Some New Families of Prime Labeling of Graphs

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Abstract: A Graph G with n vertices is said to admit prime labeling if its vertices can be labeled with distinct positive integers not exceeding n such that the labels of each pair of adjacent vertices are relatively prime. A graph G which admits prime labeling is called a prime graph. In this paper we investigate the existence of prime labeling of some graphs related to cycle Cn, wheel Wn, comb Pn, crown Hn and helm Hn. We discuss prime labeling in the context of the graph operation namely duplication.

Keywords: Graph Labeling, Prime Labeling, Duplication, Prime Graphs

1. Introduction

In this paper, we consider only finite simple undirected graph. The graph G has vertex set V = V(G) and edge set E = E(G). The set of vertices adjacent to a vertex u of G is denoted by N(u). For notations and terminology we refer to Bondy and Murthy[1].

The notion of prime labeling was introduced by Roger Etringer and was discussed in a paper by Tout[6]. Two integers and share a relatively prime if their greatest common divisor is 1. Relatively prime numbers play an important role in both analytic and algebraic number theory. Many researchers have studied prime graph. Fu.H [3] has proved that the path Pn on n vertices is a prime graph. Deretsky et al [2] have proved that the cycle Cn on n vertices is a prime graph. Around 1980 Roger Etringer conjectured that all trees have prime labeling which is not settled till today.

The Prime labeling for planar grid was investigated by Sundaram et al [5], Lee.S.et.al [4] have proved that the wheel Wn is a prime graph if and only if n is even.

Definition 1.1[7] Duplication of an edge e = uv by a new vertex in a graph G produces a new graph G′ such that N(w) = {u,v}.

Definition 1.2 The graph obtained by duplication all the edges of a graph G is called duplication of G.

Definition 1.3 The comb Pn∗ is obtained from a path Pn by attaching a pendant edge at each vertex of the path Pn.

Definition 1.4 The crown graph Cn∗ is obtained from a cycle Cn by attaching a pendant edge at each vertex of the cycle.

Definition 1.5 The helm Hn is a graph obtained from a wheel by attaching a pendant edge at each vertex of the n-cycle.

In this paper we proved that the graphs obtained by duplication of every edge by a vertex in cycle Cn, the wheel Wn, and the comb Pn∗, the graph obtained by duplicating every rim edge by a vertex in crown Cn, and duplicating every edge by a vertex in crown Cn, the graph obtained by duplicating every rim edge by a vertex in Helm Hn and duplicating every rim and pendant edge by a vertex in Helm Hn are all prime graphs.

2. Main Results

Theorem 2.1

The graph obtained by duplicating every edge by a vertex in Cn, is a prime graph.

Proof

Let V(Cn) = {ui / 1 ≤ i ≤ n} and E(Cn) = {ui, ui+1 / 1 ≤ i ≤ n − 1} ∪ {un, u1}.

Let G be the graph obtained by duplicating every edge by a vertex in Cn and let u1, u2, ..., un be the new vertices by duplicating the edges u1u2, u2u3, ..., un−1un, unu1 respectively.

Then G′(G) = {ui, ui, 1 ≤ i ≤ n} and E(G) = {ui, ui+1 / 1 ≤ i ≤ n − 1} ∪ {un, u1}.

Define a labeling f : V(G) → {1, 2, 3, ..., 2n} as follows:

Let f(u1) = 2i − 1 for 1 ≤ i ≤ n,

f(u1) = 2i for 1 ≤ i ≤ n − 1.

gcd(f(u1), f(ui)) = gcd(2i − 1, 2i + 1) = 1 for 1 ≤ i ≤ n − 1.

gcd(f(un), f(u1)) = gcd(2n − 1, 1) = 1.

gcd(f(u1), f(u1)) = gcd(2i − 1, 2i) = 1 for 1 ≤ i ≤ n

gcd(f(u1), f(ui)) = gcd(2i, 2i + 1) = 1 for 1 ≤ i ≤ n − 1

gcd(f(un), f(u1)) = gcd(2n, 1) = 1

Thus f is a prime labeling.

Hence G is a prime graph.

Illustration 2.1

Figure 1: Prime labeling of duplication of every edge by a vertex in Cn
Theorem 2.2
The graph obtained by duplicating every edge by a vertex in Wheel $W_n$ is a prime graph.

