Combining reliability, reputation and honesty to enhance QoS on Federated Computing Infrastructures

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***Abstract*—In this paper, we suggest an approach aimed at maximising the "global utility" (i.e., QoS) perceived into a large-scale federated computing infrastructures. Our approach computes the node and starts a procedure for the formation of coalitions between them. In particular, it is based on a trust model that allows actors to quantify the trustworthiness of their peers, and on a decentralised procedure that allows the Computing Federation to optimise the QoS. We define the generic SLA-based federated architecture, that is the global QoS offered by the federation, and we describe the theoretical foundation on which our proposal is based. Finally, we illustrate the experimental results which prove that the Global Capital of the Computing Federation improves.**

***Index Terms*—Cloud federation, Multi-agent System, Grid Federations, Trust, Group Formation.**

I. Introduction

In the last few years, the increasing complexity of grid tasks has brought a remarkable change in the grid infrastructure. In particular, the grid computing paradigm has evolved from the Virtual Organisations (VO) to the federated grid architectures, in which grid brokers and grid institutions share resources among different grid infrastructures thus resulting in a more flexible approach.

Indeed, as grid clients send requests composed by complex requirements, they will relay on the *collaboration* between grid VOs, which are able to provide specialised resources to the result of the expected computation. Therefore, the main objective is represented by the need of achieving high efficiency in allocating federated resources.

This scenario produces competition among computing nodes, which want to improve performances provided to their clients [1]–[7]. At the same time, it implies the presence of possible malicious behaviours, because the service providers promise performances that will not be actually realised. Based on the considerations above, a trust model [3], [8]–[10] can assist clients and grid nodes to quantify the expected level of performance and mutual trust.

In the literature, past proposals present strategies for resource allocation, without to consider trust issues. For this reasons, we present a trust-based approach aiming at maximising the QoS perceived within the grid federation.

Our solution is based on the use of software agents [11] that manage every node which may be a grid computing element, a grid site, a part of a cloud centre. We focus on two concepts: the *resource sets* that is the sets of computational resources characterising complex requirements in federated computing infrastructures, and the *agent aggregation* that allows collaboration between federated nodes.

In particular, we propose an algorithm for agent *Friendship and Group Formation* (FGF) to maximise the "global utility" also said *Global Capital*, of the whole federation. This trust model combines some measures of reliability and reputation to obtain a unique synthetic trust measure.

The plan of the paper is as follows. In Section II, we survey the related work of the recent literature Section III describe the software agent used for the formation of nodes. Section IV introduces the trust model, while in Section V we propose the FGF algorithm for forming friendships and groups. Section VI shows a few experiments to prove the effectiveness of our approach. Finally, in Section VII, we draw our conclusions.

II. Related Work

In this section, we survey the literature related to the issue of partner/node selection in the context of self-interested agents and grid systems and focus on the principal metrics proposed to deal with the the problem addressed in this work.

Various types of evaluation metrics were proposed to select appropriate partners, for example by exploiting local decision and models [12]–[16] or by promoting agent interactions to realise a distributed social control mechanism for evaluating other agents or their provided services [17], [18]. Many of such models are based on direct observations and/or on communications with other agents. Moreover, they consider different criteria as trust, reputation, provided QoS, etc.

In this context, the concept of *belief* can be considered as a situational awareness, and its modification can require to select the most appropriate providers for information. To achieve this aim, the authors suggest the use of *social control* [19] as a way to create secure open systems. Them idea is to let the agents in the system be responsible for the security of the system but without having a global authority.

In the information exchange domain, research on belief revision also involves how to select appropriate information providers. Belief is, in general, a situational awareness, and research investigating belief revision in multi-agent systems [20]–[23] pursues a similar objective: build the agents' beliefs accurately and efficiently by using all the information provided. In these approaches, the beliefs are assigned preferences by epistemic relevance in a symbolic logic [20], or ordered by credibility in [21] by using a belief function. Also preferences can be determined by evaluating the information source trustworthiness by exploiting Bayesian networks [22] by means of a soft or a statistical approach [23]. Observe that these techniques result to be computational expansive [24], [25] and therefore some approximate and less expensive solutions have been proposed in this context [26]. To this purpose, a method for selecting appropriate service providers based on quality of service (QoS) among Web services is proposed in [12].

