Workflow Resource Allocation through Auctions

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Abstract

Nowadays business processes of the manufacturing industries are becoming more complex delocalizing its production plants and outsourcing more parts of their production processes. This involves a lot of uncertainty, making the production planning, control and resource allocation complex. To deal with that issue, we propose a methodology for allocating resources into distributed manufacturing environments using a multi agent workflow management system and reverse sealed bid auctions. In this paper two different auctioning strategies are presented, one for reducing economic costs and one for reducing production time. In order to test our approach we simulated different situations using different kinds of workflows and resources, getting promising results both in economic and time terms.

1 Introduction

The economy globalization is driving many manufacturing industries towards the decentralization of their production processes. This means not only to distribute the production into different factories and production plants but also to outsource some steps of the chain production, increasing the complexity of the supervision and the planification of the production processes.

The production chain is no longer able to be controlled by a single entity. The status of the production resources (e.g. technicians, transports, services, etc.) is unknown as they can be managed by different departments inside the organization or even by outsourcing companies which are in charge of dealing with a certain part of the business process. Moreover, the intervention of third party elements also difficults the cost optimization creating a confrontation between the manufacturers, which try to obtain the lowest price and the higher quality in the market, and the outsourcing companies which tries to maximize its benefits and its occupation. Each outsourcing company has it's own schedule with customers which cannot be seen by others due to privacy issues. An example of this situation is a medical device maintenance service of an hospital. In a medical environment, medical devices need different maintenance operations such as revisions, reparations, reconfigurations, etc. Some of them can be scheduled in advance, nevertheless others such as fault reparations or contingencies cannot be planned thus affecting the normal development of the hospital. This tasks must be carried out by qualified technicians which can be part of the hospital staff itself but some times outsourcing technicians are required.

Production methodologies such as *Lean Manufacturing* [Shah and Ward, 2003], which are strongly customer-oriented, postulate that production must strictly satisfy customer demand and specifications to avoid creating any unnecessary values and without resorting to unnecessary work. This approach encourages the interaction between the manufacturer and the customer and it also empowers the customization of the final product. Thus, the flexibility in the production chain allows the producer to introduce modifications into the original design without affecting other tasks. The Lean philosophy can be used in embedding processes where the customer can personalize its order, assembling only the required pieces and without having pre-assembled stock, saving storage space and reducing the number of waste stocks. To meet these requirements, production can be realized under demand: allocating resources on real time without taking into account possible future processes which could never be started. From the scheduling point of view, this means that the planing for a business process is not planned until it is demanded and that the business process do not allocate a resource until the task which requires the resource is about to start.

The main characteristics of these new manufacturing scenarios are dynamism, decentralization, collaboration with outsourcing third partys, contingency robustness and customer orientation. Therefore a lot of uncertainty is involved, making the production planing and control complex. Our work concerns the research for new tools that support managers in these environment. We propose a methodology for allocating resources into distributed manufacturing environments based on compounding workflows with multi agent system (MAS) and auctions for resource allocation being resource used from a wide scope: a technician intern to a company, a service provided by third party company, etc.

On the one hand, MAS provide an infrastructure in which different companies can be coordinated to deploy an activity while maintaining their schedule and customers appointments in privacy. On the other hand, auctions offer companies the

