Network Simulation and Testing

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Today

General System Analysis

The Internet

Evaluating the Internet

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The Engineering Cycle

Workload Characterization

Usage Monitoring

General System

Performance Prediction

System Instrumentation

Alternatives Selection

- For a running system
  - Monitor the usage
  - Characterize the workload
  - Predict for the future
  - Revise original design
  - Instrument the changes
  - And back to the top

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Chicken or Egg

Workload Characterization

Usage Monitoring

General System

Performance Prediction

System Instrumentation

Alternatives Selection

- But where did it all start?
  - It depends
  - The Internet case?
  - The alternatives selection
  - But it's really just experts' intuition

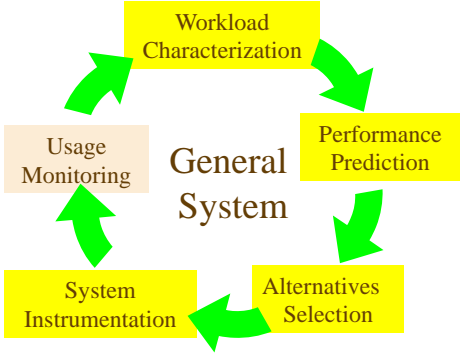Polly @ NTU

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Sounds Easy…

Yah, easy to talk about it…
All Sorts of Problems in Practice…

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Monitoring the Usage

Workload
Characterization

Performance
Prediction

Usage
Monitoring

General
System

System
Instrumentation

Alternatives
Selection

- Monitor the usage
  - Measurement methodology
  - Measurement tools
- Characterize the workload
- Predict for the future
- Revise original design
- Instrument the changes

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Characterizing the Workload

Workload Characterization

Usage Monitoring

General System

Performance Prediction

System Instrumentation

Alternatives Selection

- Monitor the usage
- Characterize the workload
  - Modeling the measured data
  - The model needs to remain valid for data from taken at different time/location
- Predict for the future
- Revise original design
- Instrument the changes

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Predicting the Performance

Workload Characterization

Usage Monitoring

General System

Performance Prediction

System Instrumentation

Alternatives Selection

- Monitor the usage
- Characterize the workload
- Predict for the future
  - Anticipate the user access pattern, demand increase
  - Evaluate the existing's capacity
- Revise original design
- Instrument the changes

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Designing the Alternatives

Workload Characterization

Performance Prediction

General System

Usage Monitoring

Alternatives Selection

System Instrumentation

- Monitor the usage
- Characterize the workload
- Predict for the future
- Revise original design
  - If the current system won't live up to the challenge, how can it be changed…
  - Effective solutions
- Instrument the changes

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Instrumenting the Changes

Workload Characterization

Performance Prediction

General System

Usage Monitoring

Alternatives Selection

System Instrumentation

- Monitor the usage
- Characterize the workload
- Predict for the future
- Revise original design
- Instrument the changes
  - Politics

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If This is the Telephone Network

- Monitor the usage
  - The big players place monitors all over the places in their own networks to collect data
- Characterize the workload
  - Fit the collected data to the well-known models
  - Human voice is Poisson
    - For some reason, the nature works this way.

Telephone Network (cont)

- Predict for the future
  - Queuing theory:
    - Safe to supply λ_1 bandwidth for a call of average rate λ_1
    - $\lambda_1 + \lambda_2$ bandwidth for calls of average rate λ_1 and λ_2
  - Linear programming:
    - Given the max tolerable blocking rate, max the profit
- Revise original design
  - Mostly infrastructure-ral
  - I.e., rearranging or adding switches&cables
- Instrument the changes
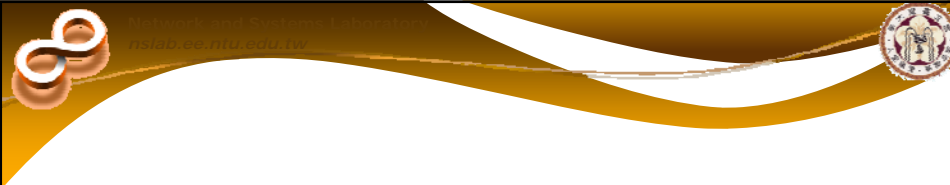 - Have full authority to change
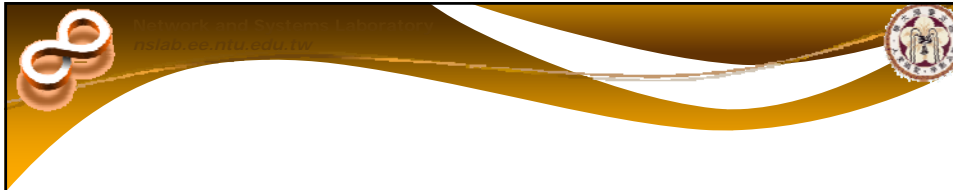
No Real Difficulties

Quite a Profitable Business

Is the data network as profitable?

Let's review the data network.

Today

General System Analysis
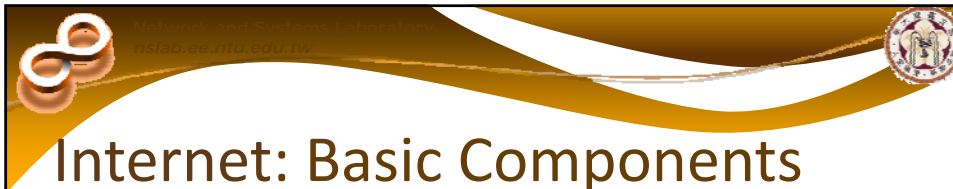
The Internet

Evaluating the Internet

Internet: Basic Components

- Think the postal system
- Nodes
  - End hosts and less number of routers
  - Homes and local/remote post offices
- Links
  - Connecting nodes (Access net, Ethernet, T1, T3, OC3, OC12, etc)
  - Roads/streets between homes and post offices

Internet: Basic Constructions

- Packets
  - Destined to IP addresses (129.132.66.28)
  - Destined to postal addresses (1, Sec. 4 Roosevelt Rd.)
- Protocols
  - Packets sent with TCP (reliable)
  - Packets sent with registered mail with confirmation
  - But no congestion control
  - Other protocols...