To solve coalition formation issues among self-interested agents, negotiation mechanisms (requiring peer-to-peer communications) can be used to find the best candidates to join with. The Contract Net Protocol (CNP) [27] is a fully automated negotiation protocol where each agent can be an initiator or a participant of a call for proposal and where only the best participants bids on that call are selected by the initiator. As above it has been specified, CNP is a fully automated negotiation protocol where each agent can be an initiator or a participant. After an initiator sent out a call for proposals, participants bid on that call and the initiator selects the best bids while rejecting other bids. Negotiation is useful especially when there are no arbiters. Although CNP provides a relatively simple mechanism for partner selection, it can still be computationally expensive in large-scale systems because of the message complexity. Also CNP may be vulnerable to the situation where commitment to the contract is not guaranteed. In other words, agents need to be cooperative for CNP to work. However, the CNP has been embedded into the Transportation Cooperation Net (TRACONET) [28] for a vehicle routing application according to the Foundation for Intelligent Physical Agents (FIPA) standard. The Adaptive Decision Making Framework (ADMF) [29] also deploys a negotiation-based partner selection scheme. ADMF is designed for a system where agents share global goals and the structures among agents are targeted to maximise these global goals. In particular, agents are able to dynamically reorganise the structure of an agent group to meet the needs of their current situation. ADMF provides a spectrum of power relations between agents, from locally autonomous to master-slave. This schema has been designed for systems where agents, assumed to be cooperative, share global goals to be maximised and allows a dynamic adjustment of agents relationships, although also this proposal has a low scalability in presence of large-scale systems.

Coalition formation seeks to partition the agents in a system into groups which maximise the utility of the group or the individual agent. The partitioning of the agents is usually modelled as a characteristic function game and involves three activities [28]: *(i)* coalition structure generation, *(ii)* solving the optimisation problem of each coalition, and *(iii)* pay-off division. The first two activities are closely related to finding appropriate partnerships from a set of potential groupings, while pay-off division is to decide how the utility gained by forming a coalition should be distributed among the agents to keep the coalition stable. Pay-off division has been a major issue in the coalition formation research and it is useful for maintaining or encouraging agents' collaboration, but recent focus has been on coalition structure generation [30], [31] in addition to the earlier research [32], [33].

Recently, some proposals adopted trust in competitive agent systems [34], [35], for instance, to constitute clusters of agents [36], [37] and for generating recommendations in social network contexts [38]–[42] or to detect group of actors in a competitive social community [43]. These approaches trade on trust measures to suggest the best agents to contact as fruitful interlocutors, but none of them deal with the issue to improve the social capital of the agent community on the basis of a meritocracy criterion. Differently, our proposal introduces a meritocratic principle in order to obtain such an advantage, also by encouraging the actors to assume correct behaviours in order to improve their reputation.

In the literature, some works deal with the scheduling problem on large-scale grids [44], [45], load balancing [46], as well as the problem of application adaptivity in heterogeneous environments [47], e.g. grid computing. Differently, by employing software agents into grid systems has always been a subject of research [48].

III. Our scenario

In this work, we focus on inter-site groups formation based on trust and resource availability. For this reason, we define that a federated node can be a grid computing element, a grid site or, for instance, a part of a cloud site. Let the federation $\mathcal{F}$ consisting of N nodes, we define the set of all heterogeneous resources available on $\mathcal{F}$, as a finite number of R incremental sets of resources, where the R-th set (i.e. the last) includes all the resources available on $\mathcal{F}$. Also, the generic service, requiring for its execution the r-th set of resources, will be identified by s^r.

We assume that when the user u_j receives a service s^r by the node n_i (with $1 \leq r \leq R$), it has to pay a fee p to the provider n_i, whose amount is based on the consumed set of resources and on the waited quality of the provided service. This shows that the context of the proposed federation is "competitive". Let A be the set of the node agents, each generic agent $a_i \in A$ is associated with the node $n_i \in \mathcal{F}$ and denoted by a "skill" mapping $\eta_i(r) \in [0, 1] \subseteq \mathbb{R}$. In detail, $\eta_i(r) = 1$ means the maximum quality in providing a service which requires the specific set r of resources and, vice versa, for $\sigma_i(r) = 0$. Each time a service s^r is provided by the agent a_i (i.e. the node n_i) to the user u_j, a feedback $f \in [0, 1] \subseteq \mathbb{R}$ is returned by u_j to a_i, where $f = 1$ means that u_j has perceived the maximum level of satisfaction for s^r and, vice versa, for $f = 0$.

