GTNA

A Framework for the Graph-Theoretic Network Analysis

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GTNA

Graph-Theoretic Network Analyzer

Outline

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1. Introduction
2. Modules and Workflow
3. Available Networks
4. Available Metrics
5. Extension
6. Evaluation
7. Conclusion and Outlook

1. Introduction

Motivation, Our Approach and Requirements

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GTNA

Graph-Theoretic Network Analyzer

Motivation

networks like
Internet, P2P, WSN, MobiAdHoc
become omnipresent in our daily lifes

- Importance of complex networks rises
- Need for analysis and evaluation
- Simulation research tool of choice
- BUT: credibility of the results decreases

different simulation tools exist, BUT
- comparison hardly possible
- results differ significantly
due to the complexity of nw sim

"... less than 15% of the published MobiHoc papers are repeatable."

Kurkowski et al. - MANET Simulation Studies: The Incredibles, 2006

survey simulation studies of MobiHoc
(= ACM international Symp. on Mobile
Ad Hoc Networking and Computing)

Main Objectives

to overcome these difficulties

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- Graph-theoretic analysis of network snapshots

don't capture dynamics
BUT: allow for in-dept structural comparison

- Many different networks and metrics

many different implementations exist
mostly designed for a special group of metrics / topologies

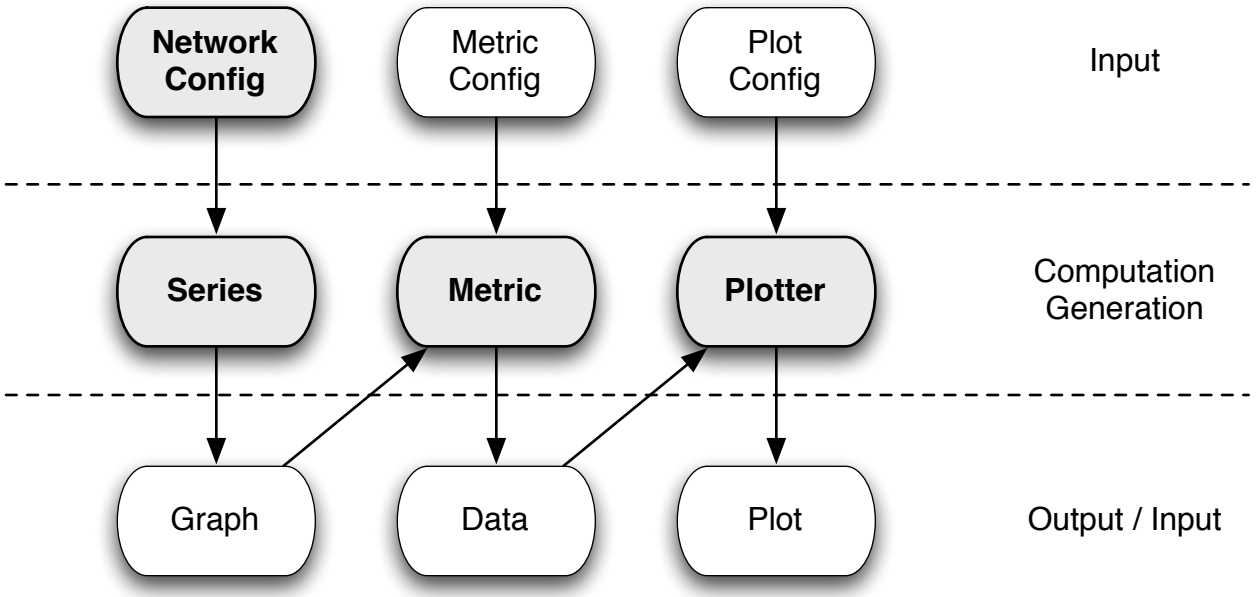
- Need for an analysis framework

=> need for a comprehensive, extendible tool for the concise evaluation of graphs

- Plugin interface
  - Snapshots
  - Topology generators
  - Metrics

2. Modules and Workflow

The four Modules and how they build GTNA



Network Config

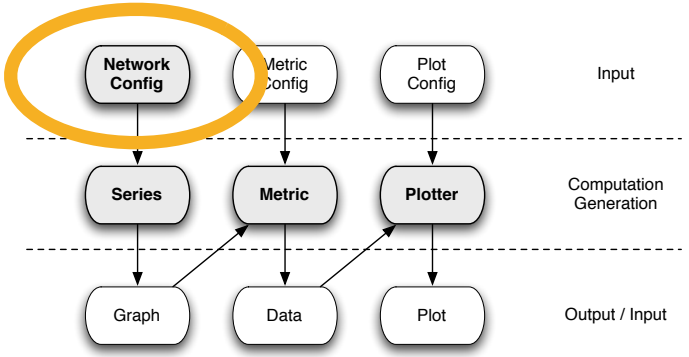
- Interface: *gtna.network.Network*

A. *Import snapshots from any source*

   1. *Snapshot in readable format*

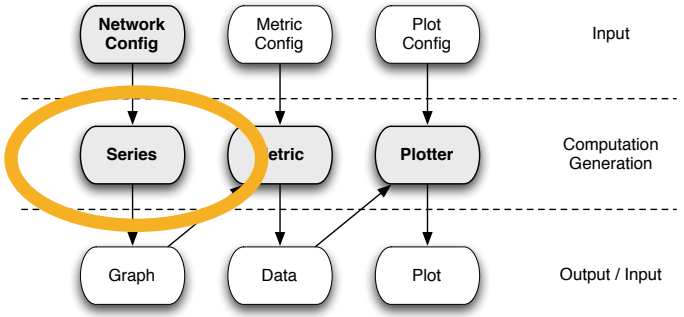
B. *Generate snapshot inside of GTNA*

   1. Set of parameters
   2. Constructor
   3. Graph generation



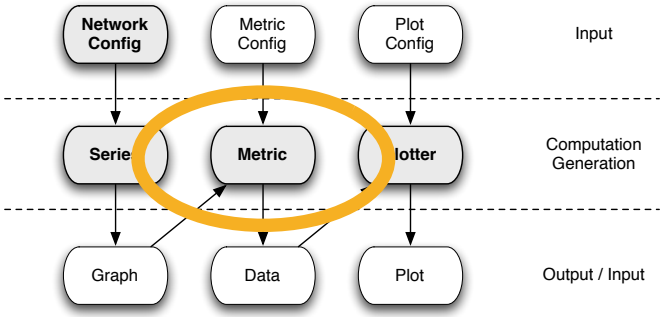
Series

- Implementation: *gtna.data.Series*
- Input
  - Network config
- Computes
  - Metrics for multiple network instances
- Aggregates data
  - Averages + confidence intervals



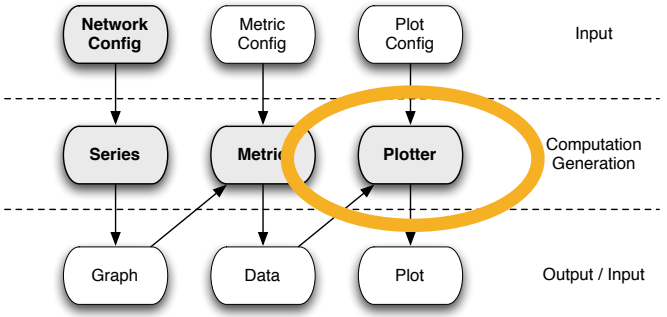
Metric

- Interface: *gtna.metrics.Metric*
- Types
  1. Multi-scalar metric
  2. Single-scalar metric
- Implementation
  1. Sub-metric attributes
  2. Constructor
  3. Computation
  4. Output generation

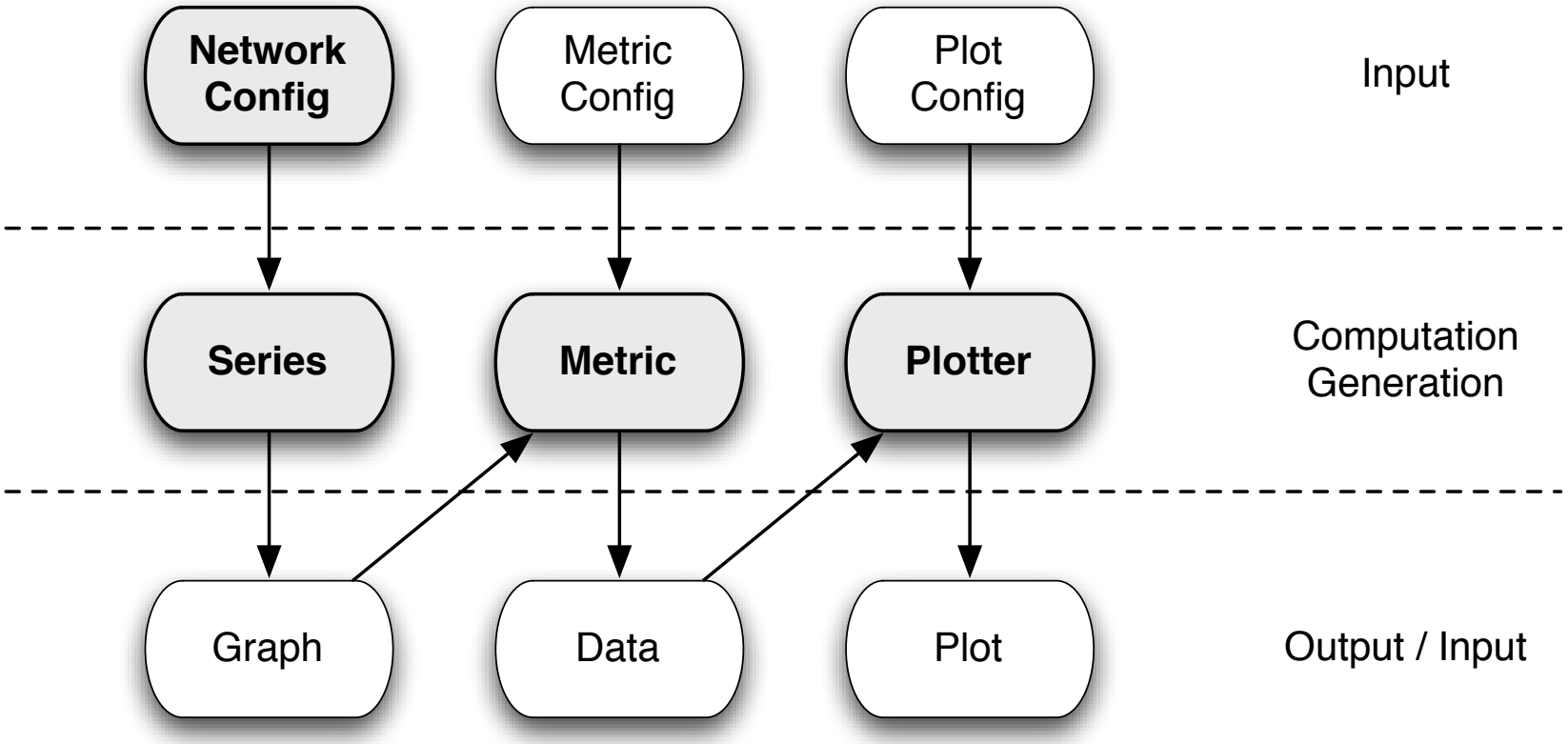


Plotter

- Implementation: *gtna.plot.Plot*
- Combinations of
  1. Multiple metrics
  2. Different configuration
  3. Different networks
- Types
  1. Multi-scalar metrics
  2. Single-scalar metrics
  3. Single-scalar metrics by edges



Workflow


Network Config
Metric Config
Plot Config
Input
Series
Metric
Plotter
Computation Generation
Graph
Data
Plot
Output / Input

Instantiating a Network Config

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```
Network can_2_1 = new CAN(100, 2, 1);
Network can_3_1 = new CAN(100, 3, 1);
Network can_4_1 = new CAN(100, 4, 1);
Network[] can_x_1 =
  new Network[]{ can_2_1, can_3_1, can_4_1 };

Network can_2_1 = new CAN(100, 2, 1);
Network can_2_2 = new CAN(100, 2, 2);
Network can_2_3 = new CAN(100, 2, 3);
Network[] can_2_x =
  new Network[]{ can_2_1, can_2_2, can_2_3 };

Network can_100 = new CAN(100, 2, 1);
Network can_200 = new CAN(200, 2, 1);
Network can_300 = new CAN(300, 2, 1);
Network can_400 = new CAN(400, 2, 1);
Network[] can_x =
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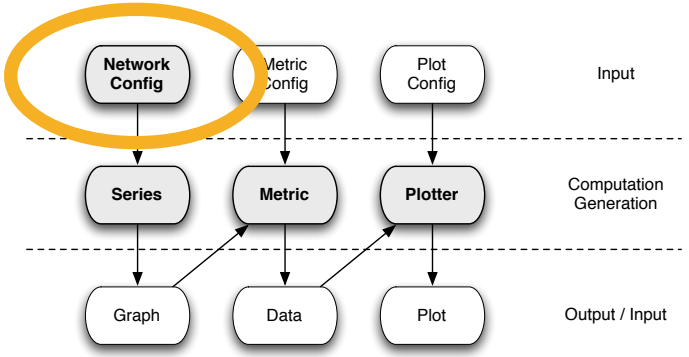

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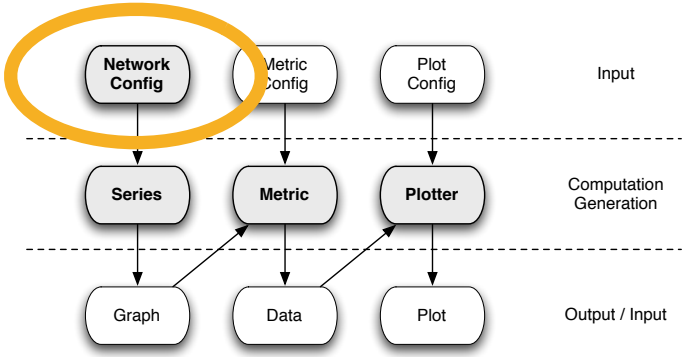

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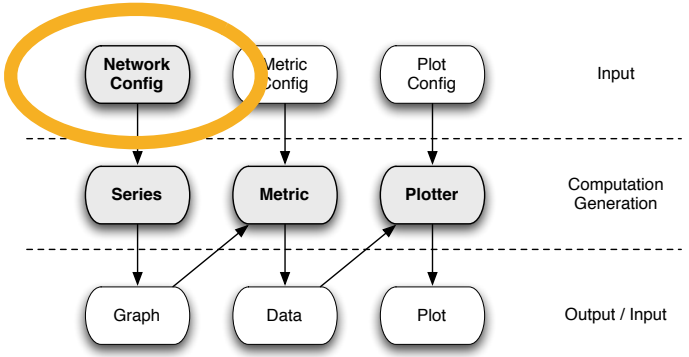

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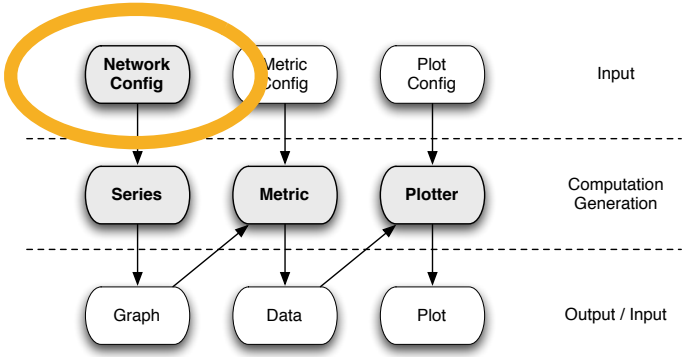

Generating a Series

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```
Network[] can_x_1 =
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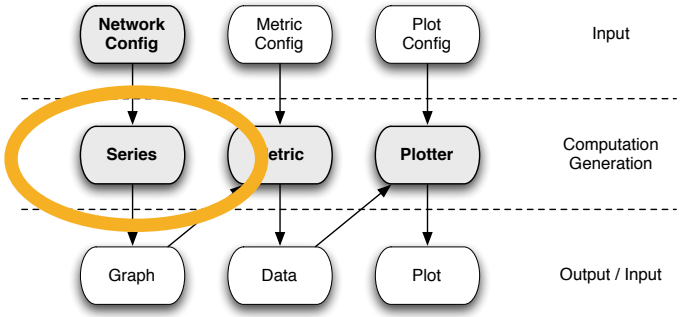
Network[] can_2_x =
  new Network[]{ can_2_1, can_2_2, can_2_3 };
Network[] can_x =
  new Network[]{ can_100, can_200, can_300, can_400 };

Series[] s_can_x_1 = Series.generate(can_x_1, 20);
Series[] s_can_2_x = Series.generate(can_2_x, 20);
Series[] s_can_x = Series.generate(can_x, 20);
```



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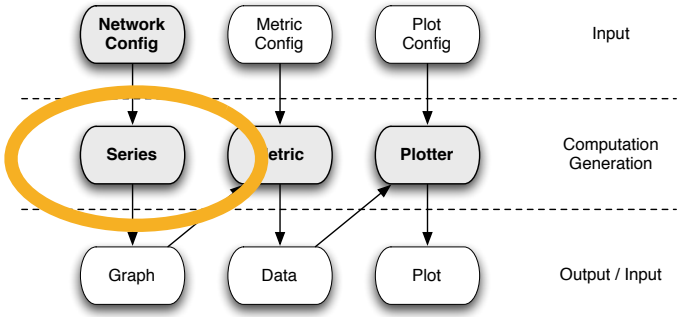
Network[] can_x =
  new Network[]{ can_100, can_200, can_300, can_400 };

Series[] s_can_x_1 = Series.generate(can_x_1, 20);
Series[] s_can_2_x = Series.generate(can_2_x, 20);
Series[] s_can_x = Series.generate(can_x, 20);
```



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Network[] can_x =
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Series[] s_can_x_1 = Series.generate(can_x_1, 20);
Series[] s_can_2_x = Series.generate(can_2_x, 20);
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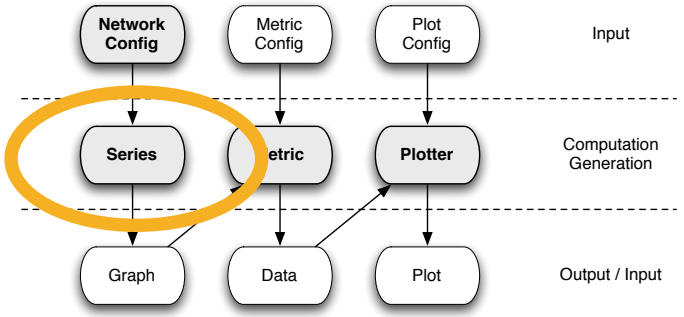
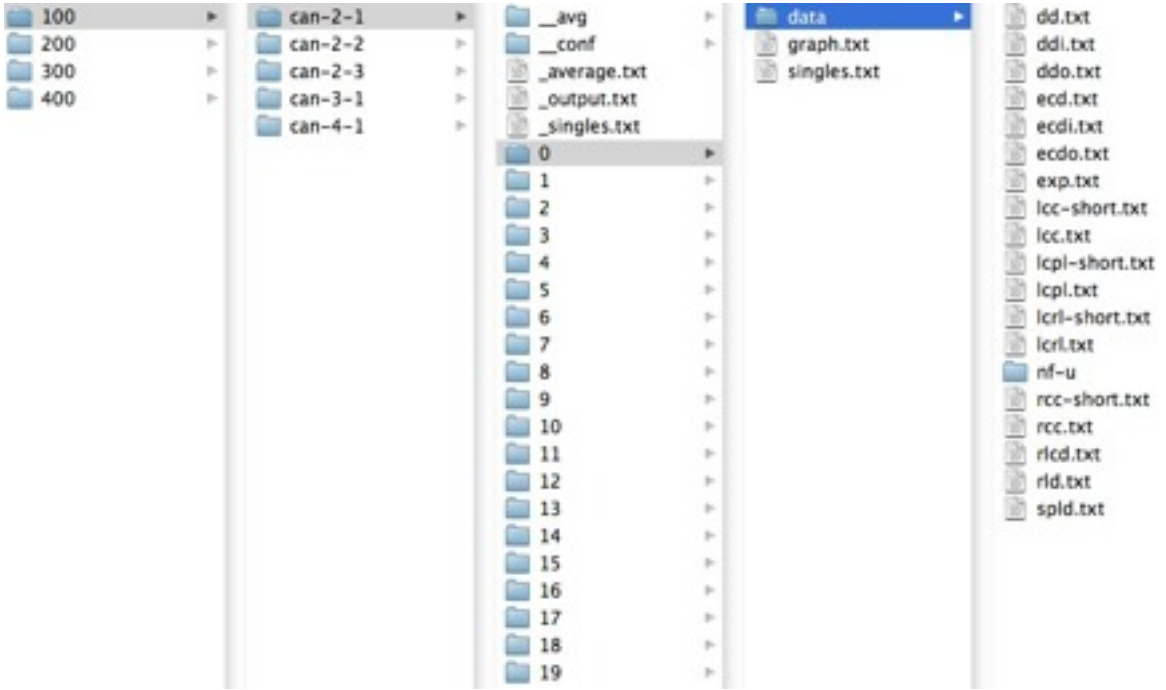
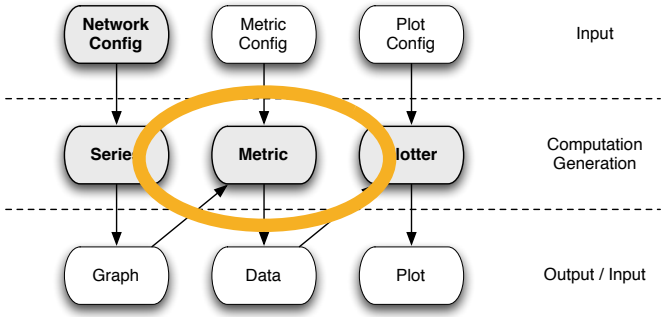
```



Data Generation





Plotting the Results

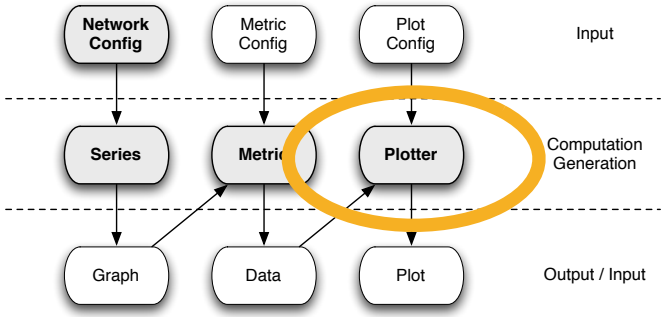
```
Series[] s_can_x_1 = Series.get(can_x_1);
Series[] s_can_2_x = Series.get(can_2_x);
Series[] s_can_x = Series.get(can_x);