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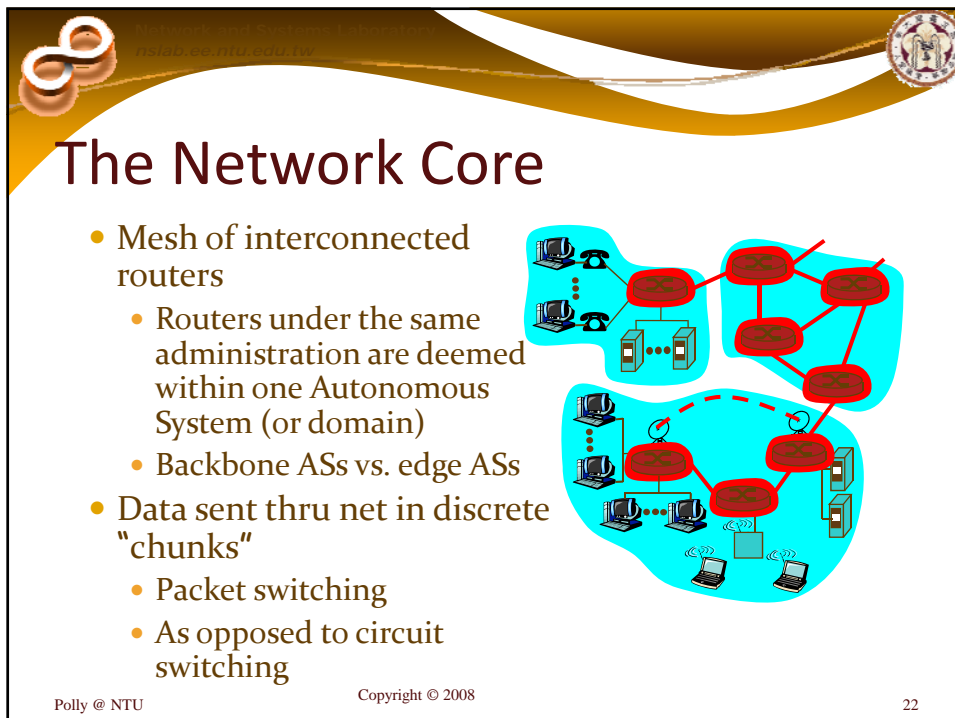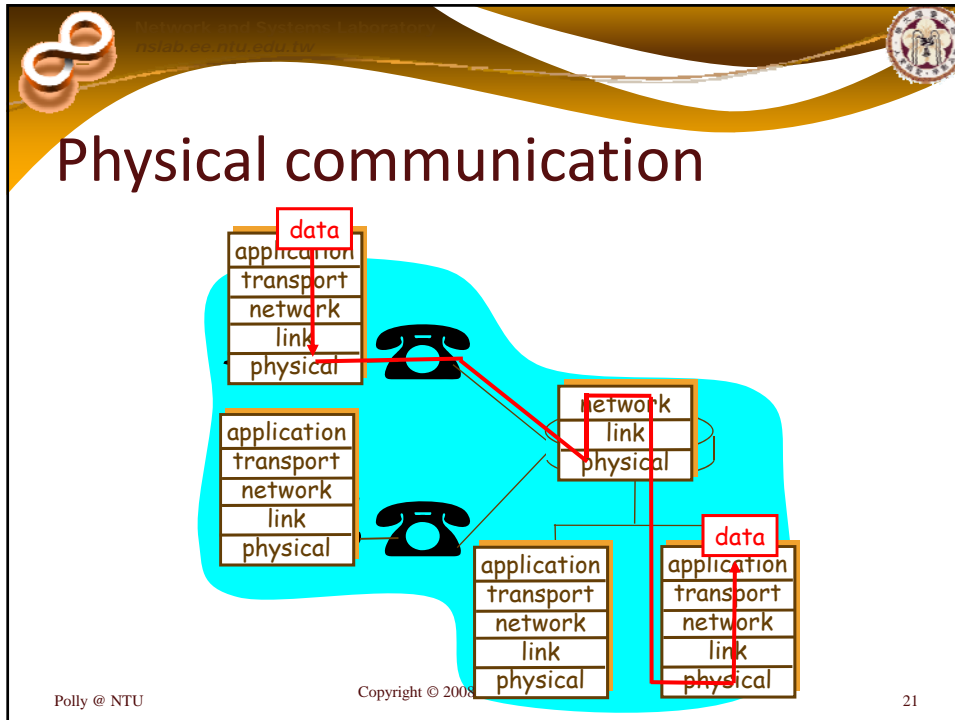# Internet Protocol Stack

- Application: supporting network applications
  - FTP, SMTP, HTTP
- Transport: host-host data transfer
  - TCP, UDP
- Network: routing of datagrams from source to destination
  - IP (addressing, routing, forwarding)
- Link: data transfer between neighboring network elements
  - Error Checking, MAC, Ethernet
- Physical: bits "on the wire"

| application |
| transport |
| network |
| link |
| physical |

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Data Network Research
(Side-Bar)

- **Application**
  - HTTP evolution
  - Web caching
- **Transport**
  - TCP evolution
- **Network**
  - Unicast routing
  - Multicast routing

- **P2P**
  - Distributed directory for effective searching

- **Mobile and Wireless**
  - Isolating drops due to bit error for TCP
  - Routing for dynamic networks
  - Handling the hidden terminal problem

- **QoS**
  - Problem Detection (loss, congestion)
  - Control (end-to-end, router-assisted)

Internet Protocol Stack
(Back to the Topic)

- **Application:** supporting network applications
  - FTP, SMTP, HTTP
- **Transport:** host-host data transfer
  - TCP, UDP
- **Network:** routing of datagrams from source to destination
  - IP (addressing, routing, forwarding)
- **Link:** data transfer between neighboring network elements
  - Error Checking, MAC, Ethernet
- **Physical:** bits "on the wire"

application
transport
network
link
physical

Physical communication

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The Network Core

- Mesh of interconnected routers
  - Routers under the same administration are deemed within one Autonomous System (or domain)
  - Backbone ASs vs. edge ASs
- Data sent thru net in discrete "chunks"
  - Packet switching
  - As opposed to circuit switching

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Internet: The Network

- The Global Internet consists of Autonomous Systems (AS) interconnected with each other:
  - **Stub AS**: small corporation: one connection to other AS's
  - **Multihomed AS**: large corporation (no transit): multiple connections to other AS's
  - **Transit AS**: provider, hooking many AS's together

- Two-level routing:
  - **Intra-AS:** administrator responsible for choice of routing algorithm within network
  - **Inter-AS:** unique standard for inter-AS routing: BGP

