CS 5229: Advanced Compute Networks

Modeling and Generating Internet Topology

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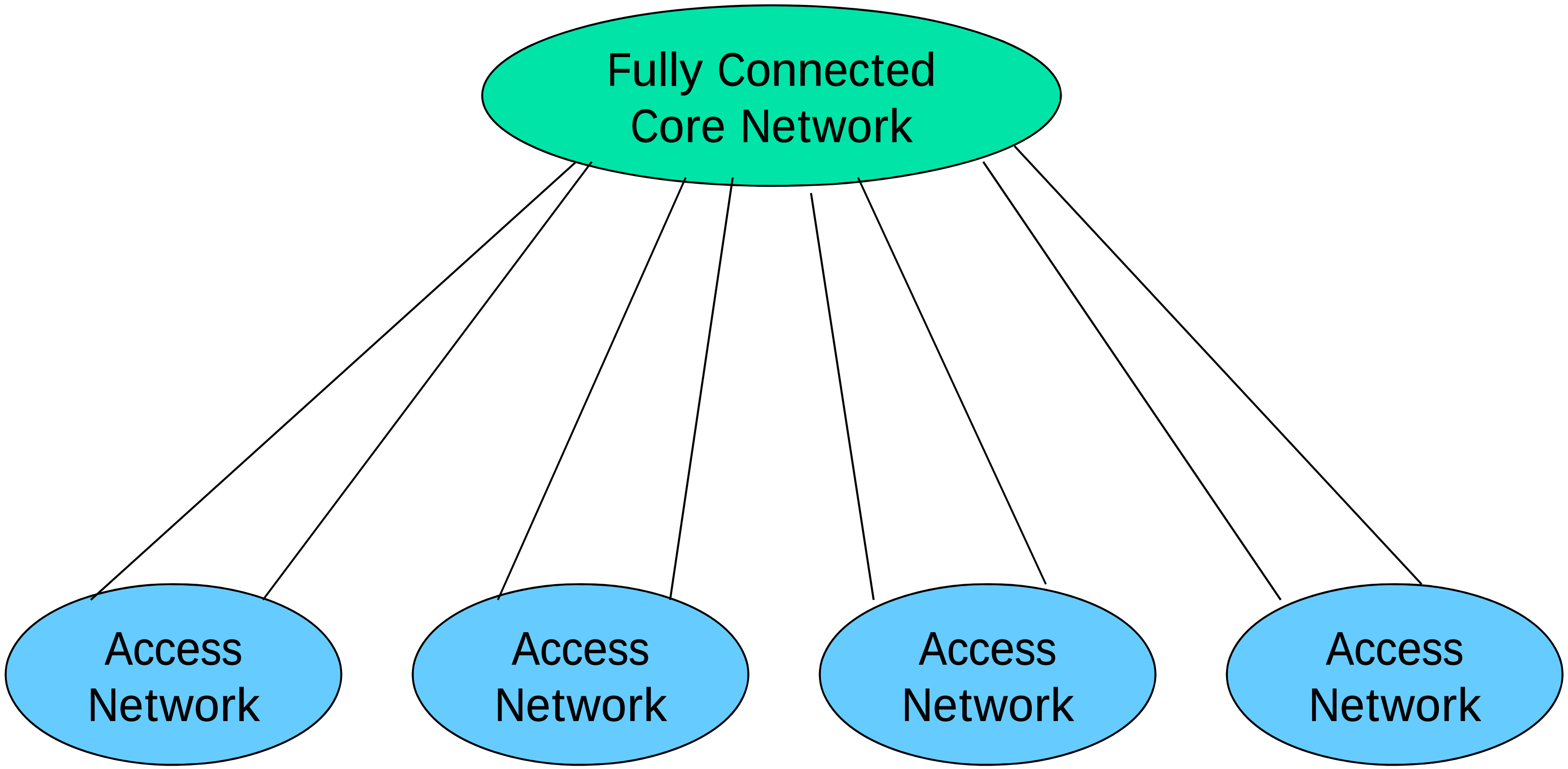
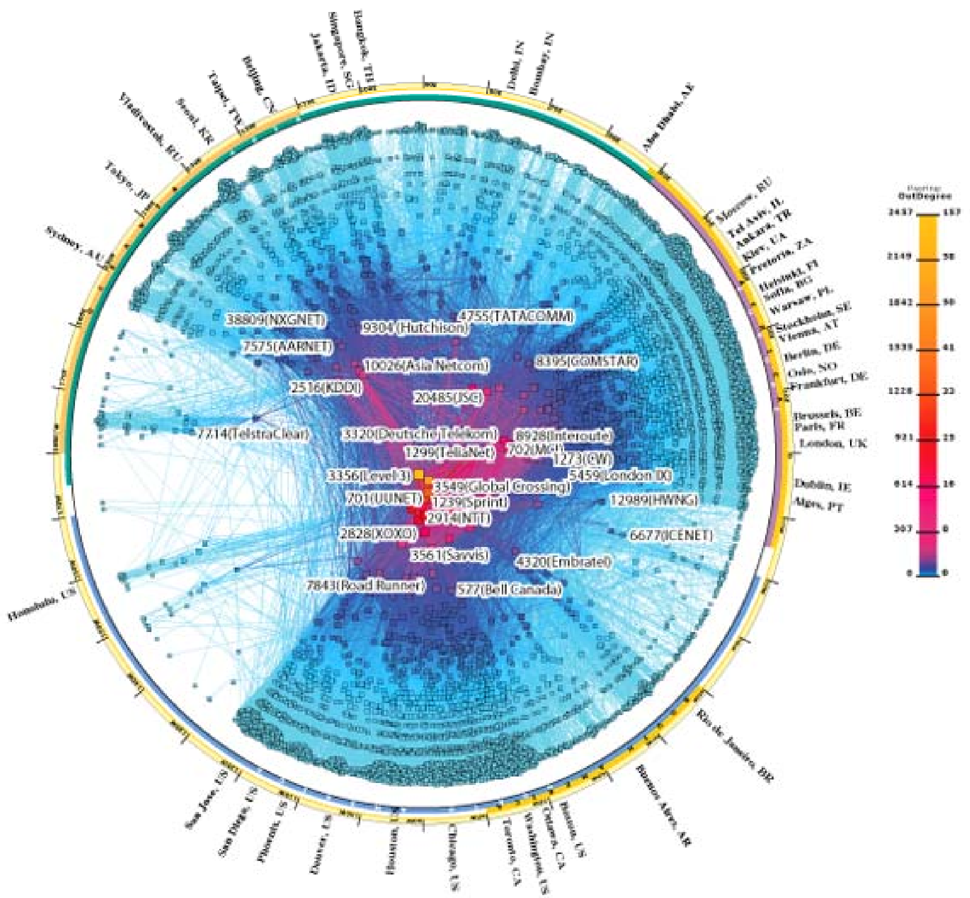
Telephone Networks



