Video Measurements: Quantity or Quality

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Abstract

Students have problems with understanding, using and interpreting graphs. In order to improve the students' skills for working with graphs, we propose Manual Video Measurement (MVM). In this paper, the MVM method is explained and its accuracy is tested. The comparison with the standardized video data software shows that its accuracy is comparable with the one of the standardized video data software, which enables it for use in physics education. Posttest conducted after the lecture with software for video measurement shows slight improvement in understanding graphs. The students were asked at the interviews to explain the answers they have given at the test. The performance was poor. The interviews conducted one month after the lecture with MVM show big improvement in students' understanding position-time graphs, higher skills for collecting data and their interpreting. In addition, the vocabulary used to explain the answers was more precise and the use of physical quantities is more correct. Despite this fact, the students still do not understand velocity-time graphs still.

Keywords: video measurement, video data analysis, understanding graphs, GAP, conservation law

Introduction: How much students understand graphs?

Many researchers report that students do not understand the graphs. They do not see the graph as something that shows relation between two or more quantities. They consider it more as a picture. This phenomenon is known as GAP phenomenon (Graph As a Picture) (McDermott, 1987). Some researchers find the GAP errors as the most critical ones (Delialioğlu, 2003).

Even when they try to look at it as a relation between two quantities, students often do not pay attention to the variables presented on the axes and they switch the variables from one to another, depending on their needs (Zajkov, 2003; Delialioğlu, 2003). They believe that graphs of these variables should be identical and appear ready to switch axis labels from one variable to another without recognizing that the graphed line should also change (Delialioğlu, 2003; Beichner, 1994). Students also do not understand the meaning of the curve slope and area under the curve (Beichner, 1994).

For example, the following question, which is part of one big research (Zajkov, 2004) requires from the students to analyze the graph, which shows the relation between the speed of a train coming into a station and the time (Figure 1). The question is what will happen with the train?

a) It will slow down and continue through the station with lower speed.
b) It will speed up and continue through the station with higher speed.
c) It will pass through the station without any change.
d) It will stop in the station.
e) ____________________.

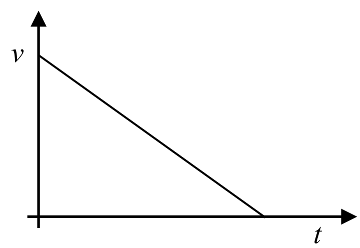

***Figure 1**. Velocity of a train versus time*

All four choices are equally selected by the students and even more, there are many other explanations given in e). Moreover, the students have "very logical" explanations. For example, some of the say that "going down the slope, the speed of the train decreases, because the slope is not big enough to increase the speed and when it comes to the flat area, the train continues with lower speed". Other says, "the train will speed up going down the slope and when it comes to the flat area, the train continues with bigger speed". Some say, "the train speeds up down the slope and slows down going through the flat area".

In some textbooks, students can see figures where the trajectory of a moving object is presented and the position of an object is determined with a position vector (Figure 2). This figure is accompanied with an explanation that the velocity is a vector that is always tangential to the path. Since the students memorize pictures, very often they do not consider what is presented on the axes. No matter what is on the axes, you can hear them saying "…if we assume that this axis is position/velocity…". This is one of the reasons, why the students see the curve in the graph as a trajectory. The vector that represents the velocity is also a reason why many of the students say that the curve represent velocity. In this way, students make big chaos of mixed concepts.

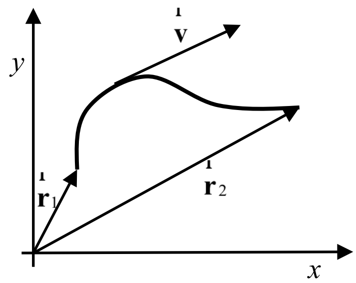

***Figure 2**. Trajectory of an object in motion*

What is Manual Video Measurement?

Video measurements or video data analysis is method, which becomes more and more popular in science and technology research. Sports, transportation safety, artificial legs and arms and humanoid robots are only part of the areas which have developed partially because of features of the video measurements (Quinn, 2001; Heck, 2010b). For its simplicity and efficiency, it becomes popular in the school as one of the tools for research based learning. Lately, even the high-speed cameras enter the schools (Heck, 2010a).