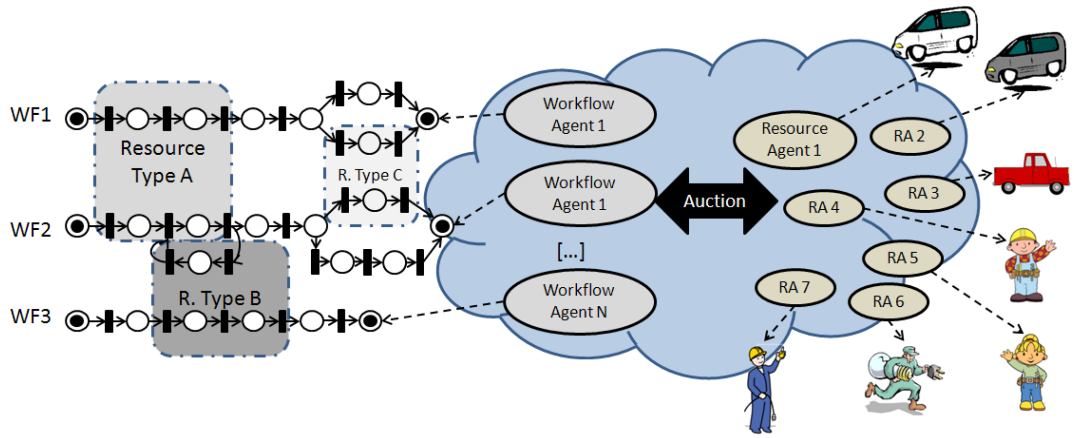

Figure 1: Schema of the system architecture: each workflow type is monitored by a Workflow Agent while each resource is represented by a Resource Agent.

chance to compete for providing a resource or service to a manufacturer without revealing private information [Chevaleyre *et al.*, 2006]. Thus, workflows are handled by agents which, in turn, use auctions for negotiating for the resources they need to accomplish their activities.

The use of auctions for resource allocation benefits the manufacturer not only decreasing the outsourcing prices, but also increasing the occupation of its own resources. On the one hand, workflows will be able to minimize the cost of the resource by comparing the different bids offered by the available resources and they will be also able to decide which resources are more suitable to fit in their timing compromises without the need of accessing to their agendas. On the other hand, when internal resources receive incentives for they use, auctions balance its workload as resources tend to maximize its occupation.

2 Background

To manage the evolution and the interactions of the business processes it is important to accurately model the steps to follow in the activity, the resources needed and the flow of information between the different parts involved (suppliers, manufacturers, clients, etc.). Workflows provide a way of describing the order of execution and the dependent relationships between the constituting activities of the business processes [Tick, 2002]. Workflows usually model single and unique business processes, nevertheless, in real life environments, workflows are rarely executed individually. Workflows usually run concurrently, sharing a limited number of resources which some times are provided by third party companies.

A workflow consists in a graph of interconnected actions which represents the tasks and interactions to be realized by a mechanism, a person, a staff, an organization, etc. Workflows can model business process, exchange of messages and software procedures or information.

A workflow instance is a workflow which is being executed in a concrete time instant. For example, a workflow can model the business process required to do maintenance in a medical equipment; then, when a medical device requires a maintenance operation, a workflow instance is created. When several workflows are coexisting in a common framework (e.g. an organization, an industry, a server, etc.) where they share resources, actors or information they are called a workflow environment. Workflows can be controlled and monitored by a workflow management system (WMS).

WMS manages and monitors the different tasks which take place inside an organization or a workflow environment. It is responsible for monitoring the status of the different workflows and to store in a log the different events related to the workflow deployment. WMS can also be responsible of the assignment of resources to workflows and their schedules.

3 Related Work

There are several previous works related to the application of agents to workflow management systems to support cooperation activities. For example, [Juan *et al.*, 2009] uses agents to facilitate the collaboration of multi-disciplinary workgroups in a company for design products following a concurrent new product development strategy They start with predefined requirements of cooperation, and the multi-agent approach is used to achieve such requirements. Conflicts can arise when there are different points of views on cooperative tasks, and they are solved by specific cooperation diagrams. Our proposal includes different ways of conflict resolution, by means of auctions. In [Guo *et al.*, 2008] a decentralized multi-agent architecture is proposed workflows. Particularly, the authors face the problem of interoperability between heterogeneous agents and they propose the use of business modeling languages as BPEL4WS [Wohed *et al.*, 2003]. In our case, we are assuming that agents are able to understand each other; so this assumption can be leveraged with the complementary approach offered in [Guo *et al.*, 2008].

A founder work in this field is [Jennings *et al.*, 2000], in which the authors explore the use of agents to enact cooperation at the business level thanks to the advent of Internet. In this case, workflows are not fixed, but agents represents collections of services that can be combined (by agents negotiation) to compound business process. This approach is a radical one, since it requires from a novel point of view of current business. Our approach is a step forward to achieve such a revolution, but by following an evolutionary approach. So we are starting from the current tools that are in the industry (workflows) and provide a way to make them more flexible thanks to agents. This less-drastically approach could be more useful to non-Internet based business models.