Proof
Let $V(W_n) = \{ c, u_i / 1 \leq i \leq n \}$
$E(W_n) = \{ u_i / 1 \leq i \leq n \} \cup \{ u_i u_{i+1} / 1 \leq i \leq n-1 \} \cup \{ u_i u_n \}$

Let G be the graph obtained by duplicating every edge by a vertex in Wheel $W_n$ and let $v_1, v_2, ..., v_n$ and $w_1, w_2, ..., w_n$ be the new vertices by duplicating the edges $u_1 u_2 u_3, ..., u_{n-1} u_n, u_n u_1$ and $c u_1, c u_2, ..., c u_n$ respectively

$V(G) = \{ c, u_i, v_i, w_i / 1 \leq i \leq n \}$
$E(G) = \{ u_i u_{i+1}, v_i u_{i+1}, w_i u_{i+1} / 1 \leq i \leq n-1 \}$
\[ \cup \{ u_i v_i, u_i w_i / 1 \leq i \leq n \} \cup \{ u_i u_n, u_n u_i \} \]

$|V(G)| = 3n + 1, |E(G)| = 6n.$

Define a labeling $f : V(G) \rightarrow \{ 1, 2, 3, ..., 3n + 1 \}$ as follows.

Let $f(c) = 1, f(u_1) = 3, f(v_1) = 4$ and $f(w_1) = 2.$

$f(u_i) = \begin{cases} 
3i - 2 & \text{if } i \text{ is odd, } 3 \leq i \leq n \\
3i - 1 & \text{if } i \text{ is even, } 2 \leq i \leq n \\
3i - 1 & \text{if } i \text{ is odd, } 1 \leq i \leq n \\
(3i + 2 & \text{if } i \text{ is even, } 2 \leq i \leq n 
\end{cases}$

$f(w_i) = 3i, for 2 \leq i \leq n$

$gcd(c, f(c)) = 1, for 1 \leq i \leq n$

$gcd(c, f(c)) = 1, for 1 \leq i \leq n$

$gcd(c, f(u_i)) = gcd(3i - 2, 3i + 2) = 1 for 3 \leq i \leq n, i \text{ is odd}$

$gcd(c, f(u_i)) = gcd(3i - 1, 3i + 1) = 1 if n \text{ is odd}$

$gcd(c, f(v_i)) = gcd(3i - 1, 2i + 1) = 1 if 3 \leq i \leq n, i \text{ is odd}$

$gcd(c, f(w_i)) = gcd(3i - 1, 3i + 2) = 1 for 2 \leq i \leq n, i \text{ is even}$

Thus f is prime labeling.

Hence G is a prime graph.

Theorem 2.3
The comb $P_n^*$ is a prime graph.

Proof
Let $V(P_n^*) = \{ u_i / 1 \leq i \leq n \}$
$E(P_n^*) = \{ u_i u_{i+1} / 1 \leq i \leq n-1 \} \cup \{ u_i v_i / 1 \leq i \leq n \}$

Then

$|V(G)| = 2n, |E(G)| = 2n - 1.$

Define a labeling $f : V(G) \rightarrow \{ 1, 2, 3, ..., 2n \}$ as follows.

Let $f(u_i) = 2i - 1, for 1 \leq i \leq n$

$f(v_i) = 4i - 3, for 2 \leq i \leq n,$

$gcd(f(u_i), f(u_{i+1})) = gcd(2i - 1, 2i + 1) = 1$

for $1 \leq i \leq n$

as these two number are consecutive odd integers

$gcd(f(u_i), f(v_i)) = gcd(2i - 1, 2i) = 1$

for $1 \leq i \leq n$

Thus f is prime labeling.

Hence $P_n^*$ is a prime graph.

Theorem 2.4
The graph obtained by duplicating every edge by a vertex in Comb $P_n^*$ is a prime graph.

