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The WaveDriving Course

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Abstract

In the last ten years our knowledge about the formation of traffic jams has changed substantially, so that the idea of "phantom traffic jam" could soon seem naive to us. But transforming traffic flows and eliminating traffic jams requires that each individual driver (human or non-human) understands their role in traffic flows, the genesis of traffic jams, and how to behave to avoid them. Based on previous studies we have termed this adaptive, anti-jam behavior Wavedriving. This paper presents the design and structure of an online WaveDriving course (WDC) conceived to teach to avoid traffic jams, as well as its first pilot tests. Although some improvements have been identified after the pilots, the preliminary results confirm that the WDC manages to transform car-following behavior of participants, from ordinary drivers to WaveDrivers.

Keywords: driving simulators; information and communication technologies; learning; traffic jams; WaveDriving

1. Background

Early in the 20th Century, massive motorization dramatically changed the road traffic system. Faster cars, in growing numbers, originated problems with vehicular flows never handled before. The way forward in the 1940-60s was managing that issue as a matter of road spacing. If a number of cars go every day from A to B, how many lanes are needed to guarantee free flow? The answer was built up upon the safety distance concept (Weingroff, 1996). If

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more cars aim to go at the same time to the same place, more road spacing is needed. Recent developments, however, have begun to challenge that standard view regarding the safety distance concept. When cars follow each other under the safe distance premise, they also turn into perfect means for wave transmission, eventually causing flow instability and congestion (Sugiyama et al., 2008; Wilson, 2008). Other studies reveal related aspects of driving behavior. Drivers move forward amidst a continuous oscillation of speed, and not only in dense traffic, but also when driving alone, or when following a car at a uniform speed (Wille and Debus, 2005; Wille, 2011). Drivers form interconnected strings when following each other: a driver taking some more time (than expected by followers) to slow down, even mild decelerations, can cause collisions between drivers following six or seven cars behind (Davis and Swenson, 2006; Brill, 1972).

2. WaveDriving

The alternative to traditional car-following schemes is *ordering vehicular flows*. The Wavedriving (WD) concept stresses the fact that congestions are the natural consequence of the way drivers are instructed to follow other drivers, particularly in dense traffic (Melchor and Sánchez, 2014). Drivers are commonly instructed to Drive to keep Distance (DD), summing up waves that eventually bring on congestions. If drivers could only Drive to keep Inertia (DI), offsetting waves, congestions would not emerge so easily (Blanch et al., 2018). However, to begin with, is that the type of driving behavior most drivers show? The answer to such question has been furnished by a number of studies in the last years aiming to create congestions artificially (Sugiyama et al., 2008; Tadaki et al., 2013). Such experimental work shows that most drivers default option is DD. However, additional work was required to check if the current car-following behavior adopted by most drivers was their “natural” Normative Driving Behavior or, on the contrary, was just the way drivers learned to car-follow. The empirical studies carried on by Blanch et al. (2018) and Carrasco (2017) have repeatedly shown that drivers can Drive DD or DI as required.

3. Teaching WaveDriving

This evidence is now being brought to a third stage. Drivers can be requested to behave in DI terms with a short verbal sentence, and they do, but they do it “blindly”, i.e., they don´t really understand the larger consequences of their actions (see Davis and Swenson, 2006) for the following platoon, including the emergence of congestions. For drivers to understand the broader traffic situation and the proper way to act, some new efforts were needed. Hundreds of thousands, perhaps millions, of drivers should be able to adopt a DI strategy particularly when encountering dense flows. However, how could so many drivers learn the concept and identify the way forward themselves? This is why the WaveDriving Course (WDC) has been designed (WDC, 2018). The present study aims to explore empirically the results of an online WDC based on graphical simulation.

