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School and Workshop on
Structure and Function of Complex Networks

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On the Lack of Typical Behavior in the Global Web Traffic Network

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On the lack of typical behavior in the global Web traffic network

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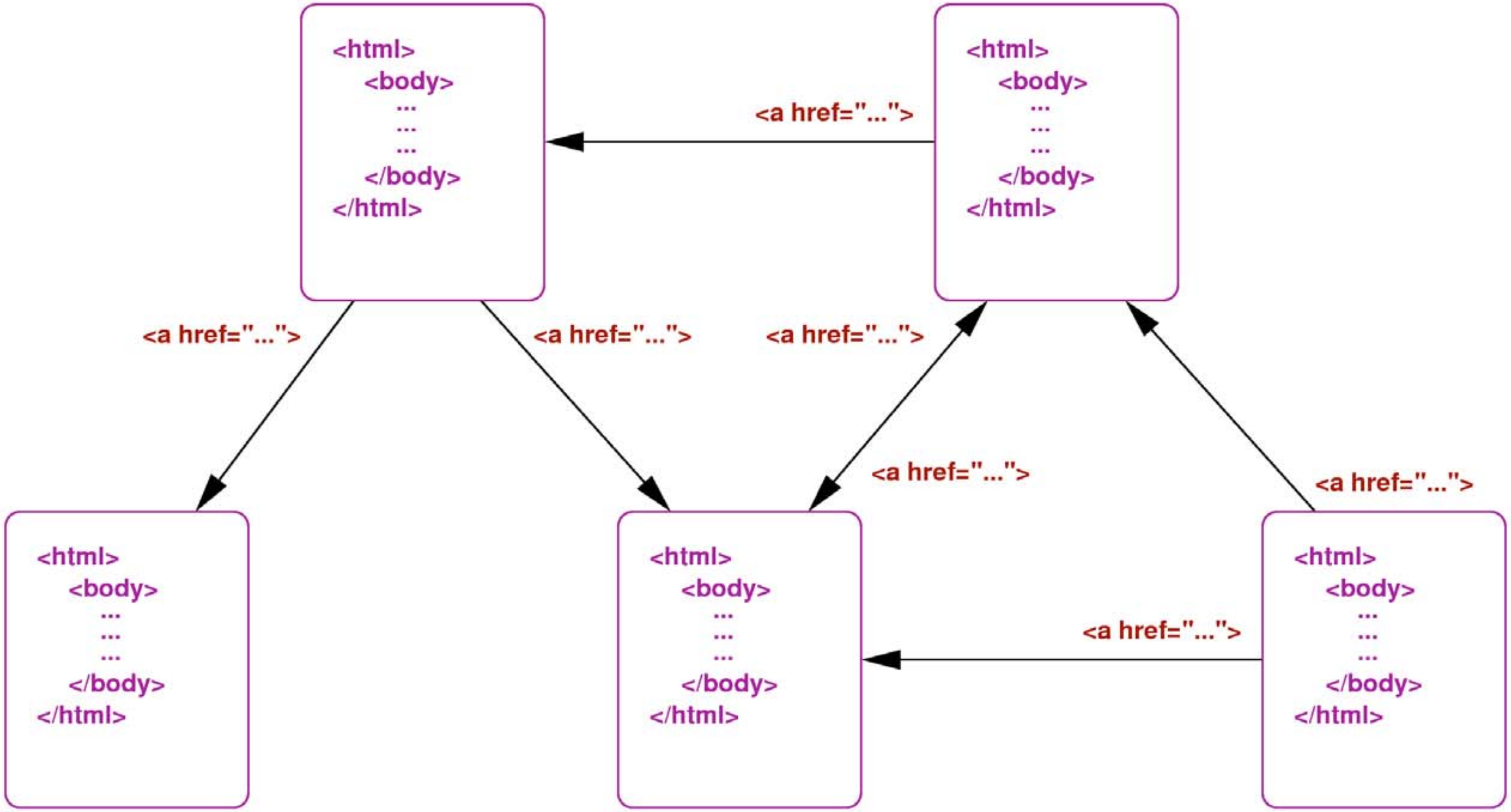
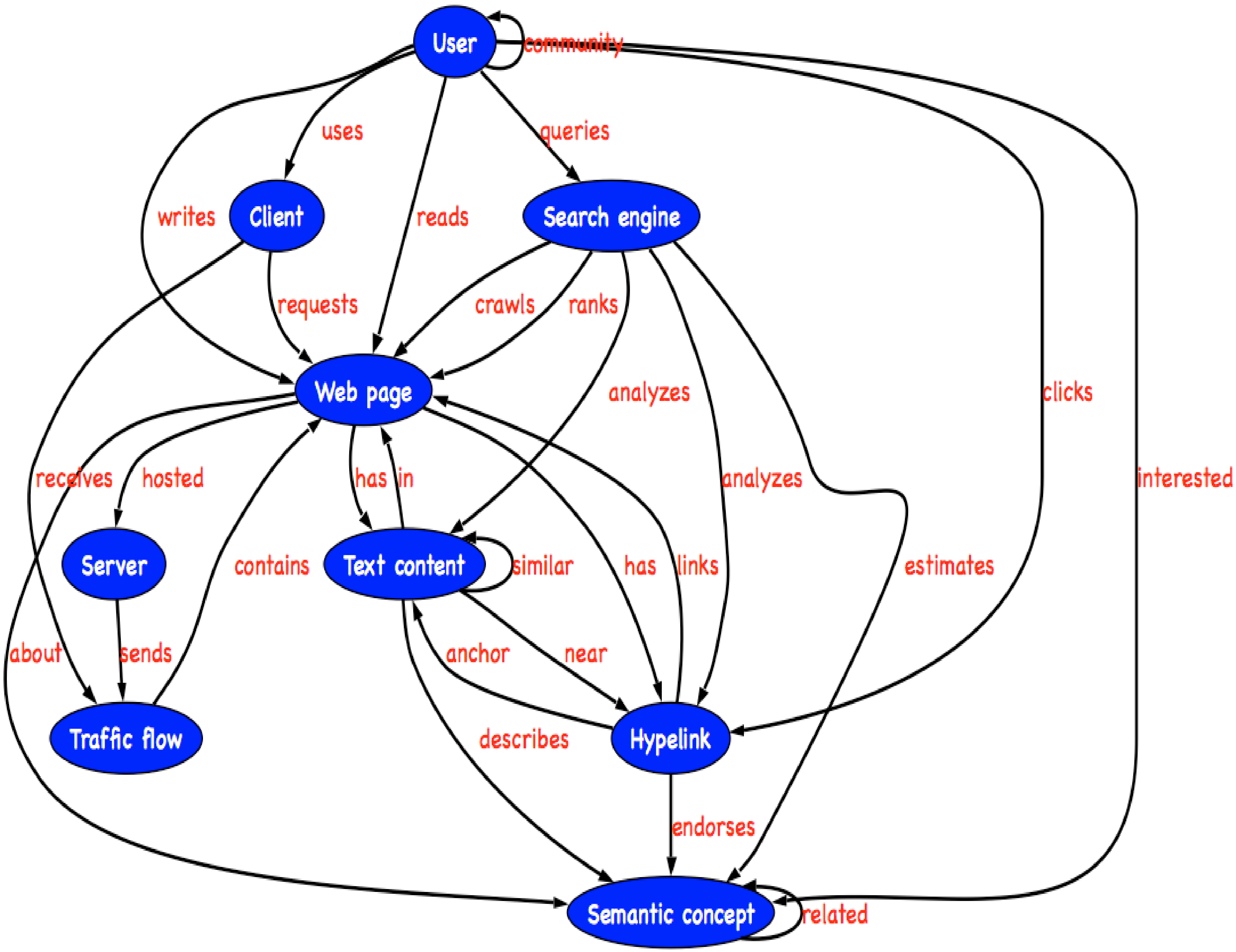
Various complex networks coevolve in the Web

