George Gabricht
56735102 - ggabrich

```
class Compare {
public:
	// O(1)
	bool operator() (Edge left, Edge right) {
		if (left.getWeight() >= right.getWeight()) { // 1
			return true; // 1
		}
		return false; // 1
	}
};

// O(E) where E is # Edges
void printKruskals(int result, int **tree, int treeSize) {
	cout << "Total Cost: " << result << endl; // 1
	for (int ndx = 0; ndx < treeSize; ndx++) { // E
		cout << "[ " << tree[ndx][0] << "-" << tree[ndx][1] << " ] ( "; // 1
		cout << tree[ndx][2] << " )" << endl; // 1
	}

}

// O(E + V)
void kruskals(Graph & g) {
	int num_vertex = g.numVert(), totalWeight = 0, num_edge = g.numEdge(); // 1
	Set sets(num_vertex); // 1
	Vertex *vertices = g.getVert(); // 1
	int **tree = new int*[num_edge], treeNdx = 0; // 1
	for (int ndx = 0; ndx < num_edge; ndx++) { // E
		tree[ndx] = new int[3]; // 1
	}
	for (int ndx = 0; ndx < num_vertex; ndx++) { // V
		if (vertices[ndx].getId() != -1) { // 1
			sets.makeSet(ndx); // 1
		}
	}
	priority_queue<Edge, vector<Edge>, Compare> pq; // 1
	// Total = E
	for (int ndx = 0; ndx < num_vertex; ndx++) { // V
		// Make Priority Queue - Ascending by Weight
		for (Edge eg : vertices[ndx].getEdges()) { // e = # edges in vertex
			pq.push(eg); // 1
		}
	}
	// for each edge in Priority Queue:
	// Total = E
	while (!pq.empty()) { // E
		Edge eg = pq.top(); // 1
		int u = eg.getSrc(), v = eg.getDst(); // 1
```

```
            if (sets.find(u) != sets.find(v)) { // 1 -> H = height of set
                totalWeight += eg.getWeight(); // 1
                tree[treeNdx][0] = u; // 1
                tree[treeNdx][1] = v; // 1
                tree[treeNdx++][2] = eg.getWeight(); // 1
                sets.unionSet(u, v); // 1
            }
            pq.pop(); // 1
        }
        printKruskals(totalWeight, tree, treeNdx); // E
        for (int ndx = 0; ndx < num_edge; ndx++) { // E
            delete[] tree[ndx]; // 1
        }
        delete[] tree; // 1
}

// O(1)
        bool Set::validId(int id) {
            if (id < 0 || id >= cap) { // 1
                return false; // 1
            }
            return true; // 1
        }

        // O(1)
        void Set::makeSet(int id) {
            if (!validId(id)) { // 1
                cerr << "ID out of bounds!" << endl; // 1
                exit(-1); // 1
            }
            setNode *curNode = &elements[id]; // 1
            curNode->parent = curNode; // 1
            curNode->rank = 0; // 1
            curNode->size = 1; // 1
        }

        // O(H) where H is height of set
        setNode * Set::findParent(setNode *node) {
            if (node->parent != node) { // 1
                node->parent = findParent(node->parent); // H
            }
            return node->parent; // 1
        }

        // O(H) where H is height of set
        setNode * Set::find(int id) {
            if (!validId(id)) { // 1
                cerr << "ID out of bounds!" << endl; // 1
```

```
                exit(-1); // 1
            }
            setNode *curNode = &elements[id]; // 1
            return findParent(curNode); // H
        }

// O(1)
        void Set::unionSet(int id1, int id2) {