3.1. Bringing on new car-following driving schemes

The main goal of WDC is enriching the car-following schemes that drivers learned through formal education in the driving schools and apply every day, particularly in dense traffic. After learning the DD scheme, drivers assimilate any coming car-following situation to it, i.e., drivers interpret that following any car ahead means driving to keep safety distance. However, the physic and mathematical analysis of car-following has shown that when the DD scheme is applied, particularly in dense traffic, congestions finally emerge (Sugiyama et al., 2008; Tadaki et al., 2013). The WDC course is intended for drivers to learn that the DD scheme is not the only one, nor the most appropriate car-following scheme to follow. However, if f we are to change current drivers’ DD schemes, we need them to understand that the car-following situation is not as they have assumed to be (in short, “as they see it”), but that the traffic flow is a more complex, dynamic collective situation. Facing these new facets of reality, drivers will have the opportunity of *accommodating* their current DD car-following scheme to the new experienced reality. This is why the WDC focuses on car-following experiences that can make drivers think differently, for example:

a) The driver learning WD never drives alone while following a leading car ahead (he/she always becomes aware of forming part of a flowing platoon of many cars).

b) The driver drives in different positions amidst other cars (the first, the fourth, the 22nd, and the like)

c) The driver can simultaneously compare the result of the driving strategies proposed (DI) with an adjacent row of cars driving differently (actually, following DD strategies).

d) The driver can see things happening to the flow he/she would rarely have access to under real circumstances. In addition to the standard rear-view mirror, the simulator incorporates screen buttons allowing for different types of bird view, drone view, viewing the end of their platoon, etc., using computer resources named as "car-following toolbox". Drivers can experience that what one car does at some point may have an influence upon cars far away behind (Fig. 1).

e) The driver is furnished with conceptual tools based on analogies (Holyoak, 2005). Drivers are helped to understand WD by making the most of experiences they likely had before: i.e., the traffic lights and spring analogies. Complex reasoning based on similarity is a key mechanism for understanding and adopting novel ideas, here the WD concept:

a. *The traffic light analogy*. Most of us have experienced how useless is accelerating only to slow down and stop in the next red traffic light. Instead, we prefer to trip connecting traffic lights in green. This is possible if we adopt the adequate average speed. Cars in front of us operate similarly: they go red (stop), go yellow (braking lights) or go green (running freely). This is the cars-behave-as-traffic-lights analogy.

b. *The spring analogy*. Cars platoon as if connected by springs. When the car ahead decelerates, drivers need to slow down: connecting springs contract and are tense and ready to spread back. The follower gains distance and feels safe. When the car ahead goes away, drivers accelerate: springs extend and need to contract again, so the follower normally accelerates to keep certain following "safe" distance and not yielding too much road space in front (Furutani, 1976). The relative violence of such extensions and contractions along the platoon, create dynamics that may favor or alleviate congestions. Driving to keep Inertia is only possible if we manage the distance with the oscillating car ahead properly.

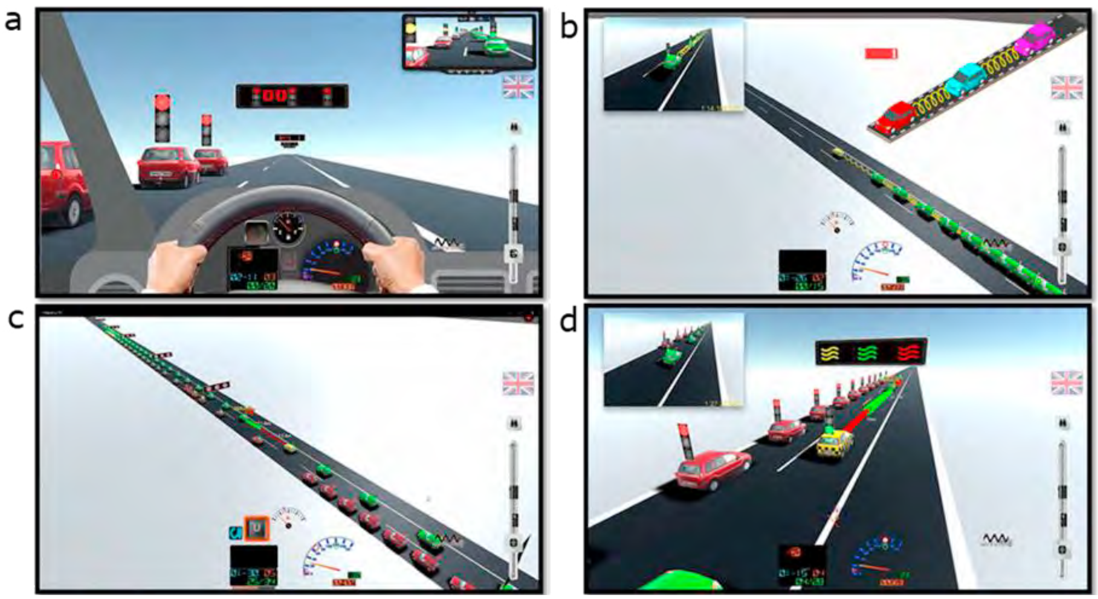

Fig. 1. Some snapshots of the WDC course: (a) the traffic light analogy; (b) the spring analogy; (c) teaching about safety vs comfort distances; (d) showing both analogies simultaneously.