- The *Link Graph*

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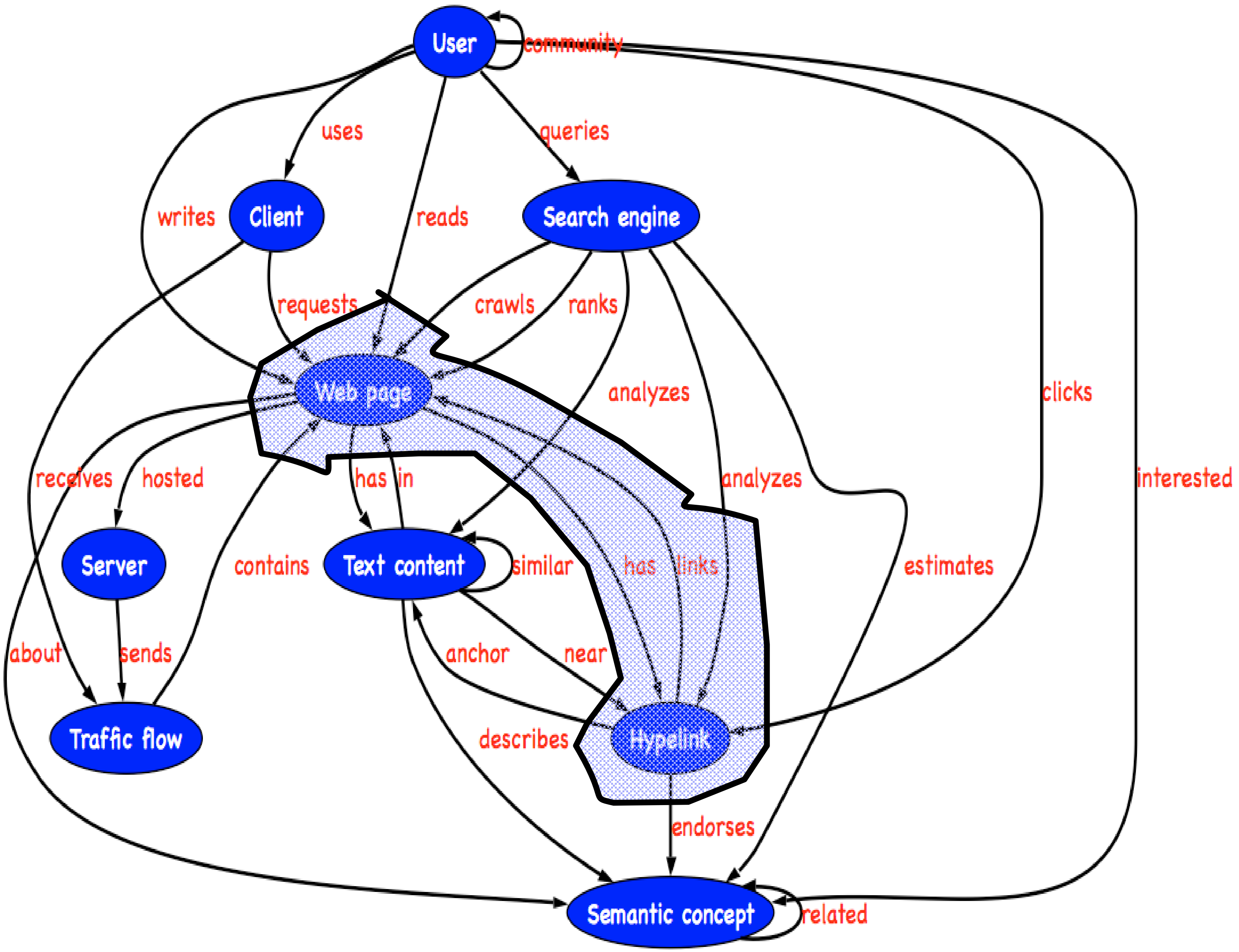
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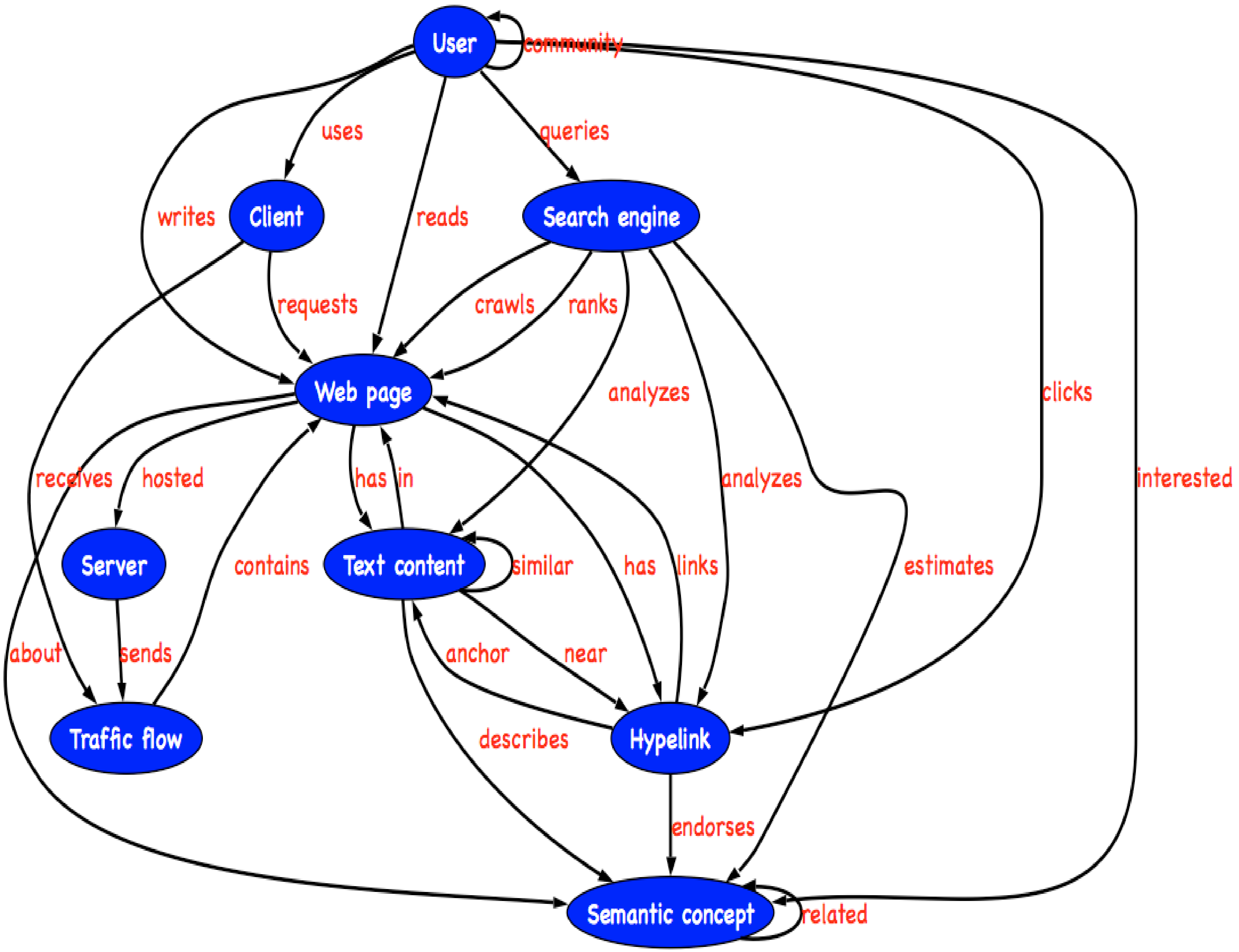
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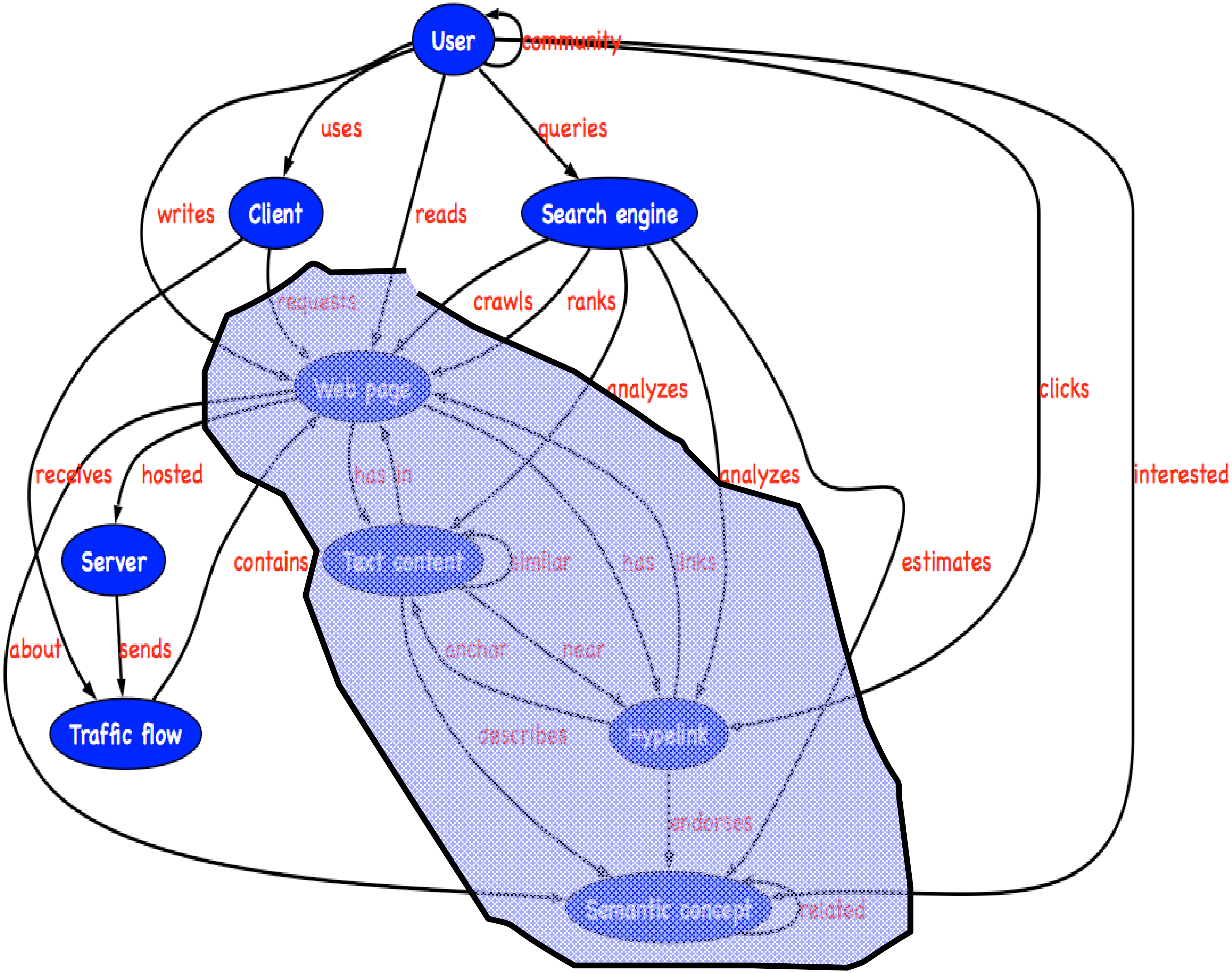