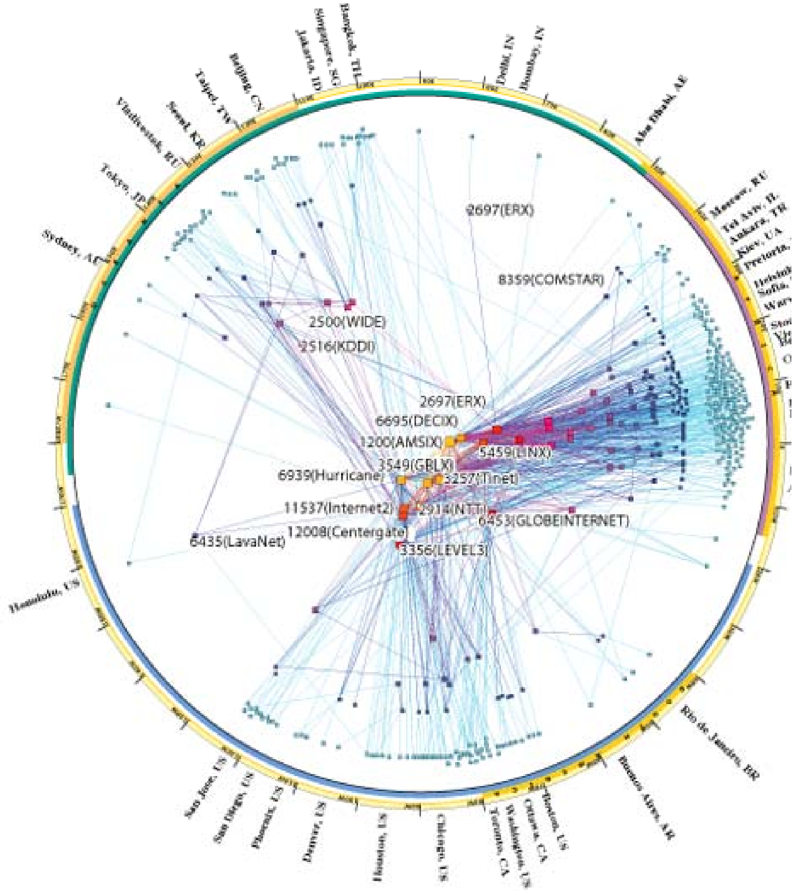
IPv4 & IPv6
INTERNET TOPOLOGY MAP
JANUARY 2009

AS-level INTERNET GRAPH

IPv4



IPv6



Question

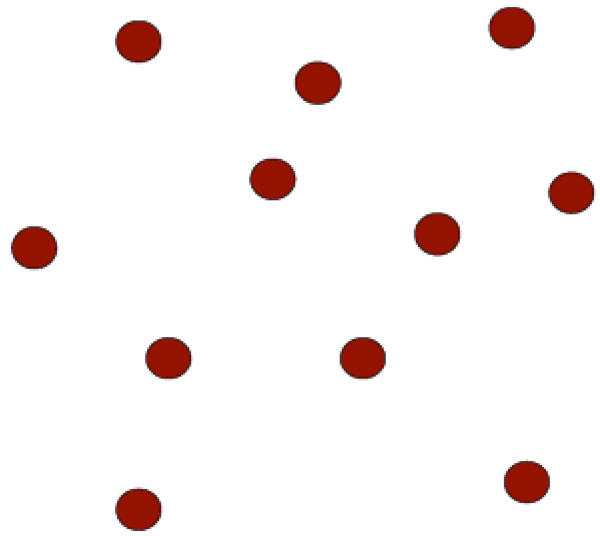
- How to generate realistic Internet topology for simulations?