There are varieties of software packages for Software Supported Video Measurement (SSVM), which are very handy and easy to use: Video Analyzer and Visual Space-Time (Ecalada, 1997), VideoPoint, Physics ToolKit and Measurement-In-Motion (Bryan, 2004) and Coach (Heck, 2009). These packages enable performing video measurement with just clicking on the video clip. The software automatically draws the graphs of distance versus time, velocity versus time and eventually acceleration versus time without any intervention by the student. In this way, students can spend time analyzing the results, searching for the solution, thinking about the model etc. However, is it good enough? Do students understand the graphs? Do they know what they read from the graphs?

Many researches show that there is not any or significant development in understanding graphs and skills for processing and operating them when using special software for video data analysis (Ecalada, 1997; Hein, 2000). One research reports some development in understanding the role of the frame of reference (Pappas, 2002). But, as the authors say, this observation needs to be further investigated.

In order to solve the problem with understanding graph and to obtain more quality knowledge, we suggest complete Manual Video Measurement (MVM).

This simple method replaces the computer and software with common TV set. Computer can be used only as a video player. The only advantage from the technical point of view is that there is no need for additional software for video measurement. On the other hand, there are many disadvantages:

- Reading data from TV monitor or PC monitor is time consuming.
- Manual collecting data.
- Manual (paper and pencil) or semiautomatic drawing graphs (if used Excel, Calc or similar software).
- Need for additional correction for the fits of the curves obtained during the "manual derivation".

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Although there are so many disadvantages, we propose this method because manual collecting experimental data, manual drawing graphs and manual calculating velocity (manual derivation) help understanding graphs and the concepts of the physical quantities, which describe motion.

In order to measure the distance from the video recording, a meter stick is placed next to the object's path. The time intervals can be measured from the recording frequency. The common recording frequency is 25 frames per second or 30 frames per second. It means that the camera takes 25 or 30 pictures in one second. If so, the time interval between two positions taken in two consecutive pictures is $\frac{1}{25}$ seconds or $\frac{1}{30}$ seconds.

Kinematics of free fall and vertical launch

In order to test the accuracy of MVM we made experiment on free fall and on vertical launch. We obtained the position-time law, velocity-time law and we checked the mechanical conservation law. Measurement made with Coach 5 software used as a control one.

Coach is a system of many packages, hardware and software and which has possibility for collecting video data and it's processing. Coach is designed and developed by AMSTEL Institute/CMA, University of Amsterdam, The Netherlands (http://www.cma.science.uva.nl/english).

The video clips were taken with Sony digital handycam, with recording frequency of 25 frames per second and with Sony digital camera, with recoding frequency of 30 frames per second. After the video clips were tested, we continued the experiments with the Sony digital camera for two reasons. First, locating the falling object is more precise with higher recording frequency. The second reason for using Sony digital camera is that it saves the video clips in the form of MPEG files, which enables easier downloading and importing video clip into Coach and video player In order to measure the location of the ball, i.e. the traveled distance, a meter stick is placed next to the trajectory of the ball. In order to measure the time, recording frequency was used.

Following this procedure, set of measurements were performed for free fall and vertical launch, using MVM and SSVM with Coach 5 as a control measurement. The obtained results for gravitational acceleration are shown in Table 1.

Table 1. *Values for gravitational acceleration obtained with the control experiments (Coach) and with SWVM*

SSVM with Coach		MVM	
Vertical Launch	Free fall	Vertical Launch	Free fall
g (m/s^2)	g (m/s^2)	g (m/s^2)	g (m/s^2)
9.95	9.36	9.59	9.66
8.60	9.32	10.72	9.64
10.94	9.38	10.88	9.62
10.04	9.52	9.74	9.84
10.54	9.72	10.06	9.70
10.28		10.14	
Average values			
10.06	9.46	10.19	9.69
9.76		9.94	
		Relative error	
		0,013	0,025

The graphical representations of the experimental data are given in Figure 3a. It is easy to conclude that for gravitational acceleration in our experiment we obtained g=10.06 m/s^2, for initial velocity v_0=0.04 m/s and for initial position x_0=0.0001 m. Since the values for initial velocity and initial position are very small, we can negligt them.