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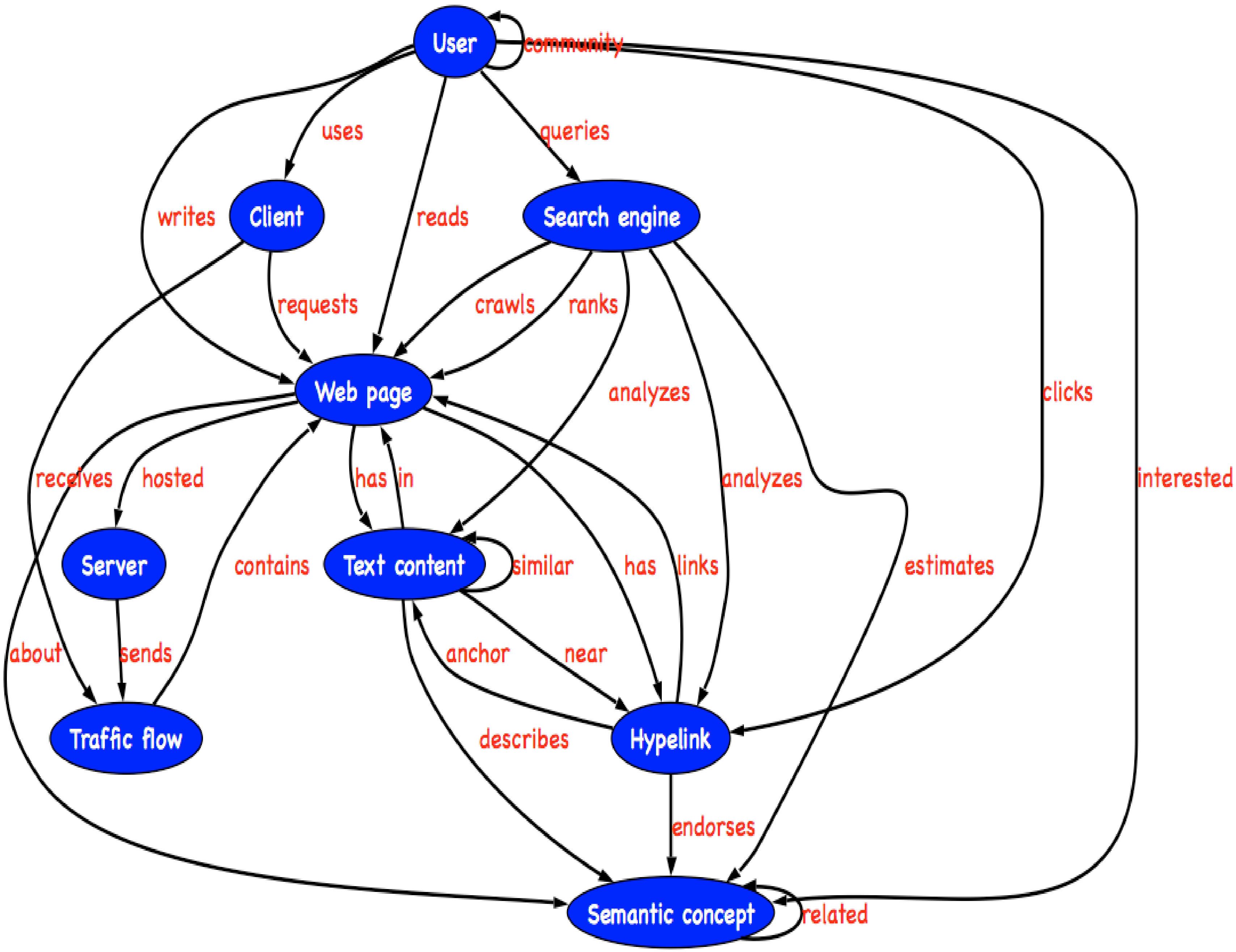
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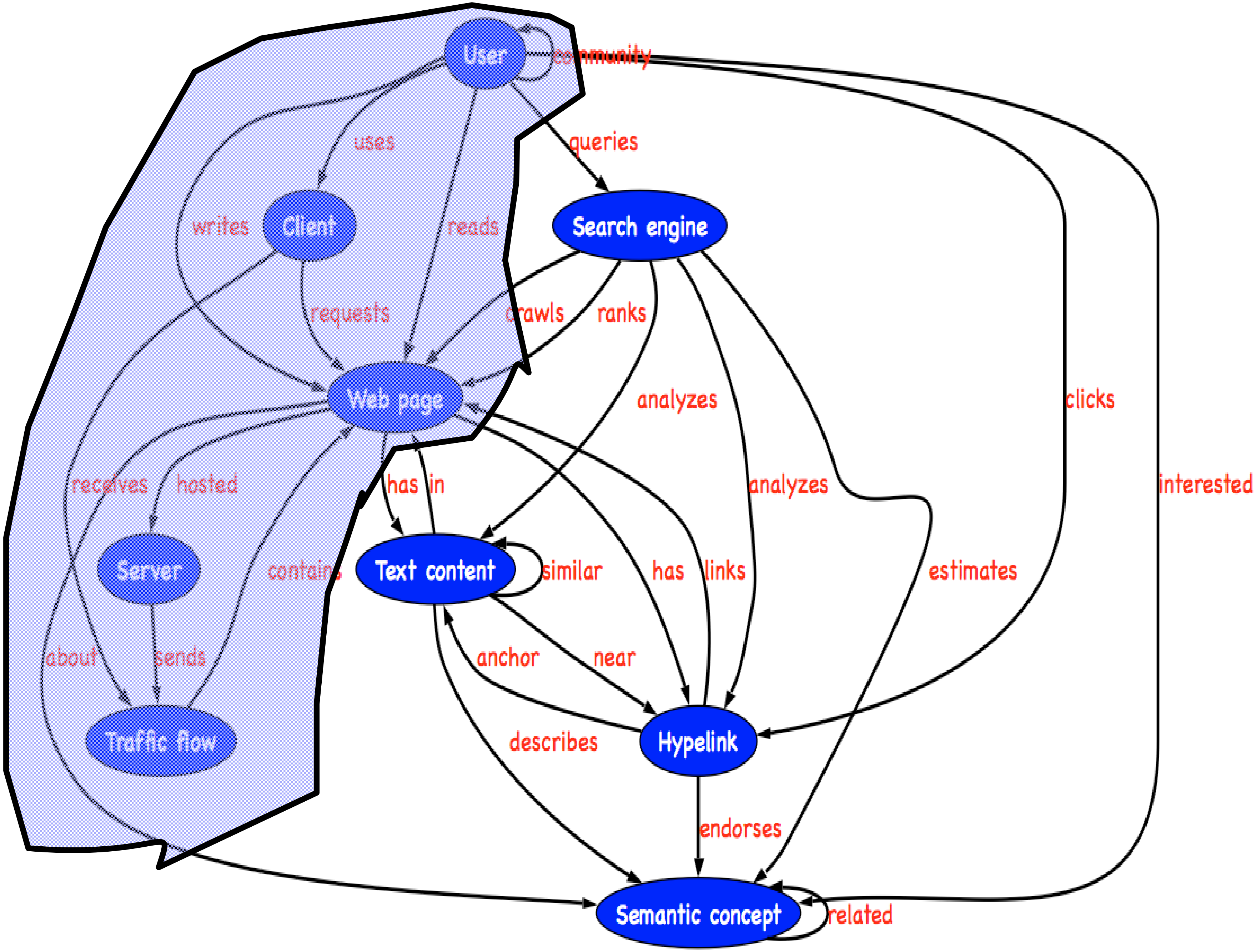
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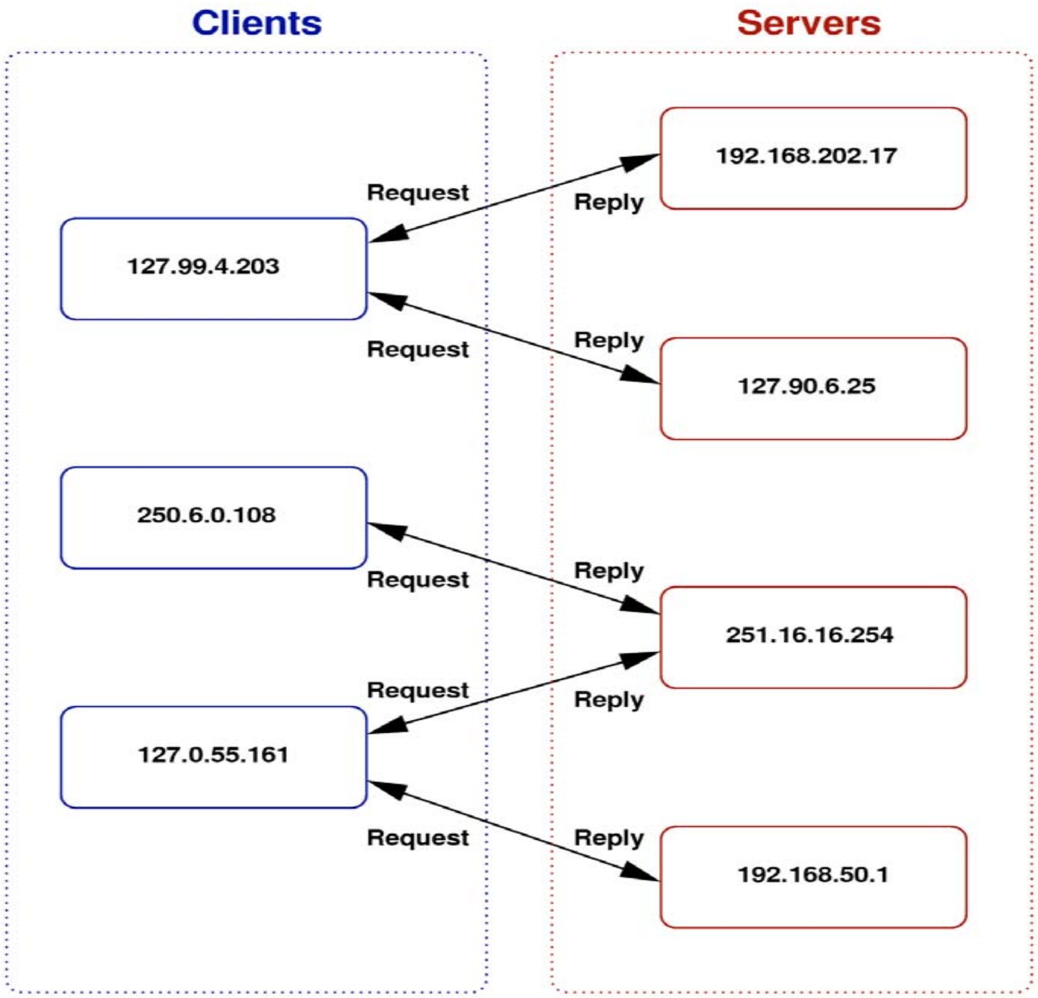
Another way of studying the Web