Approach

- Model Internet as a Graph
- Router-Level:
  - node = router
  - edge = 1-hop link
- AS-Level:
  - node = AS domain
  - edge = Peering

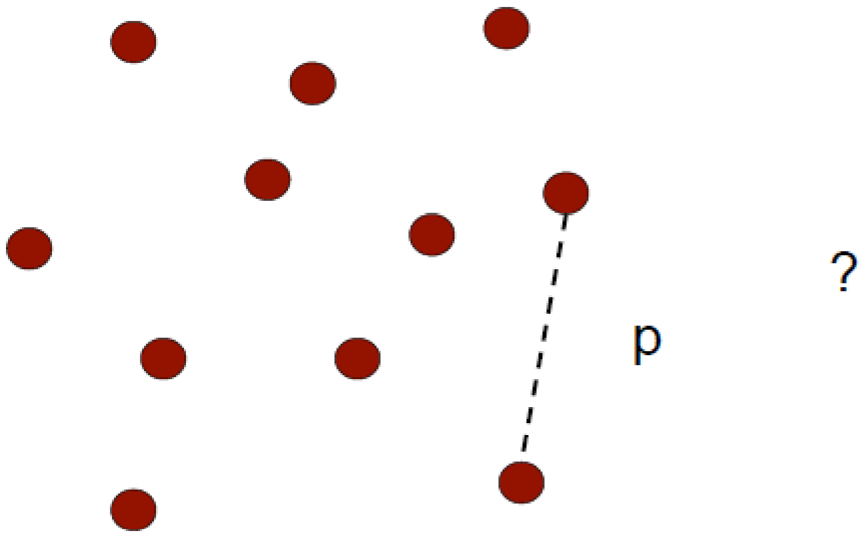
Random Graph

Randomly generate points on a plane



Random Graph (cont'd)

Connects two nodes with fixed probability p



Topology Model

- Waxman Model
  - Commonly used
  - Random placement
  - A link is probabilistically placed between any two nodes

Drawbacks

- Shortcomings
  - No sense of backbone or hierarchy
  - Does not guarantee a connected network
  - Number of links grow linearly with number of nodes
- Does not “look like” a “real” network
  - What is missing?

Internet Topology Model

- Unlike the phone network, Internet growth is decentralized and there is no central coordination.
- How does the Internet looks like?
- How should an Internet-like topology be described?
- Are there any topological properties that remain the same even as the Internet continues to grow?

Internet Topology Model (94-97)

- Exhibits hierarchy and locality
- Model the Internet as a collection of interconnected routing domains
  - Each routing domain is a group of nodes (routes, switches and hosts) under a single administration
- Two kinds of routing domain
  - stub – carries only traffic that originates or terminates in the domain
  - transit – no restriction on traffic, interconnects stub domains

Node Parameters

- Total number of transit domains
  - Average number of nodes per transit domain
- Average number of stub domains per transit domain
  - Average number of nodes per stub domain
- Average number of LANs per stub domain and hosts per LAN