Proof
Let $V(P_n^*) = \{ u_i, w_i / 1 \leq i \leq n \}$
$E(P_n^*) = \{ u_i u_{i+1} / 1 \leq i \leq n-1 \} \cup \{ u_i w_i / 1 \leq i \leq n \}$

Let G be the graph obtained by duplicating every edge by a vertex in $P_n^*$ and let $v_1, v_2, ..., v_{n-1}$ and $x_1, x_2, ..., x_n$ be the new vertices by duplicating the edges $u_1 u_2 u_3, ..., u_{n-1} u_n$ and $u_1 w_1 w_2 w_3, ..., u_n w_n$ respectively.

Then,

$V(G) = \{ u_i, v_i, x_i / 1 \leq i \leq n \} \cup \{ v_i / 1 \leq i \leq n - 1 \}$

$E(G) = \{ u_i u_{i+1}, u_i v_i / 1 \leq i \leq n - 1 \}$
\[ \cup \{ u_i w_i, u_i x_i / 1 \leq i \leq n \} \]

$|V(G)| = 4n - 1, |E(G)| = 6n - 3.$

Define a labeling $f : V(G) \rightarrow \{ 1, 2, 3, ..., 4n - 1 \}$ as follows.

Let $f(u_1) = 1, f(w_1) = 2, f(x_1) = 3$, and $f(v_i) = 4.$

$f(u_i) = 4i - 3, for 2 \leq i \leq n, i \neq 0(mod 3)$

$f(w_i) = 4i - 2, for 2 \leq i \leq n, i \neq 0(mod 3)$

$f(x_i) = 4i - 1, for 1 \leq i \leq n - 1,$

$f(v_i) = 4i - 1, for 2 \leq i \leq n, i \equiv 0(mod 3)$

$gcd(f(u_i), f(u_{i+1})) = gcd(2i - 1, 2i + 1) = 1$

Since $f(u_1) = 1$

$gcd(f(u_i), f(v_i)) = 1$

$gcd(f(u_i), f(x_i)) = 1$

$gcd(f(u_i), f(w_i)) = 1$
Clearly, 
\[
gcd(f(u_i), f(u_{i+1})) = gcd(4i - 3, 4(i + 1) - 3)
\]
for \(2 \leq i \leq n - 1, i \neq 0 (\mod 3)\)

\[
gcd(f(u_i), f(u_{i+1})) = gcd(4i - 1, 4i + 1) = 1
\]
for \(2 \leq i \leq n - 1, i \equiv 0 (\mod 3)\)
as these two numbers are odd and their differences are 4, 2 respectively.

\[
gcd(f(u_{i-1}), f(u_i)) = gcd(4i - 1, 3, 4i - 1) = 1
\]
for \(2 \leq i \leq n - 1, i \equiv 0 (\mod 3)\)
as these two numbers are odd and their differences is 2

\[
gcd(f(u_i), f(w_i)) = gcd(4i - 3, 4i - 1) = 1
\]
for \(2 \leq i \leq n, i \neq 0 (\mod 3)\)

\[
gcd(f(u_i), f(x_i)) = gcd(4i - 3, 4i - 2) = 1
\]
for \(2 \leq i \leq n - 1, i \equiv 0 (\mod 3)\)

\[
gcd(f(u_{i-1}), f(x_i)) = gcd(4i-4, 4i-1) = 1
\]
for \(2 \leq i \leq n, i \equiv 0 (\mod 3)\)
as these are consecutive integers

\[
gcd(f(u_i), f(v_i)) = gcd(4i - 3, 4i) = 1
\]
for \(2 \leq i \leq n, i \equiv 0 (\mod 3)\)

Thus \(f\) is a prime labeling. Hence \(G\) is a prime graph.

**Illustration 2.4**

![Figure 3: Prime labeling of duplication of every edge by a vertex in \(P_i\)](image)

**Theorem 2.5**
The graph obtained by duplicating every rim edge by a vertex in Crown \(C_n^*\) is a prime graph.

**Proof**
Let \(V(C_n^*) = \{u_i, w_i / 1 \leq i \leq n\}\)

\[
E(C_n^*) = \{u_iw_i / 1 \leq i \leq n\} \cup \{u_iu_{i+1} / 1 \leq i \leq n - 1\} \cup \{u_1u_n\}
\]

Let \(G\) be the graph obtained by duplicating every rim edge by a vertex in \(C_n^*\) and let the new vertices be \(v_1, v_2, ..., v_n\) by duplicating the edges \(u_1u_2, u_2u_3, ..., u_{n-1}u_n, u_nu_1\).

