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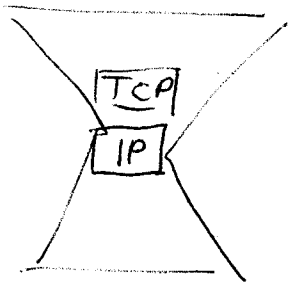
The many facets of internet topology.

Area of confusion, because: • illusion of simple, robust resource.
• increasing complexity ~ biology.

the internet hourglass:



Applications

Transport protocols

Link technologies

• Consider a layer

⇒ different topologies depending on layer of hourglass.

bottom ↓ top
- Router level (physical)
- IP-level (traceroute-based data)
- Autonomous System graph
- Web - email - peer to peer graph.

So: 'topology' depends on level

⇒ source of confusion.

- As - topology obscures physical topology.
  - bottom: physical
  - top: virtual
- ~~Dynamics:~~ ~~bottom: dyn~~
  - top: dynamic
  - bottom: static

So:
- Know your measurements
- Modeling: Designed or random?
- Insight into "robust, yet fragile" nature.
- Power laws: "Full of sound & fury, signifying nothing?" (Strogatz).

Focus of this talk: router-level topology (physical)
- nodes are machines
- measurements based on traceroute-experiments.

Power laws and Internet topology:
- Few nodes have many connections
- Most " " few "

=> Traditional approach: - Focus on power law
- Develop graph models that reproduce the powe laws.

" Degree-based models.
preferential attachment.
powe-law graphs

Features: "scale-free"
existence of hubs:
"Achilles-heel" of networks.

Main Message (of talk)

| Internet is exactly opposite of what scale-free claims.

Our approach: Focus on high variability
- Develop graph models with high var.
- Look at real networks to explain high variability.

Example: Abilene Backbone, physical connectivity.

No high connectivity in backbone!!

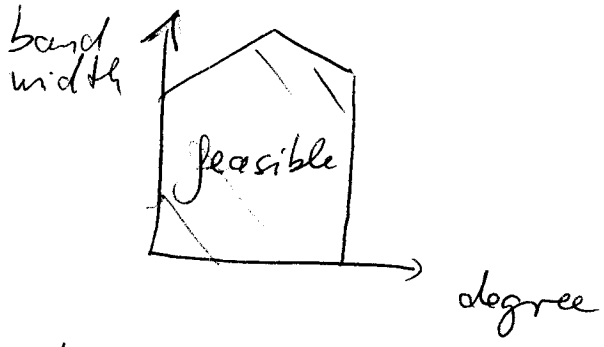
Also in CENIC network.

Question: Why? What is a router? router capacity is limited!

E.g. Cisco ~~1600~~ router: 15 slots.

Price for more connection: less bandwidth.

1st Key factor → Technology constraints.
Scale-free networks ignore this.



2nd Key factor: Economic constraints.
Network operators have limited budget.

Yields: Heuristically Optimal Topology.

Two perspectives:

Random graph

First principle networks.

3rd factor: performance

Internet-Relevant Performance metric:

Step 1: Constrain to be feasible

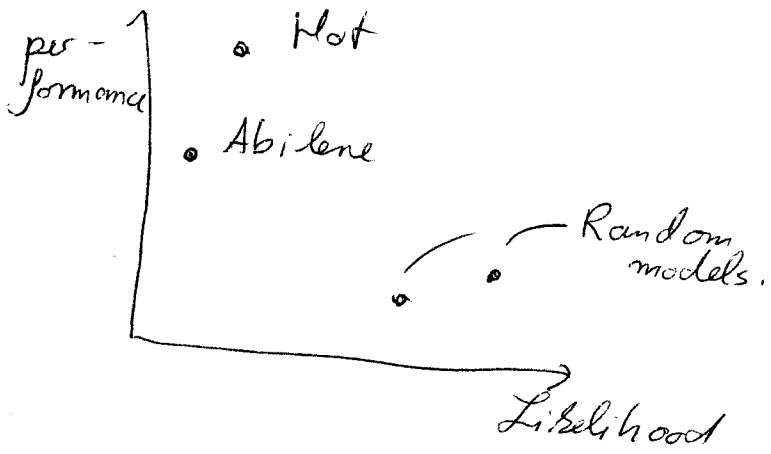
Step 2: Compute traffic demand

Step 3: Compute max. flow.

HOT model has best performance.

Compare designed / random using a Graph-theoretic metric.

So in fact:



High variability of node degrees

End-user bandwith demand yields different distributions.