Other approaches regarding workflows and agents can be found in the recent published survey [Delias *et al.*, 2011]. Our approach differs from the previous ones in the way resource conflicts are being handled, taking into account penalties. Moreover, we respect current WMS while proposing an extension that takes advantage of current advances on agents, which improves monitoring capabilities of WMS (reducing, for example, delays).

4 Auction-based workflow resource allocation

We propose to handle both workflows and resources within a multiagent WMS which monitors and organizes the course of the manufacturing process. For that purpose two different kind of agents are used: the workflow agents (WA), one per workflow, and the resource agents (RA), one per existing resource. As Figure 1 shows, WA supervises the workflow it represents and when a resource is needed it summons a reverse sealed bid auction [Amelinckx *et al.*, 2008] indicating the desired conditions (minimum starting time, maximum ending time, resource type, etc.) and a penalty to pay if a contract is broken, becoming, thus, an auctioneer. Then, resource agents evaluate their agendas and decide to participate or not to the auction depending on the auction conditions and the possibilities the resource have to finish the task on time.

Auctions have three main elements:

- **Winning Determination Problem** (WDP), handled by the auctioneer (WA).
- **Bidding Policies**, which are the bidding strategies followed by the bidders (RA).
- **Pricing Mechanism**, which defines the payment methods between agents.

In our approach we follow a reverse sealed bid auction, meaning that the role between the auctioneers and the bidders is reversed as the auctioneer is the one who wants to buy a good, not to sell it. While ordinary auctions provide suppliers a chance to find the best buyers, reverse auctions give buyers an opportunity to find the lowest-price supplier and improving the chances of improving a fair market value. To encourage the resources to bid according to the market value, bidders submit its proposals simultaneously, without knowing other participants bids and the one with a lowest value becomes the winner. To prevent fraudulent bids, agreement repudiation or delays into the ending time agreement, auctions are endowed with a penalty mechanism that allows the agent to fine the resources which do not accomplish the established agreements.

4.1 Workflow Agents: The Auctioneers

Workflow agents are the ones responsible for monitoring running workflows and for obtaining the necessary resources to

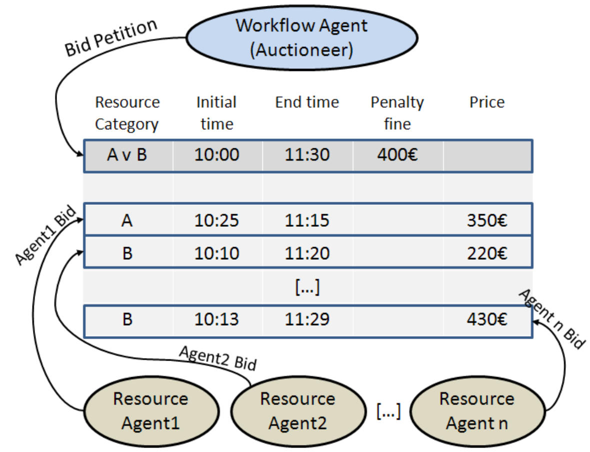

Figure 2: Example of a resource action. If the WDP considers the lowest price as the winning policy, Resource Agent 2 would be the winner, otherwise, if time is considered, Resource Agent 1 would be the winning resource

finish them in the required time. Each WA monitors just one workflow, which is modeled using high level Petri nets (PN). Each time a workflow should be started, a token is add to the start node of the PN. For example, a workflow can model the repair process of a medical device. Thus, each time a medical device needs to be repaired, a token is added to the workflow, meaning the instantiation of the workflow.

Workflow modeling using high level Petri nets has been broadly studied [Alt *et al.*, 2006]. As our work is specially focused on resources, we need to take care of the kind and number of resources needed for every task inside the workflow. In order to satisfy this requirement we extended the Petri Net representation with a new *resource* element [Pla *et al.*, 2011]. We called this extension *resource-aware Petri nets* (RAPN). RAPN incorporate resources to high level Petri nets. Resources are related with sets of consecutive transitions where the first transition is the one which allocates the resource and the last is the one which releases it. If there are not available resources of the required type by a transition this transition cannot be fired until a resource of the desired type can be used.

