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CSCI-351-01
Report - Programming Project 2

1. Each of my programs takes in the name of a graph file in Graph File Format at the command line. The graph is an Arxiv High Energy Physics Theory (HEP-TH) collaboration network from the Stanford Large Network Dataset Collection.

   `Regression` performs two linear regressions on the degree distribution of the HEP-TH graph: one fitted to an exponential function, and one fitted to a power function. It then gives me a table of the Degree *d* and Probability *pr(d)*. `Regression` then outputs the respective equations for *log pr(d)* and *pr(d)* and correlation coefficients for both linear regressions.

   `ConnectedComponents` finds all the connected components of the HEP-TH graph. It outputs the total number of connected components, then a table of each component's number and the number of vertices in that component. Next, it prints the number of each component, and the number of each vertex in that component. Finally, it tells me the size of the smallest and largest components, and the percentage of the graph's vertices that are contained in the largest component.

   `TopRank` finds the top-40-ranked vertices of the HEP-TH graph, with respect to both degree centrality and closeness centrality, and outputs the results.

2. `Regression.java` uses classes from the Parallel Java 2 Library, so the classpath must be set accordingly before this code can be compiled.

   Once the files have been compiled, the command lines to run my programs are as follows:

```
java Regression <fileName>
where <filename> = the name of a file in Graph File Format

java ConnectedComponents <fileName>
where <filename> = the name of a file in Graph File Format

java TopRank <fileName>
where <filename> = the name of a file in Graph File Format
```

