SZÉCHENYI EGYETEM
UNIVERSITY OF GYŐR

Doctoral School of Multidisciplinary Engineering Sciences (MMTDI)

Performance Analysis of ICT Systems

Lecture 1

Introduction to the methods for performance analysis of ICT systems and presentation of results

https://www.tilb.sze.hu/cgi-bin/tilb.cgi?0=m&1=targyak&2=NGD_MDA64_1

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Agenda

- Reminder: ICT systems
- Introduction to the methods for performance analysis of ICT systems.
- The fundamentals and terminology of modelling and simulation.
- Methods and tricks for presenting results.

Legacy ICT systems

- Standalone systems, dedicated for a single purpose
  - PSTN (analogue, digital), ISDN
  - Cellular phone systems (GSM in Europe, CDMA in the USA)
  - Digital Trunked Radio Systems, e.g. TETRA
  - Analogue/Digital radio broadcasting systems
  - Analogue/Digital video broadcasting (DVB-S/C/T)

IP-based ICT systems

- Common part: Internet Protocol version 4 or 6
- Several solutions to carry the IP datagrams
- A few higher layer protocols over IP
- A high number of application on the top

IP-based ICT systems

- Physical / Data link layer implementations to carry IP datagrams:
  - LAN (Ethernet)
  - Wireless LAN (IEEE 802.11, 11a/b/g/n/ac)
  - [PAN (802.15)]
  - Wired access (ADSL, DOCSIS, FTTx)
  - Wireless access (GPRS, UMTS, HSDPA/HSUPA, LTE)
  - WAN (X.25, frame-relay)
  - SDH (as long distance carrier of IP)

IP-based ICT systems

- Most important protocols
  - TCP/IP protocol stack
    - IPv4/IPv6, ICMP/ICMPv6, TCP, UDP, IGMP/MLD
  - Routing protocols
    - Unicast routing: RIP, OSPF, BGP
    - Multicast routing: PIM-SM/DM, MOSPF, DVMRP
  - QoS Methods
    - IntServ, DiffServ, MPLS
  - Higher layer protocols
    - RTP, RTCP; RTSP

IP-based ICT systems

- Network Applications
  - DNS
  - SMTP, POP3/POP3S, IMAP4/IMAP4S,
  - FTP, NFS, SMB, HTTP/HTTPS,
  - TELNET, SSH, SCP
  - SIP, H.323
  - IPTV
  - BitTorrent

Typical questions

- Many times not really technical, sometimes vague and not clear…
  - What are the limits of the system?
  - What performance reserve does the system have?
  - What will be the delay and jitter, if…?
  - How much extra traffic may be allowed to the system, while maintaining certain QoS parameters?
  - Where are the bottlenecks?
  - What kind of resources should be added?