            setNode *root1 = find(id1), *root2 = find(id2); // 1
            if (root1 != root2) { // 1
                if (root1->size < root2->size) { // 1
                    setNode *curNode = root1; // 1
                    root1 = root2; // 1
                    root2 = curNode; // 1
                }
                root2->parent = root1; // 1
                root1->size = root1->size + root2->size; // 1
            }

        }
// O(e) where e is # edges in vertex
        bool Vertex::isEdge(Edge e) {
            for (Edge eg : edges) { // E
                if (eg.getDst() == e.getDst()) { // 1
                    eg.setWeight(e.getWeight()); // 1
                    return true; // 1
                }
            }
            return false; // 1
        }

 // O(V + E)
        Graph(string file_name)
        : num_vertex(0), num_edge(0)
        {
            ifstream iFile(file_name); // 1
            if (!iFile.is_open()) { // 1
                cerr << "File Could Not be Opened!" << endl; // 1
                exit(-1); // 1
            }
            string curLine; // 1
            getline(iFile, curLine); // 1
            num_vertex = stoi(curLine); // 1
            vertices = new Vertex[num_vertex]; // 1
            for (int ndx = 0; ndx < num_vertex; ndx++) { // V
                vertices[ndx] = Vertex(ndx); // 1
            }
```

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```
        while (getline(iFile, curLine)) { // E
            istringstream strm(curLine); // 1
            int src, dst, wt; // 1
            strm >> src; // 1
            strm >> dst; // 1
            strm >> wt; // 1
            Edge newEdge(src, dst, wt); // 1
            if (!vertices[src].isEdge(newEdge)) { // e
                vertices[src].add_edge(newEdge); // 1
            }
            if (!vertices[dst].isEdge(newEdge.reverse())) { // e
                vertices[dst].add_edge(newEdge.reverse()); // 1
            }
            num_edge++; // 1
        }
    }
```

Kruskals on large.graph.txt

```
ggabrich@andromeda-54 15:12:22 ~/ics46/hw/ggabrich_hw8
$ make
echo ---------compiling testMain.cpp to create executable program kruskals---------
---------compiling testMain.cpp to create executable program kruskals---------
g++ -ggdb -std=c++11 -Wpedantic -Wall -Wextra -Werror -Wzero-as-null-pointer-constant testMain.cpp -o kruskals
ggabrich@andromeda-54 15:19:54 ~/ics46/hw/ggabrich_hw8
$ valgrind kruskals large.graph.txt
==9095== Memcheck, a memory error detector
==9095== Copyright (C) 2002-2017, and GNU GPL'd, by Julian Seward et al.
==9095== Using Valgrind-3.13.0 and LibVEX; rerun with -h for copyright info
==9095== Command: kruskals large.graph.txt
==9095==
Total Cost: 315
[ 98-95 ] ( 1 )
[ 93-97 ] ( 1 )
[ 75-71 ] ( 1 )
[ 65-62 ] ( 1 )
[ 16-14 ] ( 1 )
[ 39-43 ] ( 1 )
[ 6-5 ] ( 1 )
[ 31-32 ] ( 1 )
[ 63-67 ] ( 1 )
[ 4-2 ] ( 1 )
[ 74-78 ] ( 1 )
[ 66-68 ] ( 1 )
[ 1-0 ] ( 1 )
[ 85-84 ] ( 1 )
[ 77-80 ] ( 1 )
[ 33-29 ] ( 1 )
[ 56-55 ] ( 1 )
[ 47-51 ] ( 1 )
[ 24-28 ] ( 1 )
[ 17-13 ] ( 1 )
[ 12-8 ] ( 1 )
[ 27-26 ] ( 1 )
[ 64-67 ] ( 2 )
[ 7-11 ] ( 2 )
[ 66-70 ] ( 2 )
