International Journal of Engineering & Technology, 7 (4.10) (2018) 852-856

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Location Domination Number of Sum of Graphs

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Abstract

Locating dominating set is the subset S of the vertex set $V(G)$ which dominate and uniquely identify all vertices of the set $V(G)-S$. In this paper we formulated the apt method for finding the location domination number of sum of graphs G_1+G_2 based on the nature of the graphs G_1 and G_2.

***Keywords**: 1 -vertex non locating dominating set; Dominating set; Locating domination set; Locating set; Sum of graphs*

1. Introduction

Dominating set [6] was defined by Oystein Ore in the year 1962 and it is stated as a subset S of the vertex set $V(G)$ such that every vertex of the G is either an element of S or adjacent to the elements of S. Cardinality of minimal dominating set is the domination number.

A set $S=\{v_1, v_2,\ldots, v_n\}$ of vertices in a connected graph G is a locating set if for every pair of distinct vertices $u,w\in V(G)$, $(d(u,v_1),, \ldots, d(u,v_n)) \neq (d(w,v_1),\ldots, d(w,v_n))$ where $d(x,y)$ is the distance between x and y. The locating number $\beta(G)$ is the minimum cardinality of a locating set of G [4].

Locating-dominating set (LD -set) was introduced by Slater [11,12] and it is defined as the subset S of the vertex set $V(G)$ which can detect and uniquely identify the position of every vertices of the set $V(G)-S$. Locating dominating set of G is called referencing-dominating set or an RD-set if G has no locating dominating set of smaller cardinality. Cardinality of RD-set is called the location-domination number of G and it is symbolised by $RD(G)$.

For simple graph $G=(V(G), E(G))$, open neighbourhood $N_G(v)$ of a vertex $v\in V(G)$ is $N_G(v)=\{u\in V(G) \mid uv\in E(G)\}$. And $N_G[v]=\{u\in V(G) \mid uv\in E(G)\}\cup\{v\}$ is the closed neighbourhood of $v\in V(G)$.

Colboum et al. [2] proved that Locating-dominating set is NP-complete. Rajasekar et al.[8,9] have found the location domination number of graph connected by a bridge and graphs obtained by fusion of single vertex. Locating dominating set was studied by various authors in [3,4,6,10,11].

In [1] Sergio R. Canoy, Jr. et al. have found location domination number of sum of graphs by using the definition of locating set. But locating set has its own downfall, as it is defined only for connected graphs. To overcome this we define 1 -vertex non locating dominating graph, with this we have conveyed a mode for finding location domination number of sum of any graphs.

2. Location Domination Number of Sum of Graphs

Theorem 2.1

Let G_1 and G_2 be any two graphs, then location domination number of graph G_1+G_2 satisfies the condition $RD(G_1)+RD(G_2)-2\le RD(G_1+G_2)\le RD(G_1)+RD(G_2)+1$.

Proof

Let us first prove that $RD(G_1+G_2)\le RD(G_1)+RD(G_2)+1$. For that it is enough to show that the graph G_1+G_2 has a LD-set with cardinality $RD(G_1)+RD(G_2)+1$.

Let S_1 and S_2 be the RD-set of G_1 and G_2. Now for the set $S=S_1\cup S_2$, we have that

$$S(u)=\begin{cases} S_1(u)\cup S_2, & \text{if } u\in V(G_1)-S_1 \\ S_1\cup S_2(u), & \text{if } u\in V(G_2)-S_2 \end{cases}$$

If S is an LD-set then there is nothing to prove. If not, then there exist atleast one pair of vertices $v_1,v_2\in V(G_1+G_2)-S$ such that

$$S(v_1)=S(v_2) \tag{1}$$

If $v_1,v_2\in V(G_1)-S_1$, then from Equation 1 one may conclude that $S_1(v_1)\cup S_2 = S_1(v_2)\cup S_2$