3.

```
import java.math.BigDecimal;
import java.math.MathContext;
import java.text.DecimalFormat;
import java.util.TreeMap;
```

```
import edu.rit.numeric.ListXYSeries;
import edu.rit.numeric.XYSeries;

/**
 * Perform regressions on a graph, and analyze the results
 * @author Joseph Ville
 *
 * Usage: java Regression <fileName>
 *                    <fileName> = the name of the graph file to be analyzed
 *
 */
public class Regression
{
	private static Collaboration collab;
	private static String fileName;
	private static Vertex[] vertices;
	private static XYSeries.Regression expReg;
	private static XYSeries.Regression powReg;

	/**
	 * Main method for this program
	 * @param args - the command line arguments
	 */
	public static void main(String[] args)
	{
		if(args.length != 1)
		{
			usage();
		}
		fileName = args[0];
		collab = new Collaboration();
		vertices = collab.readFile(fileName);
		TreeMap<Integer, Integer> occurrences = degreeOccurrences(vertices);

		executeRegressions(occurrences);

		MathContext mathContext = new MathContext(5);

		// power
		double cP = Math.exp(powReg.a);
		System.out.print("log pr(d) = " + new BigDecimal(Math.log(cP),
mathContext) + " + " + new BigDecimal(powReg.b, mathContext) + " log d");
```

```
                System.out.println(", corr = " + new BigDecimal(powReg.corr,
mathContext));
                System.out.println("pr(d) = " + new BigDecimal(cP, mathContext) + " d^" +
new BigDecimal(powReg.b, mathContext));

                // exponential
                double cE = Math.exp(expReg.a);
                double d = Math.exp(expReg.b);
                System.out.print("log pr(d) = " + new BigDecimal(Math.log(cE),
mathContext) + " + " + new BigDecimal(Math.log(d), mathContext) + " d");
                System.out.println(", corr = " + new BigDecimal(expReg.corr,
mathContext));
                System.out.println("pr(d) = " + new BigDecimal(cE, mathContext) + " * " +
new BigDecimal(d, mathContext) + "^d");
        }

        /**
         * Performs linear regressions on an exponential function and a power function
         * @param degreeCounts - map of degrees to the number of occurrences
         */
        public static void executeRegressions(TreeMap<Integer, Integer> degreeCounts)
        {
                ListXYSeries expXYSeries = new ListXYSeries();
                ListXYSeries powXYSeries = new ListXYSeries();
                DecimalFormat d = new DecimalFormat("#");
                DecimalFormat d1 = new DecimalFormat("0.00000E00");
                System.out.println("d\tcount\tpr");
                for(Integer key : degreeCounts.keySet())
                {
                        double probD = (double)degreeCounts.get(key) / collab.V();
                        System.out.println(key + "\t" + d.format(degreeCounts.get(key)) +
"\t" + sFormat(d1.format(probD).toString()));
                        expXYSeries.add(key, Math.log(probD));
                        powXYSeries.add(Math.log(key), Math.log(probD));
                }
                expReg = expXYSeries.linearRegression();
                powReg = powXYSeries.linearRegression();
        }

        /**
         * Find the number of occurrences of each degree in an of an
         * array of vertices
         * @param vertices
         */
```

```
	public static TreeMap<Integer, Integer> degreeOccurrences(Vertex[] vertices)
	{
		// Using a TreeMap so it will be ordered automatically by vertex degree
		TreeMap<Integer, Integer> occurrences = new TreeMap<Integer,
Integer>();

		for(Vertex v : vertices)
		{
			if(occurrences.containsKey(v.degree()))
			{
				int value = occurrences.get(v.degree());
				occurrences.put(v.degree(), ++value);
			}
			else
			{
				occurrences.put(v.degree(), 1);
			}
		}
		return occurrences;
	}

	/**
	 * Format the given string so that "E"s are "e"s
	 * @param input - the given string
	 * @return the formatted string
	 */
	public static String sFormat(String input)
	{
		return input.replaceAll("E", "e");
	}

	/**
	 * Print a usage message and exit.
	 */
	public static void usage()
	{
		System.err.println("Usage: java Regression <fileName>\n" +
				"<fileName> = the name of the graph file to be analyzed");
		System.exit(0);
	}
}


import java.text.DecimalFormat;
```

```
import java.util.ArrayList;
import java.util.Collections;
import java.util.LinkedList;
import java.util.TreeMap;

/**
 * Find the connected components of a graph
 * @author Joseph Ville
 *
 * Usage: java ConnectedComponents <fileName>
 *                    <fileName> the name of the graph file to be analyzed
 *
 */
public class ConnectedComponents
{
	private static String fileName;
	private static int smallestCCSize;
	private static int largestCCSize;
	private static int largestCC;
	private boolean printData;
	private static TreeMap<Integer, ArrayList<Integer>> ccIndexes;

	/**
	 * Default constructor
	 */
	public ConnectedComponents()
	{
		smallestCCSize = Integer.MAX_VALUE;
		largestCCSize = Integer.MIN_VALUE;
	}

	/**
	 * Construct an object of this class
	 * @param printResults
	 */
	public ConnectedComponents(boolean printData)
	{
		this.printData = printData;
		smallestCCSize = Integer.MAX_VALUE;
		largestCCSize = Integer.MIN_VALUE;
	}

	/**
	 * Main method for this class
```

```
	 * @param args - the command line arguments
	 */
	public static void main(String[] args)
	{
		if(args.length != 1)
		{
			usage();
		}
		fileName = args[0];

		Collaboration collab = new Collaboration();
		Vertex[] vertices = collab.readFile(fileName);
		ConnectedComponents cc = new ConnectedComponents(true);

		cc.findComponents(vertices);
		DecimalFormat df = new DecimalFormat("0.#####");
		System.out.println("Size of smallest CC = " + smallestCCSize);
		System.out.println("Size of largest CC = " + largestCCSize);
		System.out.println(largestCCSize + "/" + collab.V() + " = " +
df.format((double)largestCCSize / collab.V()));
	}

	/**
	 * Find all connected components of an array of vertices
	 * @param vertices - the array of vertices
	 * @return the total number of connected components in the graph
	 */
	public int findComponents(Vertex[] vertices)
	{
		LinkedList<Integer> unvisited = new LinkedList<Integer>();
		LinkedList<Integer> queue = new LinkedList<Integer>();
		ccIndexes = new TreeMap<Integer, ArrayList<Integer>>();
		ArrayList<Integer> components;

		for(int a = 0; a < vertices.length; a++)
		{
			unvisited.add(a);
		}

		String outString = "connected components\nComp\tSize\n";
		int i = -1, m = -1, n = 0;
		while(unvisited.size() > 0)
		{
			i = unvisited.poll();
```

```
                queue.add(i);

                components = new ArrayList<Integer>();
                components.add(i);
                while(queue.size() > 0)
                {
                        m = queue.poll();

                        for(Integer neighbor : vertices[m].getNeighbors())
                        {
                                if(unvisited.contains(neighbor))
                                {
                                        unvisited.remove(neighbor);
                                        queue.add(neighbor);
                                        components.add(neighbor);
                                }
                        }
                }

                if(components.size() > largestCCSize)
                {
                        largestCC = n;
                        largestCCSize = components.size();
                }
                if(components.size() < smallestCCSize)
                {
                        smallestCCSize = components.size();
                }
                outString = outString.concat(n + "\t" + components.size() + "\n");
                Collections.sort(components);
                ccIndexes.put(n++, components);
        }

        if(printData)
        {
                System.out.print(n + " " + outString);
                printFormat(ccIndexes);
        }
        return n;
}

/**
 * Print the CCs and their associated indexes in a readable format
 * @param ccIndexes - a map of indexes to their CCs
```

```
	 */
	public static void printFormat(TreeMap<Integer, ArrayList<Integer>> ccIndexes)
	{
		for(int i = 0; i < ccIndexes.size(); i++)
		{
			System.out.printf("Comp %d = ", i);
			for(int j = 0; j < ccIndexes.get(i).size(); j++)
			{
				System.out.printf("%d ", ccIndexes.get(i).get(j));
			}
			System.out.println();
		}
	}

	/**
	 * @return the largest connected component
	 */
	public ArrayList<Integer> getLargestComponent()
	{
		return ccIndexes.get(largestCC);
	}

	/**
	 * Print a usage message and exit
	 */
	public static void usage()
	{
		System.err.println("Usage: java ConnectedComponents <fileName>\n" +
				"<fileName> = the name of the graph file to be analyzed");
		System.exit(0);
	}
}// end class ConnectedComponents


import java.util.AbstractMap.SimpleEntry;
import java.util.ArrayList;
import java.util.Collections;
import java.util.Comparator;
import java.util.LinkedList;
import java.util.List;

/**
 * Analyze a graph and make conclusions about the top-40-ranked vertices
 * @author Joseph Ville
```

```
 *
 * Usage: java TopRank <fileName>
 *                    <fileName> = the name of the graph file to be analyzed
 */
public class TopRank
{
	private static String fileName;
	private static Vertex[] vertices;

	/**
	 * Main method for this program
	 * @param args - the command line arguments
	 */
	public static void main(String[] args)
	{
		if(args.length != 1)
		{
			usage();
		}
		fileName = args[0];

		Collaboration collab = new Collaboration();
		ConnectedComponents cc = new ConnectedComponents(false);
		vertices = collab.readFile(fileName);
		int n = cc.findComponents(vertices);
		ArrayList<Integer> largestCC = cc.getLargestComponent();

		int vertex;
		List<SimpleEntry<Integer, Integer>> cloCent = degreeCent(largestCC);
		System.out.println("Rank\tVertex\tDegCen");
		for(int i = 0; i < 40; i++)
		{
			vertex = largestCC.get(i);
			System.out.println((i+1) + "\t" + cloCent.get(vertex).getKey() + "\t"
+ cloCent.get(vertex).getValue());
		}

		List<SimpleEntry<Integer, Float>> avgDistances =
closenessCent(largestCC);
		System.out.println("Rank\tVertex\tCloCen");
		for(int i = 0; i < 40; i++)
		{
			vertex = largestCC.get(i);
```

```
                        System.out.println((i+1) + "\t" + avgDistances.get(vertex).getKey()
+ "\t" + avgDistances.get(vertex).getValue());
                }
        }

        /**
         * Compute the closeness centrality of the given connected component
         * @param cc - the connected component
         * @return - an ArrayList<SimpleEntry<Integer, Float>> which stores the vertex
number and its
         *                  associated closeness centrality
         */
        public static List<SimpleEntry<Integer, Float>>
closenessCent(ArrayList<Integer> cc)
        {
                List<SimpleEntry<Integer, Float>> avgDistances = new
ArrayList<SimpleEntry<Integer, Float>>(cc.size());
                int current = 0;
                for(int i = 0; i < cc.size(); i++)
                {
                        current = cc.get(i);
                        avgDistances.add(new SimpleEntry<Integer, Float>(current,
avgDistance(current)));
                }

                // sort the distances
                Collections.sort(avgDistances, new Comparator<SimpleEntry<Integer,
Float>>(){
                                @Override
                                public int compare(SimpleEntry<Integer, Float> arg0,
SimpleEntry<Integer, Float> arg1)
                                {
                                        return
arg0.getValue().compareTo(arg1.getValue());
                                }
                        });
                return avgDistances;
        }

        /**
         * Compute the degree centrality of the given connected component
         * @param cc - the connected component
         * @return an ArrayList<SimpleEntry<Integer, Integer>> which stores the vertex
number and its
```

```
	 *		associated degree centrality
	 */
	public static List<SimpleEntry<Integer, Integer>> degreeCent(ArrayList<Integer>
cc)
	{
		List<SimpleEntry<Integer, Integer>> degrees = new
ArrayList<SimpleEntry<Integer, Integer>>(cc.size());
		int current = 0;
		for(int v = 0; v < cc.size(); v++)
		{
			current = cc.get(v);
			degrees.add(new SimpleEntry<Integer, Integer>(current,
vertices[current].degree()));
		}
		Collections.sort(degrees, new Comparator<SimpleEntry<Integer,
Integer>>(){
			@Override
			public int compare(SimpleEntry<Integer, Integer> arg0,
SimpleEntry<Integer, Integer> arg1)
			{
				return arg1.getValue().compareTo(arg0.getValue());
			}
		});
		return degrees;
	}

	/**
	 * Compute the average of the distances between the given vertex and every
other vertex
	 * @param vertex - the vertex to find distances from
	 * @return the average distance from this vertex to every other vertex
	 */
	public static float avgDistance(int vertex)
	{
		LinkedList<Integer> queue = new LinkedList<Integer>(); // queue of
vertex indices
		boolean[] seen = new boolean[	vertices.length]; // whether this
vertex has been seen
		int[] distances = new int[vertices.length]; // distances from this to all other
vertices

		for(int i = 0; i < vertices.length; i++) // initialize the arrays
		{
			distances[i] = Integer.MAX_VALUE;
```

```
                seen[i] = false;
            }

            seen[vertex] = true;

            queue.add(vertex);
            int a = 0;
            int count = 0;
            distances[vertex] = 0;

            while(queue.size() != 0)
            {
                a = queue.poll(); // remove the head of the queue
                for(Integer b : vertices[a].getNeighbors()) // loop through all
neighbors of current vertex
                {
                    if(!seen[b])
                    {
                        seen[b] = true;
                        queue.add(b); // add b to end of queue
                        count++;
                        distances[b] = distances[a] + 1;
                    } // end if
                } // end for
            } // end while

            int sum = 0;
            for(int i = 0; i < vertices.length; i++)
            {
                if(distances[i] != Integer.MAX_VALUE)
                {
                    sum += distances[i];
                }
            }
            return (float) sum / count;
        }

        /**
         * Print a usage message and exit
         */
        public static void usage()
        {
            System.err.println("Usage: java TopRank <fileName>\n" +
                    "<fileName> = the name of the graph file to be analyzed");
```

```
                System.exit(0);
        }
}


import java.io.FileReader;
import java.io.BufferedReader;

/**
 * Analyzes a Collaboration Graph
 *
 * @author Joseph Ville
 */
public class Collaboration
{
        private int V;
        private int E;
        private Vertex[] vertices;

        /**
         * Construct an object of this class
         */
        public Collaboration()
        {
        }

        /**
         * Reads and processes a file in the Graph File Format
         * @param fileName - the file to process
         * @return vertices - an array of vertices for the graph
         * @throws Exception
         */
        public Vertex[] readFile(String fileName)
        {
                String line = "";

                try
                {
                        BufferedReader buff = new BufferedReader(new
FileReader(fileName));

                        boolean gLine = false;
                        boolean eLine = false;
```

```
                        while((line = buff.readLine()) != null)
                        {
                                String[] lineArr;

                                // ignore any blank line
                                if(!line.equals(null) && !line.isEmpty())
                                {
                                        lineArr = line.split(" ");

                                        /* Required. Edges of the graph.
                                        First field - source vertex #, 0 <= an int <= V-1
                                        Second field - destination vertex #, 0 <= an int <=
V-1
                                        Third field - edge weight, a floating pt #. If 3rd field
omitted,
                                                assume to be 1 by default.
                                        */
                                        if(lineArr[0].equals("e"))
                                        {
                                                eLine = true;
                                                int index = Integer.parseInt(lineArr[1]);
                                                int neighbor = Integer.parseInt(lineArr[2]);

                                                initializeIfNull(vertices, index);
                                                initializeIfNull(vertices, neighbor);
                                                vertices[index].addNeighbor(neighbor);
                                                vertices[neighbor].addNeighbor(index);
                                        }
                                        /* Required. Occurs once, at beginning of file
                                        The parameters of the graph.
                                        First field is # of vertices V, an int >= 0
                                        Second field is # of edges E, an int >= 0
                                        */
                                        else if(lineArr[0].equals("g"))
                                        {
                                                gLine = true;
                                                int numVertices =
Integer.parseInt(lineArr[1]); // V and E are guaranteed to be >= 0
                                                int numEdges = Integer.parseInt(lineArr[2]);

                                                /* ok to do this here, because this will be
executed before
                                                any of the other if statements on this or any
other
```

```
                                        pass of the while loop */
                                        this.V = numVertices;
                                        this.E = numEdges;
                                        vertices = new Vertex[V];
                                }
                                // ignore any lines beginning with v, c, or d
                                else if(lineArr[0].equals("v"))
                                {
                                        continue;
                                }
                                else if(lineArr[0].equals("d"))
                                {
                                        continue;
                                }
                                else if(lineArr[0].equals("c"))
                                {
                                        continue;
                                }
                        }// end if
                }// end while

                buff.close();

                // make sure the file contained the required lines
                if(gLine == false || eLine == false)
                {
                        System.err.println("The file is in an invalid format.");
                        System.exit(0);
                }
        }
        catch(NumberFormatException nfe)
        {
                System.err.println("A number in the file had invalid format");
                System.exit(0);
        }
        catch(Exception ex)
        {
                System.err.println("There was an error reading the file");
                System.exit(0);
        }
        return vertices;
}// end readFile()

/**
```

