Chapter 7.1

并查集

The Disjoint Set ADT

Equivalence Class 等价类

1) **Definition of Equivalence Class:**

Suppose we have a set U={1,2,…,n} of n elements and a set R={(i_1,j_1), (i_2,j_2)…… (i_r,j_r)}of r relations. The relation R is an equivalence relation iff the following conditions are true(symbol'≡' represent the equivalence relation on sets, x,y,z are elements in set) :

- **Reflexive x ≡x.** 自反
- **Symmetric x ≡y,y ≡x** 对称
- **Transitive x ≡y and y ≡z,then x ≡z** 传递

Equivalence Class

例如：

判别3个数a, b, c能否构成三角形的三条边？

能构成三角形的等价类：

{ (3,4,5), (4,5,6), (5,6,7), …..}

不能构成三角形的等价类：

{ (1,2,3), (2,3,5), ….. }

Equivalence Class

2) **Example:**

set s= {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11}

pairs of equivalence:

(0 4),(3 1),(6 10),(8 9),(7 4),(6 8),(3 5),(2 11),
(11 0)

等价关系、
⇒合并等价类
构造并查集

Initial:{0}，{1}，{2}，{3}，{4}，{5}，{6}，{7}，{8}，
{9}，{10}，{11}

0≡4 {0，4}，{1}，{2}，{3}，{5}，{6}，{7}，{8}， {9},
{10}，{11}

等价类合并

3 ≡1 {0，4}，{1，3}，{2}，{5}，{6}，{7}，{8}，{9}，
{10}，{11}

Equivalence Class

6 ≡10 {0，4}，{1，3}，{2}，{5}，{6，10}，{7}，{8}，
{9}，{11}

8 ≡9 {0，4}，{1，3}，{2}，{5}，{6，10}，{7}，
{8，9}，{11}

7 ≡ 4 {0，4，7}，{1，3}，{2}，{5}，{6，10}，{8，9}，{11}

6 ≡ 8 {0，4，7}，{1，3}，{2}，{5}，{6，8，9，10}，{11}

3 ≡ 5 {0，4，7}，{1，3，5}，{2}，{6，8，9，10}，{11}

2 ≡ 11 {0，4，7}，{1，3，5}，{2，11}，{6，8，9，10}

11 ≡ 0 {0，4，7，2，11}，{1，3，5}，{6，8，9，10}

Equivalence Class

3) Online equivalence class operation 逻辑层允许的操作

- **Combine(a,b) : combine the equivalence classes that contains elements a and b into a single class**

- **Find(e) : determine the class that currently contains element e.**

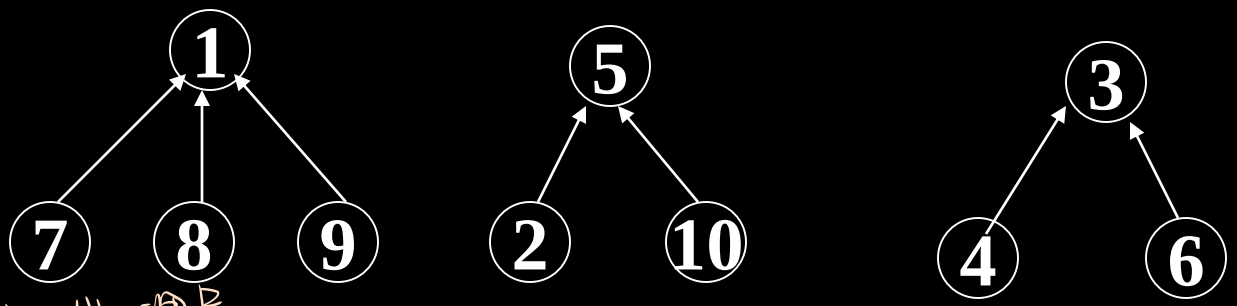
Combine(a,b) is equivalent to
i=Find(a); j=Find(b); if(i!=j) Union(i,j);

Equivalence Class

4) Tree Representation(Union-Find sets)

Example:

