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Revisiting Social Welfare in P2P

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Abstract

Extensive work has been done on studying freeriding and incentivizing cooperation in peer-to-peer (P2P) systems in general and BitTorrent in particular. We argue for incentives from the point of view of the political economy of P2P networks. Political economists, unlike mainstream economists, strive to situate the study of economics in the broader realities of human society. We invest our efforts in studying incentivizing cooperation in P2P systems by underpinning our analysis on the disparity in Internet bandwidth between P2P users. Consequently, we come up with a new definition of fairness in P2P systems, one that recognizes that there are different classes of P2P users and seeks to be equitable to those who are less resourceful. We make the following contributions: 1) We argue that the works done on fairness in BitTorrent are, by our definition, unfair, 2) We propose that the basic goal of most works on incentives in P2P is limited because the welfare achieved by the proposed systems ('Pareto optimality'-'efficient outcomes') is not 'social welfare' and 3) We advocate that using principles from an alternate economic vision, Participatory Economics, could lead to systems which are fair and ensure maximization of the social welfare, while being efficient at the same time.

Contents

1 Introduction

Early P2P studies documented that popular P2P systems had rampant freeriding [1, 41]. Freeriding by people using the system suggested that they weren't using the software as it was intended to be used by its designers. To put it another way, users weren't 'faithful' to the algorithms and protocols [43]. In a seminal work in P2P, 'Rationality and Self-Interest in P2P Networks', Shneidman and Parkes proposed that the view where peers were only regarded as obedient (always following the protocol), was insufficient [42]. Borrowing from economics and game theory, they proposed that nodes could be rational. Since then, much work on incentives in P2P has been derived from the concept of rationality [17, 46, 19, 33, 18].

A case could be made that considering peer-to-peer users as rational, utility maximizing agents is a flawed viewpoint. After all, there are lots of thriving public BitTorrent communities [34] with millions of users. Recently the biggest BitTorrent community, *PirateBay* broke the 15 million user barrier [38]. And as BitTorrent users would know, public BitTorrent communities like *Piratebay* only function because people seed files and share bandwidth, willingly of their own accord and without any coercion.

However, to stress upon this would be to push an open door. In mainstream economics, "the last two decades have seen significant work undermining the selfishness hypothesis commonly used as a simplifying device for analysis based on the rational actor model" [8]. A long line of work in economics (and sociology for that matter) is highly critical of the rational action framework [40, 32].

Furthermore, even in the P2P community it has long been accepted that mapping the rational action framework directly to P2P networks is unadvisable. In an important work, Dash et al. [14] state, "[...] in reality we will need mechanisms based on assumptions about a mixture of agent behaviors, including obedient, strategic, and faulty agents. Traditional equilibrium solution concepts might be inappropriate in these systems with mixed agent behaviors." In the same paper they also note that "the theory's underlying assumptions can be inappropriate in computational settings because software agents are invariably bounded-rational...and the design problem is itself often intractable." In a similar vein, Feldman et al. note that, "purely self-interested models usually fail to explain the observed behavior of people" [16]. Tamilmani et al. stress that "as system designers, it is important to recognize that our goal is not merely to achieve a Nash equilibrium when all peers are rational" [45].

Instead of focusing on the inadequacies of the rational action framework, which are well understood, we focus on another problem that is present in most incentive works. Most designers working on incentives in P2P state that their goal is to design systems where nodes are incentivized to take actions that lead to the maximization of the social welfare. We argue that in such works, nowhere do we find an analysis of what social welfare entails. Generally, social welfare is equated with efficiency while equity takes a back seat [20], [13].

Further, we also argue that this conflation of efficiency with social welfare has led designers to paths which are impractical and shortsighted. So in this paper, while traversing the great body of work which has been done on ensuring 'fairness' in BitTorrent, we argue that such works are unfair as they don't pay attention to the limited capabilities of many real life P2P users.

In this paper, we hope to inspire new ways of looking at problems of incentives and social welfare in P2P networks. We argue that traditional methods of incentivizing and rewarding peers, lead to the welfare of the fast peers while punishing honest, slow peers. For the first time in this field, to our knowledge, we apply principles of Participatory Economics (*parecon*), an alternative economic vision, to P2P systems. We argue that these principles can be adopted to design systems that are efficient while being fair and that lead to social welfare [3].