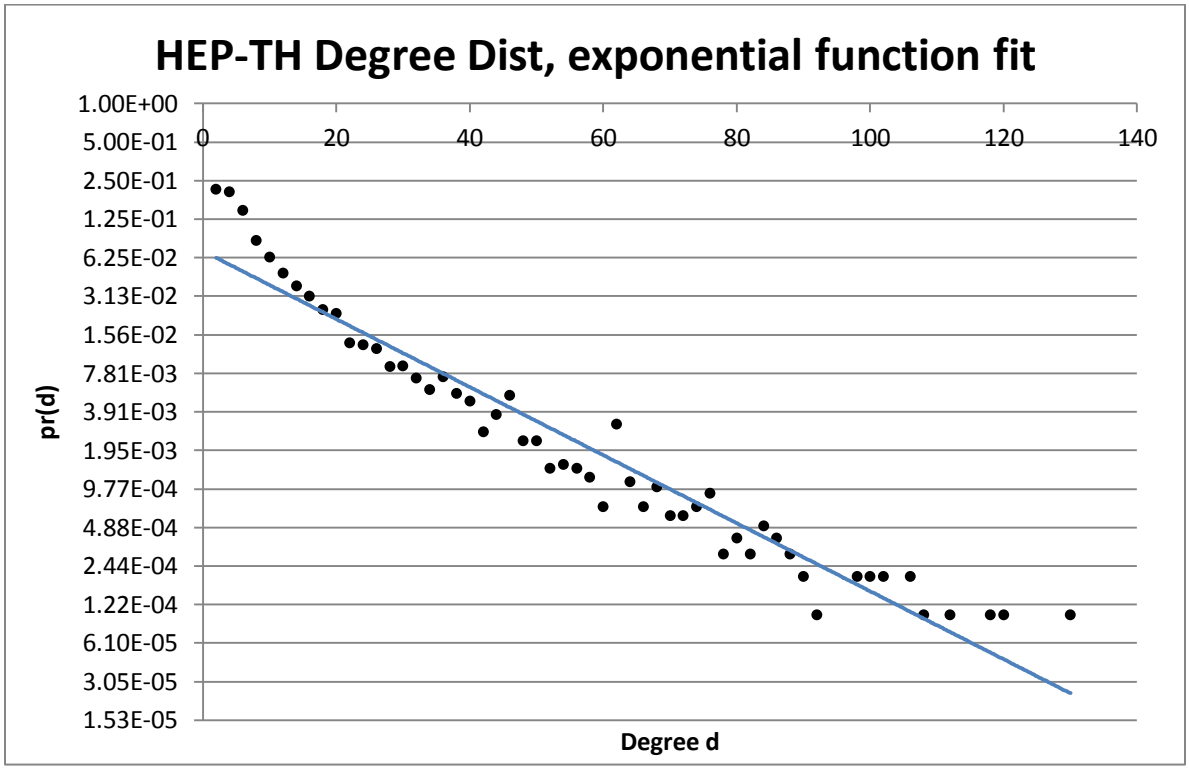
```
	 * @return the number of vertices
	 */
	public int V()
	{
		return V;
	}

	/**
	 * @return the number of edges
	 */
	public int E()
	{
		return E;
	}

	/**
	 * Check if a vertex is null, and if it is, initialize it.
	 * @param v - the vertex to check
	 */
	private void initializeIfNull(Vertex[] vertices, int v)
	{
		if(vertices[v] == null)
		{
			vertices[v] = new Vertex();
		}
	}
}// end class Collaboration


import java.util.ArrayList;

/**
 * A class to store all the attributes of a vertex object
 * @author Joseph Ville
 */
public class Vertex
{
	private ArrayList<Integer> neighbors; // neighbors of the current vertex

	/**
	 * Construct an object of this class, by setting
	 * the class variables to their default values
	 */
	public Vertex()
```

```
	{
		neighbors = new ArrayList<Integer>();
	}

	/**
	 * Find the degree of this vertex. Will only work after
	 * neighbors list has finished populating.
	 * @return the degree of this vertex
	 */
	public int degree()
	{
		return neighbors.size();
	}

	/**
	 * Get the list of vertices that are adjacent to the current vertex
	 * @return the list of neighbors
	 */
	public ArrayList<Integer> getNeighbors()
	{
		return neighbors;
	}

	/**
	 * Appends a vertex number to the end of this vertex's neighbor list
	 * @param n - the neighbor to be added
	 */
	public void addNeighbor(int n)
	{
		this.neighbors.add(n);
	}
}// end class Vertex
```

