Artificial Bee Colony Optimized Scheduling Framework based on resource service availability in Cloud Manufacturing

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***Abstract*—The research on Cloud manufacturing (CMfg) is mainly articulated around the promotion of collaboration among service providers to increase the global manufacturing capabilities and create virtual enterprises that satisfy complex service requirements and designs. For manufacturers, here denoted as service providers, CMfg also presents a valuable enhancement of their resources' occupancy and a way to rapidly expend their business. However, the interplay among service providers is an important parameter to issue when it comes to cloud service scheduling. The collaboration orientation and the resource occupancy must be addressed as the main driver for the scheduling framework establishment. Therefore, this paper proposes a strategy concerning the scheduling approach in CMfg based on resource service availability and globally optimized through Artificial Bee Colony (ABC) algorithm. The precision and efficiency of the present method are discussed in the experiments section.**

Keywords—scheduling; resource availability; artificial bee colony; cloud manufacturing

I. Introduction

The explosion and rapid expansion of the IT spheres along with the emergence of new concepts and trends(e.g. Cloud computing, Cloud services, IoT (Internet of Things), Servitization) are raising new challenges in terms of collaboration and resource orchestration. Indeed, collaboration among the various service providers creates new opportunities and new means of capabilities. It is the foundation layer to enable the structuration of new models like Cloud computing or Cloud manufacturing (CMfg). Collaboration is an essential vectorfor innovations and answers complex requirements and service designs. In this purpose, flexibility at the structural and procedural level must insure the integrity of service providers leading their business the way they always did, but enabling their interplay by a light integration of orchestration for resource service composition, evaluation and scheduling. For instance, CMfg promotes the creation of dedicated manufacturing cloud i.e. virtual enterprises, to manufacture single or mass manufacturing demands. A manufacturing cloud is the result of a procedural sequence to build the right cloud service model in order to achieve the service requirements and design. Once a cloud service composition determined through the requirements definition and service evaluation based on its global QoS level, the resource services selected as cloud services have to be scheduled according to their associated availability and the deadline fixed at the requirements level. Indeed, a service provider might give priority to its own profitability insuring a continuous and equilibrated use of their resources. Therefore, the scheduling process has to locally enhance the resource occupancy and be globally optimized for the whole resource service set. By definition the agent based system, denoted Cloud service platform, must plan the procedure for cloud services to be manufactured, according to the composition model and time allocated for the whole service completion. In distributed systems, action and information time lines are often end-to-end e.g. a causally dependent, multi-node, sensor to actuator sequential flow of execution in networked embedded systems that control physical manufacturing processes [1]. But such an exchange flow is an important time consumption that can be critical with short deadlines. In other words, it is possible for a provider to make a scheduling decision that is locally optimal in terms of the utility that can be accrued, but compromises global optimality. The scheduling exercise is very extensive in the research area, and consequently many methods were proposed over the years. But the emergence of Cloud services and the composition process requires refreshing and innovative approaches to orchestrate their execution overtime depending on the provider's availability and the composition model. Consequently this paper proposes a new scheduling framework for the orchestration of resource service manufacturing based on the service providers' available time slots their availability overtime. But since the pool of selected resources to build the final service can be very large, and according to the service delivery deadline, the number of possible solutions to browse can reach unrealistic levels. The use of an optimization algorithm to smartly query the population of possible solution is fundamental. In this research, we rely on Artificial Bee Colony (ABC) to satisfy a realistic time consumption while maximizing the reliability and manufacturing duration objectives.

II. Related Work

Many scheduling techniques have been developed, applied and proved over the years [2]. Nevertheless new techniques appeared, showing promising results with accrued popularity

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[3, 4]. But the plurality and discordances among the service providers due to the way they run their business, require a higher sphere to orchestrate and deal with resource service manufacturing available time slots. Meanwhile during the past recent years some collaborative scheduling solutions have been proposed. However the drivers and motivations might vary from to another. For instance [5] relies on trust mechanism for the resource collaborative scheduling, and [6] integrates the planning and scheduling to a decision making framework. But in our case, the scheduling process is posterior to a composition and evaluation process that already manages the different QoS, and match the level of requirements. Some relevant scheduling framework have been developed for particular environment and context (e.g. [7] for new Product development (NPD), [8] for mobile robots) but imply service provider to subscribe a full planning management from the agent-based system. From a business perspective, it is preferable to let the providers deal with their planning the way the always did, but to only affect them manufacturing demands on time windows. Very recent publications also include the use of artificial bee colony for optimization [9, 10] but omit the consideration of availability overtime, vector of flexibility for unexpected orders or changes in the manufacturing process.

