

A Potential Energy based Clustering Algorithm of Nodes for Network Media Services

Jiali You*, Pengfei Zheng**, Jinlin Wang*

*National Network New Media Engineering Research Center, Institute of Acoustics,
Chinese Academy of Sciences, China

**University of Chinese Academy of Sciences, China

[youjl, zhengpf, wangjl}@dsp.ac.cn](mailto:{youjl, zhengpf, wangjl}@dsp.ac.cn)

Abstract—For some media service systems in Internet, providing the service in real time is the key point to obtain the satisfying performance. In order to get good user experience, nodes are often organized as groups and the nodes in a same group can cooperate with each other. Accordingly, how to organize the nodes is an important problem that affects the performance of systems. Usually, enough node capability and the required media content are the two essential elements of nodes to provide the media service. In this paper, the relationship among nodes about these two elements are analogized as the spring tension and gravitation between particles, and a novel potential energy based clustering algorithm is proposed to generate node groups for media services. Moreover, an overlay structure for several media service applications is designed, in which a priority neighbor list is generated for each node by the proposed clustering approach. Based on this structure, nodes in the priority neighbor list may be the potential service helpers in the future. To evaluate our algorithm, a service scenario is simulated and different parameters in the media system are discussed adequately. Compared with some other clustering algorithms, if the potential energy based clustering algorithm is used, there is a chance to improve the service response time obviously and the average execution time of tasks can be reduced.

Keywords—Media service, cluster, potential energy, overlay structure, node group

I. INTRODUCTION

In the Internet, most network traffic is caused by media flow, and the user amount of media services is increasing rapidly. Currently, different types of media services are deployed in the Internet, which include P2P media system[1], content distribution network(CDN)[2] and virtual network such as cloud[3]. P2P media system is an important media service providing mode in Internet, in which the user node is both the data receiver and the provider. In this system, peers are organized as a structure to share their content with each other, which can obviously reduce the server load and improve the user experience. CDN is a structure that some servers are set close to the users. When users access the content, they can get it quickly from these nodes. Besides, cloud platform shields the details of the service nodes, and the users can request the resource based on their need. In different systems, whether the system can provide the service in real time is the same measuring metric. In the Internet, an overlay

network for different services is usually structured, which is used to share the content and communicate among nodes. If a reasonable structure is designed, both the service cost and the performance can be improved a lot. Therefore, how to organize the nodes is an important problem for media service systems. In some media networks, nodes are clustered as groups based on different factors, such as geographic information and position of playback, and the content locating and service providing process can be accelerated.

Actually, the node capability which refers to the link states among nodes, the task execution ability of nodes, and the content, are the essential factors for media service. If a node can aggregate a group of nodes that have the tight relationship based on above properties, when some timing-related requests are arrived, it has the chance to pass the request to the nodes in the group to get better performance than executing it by itself. Based on this structure, in one hand, the real-time service may be ensured to some extent; in the other hand, the large bandwidth occupation caused by the content moving may be avoided. Therefore, nodes in the media service system may be assigned to different clusters based on their content and capability characters, and the cluster is seen as a big granularity unit to improve the performance of services.

Based on above ideas, we propose a potential energy based peer clustering algorithm. In this algorithm, different information, including the node capability and the content, is mapped to the potential energy and combined together to model the relationship among nodes. Based on the clustering results, a hierarchical structure is designed, in which the service nodes can be managed more efficiently than before, and this structure is convenient to be applied in different media applications.

The remainder of this paper is structured as follows. Section II describes the related work. The potential energy based clustering algorithm is discussed in Section III. Besides, the overlay structure and the discussion of the corresponding applications are introduced in Section IV. Section V evaluates our algorithm. Finally, conclusions and future work are drawn in Section VI.