S_1={1,7,8,9}, S_2={5,2,10}, S_3={3,4,6},they all belong to S={1,2,3,……,10}



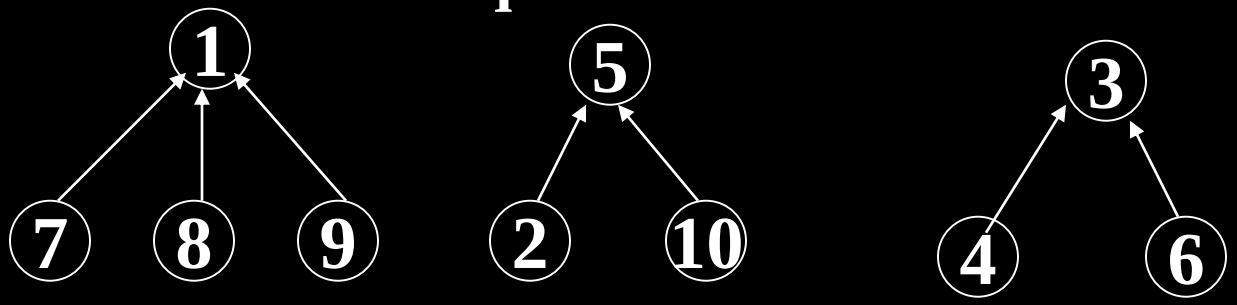
	0	1	2	3	4	5	6	7	8	9	10
parent		0	5	0	3	0	3	1	1	1	5

Equivalence Class

simple tree solution to union-find problem

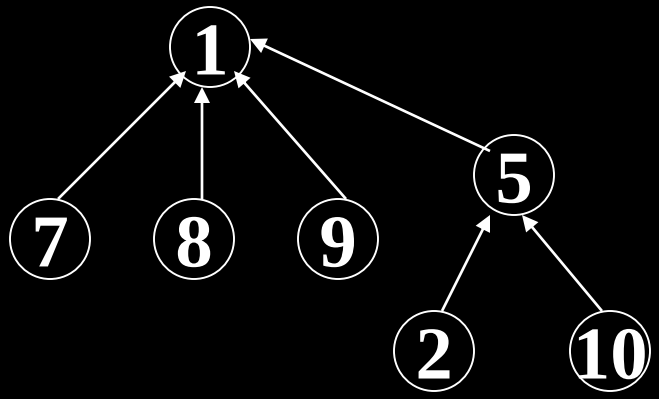
```
void Initialize(int n)
  {  parent=new int[n+1];
     for(int e=1;e<=n;e++)
        parent[e]=0;
  }

int Find(int e)
  {  while(parent[e])
          e=parent[e];
     return e;
  }

void Union(int i, int j)
  { parent[j]=i;
  }
```

Equivalence Class



	0	1	2	3	4	5	6	7	8	9	10
parent		0	5	0	3	~~10~~	3	1	1	1	5

Union (1,5)

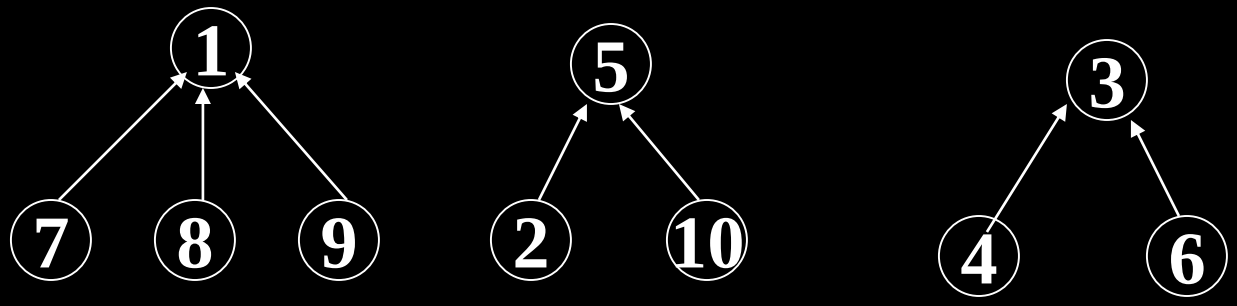


Equivalence Class

```
Java
 public class DisjSets
{  public DisjSets( int numElements )
    public void union( int root1, int root2 )
    public int find( int x )
    private int [ ] s;
}

public DisjSets( int numElements )
{   s = new int [ numElements ];
     for( int i = 0; i < s.length; i++ )
          s[ i ] = -1; //一个根结点
}
```