Moreover, we assume that each agent a_i maintains a set F_i of *friend agents*, such that $F_i \subseteq A$, and a set of *groups* $G_i = \{g_{i_1}, \ldots, g_{i_k}\}$ where $\bigcup_{1<l<k} g_{i_l} \subseteq A$. For each service s^r, the agent a_i can require the *support* of another node n_j (i.e. agent a_j). If a_j collaborates with a_i by providing the required set of resources and it is a friend of a_i or it belongs to the same group of a_i, this help is provided for free; otherwise, a fee p_s has to be payed from a_i to a_j after such a support has been provided.

To select the best agents to collaborate for the service s^r, the agent a_i can require a recommendation $rec_j(r)$ about the skill $\eta_j(r)$ of a_j for a given service s^r to an agent a_k. If a_k accepts and it is a friend of a_i or it belongs to the same group with a_i, this recommendation will be provided for free; otherwise, a price p_r has to be payed from a_i to a_k after the recommendation has been provided.

However, the final choice is performed by the agent a_i based on the trust model described in Section IV. In the proposed scenario, we assume that the names of agents, groups and agents belonging to each group have to be appropriately registered in a Directory Facilitator (DF), published across the different nodes.

IV. The Trust Model

The presence of competitive agents also implies that possible misbehaviours due to malicious agents might happen. To this reason, each agent a_i maintains a triple of values $< REL, O, REP >$ ranging in $[0,1] \in \mathbb{R}$ (called respectively *Reliability*, *Honesty* and *Reputation*) for each agent a_j which a_i interacted in the past. The reliability $REL_{ij}(r)$ of a_j in providing a set r of resources, represents how much a_i trusts a_j in its capability to provide resources for a service s^r. Furthermore, once a_i received a feedback f for a service s^r, if a_j has contributed to the service S^r, f will include a share $f_j^* \leq f$ due to a_j that will be assigned to it proportionally to its contribution. . Thus if a_i completely delegated a_j in providing s^r then the feedback f will be totally referred to a_j, i.e. $f_j = f = f_j^*$. More formally, the reliability is $REL_{i,j}(r) = \frac{1}{l}\sum_{m=1}^{l} f_j^m$ for $l \neq 0$ and $REL_{i,j}(r) = \overline{REL}$ for $l = 0$, where $\overline{REL}$ is cold start value if there were no previous interactions between a_i and other agents.

The honesty $O_{i,j}(r)$ of a_j in giving a recommendation to a_i represents the overall reliability of the agent a_j in recommending some other agents in providing a set r of resources (i.e., $O_{i,j}(r) = \frac{1}{s}\sum_{m=1}^{s} |rec_j^m(r) - f_{x_m}(r)|$). It is computed by averaging all the difference between the feedbacks and the associated recommendation received by a_i for some s agents suggested by a_j. If a_i has not interacted with other agent, $O_{i,j}(r) = \overline{O}$, where $\overline{O}$ is cold start value.

The reputation $REP_{i,j}(r)$, represents how much, in average, the agents interrogated by a_i provided an estimated value of capability of a_j – in terms of performance referred to the resource set of a_j – which is close to the measured value. $REP_{i,j}(r) = \frac{1}{l}\sum_{m=1}^{l} rec_j^m(r)\beta_{im}(r)$ is the mean of all the recommendations received by a specific agent a_i, about another agent a_j on a resource set r and weighted by the *honesty* of the recommenders. If $l = 0$, $REP_{i,j}(r) = \overline{REP}$.

The value of trust is denoted by $T_{i,j}(r) = \delta_i \cdot REL_{i,j}(r) + (1-\delta_i) \cdot REP_j(r)$, where $\delta \in [0,1] \subset \mathbb{R}$ weights the relevance assigned by a_i to the reliability with respect to the reputation.