The general aim of the WDC is giving drivers a wider set of experiences under different car-following situations. Having learned a new car-following scheme, drivers will be able to adapt to the new representation of the traffic flow envisioned along the WDC. So, the main purpose is that drivers enrich their DD car-following schemes, learning the possibility of adopting Driving to keep Inertia (DI) schemes too, which are better suited to the WD principles.

3.2. WDC: the virtual driving school

The WDC is based on a combination of instructional and cognitive techniques and processes. The basic structure of WDC is based on a simple instructional technique: modelling (Bandura, 1971; Dweck, 1986). Research has shown that modelling is an effective instructional strategy in that it allows students to observe the teacher's thought and behavioural processes. Using this type of instruction, teachers engage students in imitation of particular behaviours that encourage learning. Simply said, as a student I first see what some expert teacher does, and then I try myself. In the present version of the WDC the teacher role is adopted by a video session that the student must follow before freely practicing with the simulator (Fig. 2). So, as in standard driving schools, in the WDC the student assumes two roles: the passive role is assumed first when the teacher (voiced video) explains and shows performance and car-following concepts and situations to be practiced in the simulator. Then the student role changes into active, entering the WD simulator and practicing in the different driving situations. Fig. 2 presents a summary of the WDC structure, divided in three main blocks:

1. Landing (session 0): learning about the simulator controls (how to accelerate, decelerate, and the like). This is very simple and done by means of the computer mouse.
2. The driver-Car-diagram (dCd, sessions 1 and 6): the dCd also works as an analogy, with main indicators of heart / car-following-use "health" (Fig. 3). These two evaluation sessions register a number of parameters concerning the way you follow another car (average speed, average distance to leader, number of violations of safety distance criteria, spacing needed by the following platoon, and fuel consumption).
3. Teaching sessions (2-5): these are the actual contents illustrated and practiced in the simulator.

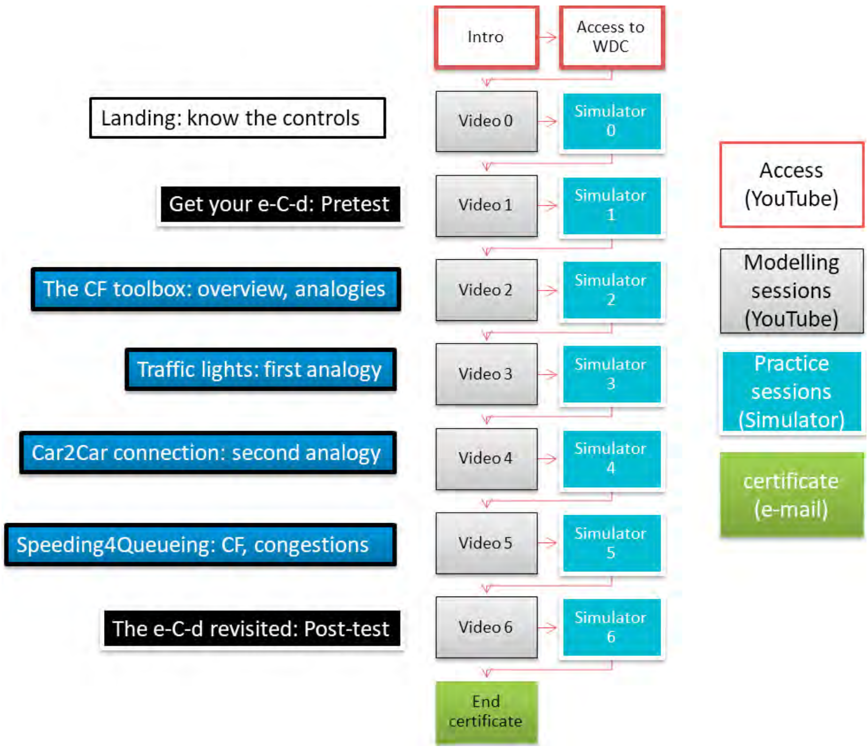

Fig. 2. The WDC structure.