Equivalence Class

```
public void union( int root1, int root2 )
{   s[ root2 ] = root1;
}
public int find( int x )
{    if( s[x ] < 0 )
          return x;
     else
          return find( s[ x ] );
}
```



	0	1	2	3	4	5	6	7	8	9	10
S:		-1	5	-1	3	-1	3	1	1	1	5

Equivalence Class

5) **Performance Evaluation**

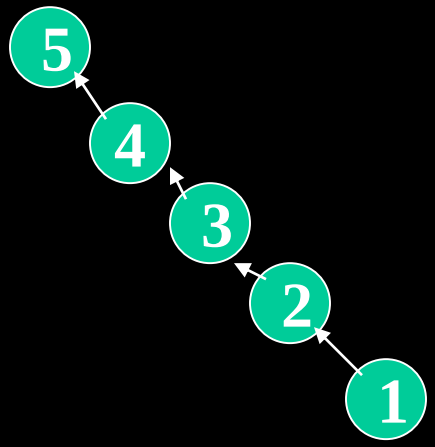
Time complexity: Find-- O(h),

Union-- θ(1)

Assume that u times unions and f times finds are to be performed, f>u,

in the worst case a tree with m elements can have a height of m:

Union(2,1),Union(3,2),Union(4,3),Union(5,4)…



Equivalence Class

★**improve Union**

two rules:

- **Weight rule: if the number of nodes in tree i is less than the number in tree j, then make j the parent of i; otherwise,make i the parent of j.**

- **Height rule: if the height of tree i is less than that of tree j, then make j the parent of i; otherwise,make i the parent of j.**

Equivalence Class

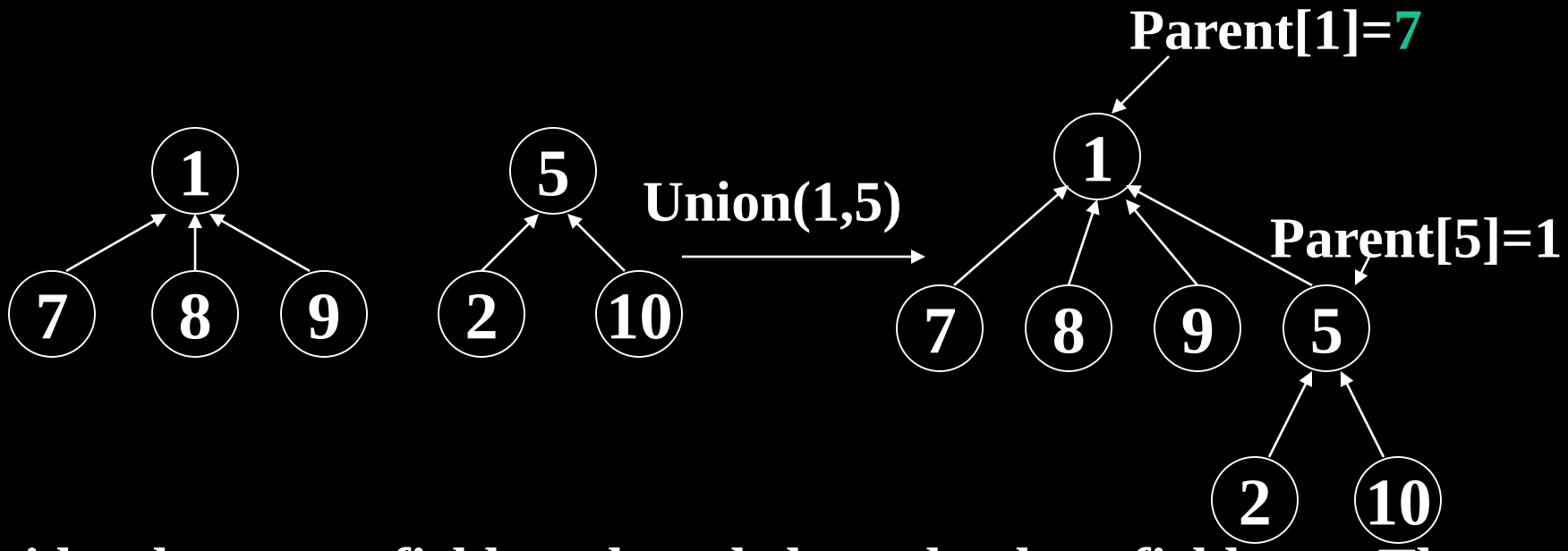
6) Performance Enhancement 2个优化.