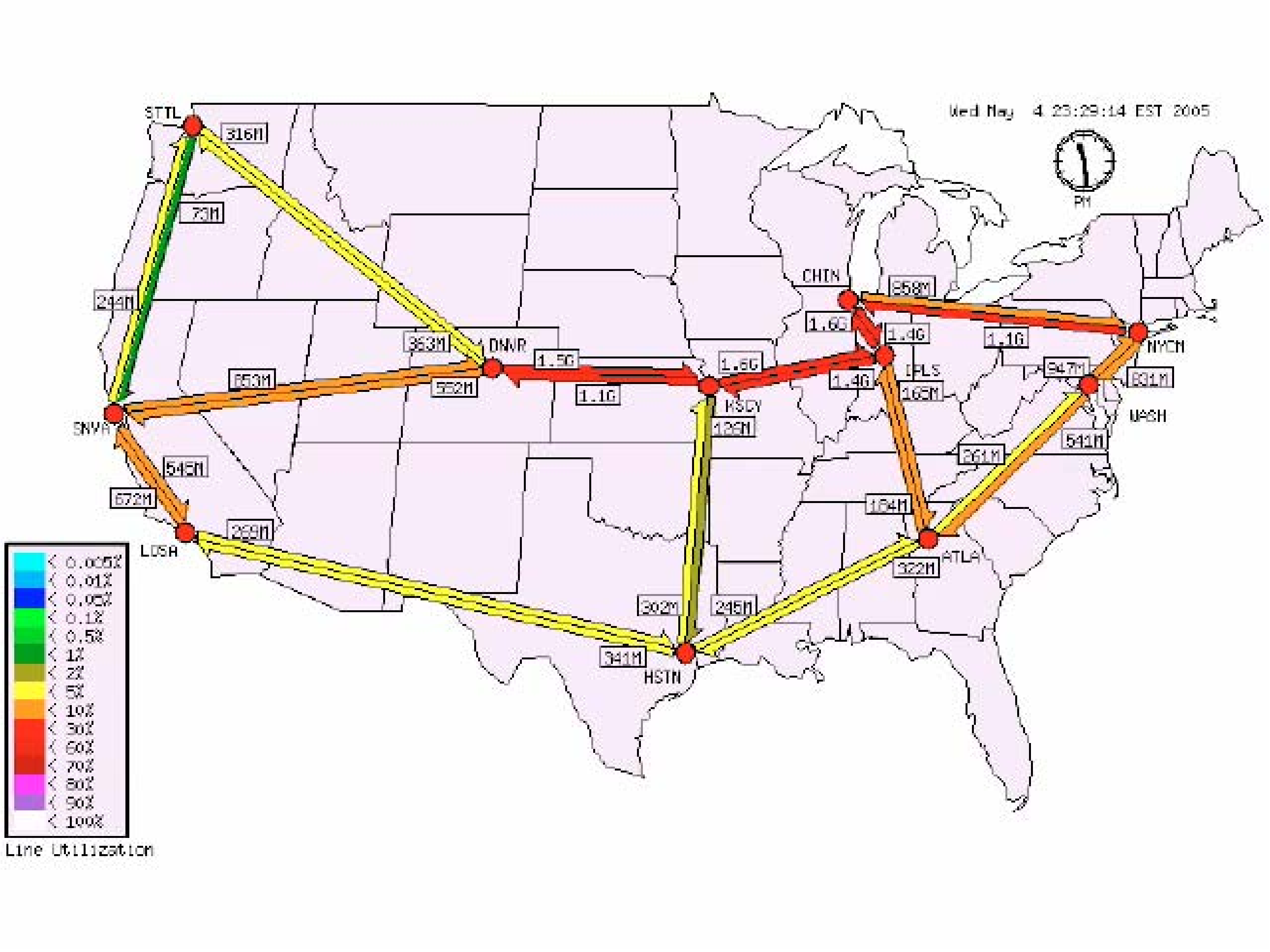
- The *Behavioral Network(s)*



Overview

1. Collection of ***network flow data*** from Internet2 core routers
2. ***Weighted bipartite digraph*** representation of Web traffic
3. Analysis of ***Web client*** behavior
4. Analysis of ***Web server*** behavior
5. ***Summary*** and future work

The Internet2/Abilene network

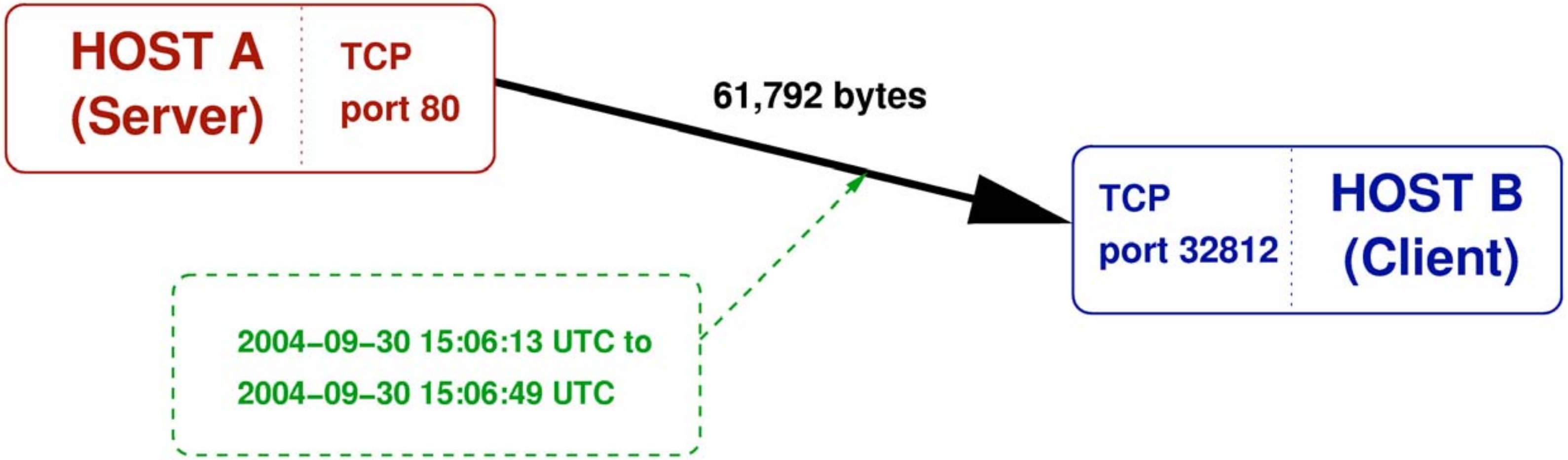


- TCP/IP network connecting ***research and educational*** institutions in the U.S.
  - Over 200 universities and corporate research labs
- Also provides ***transit service*** between Pacific Rim and European networks

Why study Abilene?

- ***Wide-area network*** that includes both domestic and international traffic
- ***Heterogeneous user base*** including hundreds of thousands of undergraduates
- ***High capacity*** network (10-Gbps fiber-optic links) that has never been congested
- ***Research partnership*** gives access to (anonymized) traffic data unavailable from commercial networks

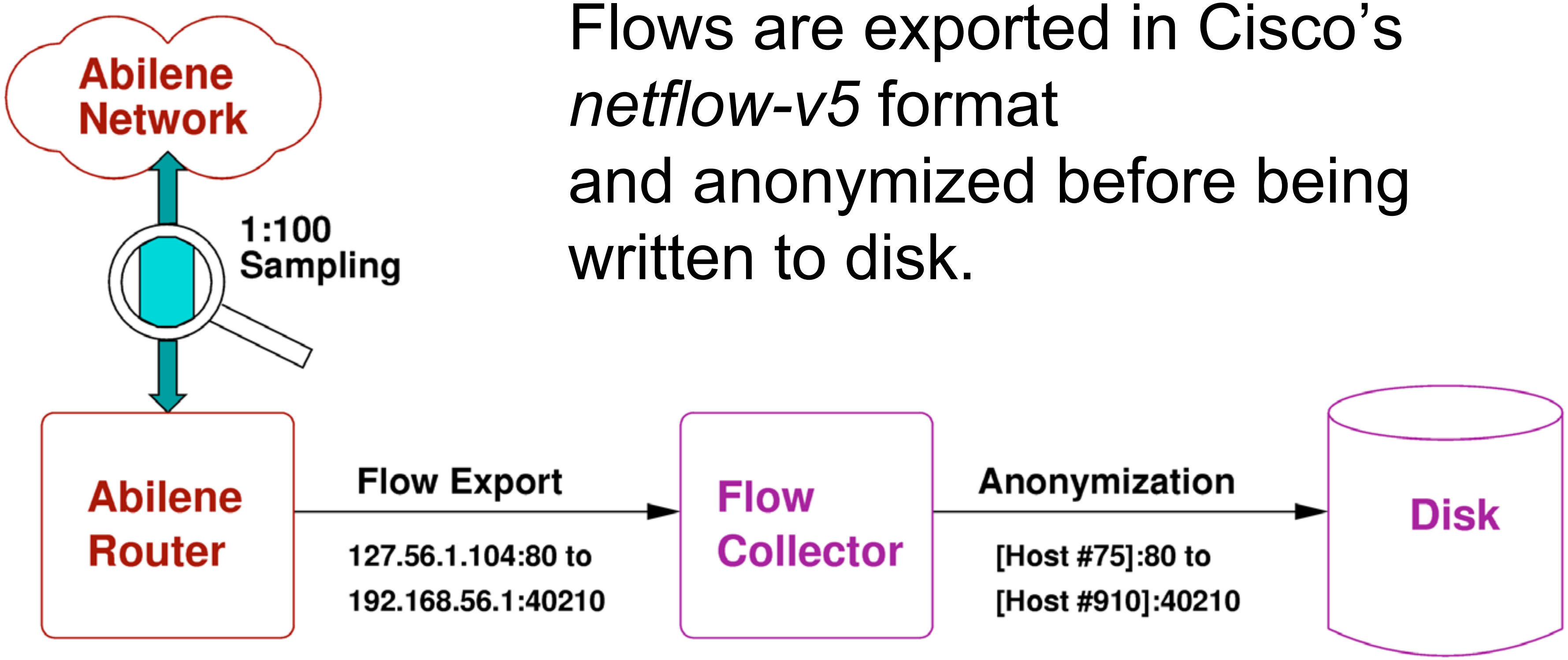
Network flow data



- A successful TCP session contains ***two*** flows

Flow collection

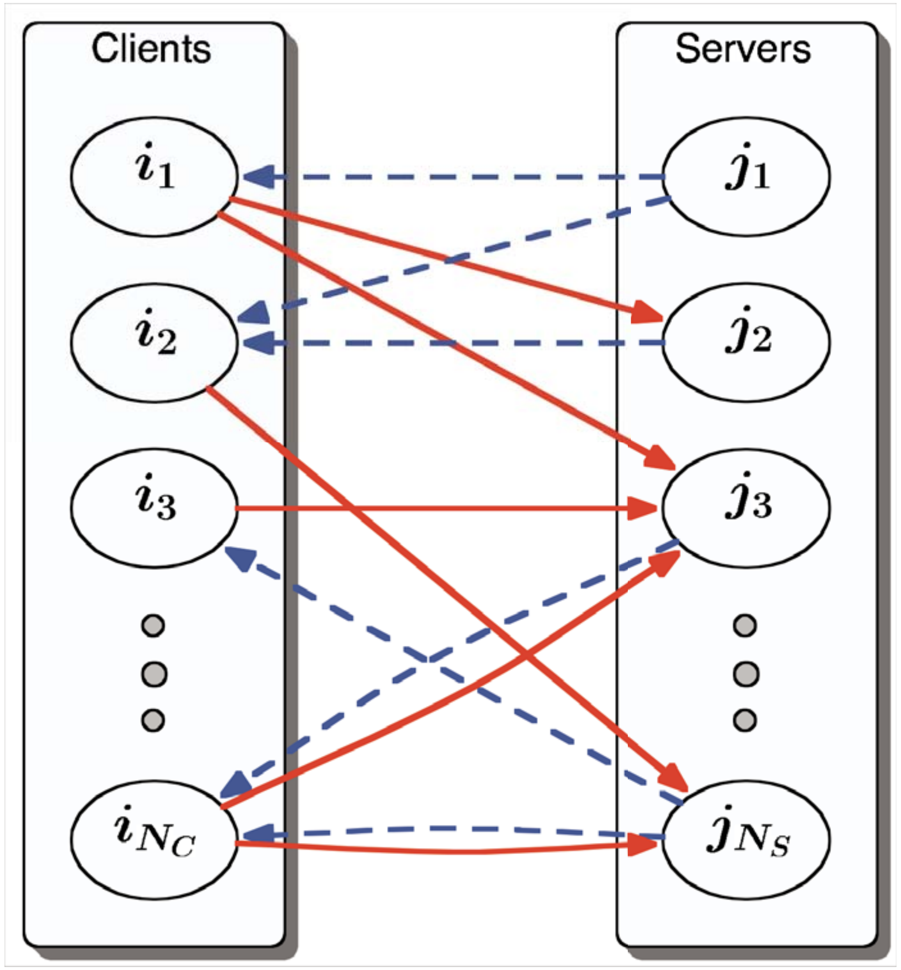
Flows are exported in Cisco's *netflow-v5* format
and anonymized before being written to disk.