Plot.allMulti(s_can_x_1, "./can-dimensions/");
Plot.allMulti(s_can_2_x, "./can-realities/");

Plot.allSingle(s_can_x_1, "./can-dimensions-singles/");
Plot.allSingle(s_can_2_x, "./can-realities-singles/");
Plot.allSingle(s_can_x, "./can-nodes-singles/");

Series[][] s_all = new Series[][]{
  s_can_x_1, s_can_2_x };

Plot.allSingleByEdges(s_all, "./can-by-edges/");
```



Plotting the Results

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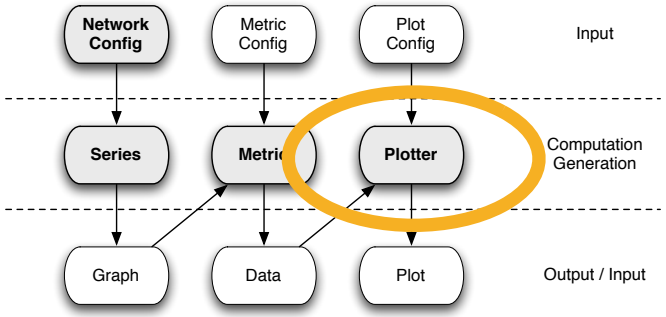

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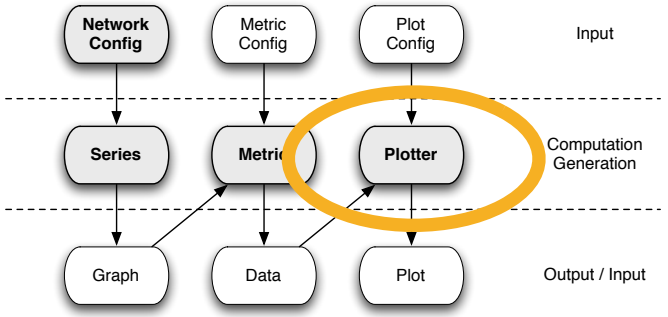
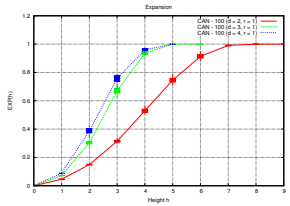
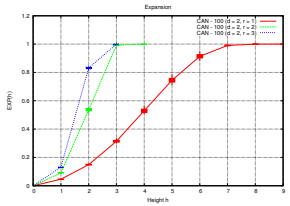
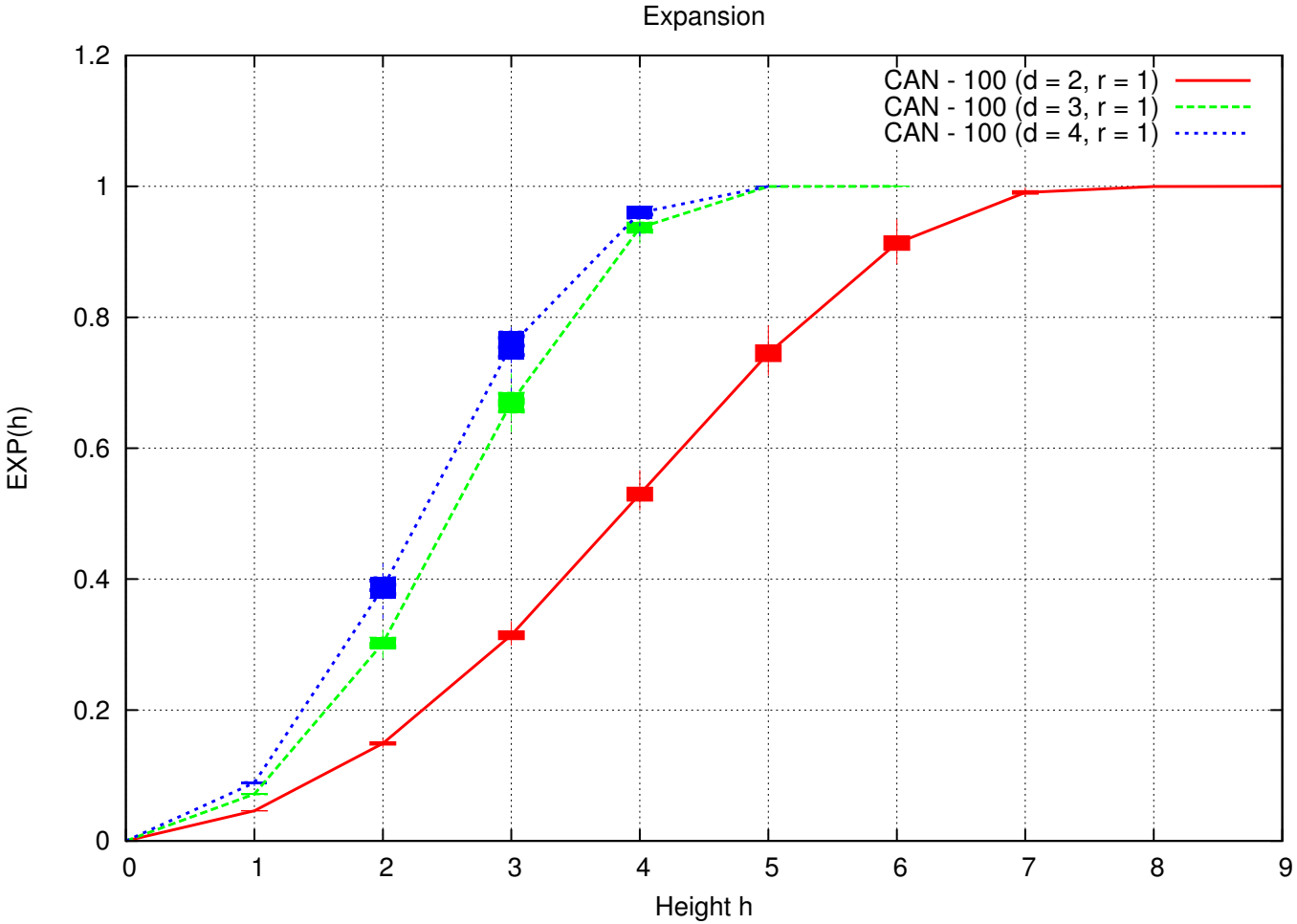
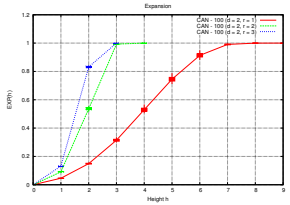




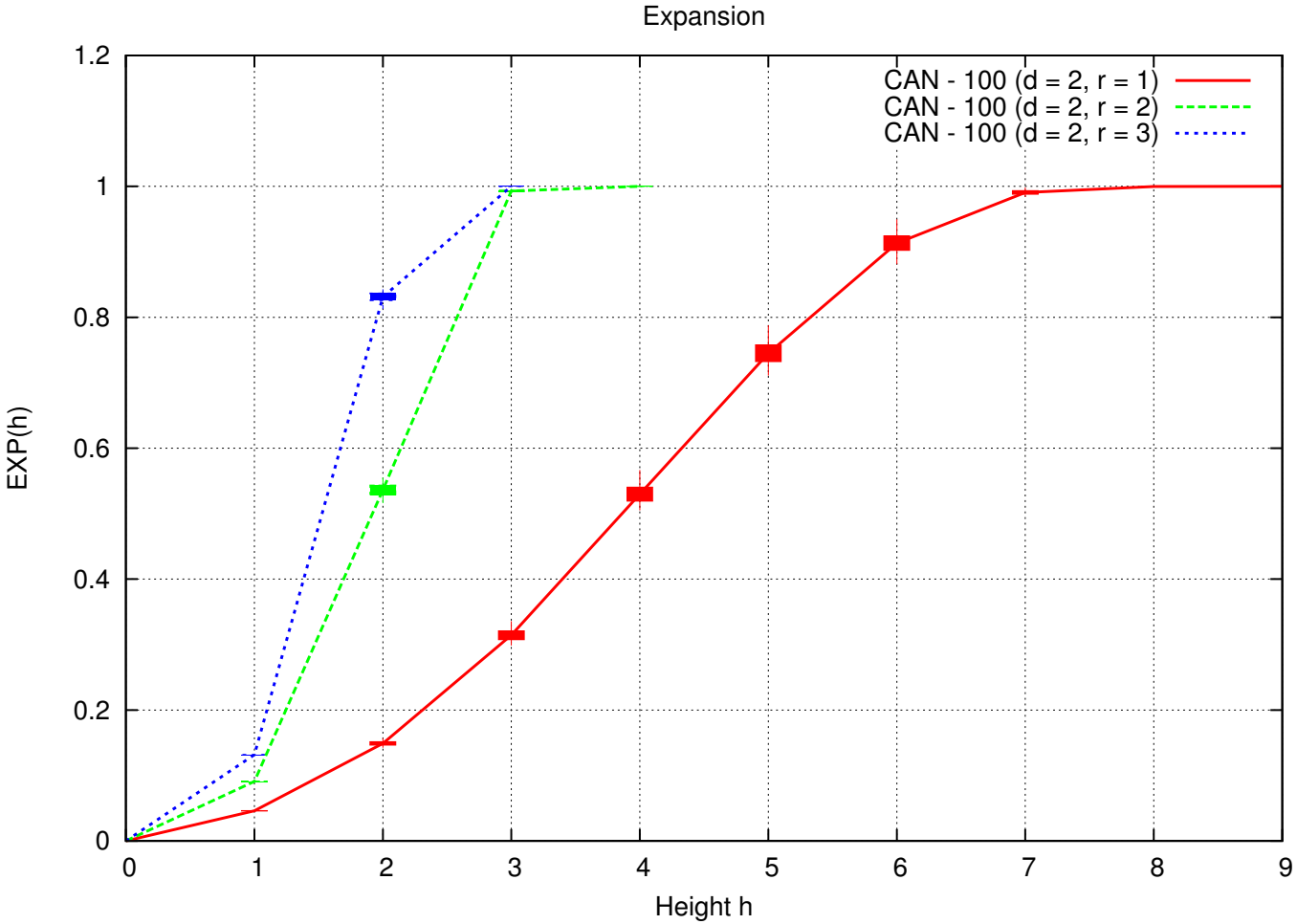


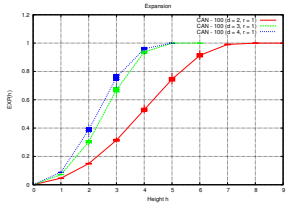
Plotting the Results





Plotting the Results





Plotting the Results

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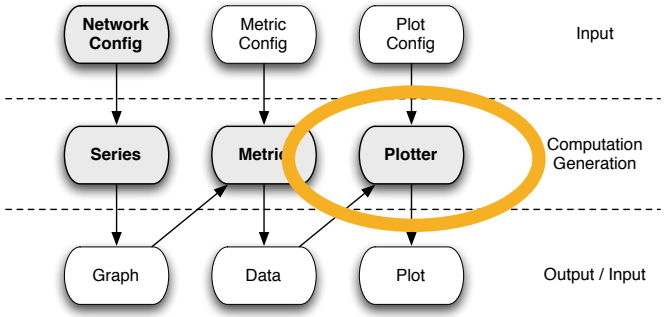

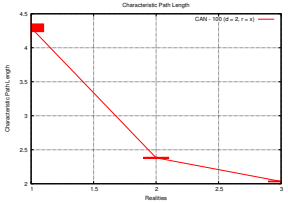

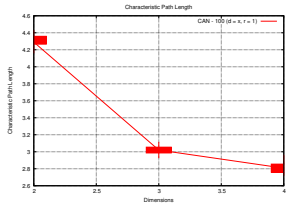

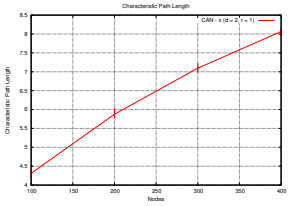

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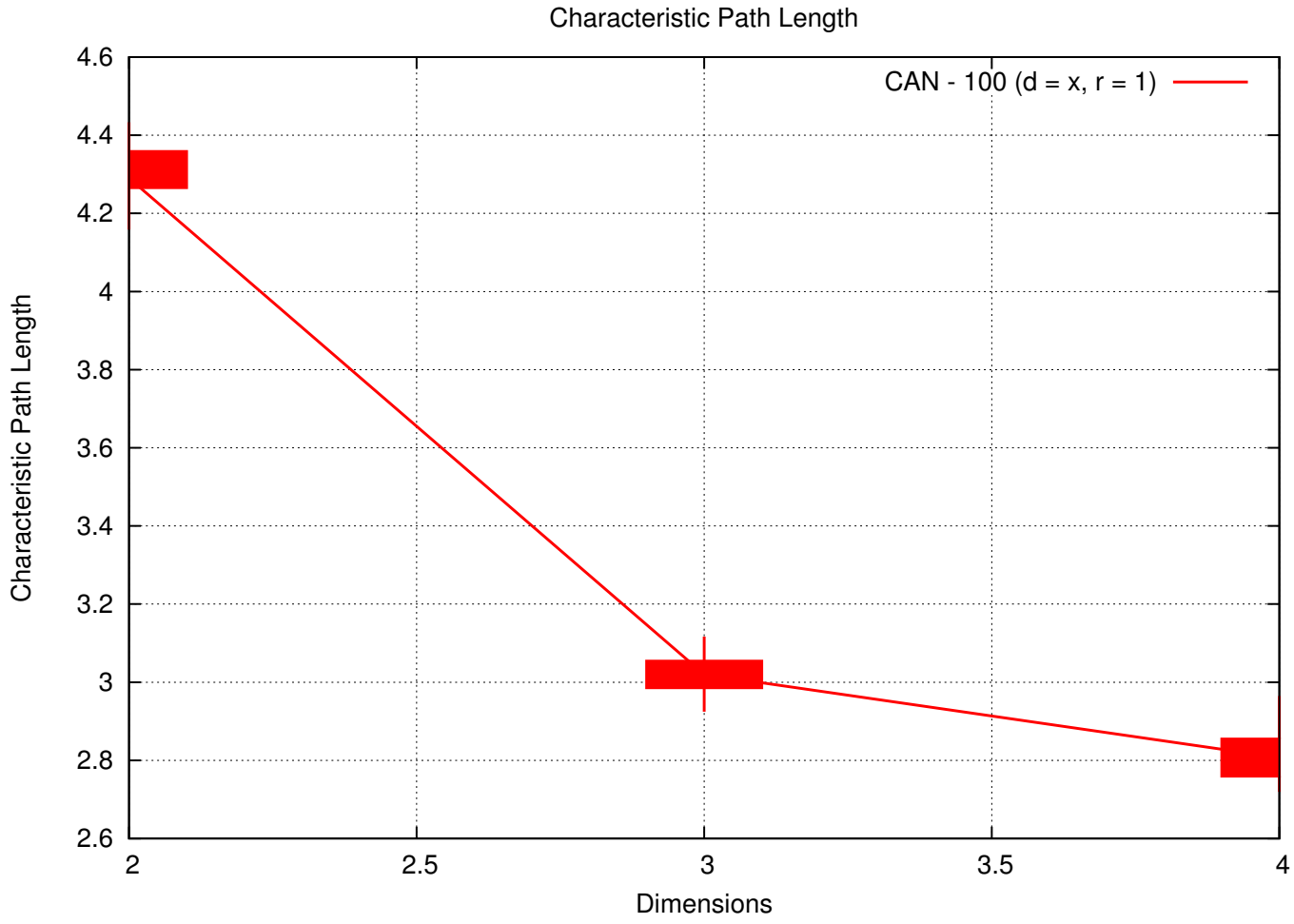
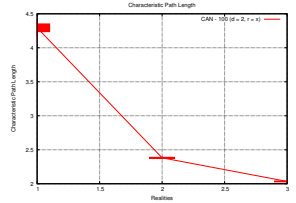
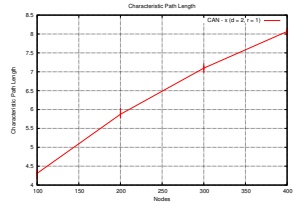
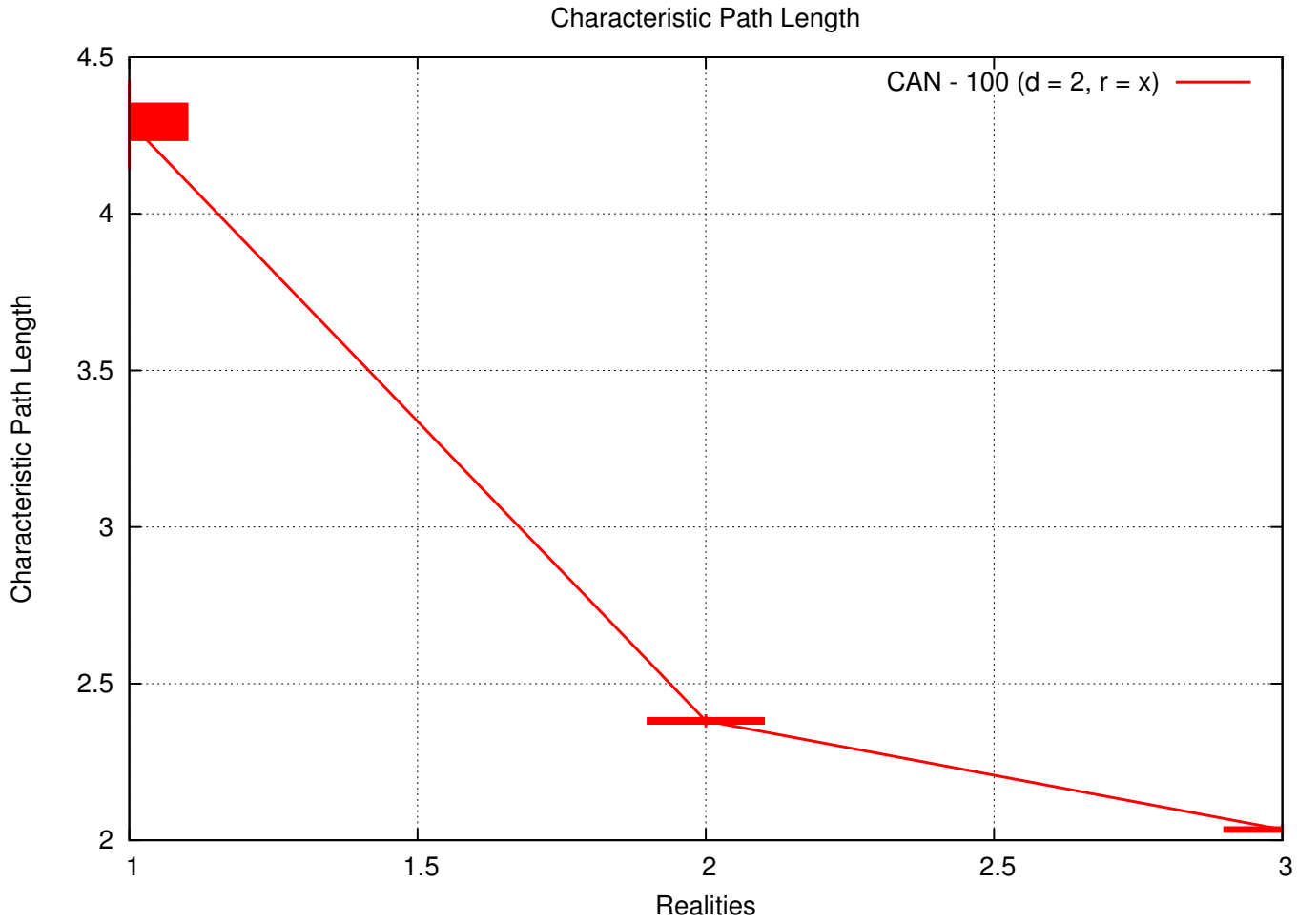
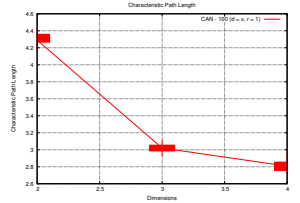


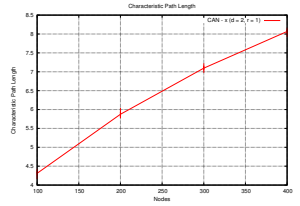




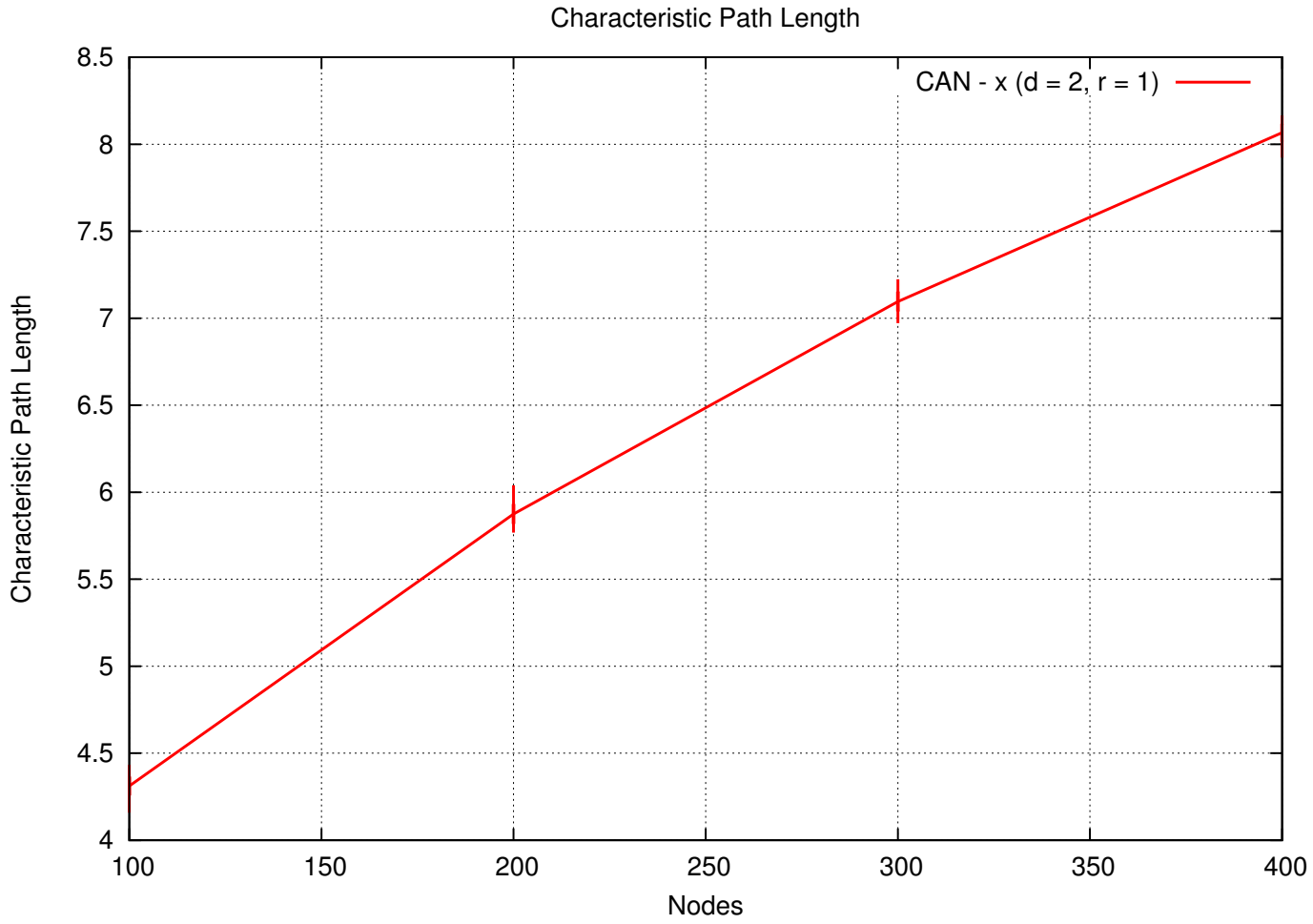
Plotting the Results

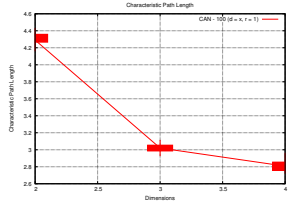


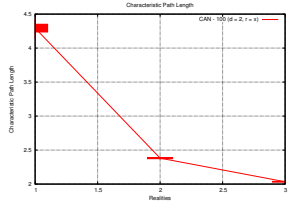




Plotting the Results







Plotting the Results

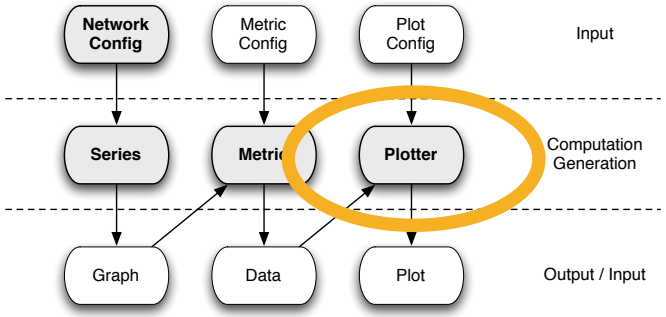
```
Series[] s_can_x_1 = Series.get(can_x_1);
Series[] s_can_2_x = Series.get(can_2_x);
Series[] s_can_x = Series.get(can_x);