V. Friendship and Group Formation

In our scenario, let the agent a_i, we define, for each set of resources r, two sets: ${PC_i}^r$ that stores the *preferred contributors* agents contacted in the past to obtain r and ${PR_i}^r$ that contains the *preferred recommenders* agents for a suggestion referred to r. In particular, ${PC_i}^r$ assumes the X highest trust values $T(r)$ and a trust value greater than the threshold $T^{\ min}$. ${PR_i}^r$ assumes the Y highest honesty values $O(r)$ and a honesty value greater than the threshold $O^{\ min}$. To maximise the performance of the services provided by the generic agent a_i, its own sets F_i (friends) and $g \in G_i$ (groups) should only include the agents belonging to ${PC_i}^r$ and ${PR_i}^r$ for all the set of resources:

$$\bigcup_{r \in R} ({PC_i}^r \cup {PR_i}^r) = F_i \bigcup (\bigcup_{g \in G_i} g) \quad (1)$$

$${PA_i}^r = {PC_i}^r \cup {PR_i}^r \qquad AG_i = \bigcup_{g \in G_i} g$$

$$\bigcup_{r \in R} {PA_i}^r \ = \ F_i \bigcup AG_i \quad (2)$$

When some agents belong to the set $\bigcup_{r \in R} {PA_i}^r$ but not to $F_i \bigcup AG_i$, there is a *loss of performance* in providing services when one of those agents are selected. In particular, we define for an agent i a factor, called *Loss of Performance*, in turn composed by two components, $L_i^{(T)}$ and $L_i^{(O)}$, defined as follows:

$$L_i^{(T)} = \frac{\sum_{j \in \left(\bigcup_{r\in R} {PC_i}^r - F_i \bigcup AG_i\right)} \left(T_{i,j}(r^*) - T_{i,alt_j}(r^*)\right)}{\| \bigcup_{r \in R} {PC_i}^r - F_i \bigcup AG_i \|}$$

and

$$L_i^{(O)} = \frac{\sum_{j \in \left(\bigcup_{r\in R} {PR_i}^r - F_i \bigcup AG_i\right)} \left(O_{i,j}(r^*) - O_{i,alt_j}(r^*)\right)}{\| \bigcup_{r \in R} {PR_i}^r - F_i \bigcup AG_i \|}$$

where r^* is the resource sets in which a_j is a preferred contributors (resp. preferred recommender) agent and alt_j is the agent in $F_i \bigcup AG_i$ having the best trust (resp. honesty) value on r^*. If a_j is a preferred contributor or recommender agent on more resources sets, r^* will be the set having the highest trust (honesty) value, then the factor $L_i^{(T)}$ (resp. $L_i^{(O)}$) is obtained by computing the average of all these contributions.

In case some agents belong to the set $F_i \bigcup AG_i$ but not to the set $\bigcup_{r \in R} {PA_i}^r$, we call *Additional Cost* the ratio of agents that will be never contacted by a_i to obtain help for free:

$$C_i = \frac{\| F_i \bigcup AG_i - \bigcup_{r \in R} {PA_i}^r \|}{\| F_i \bigcup AG_i \|}$$

We also define the "disadvantage" D_i of a_i, as the average of the sum of the factors $L_i^{(T)}$, $L_i^{(O)}$ and C_i. Finally, we define the *Global Capital* (GC), by taking into account the whole federation $\mathcal{F}$, as the mean value of all the contributions $(1 - D_i)$ provided by each agent a_i:

$$GC = \frac{\sum_{a_i \in A}(1 - D_i)}{\|A\|}$$

Now, we introduce the Friendship and Group Formation (FGF) algorithm to minimise the disadvantage D_i. For each epoch T (i.e., the time occurring between two consecutive epochs), some preferred agents provide to join with the set $F_i \bigcup AG_i$ to replace those agents provided of the worst trust or honesty values. The FGF algorithm consists of two parts: the (*First Task*) is periodically executed by each agent a_i to obtain the friendship or the membership in a group of those agents belonging to the set $\bigcup_{r \in R} PA_i{}^r$ but not yet belonging to the set $F_i \bigcup AG_i$. The (*Second Task*) is composed of a set of subtasks to handle the requests of friendship of the other agents and those of joining sent by the other agents to the groups with which a_i is joined or is a leader (administrator).