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Internet AS Hierarchy

Inter-AS border (exterior gateway) routers
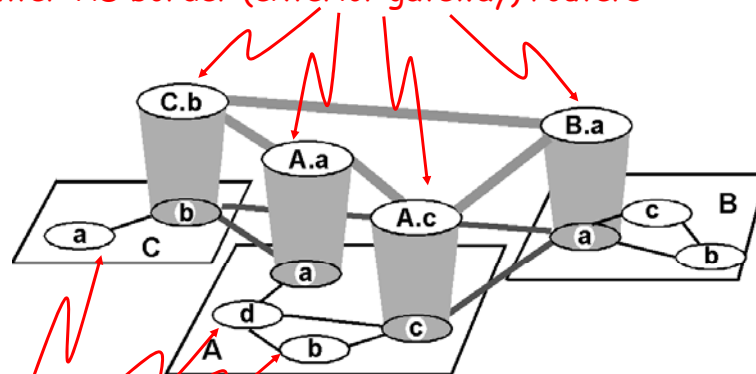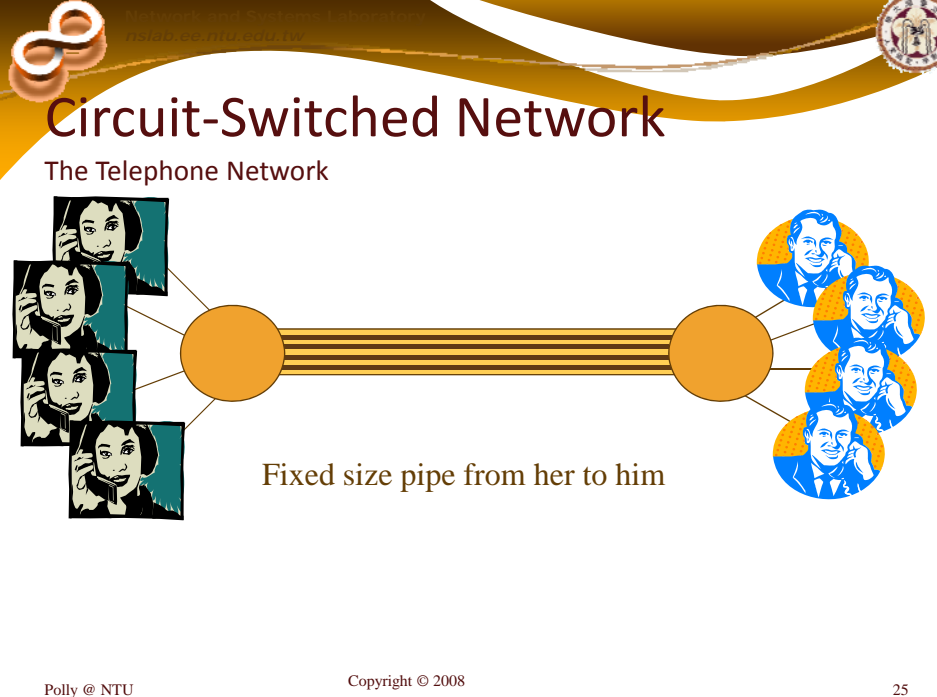
Intra-AS interior (gateway) routers

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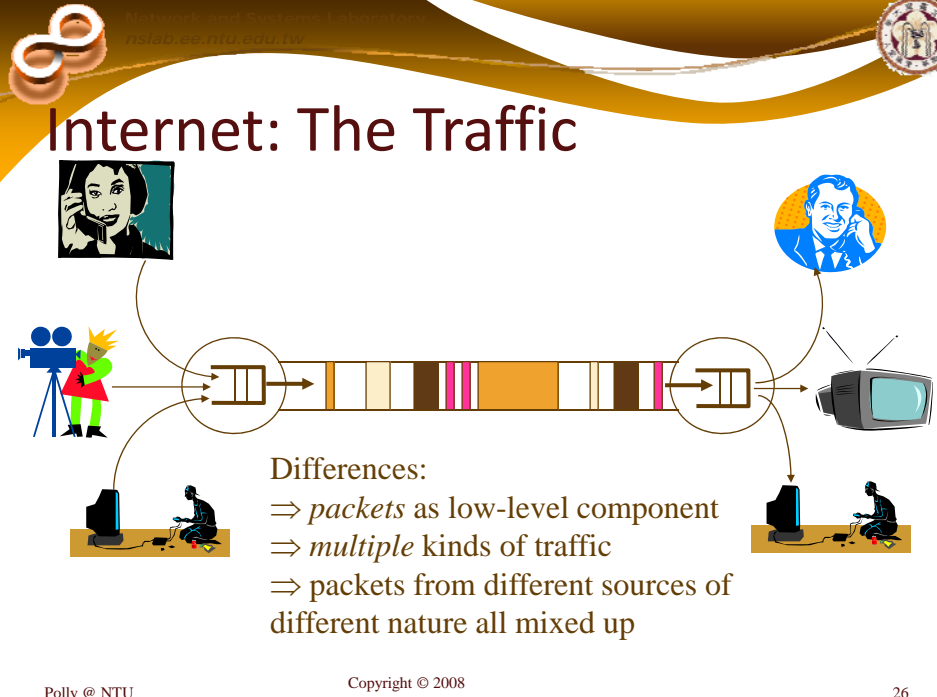
Circuit-Switched Network

The Telephone Network

Fixed size pipe from her to him

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Internet: The Traffic

Differences:
$\Rightarrow$ *packets* as low-level component
$\Rightarrow$ *multiple* kinds of traffic
$\Rightarrow$ packets from different sources of different nature all mixed up
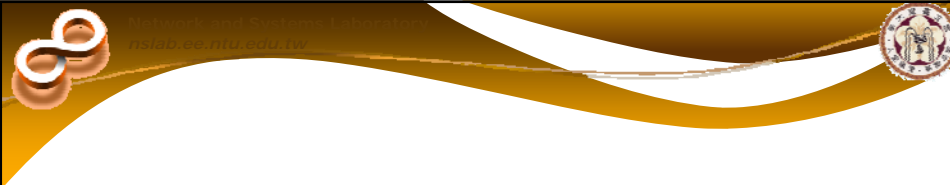
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Let's come back to this question:

Is the data network as profitable?

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Today

General System Analysis
The Internet
Evaluating the Internet

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What If This is the Internet

- Monitor the usage
  - The big players place monitors all over the places in their own networks to collect data
  - Would this give you representative data?
- Characterize the workload
  - Fit the collected data to the well-known models
  - Human voice is Poisson
  - Are Web browsing, Email, P2P, etc traffic Poisson?