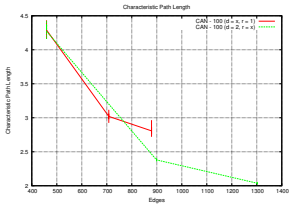
Plot.allMulti(s_can_x_1, "./can-dimensions/");
Plot.allMulti(s_can_2_x, "./can-realities/");

Plot.allSingle(s_can_x_1, "./can-dimensions-singles/");
Plot.allSingle(s_can_2_x, "./can-realities-singles/");
Plot.allSingle(s_can_x, "./can-nodes-singles/");

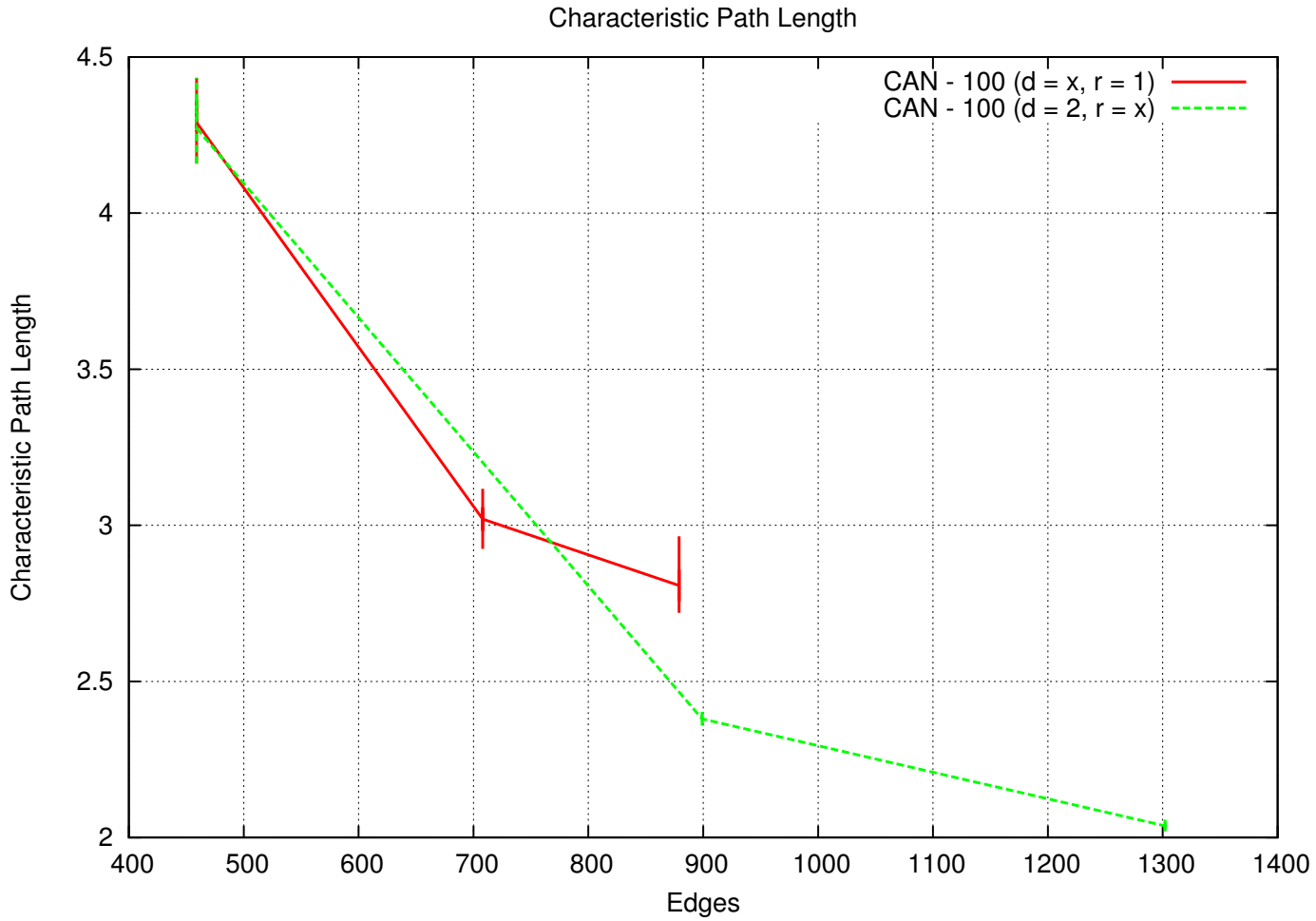
Series[][] s_all = new Series[][]{
  s_can_x_1, s_can_2_x };

Plot.allSingleByEdges(s_all, "./can-by-edges/");
```





Plotting the Results

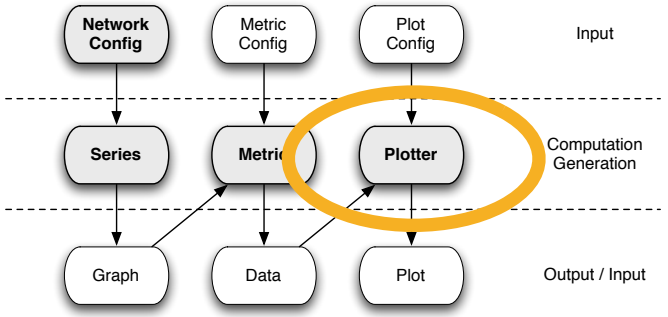


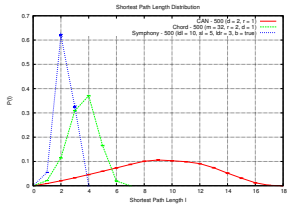
Plotting the Results (cont.)

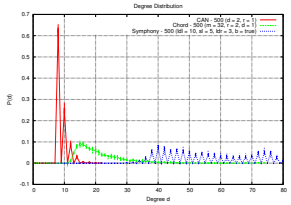
```
Series can = Series.get(new CAN(500, 2, 1));
Series chord = Series.get(new Chord(500, 32, 2, 1));
Series sy = Series.get(new Symphony(500, 10, 5, 3, true));

Series[] all = new Series[]{can, chord, sy};