4. Command line: java Regression CA-HepTh-graph.txt

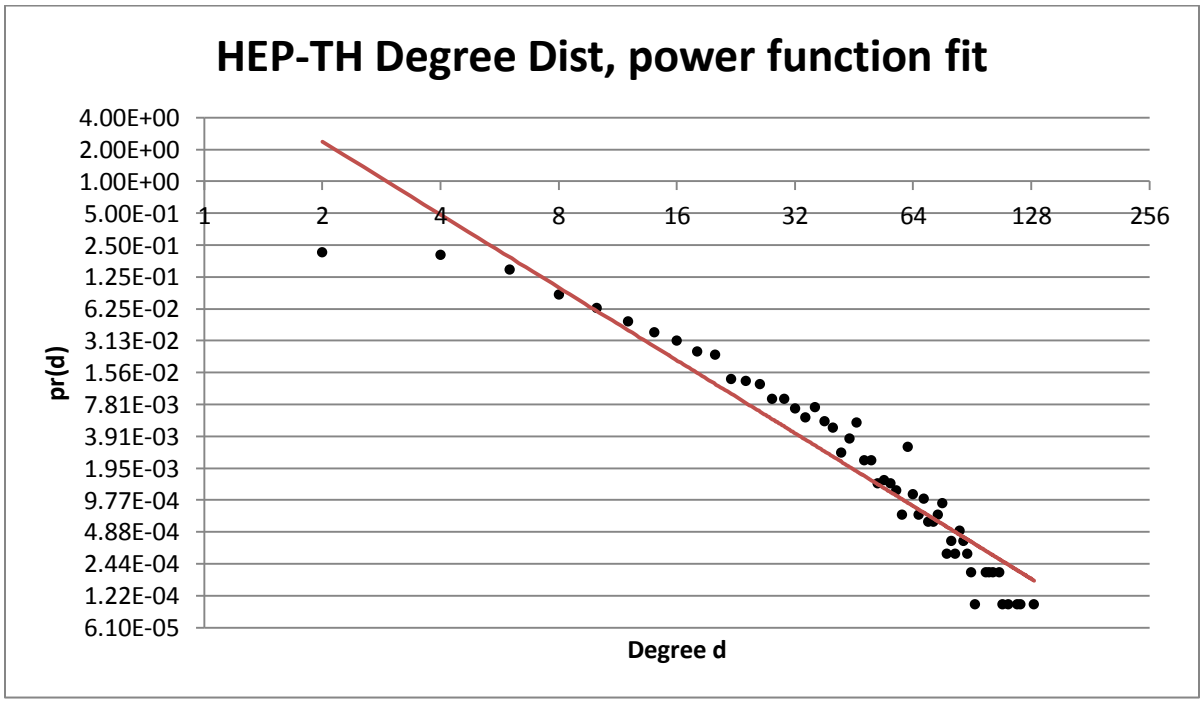
d	count	pr
2	2110	2.13628E-01
4	2015	2.04009E-01
6	1446	1.46401E-01
8	847	8.57548E-02
10	628	6.35821E-02
12	468	4.73828E-02
14	371	3.75620E-02
16	311	3.14873E-02
18	244	2.47039E-02

20	227	2.29827E-02
22	134	1.35669E-02
24	129	1.30606E-02
26	120	1.21494E-02
28	87	8.80834E-03
30	88	8.90959E-03
32	71	7.18842E-03
34	58	5.87223E-03
36	73	7.39091E-03
38	54	5.46725E-03
40	47	4.75853E-03
42	27	2.73362E-03
44	37	3.74608E-03
46	52	5.26476E-03
48	23	2.32864E-03
50	23	2.32864E-03
52	14	1.41743E-03
54	15	1.51868E-03
56	14	1.41743E-03
58	12	1.21494E-03
60	7	7.08717E-04
62	31	3.13860E-03
64	11	1.11370E-03
66	7	7.08717E-04
68	10	1.01245E-03
70	6	6.07472E-04
72	6	6.07472E-04
74	7	7.08717E-04
76	9	9.11208E-04
78	3	3.03736E-04
80	4	4.04981E-04
82	3	3.03736E-04
84	5	5.06227E-04
86	4	4.04981E-04
88	3	3.03736E-04
90	2	2.02491E-04
92	1	1.01245E-04
98	2	2.02491E-04
100	2	2.02491E-04
102	2	2.02491E-04
106	2	2.02491E-04
108	1	1.01245E-04
112	1	1.01245E-04
118	1	1.01245E-04
120	1	1.01245E-04
130	1	1.01245E-04



$\mathrm{pr}(d) = 0.070479 * 0.94064^{d}$

Correlation = -0.96800



$\mathrm{pr}(d) = 11.529\ d^{-2.2857}$

Correlation = -0.95723

The exponential function fit has a stronger correlation coefficient, therefore the HEP-TH graph more closely resemble a small-world graph.