We define 'fairness' in terms of equity and argue that systems which are inequitable to the less resourceful peers are unfair. There are various ways in which 'fairness' has been defined in the literature. Generally, a system is deemed fair if those peers who contribute more, receive a better service than those who contribute less [15]. In view of the parecon principle of rewarding *effort as opposed to size of the contribution or output*, we suggest that a system will be fair if those peers who make more effort and sacrifice, receive a better service than those who make less effort and sacrifice. We believe this a better definition of fairness; one that gives equal opportunity to both slow and fast peers to be rewarded. On a similar note, we define 'social

welfare' as the achievement of efficiency under equitable and fair arrangements.

In section II, we give a concise overview of the BitTorrent protocol. In section III we present a brief synthesis of an extensive survey by us of works on incentivizing cooperation and preventing freeriding in P2P in general and BitTorrent in particular. We tie this discussion to our underlying theme, social welfare and equity in P2P. In section IV, we present our case for an alternative economic framework-participatory economics; furthermore we elucidate what is wrong with 'social welfare' as it has been commonly defined, and highlight principles and values that could lead to fairness and social welfare in P2P systems.

2 BitTorrent Overview

In order to provide enough background for the remainder of our analysis we will give a concise overview of the BitTorrent (BitTorrent) P2P protocol. Over the past decade, BitTorrent has spawned thousands of networks all over the world that together encompass tens of millions of users and make it the most widely used P2P protocol today. The two most important properties of BitTorrent are that files are split into pieces, and that these pieces are exchanged among peers in a manner that is inspired by *tit-for-tat*, the game theoretic cooperation strategy made famous by Axelrod et al. [7]. We should note that piece exchange is performed only among peers downloading the same file, together called a *swarm*. In other words, in plain BitTorrent the consequences of the behavior of a peer regarding one file is completely independent from the consequences of its behavior regarding another file.

While BitTorrent's designer Bram Cohen explicitly stated that the exchange protocol is inspired by tit-for-tat [11], it is in almost all work often wrongly reported to *be* tit-for-tat. It is rarely pointed out that its actual details are only subtly reminiscent of it. We need to keep in mind that in the original tit-for-tat, the essence is that cooperation of one agent without exception results in the cooperation of its recipient, i.e., there is no notion of global competition where the contribution of one agent would be 'better' than that of another one. Here lies the crux of one of the conceptual misunderstandings of BitTorrent's 'fairness'. While in BitTorrent a downloading peer does not upload pieces to peers that do not reciprocate (in line with tit-for-tat), it chooses from those peers that do reciprocate, *the fastest few*, a competitive innovation that has no relationship whatsoever with the original tit-for-tat strategy. Arguably, it would hence be more accurate to call the BitTorrent protocol *fastest-first* instead of *tit-for-tat*. As a consequence, cooperation doesn't guarantee slow, honest peers a respected place in the gang, even though it is often wrongly perceived to do so. Meager relief is provided by the fact that a peer periodically grants requests from a random peer so as to give peers the opportunity to bootstrap the process and to discover faster reciprocating peers for their own benefit (*optimistic unchoking*). The only realistic resort of slower participants is to rely on enough altruism by finished downloaders (see below), but even this option is reduced by the introduction of incentive systems. We will see later on that most, basically well-meant, credit and incentive systems decrease the performance of slower peers instead of increasing it.

Peers that already finished their download but stay voluntarily in the network are called *seeders*. While actual implementations vary, most BitTorrent clients use a policy where seeders prefer to upload to peers that download the fastest so as to ensure the most efficient distribution of the data overall. In case of *over-seeding* (i.e., more supply than demand), the crumbs are left for the slower peers. In addition, with the seeder mechanism come the main perceived weaknesses of BitTorrent: there is no incentive for peers to become seeders.

3 Freeriding and Incentives in P2P

We can classify the studies on freeriding and incentive mechanisms in BitTorrent and P2P along the following two broad dimensions. This can be seen in Figure 1.

- ***Incentives in a Single Swarm:*** These studies focus on avoiding freeriding and incentivizing cooperation in a single BitTorrent swarm [9, 30].