Then \(V(G) = \{u_i, v_i, w_i / 1 \leq i \leq n\}\)

\[
E(G) = \{u_iv_i, u_iw_i / 1 \leq i \leq n\} \cup \{u_iu_{i+1}, v_iu_{i+1} / 1 \leq i \leq n - 1\} \cup \{u_1u_n\}
\]

\([V(G)] = 3n, [E(G)] = 4n\).

Define a labeling \(f : V(G) \rightarrow \{1, 2, 3, ..., 3n\}\) as follows

Let \(f(u_1) = 1, f(v_1) = 2, f(w_1) = 3n\)

\[
f(u_i) = \begin{cases} 
3i - 3, & \text{for } 2 \leq i \leq n, i \text{ is even} \\
3i - 4, & \text{for } 3 \leq i \leq n, i \text{ is odd}
\end{cases}
\]

\[
f(w_i) = \begin{cases} 
3i + 1, & \text{for } 2 \leq i \leq n, i \text{ is even} \\
3i - 1, & \text{for } 1 \leq i \leq n, i \text{ is odd}
\end{cases}
\]

Since \(f(u_1) = 1\)

\[
gcd(f(u_i), f(u_{i+1})) = 1\]

\[
gcd(f(u_i), f(u_{i-1})) = 1\]

\[
gcd(f(u_i), f(v_i)) = gcd(3i - 3(i - 1) + 4) = gcd(3i - 3i - 1) = 1\]

for \(2 \leq i \leq n, i \text{ is even}\)

\[
gcd(f(u_i), f(w_i)) = gcd(3i - 4(i + 1) - 3) = gcd(3i - 4i - 3) = 1\]

for \(3 \leq i \leq n, i \text{ is odd}\)
as these two numbers are odd and their differences are 2 and 4 respectively.

\[
gcd(f(u_i), f(v_i)) = gcd(3i - 3i + 1) = 1\]

for \(2 \leq i \leq n, i \text{ is even}\)

\[
gcd(f(u_i), f(w_i)) = gcd(3i - 3i - 1) = 1\]

for \(3 \leq i \leq n, i \text{ is odd}\)
as these two numbers are odd and their differences is 4

\[
gcd(f(u_i), f(v_i)) = gcd(3i - 4i - 1) = 1\]

for \(3 \leq i \leq n, i \text{ is odd}\)
as these two numbers one is odd and other is even and their differences is 3

\[
gcd(f(v_i), f(u_{i+1})) = gcd(3i + 1, 3i - 1) = 1\]

for \(2 \leq i \leq n - 1, i \text{ is even}\)
as these two numbers are odd and their differences is 2

\[
gcd(f(v_i), f(u_{i+1})) = gcd(3i - 1, 3i - 1) = 1\]

for \(2 \leq i \leq n - 1, i \text{ is even}\)
as these are two consecutive numbers.

Thus \(f\) is a prime labeling.

Hence \(G\) is a prime graph.

**Illustration 2.5**

![Figure 4: Prime labeling of duplication of every rim edge by a vertex in \(C_i\)](image)
**Theorem 2.6**
The graph obtained by duplicating every edge by a vertex in $C_n$ is a prime graph.

**Proof**
Let $V(C_n) = \{u_i, w_i \mid 1 \leq i \leq n\}$
$E(C_n) = \{(u_i, w_i/1 \leq i \leq n) \cup \{u_i, u_{i+1} \mid 1 \leq i \leq n-1\} \cup \{u_n, u_1\}\}

Let $G$ be the graph obtained by duplicating every edge by a vertex in $C_n$ and let the new vertices be $v_1, v_2, ..., v_n$ and $x_1, x_2, ..., x_n$ by duplicating the edges $u_1u_2, u_2u_3, ..., u_{n-1}u_n, u_nu_1$ and $u_1w_1, u_2w_2, ..., u_nw_n$, respectively. Then
$$V(G) = \{u_i, v_i, w_i, x_i, 1 \leq i \leq n\}$$
$$E(G) = \{(u_i, v_i, u_i, w_i, u_i, x_i, 1 \leq i \leq n) \cup \{u_i, u_{i+1}, v_i, u_{i+1} \mid 1 \leq i \leq n-1\} \cup \{u_n, u_1, v_n, u_1\}\}

Define a labeling $f : V(G) \rightarrow \{1, 2, 3, ..., 4n\}$ as follows

- $f(u_i) = 1, f(v_i) = 4, f(w_i) = 2$, and $f(x_i) = 3$.