The experimental data for distance versus time were used to calculate the velocity using the definition:

$$v = \frac{\Delta x}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

When setting the graph for velocity versus time correction should be done. Since the time interval $\Delta t = t_2 - t_1$ is not infinitely small, the obtained value for the velocity is average velocity for this time interval. This means that the obtained value corresponds to the time $t_{21} = \frac{(t_2 + t_1)}{2}$. This correction was made for all calculated velocities. Example is given in Figure 3b.

Conservation energy law

Second test for the possibilities and accuracy of MVM was the conservation energy experiment. For this purpose we used the same video clips that were used in the free fall experiment. The only additional data that was added was the mass of the ball.

The mechanical energy of an object is sum of kinetic energy, E_k and potential energy, E_p. If an object is free falling at the position 1 the mechanical energy of the object will be:

$$E_1 = E_{k1} + E_{p1} = \frac{m \cdot v_1^2}{2} + mgh_1$$

In another position 2 the mechanical energy will be:

$$E_2 = E_{k2} + E_{p2} = \frac{m \cdot v_2^2}{2} + mgh_2$$

If the conservation energy law is valid, then:

$$E_1 = E_2 \quad \Rightarrow \quad E_{k1} + E_{p1} = E_{k2} + E_{p2}$$

$$E_{k1} - E_{k2} = E_{p2} - E_{p1} \quad \Rightarrow \Delta E_k = \Delta E_p$$

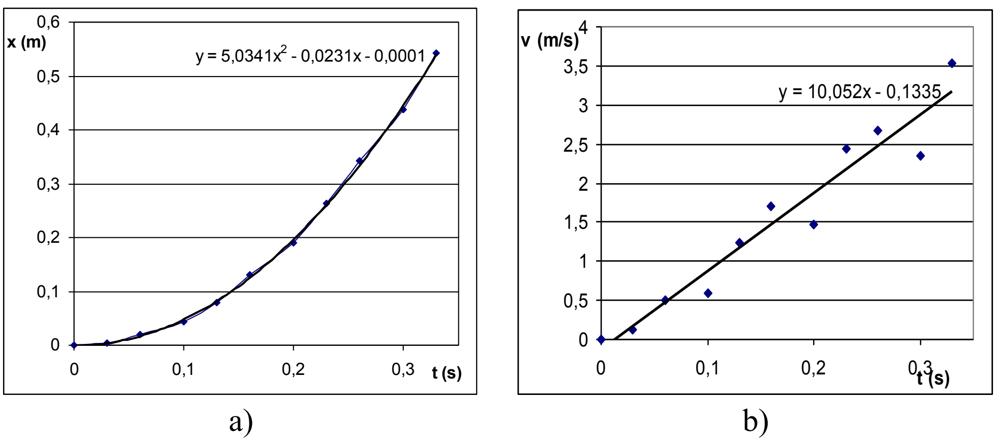


Figure 3. *Distance versus time a), and velocity versus time b), obtained from the free fall experiment*

The last equation was used in free fall and vertical launch experiments to check how much MVM is satisfactory. The experimental results are given in Table 2.

Table 2. *Results for the conservation energy law*

	ΔE_p (J)	ΔE_k (J)	Rel.Error
Free Fall	0,032	0,034	0,014
	0,037	0,039	0,014
	0,024	0,025	0,014
	0,029	0,031	0,014
	0,034	0,036	0,014
	0,040	0,042	0,014
	0,025	0,0267	0,015
	0,028	0,029	0,015
	0,019	0,020	0,013
	0,024	0,025	0,014
Vertical launch	0,025	0,026	0,014
	0,015	0,016	0,011
	0,030	0,032	0,016

How MVM affects the knowledge?

In order to investigate the influence of MVM on understanding graphs, we tested students. The sample consists of 10 students in 4th year of studies, future teacher of mathematics and physics in lower secondary education, from 5th to 9th grade.

In order to obtain the base line for the students' knowledge in mechanics, they were firstly tested with test, which consists of 10 conceptual questions and 7 conventional questions, all multiple-choice questions. All students have passed the exam in Mechanics in their 1st year of studies. The grading system in Macedonian university education system is from five (not sufficient to pass) to 10 (best performance). The results show that there is no correlation between scores on the test and marks (Figure 4). The results from this test were used to create another test, which will serve as a basis for further investigation.