[ 34-35 ] ( 2 )
[ 69-73 ] ( 2 )
[ 73-75 ] ( 2 )
[ 37-40 ] ( 2 )
[ 72-74 ] ( 2 )
[ 37-38 ] ( 2 )
[ 75-78 ] ( 2 )
[ 38-41 ] ( 2 )
[ 41-42 ] ( 2 )
[ 21-20 ] ( 2 )
[ 5-3 ] ( 2 )
[ 83-87 ] ( 2 )
[ 45-46 ] ( 2 )
[ 11-14 ] ( 2 )
[ 92-94 ] ( 2 )
[ 96-99 ] ( 2 )
[ 3-7 ] ( 2 )
[ 53-54 ] ( 2 )
[ 26-29 ] ( 2 )
[ 58-62 ] ( 2 )
[ 2-0 ] ( 3 )
[ 67-69 ] ( 3 )
[ 34-30 ] ( 3 )
[ 37-39 ] ( 3 )
[ 19-20 ] ( 3 )
```

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[ 90-91 ] ( 3 )
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[ 50-52 ] ( 3 )
[ 27-28 ] ( 3 )
[ 56-59 ] ( 3 )
[ 56-58 ] ( 3 )
[ 58-60 ] ( 3 )
[ 67-70 ] ( 4 )
[ 2-3 ] ( 4 )
[ 76-78 ] ( 4 )
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[ 84-87 ] ( 4 )
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[ 94-96 ] ( 4 )
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[ 59-63 ] ( 4 )
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[ 32-35 ] ( 5 )
[ 16-17 ] ( 5 )
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[ 93-96 ] ( 5 )
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[ 12-13 ] ( 5 )
[ 51-55 ] ( 5 )
[ 54-57 ] ( 5 )
[ 54-58 ] ( 5 )
[ 16-19 ] ( 6 )
[ 75-79 ] ( 6 )
[ 9-10 ] ( 6 )
[ 86-88 ] ( 6 )
[ 88-89 ] ( 6 )
[ 97-0 ] ( 6 )
[ 34-37 ] ( 7 )
[ 21-25 ] ( 7 )
[ 61-63 ] ( 7 )
[ 22-25 ] ( 8 )
==9095==
==9095== HEAP SUMMARY:
==9095==     in use at exit: 0 bytes in 0 blocks
==9095==   total heap usage: 917 allocs, 917 frees, 147,236 bytes allocated
==9095==
==9095== All heap blocks were freed -- no leaks are possible
==9095==
==9095== For counts of detected and suppressed errors, rerun with: -v
==9095== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
ggabrich@andromeda-54 15:20:02 ~/ics46/hw/ggabrich_hw8
$
```

Kruskals on rdm.txt

```
ggabrich@andromeda-54 15:20:02 ~/ics46/hw/ggabrich_hw8
$ valgrind kruskals rdm.txt
==9259== Memcheck, a memory error detector
==9259== Copyright (C) 2002-2017, and GNU GPL'd, by Julian Seward et al.
==9259== Using Valgrind-3.13.0 and LibVEX; rerun with -h for copyright info
==9259== Command: kruskals rdm.txt
==9259==
Total Cost: 3384
[ 1023-1020 ] ( 1 )
[ 758-759 ] ( 1 )
[ 636-640 ] ( 1 )
[ 565-564 ] ( 1 )
[ 533-534 ] ( 1 )
[ 510-513 ] ( 1 )
[ 381-384 ] ( 1 )
[ 271-267 ] ( 1 )
[ 255-251 ] ( 1 )
[ 316-318 ] ( 1 )
[ 532-535 ] ( 1 )
[ 514-518 ] ( 1 )
[ 514-515 ] ( 1 )
[ 76-79 ] ( 1 )
[ 69-68 ] ( 1 )
[ 183-179 ] ( 1 )
[ 131-134 ] ( 1 )
[ 91-90 ] ( 1 )
[ 118-115 ] ( 1 )
[ 134-133 ] ( 1 )
[ 132-133 ] ( 1 )
[ 549-551 ] ( 1 )
[ 544-542 ] ( 1 )
[ 541-544 ] ( 1 )
[ 269-271 ] ( 1 )
[ 546-545 ] ( 1 )
[ 545-544 ] ( 1 )
[ 563-560 ] ( 1 )
[ 556-555 ] ( 1 )
[ 19-22 ] ( 1 )
[ 61-58 ] ( 1 )
[ 42-43 ] ( 1 )
[ 559-558 ] ( 1 )
[ 636-635 ] ( 1 )
[ 594-598 ] ( 1 )
[ 586-587 ] ( 1 )
[ 315-319 ] ( 1 )
[ 280-284 ] ( 1 )
[ 76-77 ] ( 1 )
[ 295-299 ] ( 1 )
[ 70-72 ] ( 1 )
[ 10-11 ] ( 1 )
[ 584-588 ] ( 1 )
[ 574-578 ] ( 1 )
[ 572-575 ] ( 1 )
[ 580-578 ] ( 1 )
[ 592-589 ] ( 1 )
[ 292-291 ] ( 1 )
[ 70-71 ] ( 1 )
[ 591-590 ] ( 1 )
[ 291-290 ] ( 1 )
[ 608-605 ] ( 1 )
[ 603-606 ] ( 1 )
[ 303-302 ] ( 1 )
[ 75-72 ] ( 1 )
```

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The Rest of the Screenshots Below...