That is $S_1(v_1)=S_1(v_2)$, this implies that S_1 is not an RD-set of G_1. Hence it contradict the assumption that S_1 is a RD-set of G_1. Thus both v_1 and v_2 cannot belongs to $V(G_1)-S_1$ simultaneously. For same reason, both v_1 and v_2 cannot be simultaneously in $V(G_2)-S_2$. Hence if $v_1 \in V(G_1)-S_1$ then v_2 must be in the set $V(G_2)-S_2$. Therefore we have $S_1(v_1)\cup S_2 = S_1 \cup S_2(v_2)$. This is possible only if

$$S_1(v_1)=S_1 \text{ and } S_2(v_2)=S_2 \tag{2}$$

Suppose, there exist another pair of vertices $u_1,u_2 \in V(G_1+G_2)-S$ such that $S(u_1)=S(u_2)$. Then by above argument as in case of v_1,v_2, one may come to conclusion that both u_1,u_2 does not belongs to $V(G_1)-S_1$ or $V(G_2)-S_2$ simultaneously.

Hence let us assume that $u_1 \in V(G_1)-S_1$ and $u_2 \in V(G_2)-S_2$. Thus $S_1(u_1)\cup S_2 = S_1\cup S_2(u_2)$, this implies that

$$S_1(u_1)=S_1 \text{ and } S_2(u_2)=S_2 \tag{3}$$

From Equation 2 and 3 we have that $S_1(v_1)=S_1(u_1)=S_1$ and $S_2(v_2)=S_2(u_2)=S_2$. That is there exist $u_1,v_1 \in V(G_1)-S_1$ such that $S_1(u_1)=S_1(v_1)$, but this contradict the assumption that S_1 is an RD-set of G_1. Similarly it also contradict the assumption that S_2 is a RD-set of G_2.

Hence with respect to the set $S=S_1\cup S_2$ there may exist only one pair of vertex $v_1,v_2 \in V(G_1+G_2)-S$ such that $S(v_1)=S(v_2)$. Thus except v_1,v_2 all other vertices are uniquely located and dominated by the set S. Hence $S\cup\{v_1\}$ and $S\cup\{v_2\}$ must be the LD-set of the graph G_1+G_2. Therefore

$$RD(G_1+G_2)\le |S\cup\{v_1\}|$$
$$=RD(G_1)+RD(G_2)+1.$$

Now let us prove that the lower bound of $RD(G_1+G_2)$ is $RD(G_1)+RD(G_2)-2$. Suppose there exist an RD- set S of G_1+G_2 such that

$$|S|\le RD(G_1)+RD(G_2)-3 \tag{4}$$

Clearly $S=S\cap(V(G_1)\cup V(G_2))=(S\cap V(G_1))\cup(S\cap V(G_2))$ and $|S|=|S\cap(G_1)|+|S\cap(G_2)|-|(S\cap(G_1))\cap(S\cap(G_2))|$.

As $V(G_1)$ and $V(G_2)$ doesn't have any vertex in common we have that

$$|S|=|S\cap(G_1)|+|S\cap(G_2)| \tag{5}$$

From Equation 4 and 5 we have

$$|S|=|S\cap(G_1)|+|S\cap(G_2)|\le RD(G_1)+RD(G_2)-3$$

This is possible only if either $|S\cap V(G_1)|\le RD(G_1)-2$ or $|S\cap(G_2)|\le RD(G_2)-2$. Without loss of generality let us assume that $|S\cap V(G_1)|\le RD(G_1)-2$. In the graph G, $S\cap V(G_2)$ dominate all the vertices of $V(G_1)-S$ and it can atmost uniquely locate only one vertex of $V(G_1)-S$, say u provided $S\cap V(G_1)$ uniquely locate remaining all vertices of $V(G_1)-(S\cup\{u\})$. Thus $S\cap V(G_1)$ is a LD-set of $V(G_1)-\{u\}$, so $(S\cap V(G_1))\cup\{u\}$ is a LD-set of $V(G_1)$ with cardinality less than or equal to $RD(G_1)-1$. This contradicts the definition of RD-set. Hence $|S\cap V(G_1)|\ge RD(G_1)-1$, similarly $|S\cap V(G_2)|\ge RD(G_2)-1$. Therefore

$$RD(G_1)+RD(G_2)-2\le|S\cap V(G_1)|+|S\cap V(G_2)|$$
$$=|S|=RD(G_1+G_2).$$

Theorem 2.2

Let G be any graph with RD-set S. If for every RD-set of G, there exist a vertex $v\in V(G)-S$ such that $S(v)=S$, then $RD(G+K_1)=RD(G)+1$ otherwise $RD(G+K_1)=RD(G)$.