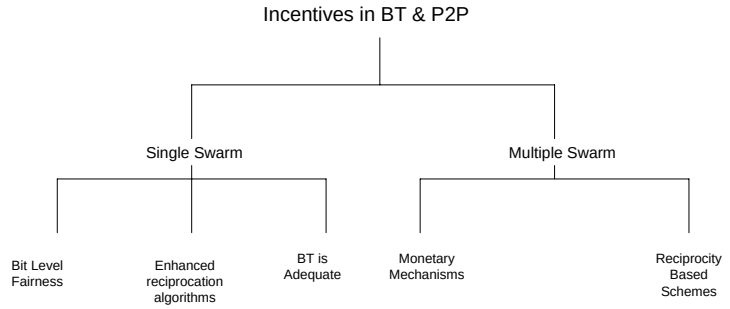

Figure 1: Diagram showing the categories of Incentive mechanisms in P2P and BitTorrent

- ***Incentives in Multiple Swarms:*** These studies focus on incentivizing cooperation across multiple swarms [21]. It should be noted that the term 'Multiple Swarm' is one of convenience. Such studies focus on P2P networks in general.

3.1 Incentives in Single Swarms

We will begin by discussing papers aimed specifically at the fairness problem in the BitTorrent protocol. The motivation behind many such works is that the incentives in BitTorrent are not 'fair'. There are many ways in which 'fairness' has been defined and the problem of fairness has been approached in BitTorrent studies. These are:

3.1.1 Bit Level Fairness

Bharambe et al. note that a P2P system should be fair in terms of blocks served by individual nodes and that asymmetries of contribution should not be systematic [9]. The claim is that if there were such asymmetries, the system would not be fair and there would be a lack of incentive for nodes to participate. The authors claim that because of BitTorrent's coarse approximation of Tit-for-Tat (TFT), based on limited download estimations, fast peers unnecessarily upload to slow peers while getting relatively little in return.

They argue for what is known as Bit Level TFT in the literature. There are several studies such as [26, 23], [22] that argue for a Bit Level TFT fairness. Bit Level TFT means that a fair system should implement byte level reciprocation. So if peer A gives x number of bytes to B, it should get the same or approximately the same number of bytes from B in return. Why should this be the case? The logic is that freeriders should be punished and reciprocation should be mandatory.

Many problems with Bit Level fairness have been identified in the literature. It has been argued that Bit Level fairness is not appropriate in the context of P2P file sharing systems. With Bit Level fairness, when there is more capacity of service in the system than request for the capacity, the excess capacity will be lost even if slow peers or freeriders could benefit from it. Bit Level fairness doesn't take into account the fact that peers can, and do in most cases, have assymetrical network connectivity, the upload capacity being lower than the download capacity. So with Bit Level fairness, such peers would never be able to utilize their full download potential [29]. Initially Bram Cohen, the creator of the BitTorrent protocol, also considered a strict TFT policy but gave it up because of severely degraded system-wide performance [10].

3.1.2 Enhanced Reciprocation Algorithms

In view of problems with Bit Level fairness, other approaches for improving fairness in BitTorrent have been proposed. It has been hypothesized that if fast peers were to interact more with other fast peers, rather than wasting resources on slow peers, they would get even faster download times. This would also mitigate

the extent to which slow peers freeride on fast peers [6]. Modifications to the BitTorrent protocol with this or similar rationales have been proposed in the literature [6, 30].

Despite a very sophisticated modification of the BitTorrent protocol, in line with Auction Theory, the results in [30] show that the average download time of peers decreases only slightly as compared to the original BitTorrent protocol. What's more, works such as [28] show that BitTorrent is already good at clustering peers based on their speeds. And, due to BitTorrent's optimistic unchoke policy, slow peers are able to gain benefit from faster peers. However, at the same time BitTorrent is fair since fast peers, peers who contribute more (though they might not get strict data volume or Bit level fairness) are rewarded by completing their download sooner.

What's wrong with the fact that faster peers end up helping slow peers at only a little loss in download speed? If the fast peers help out slow peers, they do it as part of the somewhat egalitarian nature of the protocol. And that shouldn't be changed as this is what keeps the system going for a diverse number of peers having wide-ranging Internet speeds. This has also been suggested by Piatek et al. Modifying the BitTorrent protocol to prevent slow peers from exploiting the bandwidth of the fast peers would be a flawed endeavor because the *"majority of the BitTorrent users benefit from this kind of unfairness"* [37].

