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A New Auction Based Approach to Efficient P2P Live Streaming

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Abstract—P2P live media streaming systems have proliferated and become indispensable vehicles for Internet based entertainment applications. However, it is also well known that scalability of such systems is limited by the lack of proper incentive mechanisms. Specifically, it is notoriously hard to efficiently allocate upload bandwidth at each peer so as to maximize overall system performance.

In this paper, we propose a new auction based mechanism for optimizing the allocation of upload bandwidth at each peer. One of the distinctive features in our approach is that peers use real “goods” (i.e., their own bandwidth resources) for payments, instead of relying on some fictitious currency. Essentially, peers use a barter mechanism in the payment step in the auction. Simulation results indicate that our proposed auction approach consistently outperforms existing practical approaches (e.g., tit-for-tat) in terms of average incoming stream rate, average playback delay, and control packets ratio.

Index Terms—P2P, media streaming, upload bandwidth, barter, auction, fairness.

I. INTRODUCTION

Following the blooming of P2P file sharing systems, such as BitTorrent [1] and Emule [2], P2P media streaming has become highly popular entertainment platforms. Indeed, practical and commercial systems, such as PPStream [3], PPLive [4], UUsee [5], and Coolstreaming [6], have become household Internet tools.

However, while such systems are widely used, their performances are far from being satisfactory, not to mentioned optimized. For instance, the startup delay is usually unacceptably large—can go all the way up to several minutes. Similarly, the streaming rate can fluctuate and becomes so low that the display resolution is severely affected. Furthermore, in live streaming system, the playback lag can also be unacceptably large. As a case in point, in the recently held WorldCup, the playback lag of some live streaming systems (e.g., UUsee) was as high as ten minutes so that some people missed the real-time events of the penalty shoot-out!

The root cause of the problem lies in the lack of proper incentive schemes to motivate optimized contributions from peers. Specifically, in P2P live media streaming systems, packets from the source stream are usually just randomly shared among peers, resulting in highly inefficient bandwidth usage. In other words, while bandwidth is used for transmitting the packets, such packets might not be needed, while some needed packets have no contributor in the system.

Obviously, it would be highly desirable that an incentive scheme is in place so that uploading bandwidth at each peer is used in an optimized manner—contributing useful packets to other needing peers.

It is important to observe that the resource to allocate is the upload bandwidth from all the peers. On the other hand, the value of such resource from each peer differs, mainly because of the aging degree. For instance, a peer with fresh chunks is obviously more popular.

Each peer in the system wants to get more high quality resource which, by definition, is scarce. We need an efficient mechanism to do the match making. According to Bertsekas [7], auction is an excellent candidate and is the focus of our proposed approach.

There are many auction based approaches suggested for P2P systems. Wu et al. [8], and Tan and Jarvis [9] modeled the P2P streaming system as a market using auction so that each peer in the system bids for upload bandwidth from others. However, as in many other existing auction approaches, Wu et al. did not give a clear statement about the maintenance of money. Similarly, Tan and Jarvis introduced payment into the system to assist the transaction among all the peers. Unfortunately, this can lead to significant overhead in maintaining each peer’s currency.

In contrast, in our proposed approach, we use barter to handle the payment issue. Specifically, the auctioneer, i.e., the peer that is trying to allocate its upload bandwidth, accepts payment from the winning bidder, i.e., another peer, in the form of the latter’s upload bandwidth for the packets needed. Different from in P2P video-on-demand streaming system, where using real goods, which is the upload bandwidth at each peer, for payment is very difficult and it is hard to get good performance because peers have different playback points with large gap, in P2P live streaming system, using real goods instead of relying on currency for payment can be a good approach. In P2P live streaming system, peers in the same channel always watch the “live” show and they share similar resources. Therefore, we believe that such a barter exchange mechanism is much more practical in a live P2P streaming system because different peers will have a finite non-overlapping time window of packets in need, thereby giving the values to their own resources, i.e., the payments.

In this paper, we propose the Dynamic Bid Adjustment Auc-
tion (DBA-Auction), which is based on the above mentioned barter payment mechanism.

We summarize our contributions below.