Proof

Let $V(K_1)=\{v_1\}$. By Theorem 2.1, we have

$$RD(G)+RD(K_1)-2\le RD(G+K_1)$$
$$RD(G)-1\le RD(G+K_1)$$

Suppose that $G+K_1$ has an RD-set S_1 with cardinality $RD(G)-1$, then v_1 must belongs to S_1. Otherwise G would have a RD-set with cardinality less than $RD(G)$. But in the graph $G+K_1$, v_1 can uniquely locate only one vertex of $V(G+K_1)-S_1$ (say u). Therefore the set $(S_1\cup\{u\})-\{v_1\}$ must be the RD-set of $G+K_1$. So we have constructed a RD-set which doesn't include the vertex $\{v_1\}$ with cardinality $RD(G)-1$. But it must also be the RD-set of G. This contradict the definition of RD-set. So $RD(G+K_1)\ge RD(G)$.

Case 1: Let $S(v)\ne S$ for all $v\in V(G)-S$.

By definition of $G+K_1$, v_1 is adjacent to all vertices of G. Hence v_1 is dominated by S and $S(v_1)=S\ne S(u)$ for all $u\in V(G)-S$, so S is a LD-set of $G+K_1$. Since the set with cardinality less than $RD(G)$ would not be a LD-set, S must be the RD-set of $G+K_1$. Hence $RD(G+K_1)=RD(G)$.

Case 2: Let for all RD-set S of graph G, $S(v)=S$ for some $v\in V(G)-S$.

Assume that $G+K_1$ has a RD-set S_1 such that $|S_1|=RD(G)$. If $v_1\notin S_1$ then by our assumption there must exist a vertex $v\in V(G)-S_1$ such that $S_1(v)=S_1$. As v_1 is adjacent to all vertices of G, $S_1(v_1)=S_1=S_1(v)$, so v_1 must belongs S_1.

Now consider the set $S_2=S_1-\{v_1\}$, its' cardinality is $RD(G)-1$. So it would not be the LD-set of G. As S_1 is the RD-set of $G+K_1$ and the vertex v_1 can atmost uniquely locate only one vertex w of $V(G)-S_1$, we must have that $S_2=S_1-\{v_1\}$ as an RD-set of $V(G)-\{w\}$ and $N_G(w)\cap S_2=\Phi$.

Now consider the set $S_3=S_2\cup\{w\}$, which is clearly the RD-set of G. But by our assumption there exist some vertex $v\in V(G)-S_3$ such that $S_3(v)=S_3$. That is $S_3(v)=S_2(v)\cup\{w\}=S_2\cup\{w\}$.

By combining the fact that $N(w)\cap S_2=\Phi$, $\{v\}\subset N(w)$ and $S_2(y)\ne S_2$ for all y other than v, we have that the set $S_2\cup\{v\}$ is an RD-set of G. But it has no vertex which is dominated by all the vertices of $S_2 \bigcup \{v\}$. This contradiction shows that $G+K_1$ cannot have any LD-set with cardinality $RD(G)$.

And so $S \bigcup \{v_1\}$ is the RD-set of $G+K_1$ with cardinality $RD(G)+K_1$.

Remark 2.1

If G is disconnected graph then $S(v) \neq S$ for any RD-set of G. Hence $RD(G+K_1)=RD(G)$.

Remark 2.2

Consider the graph $\bar{K}_n$ where $n \geq 2$. Clearly $\bar{K}_n$ is a disconnected graph and by Remark 2.1, $RD(\bar{K}_n + K_1) = RD(\bar{K}_n) = n$.

Definition 2.1

For the given graph G, a set $S_\alpha \subseteq V(G)$ is said to be 1-vertex non locating dominating set if it satisfies the following conditions

(i) *With respect to some vertex $v \in V(G)$, S_α must be the RD-set of $G-\{v\}$*

(ii) $N_G[v] \bigcap S_\alpha = \Phi$

(iii) $|S_\alpha| \leq RD(G)$

(iv) *Any set with cardinality less than $|S_\alpha|$ will not satisfies* (i), (ii) *and* (iii)

(v) *If $|S_\alpha| = RD(G)$ with $S_\alpha(u) = S_\alpha$ for some vertex $u \in V(G)-S_\alpha$ then for every RD-set S of the graph G there exist some vertex $w \in V(G)-S$ such that $S(w)=S$.*

Graphs for which the 1-vertex non location domination set can be found are said to be 1-vertex non locating dominating graph.