3.2 Incentives in Multiple Swarms

Works dealing with incentives for cooperation in multiple swarms, or across P2P systems, comprise a greater body of work than works focusing on BitTorrent. Works dealing with incentives for cooperation in a P2P system can be classified into two categories: *Monetary Payment Schemes* and *Reciprocity Based Schemes*. These classes have also been delineated elsewhere [16].

The policy objectives of both are generally the same: To provide better service to peers with high reputation or more money and to degrade or block the service received by peers with low reputations and less money.

Credit crunches and crashes have been studied in Scrip Systems by Kash et al [27]. They show that in a P2P system, both an overabundance of money supply and its shortage lead to inefficiency. An overabundance in the money supply leads to a monetary crash where no one is willing to work and freeriding is encouraged. On the other hand, a shortage in the money supply, a result of willful hoarding on part of some peers, leads to peers going broke and not being able to afford services in the system.

Most indirect reciprocity or reputation schemes for incentives that reward peers for contribution suffer from another problem, namely: The gap between the rich and poor keep widening. We argue that these mechanisms including sharing ratio enforcement schemes employed by private BitTorrent trackers such as BitGamer, Cinematics etc are unfair. Sharing ratio is the ratio of the amount uploaded to the amount downloaded. Sharing ratio enforcements schemes are used to punish peers with bad ratios by blocking or delaying their access to content. In our opinion, such schemes are unfair. This is because we argue, like Bram Cohen, that "enforcement of sharing ratios tilts the balance highly to uploading and peers even if they are willing to upload have a hard time maintaining a good ratio" [12].

In the context of BitTorrent, we believe that the presence of a reputation scheme or enforcement of sharing ratios, or a credit based scheme employed by some trackers, places an undue burden on slow peers who, in order to maintain a good ratio, have to seed heavily while the faster peers can simply maintain a good ratio by being part of a swarm. These conclusions are backed up by the findings in [4]. Their main contributions include showing that only a minority contributes the majority of the resources and that the upload contribution of peers is not correlated to the time that they invest in seeding content. The fact that the heavy contributors are able to contribute without seeding for long periods suggests that these heavy contributors are the fast peers. As has been shown in [9], in a single BitTorrent swarm, fast peers can upload up to *seven* times as much data as they download. Hence in a sharing ratio or credit based scheme, such peers can maintain a good ratio or gather more credits by simply being part of a swarm, without any need to seed. Conversely, the slower peers, emerging with a weak ratio from a single swarm, would need to seed for long periods to boost their sharing ratio.

Furthermore, in a recent work we indicate that such BitTorrent communities that rely on monetary

mechanisms, are also facing the credit crunch problem described above, and also present some ways in which these problems can be rectified [24].

4 Alternate Economic Vision and Goals

What do we want from the P2P economy? What kind of system do we desire? What are the values that underlie any economic system that we propose and how do we want to affect the behavior of peers using the system? Specifically, we want:

- ***More cooperation and less selfishness***
- ***More efficiency and less wastefulness***
- ***More equity and less unjustness***

To foster more cooperation and to reduce or even eliminate selfishness has been the goal of all incentive studies in P2P. Increasing cooperation leads to greater utilization of all resources, thus leading to efficient outcomes. Incentivizing cooperation and maximizing efficiency have been the subject of many studies. The achievement of these two goals has been thought sufficient to ensure social welfare.

Engendering equity and eliminating unjustness resulting from differentiated output based on bandwidth, are ignored in most studies. We advocate that incentive schemes should be such that the slower peers are provided the same opportunities as the faster peers. We also argue below that social welfare can't be achieved simply by maximizing efficiency, but requires both efficiency and equity.

We shall next consider each of the desired goals in turn.

4.1 More Cooperation and Less Selfishness

This is the simplest and most straightforward of all our goals and about which we shall not say much. As stated above, fostering cooperation and eliminating selfishness is the primary goal of all incentive works in P2P. We want peers to contribute their resources to the network. Resources encompass content, time spent sharing content and the rate at which it is contributed. So we would like people to share content for long periods of time at as high a rate as they possibly can.