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```
[ 860-861 ] ( 6 )
[ 439-440 ] ( 6 )
[ 878-882 ] ( 6 )
[ 892-895 ] ( 6 )
[ 898-902 ] ( 6 )
[ 921-924 ] ( 6 )
[ 924-925 ] ( 6 )
[ 941-942 ] ( 6 )
[ 944-946 ] ( 6 )
[ 946-947 ] ( 6 )
[ 948-949 ] ( 6 )
[ 953-956 ] ( 6 )
[ 954-958 ] ( 6 )
[ 242-246 ] ( 6 )
[ 957-961 ] ( 6 )
[ 964-968 ] ( 6 )
[ 968-972 ] ( 6 )
[ 973-975 ] ( 6 )
[ 486-489 ] ( 6 )
[ 246-248 ] ( 6 )
[ 990-992 ] ( 6 )
[ 1000-1003 ] ( 6 )
[ 500-503 ] ( 6 )
[ 1008-1009 ] ( 6 )
[ 512-508 ] ( 7 )
[ 953-952 ] ( 7 )
[ 64-66 ] ( 7 )
[ 526-530 ] ( 7 )
[ 530-534 ] ( 7 )
[ 278-279 ] ( 7 )
[ 281-285 ] ( 7 )
[ 36-40 ] ( 7 )
[ 77-81 ] ( 7 )
[ 643-647 ] ( 7 )
[ 647-650 ] ( 7 )
[ 342-343 ] ( 7 )
[ 42-44 ] ( 7 )
[ 725-726 ] ( 7 )
[ 471-475 ] ( 7 )
[ 943-940 ] ( 7 )
[ 94-97 ] ( 7 )
[ 390-392 ] ( 7 )
[ 2-1023 ] ( 7 )
[ 100-102 ] ( 7 )
[ 808-810 ] ( 7 )
[ 101-105 ] ( 7 )
[ 204-205 ] ( 7 )
[ 825-829 ] ( 7 )
[ 828-832 ] ( 7 )
[ 58-55 ] ( 7 )
[ 893-894 ] ( 7 )
[ 893-897 ] ( 7 )
[ 935-939 ] ( 7 )
[ 507-510 ] ( 7 )
[ 265-269 ] ( 8 )
[ 534-538 ] ( 8 )
[ 120-121 ] ( 8 )
[ 1020-1022 ] ( 8 )
[ 274-275 ] ( 8 )
[ 35-39 ] ( 8 )
[ 295-298 ] ( 8 )
[ 507-503 ] ( 8 )
[ 153-156 ] ( 8 )
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[ 1010-1011 ] ( 5 )
[ 1012-1015 ] ( 5 )
[ 1012-1016 ] ( 5 )
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[ 295-296 ] ( 6 )
[ 592-594 ] ( 6 )
[ 299-300 ] ( 6 )
[ 1015-1013 ] ( 6 )
[ 606-609 ] ( 6 )
[ 611-615 ] ( 6 )
[ 4-7 ] ( 6 )
[ 317-321 ] ( 6 )
[ 642-643 ] ( 6 )
[ 165-167 ] ( 6 )
[ 332-336 ] ( 6 )
[ 676-679 ] ( 6 )
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[ 174-175 ] ( 6 )
[ 349-353 ] ( 6 )
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[ 747-751 ] ( 6 )
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[ 192-195 ] ( 6 )
[ 386-390 ] ( 6 )
[ 779-783 ] ( 6 )
[ 994-992 ] ( 6 )
[ 784-787 ] ( 6 )
[ 98-102 ] ( 6 )
[ 795-798 ] ( 6 )
[ 200-203 ] ( 6 )
[ 401-402 ] ( 6 )
[ 808-812 ] ( 6 )
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[ 821-824 ] ( 6 )
[ 414-417 ] ( 6 )
[ 51-55 ] ( 6 )
[ 859-860 ] ( 6 )
[ 860-861 ] ( 6 )
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[ 714-718 ] ( 5 )
[ 367-368 ] ( 5 )
[ 92-93 ] ( 5 )
[ 744-748 ] ( 5 )
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[ 688-691 ] ( 5 )
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