As Fig. 2 shows, the whole process is interconnected. Participants begin by opening a navigator, enter a YouTube link, and watch the first explanatory video (Intro) and the first session explaining the controls (Video 0). Then they are invited to pause the video, and click the available hyperlink that addresses them to the simulator. Then they practice the knowledge and indications that were taught to them (Simulator 0). Once this first practice is finished, the return to the Youtube browser tab, and look at the next lesson (Video 1) and then return to the simulator (Simulator 1), and so on. The teaching-video sessions take about 120-180 seconds each. Practicing each session in the simulator takes 150 seconds each, so the whole WDC takes about 35-40 minutes. Crashing with the car ahead is possible, but then the specific practice session when the crashing happened needs to begin again (on that particular level). Once participants have finished the WDC some demographics and information concerning their driving experience is required to them. Last but not least, and provided that certain degree of car-following proficiency was reached, some participants could get a WD Certificate and their final driver-CAR-diagram via electronic mail.

4. Pilot testing

The WDC has been conceived and designed as a learning tool available via Internet (see WDC, 2018) by means of computers, tablets or smartphones. The first version of the WDC has been checked with two pilot samples, in order to obtain information ranging from user-friendly interfaces, scheduling and timing of the sessions. But first and foremost, we need to check if the tools and instruments devised as well as the concepts and analogies applied help to learn WD unambiguously. The previous section explained the procedure followed, we will now focus on first empirical results.

4.1. Pilot 1

4.1.1. Procedure and participants

The study was carried on in a computer classroom with capacity for 45 students. All computers were standard PC type with wired network connection and each student worked independently on a computer. The experimenter displayed the videos in a projector and then gave way to practice in the simulator, following the cycle in Figure 2.

Forty-four participants were invited to perform the driving course. Most were Civil Engineering students participating in exchange of a 30 minute bonus for using an electric car. Their average age was 24.05 years, and 79.5% were men; 88.6% were university students. Participants held a driving license for about 4.9 years; 81.1% of them drove in cities, 15.9% were interurban drivers and 2.3% drove in rural roads. A 50% of them drive less than 10000 km per year, 25% drive between 10000 and 20000 km per year, and 4.5% drive more than 20000 km per year (20.5% do not drive much). Considering their driving habits along the week, 45.5% drive only a couple of days per week, 15.9% drive on the week-end, 11.4% drive five days a week, and 27.3% drive every single day.

Table 1. Pilot 1: main descriptive and results after inferential analysis.

		Level 1 (n=13)	Level 6 (n=31)	Student *t*	*p*
Speed	*Mean (m/s)*	6.98	6.64	2.26	.05
	Standard dev. (m/s)	4.17	1.88	4.06	.001
Space	*Mean (m)*	44.47	63.52	-1.86	.07
	Standard dev. (m)	18.74	28.31	-2.95	.001
Platoon elongation	*Difference max-min*	103.77	57.56	3.19	.003
	Mean (m)	118.44	116.91	1.21	.23
	Standard dev. (m)	30.64	13.60	4.07	.001
Fuel	*Mean (liters/100 km)*	19.60	11.00	4.14	.001

Only 31 participants finished the course (Level 6, post-test, after following the course). However, not every participant completed Level 1 (pre-test), due to different reasons (but basically, crashing with the leading car before finishing, then passing to the next level). The following data compare both groups of drivers: those having performed Level 1 (control group) vs those having performed Level 6 (experimental group). The main factors analyzed were speed and distance while following the leader, platoon elongation and fuel consumption. Table 1 presents the main descriptive for both groups, and also the Student *t* coefficient and the corresponding *p* value.