II. RELATED WORK

Currently, some cluster based overlay construction protocols are investigated by researches. [4] proposed a

locality-aware network structure named mOverlay. The character of the mOverlay is to consider the locality of nodes in network construction, in which the nearby nodes are constructed as neighbors and neighbor groups are connected. Based on this structure, the information delivery time among nodes will be significantly reduced. Due to various behaviors and resources of nodes in the real world, the basic operation, such as the key lookup, of current P2P overlay is far from efficient and hard to be improved. Thus, a physical network based overlay structure is proposed by [5]. In this network, nodes are divided into groups by their Autonomous Systems (AS) locus, and teams are also generated in an AS group. Based on this two-level structure, it is easy to route to the target group directly and locate the corresponding team by the routing strategy. In addition, several replicas of objects are stored to boost the robustness of system. This overlay not only has high efficiency in routing, but also reduces the maintenance cost and the security problems. SOBIE[6] is a network that several factors are considered in overlay constructing, like delay, distance, and information exchange frequency. In this system, the nodes being nearby to each other are grouped in a same Autonomous System (AS). Each AS selects its own super node as a manager which guarantees the fast routing in the overlay. In [7], field theory is used in overlay construction, in which nodes with identical semantic resources were connected together to form an equipotential line. Thus, a certain amount of equipotential lines consist of the overlay. When a query arrives, it will be routed to identical or similar equipotential lines based on its semantic information, and only the nodes in this line can response the query. This overly network can make the query process quickly and decrease the amount of messages in routing. In SLUP[8], a two layer structure is designed that nodes are clustered into domains according to their physical distance, and the nodes in a domain with similar resources are clustered into groups. This structure can reduce the routing distance and network bandwidth.

In the above introduction, most aggregation or clustering algorithms just considered the geographic information or network distance[4-6]. Actually, for the media service, whether the node contains the content is an important factor to get the high quality service. For some work[7,8], the location of the underlying network and the semantic similarity of shared resources are both take into account during the construction of P2P networks. However, two problems are still unconsidered. One is that two-level query processing is hard to meet the real-time demand of the media services; the other is that most overlay structures are constructed for searching the content conveniently, but whether the corresponding node can execute the task in time and whether the node capability is sufficient enough are both ignored. Accordingly, in this paper, we focus on how to combine different information to model the relationship among nodes and how to aggregate the peers to construct an overlay for real-time media services.

III. A POTENTIAL ENERGY BASED CLUSTERING ALGORITHM OF NODES

In this section, we propose a potential energy based clustering algorithm, in which the node capability and the similarity of the content are mapped to a same physical quantity and combined together for cluster calculation. Then, the appropriate cluster for each node is generated based on this approach.

It is assumed that A and B are two nodes in a media service network, and the delay from B to A is $D(A, B)$.

$N_{nbr}(A) = \{n_i, 1 \leq i \leq k\}$ is the candidate neighbors for generating cluster for node A . For an arriving request, the task execution time of two nodes is $O(A)$ and $O(B)$ individually.

If $O(A) \geq D(A, B) + O(B)$, namely $O(A) - [D(A, B) + O(B)] \geq 0$, which means that the task of A can be implemented well by B , and the performance cannot be affected, evenly better than before. Accordingly, the greater the difference is, the more possible B joins in the cluster of A . If the difference is a negative value, it represents that the task is not worth to implement by B , and two nodes cannot be aggregated in a cluster. This process is similar to the scene of two particles connected by a spring in physics. And $O(A) - [D(A, B) + O(B)]$ can be seen as the length of spring stretching or compressing. Therefore, the network characters between nodes may be modelled by the elastic formula of spring. We assume that A and B are fixed in the network, and they are connected by the network link like a spring. Then, based on the Hooke's law, we define the action force between two nodes to present the network relationship. Here, the normalized delay is used in calculation and the tension between two nodes is as formula (1).

$$F(A, B) = s \left\{ \frac{O(A) - [D(A, B) + O(B)]}{\max_{n_i \in N_{nbr}(A)} [O(A) - [D(A, n_i) + O(n_i)]]} \right\} \quad (1)$$

Where s is the elastic coefficient that can be seen as the weight of the network character. If $F(A, B) > 0$, it means that B tends to join the cluster with center A .

Besides, the content stored in nodes is also play an important role for cluster generation. Two nodes with similar content are prone to be clustered together to help each other in data providing process. Thus, more similar content two nodes stored, closer relationship they have, which coincides the law of gravitation. Consequently, we define the gravitation of nodes to describe the impact of content for node clustering.