- In the market model of our incentive mechanism, there is not any form of money involved, thus avoiding a huge and complex system for maintaining banking clearance system, which is commonly needed in existing incentive mechanisms using money.
- Auction is efficient in the sense that the resource is allocated at the highest valuation.
- Free-riding is impossible because every peer has to use barter to exchange packets in need.
- Deciding the allocation amount is done dynamically during the auction process, thereby avoiding the trouble of price setting, which is a common problem in existing auction algorithms.

This paper is organized as follows. Section II presents the market model and the proposed DBA-Auction approach. In Section III, we describe our simulation results. Section IV gives the literature review. Finally, in Section V, we provide some concluding remarks.

II. SYSTEM MODEL

A. Market Model

We model the overlay network as a market. Each peer involved in the overlay network is denoted as \( p_i \). The upload capacity of each peer is denoted as \( U_i \), and the download capacity is denoted as \( D_i \). The minimum stream rate for playback is \( S^p \) and we assume that every peer involved in the overlay network has download capacity \( D_i \) larger than \( S^p \). The neighbor list size of \( p_i \) is denoted as \( C_i \). Each peer bids for upload bandwidth from other peers, and the payment is their own upload bandwidth. Thus, in our market model, every peer barter with each other for upload bandwidth to get a steady streaming rate for playback. Any fictitious currency is not needed in our market model, thus avoiding the overhead of maintaining each peer’s currency. The bid of peer \( p_i \) is denoted as \( b_i \). This indicates that \( p_i \) is obliged to trade \( b_i \) packets for one packet.

We denote the barter ratio between \( p_i \) and \( p_j \) as \( t_{ij} \), which means that when \( p_j \) gives \( p_i \) \( k \) packets, \( p_i \) should give back \( \frac{1}{t_{ij}} \) packets for payment. Note that \( t_{ji} = \frac{1}{t_{ij}} \). After \( p_i \) accepts the bid \( b_j \) of \( p_j \), the barter ratio \( t_{ji} \) of \( b_j \). In our market model, each peer could behave as a bidder and an auctioneer simultaneously as shown in Figure 1.

![Fig. 1: Two concurrent auctions in a P2P live media streaming system.](image)

There are two concurrent auctions in Figure 1. Auction 1 has \( p_4 \) as the auctioneer and there are four bidders: \( p_1, p_2, p_5, \) and \( p_0 \). Auction 2 has \( p_7 \) as the auctioneer and there are also four bidders: \( p_3, p_4, p_6, \) and \( p_8 \). We can see that \( p_4 \) acts as an auctioneer in auction 1 and as a bidder in auction 2.

Specifically, there are two stages in our system model: auction stage during which the neighbor relationships and the barter ratios are established, and barter stage during which the real transaction is conducted. Barter stage is on the basis of auction stage.

B. Auction Stage

In the auction stage of our system model, only the neighbor relationships and the barter ratios are established. The allocation amount and the specific packets for barter are not determined at this stage. Instead, peers dynamically decide the allocation amount and the specific packets for barter during the barter stage, which will be elaborated in detail in Section II-C.

Each peer in the system maintains a list of neighbors with a size not larger than \( C^m \), i.e., \( C_i \leq C^m \). As soon as one peer joins the overlay network, it begins to find neighbors to get needed packets in the stream for playback. Peers also check their neighbor lists periodically. When there are neighbors which do not behave according to their agreements made in the auction stage, these peers will be deleted from the neighbor list. Furthermore, when the size of the neighbor list is smaller than \( C^m \), the peer will start finding new neighbors.

A peer in need of new neighbors can get a list of peers from the well known trackers. Subsequently the peer selects peers randomly from the neighbor list, and sends its bid to them. The auctioneer who decides to accept the peer’s bid will add this peer into its neighbor list and send an acknowledgment message to this peer. (The auctioneer behaviors will be presented in detail in Section II-B2.) After receiving an acknowledgment from the auctioneer it has sent a bid to, the peer will add this auctioneer into its neighbor list. The neighbor relationship and the barter ratio are therefore established.