III. PROBLEM & CONSTRAINTS DEFINITION

Ahead of the mathematical demonstration for the definition of an optimal scheduling time allocation, we propose the following table to define the constraints and variables related to our approach.

TABLE I. CONSTRAINTS AND PROBLEM VARIBALES DEFINITION

Symbol	Definition
S	The service to manufacture, result of a cloud service composition
tstart	The cloud service composition issuing date
tend	The service delivery deadline requested by the customer
cs_i	A given cloud service *i* that can be fulfilled by a single resource service
rs_i	The resource service attached to a given cs_i
Ts_i	The set of time slots for the manufacturing of cs_i using rs_i
ts_j^i	A given time slot *j* defined by a starting time $tstart_j^i$ and a finish limit $tend_j^i$
$tstart_j^i$	The starting time for a given timeslot ts_j^i
$tend_j^i$	The ending time for a given timeslot ts_j^i
$focp_i(t)$	The best fit function along time *t* representative of the resource service occupancy over time
$Mocp_i$, Mav_i	Respectively the maximum occupancy and availability rate allowed for the resource service rs_i (in our case 100%).
$mfgD_i$	The cloud service manufacturing process duration using rs_i for a total availability (i.e. 100%)
Dt_i	The randomly selected starting time such as $\exists ts_j^i$ that $Dt_i + mfgD_i < tfinish_j^i$ and $Dt_i > tstart_j^i$
$t\_mfgD_j^i$	The cloud service manufacturing duration function of the randomly selected Dt_i and $focp_i(t)$.
ε_i	The aggregated margin time between the following service manufacturing starting time and the ending time of the current manufacturing process.

The objective and benefits of the scheduling framework must be appreciated from two different angles. From a customer's view, the goal of the scheduling process is to allocate the resource service to manufacture in such way that the final service will be delivered to him before his requested delivery date. Therefore one objective would be to minimize *Tmfg* the global manufacturing duration for the service order *S* and so increase the customer's satisfaction. From a service provider's consideration, a large time window allocated for the resource manufacturing is an important vector of his flexibility to locally arrange his schedule. To fully present the present scheduling framework, we must focus on the time slots and availability definition, vectors of the fitness function i.e. the vector of customer's and provider's satisfaction. But beforehand we introduce the different resource service composition model.

IV. RESOURCE SERVICE COMPOSITION MODEL

The four composition models i.e. sequence, parallel, selective, cycle, are presented as follow i.e. fig. 1.

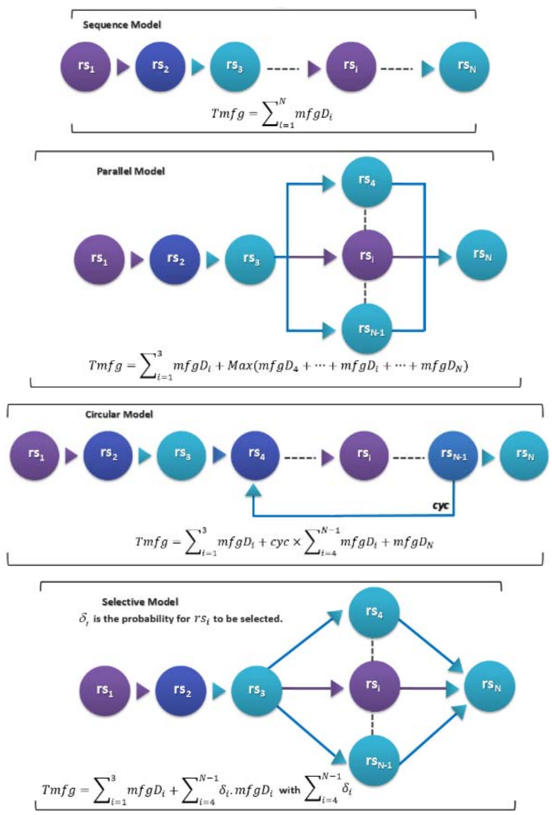

Fig. 1. Resource service composition models (i.e. sequence, parralel, cycle, selective)