4.1.2. Main results after Pilot 1

Before receiving the WDC, drivers behaved as expected, i.e., driving to keep distance, mimicking the leader behavior (Sugiyama et al., 2008; Blanch et al., 2018). When driving to keep distance with regards to a swinging leader, the followers speed oscillates significantly more and spacing oscillates significantly less. After the WDC, drivers confronted the very same situation, but they now understood themselves to drive to keep inertia. As a result, they drive with less speed oscillation, and distance oscillation grows in order to adapt to the leader's average speed without coming to a halt (Table 1). The platoon elongation mirrors either state of affairs. Platooning behind a Level-1 ordinary driver that focuses on keeping distance (i.e., summing waves) is more unstable (distance between the first and the last car; standard deviation) that platooning after a Level-6 WaveDriver (i.e., offsetting waves). As a result, fuel consumption is also significantly higher before than after following the WDC (Table 1).

4.2. Pilot 2

4.2.1. Procedure and participants

The study was done in a computer classroom with capacity for 25 students. All other conditions were similar to the ones described in section 4.1.1.

Fifteen participants were invited to perform the driving course. Their average age was 21.64 years, and 71.4% were women; 93.3% were university students (belonging to the first year, Degree on Psychology) participating in exchange of a course credit. Participants held a driving license for about 1.86 years; 7.1% of them drove in cities, 64.3% were interurban drivers and 28.6% drove in rural roads. A 71.4% of them drove less than 10000 km per year, and 28.6% did not drive much. Considering their driving habits along the week, 64.3% drove only a couple of days per week, 7.1% drove on the week-end, and 28.6% drove five days a week. None of them drove every single day.

All fifteen participants finished the course. The following data compare performance on level 1 (pre-test) and level 6 (post-test), according to a within-subject design. The main factors analysed were speed and distance while following the leader, platoon elongation and fuel consumption. Table 2 presents the main descriptive for both groups, and also the Student *t* coefficient (related samples) and the corresponding *p* value.

Table 2. Pilot 2: main descriptive and results after inferential analysis (asterisks mark similarities to Pilot 1).

		Level 1 (n=15)	Level 6 (n=15)	Student *t*	*p*
Speed	*Mean (m/s)*	6.84	6.83	.03	.98
	Standard dev. (m/s)	4.72	3.01	2.93	.01*
Space	*Mean (m)*	42.07	49.68	-1.12	.28
	Standard dev. (m)	16.86	22.48	-2.54	.02*
Platoon elongation	*Difference max-min*	116.73	81.80	2.73	.02*
	Mean (m)	117.57	118.16	-.53	.58*
	Standard dev. (m)	34.39	21.81	2.90	.01*
Fuel	*Mean (liters /100 km)*	19.03	14.67	1.90	.08*

4.2.2. Main results after Pilot 2

Overall, results are very similar to the ones obtained with the first pilot. The average standard deviation on speed differed significantly, showing that drivers have learned to car-follow adopting a different DI strategy after following the WDC. Distance to leader shows the reverse face: before following the WDC, the average standard deviation in particular, was significantly smaller. Drivers begin by following the DD rule. Once the WDC was passed, drivers increased distance to leader and played with it in order to avoid swinging behavior. Platoon elongation follows the same pattern. Cars that slowed down and then accelerated generated a more violent pattern of extensions and retractions behind. This pattern favors crashes because following distance descends abruptly, in little time (Davis and Swenson, 2006). Fuel consumption was lower after following the WDC course, although the difference was only marginally significant (Table 2). All in all, results concerning the second pilot follow the same pattern observed in the first one. The effects were not as strong though, probably due to participants' having less driving experience. Interestingly, the same result (following a leader) brings on very different consequences and implications for mobility, safety and health (Caiazzo et al., 2013).