The HepTh graph more closely resembles a small-world graph, because the exponential function has the stronger correlation coeffiecient.

5. Command line: java ConnectedComponents CA-HepTh-graph.txt

429 connected components

Comp	Size
0	8638
1	2
2	2
3	2
4	7
5	2
6	2
7	2
8	2
9	2
10	2
11	4
12	3
13	2
14	2
15	5
16	7
17	2
18	4
19	2
20	2
21	4
22	2
23	3
24	11
25	2
26	3
27	2
28	2
29	5
30	4
31	6
32	7
33	2

34 2
35 3
36 2
37 3
38 8
39 2
40 2
41 2
42 2
43 2
44 7
45 2
46 2
47 6
48 5
49 4
50 2
51 2
52 5
53 4
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7590 7591 7592 7593 7594 7595 7596 7597 7598 7599 7600 7601 7602 7603 7604 7605

7606 7607 7608 7609 7610 7611 7612 7613 7614 7615 7616 7617 7618 7619 7620 7626
7627 7628 7629 7630 7631 7632 7633 7634 7635 7636 7637 7638 7639 7640 7641 7642
7643 7644 7645 7646 7647 7648 7649 7650 7651 7652 7653 7656 7657 7658 7659 7660
7661 7662 7663 7664 7665 7666 7669 7670 7671 7672 7673 7674 7675 7676 7677 7678
7679 7680 7681 7688 7689 7690 7691 7692 7693 7694 7695 7696 7697 7698 7699 7702
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7804 7805 7806 7807 7808 7809 7810 7811 7812 7813 7814 7815 7816 7817 7818 7819
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7859 7860 7861 7862 7863 7864 7865 7866 7867 7868 7869 7870 7871 7872 7873 7874
7875 7876 7877 7878 7879 7880 7881 7882 7883 7884 7885 7886 7887 7888 7889 7890
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8648 8649 8650 8651 8652 8653 8654 8655 8656 8657 8658 8659 8660 8663 8664 8665
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8814 8815 8816 8817 8818 8819 8820 8821 8822 8823 8824 8825 8826 8827 8828 8829
8830 8831 8834 8837 8838 8839 8840 8841 8844 8845 8846 8847 8848 8849 8850 8851
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8874 8875 8876 8877 8882 8883 8886 8887 8888 8889 8892 8893 8894 8895 8896 8897
8898 8899 8900 8901 8902 8903 8904 8907 8914 8915 8916 8917 8918 8919 8920 8921
8926 8927 8928 8929 8930 8941 8942 8950 8956 8961 8962 8963 8964 8965 8966 8967
8968 8969 8970 8971 8972 8973 8976 8979 8980 8981 8982 8983 8984 8985 8986 8987
8993 8994 8995 8996 8997 8998 8999 9000 9005 9006 9007 9011 9012 9013 9014 9017
9018 9019 9020 9021 9022 9023 9028 9029 9030 9035 9038 9041 9042 9045 9046 9047
9048 9049 9050 9051 9052 9057 9058 9061 9062 9063 9064 9065 9066 9067 9068 9069
9070 9071 9072 9073 9077 9078 9079 9080 9081 9082 9083 9084 9087 9088 9092 9102
9103 9112 9113 9114 9115 9116 9129 9130 9133 9134 9135 9136 9137 9138 9139 9142
9149 9150 9151 9152 9153 9154 9155 9160 9161 9162 9163 9164 9165 9166 9167 9168
9169 9170 9171 9172 9173 9174 9175 9178 9179 9180 9181 9190 9191 9192 9193 9200
9201 9204 9205 9206 9207 9210 9211 9212 9215 9216 9217 9220 9225 9229 9230 9231
9234 9235 9241 9242 9243 9244 9245 9249 9250 9251 9252 9253 9254 9255 9256 9257
9258 9259 9260 9261 9262 9263 9264 9265 9266 9267 9268 9269 9270 9271 9272 9273
9274 9275 9290 9291 9292 9295 9296 9299 9303 9309 9323 9324 9325 9326 9329 9335
9336 9337 9346 9347 9348 9349 9350 9351 9357 9360 9361 9362 9363 9364 9365 9369
9372 9373 9374 9375 9376 9377 9381 9382 9386 9387 9388 9393 9398 9399 9400 9407
9410 9411 9412 9421 9422 9423 9424 9425 9426 9427 9430 9431 9432 9433 9434 9439
9445 9459 9476 9484 9485 9486 9489 9490 9491 9492 9493 9504 9505 9508 9509 9510
9511 9512 9513 9514 9523 9524 9525 9526 9533 9538 9541 9544 9547 9548 9550 9551
9552 9553 9556 9557 9558 9559 9560 9561 9562 9563 9564 9565 9566 9567 9568 9569
9575 9576 9577 9578 9579 9580 9588 9589 9592 9593 9594 9595 9596 9597 9598 9599
9601 9619 9623 9624 9629 9630 9631 9632 9635 9644 9645 9648 9649 9650 9651 9656
9657 9662 9665 9666 9677 9678 9679 9684 9699 9700 9703 9713 9714 9717 9726 9734
9745 9746 9776 9780 9781 9782 9800 9801 9829 9830 9833
Comp 1 = 2078 2079
Comp 2 = 2887 2888
Comp 3 = 3784 3785
Comp 4 = 4274 4275 4276 4277 4278 4279 4280