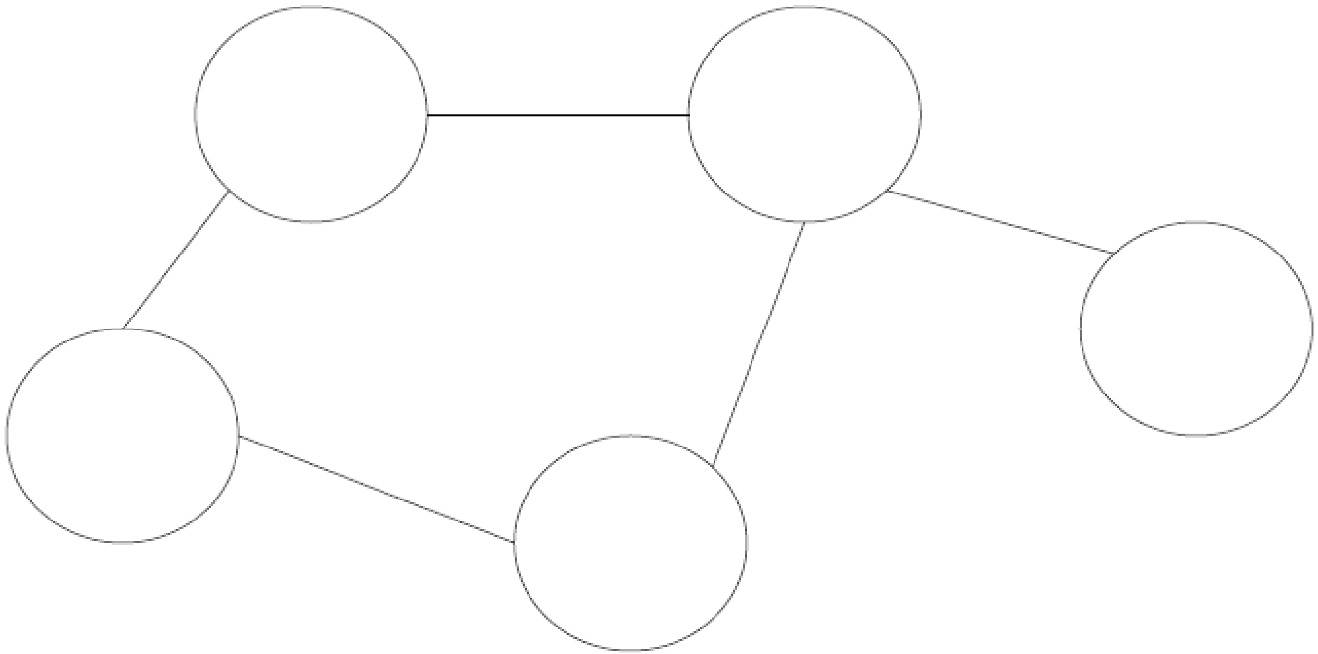
Link Parameters

- Edge degree among transit nodes in different domains
- Edge degree among transit nodes in the same domain
- Edge degree among stub nodes

- Edge degree between stub and transit nodes
- Edge degree between stub node and LAN

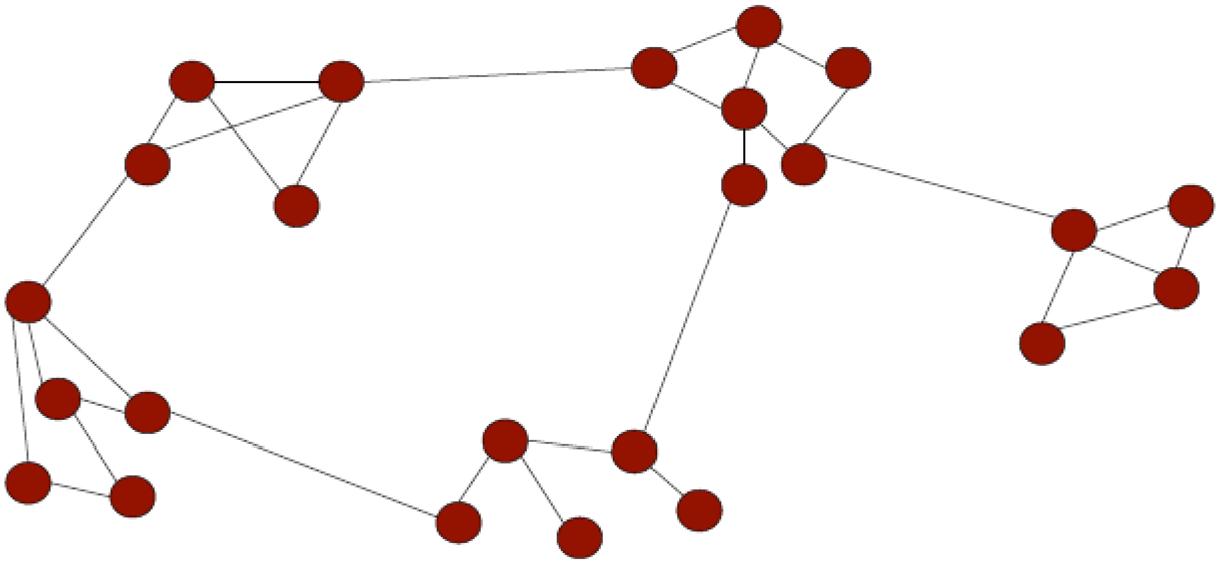
Example

Randomly generate a graph using Waxman's method



Example

Each node is expanded to form a random graph (transit domain)