- $f(u_i) = 4i - 3, for 2 \leq i \leq n, i \equiv 0 \pmod{3}$

- $f(w_i) = 4i - 2, for 1 \leq i \leq n$,

- $f(x_i) = 4i - 1, for 1 \leq i \leq n, i \equiv 0 \pmod{3}$

- $f(v_i) = 4i, for 1 \leq i \leq n$,

- $f(u_i) = 4i - 1, for 1 \leq i \leq n, i \equiv 0 \pmod{3}$

- $f(x_i) = 4i - 3, for 1 \leq i \leq n, i \equiv 0 \pmod{3}$

Since $f(u_1) = 1$
$gcd(f(u_i), f(u_{i+1})) = 1$
$gcd(f(u_n), f(u_1)) = 1$
$gcd(f(v_n), f(u_1)) = 1$
$gcd(f(v_i), f(u_1)) = 1$
$gcd(f(u_i), f(w_i)) = gcd(4i - 3, 4i - 1) = 1$
$gcd(f(u_i), f(x_i)) = gcd(4i - 4, 4i - 2) = 1$

as these two numbers are odd and they are not the multiples of 3 and their difference is 6
$gcd(f(u_i), f(u_{i+1})) = gcd(4i - 3, 4i + 1) = 1$
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
as these two numbers are odd and also their differences is 4
$gcd(f(u_i), f(u_{i+1})) = gcd(4i - 1, 4i + 1) = 1$
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
as they are consecutive odd integers
gcd(f(u_i), f(w_i)) = gcd(4i - 3, 4i - 2) = 1
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
gcd(f(u_i), f(x_i)) = gcd(4i - 4, 4i - 2) = 1
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
as they are consecutive integers
gcd(f(u_i), f(x_i)) = gcd(4i - 3, 4i - 1) = 1
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
as these two numbers are odd and also their differences is 2
gcd(f(w_i), f(x_i)) = gcd(4i - 2, 4i - 1) = 1
for $1 \leq i \leq n, i \equiv 0 \pmod{3}$
gcd(f(w_i), f(x_i)) = gcd(4i - 2, 4i - 1) = 1
for $1 \leq i \leq n, i \equiv 0 \pmod{3}$
gcd(f(w_i), f(u_{i+1})) = gcd(4i, 4i - 1) = 1
$gcd(4i, 4i + 1) = 1$
for $1 \leq i \leq n, i \equiv 1 \pmod{3}$
gcd(f(u_i), f(v_i)) = gcd(4i - 4, 4i - 1) = 1
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
as they are consecutive integer

$gcd(f(v_i), f(u_{i+1})) = gcd((4i, 4i + 3) = 1$
for $1 \leq i \leq n - 1, i + 1 \equiv 0 \pmod{3}$
gcd(f(u_i), f(x_i)) = gcd(4i - 1, 4i - 3) = 1
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
gcd(f(u_i), f(v_i)) = gcd(4i - 3, 4i) = 1
for $2 \leq i \leq n, i \equiv 0 \pmod{3}$
as these two numbers one is even and other is odd and their differences is 3 and they are not multiples of 3.
Thus $f$ s is a prime labeling.

Hence $G$ is a prime graph.

**Illustration 2.6**

![Figure 5: Prime labeling of duplication of every edge by a vertex in $C_5$](image)

**Theorem 2.7**
The graph obtained by duplicating every rim edge by a vertex in $H_n$ is a prime graph.

**Proof**
Let $V(H_n) = \{c_u, u_i, w_i, v_i \mid 1 \leq i \leq n\}$
$E(H_n) = \{(u_i, v_i, u_i, v_{i+1} \mid 1 \leq i \leq n) \cup \{u_n, u_1\}\}

Let $G$ be the graph obtained by duplicating every rim edge by a vertex in $H_n$ and let the new vertices be $v_1, v_2, ..., v_n$
by duplicating the edges
$u_1u_2, u_2u_3, ..., u_{n-1}u_n, u_nu_1$ respectively.

