole. Surprisingly maybe, his notion of true incorporation is relatively modest. It

corresponds only to what I call weak embodiment. It involves the integration of the external device into the body schema. **By contrast, Clark claims that mere use would involve some kind of inferences based on propositional knowledge about the physical and functional properties of the tool. One might say, for instance, that one merely uses an ATM, whereas one truly incorporates an exoskeleton.** Though I agree with Clark's distinction, I fail to see how it shows that an extra artificial arm makes more difference to the agent than a rake. Indeed, there are numerous findings that show that tools can be integrated into the body schema. In one study by Cardinali and coll. (2009), for instance, participants used a long mechanical grabber to grasp various objects. After their training session, they were subsequently re-tested with their hand alone without the grabber. The kinematics of their movements were then significantly modified, not only when performing movements that they trained with (reaching to grasp), but also when performing other movements that they had never done before with the grabber (pointing on top of objects). In brief, they planned their movements as if their arm were longer than before using the grabber. Hence, tools can be truly incorporated in Clark's words, or weakly embodied in mine.

The question now is whether it would be problematic if artificial devices were processed in the same manner as tools. It is true that **the tool model keeps** the body and the external object as distinct, instead of fusing the two into a new systemic whole agent, but there are advantages to the preserved boundary between the biological and the artificial. Indeed, we do not have the same kind of use for the two. Across the day, we keep switching from one tool to another. Unlike body parts, the dynamics are flexible, involving discontinuous use. The same could be true of human augmentation. It can involve many devices that we take and remove depending on the circumstances. To adjust to augmentations as we doff and don them, it is better to keep a representation of the body independently of them, a default body to come back to when we remove the device. This allows for increased malleability. Furthermore, as I

defended elsewhere (Vignemont, 2018), the body that one experiences as one's own is the body that has a unique affective significance, which grounds the primitive urge to protect it. If external devices were experienced as proper parts of one's own body, then one would tend to protect them in the same way as one protects one's body. However, part of the interest of human augmentation is to be able to do things in dangerous contexts in which one would not directly use one's body. In the same way one uses a spoon to stir one's burning coffee, one can wear one's exoskeleton to walk in an acid lake. In brief, human augmentation is more optimal if the biological and the artificial are not functionally identical. This proposal is in stark contrast to the standard conception of the extended mind. According Clark and Chalmers (1998), for instance, Otto uses in the same way his memory and his notebook. Here I propose that the notebook can afford more to Otto if it is *not used* in the same way as his own memory.

At this stage, one may worry about the subjective experience that one might have if human augmentation involves only new tools. The phenomenology associated with smooth control over tools is mainly of transparency and agency. We can almost forget the rake or the fork that we are holding in our hand, our attention being mainly focused on the leaves that we are picking or on the green peas that we are trying to skewer. We are only aware that the tool is under our control, but it remains at the background of consciousness. The same can actually be said with our biological limbs. When walking, we are barely aware of our legs, unless we are tired and it requires an effort. One can wish for a similar sense of agency associated with phenomenal transparency in successful human augmentation. The difference between legs and tools, however, is that there is normally a sense of bodily ownership associated with the former, but not with the latter. We are aware of our legs as being our own. By contrast, we typically do not experience ownership for the rake or the fork, even after spending hours using them. Is this absence of ownership feeling problematic for human augmentation?

One of the reasons that has been put forward to explain the amputees' limited use of their prostheses is that they often do not experience ownership towards them. One might then generalize and argue that without ownership, one is less likely to use the augmented system. This conclusion, however, relies on the assumption that the same principles apply for restorative and augmentative technologies. The amputees have phenomenological expectations about the prosthesis. To successfully replace their missing limb, it should feel the same. Therefore, it should feel like a part of their body. They should feel sensations in it. They should also feel ownership towards it. By contrast, there are no such expectations for human augmentation. Since it is completely new, one has no anticipation on how it should feel, and thus, one does not reject it when it does not feel like a proper part of the body. The absence of ownership is then no more of a problem than for tools. Roughly speaking, we do not eat with our fingers just because we do not feel ownership for the fork. Hence, the fact that we experience no ownership for the augmented system does not entail that we shall use it less. Ownership is not compulsory for active use.⁵

5. The multiplicity of body schemata

Though human augmentation shares many common features with tool use, one might note that some of the augmentation technologies have an interesting specificity. Most tools involve a body part, generally the hand, to hold them and manipulate them. You cannot simultaneously use a rake and prune the trees, for instance. You need to drop one tool to be able to take the other. By contrast, wearing an exoskeleton does not impinge your ability to do many other things. We saw earlier that one of the challenges for augmentation technologies is

⁵ This is not to say that one can never experience ownership in human augmentation or in tools. One can induce what is known as the Toolish illusion, an equivalent of the RHI but for tools (Cardinali et al., 2021). It has also been shown that participants rated their sense of ownership significantly higher over the third thumb after using it for five days (Kieliba et al., 2021).