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Internet (cont)

- Predict for the future
  - Queuing theory:
    - Save to supply λ_1 bandwidth for a call of average rate λ_1
    - $\lambda_1 + \lambda_2$ bandwidth for calls of average rate λ_1 and λ_2
  - Average, a good measure? Does traffic add up?
- Revise original design
  - Mostly infrastructure-ral
  - Still infrastructure-ral?
- Instrument the changes
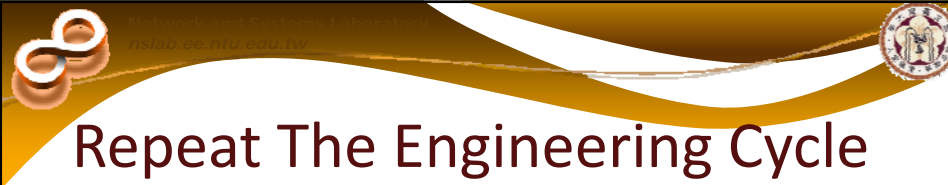 - Have full authority to change
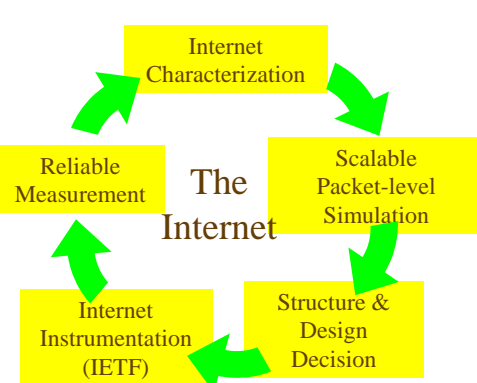 - Can the big players dictate?

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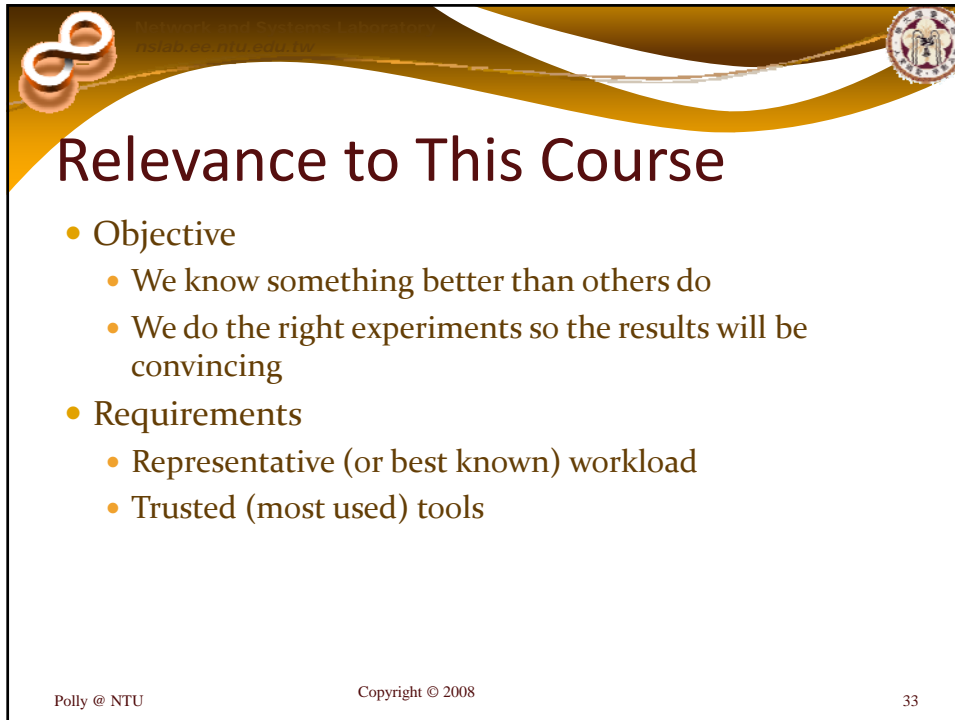30

For the Most of These Questions

The Answer is NO

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Repeat The Engineering Cycle

Internet Characterization

Reliable Measurement

The Internet

Scalable Packet-level Simulation

Internet Instrumentation (IETF)

Structure & Design Decision

- For the Internet
  - Monitor the usage
    - Passive and active measurement
  - Characterize the workload
    - Traffic, topology, routing errors, access pattern modeling
  - Predict for the future
    - Scalable simulation & testing tools
  - Revise original design
    - Protocol and Infrastructure
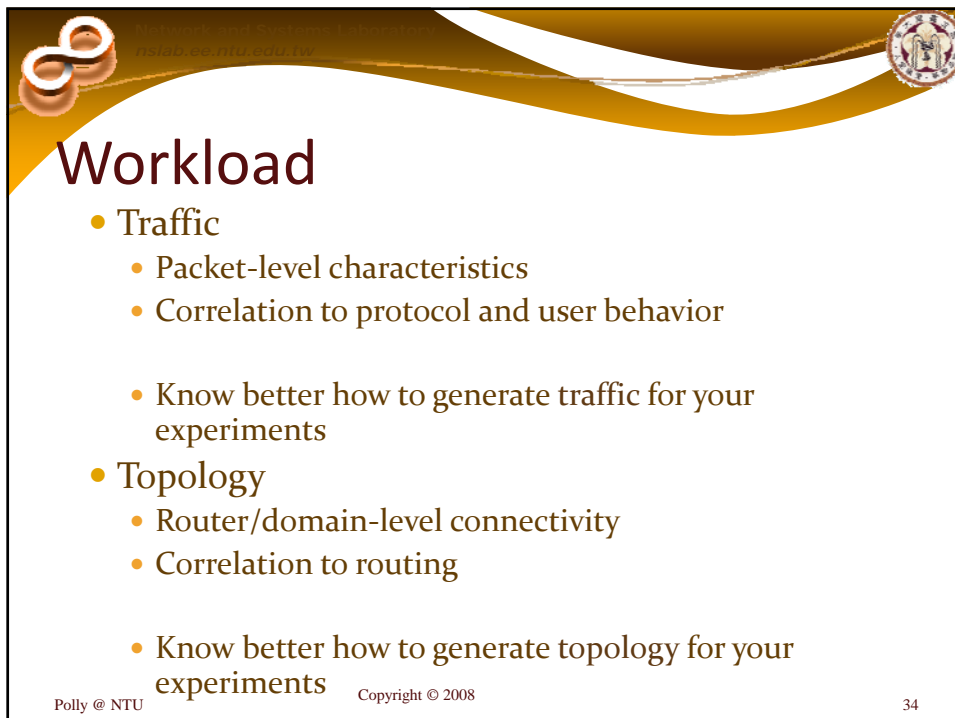 - Instrument the changes
    - IETF