Remark 2.3

Every graph need not be a 1-vertex non location dominating graph.

Remark 2.4

1-vertex non location domination set for the given graph can be obtained from the RD-set S of the graph G by removing a vertex from S or interchanging a vertex from S with vertex from $V(G)-S$. Hence cardinality of S_α can be either $RD(G)$ or $RD(G)-1$.

Note: Graph G_1, G_2 which are mentioned in Theorem 2.3, 2.4, 2.5, 2.6 and Remark 2.5 can be any graph except the graph K_1.

Theorem 2.3

The set S is a RD-set of G_1+G_2, then the following one of the condition must be true in regarding to the set $S \bigcap V(G_1)$.

(i) If G_1 has 1-vertex non location domination set S_{α_1} with cardinality $RD(G)-1$ then $S_{\alpha_1} \subseteq S \bigcap V(G_1)$.

(ii) If G_1 has 1-vertex non location domination set S_{α_1} with cardinality $RD(G)$ then $S_{\alpha_1} \subseteq S \bigcap V(G_1)$ or $S \bigcap V(G_1)$ may or may not contains S_1 the RD-set of G_1.

(iii) If G_1 is not a 1-vertex non locating dominating graph then $S_1 \subseteq S \bigcap V(G_1)$, where S_1 is the RD-set of G_1.

Similar condition are also true for the set $S \bigcap V(G_2)$.

Proof

In the graph G_1+G_2, $S \bigcap V(G_2)$ can atmost uniquely locate only one vertex of G_1 provided $S \bigcap V(G_1)$ locates and dominate remaining all vertices of $G_1 - (S \bigcap (G_1))$. That is, if G_1 has a 1-vertex non location domination set and S is a RD-set of G_1+G_2 then

$S \bigcap V(G_1)$ contains 1-vertex non location domination set (6)

Case 1: Assume G_1 has 1-vertex non location domination set S_{α_1} with cardinality $RD(G_1)-1$. By Equation (6), $S_{\alpha_1} \subseteq S \bigcap V(G_1)$.

Case 2: By Equation (6), $S_{\alpha_1} \subseteq S \bigcap V(G_1)$. As $|S_{\alpha_1}| = RD(G_1)$, instead of 1-vertex non location domination set S_{α_1}, $S \bigcap V(G_1)$ may contains a locating dominating set S_1 of the graph G_1 also, provided S_1 satisfies some conditions. The following are various situations:

i) $S_{\alpha_1}(u) \neq S_{\alpha_1}$ for all $u \in V(G_1)-S_{\alpha_1}$ and $S_1(v)=S_1$ for some $v \in V(G_1)-S_1$ then $S_{\alpha_1} \subseteq S \bigcap V(G_1)$ and $S_1 \not\subset S \bigcap V(G_1)$.

ii) $S_{\alpha_1}(u) \neq S_{\alpha_1}$ for all $u \in V(G_1)-S_{\alpha_1}$ and $S_1(v) \neq S_1$ for all $v \in V(G_1)-S_1$ then $S_{\alpha_1} \subseteq S \bigcap V(G_1)$ or $S_1 \subseteq S \bigcap V(G_1)$.

iii) $S_{\alpha_1}(u) = S_{\alpha_1}$ for some $u \in V(G_1)-S_{\alpha_1}$ and $S_1(v)=S_1$ for some $v \in V(G_1)-S_1$ then $S_{\alpha_1} \subseteq S \bigcap V(G_1)$ or $S_1 \subseteq S \bigcap V(G_1)$.

iv) $S_{\alpha_1}(u) = S_{\alpha_1}$ for some $u \in V(G_1)-S_{\alpha_1}$ and $S_1(v) \neq S_1$ for all $v \in V(G_1)-S_1$ then S_α is not a 1-vertex non locating dominating set. This case will not occur, as G_1 is a 1-vertex non locating dominating graph.