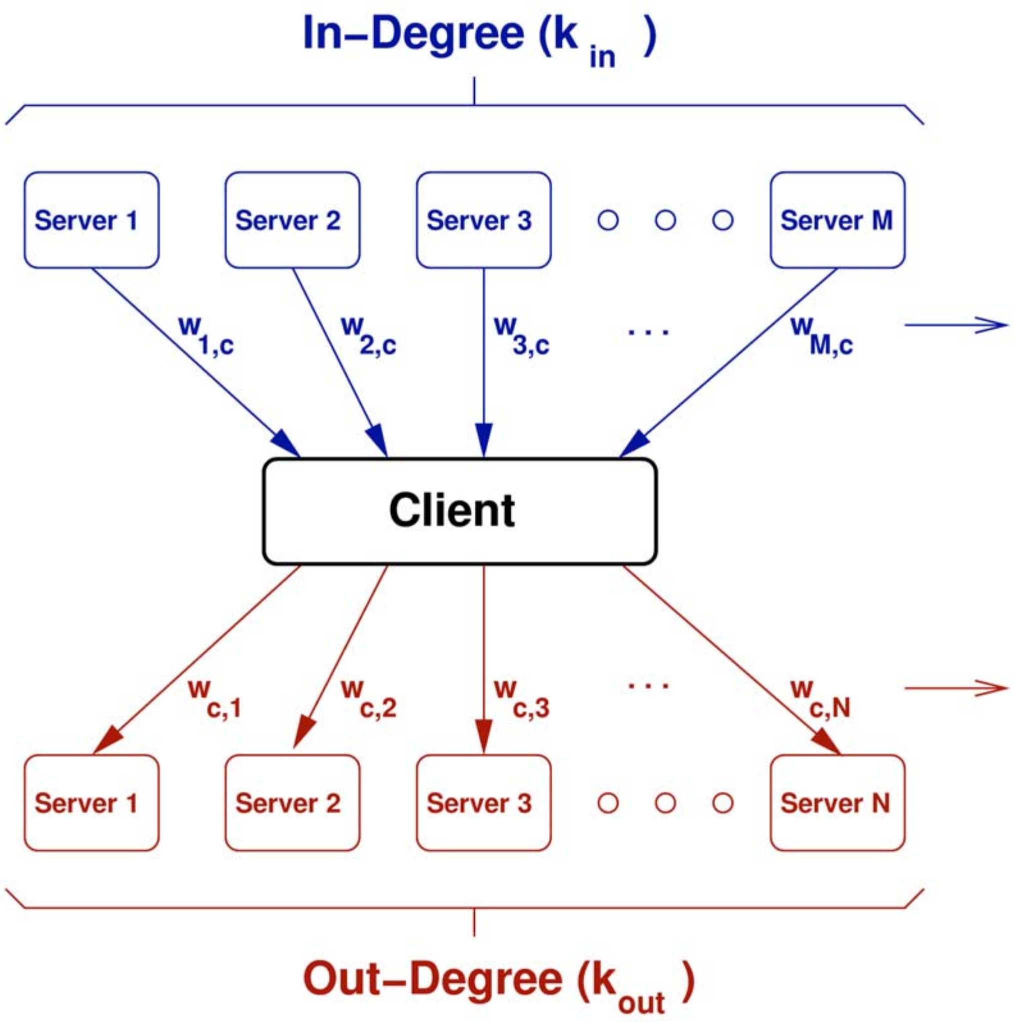


Data set for analysis

- Full 24-hour day of network flow data starting at 2004-09-30 05:00:00 UTC
  - 742,000,000 flows
  - 30,000,000 unique hosts
  - 319,000,000 flows involving port 80

Weighted bipartite digraph





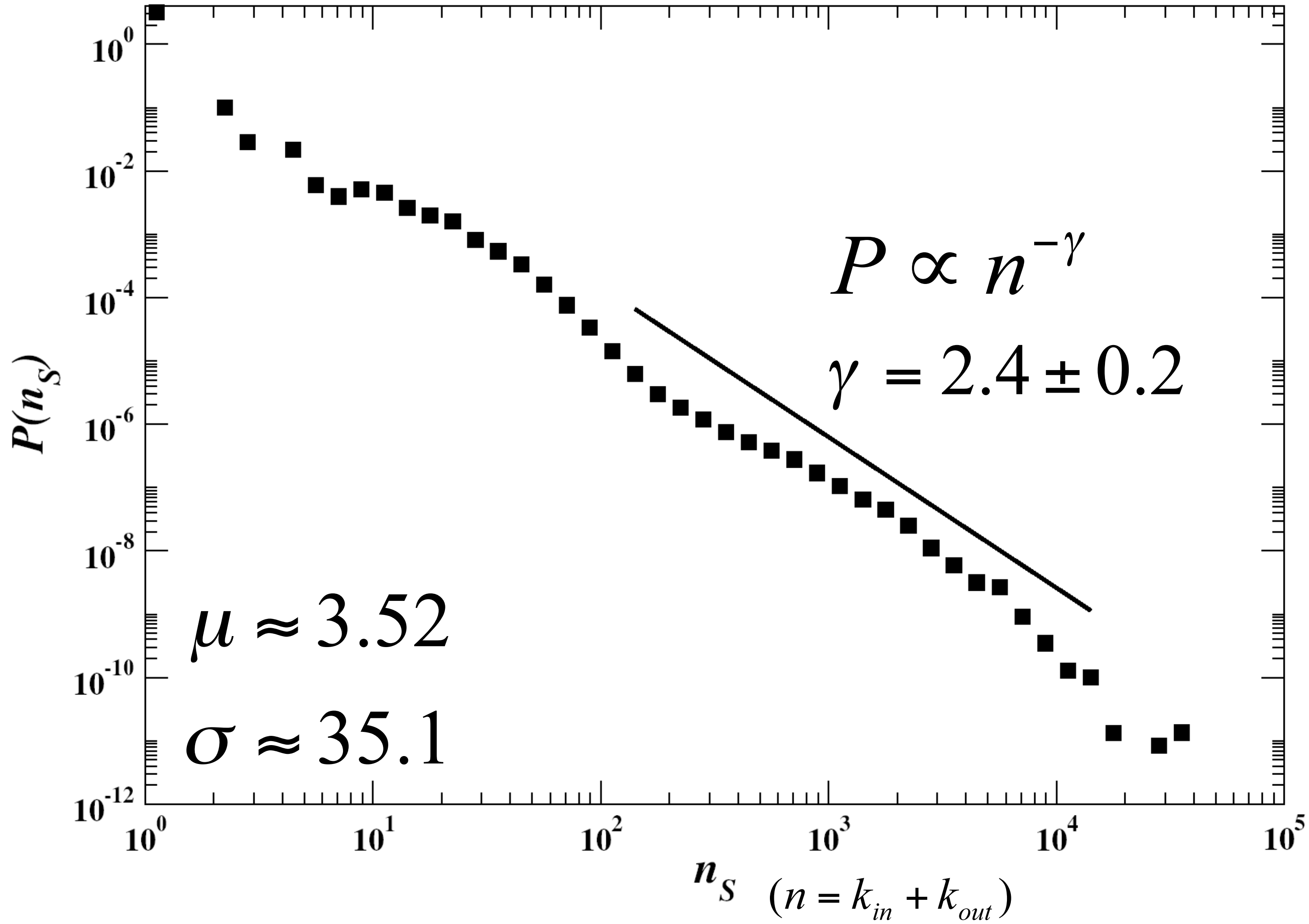
In–Strength (s_{in})

$$s_{in} = \sum_{i=1}^{M} w_{i,C}$$

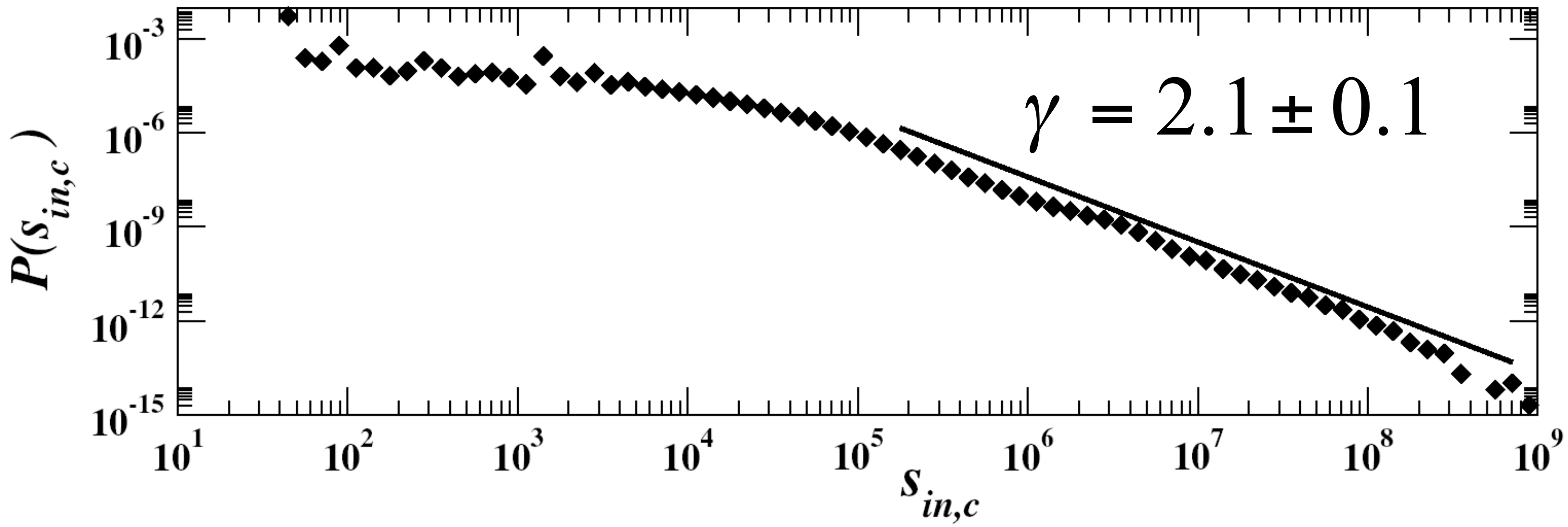
Out–Strength (s_{out})