These representations will help us to introduced the global manufacturing time for the four composition cases, and determine the feasibility or not within the time window *tstart* and *tend*. Indeed, before exploring the possible solutions we must insure that *tend* is sufficient to trigger the scheduling process. The different composition models affect the global manufacturing duration calculation. Therefore, the cloud platform service must insure the feasibility of the service order *S*. From a readability concern, the associated equations (i.e. equation 1, 2, 3, and 4) to calculate the global manufacturing duration for the four composition models are indexed as represented on the picture ($i = 4$ to $i = N - 1$).

$$Tmfg_{seq} = \sum_{i=1}^{N} mfgD_i \quad (1)$$

$$Tmfg_{par} = Max(mfgD_i);\ \forall i \in [4, N-1] \quad (2)$$

$$Tmfg_{sel} = \sum_{i=4}^{N-1} \delta_i \times mfgD_i \quad (3)$$

$$Tmfg_{cyc} = cyc \times \sum_{i=4}^{N-1} mfgD_i \quad (4)$$

The objective is to insure the following equation to trigger the scheduling process with the resource services selected i.e. equation 5.

$$Tmfg + tsart < tend \quad (5)$$

Now we can concentrate on the time slots and availability definition for the solution fitness evaluation.

V. TIME SLOTS AND AVAILABILITY OVERTIME DEFINITION

Our approach concerning the establishment of the scheduling framework is based on the consideration of a realistic view of collaboration and sharing. Indeed the degree of involvement to the cloud platform is driven by the will of the service provider himself. To promote such a model as CMfg, the level of integration from a service provider perspective must restrain itself to the resource capabilities and occupancy. When considering a full collaborative integration the flow of planning between the cloud platform service and the associated service providers can represent an important loss of time. To overcome this limitation we fix our scope on the availability (or by opposition occupancy) of the employed resources. Technically when a resource service candidate is selected as cloud service, a request form is issued to the service provider to return the available time slots until the deadline fixed by the customer's requirements. The time slots can not only be under resource availability limitations but also human resources for machinery exploitation. Figure 2 is an example of time slots definition for a given resource and a given time window i.e. *tstart* and *tend* the service delivery deadline.

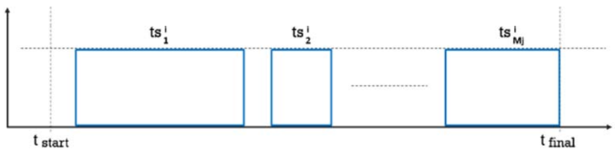

Fig. 2. Available time slots for resource service manufacturing

Beforehand we consider a service to manufacture *S* defines by the following equality i.e. $S = \{rs_1, rs_2, \ldots, rs_i, \ldots, rs_N\}$ with $i = 1,2, \ldots N$ and $N \in \mathbb{N}$. For a given resource rs_i , the available timeslots returned are defined as $Ts_i = \{ts_1^i, ts_2^i, \ldots, ts_j^i, \ldots, ts_{M_i}^i\}$ with $j = 1,2, \ldots M_j$ and $M_j \in \mathbb{N}$. A time slot ts_j^i is defined by the couple $tstart_j^i$ and $tend_j^i$ i.e. respectively the starting time and finish time of ts_j^i. We note that $\forall M_j \in \mathbb{N}, tend_{Mj}^i \leq tend$ with $tend$ the requested delivery date.

As already mentioned, the timeslots are returned by the service provider to indicate the time windows when the resource can perform the manufacturing service between the service processing starting date and the final deadline. The objective is to select a time slot where the availability is maximal (i.e. occupancy minimal) to minimize the manufacturing duration (Fig. 3.).