1) Bid Adjustment: In P2P live media streaming system, each peer tries to get enough packets from the stream to ramp up its incoming rate as quickly as possible. To get a higher incoming stream rate, the peer should give a higher bid. Indeed, in order to quickly ramp up its incoming stream rate, the peer should at the outset give the highest bid it can offer, instead of increasing the bid little by little. On this basis, we propose a dynamic bid adjustment strategy and we call the auction mechanism using this dynamic bid adjustment strategy Dynamic Bid Adjustment Auction (DBA-Auction).

In DBA-Auction, when \( p_i \) sends a bid to other peers, it always uses the highest bid value which is the highest barter ratio it can offer, i.e., \( b_i = t_{ij}^* \). We use \( t_{ij}^* \) to denote the highest barter ratio of \( p_i \). In DBA-Auction, the highest barter ratio of \( p_i \) is calculated according to Equation (1). As shown in Equation (1), \( t_{ij}^* \) is calculated dynamically in DBA-Auction.

\[
t_{ij}^* = \frac{U_i - O_i}{S^p - I_i}
\]  

(1)

Here, \( U_i \) denotes the upload capacity of \( p_i \), \( S^p \) denotes the minimum stream rate for playback in the system, \( O_i \) denotes
the overall outgoing stream rate of \( p_i \) and \( I_i \) denotes the incoming stream rate which is defined in Section III-B. For example, in a system with a minimum stream rate for playback of 300kbps, at a certain moment, one peer with upload capacity of 384kbps has the overall outgoing stream rate of 104kbps and the incoming stream rate of 150kbps. Then the highest barter ratio of this peer at this moment is \( \frac{104}{150} = \frac{28}{37.5} \). 

2) Auctioneer Behaviors: In our system model, the auctioneer does not preserve any bids. Instead, it deals with each bid the moment it receives the bid as shown in Figure 2. In the example of Figure 2, we have \( C^m = 3 \), which means that each peer in this system maintains a neighbor list with a size not larger than 3. Peer \( p_3 \) has a full neighbor list and is conducting transactions with the neighbors on the list. When \( p_3 \) receives a new bid \( b_5 = 2 \) from another peer \( p_5 \), it compares the new bid with the neighbors on its neighbor list and finds that \( b_5 \) is larger than \( b_4 = 1 \). Thus, \( p_3 \) stops the transaction with \( p_4 \) and removes \( p_4 \) from its neighbor list and adds \( p_5 \) to its neighbor list.

This process of dealing with new bids at one peer is formalized in Algorithm 1.

![Algorithm 1](image)

**Algorithm 1** The algorithm at \( p_i \) as an auctioneer

1: while \( p_i \) receives a new bid \( b_j \) from another peer \( p_j \) do
2:    if \( b_j \geq \frac{1}{11} \) then
3:        if \( C_j < C^m \) then
4:            Insert \( p_j \) into the neighbor list and send an acknowledgment message to \( p_j \);
5:        else
6:            if \( b_j > b_k \), \( p_k \) is the peer with the smallest bid value on the neighbor list of \( p_i \) then
7:                Delete \( p_k \) and then insert \( p_j \) into the neighbor list, send disconnect message and acknowledgment message to \( p_k \) and \( p_j \), respectively;
8:            else
9:                Discard \( b_j \);
10:           end if
11:      end if
12: else
13:    Discard \( b_j \);
14: end if
15: end while

C. Barter Stage

After the neighbor relationship and the barter ratio are established in auction stage, real transaction is conducted between the peers at barter stage. In our system model, the allocation amount and the specific packets for barter are not fixed in auction stage. Instead, they are determined during the barter process.

1) Bid-oriented Request Mechanism: In our system model, peers do not share buffer maps unless they are neighbors, avoiding a lot of control packets overhead of updating buffer map packets. After the neighbor relationship is established, peers send buffer maps to each other. The request mechanism in our system is bid oriented. When one peer wants to request a specific packet, it checks the buffer maps of all its neighbors and gets a list of neighbors which have this packet, then sends the request to the neighbor with the highest bid value on the list. Therefore, one peer could barter for more packets with the neighbor which has higher barter ratio thus achieves the aim of using the least upload capacity to get the most packets from others. By adopting this bid-oriented request mechanism, peers could get more valuable packets without contributing excessive upload bandwidth.

We compared the performance of bid-oriented request mechanism and random request mechanism, in which one peer sends packet requests to its neighbors randomly. We use the same simulation setup as that in Section III-C. The results are shown in Figures 3 to 5.