First Task. It consists of the following sequence of steps:

1) First, it computes the sets $F_i \bigcup AG_i$, and $\bigcup_{r \in R} PA_i{}^r$.
2) A friendship request is sent by a_i to each agent $a_j \in (\bigcup_{r \in R} PA_i{}^r - F_i \bigcup AG_i)$.
3) The agent a_j is added to F_i if it accepts the friendship request.
4) If the request is refused, then a_i executes the steps:
   a) a_i requires the set G_j of all the groups having a_j as a DF member.
   b) a_i computes the disadvantage D_i^* for each group $g \in G_j$.
   c) a_i sends a joining request to all the group $g \in G_j$ such that $D_i^* < D_i$.
   d) If g accepts then this group is added to G_i, otherwise a_j is added to the set C_i.
5) If C_i is not empty, then a *call for a new group* is sent to all the agents belonging to it by a_i. If some agents agree, a new group is formed and registered into the DF.
6) When an agent a_j is added to the set F_i, then the worst friend agent a_k will be removed from F_i. More in detail, the agent a_k is selected as follows: $a_j \in PC_i^r$, then the agent $a_k \notin (\bigcup_{r \in R} PA_i{}^r)$ having the worst trust value $\tau_{i,k}(r)$ is selected; if $a_j \in PR_i^r$, then the agent $a_k \notin (\bigcup_{r \in R} PA_i{}^r)$ having the worst honesty value $\beta_{i,k}(r)$ is selected.

Second Task. It consists of three subtasks: friendship request, membership request and a call for a new group. When a_j sends a friendship request arrives to a_i, a_i computes a new value for the disadvantage $D_i{}^*$ by adding a_j to F_i and, at the same time, it removes an agent a_k as described in the First Task. Recall that a_i will accept the request coming from a_j only if $D_i{}^* \leq D_i$. When a_j sends to the administrator A_g of a group g receives the membership request, then A_g asks for a vote (positive or negative) to all the agents belonging to g. In particular, each agent a_k will send a consensus only if the insertion of a_j in its same group g will not increase its disadvantage D_k. A call for a new group is sent from an agent a_j and it is accepted by a_i only if the insertion of a_j in the set $F_i \bigcup AG_i$ does not increase its disadvantage D_i.

VI. Experiments

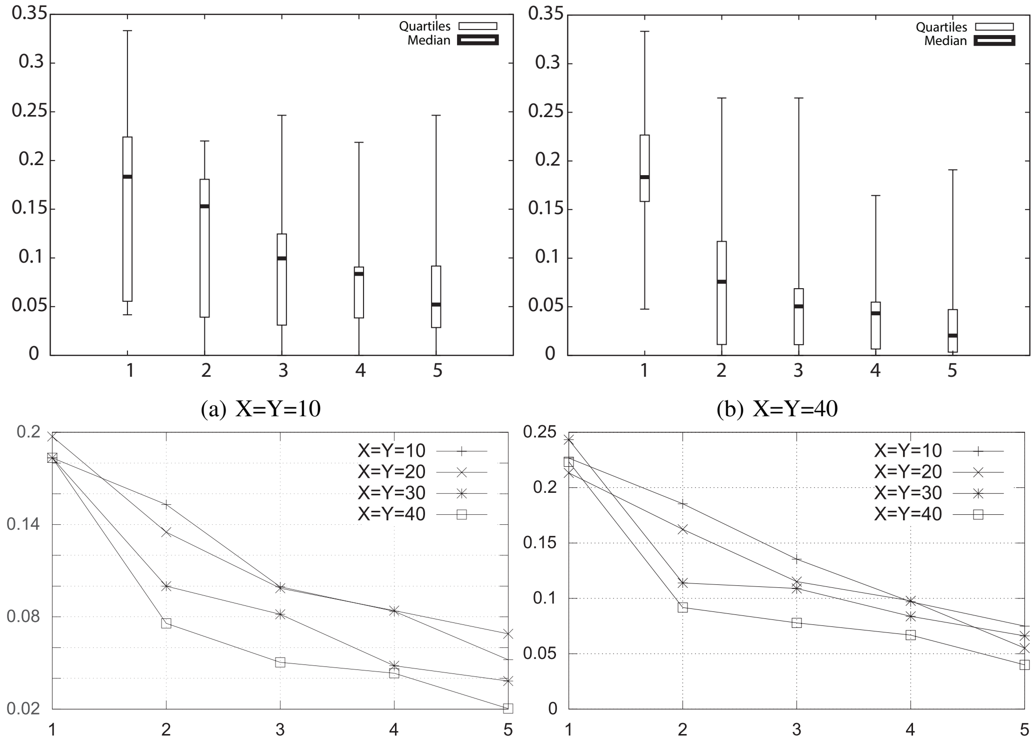
The simulation campaign is conducted on a federation of 1000 nodes. We suppose that the nodes show different behaviours in terms of reliability. Recall that the trust model presented in Section IV provides a single value for measuring the reliability of a federated node. For this reason, we simulate an overall index of reliability for each node, which is intended as the final performance, in terms of overall QoS, of the node which provided the service.