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Relevance to This Course

- Objective
  - We know something better than others do
  - We do the right experiments so the results will be convincing
- Requirements
  - Representative (or best known) workload
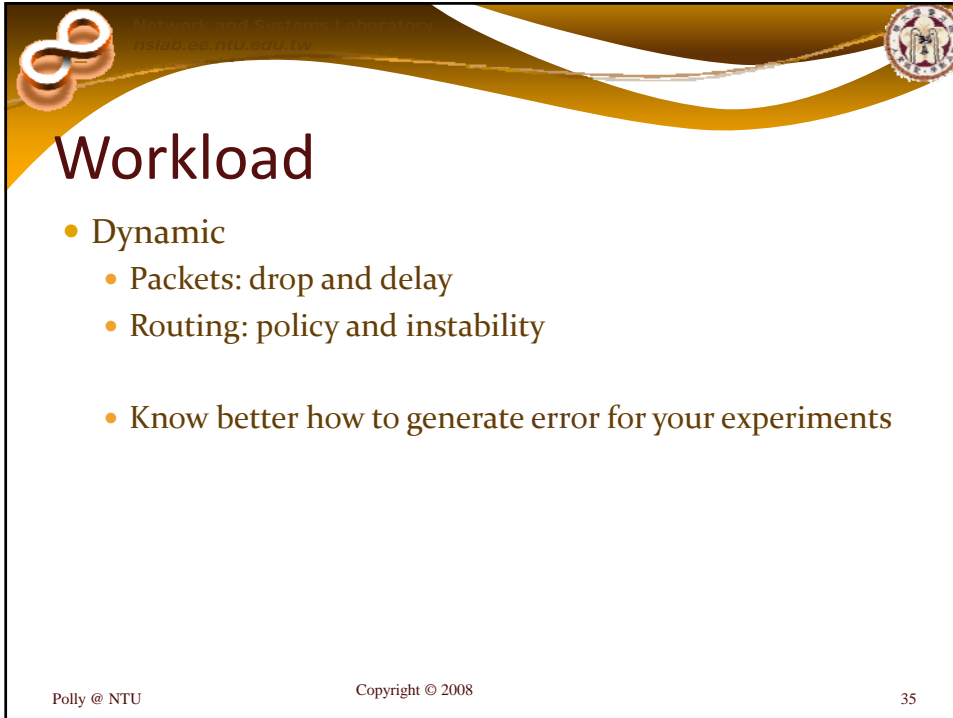 - Trusted (most used) tools

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Workload

- Traffic
  - Packet-level characteristics
  - Correlation to protocol and user behavior

  - Know better how to generate traffic for your experiments
- Topology
  - Router/domain-level connectivity
  - Correlation to routing

  - Know better how to generate topology for your experiments
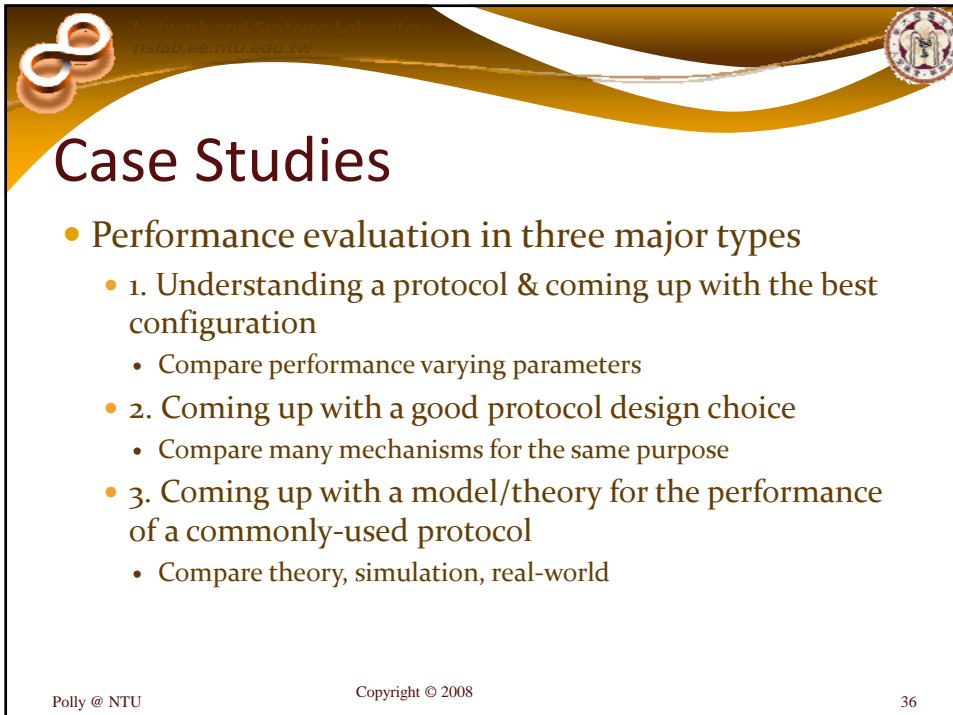
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Workload

- Dynamic
  - Packets: drop and delay
  - Routing: policy and instability

  - Know better how to generate error for your experiments

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Case Studies

- Performance evaluation in three major types
  - 1. Understanding a protocol & coming up with the best configuration
    - Compare performance varying parameters
  - 2. Coming up with a good protocol design choice
    - Compare many mechanisms for the same purpose
  - 3. Coming up with a model/theory for the performance of a commonly-used protocol
    - Compare theory, simulation, real-world
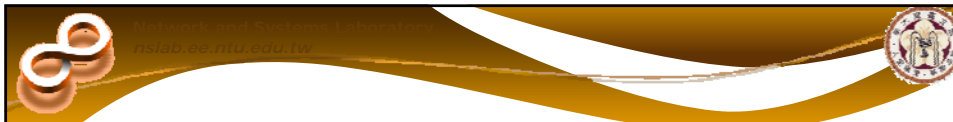
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Tools

- ns-2
  - About the most popular in the research community
  - Platform for cross-examination
- tcpdump
  - Not the only one but the most efficient one
  - Also the most popular one in the research community
- dummynet
  - Not the only one
  - But an easy and thus often-used one
- PlanetLab
  - The only one
  - Real Internet (A small subset)

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The Useful Theory

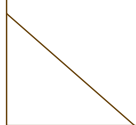Statistics

Evaluation Methodology

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Keyword: Heavy-Tailed

- It turned out computer processes tend to be heavy-tailed or power-law distributed!
  - CPU time consumed by Unix processes
  - Size of Unix files
  - Size of compressed video frames
  - Size of FTP bursts
  - Telnet packet interarrivals
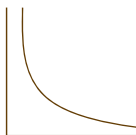 - Size of Web items
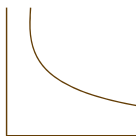 - Ethernet bursts

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Illustrated

$y = a - b\, x$ linear

$y = a\, e^{-bx}$, b>0   exponential

$y = a / x^b$, b>0   heavy-tailed

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How to tell when you see one?