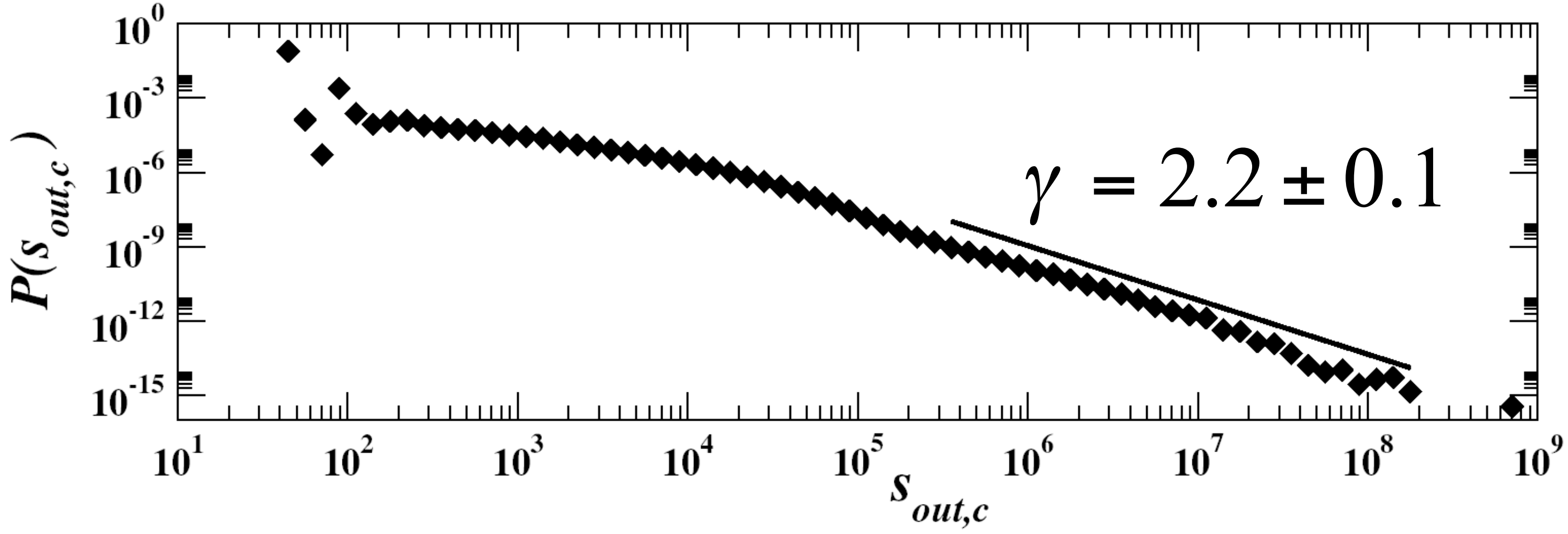
$$s_{out} = \sum_{j=1}^{N} w_{C,j}$$

Clients: Degree distribution

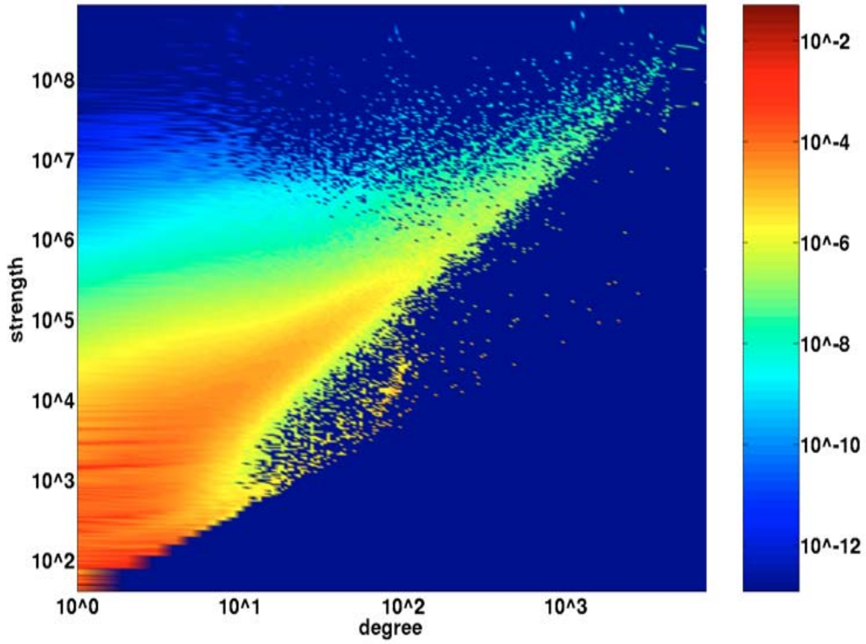


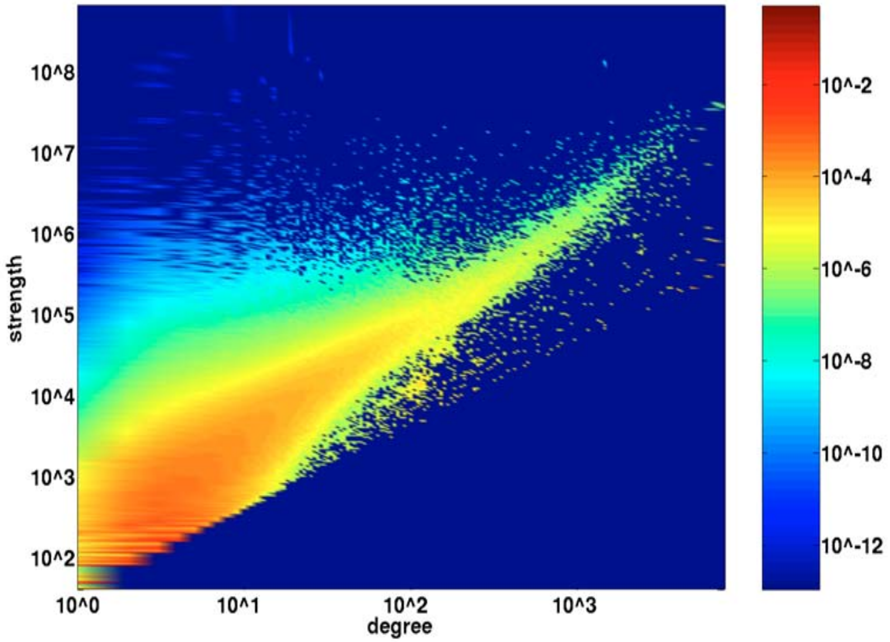
Clients: Strength distributions





Clients: Strength vs. Degree





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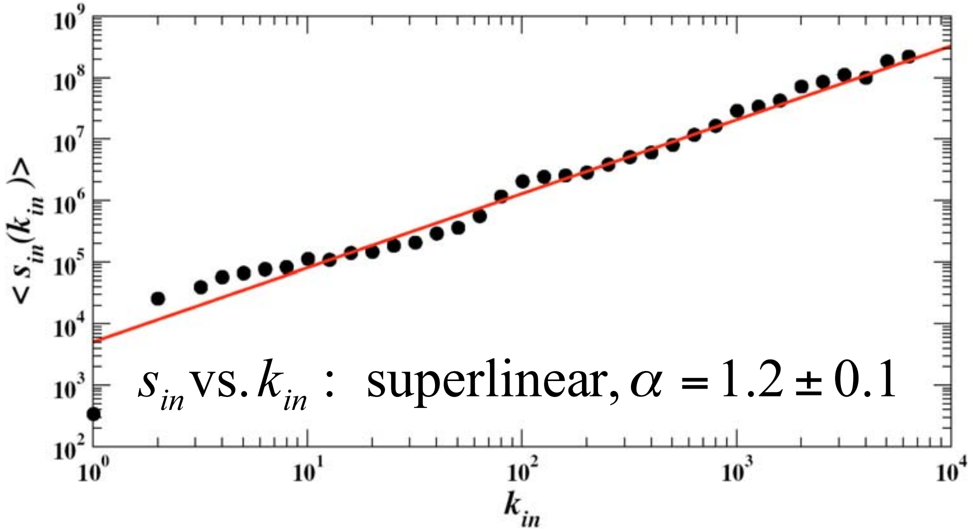
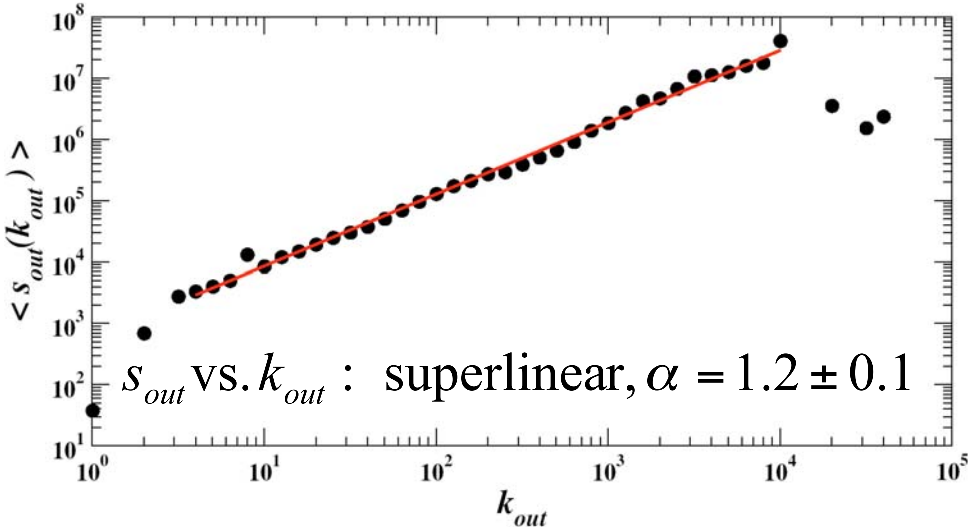