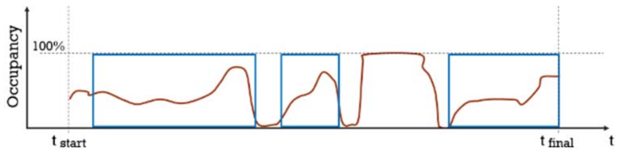

Fig. 3. Availability overtime

The occupancy for a given time slot ts_j^i is expressed using the following definite integral (i.e. equation 6).

$$ocpRs_i(ts_j^i) = \int_{tstart_j^i}^{tend_j^i} focp_i(t)dt \quad (6)$$

By analogy, we can express the availability $avRs_i(ts_j^i)$ by subtracting the occupancy $ocpRs_i(ts_j^i)$ to the maximum occupancy allowed, i.e. the equation 7.

$$avRs_i(ts_j^i) = Mocp_i(tend_j^i - tstart_j^i) - \int_{tstart_j^i}^{tend_j^i} focp_i(t)dt \quad (7)$$

In our approach, we should now focus on the selection of a manufacturing starting time Dt_i and its impact on the objectives definition.

VI. FITNESS EVALUATION BASED ON MFG STARTING TIME

For a given cloud service to manufacture using the resource rs_i , the duration $mfgD_i$ issued by the service provider himself, encompasses the resource setup and the manufacturing duration for a full availability (i.e. Mav_i). However if the resource present an existing occupancy overtime, the manufacturing duration will raise higher than $mfgD_i$. Thus we obtain the real manufacturing duration $t\_mfgD_j^i$ from the time slot where $Dt_i \in ts_j^i$ expressed using the following equation (i.e. equation 8).

$$t\_mfgD_j^i = \frac{Mav_i(tend_j^i - tstart_j^i)}{avRs_i(ts_j^i)} \times mfgD_i \quad (8)$$

With $t_mfgD_j^i$satisfying the condition:

$$tstart_j^i \leq Dt_i + t\_mfgD_j^i \leq tend_j^i \quad (9)$$

Now for the fitness evaluation of the solution generated we consider the benefits in terms of manufacturing duration and service order manufacturing reliability. The total manufacturing duration *Tmfg* can be calculated from the equation 1, 2, 3 and 4 using $t\_mfgD_j^i$. To evaluate manufacturing duration we rely on the use of a utility function to return the score of a solution according to the composition model considered (i.e. equation 10, 11, 12 and 13).

$$U(t)_{seq} = \frac{mfgS - \sum_{i=1}^{N}(t\_mfgD_j^i + \varepsilon_i)}{mfgS - \sum_{i=1}^{N} mfgD_i} \quad (10)$$

$$U(t)_{par} = \frac{mfgS - Max(t\_mfgD_j^i + \varepsilon_i)}{mfgS - Max(mfgD_i)} \quad (11)$$

$$U(t)_{sel} = \frac{mfgS - \sum_{i=1}^{N} \delta_i \times (t\_mfgD_j^i + \varepsilon_i)}{mfgS - \sum_{i=1}^{N} \delta_i \times mfgD_i} \quad (12)$$

$$U(t)_{cyc} = \frac{mfgS - cyc \times \sum_{i=1}^{N}(t\_mfgD_j^i + \varepsilon_i)}{mfgS - cyc \times \sum_{i=4}^{N-1} mfgD_i} \quad (13)$$

With $mfgS = tend - tsart$, i.e. the time window for the manufacturing of the service S.

The reliability associated to a resource rs_i is vector of the flexibility offered by the scheduling solution determined and characterized through ε_i.

$$Rel_i = \begin{cases} relrs_i + \dfrac{\varepsilon_i}{t\_mfgD_j^i} \times \dfrac{relrs_i}{Rel_{max}}, \text{if} > Rel_{max} \\ Rel_{max} \quad \text{otherwise} \end{cases} \quad (14)$$

The variable Rel_{max} is the maximum reliability i.e. in our case 100%. Thus, the utility function associated for the reliability quality evaluation is defined as follow (i.e. equation 15 and 16).

$$U(rel) = \frac{\prod_{i=1}^{N} Rel_i}{Rel_{max}} \quad (15)$$

$$U(rel)_{sel} = \frac{\sum_{i=1}^{N} \delta_i \times Rel_i}{Rel_{max}} \quad (16)$$

Consequently the fitness is the balance between the manufacturing duration and the reliability. For this purpose we introduce the weights ω_t and ω_{rel} such as $\omega_t + \omega_{rel} = 1$, and vector of the customer's and provider's priorities.

$$fit = \omega_t \,.\, U(t) + \omega_{rel} \,.\, U(rel) \quad (17)$$

In the present evaluation process the unknown variable to decide Dt_i is randomly chosen. Since the population of possible solutions can encompass a large set, if to evaluate all the possibilities one after another, the process might lead to unacceptable time consumption. That's we rely on ABC (Artificial Bee Colony) to optimize our scheduling framework.