When a resource is needed in a workflow activity, the WA must obtain a suitable resource to satisfy the agent requirements. By suitability we mean that activities have not a specific resource assigned to them (e.g. technician 1) but features of the resource (e.g. a technician with a specific license). In the call, the auctioneer specifies the different attributes to be fulfilled by the resource willing to deploy the task (e.g. minimum resource license, starting time and ending time.). According to the interests of the workflow agent the determination of the auction winner can be solved in two different ways:

- **Balanced Strategy:** The winner of the auction is the bid which offers the lowest price (in Figure 2 winner agent would be Resource Agent2). This strategy decreases the costs for the workflow agent while promotes a balanced market price as bidders tend to offer reasonable prices in order to avoid the loss of customers. The balanced strategy is suitable for dealing with outsourcing resources as it can obtain fair prices. However, it is also useful when dealing with inside company resources as when an equilibrium market price is reached since bidders try to maximize its benefits by increasing its occupation arising the productivity of the local company resources.

- **Delay Prevention Strategy:** This strategy favors the shortening of the workflow timings and in a reduction of delays by setting the auction winner taking into account the ending time (in Figure 2 winner agent would be Resource Agent1). By setting as winner the bid with an earliest ending time, the ending time for the workflows will be shortened but the economic cost will be higher than the one obtained in the balanced strategy. This fact makes this strategy specially indicated for dealing with the own company resources where costs are not the hardest constraint.

As seen in Figure2, the policy adopted in the WDP will change the system behavior and benefits.

4.2 Resource Agents: The Bidders

The interests of the resources are also defended by agents. Each resource is represented by RA which is defined by its category (the set of tasks feasible by the resource), the schedule of tasks (agenda), an estimation of the time needed to achieve certain procedures and its time constraints. The main goal of each agent is to maximize its benefit and, in consequence, to maximize and to capitalize its occupation.

Resources are free to decide whether to participate in an auction or not and to set the bid they consider convenient, however the bidding strategies they choice must be in concordance with their aims. RAs must bid taking into account their agenda, the benefits that behave their schedules and the penalties that accomplishing their timetables. These facts will define the character of the RA. For example an agent could decide to cancel one of its planned activities if the benefits of accepting another task and paying the corresponding penalty overcomes the profits generated by the scheduled task. Agents can also offer risky bids, using its experience they can analyze the probability of ending a task on time; as RA are charged with penalties when they do not end tasks on time, they can assume the risk arising the bid price according to this probability in order to amend the fine in case of delay. As a first approach we have defined bidders capable to adapt their prices to the market, increasing its prices when the demand is high and decreasing them when demand is lower[Lee and Szymanski, 2005]. Fines evaluation will be included in a future work.

5 Experimentation

In this section the previously presented methodology is tested to evaluate the Multi-agent WMS performance and benefits when using different auctioning strategies. Using the workflow simulation engine presented in [Pla *et al.*, 2011] a workflow environment with common resources have been simulated. The experiments are evaluated in terms of economic cost (agent benefits and costs), workload balancing and delays in the process execution.

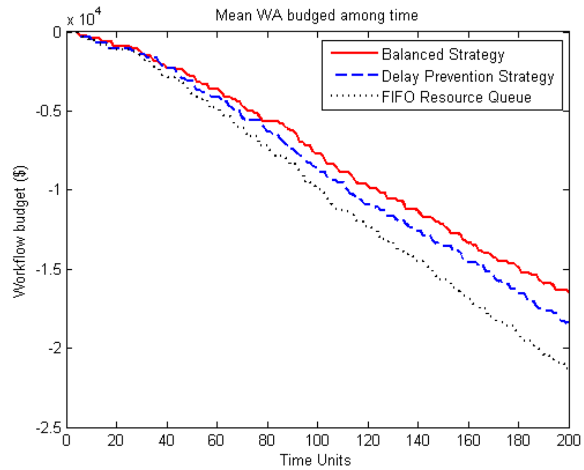

Figure 3: Mean Workflow agents' budget in Scenario1

5.1 Experimental Set Up

To test the performance of our system we modeled and simulated a set of three synthetic workflows. Each of these workflows is composed by four different tasks which have a duration compressed between 10 an 15 time units and needs a resource of a randomly assigned category (between A and F). In consequence, each workflow has a duration between 40 and 60 time units and requires between 1 and 4 different resources. In the simulation, the number of tasks that will be executed is unknown as it simulates and organization where workflows are not scheduled, they arrive under demand.