precisely to develop new systems to control the devices without interfering with normal bodily functioning. We might not have reached this stage but hopefully multitasking will be achievable in the close future. We may then summarize the difference with tools as follows: one does not ‘use’ a sixth finger or an exoskeleton; one ‘wears’ them. One then talks of *wearable robotics*. We wear our clothes, our watch, our ring, our glasses, and they are not strictly speaking tools. Still, we entertain a special relationship with them. Sometimes it is because they have a personal value and we never take them off, but even for clothes that we keep changing, they must somehow be processed in their continuity with the body so that we adjust our bodily movements. In Clark’s terms, one might even say that they must be truly incorporated. Indeed, as Head and Holmes (1911, p. 188) famously noted when they first introduced the notion ‘body schema’:

Anything which participates in the conscious movement of our bodies is added to the model of ourselves and becomes part of these schemata [body schemata]: a woman's power of localization may extend to the feather in her hat.

On this definition, many things can be integrated into the body schema, including many objects that do not look like a body part and that are not conceived as proper parts of the body: the feather at the top of the hat, a rake, a third thumb, and so forth.⁶ Hence, though it is called *body* schema, it does not entail that this type of internal sensorimotor model represents only *bodily* effectors. Is this definition too liberal? Since it is not constrained by bodily resemblance, does that mean that it can represent any objects under our control, how remote they are? This does not seem likely. One may propose that the body schema only encodes what is *in contiguity with the body*. Contiguity does not need to be direct because it can be conceived as a transitive relation. For instance, holding a rake with one’s gardening gloves

⁶ Though we do not act with the feather, we need to take it into account when moving, to avoid damaging it when getting into a car, for instance. In one sense, it is part of the head effector.

does not prevent incorporating the tool: the rake is in contact with the gloves, which are in contact with the hands. The notion of *wearable* robotics well captures the spatial feature of contiguity. By contrast, the cursor on the screen is not represented in the body schema. Though we plan and control our movements on the trackpad on the basis of the cursor location and we are aware that its motion is under our control, there is no contiguity with our body, not even indirect.

We can now refine our definition of the body schema. Its function is to carry information about effector(s) in bodily contiguity in a sensorimotor format to guide action planning and control. The schema qualifies as bodily, not because of bodily resemblance but only because of bodily contiguity. However, something still seems to be missing. It is too often assumed that all the effectors are represented within a unique bodily representation but, as noted by the neurologist Jacques Paillard, who reintroduced the term of body schema in the eighties after Head and Holmes, there is more than one sensorimotor representation:

It would thus seem that the ‘body schema’ could be fragmented into action subsystems corresponding to the motor instruments involved in the specification of the structure of the paths of considered visuomotor sub-spaces. (Paillard 1982, p. 66, my translation).

To claim that a tool or an augmentation technology is represented in the body schema thus does not entail that it is represented in the same inner model as the biological limbs. It only means that there is a specific representation whose function is to carry information about the artificial system in relation to the specific actions it can perform. One may further propose that this augmentation-specific body schema recycles the sensorimotor loops normally dedicated to the control of biological body parts (Makin et al., 2020). But at no point does it

require that the biological and the artificial are fused together within the same internal model and that the boundaries between the two are erased.

In addition to these local body schemata that are effector-specific, Paillard (1982, p. 67) further proposes that we have a higher-order representation (a “super-space”) that serves to coordinate the subordinate effector-specific elements.⁷ This super-space needs not be conceived as a holistic body schema that depicts the whole body with all its extensions. It can simply index the various sub-spaces and encode their spatial and functional relationships. New skills enabled by augmentation devices thus require adding new local body schemata that specifically encode the artificial systems. They also require updating the higher-level representation that coordinates the various body schemata when the augmentation devices cooperate with the biological limbs (e.g. the third thumb with the other fingers).

6. Conclusion

The notion of embodiment is no more than an umbrella term that covers many different relations to the body. Here I distinguished between strong and weak embodiment, arguing that augmentation technologies should only claim for the weak version. Their successful use does not require that we represent them as proper parts of the body. On the contrary, strong embodiment can be detrimental. However, even within weak embodiment, we need to be able to account for differences among all the things that can be integrated into the body schema, including biological limbs, rubber hands, tools, hat feathers, restorative prostheses, and augmentation technologies. Should we say that in every single case the agent is extended, as suggested by Clark? This would rely on an extremely weak notion of extension, which would be neither threatening nor exhilarating. The interest of human augmentation is not that it may

⁷ See Alsmith (2021) for a discussion of local and global body schema.

give us a new body. It is that it gives us new skills. We should thus leave aside the notion of embodiment and focus instead on skill acquisition.

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