Comp 5 = 4282 4283
Comp 6 = 4528 4529
Comp 7 = 4576 4577
Comp 8 = 4612 4613
Comp 9 = 4635 4636
Comp 10 = 4648 4649
Comp 11 = 4815 4816 4817 4818
Comp 12 = 4853 4854 4855
Comp 13 = 4902 4903
Comp 14 = 4968 4969
Comp 15 = 5010 5011 5012 5013 5014
Comp 16 = 5101 5102 5103 5104 5105 5106 6196
Comp 17 = 5152 5153
Comp 18 = 5341 5342 5343 5344
Comp 19 = 5372 5373
Comp 20 = 5400 5401
Comp 21 = 5561 5562 5563 5564
Comp 22 = 5589 5590
Comp 23 = 5643 5644 5645
Comp 24 = 5691 5692 5693 5694 5695 5696 5697 6493 6494 6495 8727
Comp 25 = 5703 5704
Comp 26 = 5751 5752 5753
Comp 27 = 5783 5784
Comp 28 = 5789 5790
Comp 29 = 5932 5933 5934 5935 5936
Comp 30 = 6014 6015 6016 6017
Comp 31 = 6066 6067 6068 6069 6070 6071
Comp 32 = 6072 6073 6074 6075 6076 6077 9676
Comp 33 = 6144 6145
Comp 34 = 6187 6188
Comp 35 = 6224 6225 6226
Comp 36 = 6278 6279
Comp 37 = 6309 6310 6311
Comp 38 = 6312 6313 6314 6315 6316 6317 9694 9695
Comp 39 = 6374 6375
Comp 40 = 6414 6415
Comp 41 = 6422 6423
Comp 42 = 6451 6452
Comp 43 = 6531 6532
Comp 44 = 6545 6546 6547 6548 6549 6550 6551
Comp 45 = 6556 6557
Comp 46 = 6558 6559
Comp 47 = 6578 6579 6580 6923 6924 6925
Comp 48 = 6589 6590 6591 6592 6593

Comp 49 = 6664 6665 6666 6667
Comp 50 = 6700 6701
Comp 51 = 6774 6775
Comp 52 = 6809 6810 6811 6812 6813
Comp 53 = 6814 6815 6816 6817
Comp 54 = 6839 6840 6841 6842
Comp 55 = 6843 6844 6845 6846 6847
Comp 56 = 6874 6875
Comp 57 = 6903 6904
Comp 58 = 6915 6916
Comp 59 = 6944 6945
Comp 60 = 6954 6955
Comp 61 = 6976 6977 6978
Comp 62 = 7080 7081
Comp 63 = 7092 7093
Comp 64 = 7096 7097
Comp 65 = 7126 7127
Comp 66 = 7137 7138 7139 7140 7141 7142 7143 7144
Comp 67 = 7155 7156 7157 7158 7159
Comp 68 = 7171 7172 7173 7174 7175
Comp 69 = 7190 7191
Comp 70 = 7215 7216
Comp 71 = 7217 7218 7219 7220 7221
Comp 72 = 7234 7235 7236
Comp 73 = 7260 7261
Comp 74 = 7275 7276 7277 7278
Comp 75 = 7280 7281
Comp 76 = 7299 7300
Comp 77 = 7303 7304 7305 7306 7307 7308 7309 7310
Comp 78 = 7324 7325
Comp 79 = 7338 7339 7340 7341
Comp 80 = 7356 7357 7358 7359 7360
Comp 81 = 7361 7362
Comp 82 = 7368 7369
Comp 83 = 7374 7375
Comp 84 = 7405 7406
Comp 85 = 7454 7455
Comp 86 = 7463 7464
Comp 87 = 7491 7492 7493
Comp 88 = 7504 7505
Comp 89 = 7521 7522 7523
Comp 90 = 7535 7536 7537 7538 7539 7540 7541
Comp 91 = 7545 7546
Comp 92 = 7575 7576

Comp 93 = 7577 7578
Comp 94 = 7579 7580 7581 7582 7583 8010 8011 8012
Comp 95 = 7584 7585
Comp 96 = 7586 7587 7588 7589
Comp 97 = 7621 7622 7623 7624 7625 8953 8954 8955
Comp 98 = 7654 7655
Comp 99 = 7667 7668
Comp 100 = 7682 7683 7684 7685 7686 7687
Comp 101 = 7700 7701
Comp 102 = 7714 7715
Comp 103 = 7728 7729 7730
Comp 104 = 7750 7751
Comp 105 = 7752 7753
Comp 106 = 7756 7757 7758 7759 7760 7761 7762
Comp 107 = 7763 7764
Comp 108 = 7769 7770 7771
Comp 109 = 7823 7824
Comp 110 = 7834 7835
Comp 111 = 7845 7846 7847
Comp 112 = 7898 7899 7900 7901 7902
Comp 113 = 7918 7919 7920 7921 7922 7923
Comp 114 = 7933 7934
Comp 115 = 7936 7937 7938
Comp 116 = 7973 7974 7975
Comp 117 = 7977 7978
Comp 118 = 8025 8026 8027
Comp 119 = 8035 8036 8037
Comp 120 = 8054 8055
Comp 121 = 8057 8058 8059 8060
Comp 122 = 8061 8062
Comp 123 = 8091 8092 8093 8094
Comp 124 = 8100 8101 8102
Comp 125 = 8105 8106
Comp 126 = 8122 8123
Comp 127 = 8124 8125 8126 8127 8128
Comp 128 = 8129 8130
Comp 129 = 8134 8135 8136
Comp 130 = 8139 8140
Comp 131 = 8148 8149 8150 8151
Comp 132 = 8158 8159
Comp 133 = 8160 8161 8162
Comp 134 = 8172 8173
Comp 135 = 8181 8182
Comp 136 = 8183 8184

Comp 137 = 8194 8195 8196 8197 8198
Comp 138 = 8199 8200 8201
Comp 139 = 8202 8203 8204 8205
Comp 140 = 8211 8212
Comp 141 = 8222 8223 8224 8225 8226 8227 8228 8229 8230
Comp 142 = 8234 8235 8236 8237
Comp 143 = 8245 8246 8247 8977 8978
Comp 144 = 8248 8249 8250 8251 8252 8253 8254
Comp 145 = 8255 8256
Comp 146 = 8257 8258
Comp 147 = 8260 8261 8262 8263 8264
Comp 148 = 8267 8268 8269 8270
Comp 149 = 8295 8296
Comp 150 = 8305 8306 8307 8308 8309 8310 8417
Comp 151 = 8318 8319
Comp 152 = 8344 8345
Comp 153 = 8359 8360
Comp 154 = 8367 8368 8369
Comp 155 = 8375 8376
Comp 156 = 8378 8379 8380 8381
Comp 157 = 8389 8390
Comp 158 = 8401 8402 8403
Comp 159 = 8405 8406
Comp 160 = 8409 8410 8411 8412 8413 8414
Comp 161 = 8418 8419
Comp 162 = 8420 8421
Comp 163 = 8422 8423 8424
Comp 164 = 8433 8434
Comp 165 = 8435 8436
Comp 166 = 8437 8438
Comp 167 = 8439 8440
Comp 168 = 8471 8472
Comp 169 = 8473 8474
Comp 170 = 8503 8504
Comp 171 = 8507 8508 8509 8510
Comp 172 = 8513 8514
Comp 173 = 8524 8525 8526
Comp 174 = 8541 8542 8543
Comp 175 = 8604 8605
Comp 176 = 8606 8607
Comp 177 = 8608 8609
Comp 178 = 8613 8614
Comp 179 = 8616 8617
Comp 180 = 8618 8619