The two previously defined auctioning strategies, *Balanced Strategy* and *Delay Prevention Strategy*, have been evaluated. Besides the auction resource allocation methodology, a simpler scheduling method have been used in order to compare the two methodologies. For that purpose a *First In First Out* resource queue have been used. Every time a workflow needs a resource of a concrete type, it checks a list of the system resources and uses the first available. In cases of two workflows requiring the same resource, according to the FIFO strategy, the first workflow to ask for the resource would be the first one to be served.

To evaluate our methodology two different scenarios have been tested:

Scenario1: This scenario simulates a workflow environment with four different resources during 200 time units and with a probability p of starting a new workflow $p = 0.2$. Each resource can perform tasks of three different categories (RA1: A-B-C. RA2:A-B-D. RA3:C-E-F. RA4:D-E-F). This experiments shows the behavior of the methodology in a common situation: the number of resources is lower than the number of workflows that requires them.

Scenario2: This scenario repeats the previous experiment but with a significant difference, this turn, each resource can perform any type of task (A-F), increasing competency between resources. This scenario lasts 200 time units and with a probability p of starting a new workflow $p = 0.2$. The aim of this experiment is to evaluate the behavior of the system when there is a high competitivity between similar agents and how the workload is distributed.

Both scenarios have been repeated 20 times for each auctioning strategy and for the FIFO resource queue in order to obtain significant results.

5.2 Results

The results of the different experiments are shown in Tables 1 and 2. In them, information about economic costs and delays produced are given. As each experiment has been repeated several times, the results are expressed in terms of mean and coefficient of variation. Some graphical examples are also presented.

Table 1 presents the results of the first scenario. Regarding delays, as it was expected, it can be seen that, while the *Balanced Strategy (BS)* and the FIFO resource queue (FRQ) produce a similar number of delays (5,6 and 6,4 in average respectively), using the *Delay Prevention Strategy (DPS)* significantly reduces the number of delays (2,2). Second, from the economic point of view, Figure 3 shows how the use of the BS reduces the money spent by WAs and, as a consequence, the average earns by RAs also decreases.This figure also shows that the DPS also reduces the costs respect the FRQ. Another interesting fact which can be observed in Table 1 is that using the BS the variance of the resources benefits is up to 4 times lower than in the other two strategies, indicating that the resource agents have offered similar prices, reaching a more balanced price market.

In Table 2 we can observe how the results of the second experiment are similar to the previous one: DPS reduces the number of delays during workflow executions while the use of agents reduces the costs for the workflows. A relevant point in this experiment is the variation coefficient of the resource agents' incomes. We can see how the use of auctions (specially using a BS) decreases the resource prices and reduces the variability of these costs respect a FRQ. In this sense it is important to notice that when all the resources of an environment have the same properties, the BS tends to homogenize the cost of the resources: the coefficient of variation of resource benefits is $6,67\%$ against the $18,33\%$ of the DPS and the $33,96\%$ of the FRQ. Comparing this coefficient with the one obtained in the first scenario (where all the resources had different capabilities) by the BS $10,74\%$ we can corrobarate how the more similar the resources are the more balanced the price market becomes. Finally, Figure 4 illustrates how the workload of the agents have been also balanced conversely the FRQ. The plot shows gaps in the RA occupation and how in the FRQ resources are not starting to work until previous resources in the resource list are occupied while using BS the occupation of the resource is rather more balanced.

The performed experiments have shown how the BS decreases the costs for the WAs and how equilibrates the benefits between similar RAs. Moreover, BS can balance the workload between agents when they have similar capabilities. Regarding DPS, we observed that it significantly reduces the number of delays respect FRQ and it also reduces the economical costs, although not as much as BS.

Table 1: Results of a common situation in therms of resource availability.

	BS	DPS	FRQ
Delayed Workflows	5,60	2,20	6,40
WF1 Spent Money	15846,00	16308,00	20758,00
WF2 Spent Money	17806,20	20723,40	19814,00
WF3 Spent Money	19280,60	22146,00	22028,00
Total Spent Money	52932,80	59177,40	62600,00
Mean Spent Money	17644,26	19725,80	20866,67
Std Dev	1723,02	3044,17	1111,00
Coef. Variation (%)	9,76	15,43	5,32
Resource1 Earned $	15068,80	18005,60	16880,00
Resource2 Earned $	12228,80	21692,40	19800,00
Resource3 Earned $	11997,60	10148,20	11616,00
Resource4 Earned $	13637,60	9331,20	14304,00
Total Earned Money	52932,80	59177,40	62600,00
Mean Earned Money	13233,20	14794,35	15650,00
Std Dev	1422,26	6036,77	3503,34
Coef. Variation (%)	10,74	40,80	22,38

Table 2: Results of a scenario where all the agents are competing to provide the same resource typology.