![Figure 3](image)

**Fig. 3:** Performance comparison in terms of the evolution of average incoming stream rate over time.

![Figure 4](image)

**Fig. 4:** Performance comparison in terms of the evolution of average playback delay over time.
In Figures 3 to 5, we can easily see that bid-oriented request mechanism outperforms random request mechanism in terms of average incoming stream rate, average playback delay and control packets ratio. The bid-oriented request mechanism has much higher average incoming stream rate, much lower control packets ratio, and consistently lower playback delay than random request mechanism during the simulation duration.

2) Barter Management Mechanism: We also design a barter management mechanism to ensure peers conduct transactions according to the barter ratio they established in auction stage. In our system model, each peer preserves the transaction records of all the neighbors. We denote the overall number of stream packets sent from \( p_i \) to \( p_j \) as \( N_{ij}^p \). This process of dealing with new packet requests at one peer is formalized in Algorithm 2. \( \delta \) and \( \sigma \) are two thresholds.

**Algorithm 2** The barter management algorithm at \( p_i \)

1. while \( p_i \) receives a packet request from its neighbor \( p_j \) do
2. \hspace{1em} if \( N_{ij}^p - N_{ji}^p \leq \delta \) or \( \frac{N_{ij}^p}{N_{ji}^p} \leq t_{ij} + \sigma \) then
3. \hspace{2em} Send this packet to \( p_j \);
4. \hspace{1em} else
5. \hspace{2em} Discard this request;
6. \hspace{1em} end if
7. end while

According to Algorithm 2, each peer \( p_i \) has a tolerance range \((\delta, \sigma)\) to its neighbors. The rationale is that \( p_i \) does not stop uploading to \( p_j \) if the barter difference \( N_{ij}^p - N_{ji}^p \) is smaller than or equal to \( \delta \) or the barter ratio \( \frac{N_{ij}^p}{N_{ji}^p} \) is smaller than or equal to \( t_{ij} + \sigma \). This barter management mechanism encourages neighbors to conduct transactions in an honest manner; otherwise, the peer who does not cooperate will be punished by its neighbor through choking, meaning that its neighbor will stop uploading packets to it.

Realistically, one peer tends to make its own tolerance range very tight due to selfishness. Each peer doesn’t want to contribute more to its neighbor than their contract, thus in realistic environment, the tolerance range of each peer must be very tight. We tested four sets of tolerance range \((\delta, \sigma)\) which are from loose to tight: \((3000, 0.1)\), \((1000, 0.01)\), \((500, 0.001)\), and \((100, 0.0001)\). Through these experiments, we proved that the performance of our DBA-Auction approach does not rely on the tightness of tolerance range of each peer. We use the same simulation setup as that in Section III-C. The results are shown in Figures 6 to 8.

![Figure 5: Performance comparison in terms of the evolution of control packets ratio over time.](image1)

![Figure 6: Performance comparison in terms of the evolution of average incoming stream rate over time.](image2)

![Figure 7: Performance comparison in terms of the evolution of average playback delay over time.](image3)

![Figure 8: Performance comparison in terms of the evolution of control packets ratio over time.](image4)

In Figures 6 to 8, we can easily see that there is hardly any difference among the results of the four sets of tolerance range in terms of average incoming stream rate, average playback delay, and control packets ratio during the simulation duration, which means that even when the peers adjust their tolerance range to very tight values the performance of the system doesn’t be affected. In this paper, we use \((100, 0.0001)\) as the tolerance range of each peer for DBA-Auction approach.
III. PERFORMANCE EVALUATION

A. Simulation Setup

In our simulation study, we use the well known and highly practical simulator p2pstrsim [10], which is originally developed by Zhang et al. We implemented our proposed mechanism on top of this simulator and conducted a series of simulation scenarios.

In our simulated system model, there is only one source server which has an upload capacity of 600 kbps. There are three kinds of peers with different upload and download capacity as shown in Table I.