Hence based on nature of S_{α_1} and S_1, $S_{\alpha_1} \subseteq S \bigcap V(G_1)$ for all cases and $S_1 \subseteq S \bigcap V(G_1)$ or $S_1 \not\subset S \bigcap V(G_1)$.

Case 3: Assume G_1 is not a 1-vertex non locating dominating graph.

As G_1 does not have a 1-vertex non location domination set and the set $S \bigcap V(G_2)$ doesn't play any role in locating the vertices of $V(G_1)-S$, the set $S \bigcap (G_1)$ must locate and dominate all the vertices of G_1. That is $S \bigcap V(G_1)$ is a LD-set of G_1.

Similarly, with regarding to the graph G_2 the set $S \bigcap V(G_2)$ will satisfy one of the conditions.

Theorem 2.4

Let G_1 and G_2 be any two 1-vertex non locating dominating graph with 1-vertex non location domination set S_{α_1} and S_{α_2} respectively. If for all 1-vertex non location domination set S_{α_1} and S_{α_2} of the graph G_1 and G_2 there exist some vertex $v_1 \in V(G_1)-S_{\alpha_1}$ and $v_2 \in V(G_2)-S_{\alpha_2}$ such that $S_{\alpha_1}(v_1)=S_{\alpha_1}$ and $S_{\alpha_2}(v_2)=S_{\alpha_2}$ then $RD(G_1+G_2)=|S_{\alpha_1}|+|S_{\alpha_2}|+1$ otherwise $RD(G_1+G_2)=|S_{\alpha_1}|+|S_{\alpha_2}|$.

Proof

As both G_1 and G_2 is 1-vertex non locating dominating graphs, by Theorem 2.3 the RD-set S of the graph G_1+G_2 is as follows, $S_{\alpha_1} \subseteq S \bigcap (G_1)$ and $S_{\alpha_2} \subseteq S \bigcap (G_2)$. That is

$$S_{\alpha_1} \bigcup S_{\alpha_2} \subseteq S \quad (7)$$

Case 1: Assume that for all 1-vertex non location domination set S_{α_1}, S_{α_2} of graph G_1, G_2 respectively, there exist some vertex $v_1 \in V(G_1) - S_{\alpha_1}$ and $v_2 \in V(G_1) - S_{\alpha_2}$ such that $S_{\alpha_1}(v_1) = S_{\alpha_1}$ and $S_{\alpha_2}(v_2) = S_{\alpha_2}$.

Now consider the set $S = S_{\alpha_1} \bigcup S_{\alpha_2}$, then we have

$S(v_1) = S_{\alpha_1}(v_1) \bigcup S_{\alpha_2} = S_{\alpha_1} \bigcup S_{\alpha_2}$

and $S(v_2) = S_{\alpha_1} \bigcup S_{\alpha_2}(v_2) = S_{\alpha_1} \bigcup S_{\alpha_2}$.

Therefore $S(v_1) = S(v_2)$ and so $S_{\alpha_1} \bigcup S_{\alpha_2}$ cannot be the LD-set of $G_1 + G_2$. Clearly $S_{\alpha_1} \bigcup S_{\alpha_2} \bigcup \{v_1\}$ and $S_{\alpha_1} \bigcup S_{\alpha_2} \bigcup \{v_2\}$ must be the LD-set of $G_1 + G_2$ with minimal cardinality. Hence $RD(G_1 + G_2) = |S_{\alpha_1}| + |S_{\alpha_2}| + 1$.

Case 2: Assume that G_1 and G_2 has 1-vertex non location domination set which can be any form other than in Case 1.

Let us consider the set $S = S_{\alpha_1} \bigcup S_{\alpha_2}$, where $S_{\alpha_1}, S_{\alpha_2}$ are 1-vertex location domination sets of G_1 and G_2. For any vertex v,

$$S(v) = \begin{cases} S_{\alpha_1}(v) \bigcup S_{\alpha_2}, \text{ if } v \in V(G_1) - S_1 \\ S_{\alpha_1} \bigcup S_{\alpha_2}(v), \text{ if } v \in V(G_2) - S_2 \end{cases}$$

Clearly $S(u) = S(w)$ is possible only if $S(u) = S(w) = S_{\alpha_1} \bigcup S_{\alpha_2}$. But by our assumption both G_1 and G_2 cannot simultaneously have a vertex $u \in (G_1) - S_{\alpha_1}$, $w \in (G_2) - S_{\alpha_2}$ such that $S_{\alpha_1}(u) = S_{\alpha_1}$ and $S_{\alpha_2}(w) = S_{\alpha_2}$. Hence $S(u) \neq S(w)$ for all $u, w \in V(G_1 + G_2) - S$. Thus S is the RD-set of $G_1 + G_2$ with cardinality $|S_{\alpha_1}| + |S_{\alpha_2}|$.