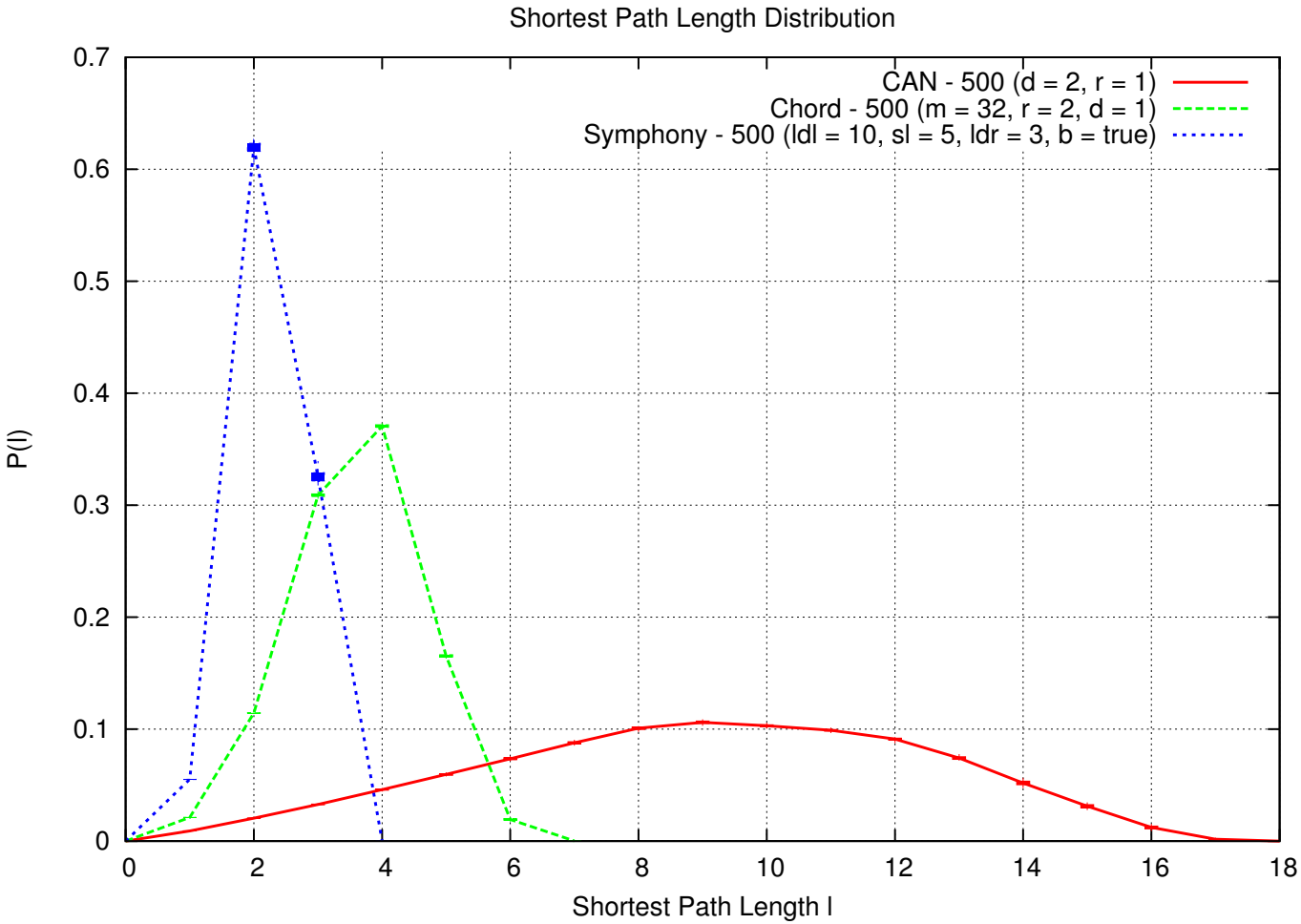
Plot.allMulti(all, "./data/all/");
```

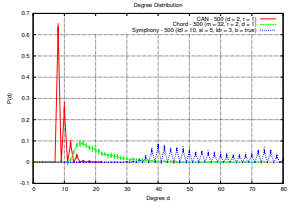




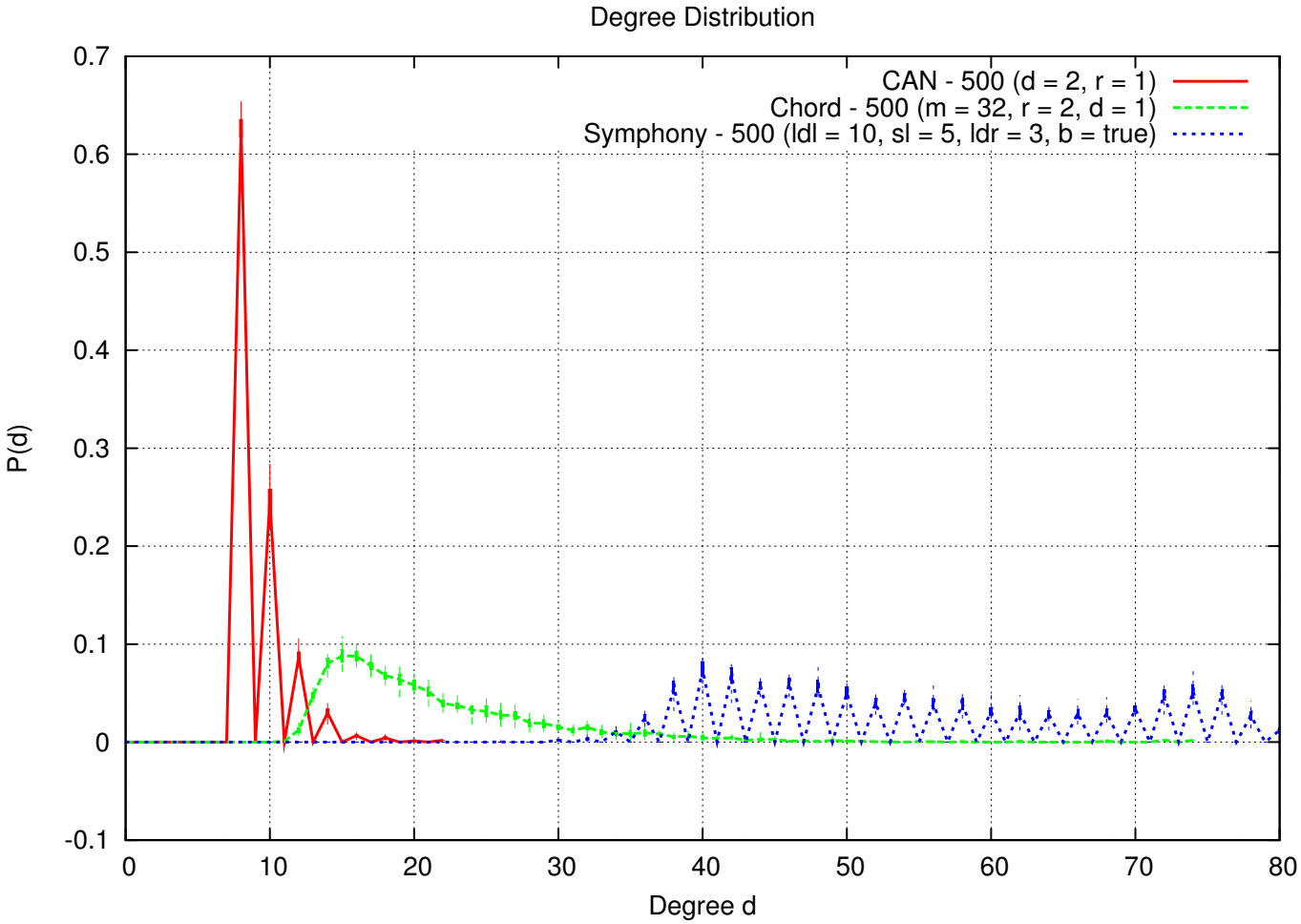


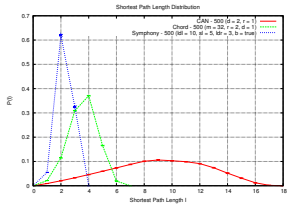
Plotting the Results (cont.)





Plotting the Results (cont.)





Internet Traces from caida.org

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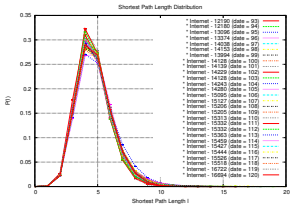
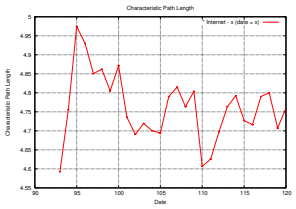
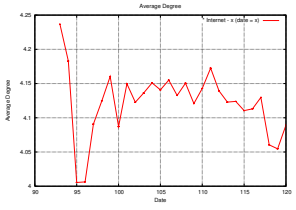
caida

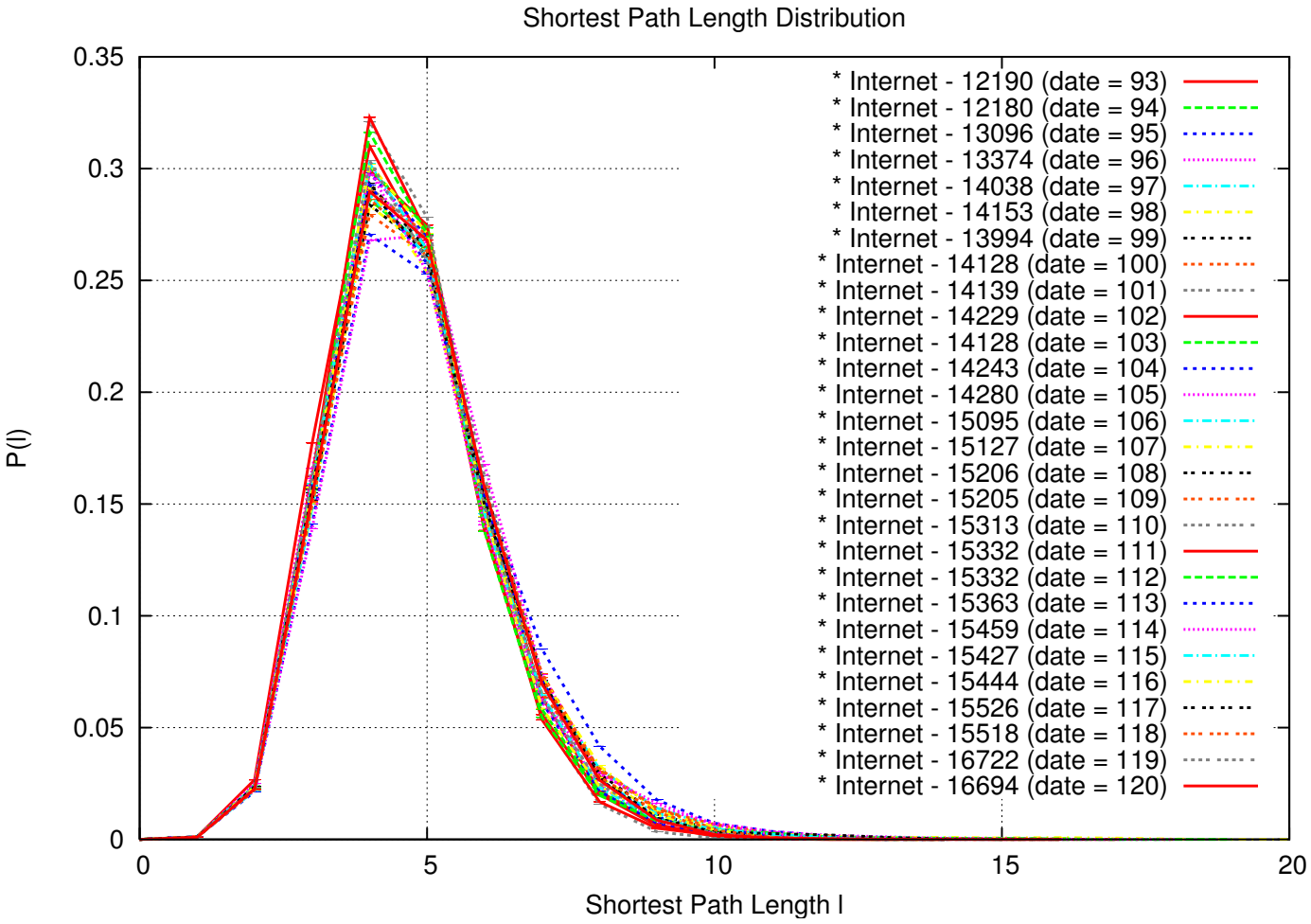
The Cooperative Association for Internet Data Analysis

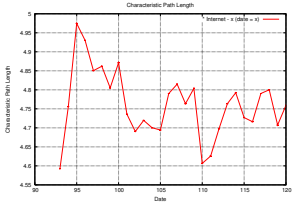


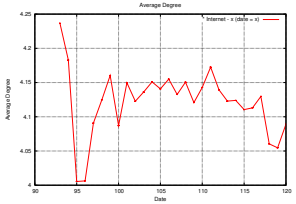




Internet Traces from caida.org







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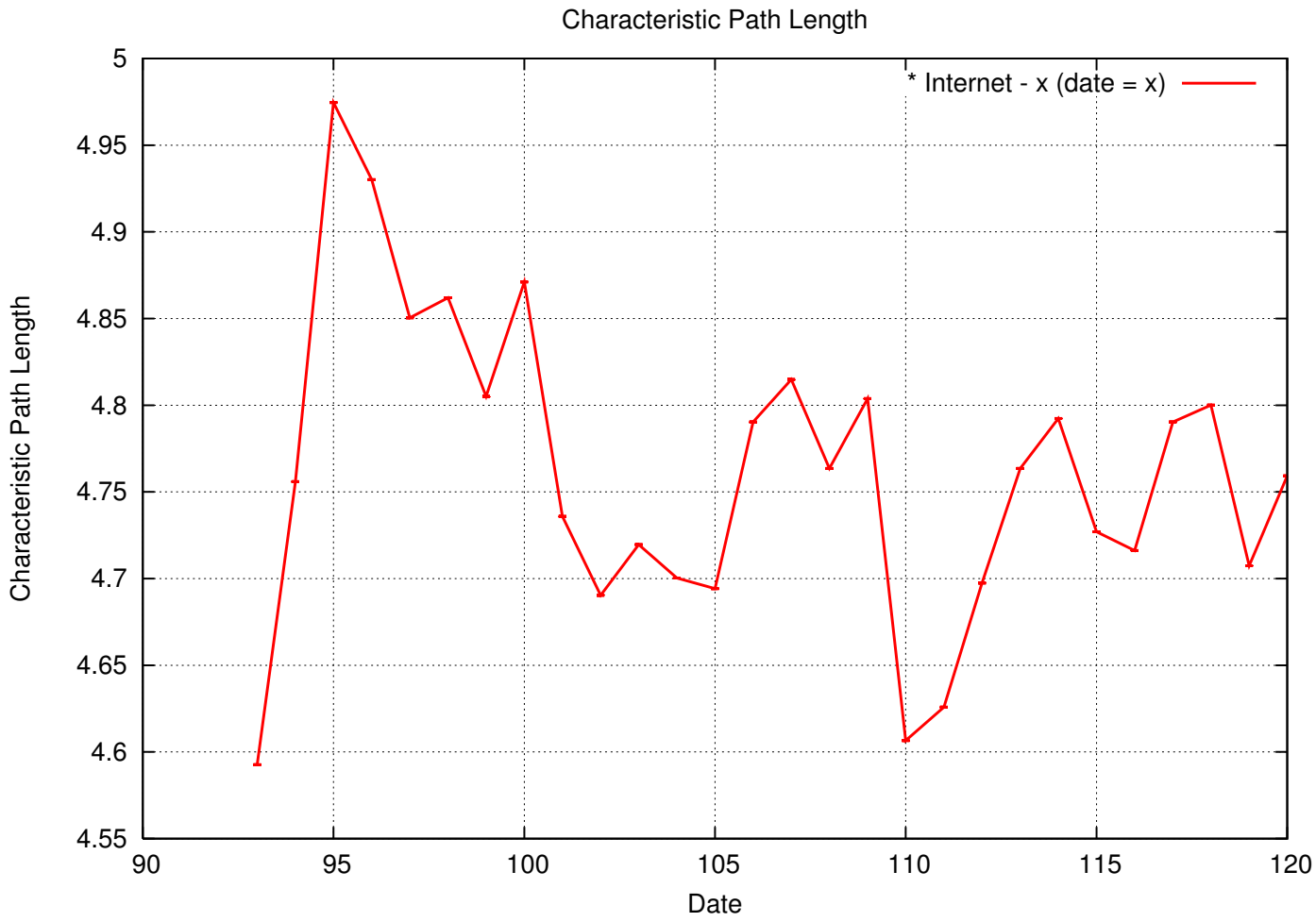
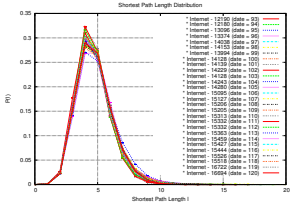
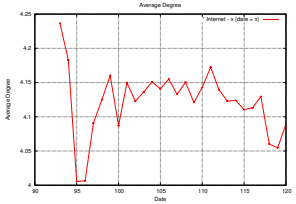
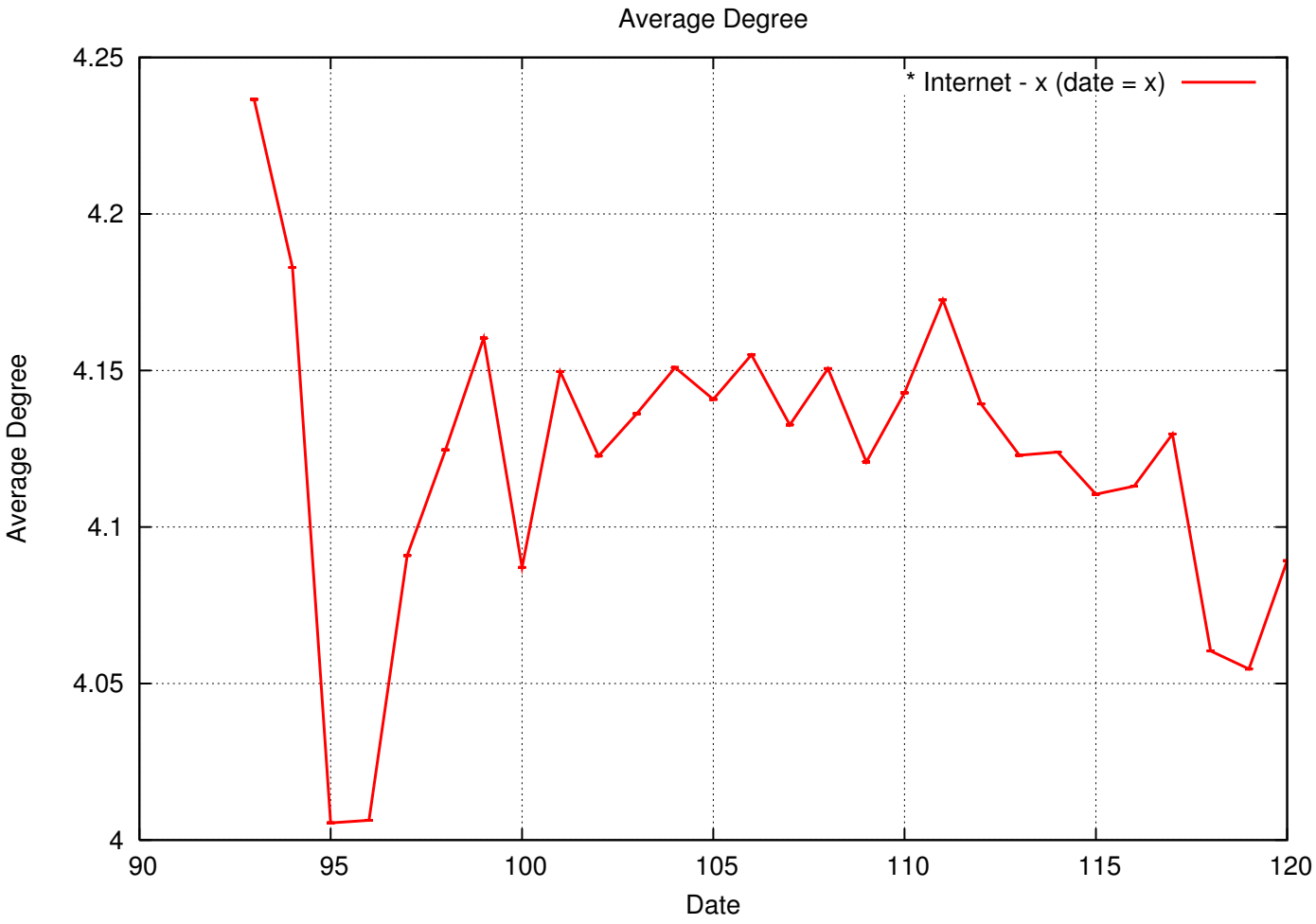
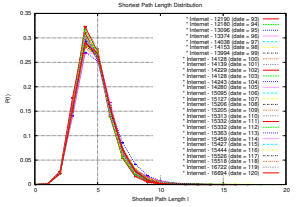


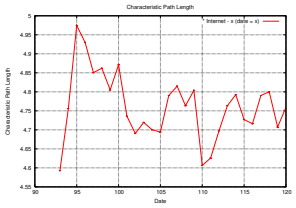




Internet Traces from caida.org

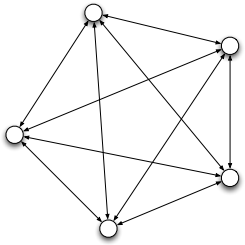


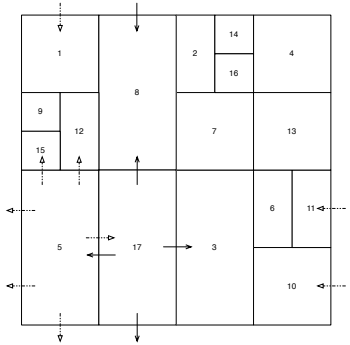


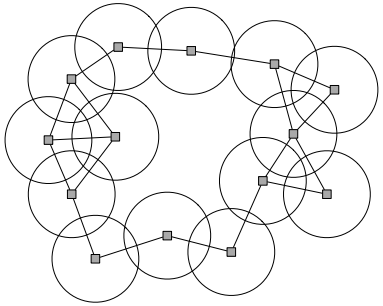


3. Available Networks

Networks already implemented in GTNA



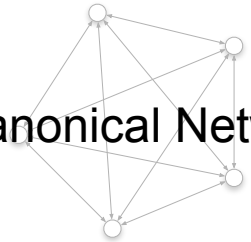




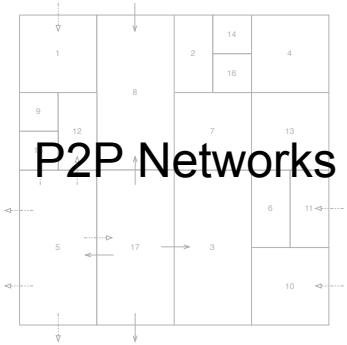
```
graph [
  comment "This is a sample graph"
  directed 1
  IsPlanar 1
  node [
    id 1
    label
    "Node 1"
  ]
  node [
    id 2
    label
    "Node 2" ]
  node [
    id 3
    labe
    "Node 3"
  ]
  edge [
    source 1
    target 2
    label "Edge from node 1 to node 2"
  ]
  edge [
    source 2
    target 3
    label "Edge from node 2 to node 3"
  ]
  edge [
    source 3
    target 1 label
    "Edge from node 3 to node 1"
  ]
]
```

3. Available Networks

Networks already implemented in GTNA

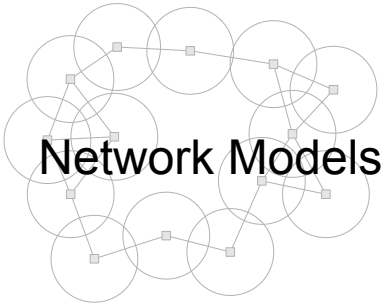


Canonical Networks

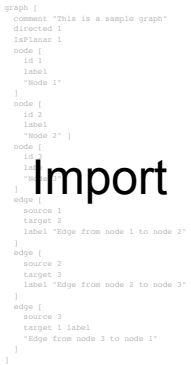


P2P Networks

Transformations



Network Models



Import

Canonical Networks

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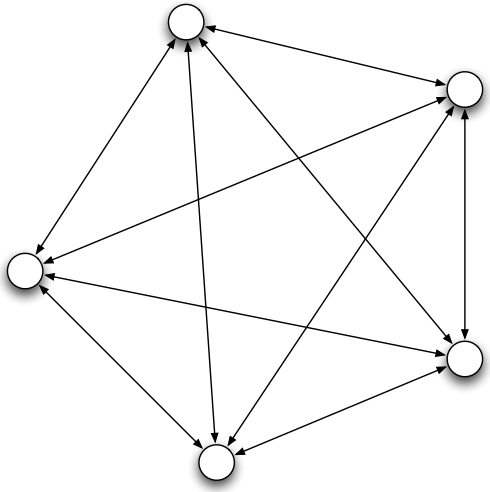
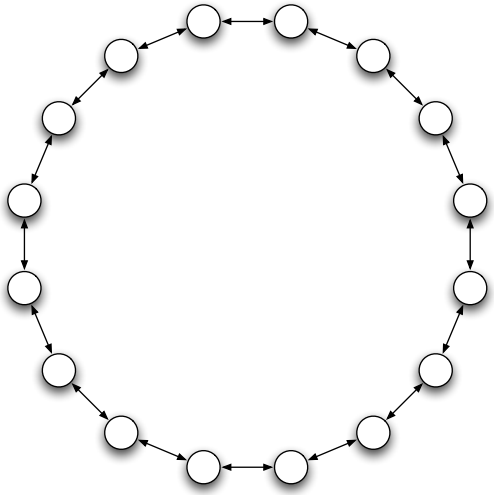
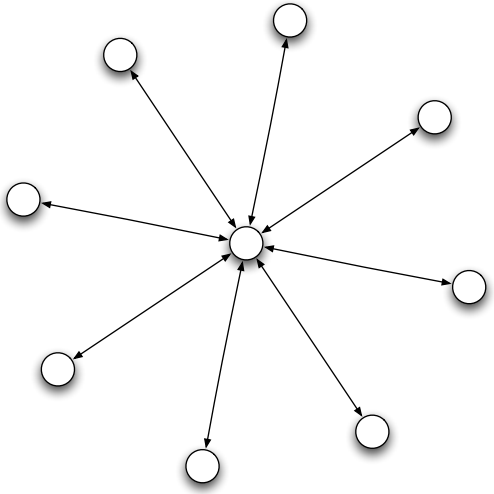
- Complete
- Ring
- Star







Network Models

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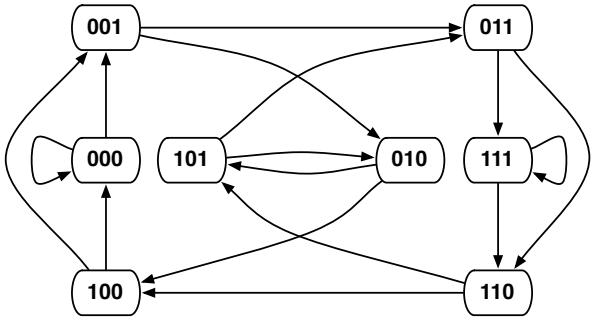
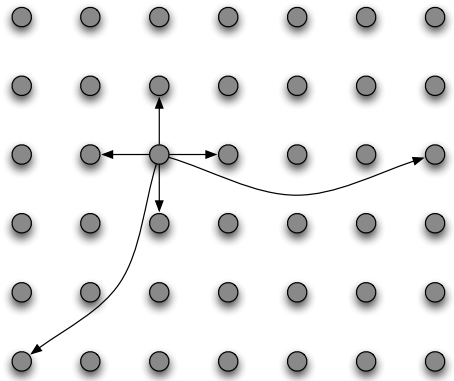
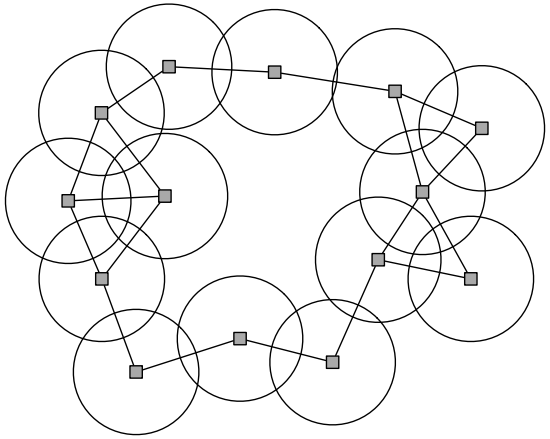
- Barabasi Albert
- De Bruijn
- Erdos Renyi
- Gilbert
- GNC - Growing Network with Copying
- GNR - Growing Network with Re-direction
- Kleinberg
- UnitDisc
- Watts Strogatz

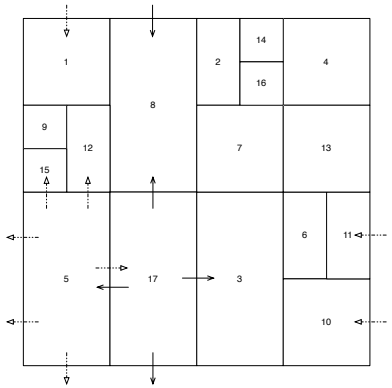


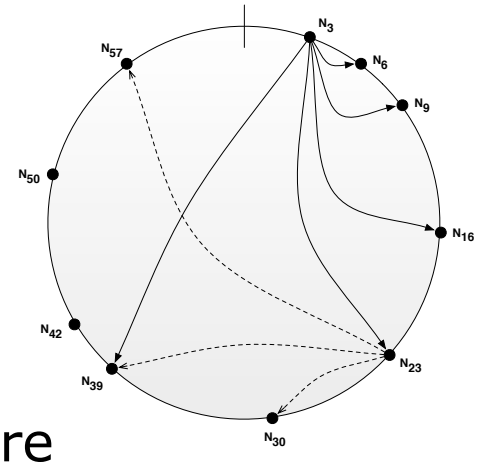


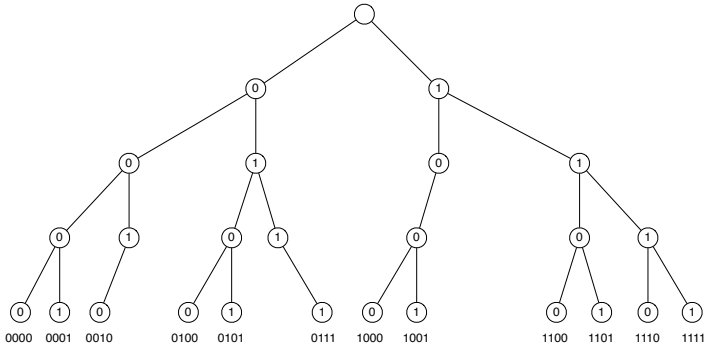


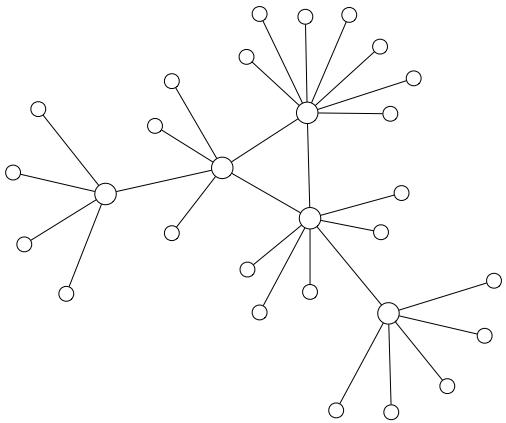
Peer-to-Peer Networks

- CAN
- Chord
- Gnutella 0.4
- Gnutella 0.6
- Kademlia
- ODRI - Optimal Diameter Routing Infrastructure
- Pastry
- PathFinder
- Symphony









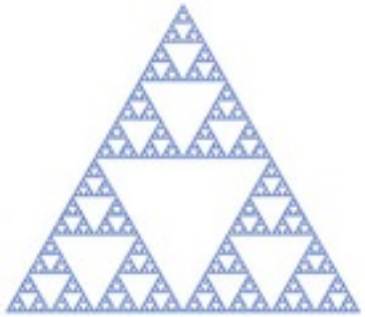
Misc Networks

- Import
  - Readable File
  - Readable List