Typical questions

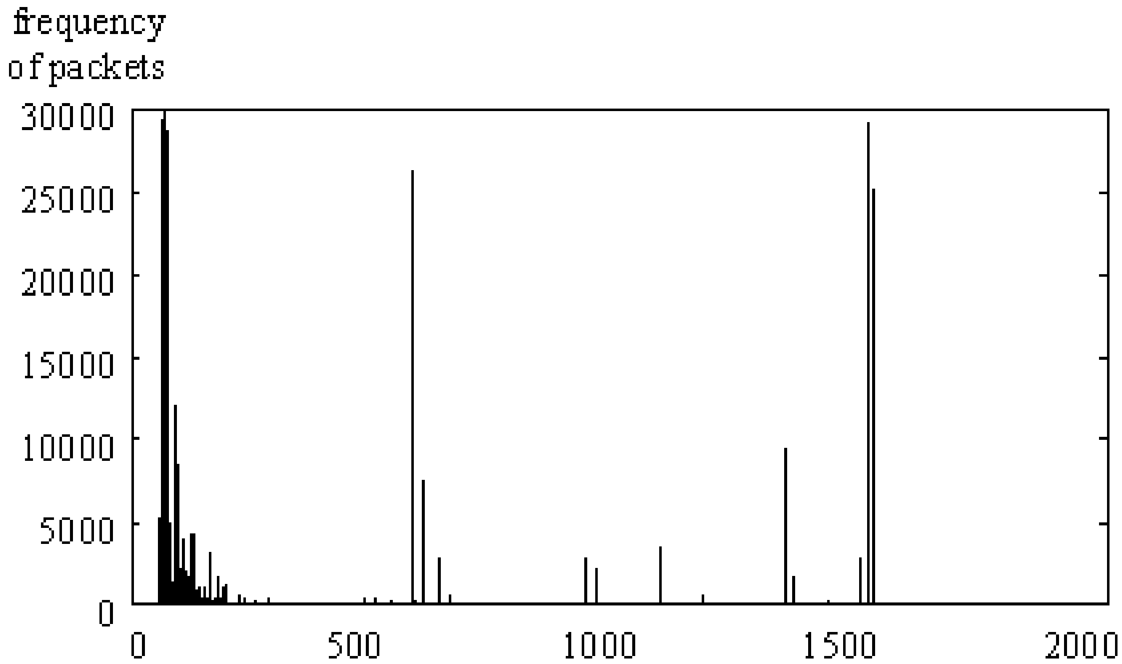
- Many times not really technical, sometimes vague and not clear…
  - After adding given resources, how certain performance characteristics will change?
  - Based on the current trends, what can we expect at a later point of time?

Methods of Performance Analysis

- Measurements (taken on a real system)
- Analytical method (mathematical examination)
- Simulation (experimentation on a computer executable model of a system)