✶improve Union in order to decrease the time each find take, so that the height of tree will not increase linearly .

✸.Improvement of *Find* –path compression

Equivalence Class

Let's discuss the weight rule(C++) :



Besides the *parent* field, each node has a boolean field *root* .The *root* field is true iff the node is presently a root node.The *parent* field of each root node is used to keep a count of the total number of nodes in the tree.

Equivalence Class

Union with the weight rule

```
void Initialize(int n)
{ root=new bool[n+1];
  parent=new int[n+1];
  for(int e=1;e<=n;e++)
  { parent[e]=1;
    root[e]=true;
  }
}
int Find(int e)
{ while(!root[e])
      e=parent[e];
  return e;
}
```

是否是根节点
记录父节点

Equivalence Class

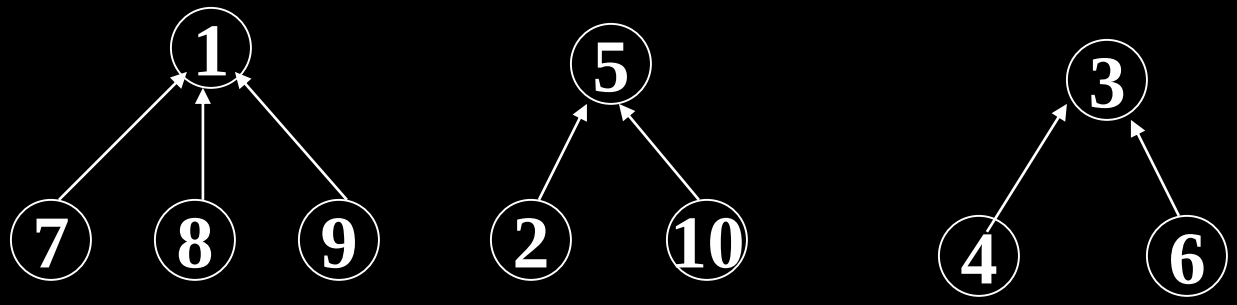
```
void Union(int i, int j)
{  if(parent[i]<parent[j])  //  i becomes subtree of j
      { parent[j]=parent[j]+parent[i];
        root[i]=false;
        parent[i]=j;
      }
   else { parent[i]=parent[i]+parent[j];
          root[j]=false;
          parent[j]=i;
        }
}
```

Equivalence Class

Java(高度规则) 不用root标志位

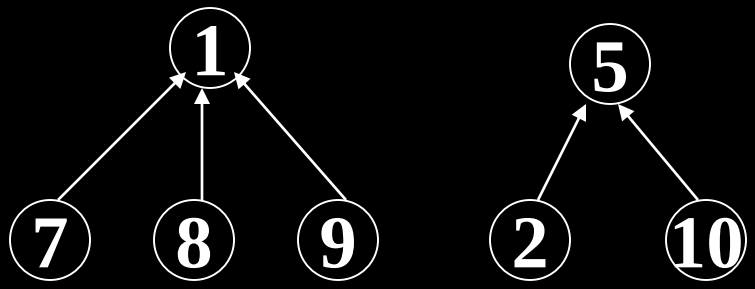
用一个数组来实现，根结点中放负数，而且是代表高度。 绝对值

```
public void union( int root1, int root2 )
{   if( s[ root2 ] < s[ root1 ] )
        s[ root1 ] = root2;
    else {   if( s[ root1 ] = = s[ root2 ] )
                 s[ root1 ]--;
             s[ root2 ] = root1;} }
```



	0	1	2	3	4	5	6	7	8	9	10
S:		-2	5	-2	3	-2	3	1	1	1	5

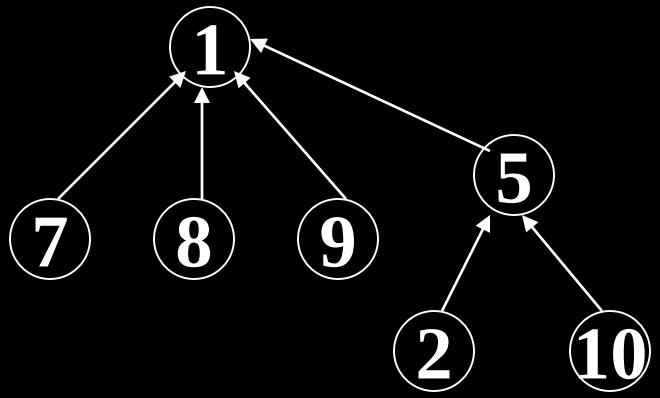
Equivalence Class



union (1, 5)