It is assumed that the amount of the content files in two nodes is M_A and M_B , and $\{M_i, 1 \leq i \leq k\}$ is the content files set of k candidate nodes for clustering. The amount of the overlap content files of A and B is $M_{A,B}$. We define the relative content level to represent the similarity among the candidate nodes. Obviously, relative content level of A to itself is 1, and the level of B to A can be measured by a

normalized value $M_{A,B} / \max_{i \in N_{nbr}(A)} M_{A,i}$. Then, the gravitation between them is as formula(2).

$$U_{A,B} = g \times \frac{1 \times (M_{A,B} / \max_{i \in N_{nbr}(A)} M_{A,i})}{[R(A,B)]^2} \quad (2)$$

$$s.t. \quad R(A,B) = \frac{M_{A,B}}{Rare_Weight_B}$$

Here, $Rare_Weight_B$ is defined as a rarity level of content in node B. It is assumed that $\{c_j, 1 \leq j \leq q\}$ is the set of the files in node B. $o_{j,k}$ is the number of candidate nodes which contains the file c_j . Then, we define that

$$Rare_Weight_B = \sum_{j=1}^q 1/o_{j,k} \text{ and we use } R(A,B) \text{ to represent the}$$

content distance between A and B. Besides, g is the gravitational constant. In our scenario, this value means the weight of the content and it is estimated by the experience.

Because there are a lot of nodes in network, and the action force among nodes is in different directions, which may be neutralized and not coincide the property of the real network. Accordingly, we use the energy caused by the action force to describe the relationship among nodes. Then, the total potential energy between A and B is as formula (3).

$$E(A,B) = E_s(A,B) + E_u(A,B) \quad (3)$$

Where, $E_s(A,B)$ is the elastic potential energy and $E_u(A,B)$ is the gravitation potential energy. Thus, the calculation process of the potential energy is like formula (4) and (5).

$$E_s(A,B) = s \int_0^{|x|} x dx = s \frac{x|x|}{2} \quad (4)$$

$$s.t. \quad x = \frac{O(A) - [D(A,B) + O(B)]}{\max_{n_i \in N_{nbr}(A)} [O(A) - [D(A,n_i) + O(C)]]} \quad (5)$$

$$E_u(A,B) = U_{A,B} \cdot R(A,B)$$

Since the elastic force in our system means whether two nodes can be aggregated, some negative values of $E(A,B)$ may be exist. $E(A,B) > 0$ means B is assigned to the cluster with center A.

Thereby, if A owns k candidates, how to find the appropriate cooperation nodes to the cluster with center A is our target. The optimal function is shown in formula (6).

$$\arg \max_x \sum_{i=1}^k E(A, B_i) x_i \quad (6)$$

$$s.t. \quad x_i \in \{0,1\} \quad \sum_{i=1}^k x_i \leq L \quad dg(B_i) \leq O$$

Here, L is the up limit of the node number in each cluster; $dg(B_i)$ is the number of the clusters that a node B_i joins in and O is the threshold.

Based on above processes, a group node will be selected for node A. The requests received by A may be executed well by the nodes in the cluster when A cannot provide enough resources.

IV. A CLUSTER BASED NETWORK STRUCTURE FOR MEDIA SERVICES

In this section, a hierarchical overlay structure is introduced, and different media service applications that can be deployed on this overlay are briefly introduced.

A. The Structure of the Cluster based Hierarchical Network

To ensure the fast locating of peers and the convenient retrieving of information, we design a two-layer network structure, which includes a peer service layer and a resource management layer. The topology is shown in figure 1.

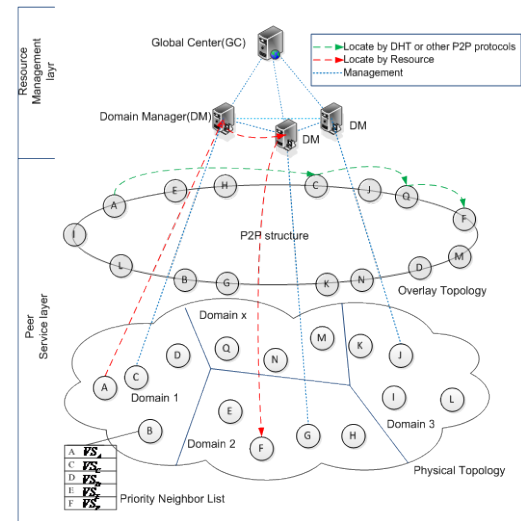


Figure 1. The cluster based hierarchical network structure.