Example

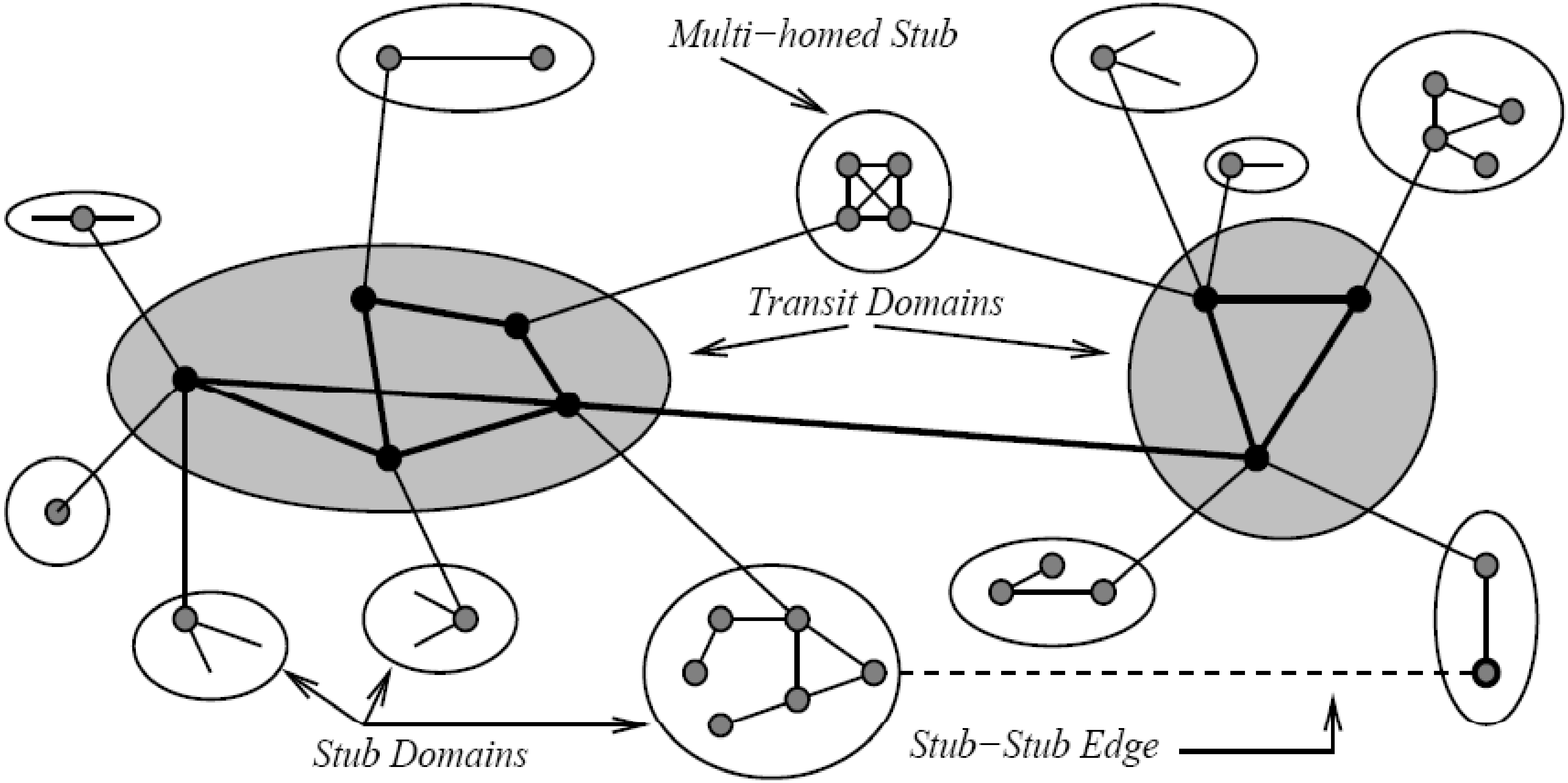
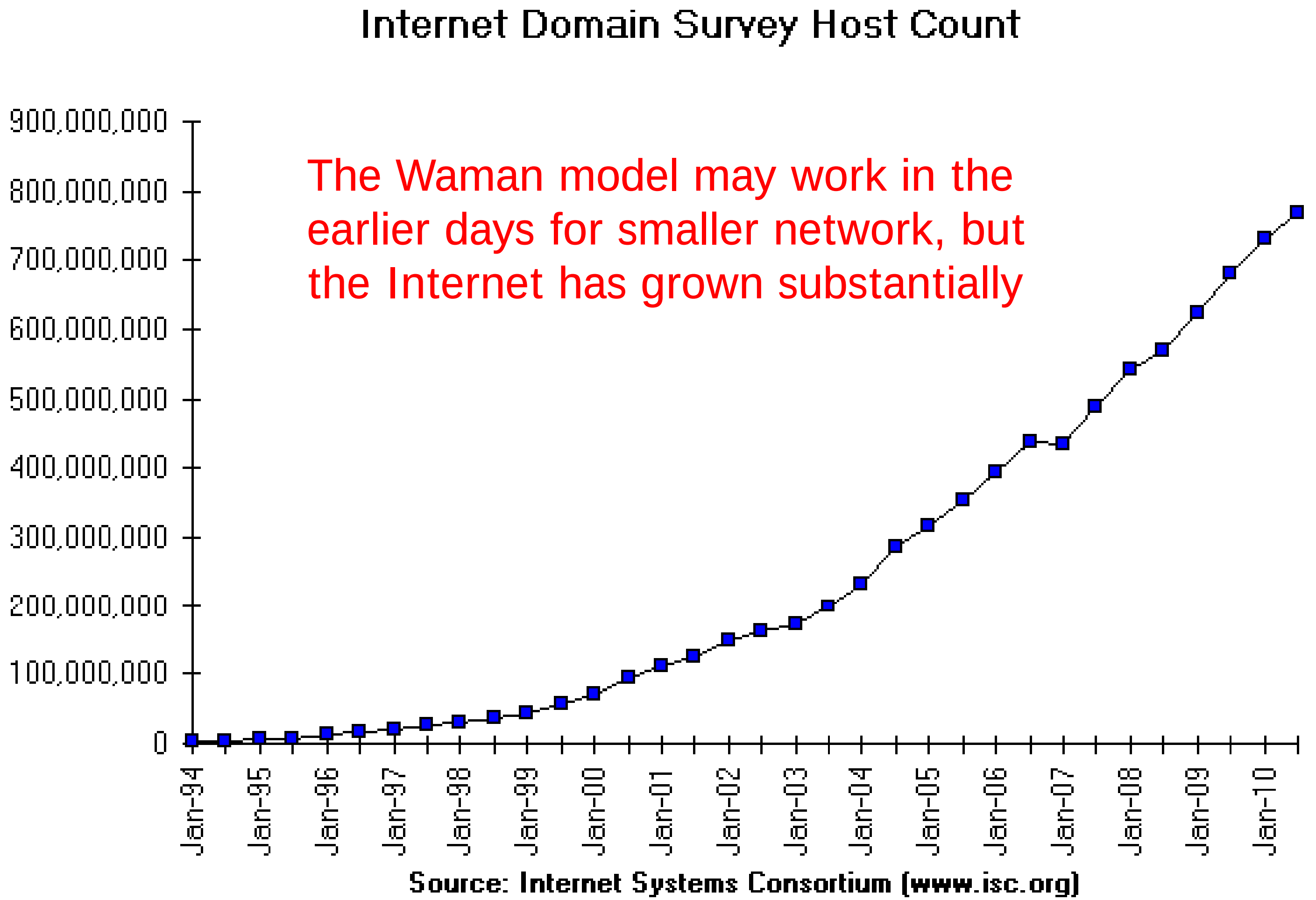