s[root1]--

s[root2] = root1

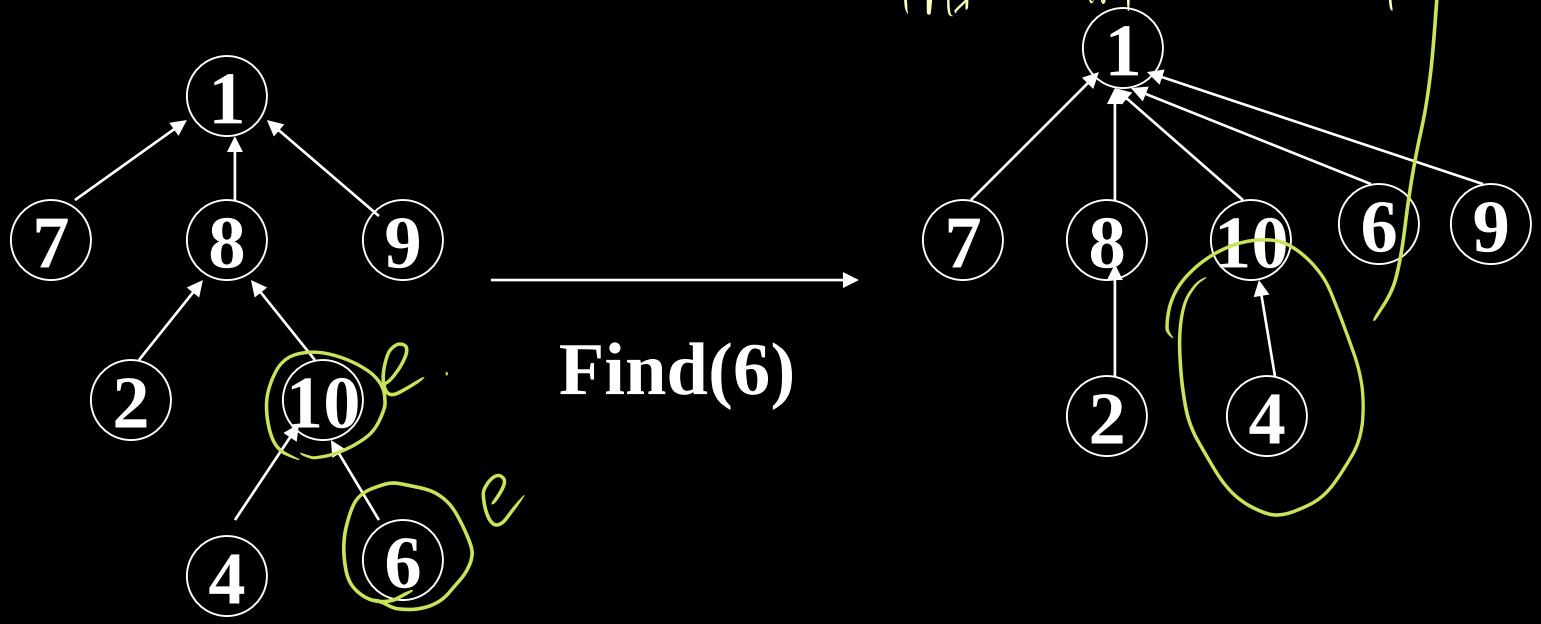


Equivalence Class

✸.Improvement of *Find* –path compression

When processing a equivalence pair, we need to operate *Find* twice, *WeightUnion* once.

Example of improvement:



Equivalence Class

```
int Find( int e) { /* C++  */ }
{  int j=e;
   while(!root[j])  j=parent[j];
   int f=e;
   while(f!=j)
     { int pf=parent[f];   parent[f]=j;  f=pf; }
}
```

Equivalence Class

Java

```
public int find( int x )
{    if( s[ x ] < 0 )
          return x;
     else
          return s[ x ] = find( s[ x ] );
}
```

根.

返回根 并把根赋给 s[x]

指到