In this structure, the role of the management layer is to collect the service information of the service layer, and the nodes in it are selected from all nodes or deployed by the administrator. Nodes in the service layer are organized based on a structure or unstructured P2P protocol to grantee the self-organization and fast routing. The nodes are divided into different domains based on their geographic information. Each domain is managed by a domain manager that can be seen as a super node for collecting and observing the resource states in this domain. Moreover, a global center should be set to manage the information of the whole network and collect the report from domain managers periodically. When a node receives a request, the overlay maintaining algorithm or domain manager can find the appropriate service node and send the request to it. When the service node receives the message, it will provide the service for users directly. In order to satisfy the real-time demand, each node has a cluster that is aggregated based on our clustering algorithm. We name this

cluster as priority neighbor list. The size of each cluster is more than 1 and any node may join in several clusters. If the size of cluster is achieve the up limit, new joining request will be declined.

B. Different Applications based on the Hierarchical Network Structure

Several upper-layer applications about the media service can be deployed on this overlay structure to improve their performance. Here, we briefly discuss some scenarios which can be applied in this network.

In P2P media streaming networks, how to organize the nodes as the swarms to share data with other nodes is the key point of the system. In this structure, nodes are connected by the service layer. Each node has its own priority neighbor list, which is generated by our clustering algorithm and used as the potential data providers. When a node needs some data, it requests the data from priority neighbors firstly. In the same time, management layer collects the information of service layer to help the node get more information to decide the appropriate neighbors. In addition, the functions in management layer can be merged into one node.

In CDNs, nodes in management layer are responsible for the work of observing and managing nodes of different domains. Domains may be divided based on their geographic information or some pre-set criteria. Replicas of files are pushed to the nodes in the service layer. The potential energy based clustering algorithm is used to select appropriate neighbors for each node, which may be the service providers in some prime time.

Similarly, in a cloud, many time-related tasks are proposed. For example, when a new media is published, several steps should be completed such as file uploading, transcoding, storing, and data transferring. Compared with the method of the serial tasks processing, if the different steps are assigned to appropriate nodes, the execution time may be reduced a lot. Therefore, nodes in the management layer analyze the resource states of nodes of the service layer. When a node in service layer receives some requests, management node can help it to decide how to assign the tasks to the nodes in its priority neighbor list.

For the above introduction, we just give some examples. Actually, both the proposed clustering algorithm and the network structure can be flexibly applied in different media services.

V. SIMULATION AND ANALYSIS

A. Simulation Setup

To evaluate the performance of the clustering algorithm and the structure, we design a service scenario to simulate media systems. Currently, some content or service providers may provide network service in different places and set different subsidiary companies to take on the management role. In our paper, it is assume that there is a scenario that a company plans to provide service in 30 different provinces or cities, and each province or city has 5 different districts. This work needs the help of a CDN or a cloud platform. For the network

provider, it should pre-set a lot of servers in different places. Therefore, the structure of the network constructed by these servers may affect the quality of services. Based on the requirements, each province should have its own management center which plays the role to publish new media files and manage the media in this area. The files published in different areas are not the same. To simulate this situation, we assume that 50000 media files are distributed in the whole network, and each file has 2-10 replicas in different areas. The link states among nodes follow the log file that is recorded by a detector in PlanetLab[9]. Then, 10000 queries are proposed synchronously to test the real-time service performance of the system. To analyze the effect of the proposed algorithm, another system in which cluster is selected randomly from the candidates is compared. In addition, the performance of systems, in which just the single impact factor is considered, such as delay or content similarity, is also compared.

B. Performance Analysis

1) The impact of the task execution capability of nodes

In media service systems, not only the accessing delay, but also the task processing time, affects the user experience. In real systems, the task execution capabilities of nodes are different, which means the task execution time of different nodes is not the same. To simulate this scenario, we assume that two types of nodes with different capabilities are deployed randomly. For a same task, the difference of the execution time of two type nodes is ρ . And in the potential energy combination process, the relationship of coefficients of elastic potential energy and the gravitation potential energy is $s/g = 3$. If the clustering algorithm is used, all requests have the chance to obtain better service quality by the help of priority neighbors. Accordingly, we use **the improved ratio of requests as a metric, which means how much requests may be served better than before**. Moreover, we test the performance of nodes with different capabilities. Figure 2 shows the improved ratio of the system with the value of ρ from 200ms to 5000ms. From the figure, we know that the larger the difference of the nodes' capability is, the more chance requests may be improved. Thus, it is worth to forward the query to high capability nodes for executing.