Figure 1: Example of Internet domain structure

How Large is the Internet?



Characterizing the Growing Internet

- Focus on Autonomous System (AS) level
- Two key features: power law and small world
- Power Law: intuitively, a small number of nodes have very high connectivity while the majority of the nodes have much lower connectivity.
- Small World: intuitively, the neighbors of any nodes in the graph are more likely to be connected than a randomly generated graph

“On Power-Law Relationships of the Internet Topology”

The Faloutsos brothers, SIGCOMM ‘99

Questions

- What does the Internet looks like?
- Are there topological properties that don’t change in time?
- How will it look like a year from now?
- How can I generate Internet-like graphs for simulation?

Motivations

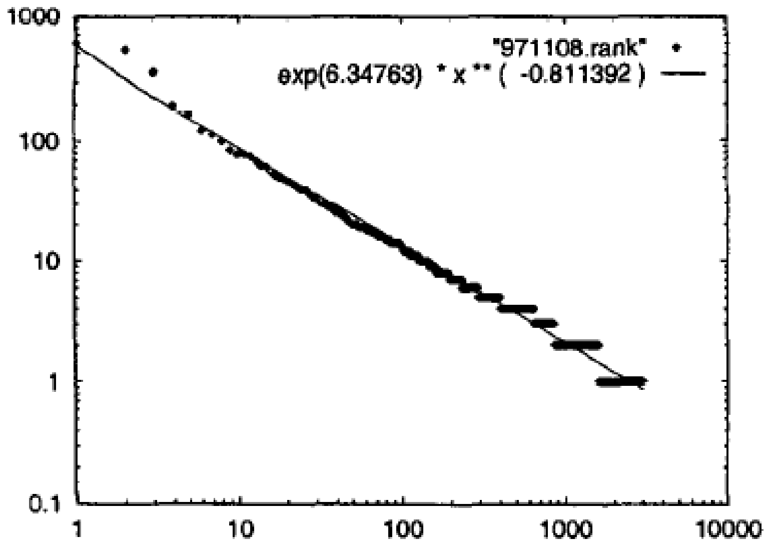
- Design protocols that can take advantage of topological properties
- Create more accurate graphs for simulation
- Estimate useful parameters (e.g. average number of neighbors within h hops)

Three traces

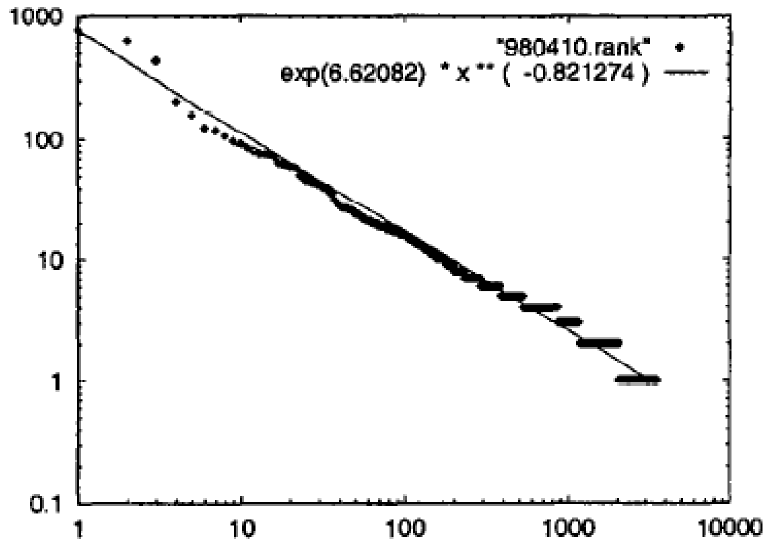
- Nov 1997, 3015 nodes, 5156 edges, average out degree 3.42
- April 1998, 3530 nodes, 6432 edges, average out degree 3.65
- December 1998, 4389 nodes, 6432 edges, average degree 3.76