```
graph [
  comment "This is a sample graph"
  directed 1
  IsPlanar 1
  node [
    id 1
    label
    "Node 1"
  ]
  node [
    id 2
    label
    "Node 2" ]
  node [
    id 3
    labe
    "Node 3"
  ]
  edge [
    source 1
    target 2
    label "Edge from node 1 to node 2"
  ]
  edge [
    source 2
    target 3
    label "Edge from node 2 to node 3"
  ]
  edge [
    source 3
    target 1 label
    "Edge from node 3 to node 1"
  ]
]
```

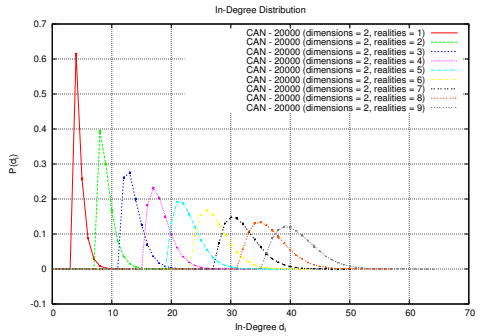
1. own format
2. edges only
3. GML
4. caida.org Internet traces

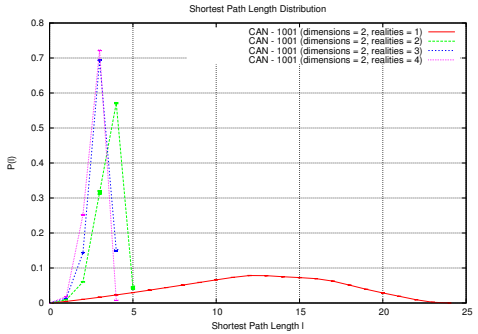
- Transformations
  - Add Edges Per Node
  - Add Edges Randomly
  - Rewire
  - Same Degree Distribution

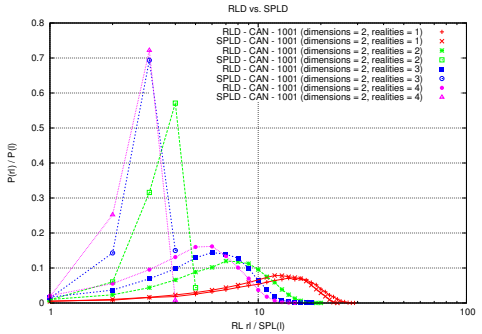


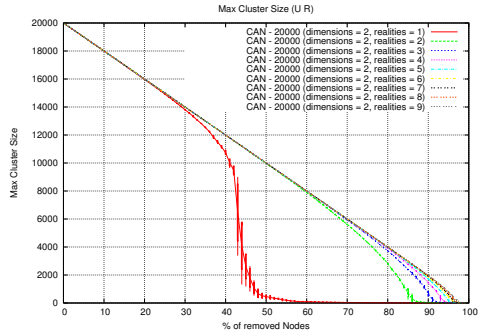
4. Available Metrics

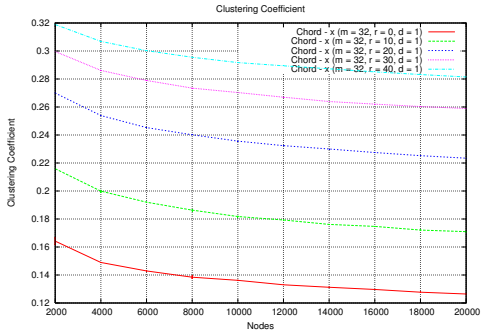
Metrics already implemented in GTNA

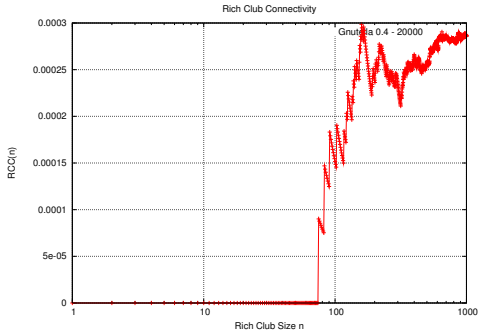






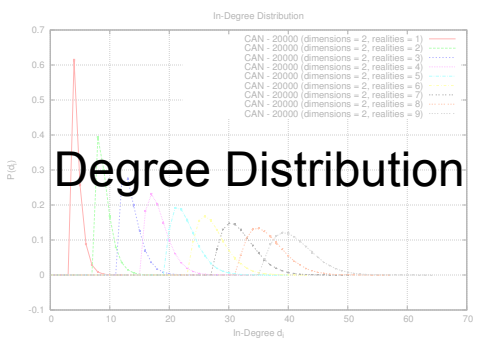


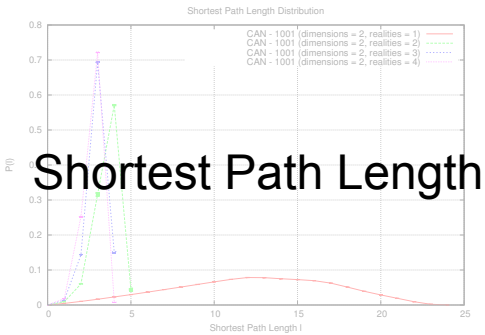


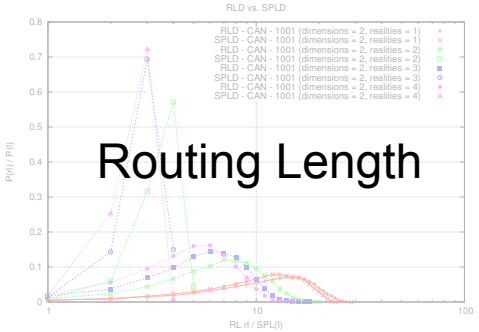


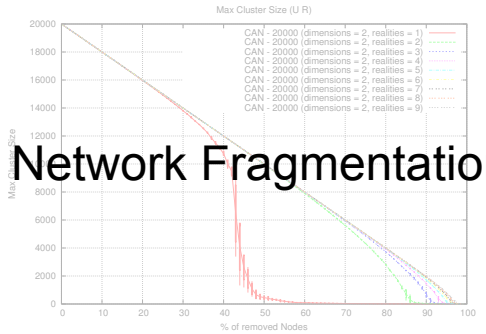
4. Available Metrics

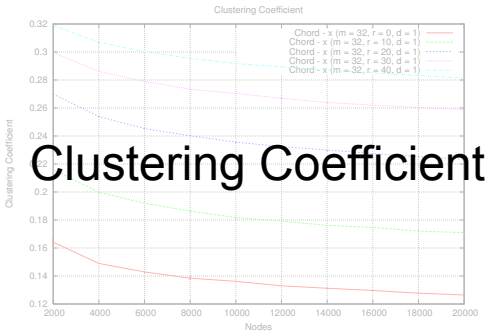
Metrics already implemented in GTNA







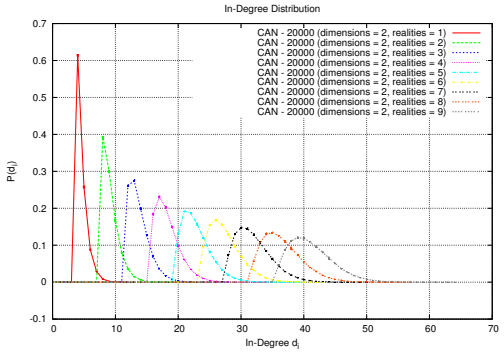


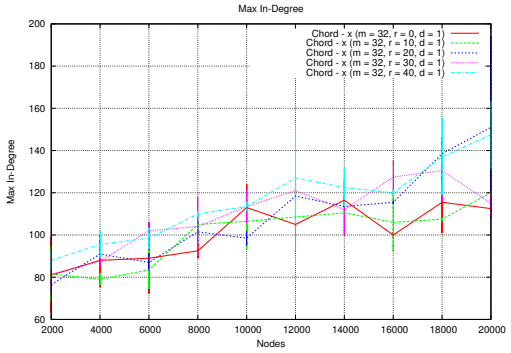


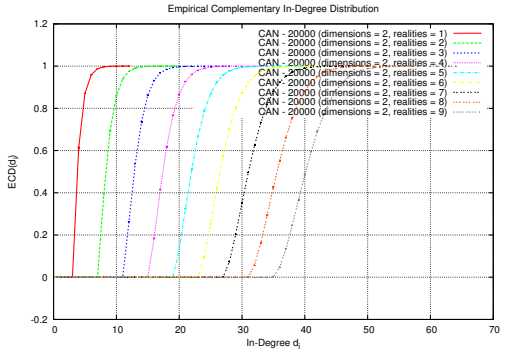
Degree Distribution

- (in-/out-)Degree Distribution
- Empirical Complementary (in-/out-)Degree Distribution

- #Nodes, #Edges
- Average Degree
- Min (in-/out-)Degree
- Max (in-/out-)Degree



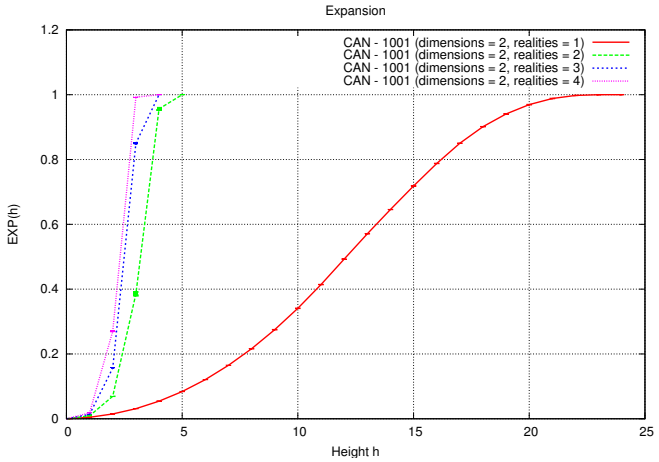


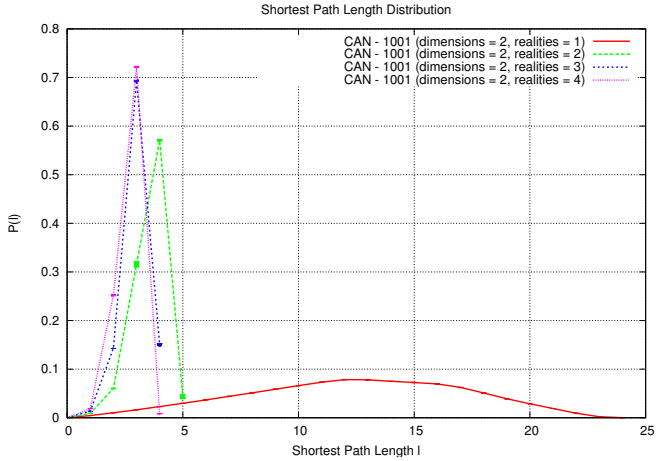


Shortest Path Length

- Shortest Path Length Distribution
- Expansion
- Local Characteristic Path Length

- Characteristic Path Length
- Diameter

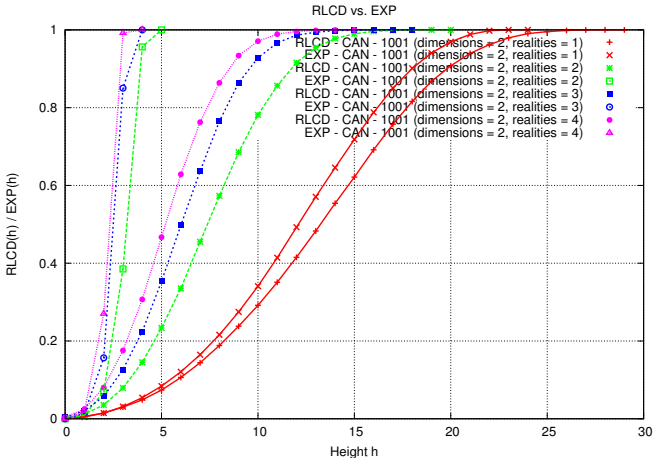


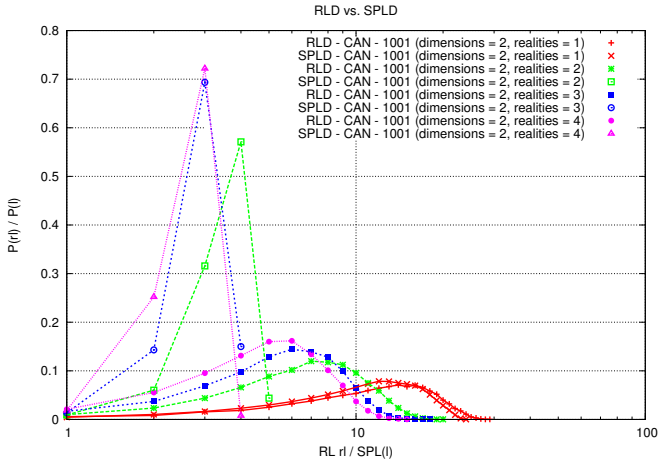


Routing Length

- Routing Length Distribution
- Routing Length Complementary Distribution
- Local Characteristic Routing Length

- Characteristic Routing Length
- Max Routing Length

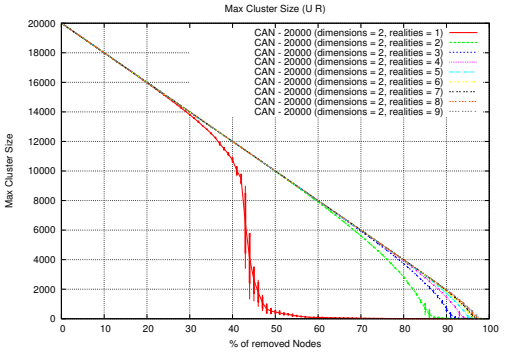


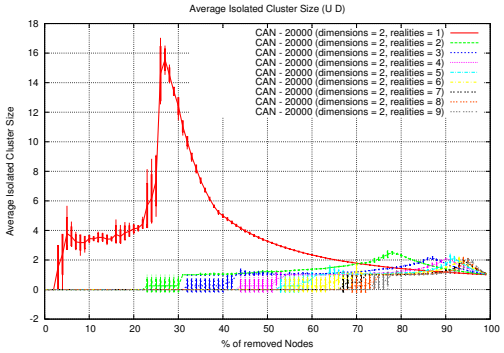


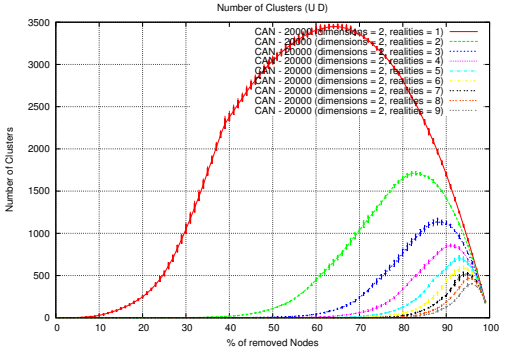
Network Fragmentation

- Max Cluster Size
- Number of Clusters
- Average Isolated Cluster Size

- Point of Rupture
- Average Number of Clusters
- Max Number of Clusters



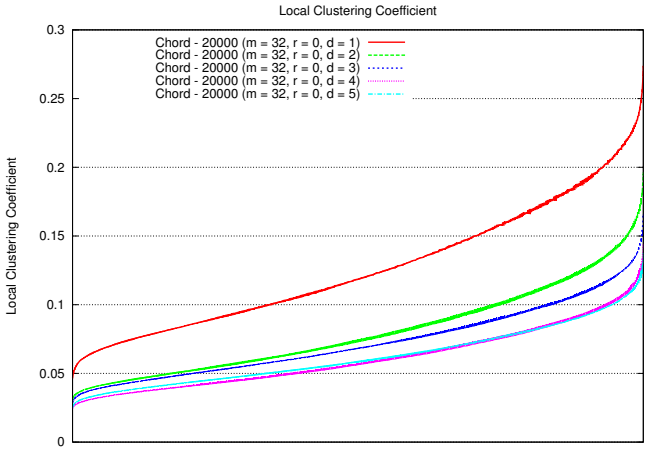


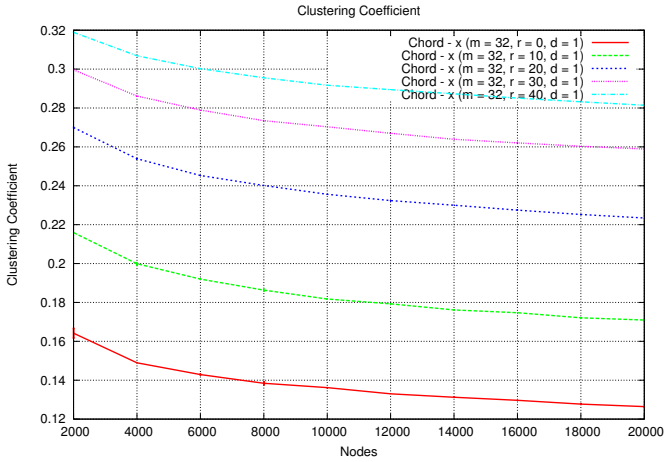


Clustering Coefficient

- Local Clustering Coefficient

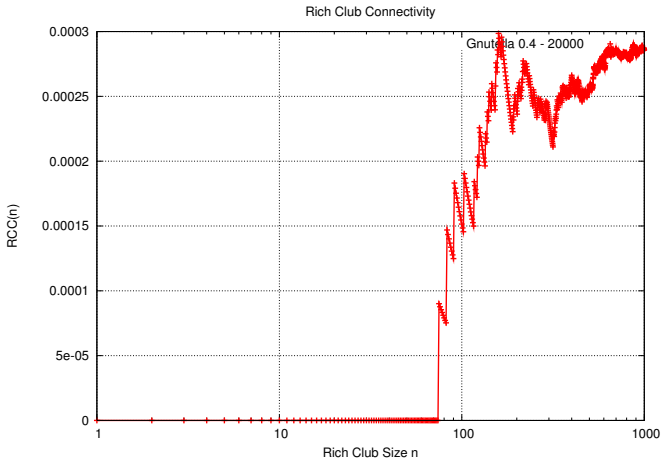
- Clustering Coefficient
- Weighted Clustering Coefficient

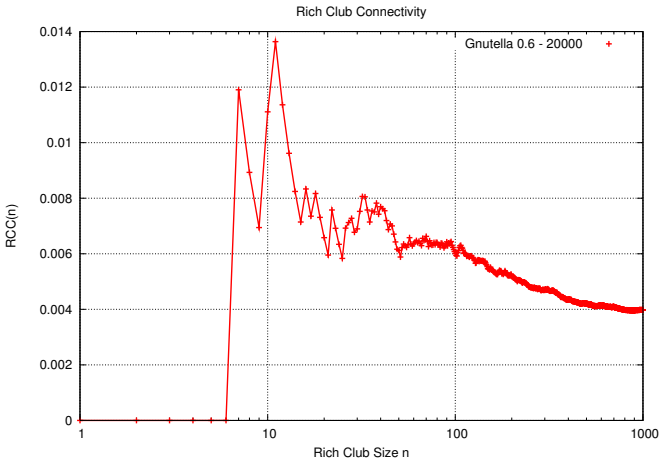




Rich Club Connectivity

- Rich Club Connectivity





5. Extension

Implementation and Configuration of new Networks / Metrics

TECHNISCHE UNIVERSITÄT DARMSTADT