Second test, consisting of nine questions, was used to measure the change in understanding physics and graphs after the video measurement lessons. Here, we will focus on the questions related to graphs, their understanding and interpreting.

After the second test was taken, the students were interviewed and asked to explain their answers: why they chose those answers, how they came to their conclusions, what was the path of thinking etc.

Two weeks later the students were given a task to investigate a kinematics of a free falling object by means of a SSVM. They used Coach 5 to discover the relation position versus time, velocity versus time and acceleration versus time by means of SSVM.

Two weeks after the tasks were fulfilled the students were interviewed. At the interview, they were asked again to explain their answers.

Two weeks later, the students obtained a task to discover again the relation position versus time, velocity versus time and acceleration versus time for the free falling object, but this time by means of MVM.

One month later, the students were interviewed again. At the interviews, they were asked again to explain their answers. All interviews were video recorded and later analyzed.

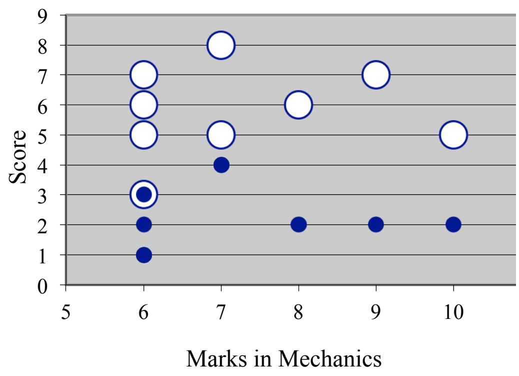
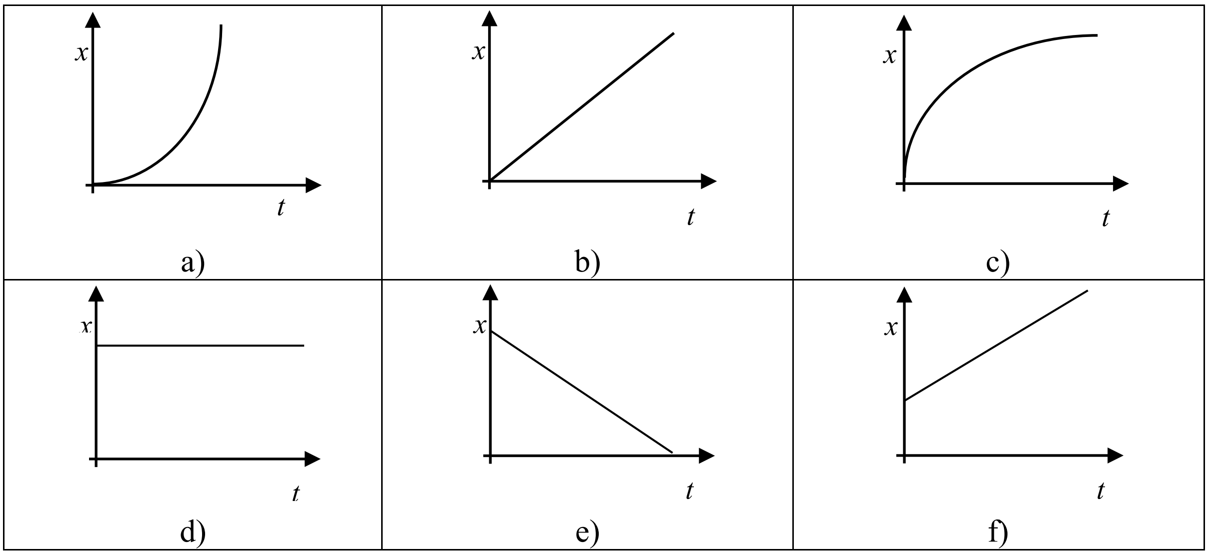


Figure 4*. Conceptual and conventional scores versus marks obtained at the exam of Mechanics*

- ○ *Conceptual scores*
- • *Conventional scores*

In this paper, we analyzed only the answers to the following question:

The motion of six objects is presented with the six position-time graphs. Which of the six objects experience nonzero net force?