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Review Some Statistics

- Density vs. Distribution
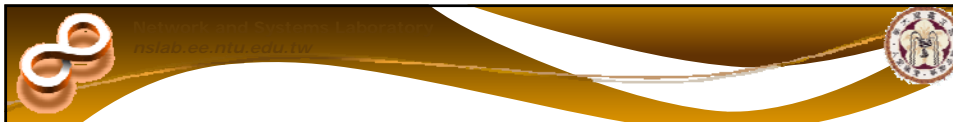- Poisson
- Exponential
- Pareto
- Self-similarity...

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Density vs. Distribution

- Density is the probability of certain events to happen
  - f(x)
- Distribution is usually referred to as the accumulative density
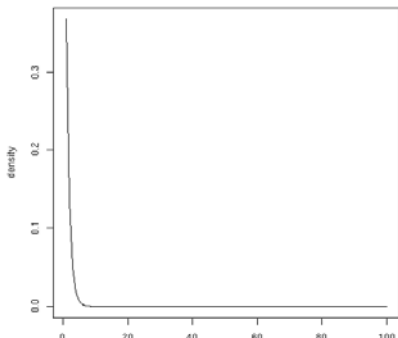 - f(0)+f(dz)+f(2*dz)+...+f(x)
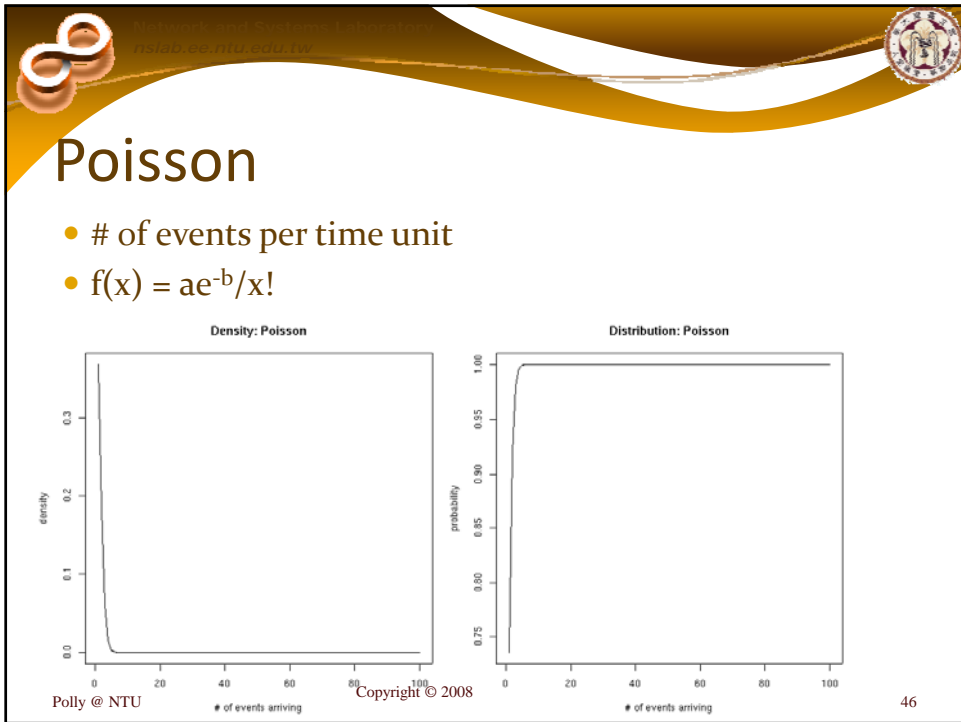 - $F(x) = \int_{0 \to x} f(z)\, dz$

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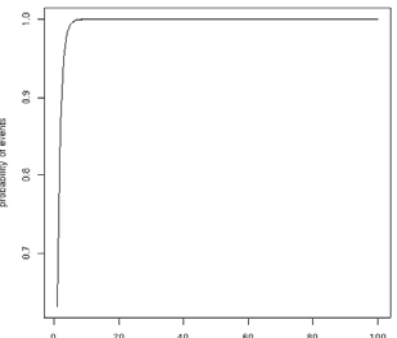
Exponential

- # of time units between events
- $f(x) = ae^{-bx}$

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Example Exponential Process
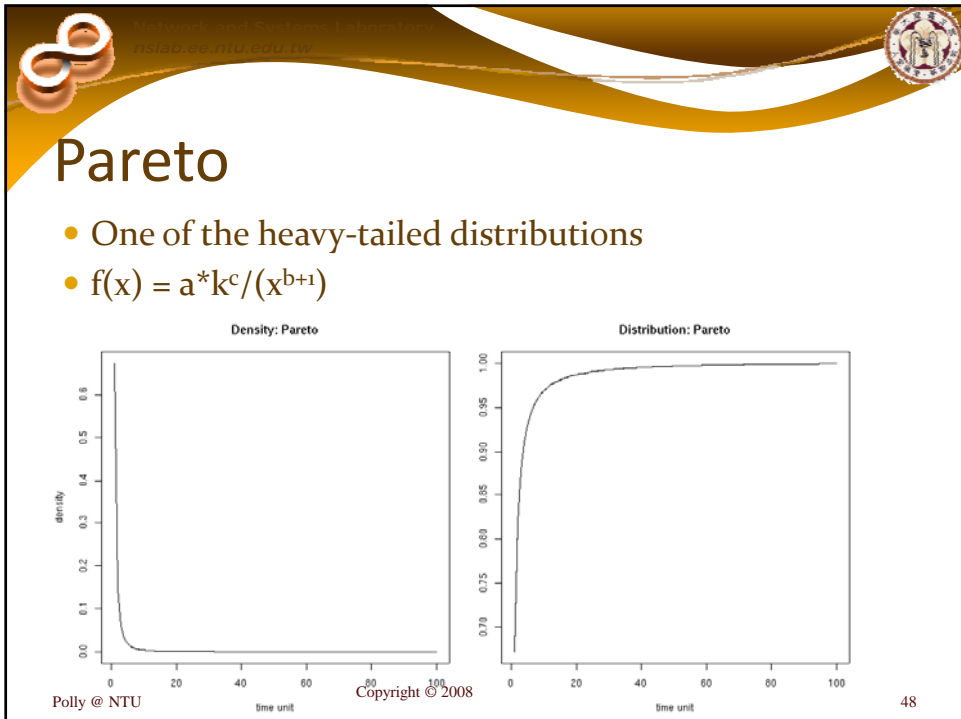
Exponential Process (average rate = 1 event per time unit)

event index
45

Poisson

- # of events per time unit
- $f(x) = ae^{-b}/x!$

Density: Poisson

Distribution: Poisson

# of events arriving
# of events arriving
46

Example Poisson Process

Poisson Process (average rate = 1 event per time unit)