```
public class MyNetwork extends NetworkImpl implements Network {
    private boolean p1;
    public MyNetwork(int nodes, boolean p1) {
        super("MY_NETWORK", nodes, new String[]{"P1"}, new String[]{"" + p1});
        this.p1 = p1;
    }
    public Graph generate(){
        Timer timer = new Timer();
        Node[] nodes = Node.init(this.nodes());
        Edges edges = new Edges(nodes, 100);
        for(int i=1; i<nodes.length; i++){
            edges.add(nodes[0], nodes[i]);
            if(this.p1)
                edges.add(nodes[i], nodes[0]);
        }
        edges.fill();
        return new Graph(this.description(), nodes, timer);
    }
}
```

+

```
NOD_CLASS = gtna.metrics.NodesOfDegree
NOD_NAME = Nodes of Degree
NOD_DATA_KEYS = NOD_NOD
NOD_SINGLES_KEYS = NOD_DOMN
NOD_DATA_PLOTS = NOD
NOD_SINGLES_PLOTS = DOMN

NOD_NOD_DATA_NAME = Nodes of Degree
NOD_NOD_DATA_FILENAME = nod

NOD_DOMN_SINGLE_NAME = Degree of Most Nodes

NOD_PLOT_DATA = NOD_NOD
NOD_PLOT_FILENAME = nod
NOD_PLOT_TITLE = Nodes of Degree
NOD_PLOT_X = degree d
NOD_PLOT_Y = # nodes of degree d

DOMN_PLOT_DATA = NOD_DOMN
DOMN_PLOT_FILENAME = domn
DOMN_PLOT_TITLE = Degree of Most Nodes
DOMN_PLOT_Y = Degree of Most Nodes
```

Implementing a new Network

TECHNISCHE UNIVERSITÄT DARMSTADT

```
public class MyNetwork extends NetworkImpl implements Network {
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    }
    edges.fill();
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  }
}
```

Implementing a new Network

TECHNISCHE UNIVERSITÄT DARMSTADT

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Implementing a new Network

TECHNISCHE UNIVERSITÄT DARMSTADT

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      if(this.p1)
        edges.add(nodes[0], nodes[i]);
    }
    edges.fill();
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  }
}
```

Parameter

Implementing a new Network

TECHNISCHE UNIVERSITÄT DARMSTADT

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        edges.add(nodes[0], nodes[i]);
    }
    edges.fill();
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  }
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```

Parameter

Constructor

Implementing a new Network

TECHNISCHE UNIVERSITÄT DARMSTADT

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      if(this.p1)
        edges.add(nodes[0], nodes[i]);
    }
    edges.fill();
    return new Graph(this.description(), nodes, timer);
  }
}
```

Parameter

Constructor

Generator

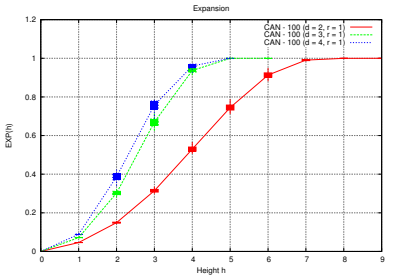
Configuring a new Network

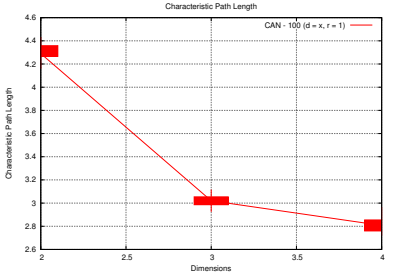
```
CAN_NETWORK_NAME = CAN

CAN_NETWORK_FOLDER = can

CAN_NETWORK_DIMENSIONS_NAME = Dimensions
CAN_NETWORK_DIMENSIONS_NAME_LONG = dimensions
CAN_NETWORK_DIMENSIONS_NAME_SHORT = d

CAN_NETWORK_REALITIES_NAME = Realities
CAN_NETWORK_REALITIES_NAME_LONG = realities
CAN_NETWORK_REALITIES_NAME_SHORT = r
```





Configuring a new Network

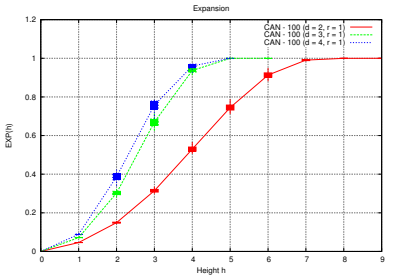
TECHNISCHE UNIVERSITÄT DARMSTADT

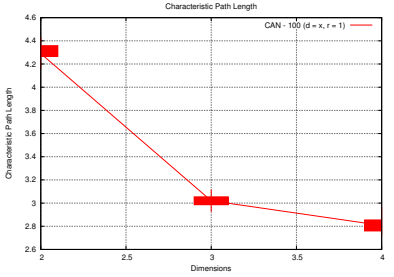
```
CAN_NETWORK_NAME = CAN

CAN_NETWORK_FOLDER = can

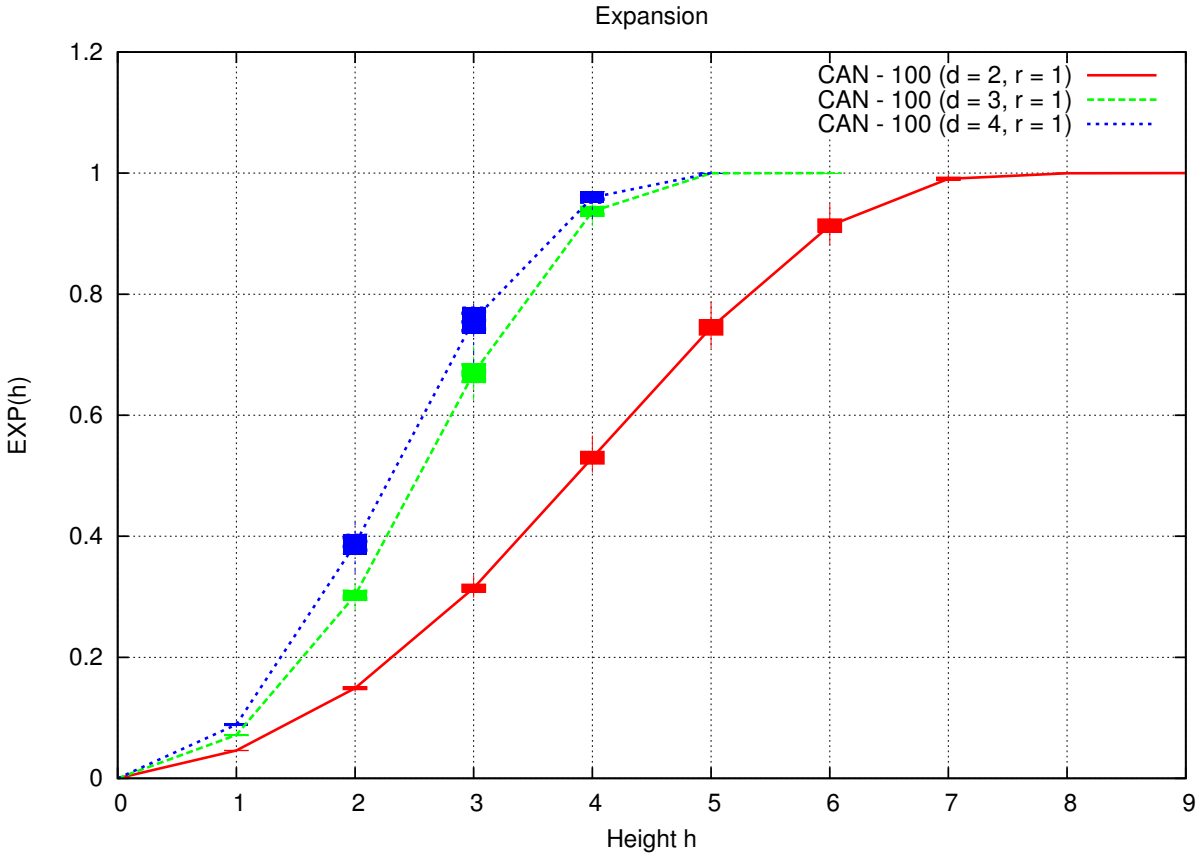
CAN_NETWORK_DIMENSIONS_NAME = Dimensions
CAN_NETWORK_DIMENSIONS_NAME_LONG = dimensions
CAN_NETWORK_DIMENSIONS_NAME_SHORT = d

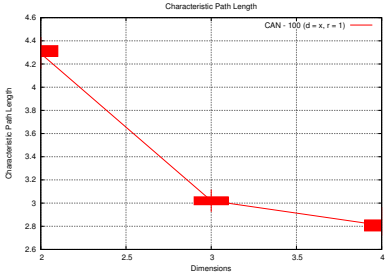
CAN_NETWORK_REALITIES_NAME = Realities
CAN_NETWORK_REALITIES_NAME_LONG = realities
CAN_NETWORK_REALITIES_NAME_SHORT = r
```





Configuring a new Network





Configuring a new Network

TECHNISCHE UNIVERSITÄT DARMSTADT

```
CAN_NETWORK_NAME = CAN

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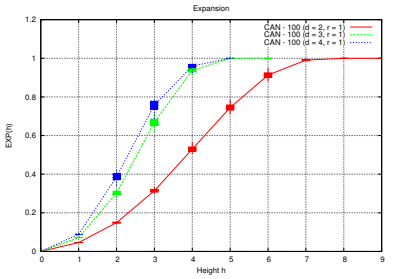
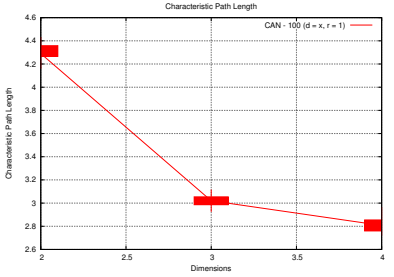
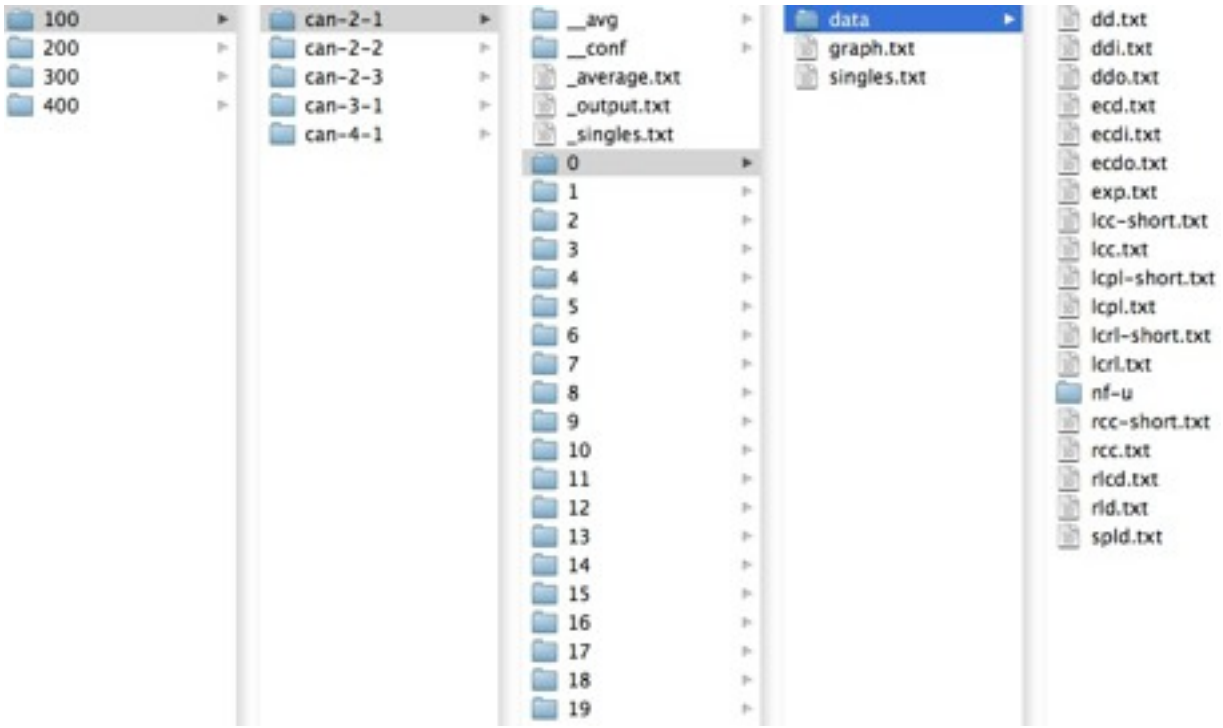
CAN_NETWORK_DIMENSIONS_NAME = Dimensions
CAN_NETWORK_DIMENSIONS_NAME_LONG = dimensions
CAN_NETWORK_DIMENSIONS_NAME_SHORT = d

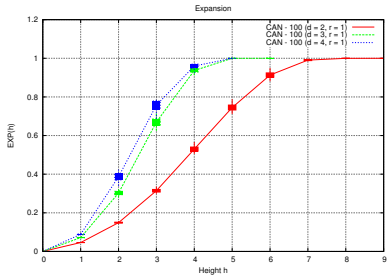
CAN_NETWORK_REALITIES_NAME = Realities
CAN_NETWORK_REALITIES_NAME_LONG = realities
CAN_NETWORK_REALITIES_NAME_SHORT = r
```

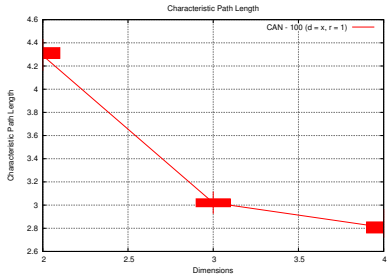




Configuring a new Network







Configuring a new Network

TECHNISCHE UNIVERSITÄT DARMSTADT

```
CAN_NETWORK_NAME = CAN

CAN_NETWORK_FOLDER = can

CAN_NETWORK_DIMENSIONS_NAME = Dimensions
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CAN_NETWORK_REALITIES_NAME = Realities
CAN_NETWORK_REALITIES_NAME_LONG = realities
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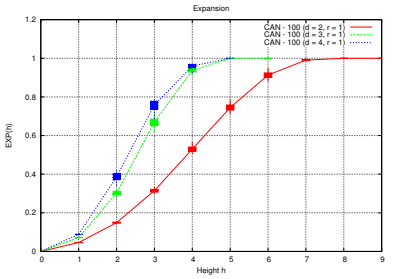
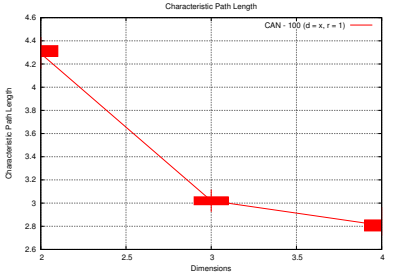
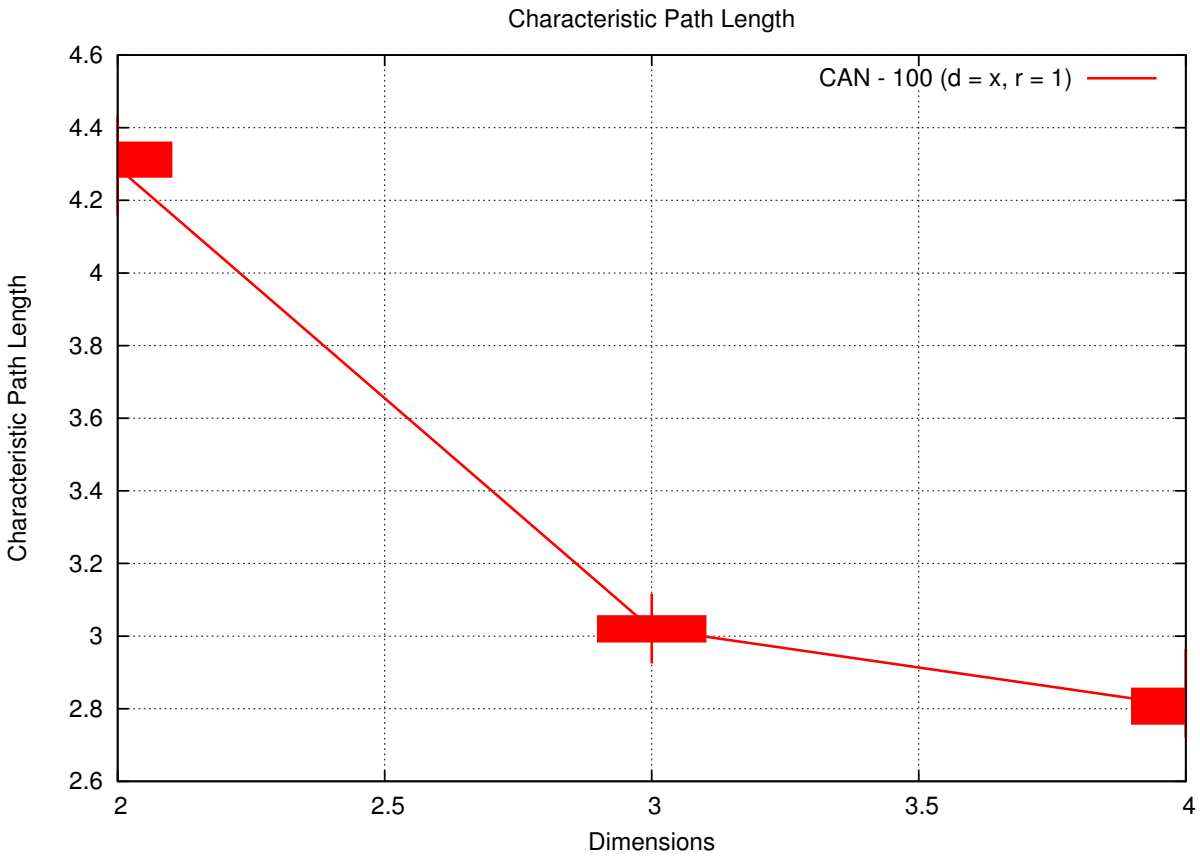
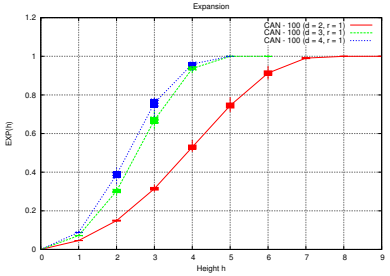
```





Configuring a new Network





Implementing a new Metric

TECHNISCHE UNIVERSITÄT DARMSTADT

```
public class MyMetric extends MetricImpl implements Metric {
  private int[] nod;
  private int domn;
  public MyMetric() { super("NOD"); }
  public void computeData(Graph g) {
    this.nod = new int[g.maxDegree + 1];
    for (int i = 0; i < g.nodes.length; i++)
      this.nod[g.nodes[i].degree]++;
    this.domn = Util.maxIndex(this.nod);
  }
  public Value[] getValues(Value[] values) {
    return new Value[] { new Value("NOD_DOMN", this.domn) };
  }
  public boolean writeData(String folder) {
    DataWriter.write("NOD_NOD", folder, this.nod);
    return true;
  }
}
```

Implementing a new Metric

TECHNISCHE UNIVERSITÄT DARMSTADT