s_{in} vs. k_{in} : superlinear, $\alpha = 1.2 \pm 0.1$

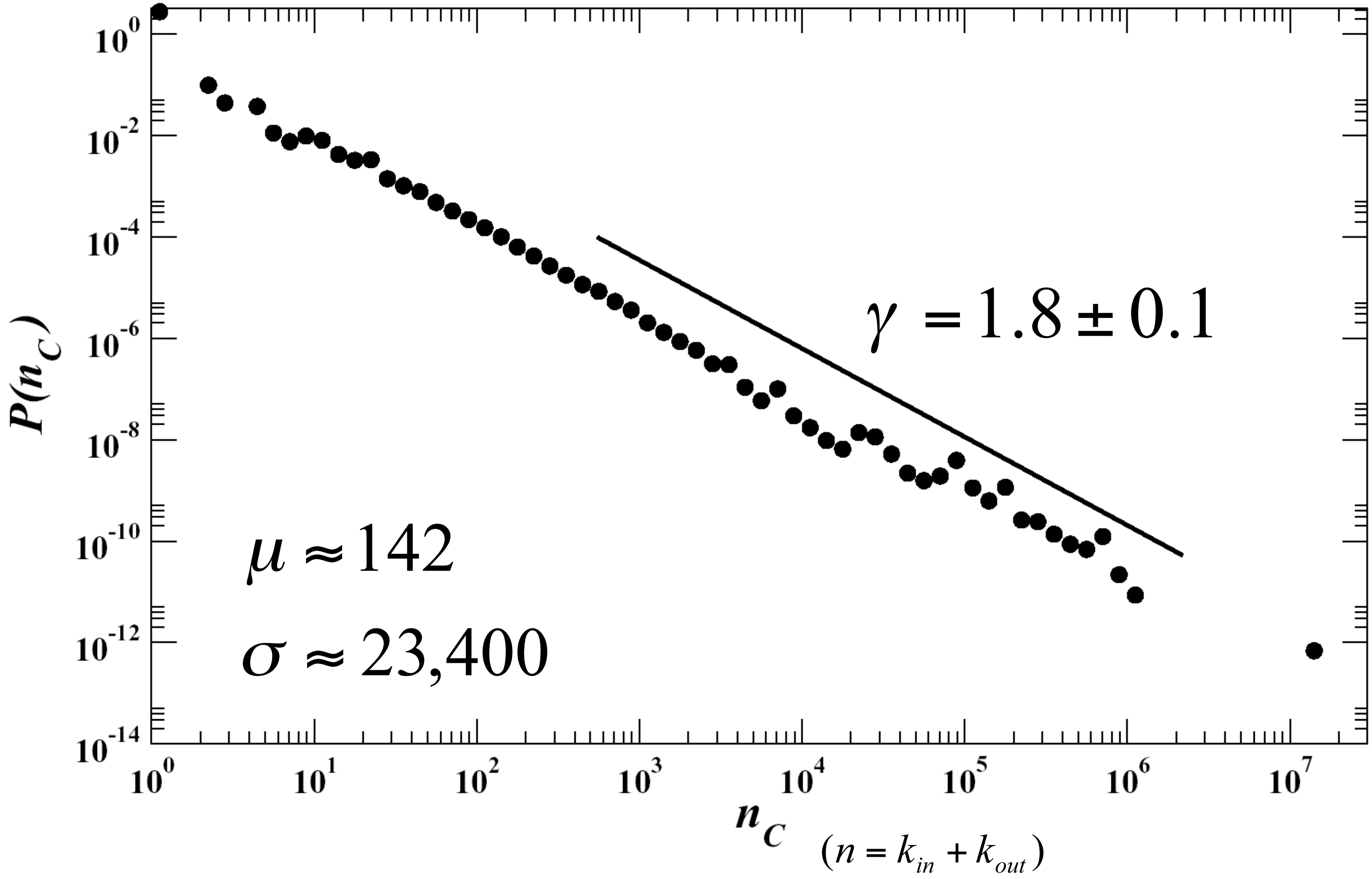


s_{out} vs. k_{out} : superlinear, $\alpha = 1.2 \pm 0.1$

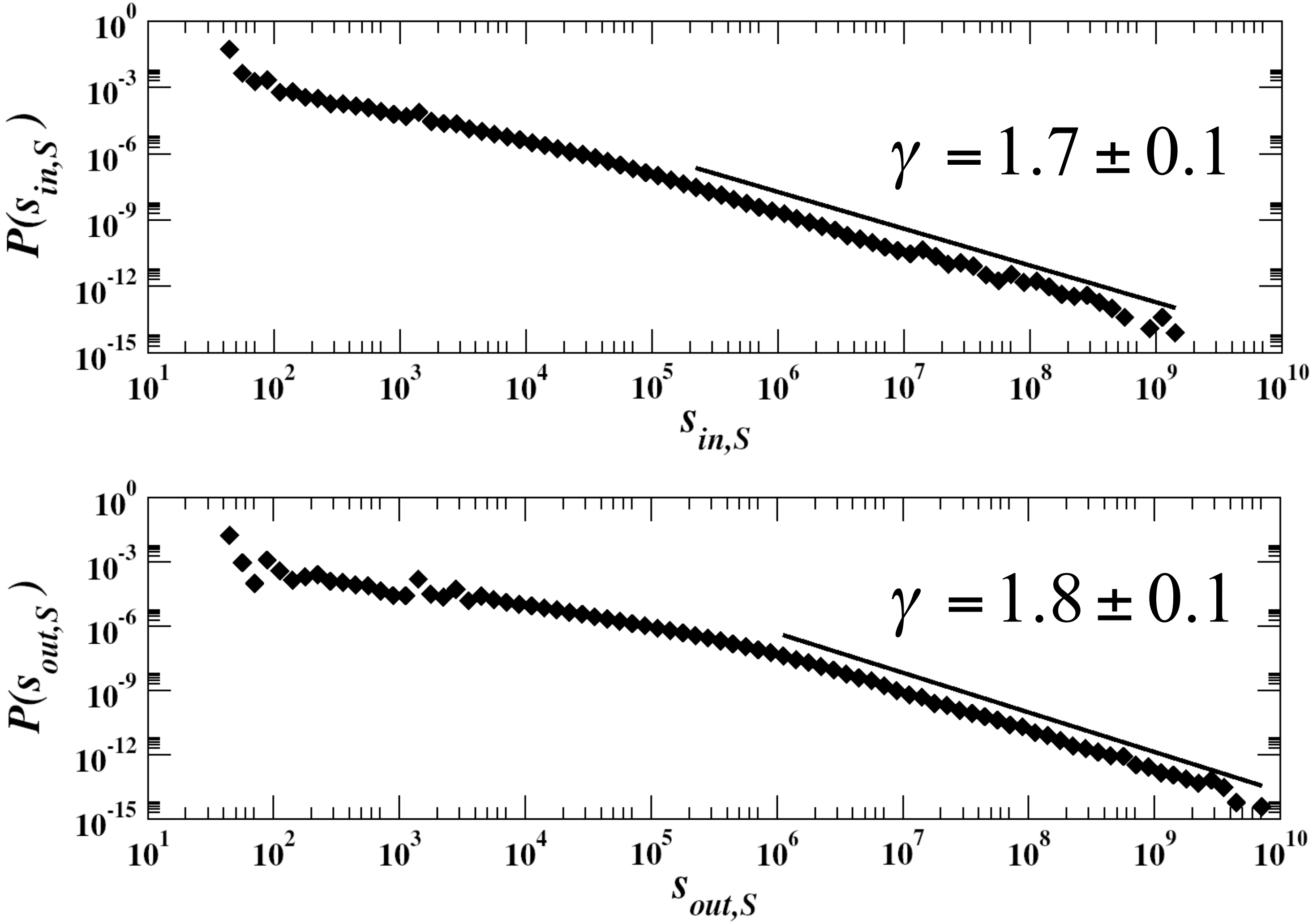
Super-linear behavior in clients

- As the ***number of servers*** in contact with a Web client ***increases***, so does the ***amount of traffic*** exchanged with ***each server***
- This points to difficulties in designing scalable client applications
- We are developing techniques to differentiate different types of client (browsers, crawlers, scanners, etc.)