<table>
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<th>Fraction</th>
<th>Upload Capacity (kbps)</th>
<th>Download Capacity (kbps)</th>
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<tr>
<td>0.15</td>
<td>1000</td>
<td>3000</td>
</tr>
<tr>
<td>0.39</td>
<td>384</td>
<td>1500</td>
</tr>
<tr>
<td>0.46</td>
<td>128</td>
<td>768</td>
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The raw stream rate of the source server is 300 kbps. The stream packet size is fixed at 1250 bytes. Each peer has a request window with a size of 20 seconds.

B. Performance Metrics

In our simulation study, we use the following performance metrics.

- **Average incoming stream rate**: Incoming stream rate is the net incoming stream rate of one peer, excluding redundant packets, overdue packets, control packets, etc. Average incoming stream rate is then the average of the incoming stream rates of all the peers involved in the system during the simulation duration. A peer which has a higher incoming stream rate has a better display quality.

- **Average playback delay**: Playback delay is the delay from the moment one packet is sent out from the source server to the moment this packet is played at one peer. Average playback delay indicates the average playback delay of all the packets which are played successfully during the simulation duration.

- **Control packets ratio**: This is the ratio of average control stream rate to average download stream rate. Control packets ratio is a measure of the control overhead imposed by the system.

C. Performance Comparison with Tit-for-Tat

We compared the performance of our proposed incentive mechanism with the widely used tit-for-tat approach. We implemented the tit-for-tat strategy according to the algorithm described in [11]. In the tit-for-tat strategy, peers do “equivalent reciprocate” to each other. One peer stops uploading to the other one when it does not cooperate, without stopping downloading from that peer.

In this experiment, there are 200 nodes in the system, and the simulation duration is 45 minutes. We measured three performance metrics: average incoming stream rate, average playback delay and control packets ratio. The results are shown in Figures 9 to 11.

In Figure 9, we can see that the average incoming stream rate of DBA-Auction approach is consistently higher than that of tit-for-tat with a huge gap during the simulation duration. During the simulation duration, the average incoming stream rate of DBA-Auction is around 250 kbps which is good and steady while the average incoming stream rate of tit-for-tat is under 150 kbps and fluctuant with time.

Figure 10 shows that DBA-Auction approach has a relatively low average playback delay during the duration, below 40000 msec. Specifically, it consistently outperforms tit-for-tat.

Figure 11 shows that DBA-Auction has much lower control packets ratio than tit-for-tat. During the simulation duration, the control packets ratio of DBA-Auction has a very steady value which is around 0.06 while the control packets ratio of tit-for-tat is above 0.5 during the first 16 minutes and around 0.2 during the last 29 minutes.

Fig. 9: Performance comparison in terms of the evolution of average incoming stream rate over time.

Fig. 10: Performance comparison in terms of the evolution of average playback delay over time.

In Figures 9 to 11, we can easily see that DBA-Auction exhibits much higher performance in terms of average incoming stream rate and control packets ratio, and also consistently outperforms tit-for-tat in terms of average playback delay. The major reason is that in the tit-for-tat strategy, peers barter with each other with the barter ratio 1:1. Consequently this strategy cannot encourage peers to contribute more upload bandwidth to the system. A peer only contributes when it can get the same amount of available upload bandwidth from other peers. However, in our auction strategy, peers can get more upload bandwidth.
bandwidth from other peers if they offer a higher barter ratio. Thus, all the peers are encouraged to contribute more upload bandwidth to the system. The whole amount of available upload bandwidth is obviously much more than that in tit-for-tat incentive systems, thus the average incoming stream rate is significantly higher than that in tit-for-tat strategy.

Moreover, in our auction strategy, if neighbor relationship is established between two peers, they will hold this relationship for a reasonably long time and conduct transactions according to the agreement they have made during the auction stage. Therefore, the performance of DBA-Auction is consistent and stable during the simulation duration.

D. The Analysis of System Resistance to Dishonest Behaviors

Nearly all the existed P2P systems suffer from dishonest behaviors of peers, and dishonest behaviors can lead to significant performance degradation of the system. In this section, we study the system resistance of DBA-Auction approach, by comparing the average incoming stream rate between honest peers which behave according to the agreements they make with their neighbors and dishonest peers which only get packets from their neighbors and never answer their neighbors’ requests. We use the same simulation setup as that in Section III-C. 20% of the peers are dishonest peers. The results are shown in Figure 12.