In particular, we calculate the nodes reliability by generating different values for the feedbacks by sampling from a normal distribution with different mean and standard deviation. We split the nodes into three groups based on their performances, i.e. high (H.P.), medium (M.P.) and low (L.P.). Each category has different values of μ and σ. We also suppose that the number of services per step and the number of recommendations are independent events. Then, we generate feedbacks and recommendations by means of the Poisson distribution with parameter $\lambda = 50$ (mean) for the feedbacks and $\lambda = 20$ for the recommendations. We generate an initial network of agents/nodes by setting the degree of the nodes (i.e. its probability distribution) being compliant to a power function $P(x) = Cx^{-\alpha}$, where $\alpha = 2.5$ [49]. To normalise the underlying area, we truncate the function at $X = X_{min} = 5$, which is the minimum degree of the generated network. Finally, a value of $C = 14.4278$ is computed [50]. In other words, we generate the network by adopting the power law model [49], [50].

Now, we show some experiments aimed at confirming that the execution of the FGF algorithm will give a contribution by lowering the Disadvantage D.

Recall that the collaborators for services were selected on the basis of the trust system, as described in Section IV. The Figures 1a-1b supply the median, quartiles and outliers of D for a set of simulations for which we set $\tau^{min} = \beta^{min} = 0.2$, i.e. the minimum value of trust and honesty to select the sets PC and PR, as previously discussed in Section V. While Figure 1a summaries the results for $X = Y = 10$, Figure 1b refers to $X = Y = 40$, where X and Y are the maximum size of the sets PC (Preferred Contributors) and PR (Preferred Recommenders). We see that the median value of the disadvantage has a downward trend. Moreover, as the sets PC and PR grow in size from $X = Y = 10$ (Figure 1a) to $X = Y = 40$ (Figure 1b), the median assumes lower values very quickly, which is the expected behaviour.

Results shown in Figures 1c and 1d report the median value of the Disadvantage D, for X and Y ranging from 10 to 40 by steps of 10. Moreover, in Figure 1c we set $\tau^{min} = \beta^{min} = 0.2$, while in Figure 1d we set $\tau^{min} = \beta^{min} = 0.5$. By comparing data of the two figures, we can observe that the more selective is the parameter τ^{min} (resp. β^{min}), which is the minimum value of trust (resp. honesty) to put a node



(a) X=Y=10 (b) X=Y=40

(c) $\tau^{min} = \beta^{min} = 0.2$. (d) $\tau^{min} = \beta^{min} = 0.5$.

Fig. 1: Disadvantage D.

into the set PC (resp. PR), the greater will be, in average, the disadvantage.

VII. Conclusion

In this paper we presented an agent based model aimed at optimising the global QoS provided in a Federation of computing infrastructures. In this scenario, the nodes are supported by software agents that manage friendships and group memberships. In particular, we introduced the following concepts: (*i*) computational *resource sets* that support tasks in the federation, (*ii*) *agent aggregation* (i.e. friendships and group memberships) as basis of collaboration among federated nodes, (*iii*) the nodes are supported by a *trust* model that compute a unique synthetic trust measure.

We propose the algorithm called FGF that supports the federated nodes to select their partners (friends and group memberships) for improving the global QoS. For this reason, the algorithm exploits trust information to calculate two measures: the (*i*) *disadvantage* (D) and the (*ii*) *Global Capital* (GC).

We presented a few experiments which allowed us to prove that the Global Capital (which reflect the global QoS) of the Global Federation is effectively improved. In our ongoing research, we plan to compare the performance of the FGF algorithm with other similar approaches which are based on aggregations and trust information.

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