Lemma 1 *The outdegree, d_v, of a node v, is a function of the rank of the node, r_v and the rank exponent, $\mathcal{R}$, as follows*

$$d_v = \frac{1}{N^{\mathcal{R}}} \; r_v^{\mathcal{R}}$$



(a) Int-11-97

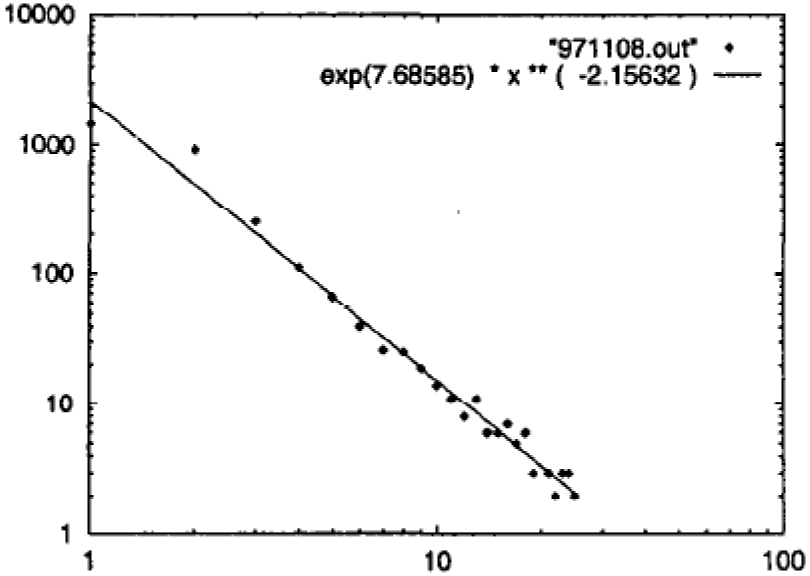


(b) Int-04-98

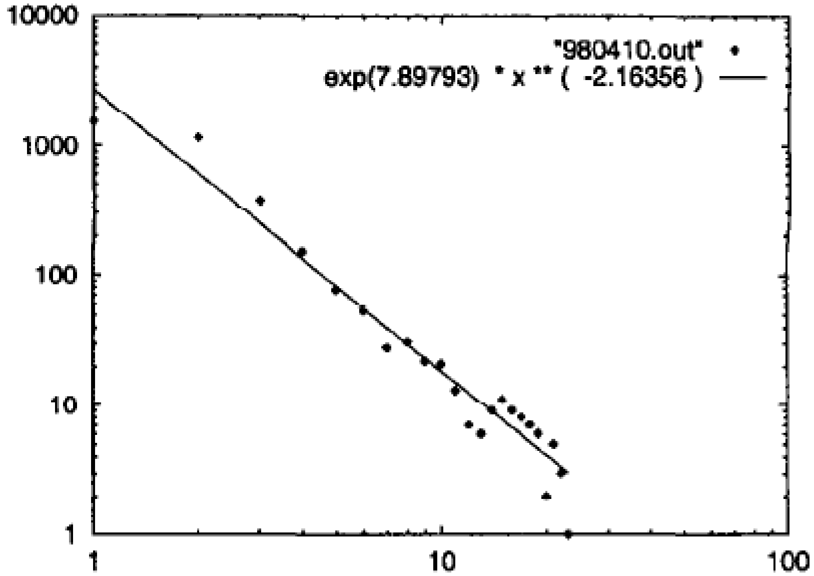
Figure 3: The rank plots. Log-log plot of the outdegree d_v versus the rank r_v in the sequence of decreasing outdegree.

Power-Law 2 (outdegree exponent)
The frequency, f_d, of an outdegree, d, is proportional to the outdegree to the power of a constant, $\mathcal{O}$:

