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Union-Find Algorithm | Set 2 (Union By Rank and Path Compression)

In the [previous post](#), we introduced *union find algorithm* and used it to detect cycle in a graph. We used following *union()* and *find()* operations for subsets.

```
// Naive implementation of find
int find(int parent[], int i)
{
    if (parent[i] == -1)
        return i;
    return find(parent, parent[i]);
}

// Naive implementation of union()
void Union(int parent[], int x, int y)
{
    int xset = find(parent, x);
    int yset = find(parent, y);
    parent[xset] = yset;
}
```

Run on IDE

The above *union()* and *find()* are naive and the worst case time complexity is linear. The trees created to represent subsets can be skewed and can become like a linked list. Following is an example worst case scenario.

Let there be 4 elements 0, 1, 2, 3

Initially all elements are single element subsets.

0 1 2 3

Do Union(0, 1)

```
  1  2  3
  /
0
```

Do Union(1, 2)

```
  2  3
  /
 1
 /
0
```

Do Union(2, 3)

```
  3
  /
 2
 /
1
```



```

/
0

```

The above operations can be optimized to $O(\log n)$ in worst case. The idea is to always attach smaller depth tree under the root of the deeper tree. This technique is called **union by rank**. The term *rank* is preferred instead of height because if path compression technique (we have discussed it below) is used, then *rank* is not always equal to height. Also, size (in place of height) of trees can also be used as *rank*. Using size as *rank* also yields worst case time complexity as $O(\log n)$ (See [this](#) for proof)

Let us see the above example with union by rank
Initially all elements are single element subsets.
0 1 2 3

Do Union(0, 1)

```

  1  2  3
 /
0

```

Do Union(1, 2)

```

  1  3
 / \
0  2

```

Do Union(2, 3)

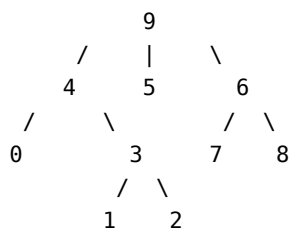
```

  1
 / | \
0  2  3

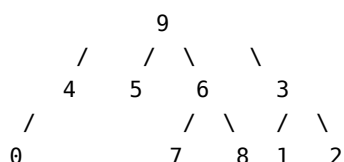
```

The second optimization to naive method is **Path Compression**. The idea is to flatten the tree when *find()* is called. When *find()* is called for an element *x*, root of the tree is returned. The *find()* operation traverses up from *x* to find root. The idea of path compression is to make the found root as parent of *x* so that we don't have to traverse all intermediate nodes again. If *x* is root of a subtree, then path (to root) from all nodes under *x* also compresses.

Let the subset {0, 1, .. 9} be represented as below and *find()* is called for element 3.



When *find()* is called for 3, we traverse up and find 9 as representative of this subset. With path compression, we also make 3 as child of 9 so that when *find()* is called next time for 1, 2 or 3, the path to root is reduced.



The two techniques complement each other. The time complexity of each operations becomes even smaller than $O(\log n)$. In fact, amortized time complexity effectively becomes small constant.

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Following is union by rank and path compression based implementation to find cycle in a graph.

```
// A union by rank and path compression based program to detect cycle in a graph
#include <stdio.h>
#include <stdlib.h>
```

```
// a structure to represent an edge in graph
struct Edge
{
    int src, dest;
};
```

```
// a structure to represent a graph
struct Graph
{
    // V-> Number of vertices, E-> Number of edges
    int V, E;

    // graph is represented as an array of edges
    struct Edge* edge;
};
```

```
struct subset
{
    int parent;
    int rank;
};
```

```
// Creates a graph with V vertices and E edges
struct Graph* createGraph(int V, int E)
{
    struct Graph* graph = (struct Graph*) malloc( sizeof(struct Graph) );
    graph->V = V;
    graph->E = E;

    graph->edge = (struct Edge*) malloc( graph->E * sizeof( struct Edge ) );

    return graph;
}
```

```
// A utility function to find set of an element i
// (uses path compression technique)
int find(struct subset subsets[], int i)
{
    // find root and make root as parent of i (path compression)
    if (subsets[i].parent != i)
        subsets[i].parent = find(subsets, subsets[i].parent);

    return subsets[i].parent;
}
```

```
// A function that does union of two sets of x and y
// (uses union by rank)
void Union(struct subset subsets[], int x, int y)
{
    int xroot = find(subsets, x);
    int yroot = find(subsets, y);

    // Attach smaller rank tree under root of high rank tree
    // (Union by Rank)
    if (subsets[xroot].rank < subsets[yroot].rank)
        subsets[xroot].parent = yroot;
    else if (subsets[xroot].rank > subsets[yroot].rank)
        subsets[yroot].parent = xroot;

    // If ranks are same, then make one as root and increment
```



```

// its rank by one
else
{
    subsets[yroot].parent = xroot;
    subsets[xroot].rank++;
}
}

// The main function to check whether a given graph contains cycle or not
int isCycle( struct Graph* graph )
{
    int V = graph->V;
    int E = graph->E;

    // Allocate memory for creating V sets
    struct subset *subsets =
        (struct subset*) malloc( V * sizeof(struct subset) );

    for (int v = 0; v < V; ++v)
    {
        subsets[v].parent = v;
        subsets[v].rank = 0;
    }

    // Iterate through all edges of graph, find sets of both
    // vertices of every edge, if sets are same, then there is
    // cycle in graph.
    for(int e = 0; e < E; ++e)
    {
        int x = find(subsets, graph->edge[e].src);
        int y = find(subsets, graph->edge[e].dest);

        if (x == y)
            return 1;

        Union(subsets, x, y);
    }
    return 0;
}

// Driver program to test above functions
int main()
{
    /* Let us create following graph
        0
        | \
        |  \
        |   \
        1-----2 */

    int V = 3, E = 3;
    struct Graph* graph = createGraph(V, E);

    // add edge 0-1
    graph->edge[0].src = 0;
    graph->edge[0].dest = 1;

    // add edge 1-2
    graph->edge[1].src = 1;
    graph->edge[1].dest = 2;

    // add edge 0-2
    graph->edge[2].src = 0;
    graph->edge[2].dest = 2;

    if (isCycle(graph))
        printf( "Graph contains cycle" );
    else
        printf( "Graph doesn't contain cycle" );

    return 0;
}

```

Run on IDE

Output:

Graph contains cycle



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