Comp 181 = 8620 8621
Comp 182 = 8633 8634 8635
Comp 183 = 8661 8662
Comp 184 = 8678 8679 8680
Comp 185 = 8692 8693
Comp 186 = 8717 8718 8719 8720 8721
Comp 187 = 8730 8731
Comp 188 = 8733 8734 8735 8736 8737 9669 9670
Comp 189 = 8738 8739
Comp 190 = 8748 8749 8750 8751
Comp 191 = 8753 8754
Comp 192 = 8755 8756 8757 8758
Comp 193 = 8768 8769 8770
Comp 194 = 8771 8772
Comp 195 = 8774 8775
Comp 196 = 8778 8779 8780 8781 8782 8783 8784 8785 8786 8787 8788 8789 8790 8878 8879 8880 8881 8908 8938 8939 8940
Comp 197 = 8792 8793
Comp 198 = 8832 8833
Comp 199 = 8835 8836
Comp 200 = 8842 8843
Comp 201 = 8862 8863
Comp 202 = 8864 8865
Comp 203 = 8872 8873
Comp 204 = 8884 8885
Comp 205 = 8890 8891
Comp 206 = 8905 8906
Comp 207 = 8909 8910 8911
Comp 208 = 8912 8913
Comp 209 = 8922 8923
Comp 210 = 8924 8925
Comp 211 = 8931 8932
Comp 212 = 8933 8934 8935 8936 8937
Comp 213 = 8943 8944 8945 8946 8947 8948 8949
Comp 214 = 8951 8952
Comp 215 = 8957 8958 8959 8960
Comp 216 = 8974 8975
Comp 217 = 8988 8989 8990
Comp 218 = 8991 8992
Comp 219 = 9001 9002 9003 9004
Comp 220 = 9008 9009 9010
Comp 221 = 9015 9016
Comp 222 = 9024 9025 9026 9027
Comp 223 = 9031 9032 9033 9034

Comp 224 = 9036 9037
Comp 225 = 9039 9040
Comp 226 = 9043 9044
Comp 227 = 9053 9054
Comp 228 = 9055 9056
Comp 229 = 9059 9060
Comp 230 = 9074 9075 9076
Comp 231 = 9085 9086
Comp 232 = 9089 9090 9091
Comp 233 = 9093 9094
Comp 234 = 9095 9096 9097
Comp 235 = 9098 9099 9100 9101
Comp 236 = 9104 9105 9106
Comp 237 = 9107 9108
Comp 238 = 9109 9110 9111
Comp 239 = 9117 9118
Comp 240 = 9119 9120 9121 9122 9123
Comp 241 = 9124 9125 9126 9127 9128
Comp 242 = 9131 9132
Comp 243 = 9140 9141
Comp 244 = 9143 9144
Comp 245 = 9145 9146
Comp 246 = 9147 9148
Comp 247 = 9156 9157 9158 9159
Comp 248 = 9176 9177
Comp 249 = 9182 9183 9184 9185
Comp 250 = 9186 9187 9188 9189
Comp 251 = 9194 9195
Comp 252 = 9196 9197 9198 9199
Comp 253 = 9202 9203
Comp 254 = 9208 9209
Comp 255 = 9213 9214
Comp 256 = 9218 9219
Comp 257 = 9221 9222
Comp 258 = 9223 9224
Comp 259 = 9226 9227 9228
Comp 260 = 9232 9233
Comp 261 = 9236 9237 9238
Comp 262 = 9239 9240
Comp 263 = 9246 9247 9248
Comp 264 = 9276 9277
Comp 265 = 9278 9279 9280 9281 9282 9283 9284 9285
Comp 266 = 9286 9287 9288 9289
Comp 267 = 9293 9294

Comp 268 = 9297 9298
Comp 269 = 9300 9301 9302
Comp 270 = 9304 9305
Comp 271 = 9306 9307 9308
Comp 272 = 9310 9311 9312 9313 9314 9315 9316
Comp 273 = 9317 9318 9319 9320 9321 9322
Comp 274 = 9327 9328
Comp 275 = 9330 9331 9332
Comp 276 = 9333 9334
Comp 277 = 9338 9339 9340 9341
Comp 278 = 9342 9343
Comp 279 = 9344 9345
Comp 280 = 9352 9353 9354 9355 9356
Comp 281 = 9358 9359
Comp 282 = 9366 9367 9368
Comp 283 = 9370 9371
Comp 284 = 9378 9379 9380
Comp 285 = 9383 9384 9385
Comp 286 = 9389 9390 9391 9392
Comp 287 = 9394 9395
Comp 288 = 9396 9397
Comp 289 = 9401 9402 9403 9404 9701 9702
Comp 290 = 9405 9406
Comp 291 = 9408 9409
Comp 292 = 9413 9414 9415 9416 9417 9418
Comp 293 = 9419 9420
Comp 294 = 9428 9429
Comp 295 = 9435 9436 9437 9438
Comp 296 = 9440 9441 9442
Comp 297 = 9443 9444
Comp 298 = 9446 9447
Comp 299 = 9448 9449 9450 9451
Comp 300 = 9452 9453 9454 9455 9456
Comp 301 = 9457 9458
Comp 302 = 9460 9461
Comp 303 = 9462 9463 9464
Comp 304 = 9465 9466 9467 9468 9469 9470 9471 9472 9473
Comp 305 = 9474 9475
Comp 306 = 9477 9478
Comp 307 = 9479 9480 9481 9482 9483
Comp 308 = 9487 9488
Comp 309 = 9494 9495 9496 9497
Comp 310 = 9498 9499
Comp 311 = 9500 9501 9502 9503

Comp 312 = 9506 9507
Comp 313 = 9515 9516 9517 9518
Comp 314 = 9519 9520
Comp 315 = 9521 9522
Comp 316 = 9527 9528
Comp 317 = 9529 9530 9531 9532
Comp 318 = 9534 9535 9536 9537
Comp 319 = 9539 9540
Comp 320 = 9542 9543
Comp 321 = 9545 9546
Comp 322 = 9549
Comp 323 = 9554 9555
Comp 324 = 9570 9571 9572
Comp 325 = 9573 9574
Comp 326 = 9581 9582
Comp 327 = 9583 9584
Comp 328 = 9585 9586 9587
Comp 329 = 9590 9591
Comp 330 = 9600
Comp 331 = 9602 9603
Comp 332 = 9604 9605 9606
Comp 333 = 9607 9608
Comp 334 = 9609 9610
Comp 335 = 9611 9612
Comp 336 = 9613 9614
Comp 337 = 9615 9616
Comp 338 = 9617 9618
Comp 339 = 9620 9621 9622
Comp 340 = 9625 9626
Comp 341 = 9627 9628
Comp 342 = 9633 9634
Comp 343 = 9636 9637 9638
Comp 344 = 9639 9640 9641
Comp 345 = 9642 9643
Comp 346 = 9646 9647
Comp 347 = 9652 9653
Comp 348 = 9654 9655
Comp 349 = 9658 9659
Comp 350 = 9660 9661
Comp 351 = 9663 9664
Comp 352 = 9667 9668
Comp 353 = 9671 9672
Comp 354 = 9673 9674 9675
Comp 355 = 9680 9681 9682 9683