$$f_d \propto d^{\mathcal{O}}$$



(a) Int-11-97

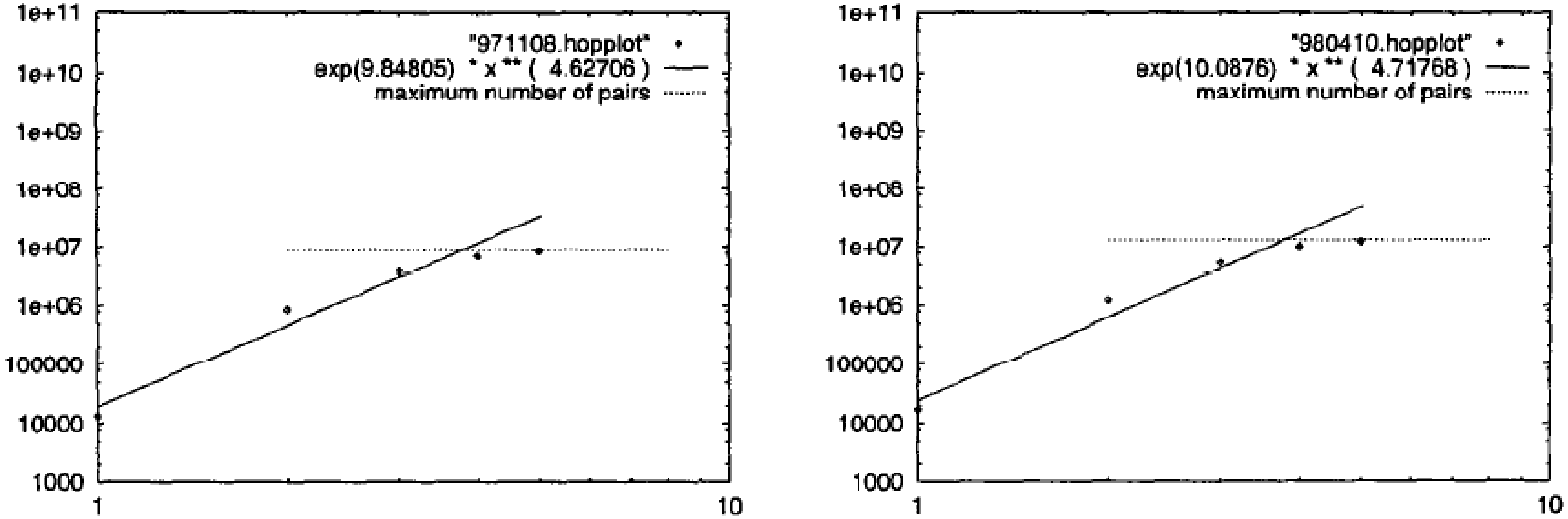


(b) Int-04-98

Figure 5: The outdegree plots: Log-log plot of frequency f_d versus the outdegree d.

Approximation 1 (hop-plot exponent) *The total number of pairs of nodes, $P(h)$, within h hops, is proportional to the number of hops to the power of a constant, $\mathcal{H}$:*

$$P(h) \propto h^{\mathcal{H}}, \qquad h \ll \delta$$



(a) Int-11-97 (b) Int-04-98

Figure 7: The hop-plots: Log-log plots of the number of pairs of nodes $P(h)$ within h hops versus the number of hops h.

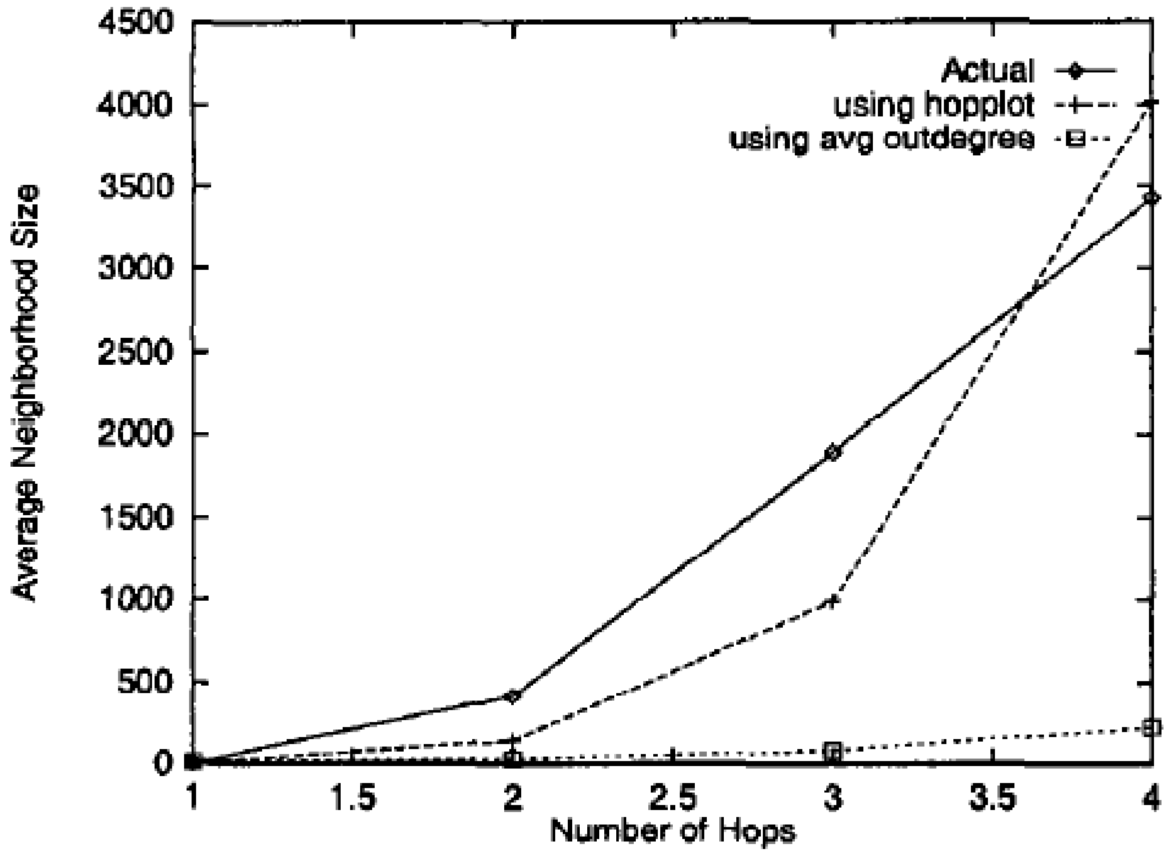


Figure 9: Average neighborhood size versus number of hops the actual, and estimated size a) using hop-plot exponent, b) using the average outdegree for Int-12-98.

Practical Use

- A way to describe graph using exponentials instead of averages
- Analysis of protocol performance
  - Example: would distributed search works better for power-law graph?
- Use to generate and “test” if graph is suitable as a model of the Internet

Q Chen, H Chang, R Govindan, S Jamin, SJ Shenker, "The Origin of Power Laws in Internet Topologies Revisited," INFOCOM 2002.

Questions

- Is strict power law relationship a good model for AS vertex degree distribution?
- Why should power law be a good model?