	BS	DPS	FRQ
Delayed Workflows	5,80	2,60	8,20
WF1 Spent Money	16003,40	18229,00	23907,40
WF2 Spent Money	19602,60	20695,80	24046,80
WF3 Spent Money	22417,20	23751,00	25802,60
Total Spent Money	58023,20	62675,80	73756,80
Mean Spent Money	19341,07	20891,93	24585,60
Std Dev	3214,89	2766,22	1056,26
Coef. Variation (%)	16,62	13,24	4,29
Resource1 Earned $	13238,00	13897,80	23240,20
Resource2 Earned $	14859,20	18832,20	24408,00
Resource3 Earned $	14668,40	12665,40	12354,60
Resource4 Earned $	15257,60	17280,40	13754,00
Total Earned Money	58023,20	62675,80	73756,80
Mean Earned Money	14505,80	15668,95	18439,20
Std Dev	880,12	2872,93	6262,31
Coef. Variation (%)	6,67	18,33	33,96

6 Conclusions and Further work

This paper concerns an important problem for the manufacturing industry: how to allocate internal and foreign resources or services in a decentralized production processes while maintaining customers appointments and providers schedules in privacy. Our work is also related with flexibility issues in the production chain as provides mechanisms for managing customer-oriented production methodologies such as *Lean Manufacturing*. We proposed a methodology which combines workflows with MAS and auctions. On one side MAS offers a framework where companies can coordinate and deploy their activities without jeopardizing privacy or flexibility. On the other side, auctions can be useful for resource allocating in different senses: minimizing costs of external

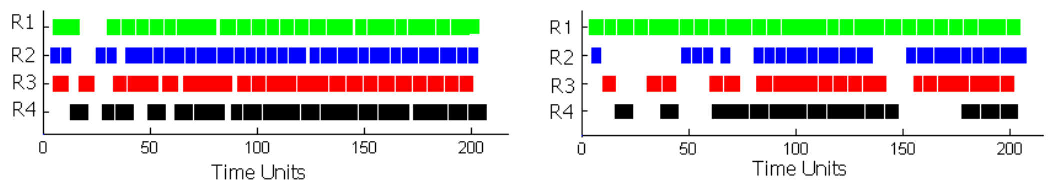

Figure 4: Resource occupation on Scenario2. Left: Occupation using BS. Right: Occupation using FRQ

services, reducing timings and balancing the occupation of internal resources.

Our approach presents a workflow management system which handles both workflows and resources using two kind of agents: workflow agents and resource agents. Resource allocation is carried out using auctions: each time a WA requires a resource, it calls a reverse sealed auction with its desired conditions while RA compete to win the auction. Two different strategies for the auctioneer agent have been presented: Balanced Strategy and Delay Prevention Strategy. The first one is focused on the resource costs and it is suitable for decreasing the resource prices (when dealing with outsourcing resource) and to equilibrate the workload balance (when allocating internal resources). The second one is centered on the time needed to finish a task and its purpose is to reduce the number of delayed workflows during the execution of several concurrent business processes.

To test the performance of our approach we simulated different synthetic workflows with different resource availability conditions. The workflows have been managed using a multiagent workflow management system endowed with the two presented auctioning strategies. The results show how the two presented auctioning strategies result in economic cost reduction, balanced market price, workload balancing and delay reduction, showing that BS is indicated for improving the three first mentioned measures while DPS enhances the last one. These results encourage to develop a new strategy which balances the 4 measures, finding a compromise between BS and DPS.

As a future work we plan to include fine evaluation to bidder agents. Moreover we want to elaborate new auctioning strategies and to consider including multi-attributive auctions. Another step would be to improve certain MAS capabilities of the system such as trust or reliability on the resources based on historical information, which will help us dealing with cheating bidder agents.

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