4.2 More Efficiency and less wastefulness

What do we mean by more efficiency? Normally Pareto optimality has been employed by P2P designers to measure efficiency. The first paper on BitTorrent, highlights the achievement of obtaining Pareto efficiency [11]. Indeed in an influential paper, Dash et al. in detailing the desiderata of mechanism design, list Pareto optimality as one of the sought after goals [14]. It is worthwhile to study what exactly Pareto optimality is and what it entails.

4.2.1 Pareto Optimality

A change from one allocation to another that can make at least one individual better off without making any other individual worse off is called a Pareto improvement. An allocation is Pareto efficient or Pareto optimal when no further Pareto improvements can be made [36]. Pareto optimality isn't necessarily fair. In fact it is a major contention of political economists that Pareto optimality is insufficient because it doesn't have anything to say about inequality [39]. For example, allocating all resources to one individual and giving nothing to the rest is a Pareto Optimal solution.

Being Pareto Optimal might not necessarily be wonderful but non Pareto outcomes are certainly undesirable because we could make someone better off without making anyone else worse off. Hence, we certainly do desire and demand Pareto optimality from the P2P economy.

But what's striking is that if P2P designers were to adhere strictly to Pareto optimality, then they wouldn't have much, if anything, left to propose. This is because most solutions make *some* people better off and *some* people worse off! Hence recommending any mechanism as a Pareto improvement would almost certainly be out of the question in most situations. (It's instructive to note that this point hasn't been stressed enough, if at all, in the literature.)

Mainstream economists try to circumvent this problem by using an extended concept of efficiency called the *efficiency criterion*. Succinctly, the efficiency criterion posits that if the overall benefits to any and all people of doing something outweigh the overall costs to any and all people, it is efficient to do it, and vice versa. As in mainstream economics, in P2P as well, social welfare has been equated with efficient outcomes [31], [5]. Next, we shall discuss why this equation of social welfare with efficiency is inadequate.

4.2.2 Social Welfare

How can it be decided that the overall benefits to some people outweigh the costs to some other people? In the context of P2P file sharing networks, who is to say that it's efficient to provide reduced download times to faster peers while increasing the download times of slow peers? Fact of the matter is that *value judgements* are implicit in the efficiency criterion. A designer has to make value judgements on what she feels is a better solution. *The questions of efficiency and equity are interlinked and it's important to note that this linkage cannot be separated.* Let's try to explain this with the following hypothetical.

Suppose there are two designers who are working on the BitTorrent protocol. The first designer might decide that modifying the optimistic unchoke policy of BitTorrent to decrease download times of faster peers at the expense of slow peers is a good idea. She notes that upon doing so, the average download time goes down and is pleased that she has come up with an efficient solution. On the other hand, the second designer might feel that even though the average download time has been reduced, there are many peers now in the system who are worse off than they previously were. And these peers might even happen to be in a majority. The designer decides that this occurrence is inefficient and resolves to leave the BitTorrent protocol as it is. Or she might even resolve that the BitTorrent should be modified in the opposite direction: to reduce the download times of the slow peers as much as possible.

The point is that the principles and values we follow dictate how we formulate and answer such questions. We desire efficient outcomes, but such that are fair and equitable to the less resourceful peers in the system. We therefore argue that the stated goal of numerous incentive works in P2P (e.g., in [14]: "achieving efficient outcomes for social welfare"), is inadequate unless qualified by the condition of equity. This brings us very nicely to the values that determine how we reward peers in a system and how we can engender fairness and equity in the system.

4.3 More equity and less unjustness

It should be straightforward to accept that there is disparity in Internet bandwidth among different p2p users. Peers that are slow will naturally get slower service as compared to the fast peers. However, it is up to P2P designers to ensure that the incentive mechanisms that we devise don't further punish slower peers.

It could be argued that it is fair that the fast peers, who contribute more to the system in terms of volume, get better service and more rewards from the system. However, we think that this would only be fair if the sole maxims of remuneration available to us were ones that rewarded peers for their fast connections. There are three maxims of remuneration as understood by political economists [25]:

a) *Payment according to value of one's personal contribution and contribution of the productive property one owns.* Peers should get out of the economy what they and their productive property (reputation or virtual money in case of P2P) contribute to the economy. If there was a credit or labor market in P2P, where people simply based on their reputations could earn even higher reputations through lending part of their reputations to others, or could use that reputation to hire others to work for them, then remuneration according to private property would be a feature of P2P networks.

b) *Payment according to the value of one's personal contribution only.* Peers should get out of the economy how much they contribute to the economy. This is in fact how people are remunerated in P2P settings currently. The faster connection that a peer has, the faster it will be able to download (BitTorrent) and the more currency or reputation it will be able to earn in monetary or reputation based schemes.