5. Discussion

All in all, we can affirm that the WDC course has been successful with the two pilot samples tested. Our data indicate that participants' default car-following strategy (pre-test) was DD, but that many participants changed to a DI strategy at the end of the WDC course (post-test), hence becoming true WaveDrivers. This is particularly evident after inspection of results concerning the first and the second dCd, obtained in the first and sixth sessions respectively (Figure 3). The dCd test consisted on a car-following situation where participants were invited to follow a swinging (stop-and-go) leader, and 10 other cars followed behind him/her. The first dCd (left) shows the evolution of an individual participant along the five main driving parameters registered during 150 s in the pre-test (from top to bottom: speed variations, distance variations with regards to the leader, variations concerning the safety distance limit, spacing occupied by the 10 following cars behind, and fuel consumption). We can see that the first trial was actually not completed (this participant crashed with the lead car –and so the lines cut). The second dCd shows the evolution of the same participant along the same five parameters during the post-test. Note the marked differences in speed and distance to leader: if our decision is to keep distance (DD), speed needs being changed (following the leader) and fuel consumption mirrors the ups and downs too. Conversely, DI sets up uniform speeds and fuel use, while distance to leader varies harmonically, in line with our previous findings (Blanch et al., 2018). The fourth line (top to bottom) reflects the changes of the road spacing occupied by the 10-car following platoon. Interestingly the average spacing occupied by the platoon is similar in both dCd (as seen in table 1 and 2), but dispersion is significantly higher on the first dCd. The distance occupied by the 10-car platoon following the participant shrinks and extends cyclically (as springs do). Importantly, the first session graph (left) shows that sharper changes in platoon spacing require abrupt changes on speed too (accelerations, decelerations). Compared to the smooth line of the sixth session graph (right), this platoon is a less safe place to be (Davis and Swenson, 2006).

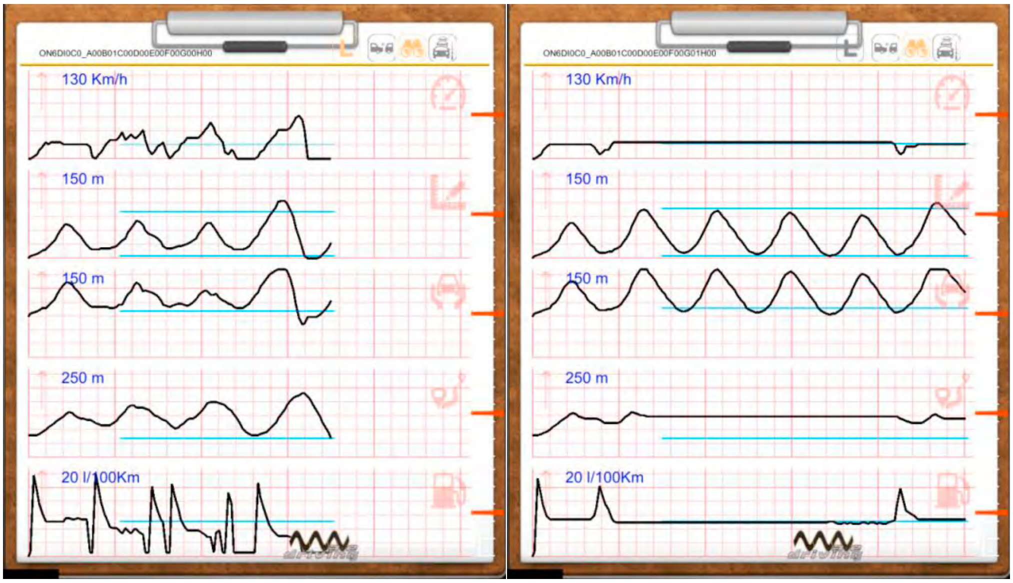

Fig. 3. Driver-Car-Diagrams during the first (left) and sixth (right) sessions (both belong to the same participant).

A number of drawbacks have been identified in these pilot studies. The samples are relatively small, and participants' driving experience (particularly in the second pilot) is not great. A number of improvements concerning the simulator interface have been identified too. The explanatory videos (prior to each session) should be shorter, and the simulator tools (i.e., the possibilities of switching and visualizing traffic lights, springs, and cameras on and off) should be made available on screen (instead of placing them only in the keyboard keys), avoiding a negative impact on working memory (Baddeley, 2007). An improved version of the WDC is now being developed, and more empirical studies will follow to replicate and consolidate the present results.

Millions of drivers in the world suffer traffic jams on a daily basis, putting their safety and health at risk, wasting their time and money, feeling anxious and aggressive, not reaching their travel goals and polluting the air (Caiazzo et al., 2013). However, the coming theoretical developments on the formation of traffic jams combined with a number of innovative and widespread learning, information and communication technologies may help us stop from being impotent in the face of traffic jams. Our preliminary data suggest that developments such as the WaveDriving Course (WDC) will be among the decisive steps to make traffic jams soon part of the past.

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