VII. ARTIFICIAL BEE COLONY (ABC) OPTIMIZATION INTRODUCTION

ABC optimization algorithm was proposed by Dervis Karaboga, reproducing the honey bees behaviour during their foraging cycle [11]. The bees swarm is divided in 3 groups i.e. employed bees, onlooker bees and scout bees. Employed bees go randomly in the food source population to exploit food sources with higher nectar. By interpretation a food source refers to a possible solution to the problem, and the related nectar amount to the associated fitness. Thus the onlooker bees positioned themselves in the space according to the fitness evaluated so far, and try to identify better food sources in the area of the one selected. Meanwhile, employed bees for which the food source have been abandoned, become scout bees to discover new random food sources. An onlooker bee chooses a solution depending on the probability value p_i associated with itsfitnesscalculated i.e. eq. (18).

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \quad (18)$$

A new schedulingsolution is generated from the previous one in the memory using the velocity equation i.e. eq. 19.

$$v_j^i = x_j^i + \varphi_j^i(x_j^i - x_j^k) \quad (19)$$

With $k \in \{1,2,\dots,SN\}, k \neq i$ and $j \in \{1,2,\dots,D\}$ randomly chosen indexes as $\varphi_j^i \in [-1,1]$.Meanwhile, ABC is function of three controlled parameters for the search and evaluation of food sources.

- The *limit* is the number of cycle, during which one, each bee will search for better food sources in its neighborhood. If the fitness is not improved by then; the food source is abandoned.
- The *NP*, the number of colony size (employed bees + onlooker bees).
- *MCN* (Maximum Cycle Number) refers to the maximum foraging cycle.

VIII. CMFG SCHEDULING FRAMEWORK

The scheduling framework is the result of our approach to maximize availability overtime and optimize through ABC. The framework can be parameterized by the ABC control parameters and is presented as follow i.e. fig. 4.

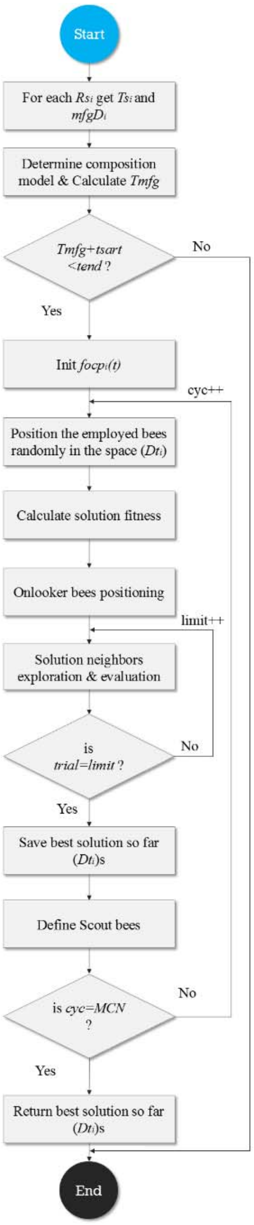

Fig. 4. CMfg scheduling framework

IX. ABC_CMFGSCH AN OPTMIZED SCHEDULING ALGORITHM FOR CMFG

ABC aims at maximizing our fitness function and reach the optimal time allocation. Thanks to our method, the global resource service manufacturing is issued for an optimal *Tmfg* along the overall reliability *Rel* without browsing all the possibilities. ABC_CMfgSCH is the result of our framework and approach based on availability analysis. ABC_CMfgSCH route is similar to the common ABC route although we integrate our own fitness evaluation and composition model discovery.