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Pareto

- One of the heavy-tailed distributions
- $f(x) = a * k^c / (x^{b+1})$

Density: Pareto   Distribution: Pareto

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Example Pareto Process

Pareto Process (average rate = 1 event per time unit)

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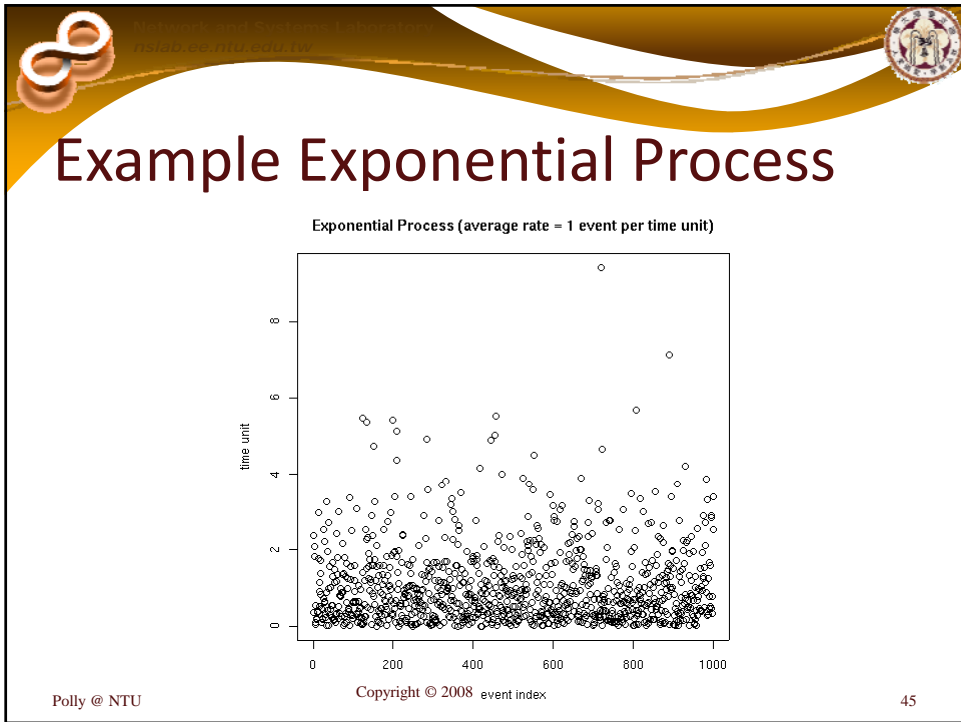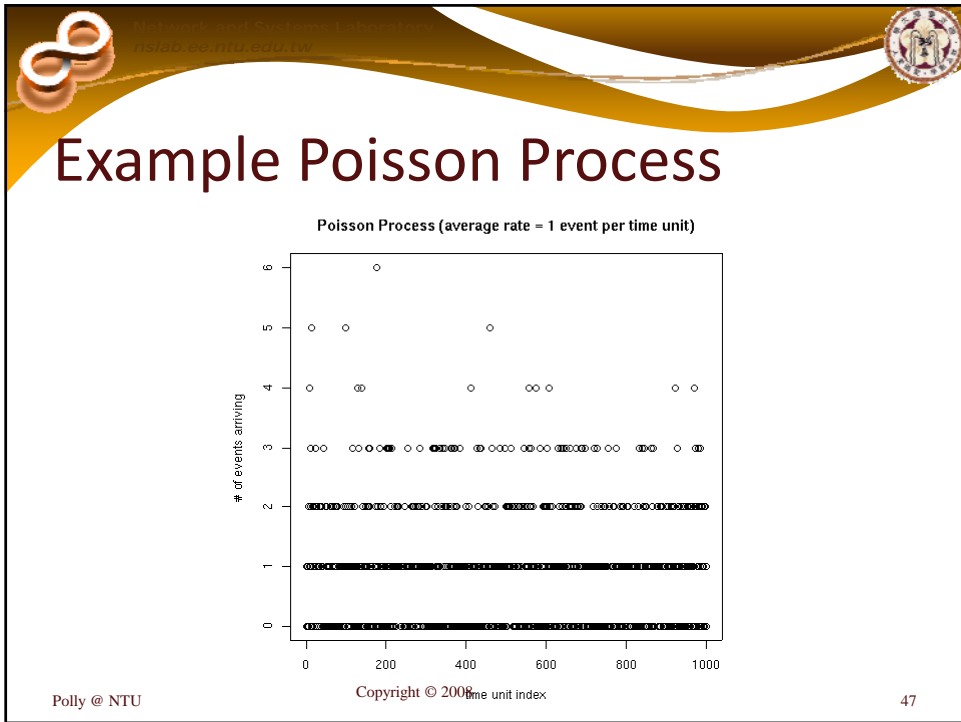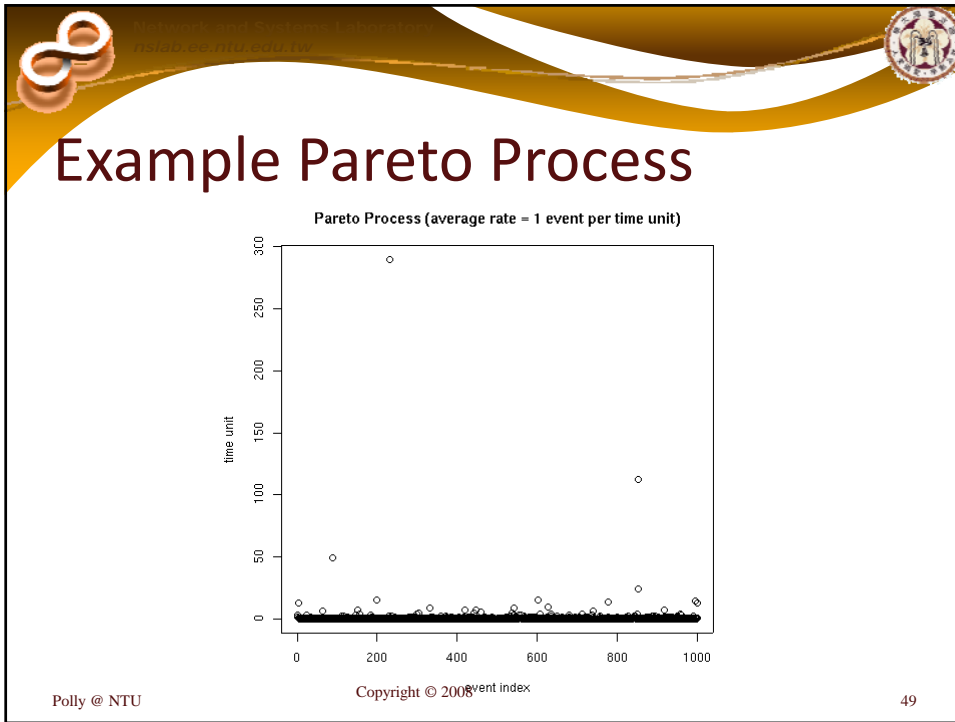
Distinguishing Them