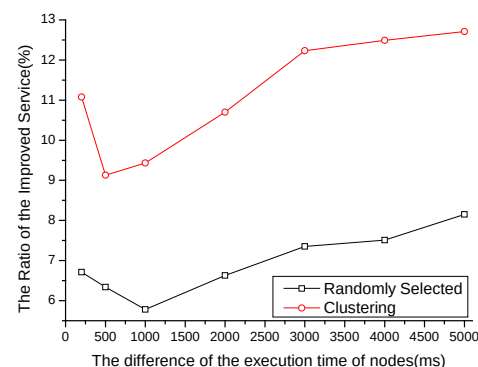


Figure 2. The performance comparison of two clustering algorithms with different execution time.

2) The impact of the size of priority neighbor list

If more nodes in the priority neighbor list, center node has more opportunity to find a helper from them. Nevertheless, it also causes more heavy maintenance cost and longer calculation time. Since it is impossible to collect all nodes in the network for clustering, just the neighbor table which is maintained by the P2P protocol forms the candidate node pool. To analyze the impact of the size of the priority neighbor list, we compare the different size of priority neighbor list as figure 3. Moreover, the size of the neighbor table is also compared in figure 4.

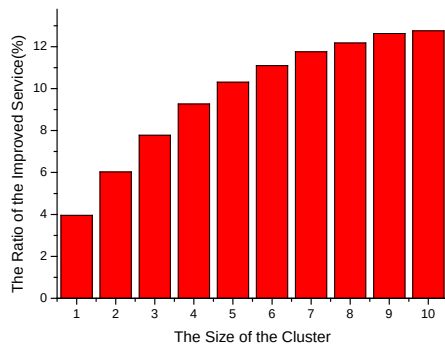


Figure 3. The comparison of the different size of the cluster.

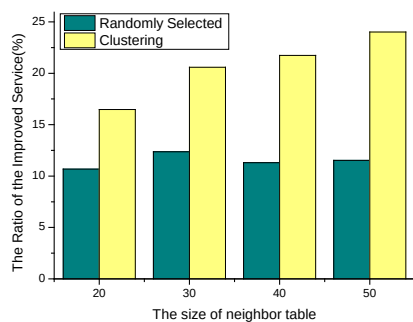


Figure 4. The comparison of the different size of the neighbor table. (The size of the cluster is 10.)

Based on figure 3, we know that although more priority neighbors can bring better performance, when the size is larger than 5, the difference from different size is not remarkable. Thus, 5~10 priority neighbors are sufficient enough. Besides, figure 4 presents that for our potential energy based cluster algorithm, more candidate nodes can obtain more improved service. However, for the randomly selected clusters, more neighbors cannot bring obvious benefit for the system performance.

3) The impact of the number of replicas of the files

In a media service system, the content is a necessary condition for providing the service. If no content exists in nodes, it is impossible to obtain the help from them. Hence, in order to borrow the capability of nodes, each file may have multiple replicas. Figure 5 gives the result comparison with

different number of content replicas in the system. This figure illuminates that if the number of replicas is small, the possibility of the high capability nodes which can be selected in the priority neighbor list is low. Accordingly, more content replicas bring more opportunity to cluster appropriate nodes together. From another point of view, this benefit is obtained by sacrificing the storage space. In current networks, due to the low cost of storage, it is acceptable in a lot of systems.

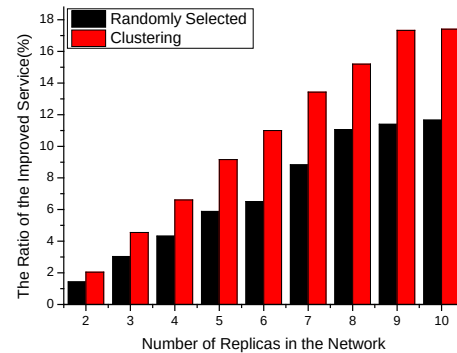


Figure 5. The comparison of the improved performance with different number of replicas.