```
public class MyMetric extends MetricImpl implements Metric {
  private int[] nod;
  private int domn;
  public MyMetric() { super("NOD"); }
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    for (int i = 0; i < g.nodes.length; i++)
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    this.domn = Util.maxIndex(this.nod);
  }
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Implementing a new Metric

TECHNISCHE UNIVERSITÄT DARMSTADT

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```

Attributes

Implementing a new Metric

TECHNISCHE UNIVERSITÄT DARMSTADT

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Attributes

Constructor

Implementing a new Metric

TECHNISCHE UNIVERSITÄT DARMSTADT

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  }
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  }
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```

Attributes

Constructor

Computation

Implementing a new Metric

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```
public class MyMetric extends MetricImpl implements Metric {
  private int[] nod;
  private int domn;
  public MyMetric() { super("NOD"); }
  public void computeData(Graph g) {
    this.nod = new int[g.maxDegree + 1];
    for (int i = 0; i < g.nodes.length; i++)
      this.nod[g.nodes[i].degree]++;
    this.domn = Util.maxIndex(this.nod);
  }
  public Value[] getValues(Value[] values) {
    return new Value[] { new Value("NOD_DOMN", this.domn) };
  }
  public boolean writeData(String folder) {
    DataWriter.write("NOD_NOD", folder, this.nod);
    return true;
  }
}
```

Attributes

Constructor

Computation

Output

Configuring a new Metric

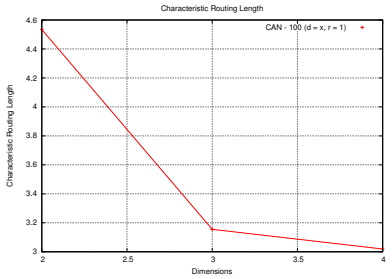
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

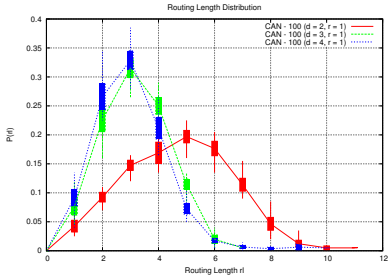
CRL_SINGLE_NAME = Characteristic Routing Length

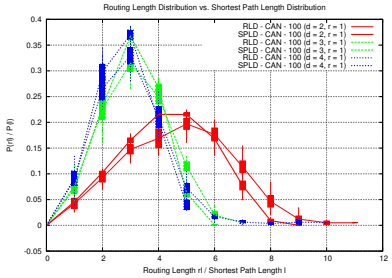
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

RLD_PLOT_DATA = RLD
RLD_PLOT_FILENAME = rld
RLD_PLOT_TITLE = Routing Length Distribution
RLD_PLOT_X = Routing Length rl
RLD_PLOT_Y = P(rl)
```







Configuring a new Metric

TECHNISCHE UNIVERSITÄT DARMSTADT

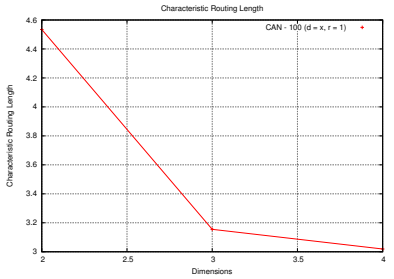
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

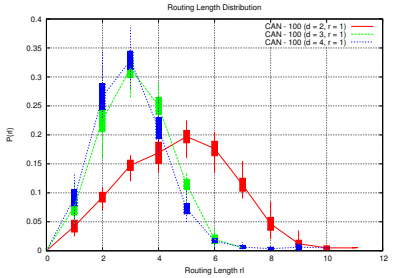
CRL_SINGLE_NAME = Characteristic Routing Length

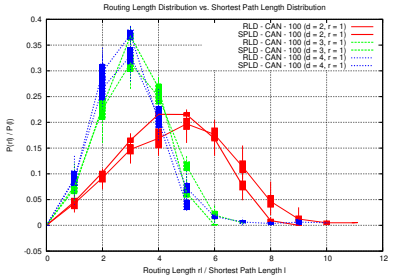
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

RLD_PLOT_DATA = RLD
RLD_PLOT_FILENAME = rld
RLD_PLOT_TITLE = Routing Length Distribution
RLD_PLOT_X = Routing Length rl
RLD_PLOT_Y = P(rl)
```







Configuring a new Metric

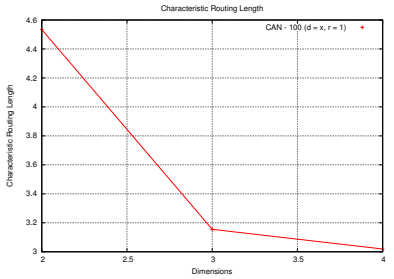
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

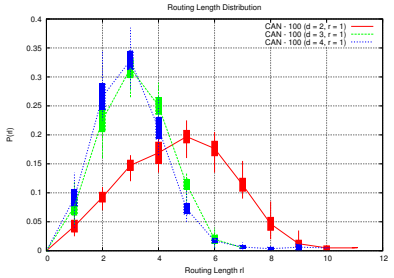
CRL_SINGLE_NAME = Characteristic Routing Length

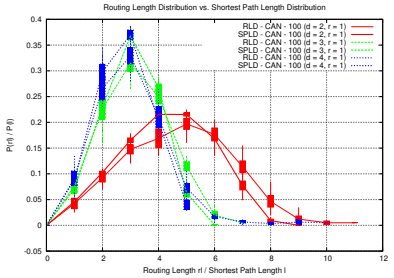
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

RLD_PLOT_DATA = RLD
RLD_PLOT_FILENAME = rld
RLD_PLOT_TITLE = Routing Length Distribution
RLD_PLOT_X = Routing Length rl
RLD_PLOT_Y = P(rl)
```







Configuring a new Metric

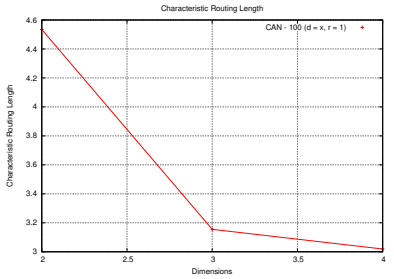
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

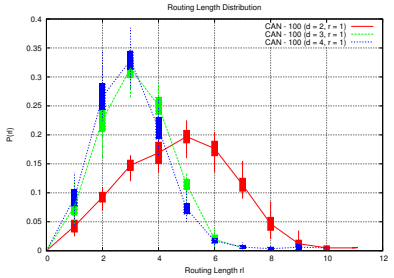
CRL_SINGLE_NAME = Characteristic Routing Length

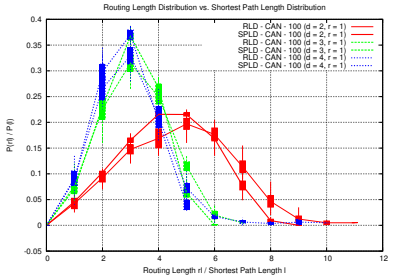
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

RLD_PLOT_DATA = RLD
RLD_PLOT_FILENAME = rld
RLD_PLOT_TITLE = Routing Length Distribution
RLD_PLOT_X = Routing Length rl
RLD_PLOT_Y = P(rl)
```







Configuring a new Metric

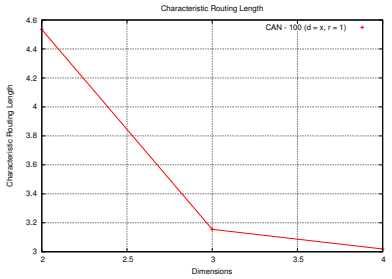
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

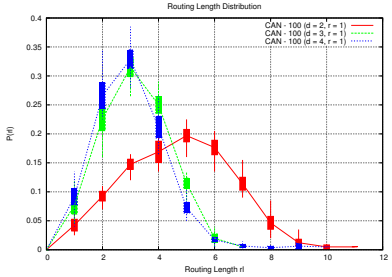
CRL_SINGLE_NAME = Characteristic Routing Length

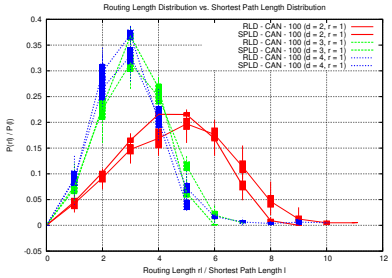
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

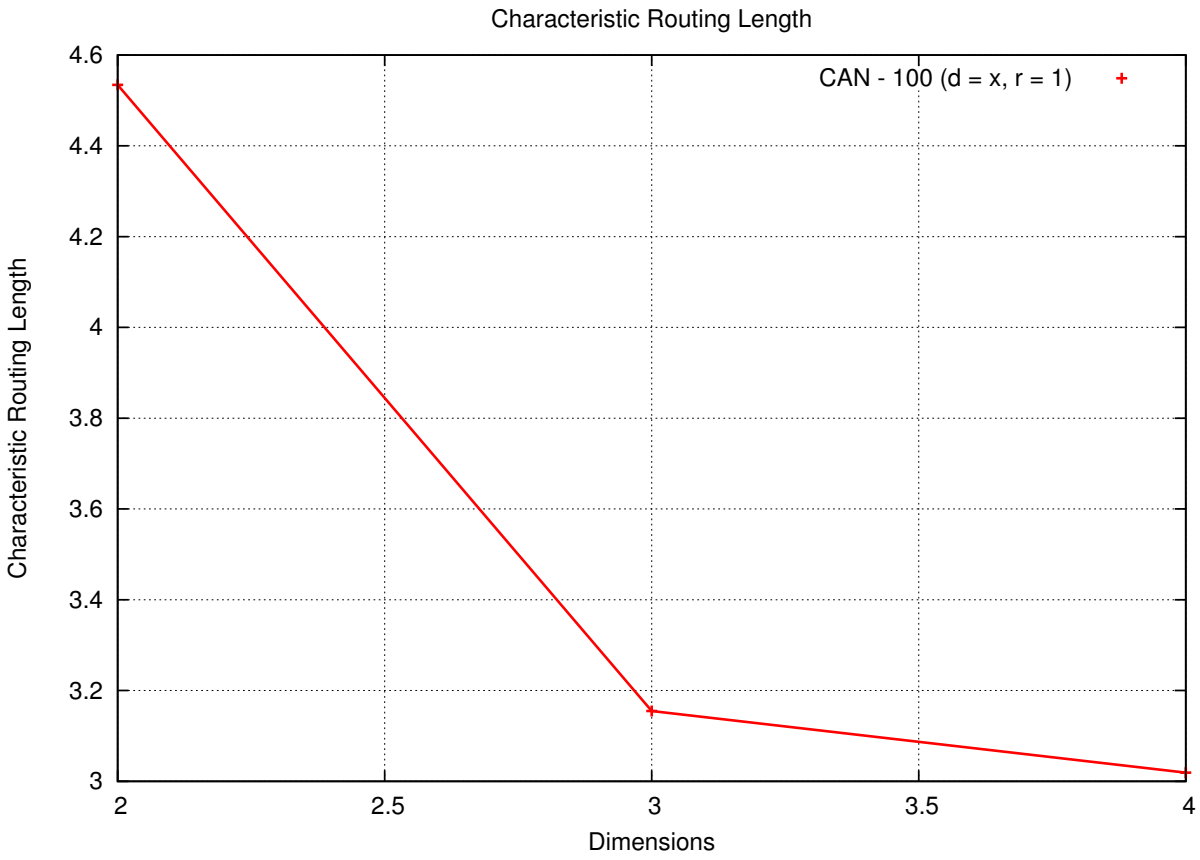
RLD_PLOT_DATA = RLD
RLD_PLOT_FILENAME = rld
RLD_PLOT_TITLE = Routing Length Distribution
RLD_PLOT_X = Routing Length rl
RLD_PLOT_Y = P(rl)
```

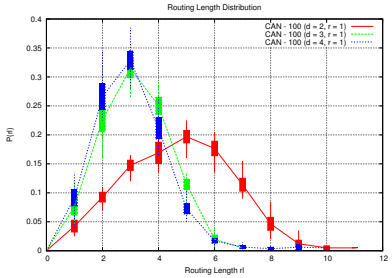


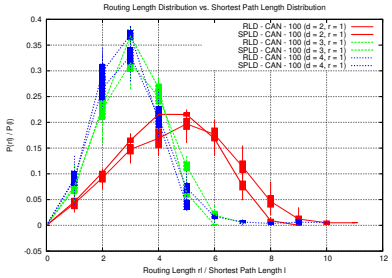




Configuring a new Metric







Configuring a new Metric

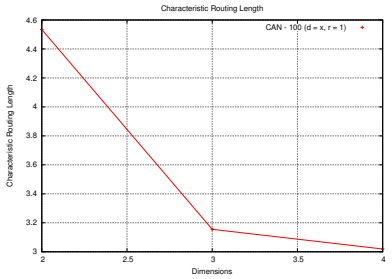
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

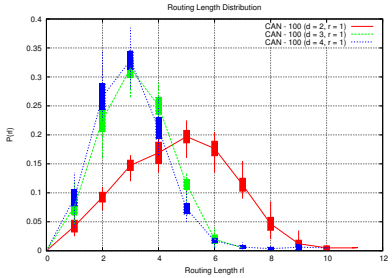
CRL_SINGLE_NAME = Characteristic Routing Length

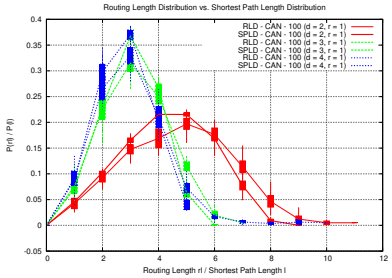
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

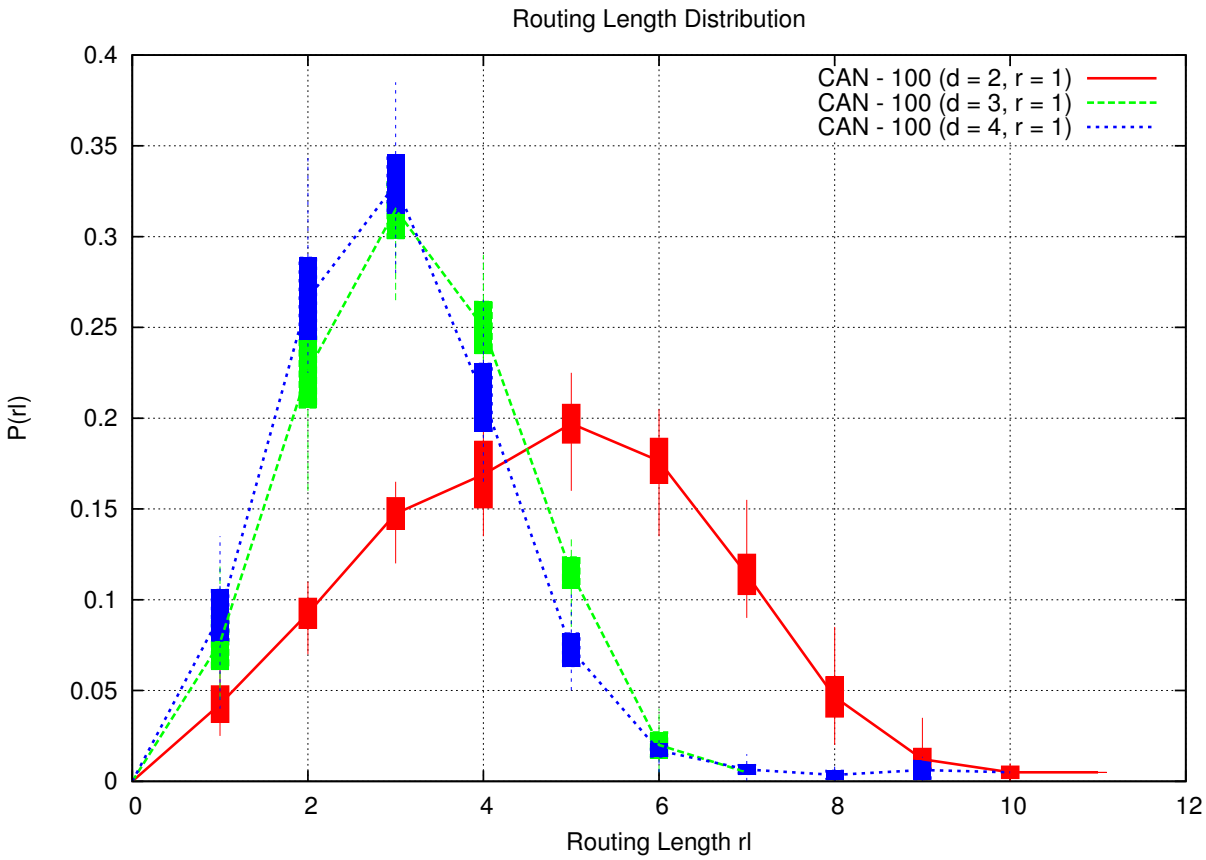
RLD_PLOT_DATA = RLD
RLD_PLOT_FILENAME = rld
RLD_PLOT_TITLE = Routing Length Distribution
RLD_PLOT_X = Routing Length rl
RLD_PLOT_Y = P(rl)
```

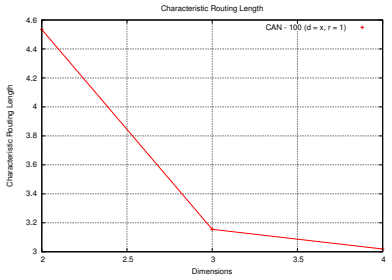


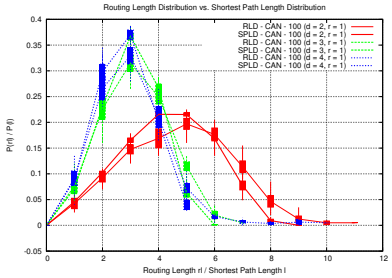




Configuring a new Metric







Configuring a new Metric

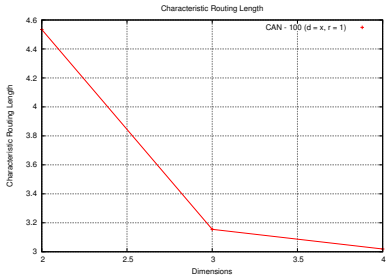
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

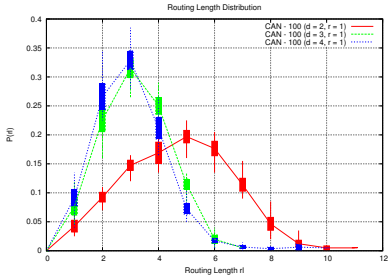
CRL_SINGLE_NAME = Characteristic Routing Length

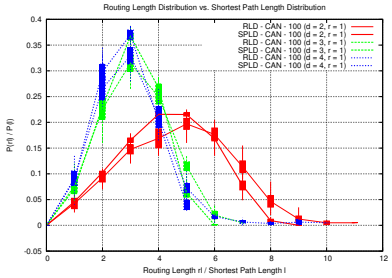
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

RLD_PLOT_DATA = RLD
RLD_PLOT_FILENAME = rld
RLD_PLOT_TITLE = Routing Length Distribution
RLD_PLOT_X = Routing Length rl
RLD_PLOT_Y = P(rl)
```







Configuring a new Metric

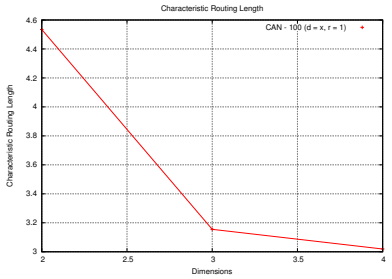
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

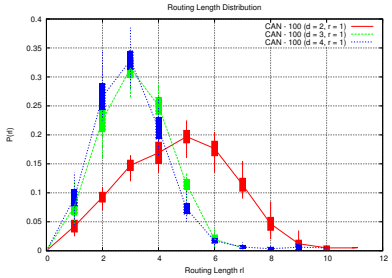
CRL_SINGLE_NAME = Characteristic Routing Length

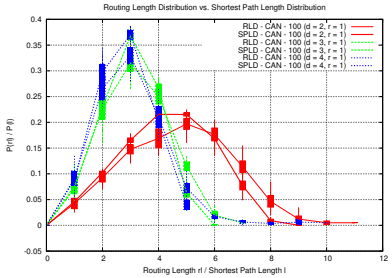
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