- Density
- Log density
- Log-log density

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Density

Log Density

Log-Log Density

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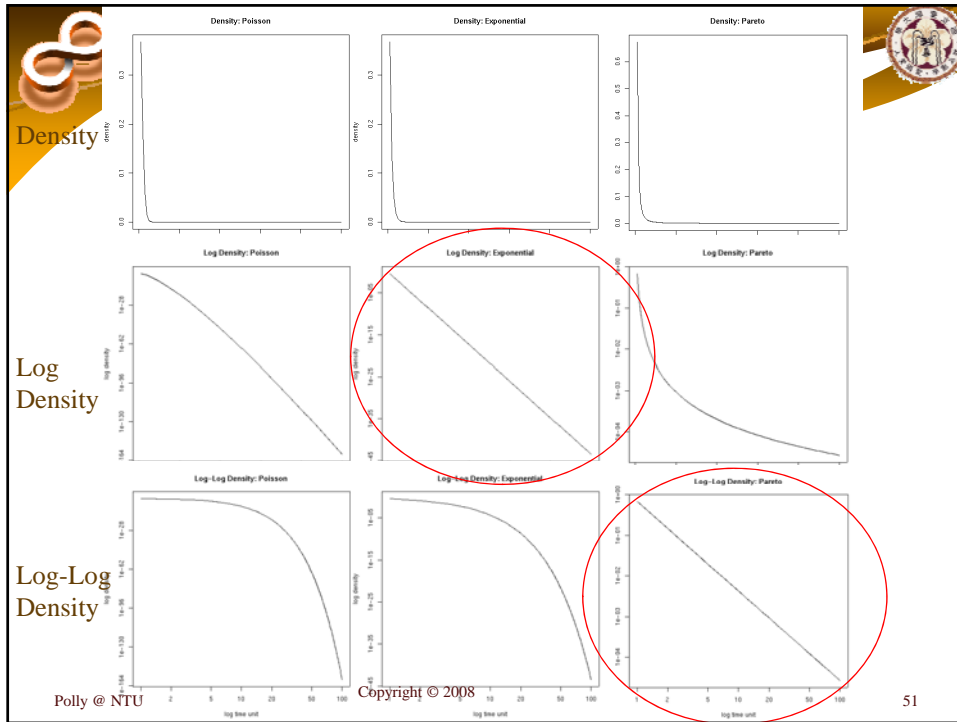
Now, what's with self-similarity…

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Teletraffic vs. Data traffic

- Teletraffic

| | | Exp | Exponential | | | | |

- Data traffic

| | | | Heavy tailed | | | | |

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Measured Internet Traffic   Poisson Process

100s

10s

1s

100ms

10ms

- Performance problem every 1-2 hours (network lags!)
- Profitable business?

- High variability (bursty)
- Long-range dependency
- Self-similarity

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Self-similarity?

- Distributions of #packets/unit look alike in different time scale

Serpgask Triangles

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End of Statistics Review

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Evaluation Methodology

- Math
  - Pen and papers
  - Economical
  - Gives you the **average**
- Simulation
  - Few computers and simulation software
  - Affordable
  - Gives you the **behavior or distribution**
- Implementation
  - Many computers and system software
  - Costly
  - Gives you the **hardware details**

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Which should you use?

Depends on what you care for the problem in hand!

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Assumptions

- It's OK to leave out details
- But
  - You need to be clear what details you leave out.
  - You need to argue it is OK to leave those details out for now.
  - And you are working on including those details and the results will be available in the future.

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Questions?

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Traffic Papers

- V. Paxson, and S. Floyd, Wide-Area Traffic: The Failure of Poisson Modeling. IEEE/ACM Transactions on Networking, Vol. 3 No. 3, pp. 226-244, June 1995
- M. E. Crovella and A. Bestavros, Self-Similarity in World Wide Web Traffic: Evidence and Possible Causes. IEEE/ACM Transactions on Networking, Vol 5, No. 6, pp. 835-846, December 1997
- Anja Feldmann; Anna C. Gilbert; Polly Huang; Walter Willinger, Dynamics of IP traffic: A study of the role of variability and the impact of control. In the Proceeding of SIGCOMM '99, Cambridge, Massachusetts, September 1999
- Vern Paxson. End-to-end internet packet dynamics. ACM/IEEE Transactions on Networking, 7(3):277-292, June 1999

Topology Papers

- E. W. Zegura, K. Calvert and M. J. Donahoo. A Quantitative Comparison of Graph-based Models for Internet Topology. IEEE/ACM Transactions on Networking, December 1997.
- M. Faloutsos, P. Faloutsos and C. Faloutsos. On power-law relationships of the Internet topology. Proceedings of Sigcomm 1999.
- H. Tangmunarunkit, R. Govindan, S. Jamin, S. Shenker, W. Willinger. Network Topology Generators: Degree-Based vs. Structural. Proceedings of Sigcomm 2002.
- D. Vukadinovic, P. Huang, T. Erlebach. On the Spectrum and Structure of Internet Topology Graphs. In the proceedings of I2CS 2002.

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Questions?

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