4) Analyzing the combination policy of the two elements

In the clustering process of the priority neighbor list, node capability and the content are both mapped to the potential energy for combining. The coefficient s and g may affect the performance. Here, we use $\sigma = s/g$ to represent the relationship between two values. Table 1 shows the performance comparison with different values of σ . In this table, when $\sigma = \infty$, the system is transformed as the one that just delay is used to generate cluster; when $\sigma = 0$, just the content similarity information is considered. From this table, we know that the combination of the two elements can obtain better performance than the result from the algorithm with any single factor.

TABLE 1. THE COMPARED SYSTEMS WITH DIFFERENT COEFFICIENTS.

Coefficient Combination	Improved Ratio of Requests (%)
$\sigma = 0$ ($s=0$)	9.43
$\sigma = \infty$ ($g=0$)	9.97
$\sigma = 1$	10.68
$\sigma = 0.5$	10.33
$\sigma = 1/3$	10.16
$\sigma = 0.25$	10.06
$\sigma = 0.2$	10.01
$\sigma = 1/6$	9.93
$\sigma = 1/7$	9.85
$\sigma = 2$	10.92
$\sigma = 3$	11
$\sigma = 4$	10.98
$\sigma = 5$	10.96
$\sigma = 6$	10.96
$\sigma = 7$	10.91

Based on the above table, we see that although the node capability and the content both affect the performance, the node capability takes on a more important role than other factors. The probable reason is that delay is related to the real-time service more tightly than other parameters, and the elastic potential energy should be set a high weight. Since $\sigma = 3$ can bring a satisfying result, we use it in other experiments.

C. Discussion

Before the priority neighbor list is applied, the node should process all received requests by itself, until all tasks are implemented completely. Actually, capabilities among different nodes are unbalance, and the total execution time of each node is not the same, which means that some tasks cannot be done in the limited time. Accordingly, to analyze whether the potential energy based cluster can accelerate the task execution process, the average execution time of nodes from three systems are compared in figure 6. In this figure, the system of Original Requests means no cluster is generated. x axis is the total execution time, and y axis is the accumulate ratio of the nodes.

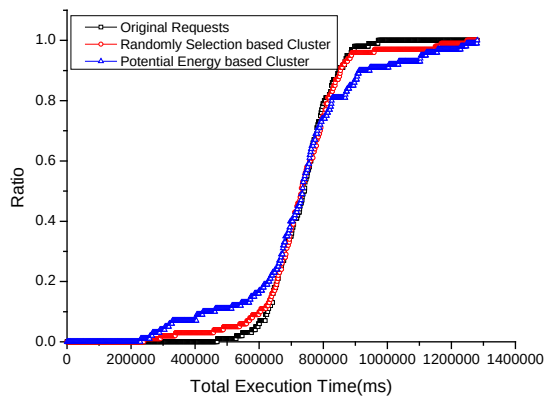


Figure 6. The accumulated distribution of the execution time.

In this figure, the variation of the total execution time of all nodes in the potential energy cluster based system is lower than the values of other systems. This result represents that in our algorithm, in one hand, the node capability can be make full use; in the other hand, the average execution time can be obviously reduced.

VI. CONCLUSIONS

In this paper, the relationship among nodes in node capability and the content similarity is analogized as the similar physical process, like the spring tension and gravitation between particles. And a novel potential energy based clustering algorithm is proposed to generate node clusters for media service applications. Based on the clustering algorithm, a hierarchical overlay structure is designed for network media services, in which the nodes with different roles are placed in different layers, and each node has its own priority neighbor list as the helpers in request

executing process. To verify the efficiency of the clustering algorithm, a media service scenario is designed and simulated, and the impact parameters are investigated carefully. Results show that after the potential energy based clustering algorithm is used, the improved ratio of requests, which means how much requests may be served better than before, will be improved obviously. Moreover, compared with the result gotten from the single factor clustering, the potential energy based clustering algorithm takes on its notable advantage. In this paper, we just brief introduce the applications and test a simple scene. In the future work, we will construct a real system and research on the overlay characters deeply.

ACKNOWLEDGMENT

The work is supported in part of the National Science Foundation of China(60903218), 863 Program(2011AA01A102), Strategic Priority Research Program of the Chinese Academy of Sciences(XDA06010301) and the Innovation Project of Institute of Acoustics, Chinese Academy of Sciences(Y154211601).

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