In Figure 12, we can see that the average incoming stream rate of dishonest peers is only around 120 kbps which has a large performance gap with the result of honest peers whose average incoming stream rate is around 170 kbps.

We can see that in the DBA-Auction mechanism, dishonest peers get much lower incoming stream rate than peers who behave honestly, meaning that DBA-Auction approach has certain degree of resistance to dishonest behaviors. In DBA-Auction approach, each peer maintains a transaction record for each of its neighbors. After the neighbor relationship is established between two peers in the auction stage, one peer only answers the requests from its neighbor when their transaction record is in its tolerance range. Therefore, dishonest peers can only get very small amount of packets which are in the tolerance range of its neighbors. Dishonest peers have to change their neighbors continuously to get free packets by cheating. However, the tolerance range of the peers in the system is very tight due to the selfishness of each peer, thus dishonest peers can never get as many packets as honest peers.

E. The Analysis of Scalability

P2P live media streaming system is becoming more and more popular nowadays, and it is very common that thousands of peers watches the same program in the system simultaneously. Thus, a good incentive mechanism which is designed for P2P live media streaming must have a good scalability. In this section, we study the scalability of DBA-Auction with comparison with tit-for-tat. We investigate the cases of 200, 500, 1000, 5000, and 8000 peers. We use the same simulation setup as that in Section III-C, with varying number of peers. The results are shown in Figures 13 to 15.

Figure 13 shows that as the number of peers grows, there is hardly any performance reduction in terms of average incoming stream rate when DBA-Auction is applied. Although there is a little performance promotion as the number of peers grows when tit-for-tat is applied, the average incoming stream rate of DBA-Auction is much higher.

Figure 14 shows that as the number of peers grows, the average playback delay of DBA-Auction increases. Nonetheless, we can easily see that DBA-Auction is better than tit-for-tat in all the five cases. The average playback delay of DBA-Auction is still acceptable when the number of peers increases to 8000.

In Figure 15, we can see that the control packets ratio of DBA-Auction is much lower than tit-for-tat in all the five
et al. [14] proposed an incentive mechanism in which peers have more flexibility to select neighbors while free-riders have very limited options in selecting neighbors. However, both mechanisms above have the problem of fairness, leading to performance gap between rich and poor peers. A peer with small upload bandwidth could be starved even if it contributed all the available upload bandwidth.

Chu et al. [16] proposed a taxation strategy, which is like the taxation system in human society. In this strategy, rich peers who have more resources are obliged to contribute more to the system and poor peers could contribute less. This mechanism has similar problems with the real taxation system in human society, namely the significant overheads incurred by the management. Rahman et al. [17] proposed another effort-based incentive mechanism which decides the contribution level of a peer according to the relative contribution which is the fraction of its upload capacity, instead of absolute contribution to implement a system which is both fair and efficient. Unfortunately, this strategy also has the problem of supervision. The system for supervision could lead to a lot of overhead and it could be very hard to guarantee the effectiveness of the supervision.

V. CONCLUSIONS

In this paper, we have proposed a new auction approach for P2P live media streaming system which is modeled as a free market. In our model, peers take part in simultaneous auctions for upload bandwidth from other peers, and no fictitious currency is involved. In DBA-Auction there are two stages which are auction stage and barter stage, and bidders change their bids dynamically according to the real-time incoming streaming rate they desire and the real-time available upload bandwidth they have.

In real life where money is used, there are quite a wide variety of goods, thus, it is necessary and effective to use money. However, in P2P live media streaming system, there is only one kind of goods, which is upload bandwidth and all the peers share similar resources which makes barter possible. We believe that “simple is great”. If a simpler way can make a system work well, all the more complex methods should be avoided.

We have conducted extensive simulation performance evaluation to evaluate our auction mechanism. According to the simulation results, our auction mechanism has very good performance in terms of average incoming stream rate, average playback delay and control packets ratio compared to the widely used tit-for-tat mechanism. In particular, the DBA-Auction mechanism not only has better performance than tit-for-tat strategy, but also effectively handles the problem of dishonest behaviors of peers, which is a very common and severe problem in incentive mechanisms for P2P live media streaming systems. The simulation results also show that our mechanism is scalable.

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