It's clear that maxims *a)* and *b)* favor the faster peers who would be rewarded higher in a system that utilized either of these two maxims.

We desire an economic system that provides incentives to peers to cooperate with each other, that increases efficiency and that also embodies fairness and equity. Therefore, we consider an economic system that that utilizes a novel, the third, maxim of remuneration, which in our view can facilitate the achievement of these goals.

4.4 Participatory Economics

Participatory Economics (*parecon*) is an alternate economic vision developed by Michael Albert and Robin Hahnel [3]. Parecon is constructed around five core principles: 1) Social ownership understood as equal ownership by all citizens; 2) Egalitarian democratic empowerment based on a principle of participation proportional to effects; 3) Jobs constructed as "balanced complexes"; 4) Remuneration for work according to effort and sacrifice; and 5) Economic coordination based on comprehensive participatory planning.A comprehensive overview of *parecon* is available at [35]. For the purposes of this study, we shall concentrate on the *parecon* principle of remuneration:

Payment according to effort and sacrifice. This maxim suggests that people should be rewarded for the efforts and sacrifice that they put in their work, rather than being paid for their output, which almost always involves someone's power, intelligence or other innate capabilities. In P2P file sharing systems, this innate capability could be translated as the power of the Internet connection that a peer possesses.

In parecon, people are remunerated on the basis of the effort and sacrifice they make for producing socially valued work rather than output. In [2], Albert and Hahnel, present a formal model of participatory economy and show that remunerating according to effort and sacrifice leads to allocations that are both efficient and equitable. We believe that for P2P systems, this is a better option because it ensures hard working peers who do their best to contribute to the system are rewarded even though they might not be well endowed in terms of bandwidth.

What constitutes effort and sacrifice in a P2P file sharing community? We know that we want peers to contribute their resources to the network. Resources encompass content, time spent sharing content and the rate at which it is contributed. So we would like people to share content for long periods of time at as high rates *as they possibly can.* This is a good approximation of the effort and sacrifice they make for the welfare of the community. Other contributions, such as sharing rare content, taking the time to rate content, and helping other peers communicate through NATs and firewalls can also constitute effort and sacrifice.

Of course there are some practical hurdles in remunerating peers in this way. For example, how do we know what proportion of its bandwidth a peer is contributing, since there is no straightforward way of knowing the upload capacity of a peer. A peer might be dissembling when it reports that its dedicating its entire bandwidth to the system.

One way of checking the veracity of this claim is to check the peer's download speed. If the download speed is proportional to the upload speed, then we can surmise that the peer is telling the truth. However, of course, if the download speed is far greater than the upload speed, then we can conjecture that something is amiss.

A recent work presents a system for evaluating the bandwidth of nodes in a P2P network, in a secure way, that is efficient and accurate [44].

5 Dicussion and Conclusion

In this paper, we explored the use of incentive mechanisms in P2P systems. We argued that generally P2P designers have an inadequate concept of social welfare. Social welfare has been superficially equated with

Pareto optimality and efficient outcomes, without a proper analysis of what these entail. We made this analysis and in view of the inadequacy of the standard definition of 'social welfare', we argued for a novel method of incentivizing peers, one that rewards their effort and sacrifice rather than output.

The merits of this method are obvious. At the very least, it gives an equal opportunity to both slow and fast peers to be rewarded. An example of a not so obvious advantage of this method is that for those incentive schemes that rely on monetary mechanisms (such as private BitTorrent communities), remunerating for effort would make the occurrence of credit crunches much less likely. This is because hoarding of credits would only occur if peers seed for long periods of time. If we remunerated peers simply for output, then peers with fast connections would very likely end up hoarding credit without even trying very hard!

Devising such algorithms that determine effort and sacrifice in a decentralized way, is a challenging and difficult task, something that could be a fruitful area for novel research.

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