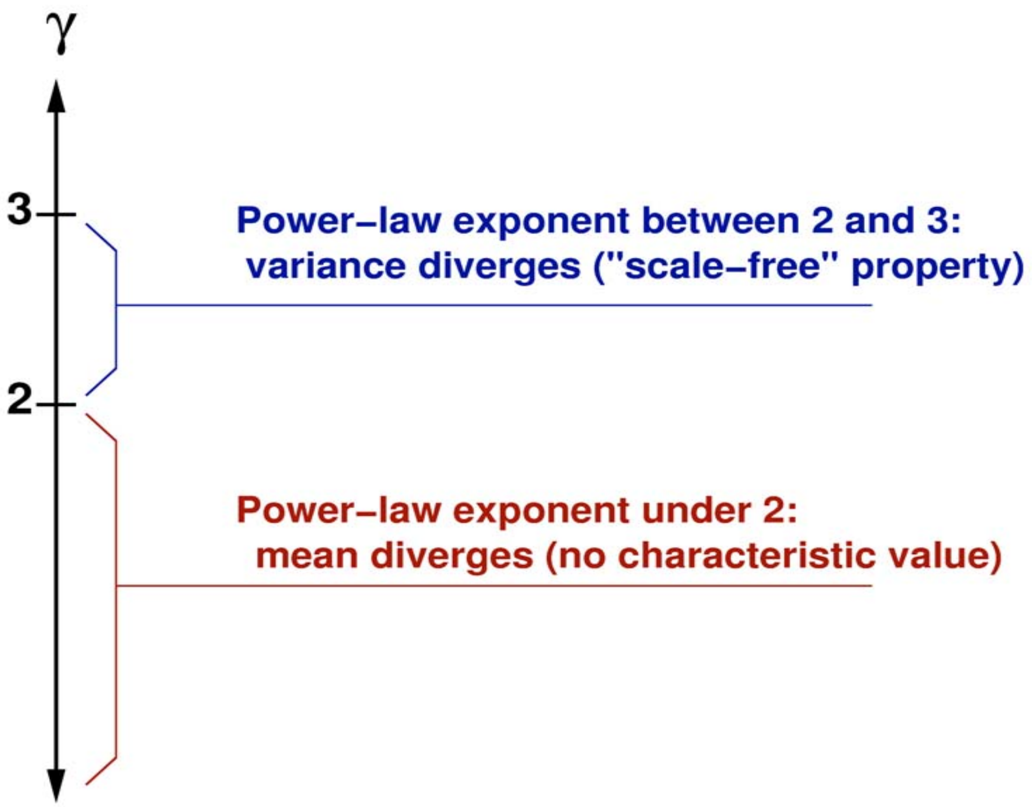
Servers: Degree distribution



Servers: Strength distributions

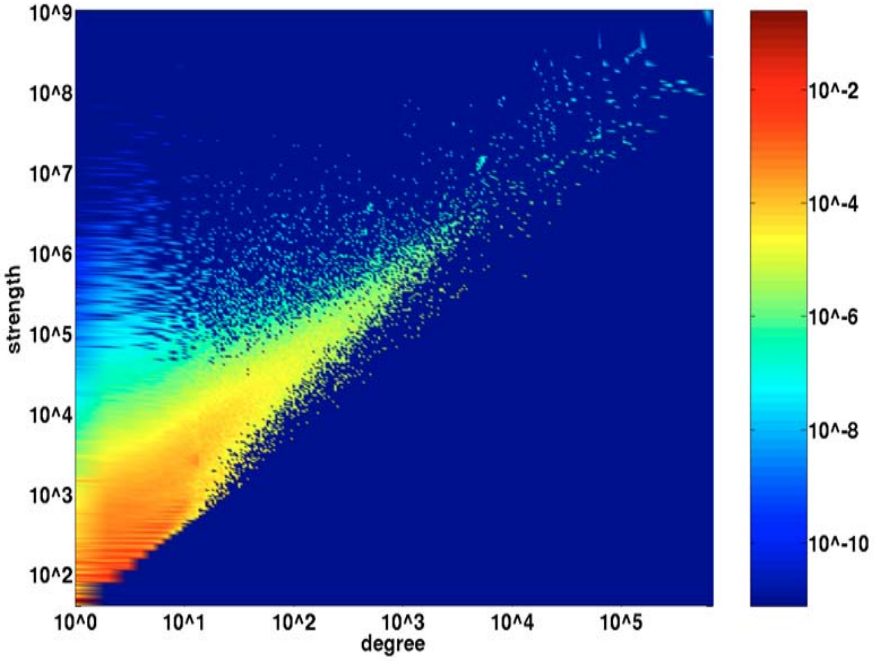


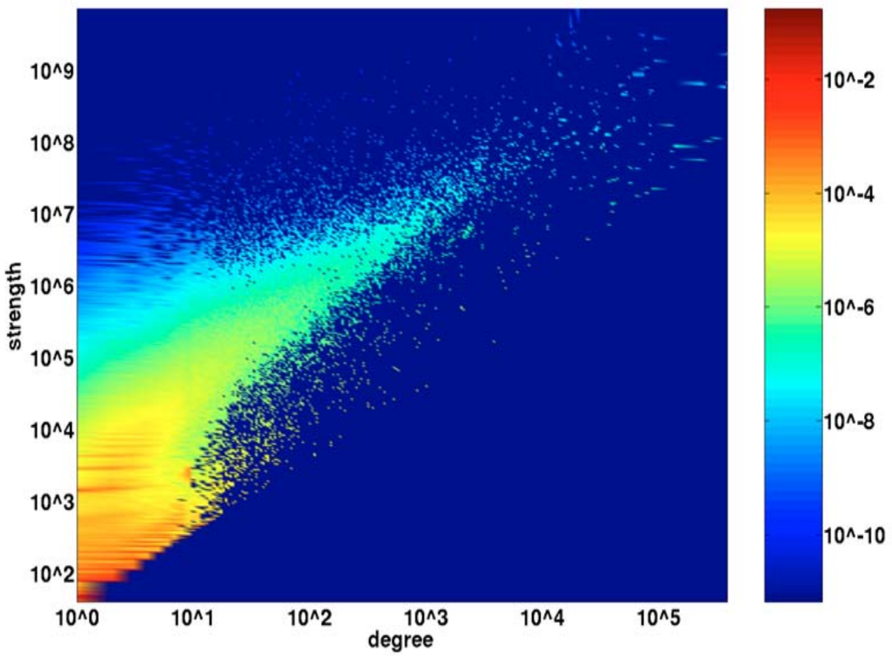
Unbounded fluctuations in server strength


γ
3
2
Power–law exponent between 2 and 3:
variance diverges ("scale–free" property)
Power–law exponent under 2:
mean diverges (no characteristic value)

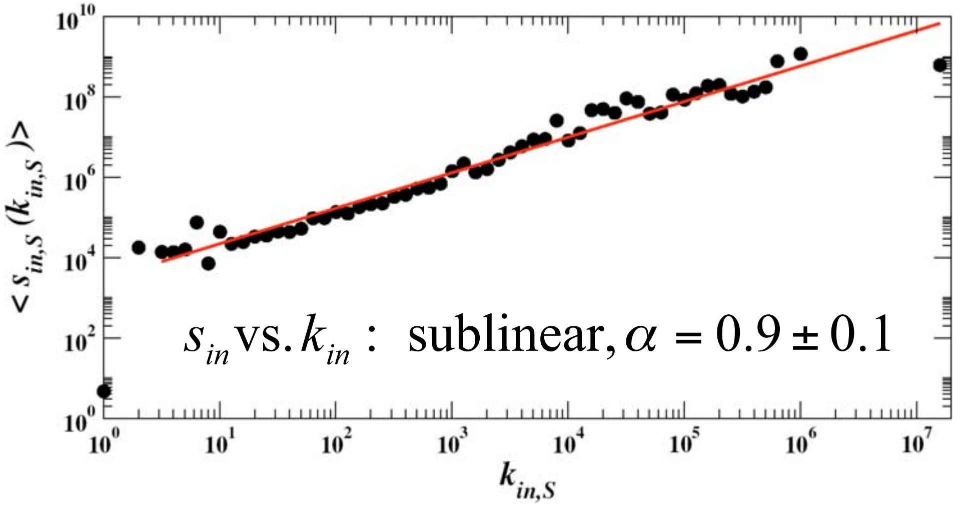
- In our sample, γ is definitely under 2
  - Mean is dependent on size of sample
  - No clear scale for a general-purpose Web server

Servers: Strength vs. Degree

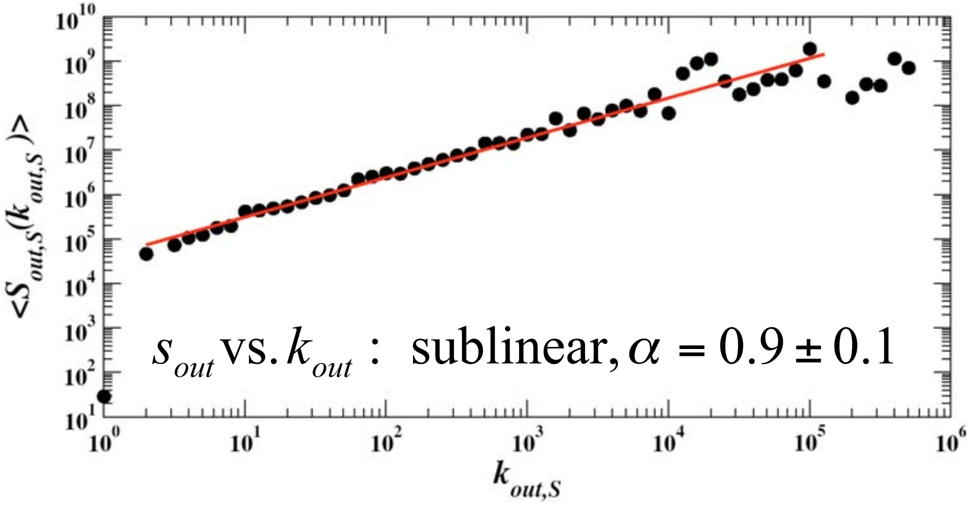




Servers: Strength vs. Degree



s_{in} vs. k_{in} : sublinear, $\alpha = 0.9 \pm 0.1$



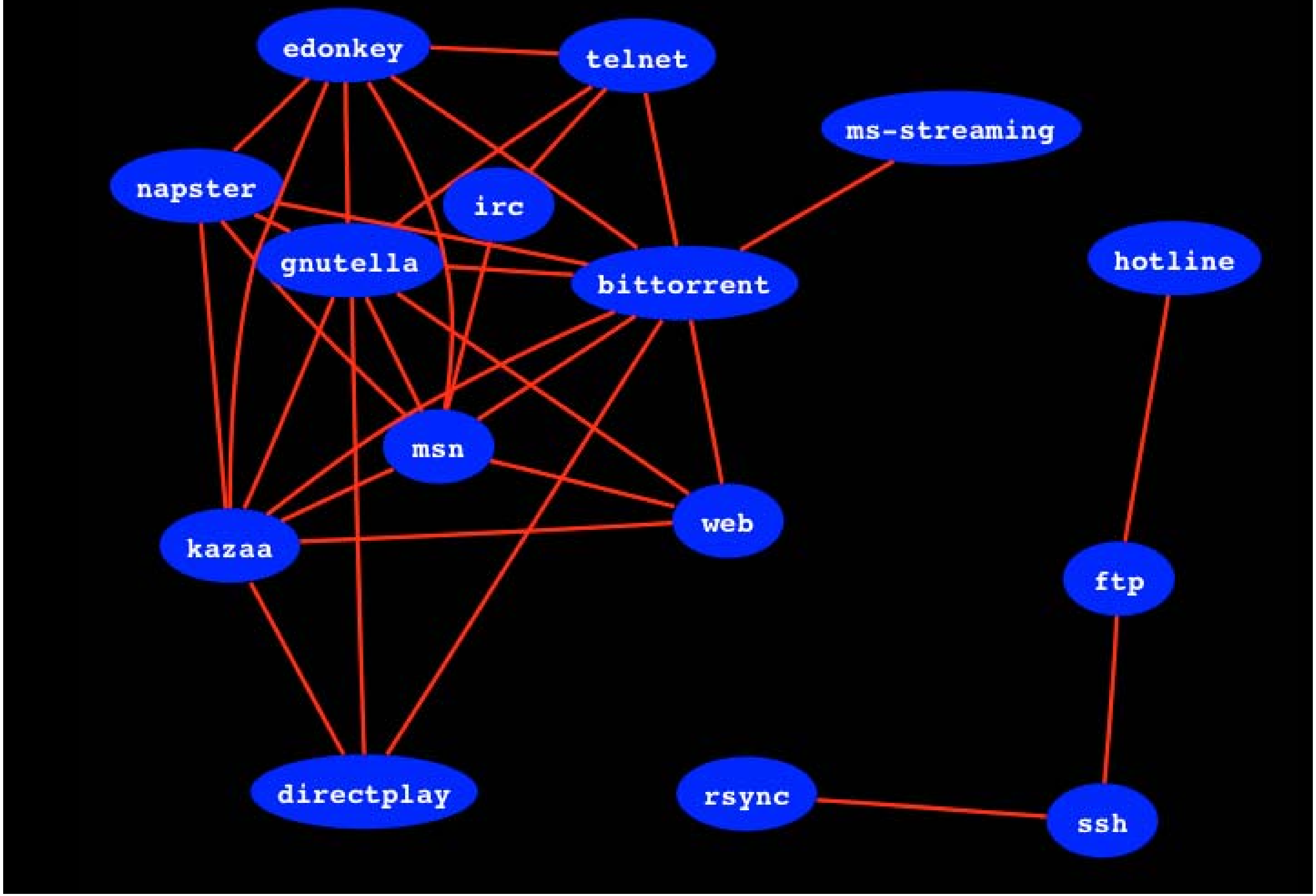
s_{out} vs. k_{out} : sublinear, $\alpha = 0.9 \pm 0.1$

Summary

- ***Power-law distributions*** are found in all aspects of the Web behavioral network
  - □ Degree, strength, and weight distributions for both clients and servers
- The relationship between ***degree*** and ***strength*** for Web clients is ***super-linear***
- The ***strength*** distribution for Web ***servers*** lacks any ***mean value***
- Models must be able to account for these heavy-tailed distributions and the non-linear coupling between degree and strength

Current Work

- Confirmation of analysis with ***more recent data***
  - Data gathered between 2005-04-08 and 2005-04-15 show the same characteristics
- Extension of analysis to ***other applications*** (especially peer-to-peer)
- Analysis of ***correlation of use*** of major network applications.


edonkey
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ms-streaming
napster
irc
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bittorrent
hotline
msn
web
kazaa
ftp
directplay
rsync
ssh

Future work

- Ongoing repetition of analysis on future data sets to identify long-term trends
- Classification of Web clients according to their purpose: *browsers, crawlers, scanners,* etc.
    - This may provide insight into scalable design
- Using flow data to improve the performance of search engines

Questions and comments