Theorem 2.5

Let G_1 and G_2 be any two graphs which do not have any 1-vertex non location domination set. If for every RD-set S_1 and S_2 of graphs G_1 and G_2 respectively, there exist some vertex $v_1 \in V(G_1) - S_1$ and $v_2 \in V(G_2) - S_2$ such that $S_1(v_1) = S_1$ and $S_2(v_2) = S_2$ then $RD(G_1 + G_2) = RD(G_1) + RD(G_2) + 1$ otherwise $RD(G_1 + G_2) = RD(G_1) + RD(G_2)$.

Proof

Let S be the RD-set of $G_1 + G_2$. Then by Theorem 2.3 we have, $S_1 \subseteq S \bigcap V(G_1)$ and $S_2 \subseteq S \bigcap V(G_2)$. That is $S_1 \bigcup S_2 \subseteq S$ and hence

$RD(G_1 + G_2) = |S| \geq |S_1| + |S_2| = RD(G_1) + RD(G_2)$

The rest of the theorem can be proved similar to the Theorem 2.4.

Theorem 2.6

Let G_1 be a 1-vertex non locating dominating graph and G_2 is not a 1-vertex non locating dominating graph. Then $RD(G_1 + G_2) = |S_{\alpha_1}| + |S_2| + 1$ if for all 1-vertex non location domination set S_{α_1} of G_1 and RD-set S_2 of G_2, there exist a vertex $v_1 \in V(G_1) - S_{\alpha_1}$ and $v_2 \in V(G_2) - S_2$ such that $S_{\alpha_1}(v_1) = S_{\alpha_1}$ and $S_2(v_2) = S_2$ otherwise $RD(G_1 + G_2) = |S_{\alpha_1}| + |S_{\alpha_2}|$.

Proof

Let S be the RD-set of $G_1 + G_2$. By applying Theorem 2.3 to the hypothesis of the theorem we get $S_{\alpha_1} \subseteq S \bigcup V(G_1)$ and $S_2 \subseteq S \bigcap V(G_2)$. Thus $S_{\alpha_1} \bigcup S_2 \subseteq S$ and hence

$|S_{\alpha_1}| + |S_2| \leq |S|$

Proof to the rest of the theorem is similar to the Theorem 2.4.

Remark 2.5

If atleast one of the graph of G_1 and G_2 is disconnected, then based on the nature of the graph, $RD(G_1 + G_2)$ can take value from either one of the following

(i) $|S_{\alpha_1}| + |S_{\alpha_2}|$ (ii) $|S_1| + |S_2|$

(iii) $|S_{\alpha_1}| + |S_2|$ (iv) $|S_1| + |S_{\alpha_2}|$

where S_{α_1} and S_{α_2} denote the 1-vertex non location domination set of G_1 and G_2 respectively. And S_1, S_2 denotes the RD-set of G_1 and G_2 respectively.

Remark 2.6

Consider the graph $\bar{K}_m, \bar{K}_n$, where $m, n \geq 2$. Clearly $\bar{K}_m$ and $\bar{K}_n$ are disconnected, 1-vertex non locating dominating graphs. Therefore by Remark 2.5 we get

$$\begin{aligned} RD(\bar{K}_m + \bar{K}_n) &= RD(\bar{K}_m) - 1 + RD(\bar{K}_n) - 1 \\ &= RD(\bar{K}_m) + RD(\bar{K}_n) - 2 \\ &= m + n - 2. \end{aligned}$$

3. Conclusion

In this paper we have define a graph namely 1-vertex non locating dominating graph. With the help of this definition we have found the location domination number of sum of any graphs.

Acknowledgement

This research is supported by UGC scheme RGNF. Award letter F1-17.1/2014-15/RGNF-2014-15-SC-TAM-80373/(SAIII/Website).

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