The interviews

There was only one student who gave correct answers at the test and correct explanations at the interviews. One of the students did not undergo any change in the knowledge quality. She gave correct answers at the test, but the explanations at the interviews were incorrect. The rest of eight students experienced positive change in the knowledge quality. Some of them had correct answers at the test and some had partially correct answers. However, they all had change in the quality of their explanations.

Here, we will take a closer look at the interviews of two students. The first one had the smallest development in the knowledge and in understanding graphs. The second student's development was ranked in the lower half.

Student 1, interview before the SSVM

Teacher: *Why did you choose these answers?*

Student: (after a short thinking) I do not remember why. I do not know why.

As one can see, the student quits immediately.

Student 1, interview *after the SSVM*

Teacher: *Why did you choose this answer?*

Student: Well… there isn't …. the net force is not zero.

Teacher: *How did you come to that conclusion?*

Student: For some travelled distance the time is ...

Teacher: *Why did you choose the f answer and afterwards canceled it?*

Student: Because it starts ...

Teacher: *Can you tell me something about the motion described with the e) graph?*

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Student: It is uniform.

Teacher: *What does it mean?*

Student: It means … the distance is not the same, the time is different. So, as we did with the cart and the oil. We set the cart in motion and we get equal distances for different times. *(It is not clear does she mean for different equal time intervals or for time intervals with different durations.)*

Teacher: *OK. What do you think about the other motions?*

Student:**.......**

Teacher: *Do you need some time to think, to reconsider?*

Student: Yes, please.

After a while, she quits.

The change between these two interviews is obvious. Compared to the first interview, when she did not have any idea about the physical quantities and motion, at the interview after the SSVM experiment she knows that there is something about travelled distance per time, and that she has to compare different distances for various time intervals, but she is not sure at all.

Student 1, interview *after the MVM*

She reads the question.

Student: I had a dilemma here, between the answer I chose and e).

Teacher: *You eliminated the others immediately.*

Student: I eliminated a) and c) immediately.

Teacher: *Why did you do it?*

Student: Because the text in the question says that, the objects move rectilinear. In a) and c) it is not rectilinear.

Teacher: *What the a) graph shows?* Suddenly something starts happening in the student's brain. You can see the change in her eyes. After a while, she starts thinking aloud.

Student: Position … traveled distance … time. I got confused now. I am reconsidering the a) graph. The force …

Teacher: *Do you need some time to think, to reconsider?*

Teacher: Yes, please.

During the thinking time, she writes the formula for the velocity, a table with numbers for the travelled distance and time and a graph.

Teacher: *After this analysis, you concluded that the correct answer is a). How did you come to this conclusion?*

The explanation that comes here is very confusing, with many unfinished sentences, with many fragments of sentences. During the process of explanation, she tries to use the pictures from the third question. However, it is clear that the thinking process has started and it takes only a little to start using graph language fluently.

Teacher: What kind of motion is described in d)?

Student: It is constant. We have a constant distance …

Teacher: *What this object does? How it moves?*

Student: Just a second … (she thinks out aloud) … we have two seconds (she draws). So, in one second there is this distance (she shows the times and distances in the graph), in two seconds there is this distance … the distance is constant.

Teacher: *So, what the objects does? What kind of motion it performs?*

Student:... it rests… yes it rests.

At the beginning of the interview after the MVM, the student starts giving incorrect explanations. The GAP phenomenon is obvious when she says that the motion described in graphs a) and c) is not rectilinear. However, it takes only a little to initiate the thinking process and to start a real analysis of the graphs. She starts using the graphs, reads the data for various moments and compares distances for various time intervals. She comes to correct conclusions, but is not able to explain properly.

Student 2 interview before SSVM

Student: The objects perform a rectilinear motion, which means the velocity should be constant. There is a constant velocity … … here … … There is a constant velocity for different .. if the time increases the travelled distance increases too … … and therefore, it should … … the line rises.

Teacher: Can you please explain to me, for any of your answers, why did you choose it?

Student: I don't know.

The student tries to read from the graphs, but without any success. She also makes mistakes when she wants to conclude something about the velocity based on the position versus time graph.