ALGORITHM I. ABC_CMFGSCH

```
for each rs_i
   get Ts_i;
end
Get composition model;
if Tmfg+tsart<tend
   Initialize focp_i(t), NP, limit, and MCN
   while cycle<MCN repeat
        //Employed bees phase
        find new food sources v_j^i;// eq. 19.
        for each Dt_i
                calculate avD_i(ts_j^i);//eq. 7.
        end
        Calculate fitness;//eq. 10-17
        Select best food sources;
        //Onlooker bees phase
        while trial<limit repeat
                Select new food sources in the area;
                for each Dt_i
                        Calculate avD_i(ts_j^i);//eq. 7.
                end
                        Calculate fitness;//eq. 10-17
        end
        Save best food source;
        //Scout bees phase
        Send scout bees to find new food sources;
        cycle++;
    end
end
return best solution Dt_1,...,Dt_i,...,Dt_N;
```

X. EXPERIMENTS

The environment for the following experiments are articulated around the ABC control parameters and the time unit variable considered, vector of the time allocation precision. Indeed, while focusing on scheduling with a concern of hours instead of days, the precision is accrued although the computational time will be increased. For the following experiment we consider a period (i.e. *tend-tsart*) of 30 days, with the unit of time expressed in hours (i.e. 12 working hours per day, so 360 hours period). We fixed the weights ω_t and ω_{rel} as $\omega_t = \omega_{rel} = 0.5$. Concerning the ABC tuning parameters, recent researches [12] on their expression according to the problem size remain fuzzy, since the bees propagation is based on a random distribution. That's why we deliberately linearized these parameters (i.e. *NP, limit* and *MCN*) according to the problem size.

$$Pop_n = \prod_{i=1}^{N} \sum_{i=1}^{N} \sum_{j=1}^{M_j} (tend_j^i - tstart_j^i) \qquad (20)$$

Consequently we expressed the 3 control parameters as follow (i.e. *NP, limit* and *MCN*), where *MCN* is main driver for the balance between time consumption and optimal fitness precision.

$$NP = \frac{N(tend - tsart)}{100} \quad (21)$$

$$limit = 5NP \quad (22)$$

$$MCN = {Pop_n}^{0.1} \quad (23)$$

For the following experiment we consider a sequence model composed of 10 resource services (i.e. $N = 10$) with 200 time units divided in 4 time slots for each resource service. Therefore the number Pop_n is equal to 1024×10^{20}.

Now we focus on the fitness evaluation over computational time. We also compare the evolution of ABC_CMfgSCH toward the same approach optimized through genetic algorithm (i.e. fig. 5).

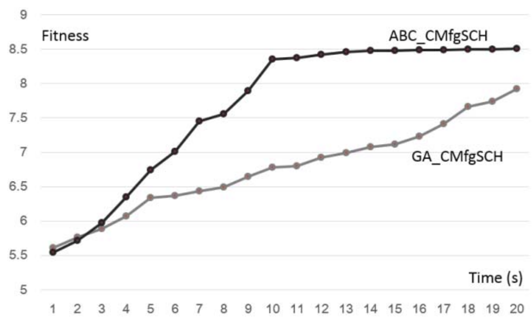

Fig. 5. ABC_CMfgSCH fitness evolution toward GA_CMfgSCH

We can easily observe the benefits of ABC optimization able to reach a higher fitness with a minimum time. In this particular test, we obtain the following manufacturing time and reliability outputs (i.e. Table 2).

TABLE II. MANUFACTURING TIME AND RELIABILITY OUPUT

Manufacturing Time $\sum_{i=1}^{N} (t\_mfgD_j^i + \varepsilon_i)$	**Reliability** $\prod_{i=1}^{N} Rel_i$
162 h ($\sum_{i=1}^{N} mfgD_i$ =110h, $mfgS$ =360h)	94%

The table 2 shows the result of our method, and the improvement for time manufacturing allocation minimizing the manufacturing duration and maximizing the reliability associated.

XI. CONCLUSION & FUTURE WORK

The present scheduling framework offers significant benefits in term of service manufacturing. From an availability concern and providers time slots, ABC_CMfgSCH is able to reach the optimal balance between the manufacturing duration and the reliability associated to the service manufacturing process. However some improvements could be integrated in order to reinforce the optimization of manufacturing duration in terms of setup and machine calibration. Indeed the service to manufacture might require complex presets and time consuming. Therefore, a correlation tool matching similar services to manufacture in the available time slots could seriously reduce the machine setup duration. By extension, our future research is centered on transportation and integration to the present scheduling framework.

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