Then
$V(G) = \{c_u, u_i, v_i, w_i, v_i, x_i, 1 \leq i \leq n\}$$E(G) = \{(c_u, u_i, v_i, u_i, v_{i+1} \mid 1 \leq i \leq n - 1) \cup \{c_u, u_n, v_n, v_1\}\}
$\[|V(G)| = 3n + 1, |E(G)| = 5n\]

Define a labeling $f : V(G) \rightarrow \{1, 2, 3, ..., 3n + 1\}$ as follows

Let $f(c) = 1, f(u_1) = 3, f(v_1) = 4$, and $f(w_1) = 2$.

- $f(u_i) = (3i - 3, for 3 \leq i \leq n, i \equiv odd)$

- $f(v_i) = (3i + 1, for 2 \leq i \leq n, i \equiv even)$

- $f(w_i) = 3i, for 2 \leq i \leq n, i \equiv even$

Since $f(c) = 1$
$gcd(f(c), f(u_1)) = 1, for 1 \leq i \leq n$
$gcd(f(u_i), f(u_{i+1})) = gcd((3n - 2, 3) = 1 if n is odd$
$gcd(f(u_i), f(u_{i+1})) = gcd((3n - 1, 3) = 1 if n is even$
$gcd(f(v_i), f(u_{i+1})) = gcd((3n + 1, 3) = 1 if n is odd$
$gcd(f(v_i), f(u_{i+1})) = gcd((3n + 2, 3) = 1 if n is even$

Cleary,
$gcd(f(u_i), f(u_{i+1})) = gcd(3i - 2, 3i + 1 - 1) = gcd(3i - 2, 2) = 1$

for $3 \leq i \leq n, i \equiv odd$

$gcd(f(u_i), f(u_{i+1})) = gcd(3i - 1, 3(i + 1) - 2) = gcd(3i - 1, 3i + 1) = 1$
for $2 \leq i \leq n, i \equiv even$
Thus \( H \) is a prime graph.

Hence \( G \) is a prime graph.

\[
\begin{align*}
\gcd(f(u_i), f(v_i)) &= \gcd(3i - 2, 3i + 1) = 1 \\
\text{for } 3 \leq i \leq n, i \text{ is odd} \\
\gcd(f(u_i), f(v_i)) &= \gcd(3i - 1, 3i + 2) = 1 \\
\text{for } 2 \leq i \leq n, i \text{ is odd}
\end{align*}
\]

as these two numbers are odd and their differences are 4 and 2 respectively.

\[
\begin{align*}
\gcd(f(u_i), f(v_i)) &= \gcd(3i + 1, 3i + 2) = 1 \\
\text{for } 3 \leq i \leq n - 1, i \text{ is odd} \\
\gcd(f(u_i), f(v_i)) &= \gcd(3i + 2, 3i + 1) = 1 \\
\text{for } 2 \leq i \leq n - 1, i \text{ is even}
\end{align*}
\]

as these two numbers one is even and other is odd and their differences is 3 and they are not multiples of 3.

\[
\gcd(f(u_i), f(v_i)) = \gcd(3i - 1, 3i) = 1 \\
\text{for } 2 \leq i \leq n, i \text{ is even}
\]

as they are consecutive integer.

\[
\gcd(f(w_i), f(v_i)) = \gcd(3i - 2, 3i) = 1 \\
\text{for } 3 \leq i \leq n, i \text{ is odd}
\]

Thus \( f \) is a prime labeling.

Hence \( G \) is a prime graph.

Illustration 2.7

![Prime labeling of duplication of every rim and pendant edge by a vertex in \( H_4 \)](Image)

Illustration 2.8

![Prime labeling of duplication of every rim and pendant edge by a vertex in \( H_4 \)](Image)

3. Conclusion

Labeled graph is the topic of current due to its diversified application. We investigate Eight new results on primelabeling. It is an effort to relate the prime labeling and some graph operations. This approach is novel as it provides prime labeling for the larger graph resulted due to certain graph operation on a given graph.

References