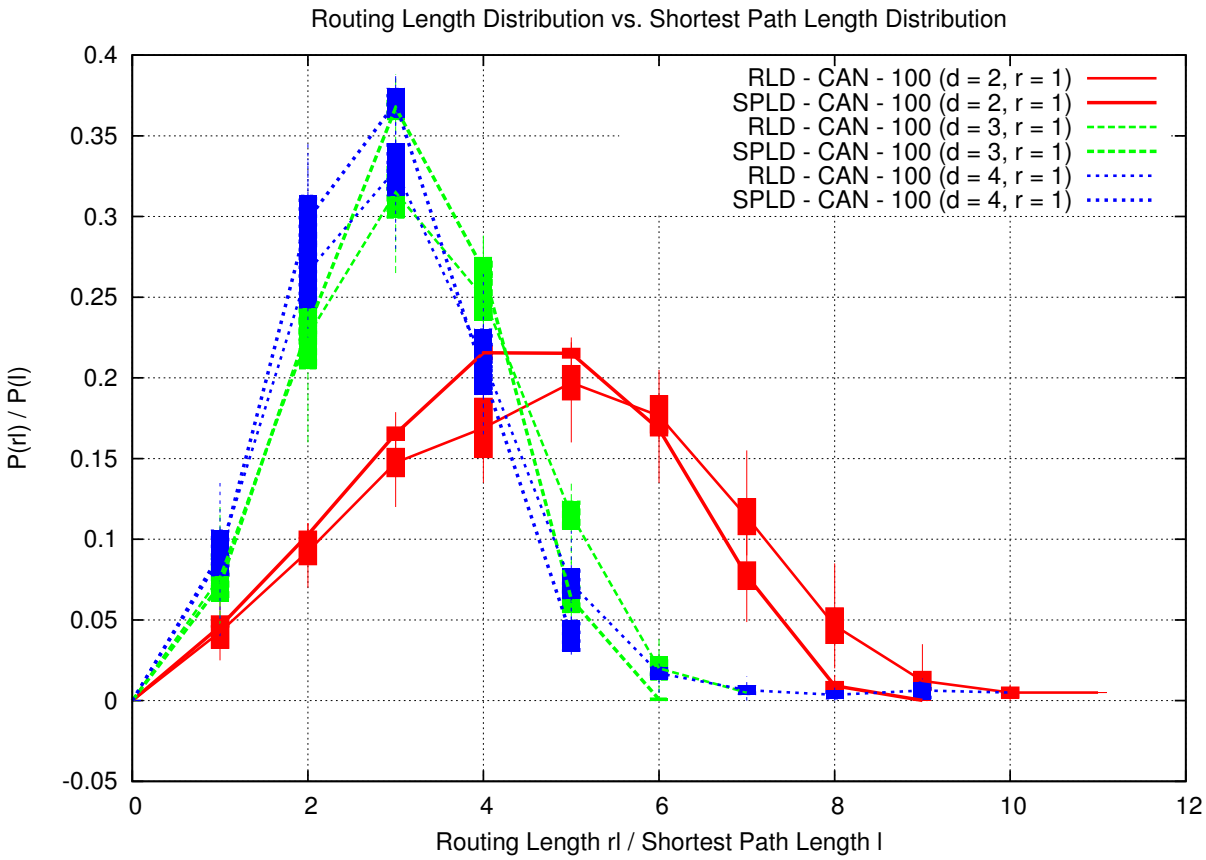
RLD_PLOT_DATA = RLD, SPLD
RLD_PLOT_FILENAME = rld-vs-spld
RLD_PLOT_TITLE = RLD vs. SPLD
RLD_PLOT_X = Routing Length rl / Shortest Path Length l
RLD_PLOT_Y = P(rl) / R(l)
```

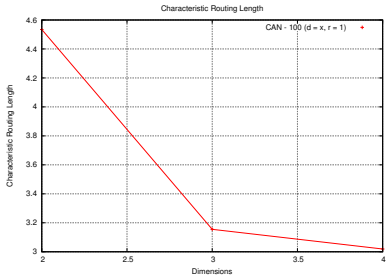


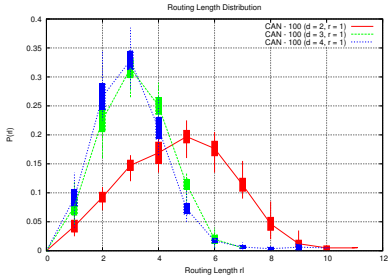




Configuring a new Metric







Configuring a new Metric

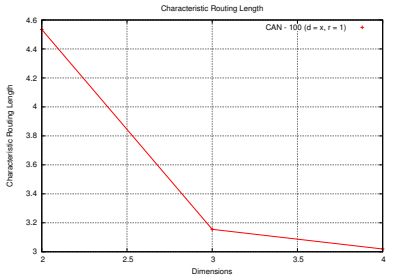
```
RL_CLASS = gtna.metrics.RoutingLength
RL_NAME = Routing Length
RL_SINGLES_KEYS = CRL
RL_DATA_KEYS = RLD
RL_SINGLES_PLOTS = CRL
RL_DATA_PLOTS = RLD

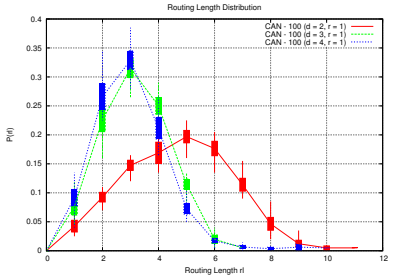
CRL_SINGLE_NAME = Characteristic Routing Length

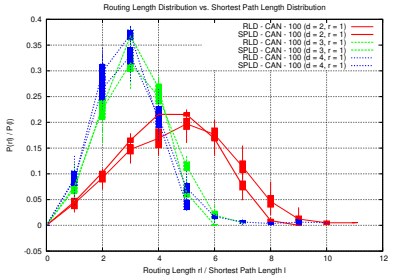
RLD_DATA_NAME = Routing Length Distribution
RLD_DATA_FILENAME = RLD

CRL_PLOT_DATA = CRL
CRL_PLOT_FILENAME = crl
CRL_PLOT_TITLE = Characteristic Routing Length
CRL_PLOT_Y = CRL

RLD_PLOT_DATA = RLD, SPLD
RLD_PLOT_FILENAME = rld-vs-spld
RLD_PLOT_TITLE = RLD vs. SPLD
RLD_PLOT_X = Routing Length rl / Shortest Path Length l
RLD_PLOT_Y = P(rl) / R(l)
```

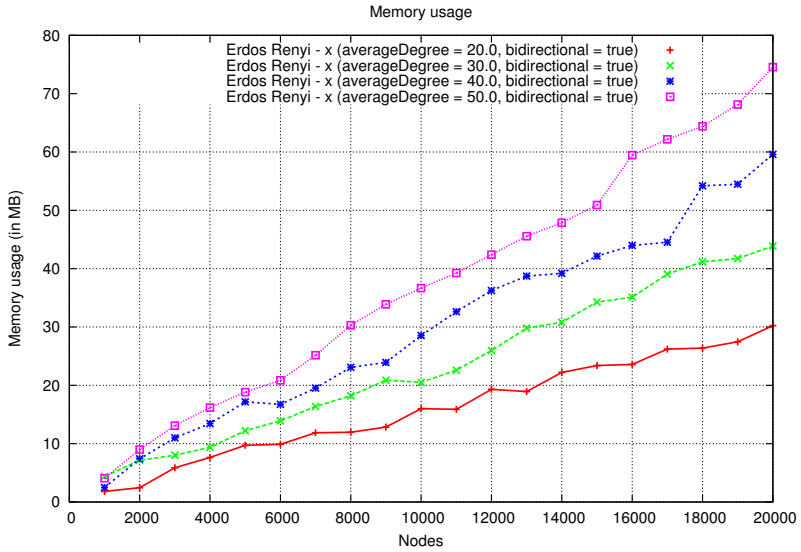


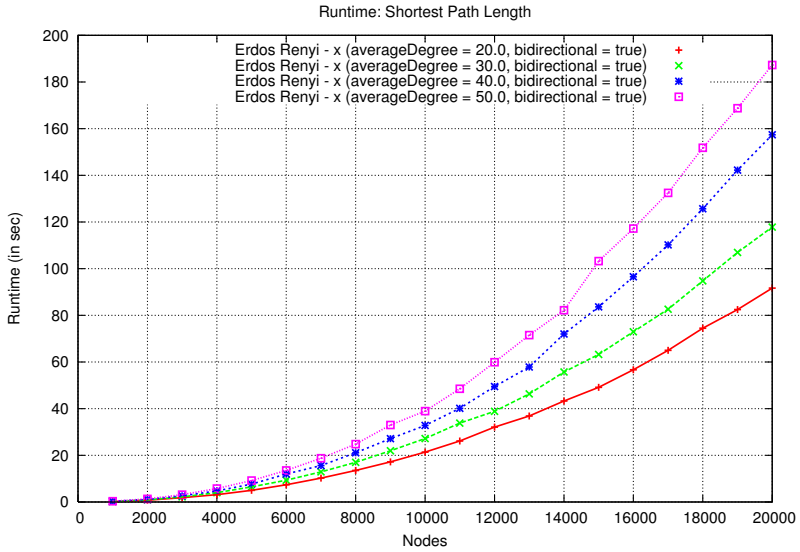




6. Evaluation

Runtime and Memory Usage Evaluation



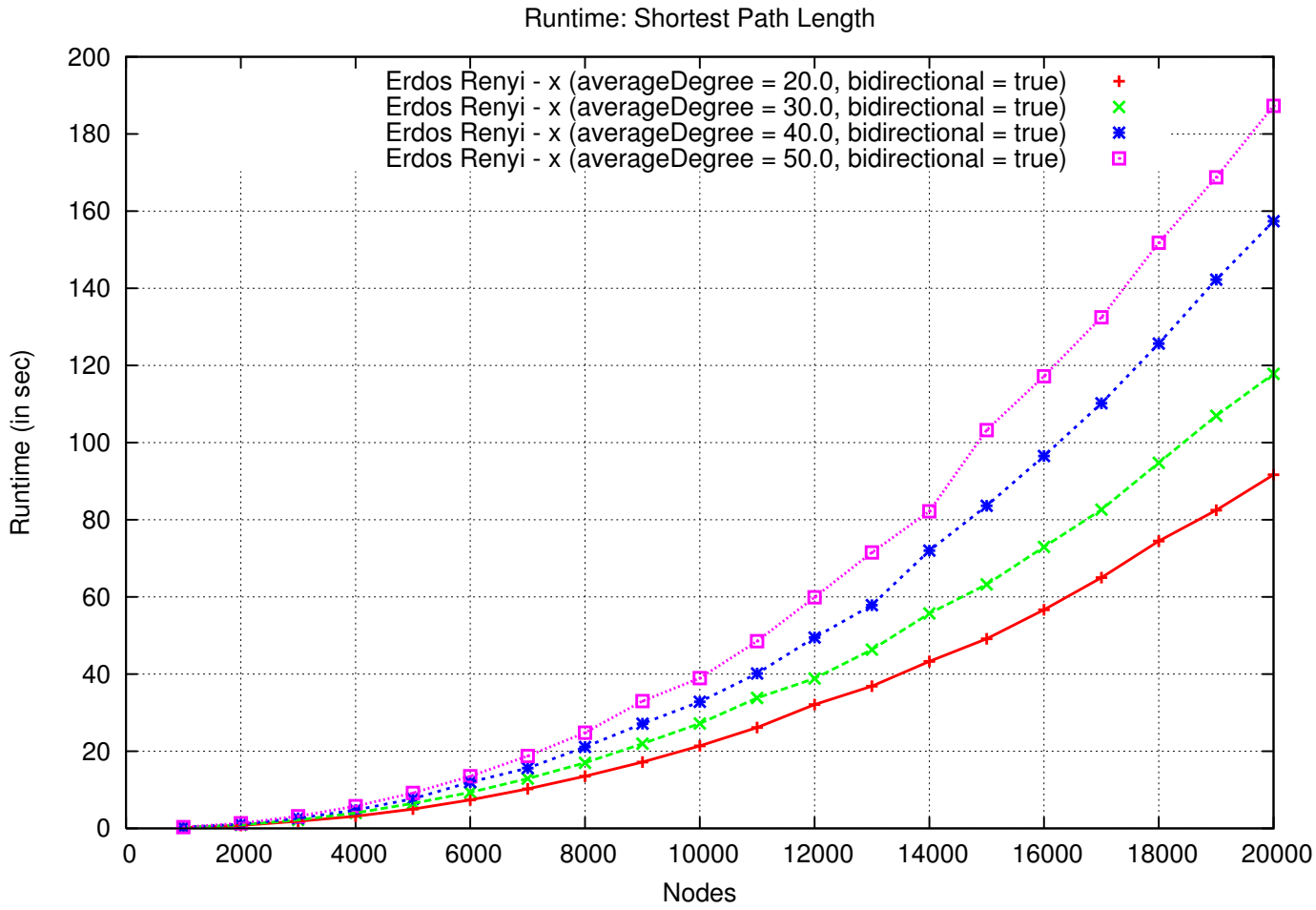


Setup

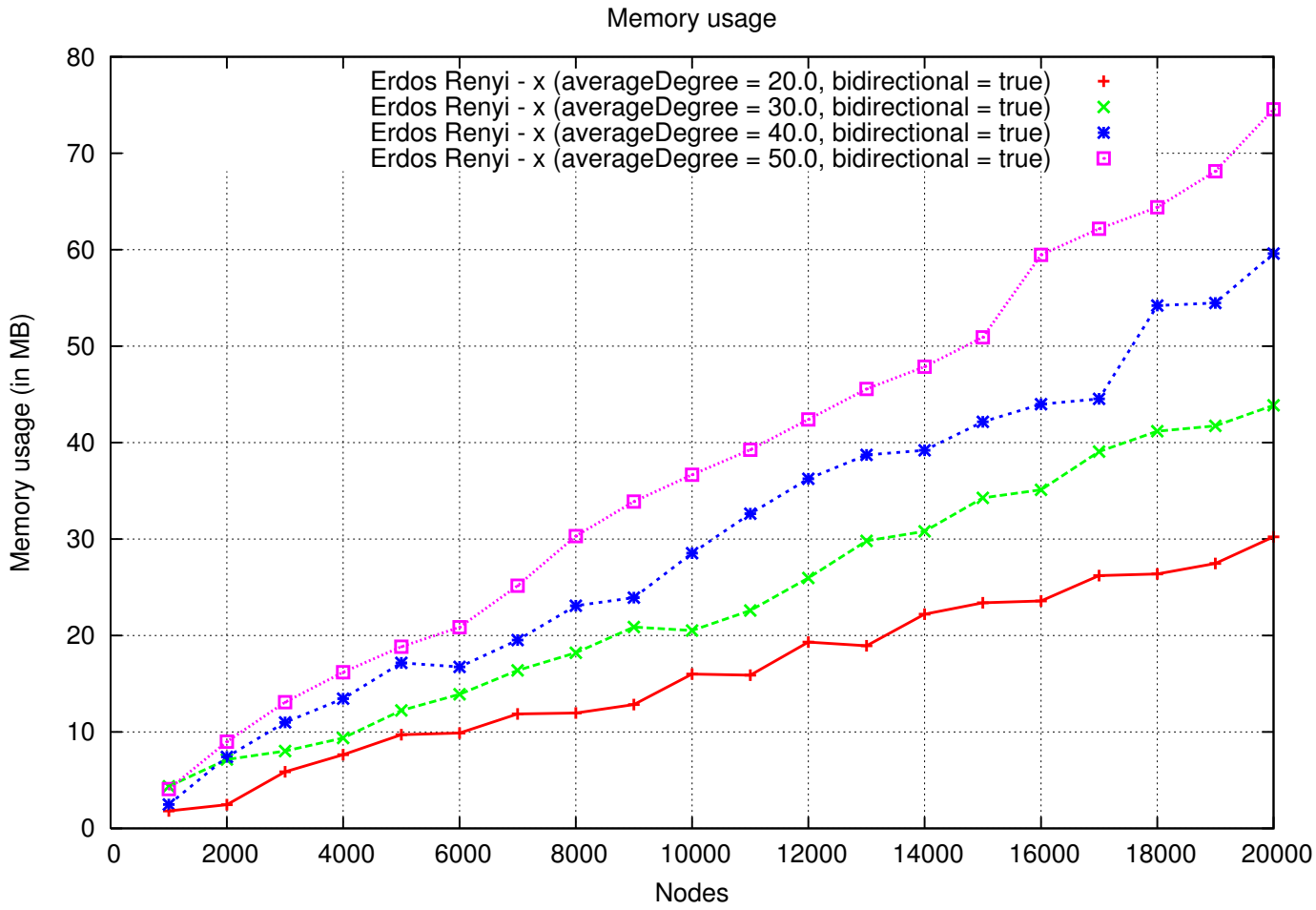
TECHNISCHE UNIVERSITÄT DARMSTADT

- Computer
  - 2.4 GHs Intel Core 2 Duo, 2 GB of Memory
  - MAC OS 10.5.8, Java version 1.5.0_22
- Networks
  - Erdös Rényi random graph
  - $d_{avg} \in \{ 20, 30, 40, 50 \}$
- Runtime: Shortest Path Length
- Memory usage: all metrics

Runtime


Runtime: Shortest Path Length
Erdos Renyi - x (averageDegree = 20.0, bidirectional = true)
Erdos Renyi - x (averageDegree = 30.0, bidirectional = true)
Erdos Renyi - x (averageDegree = 40.0, bidirectional = true)
Erdos Renyi - x (averageDegree = 50.0, bidirectional = true)
Runtime (in sec)
Nodes
0
20
40
60
80
100
120
140
160
180
200
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000

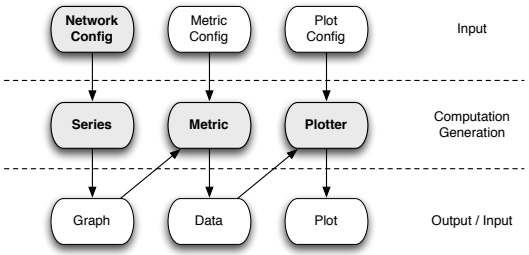
Memory Usage

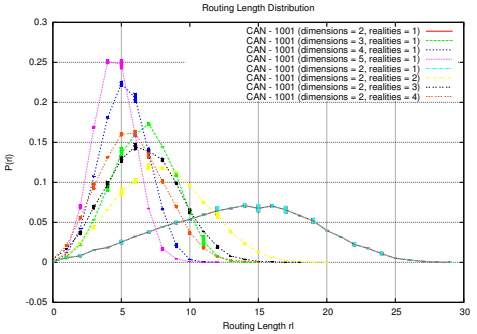


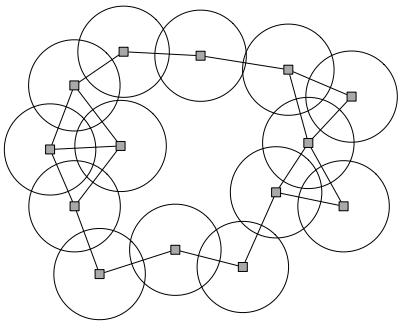
7. Conclusion and Outlook

Planned Extensions to GTNA

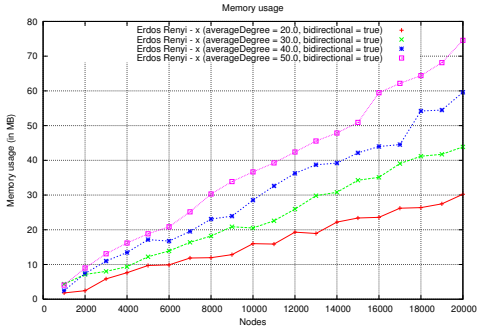
GTNA
Graph-Theoretic Network Analyzer







```
public class MyNetwork extends NetworkImpl implements Network {
     private boolean p1;
     public MyNetwork(int nodes, boolean p1) {
          super("MY_NETWORK", nodes, new String[]{"P1"}, new String[]{"" + p1});
          this.p1 = p1;
     }
     public Graph generate(){
          Timer timer = new Timer();
          Node[] nodes = Node.init(this.nodes());
          Edges edges = new Edges(nodes, 100);
          for(int i=1; i<nodes.length; i++){
               edges.add(nodes[0], nodes[i]);
               if(this.p1)
                    edges.add(nodes[i], nodes[0]);
          }
          edges.fill();
          return new Graph(this.description(), nodes, timer);
     }
}
```



Conclusion

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- Graph-theoretic analysis helps understand complex networks
- Often difficult task
  - adapting specific algorithms to special network formats
- GTNA - Graph-Theoretic Network Analyzer
  - Java-based framework
  - Easily extendable
  - Many network generators and metric implementations exist

Outlook

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- Implementing additional metrics
- Providing Internet topology g
- Add dynamics to snapshot creation
- Graphical user interface

Motifs
Role-to-role connectivity profiles

PFP - Positive-Feedback Preference model
PARG - Parallel Addition and Reqiring Growth model

Different procedures for topology generation (join, crash, leave)

Configuration
Plot-Organization

GTNA

A Framework for the Graph-Theoretic Network Analysis

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GTNA

Graph-Theoretic Network Analyzer

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