Student 2 interview after the SSVM

Student: Well, the net force. It means a sum of two forces … it should be. Well … I thought this (d) is not the correct answer, because we get constant velocity … I mean straight line. If we take, here for example … … x and y axes, if we take from here, if we draw a parallel line to this one and parallel line to that one, we will get … … the same point … … because we have straight line....

She draws vectors on the graph d), one along the curve of the graph and another one parallel to the *x*-axis, and concludes that the velocity is constant.

Teacher: What is the situation in the b) graph?

Student: It is similar to … … the first one.

Teacher: Can you please explain to me?

Student: In the same way, we use the parallelogram rule of addition in order to obtain the net force. Because this is the velocity.

Teacher: The line (the curve in the graph) is the velocity?

Student: Yes.

Teacher: What is the situation in the e) graph?

Student: The last lesson you said … when we had … at least for us, we think that the line should only rise and it makes confusion when it goes down and we think that the distance decreases, because we approach to the same place. Here (in b) we go away from one place, and here (in e) we approach to some place. Only ……

Teacher: How did you conclude that there is nonzero net force?

Student: ... .

Teacher: Can you please draw the forces? Start from the first graph.

Student: (she draws vectors along the t-axis and x –axis and their sum vector beginning at the origin.

The confusion in this case is obvious. The GAP phenomenon is again present. Although it is position versus time graph, the student draws force vectors along the curve, seeing it as a trajectory, where the object is moving and thus the forces act on the object. She even considers the curve as something that represents the velocity.

Student 2 interview after the MVM

Student: The net force will be zero if the object is in rest or in uniform rectilinear motion. If the motion is accelerated or decelerated, the net force will be different from zero. In this case (graph a), we can divide the t-axis in equal intervals, as well as the x-axis (she divides the x-axis in equal intervals.

Using the relation between *x* and *t*, she tries to explain that the motion is accelerated, but she is still confused and not sure how to use the graph. She knows that the graph a) represents accelerated motion, which means that there must be a nonzero net force. However, she does not read the data from the graph correctly. At the end, she concludes that for equal time intervals the object travels different, non-equal distances.)

Student: This means that the velocity is not constant and therefore the net force will be nonzero.

When talking about the graph in b) she says:

Student: In this case, for equal time intervals (at the same time she divides the *t*-axis into equal time intervals) the traveled distances will be equal. This means the velocity will be constant. When we calculate the velocity from $t_2 - t_1$ (she marks the times) and here $s_2 - s_1$ (she marks the distances) … the velocity is $v = \frac{s}{t}$… This means the motion is uniform rectilinear and the net force will be zero.

In the c) graph, it is the same as in the a) graph.

Without any analysis, she draws conclusion that graphs a) and c) represent equal motions. However, the teacher reacts to this conclusion with a question.

Teacher: What is the difference between a) and c)? Since the curves are different, there must be difference in the motions.

When she is in a situation to compare, she starts the real analysis. Comparing the two graphs, she starts using them correctly. She marks correctly the time intervals and corresponding positions and finally concludes that the motion in a) is accelerated, and the one in c) is decelerated.

The answers and explanations in this interview are completely different from the ones in the previous interview. Even more, the vocabulary and explanations used in this interview reveal completely different way of thinking. It seem like it is not the same student.

Conclusion

Manual Video Measurement requires more time and more efforts. It requires additional steps in the collecting data and their processing, which are time consuming. The accuracy of this method is comparable with the one, which uses Software Supported Video Measurement.

On the other hand, the positive change in the skills for processing graphs and operating them when using MVM is very significant. The difference between the acquired knowledge and skills by SSVM and by MVM is huge. The ones obtained by MVM are very significantly higher and more quality. Understanding graphs is on a higher level. Explanations are much better i.e. more comprehensible. Sentences are clearer, vocabulary is more precise, use of physical quantities is more correct, and the gained knowledge is much better. During the manual processing data, the students use their preknowledge and face it with the new acquired knowledge, which initiates cognitive conflict. The students construct their knowledge as they construct the graphs. This approach is closer to the real experiment and gives opportunity for more interaction between the students and the environment, which makes it more efficient than the ones, which offer the students instant results and knowledge (Etkina, 2002; Sokoloff, 1997). If we take in account that the presented results are obtained from the student, which had the worst development of all examinees and a student, which was in the lower half, we can conclude that the change in the knowledge is very huge.

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