Comp 356 = 9685 9686
Comp 357 = 9687 9688
Comp 358 = 9689 9690
Comp 359 = 9691 9692 9693
Comp 360 = 9696 9697 9698
Comp 361 = 9704 9705 9706
Comp 362 = 9707 9708
Comp 363 = 9709 9710
Comp 364 = 9711 9712
Comp 365 = 9715 9716
Comp 366 = 9718 9719
Comp 367 = 9720 9721
Comp 368 = 9722 9723
Comp 369 = 9724 9725
Comp 370 = 9727 9728
Comp 371 = 9729 9730
Comp 372 = 9731 9732 9733
Comp 373 = 9735 9736
Comp 374 = 9737 9738 9739 9740
Comp 375 = 9741 9742
Comp 376 = 9743 9744
Comp 377 = 9747 9748
Comp 378 = 9749 9750 9751
Comp 379 = 9752 9753
Comp 380 = 9754 9755
Comp 381 = 9756 9757 9758 9759
Comp 382 = 9760 9761
Comp 383 = 9762 9763
Comp 384 = 9764 9765
Comp 385 = 9766 9767
Comp 386 = 9768 9769
Comp 387 = 9770 9771
Comp 388 = 9772 9773
Comp 389 = 9774 9775
Comp 390 = 9777 9778 9779
Comp 391 = 9783 9784
Comp 392 = 9785 9786
Comp 393 = 9787 9788
Comp 394 = 9789 9790
Comp 395 = 9791 9792
Comp 396 = 9793 9794 9795
Comp 397 = 9796 9797
Comp 398 = 9798 9799
Comp 399 = 9802 9803 9804

Comp 400 = 9805 9806
Comp 401 = 9807 9808 9809
Comp 402 = 9810 9811
Comp 403 = 9812 9813
Comp 404 = 9814 9815
Comp 405 = 9816 9817 9818 9819
Comp 406 = 9820 9821
Comp 407 = 9822 9823 9824
Comp 408 = 9825 9826
Comp 409 = 9827 9828
Comp 410 = 9831 9832
Comp 411 = 9834 9835
Comp 412 = 9836 9837
Comp 413 = 9838 9839
Comp 414 = 9840 9841 9842 9843
Comp 415 = 9844 9845 9846 9847
Comp 416 = 9848 9849
Comp 417 = 9850 9851 9852
Comp 418 = 9853 9854
Comp 419 = 9855 9856
Comp 420 = 9857 9858
Comp 421 = 9859 9860
Comp 422 = 9861 9862 9863
Comp 423 = 9864 9865
Comp 424 = 9866 9867
Comp 425 = 9868 9869
Comp 426 = 9870 9871
Comp 427 = 9872 9873
Comp 428 = 9874 9875 9876
Size of smallest CC = 1
Size of largest CC = 8638
8638/9877 = 0.87456

The HepTh graph contains 429 connected components. The smallest connected component contains one vertex, and largest component contains 8638 vertices.

The largest component contains 8638 of the 9877 total vertices in the graph. 8338/9877 = 0.87456, so the largest component contains 87.456% of the graph's vertices. Thus, the graph does contain a giant component.

6. Command line: java TopRank CA-HepTh-grap.txt

Rank	Vertex	DegCen
1	86	130
2	15	120
3	54	118
4	920	112
5	163	108
6	35	106
7	1546	106
8	1420	102
9	1873	102
10	8	100
11	38	100
12	2	98
13	277	98
14	67	92
15	40	90
16	1907	90
17	220	88
18	252	88
19	1305	88
20	32	86
21	386	86
22	442	86
23	590	86
24	1	84
25	62	84
26	141	84
27	1094	84
28	1332	84
29	26	82
30	76	82
31	1904	82
32	13	80
33	527	80
34	1461	80
35	1687	80
36	582	78
37	851	78
38	1231	78
39	36	76
40	173	76

7. Command line: java TopRank CA-HepTh-graph.txt

Rank	Vertex	CloCen
1	15	4.045849
2	920	4.074215
3	40	4.095751
4	38	4.121107
5	1	4.147042
6	1461	4.154799
7	1094	4.163946
8	54	4.168924
9	1332	4.169851
10	442	4.183281
11	13	4.190228
12	8	4.19486
13	163	4.195323
14	30	4.211879
15	17	4.213268
16	62	4.221605
17	35	4.222184
18	277	4.222415
19	1420	4.228551
20	429	4.229015
21	14	4.240245
22	67	4.242446
23	1873	4.247771
24	582	4.248582
25	386	4.249508
26	31	4.250434
27	26	4.253676
28	252	4.259697
29	87	4.264675
30	1443	4.264675
31	141	4.269191
32	851	4.272548
33	171	4.274517
34	618	4.278685
35	76	4.2832
36	173	4.291884
37	413	4.296515
38	590	4.298483
39	1546	4.300104
40	24	4.310293

8. As stated in my answer to question 4, the HEP-TH graph is more closely related to a small-world graph than a scale-free graph. This is because the correlation coefficient of the exponential function fit of the degree distribution was stronger than that of the power function fit. However, the graph appears to exhibit properties of a scale-free graph as well a small-world graph.

   My results from question 5 show that most of the vertices are indeed connected to just a few nearby vertices, but that a few are connected to distant random vertices. This is to be expected in a small-world graph.

   My answer to question 4 shows that there are many vertices of low degree and a few vertices of high degree, known as hubs. This is a characteristic of a scale-free graph. This characteristic is not as strong as the properties of the small-world graph, however. This accounts for the fact that the correlation coefficient is stronger towards a small-world graph.

   Based on my results, it appears that many high energy physics theory researchers collaborated on a few papers with other nearby researchers, and a few of them collaborated on a smaller number of papers with researchers to whom they were distantly connected.

9. In this project I learned a lot about programmatic analysis of graphs. I found it beneficial to learn how it is useful to fit a dataset to logarithmic functions. I thought it was fascinating to see how so much information can be drawn from the same set of data by looking at the data in a few different ways. I also learned better how program design so greatly affects the ability of the program to process large amounts of data. Originally, I was concerned with running out of time and memory, but then I redesigned some parts of the programs to more efficiently handle the volume of data.