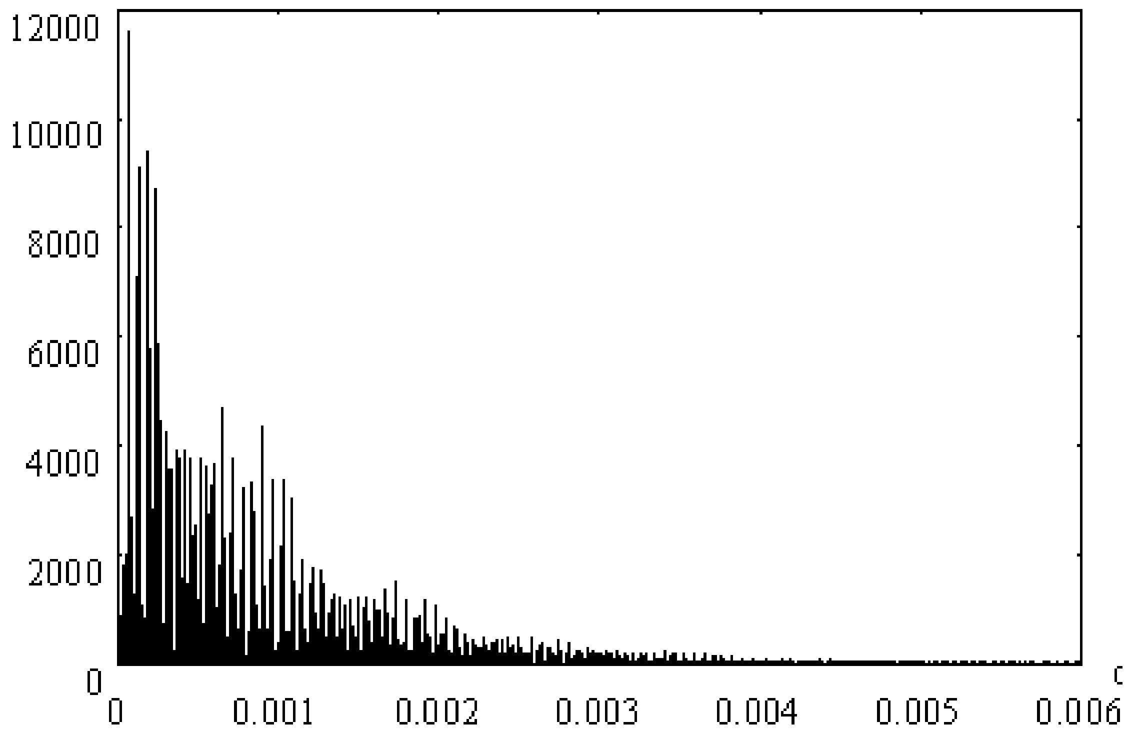
Measurements

- Can give the most accurate and reliable results
- Very important, necessary for the other two methods, too
- Examples:



Packet length statistics measured on the FDDI backbone of BUTE in 1996.

Measurements



*Inter-arrival time statistics** measured on the FDDI backbone of BUTE in 1996.

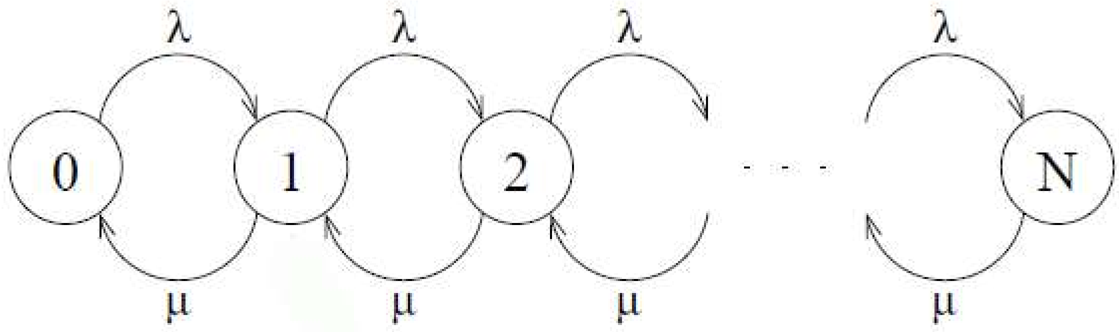
**The frequency of the events that so long time (measured in seconds) elapsed between the arrival of two consecutive packets*

Problems with Measurements

- The examined system MUST exist
  - It is costly and time consuming to build it
  - Its building elements may not be available yet
- A measurement is an intervention into the operation of the examined system
  - Is it allowed? Trust, legal, security, safety problems
- Problems and cost of the execution
  - Measurement devices, experts, …
  - Collection and evaluation of the results

Analytical Method

- We have good models for simple cases
  - Queueing theory is well established
    - Markov chains



    - Poisson process: the new requests arrive with exponential inter-arrival time
  - Simple cases do not characterize our real systems well enough
  - There are solvability problems in complex cases

Simulation: Model Creation

- We build a *computer executable model* of the system to be examined
  - The model is a simplified version of the system to be examined
  - The model can be executed by computer
  - The model characterizes the system well regarding the properties important for us
    - Medicine tests: a mouse is a model of humans
    - At a shop window: manikin is a model of humans
  - We always build a model <u>for a purpose</u>!

Simulation: Experimenting

- We design the experiments (depending on the aims of our investigations)
- We perform the experiments on the model and collect “measurement” results
- We evaluate our results
  - We may get answers to our questions (ready)
  - We may need further experiments
    - → go back to the design of experiments
  - We may need to improve our model
    - → go back to model building

Advantages of Simulation

- Can be carried out if the system to be examined (or even its building elements!) do not exist yet
- Types of experiments may be carried out, which are impossible on a real system
  - e.g. nuclear power plant, Internet
- May have much less cost than building a real system or even than experimenting on an existing system
- Good models may produce sufficiently accurate results

Limitations of Simulation

- Model building is time consuming
- Detailed models may result in unacceptably long execution time
- How well the results of the simulation characterize the modelled system?
  → Validation

Simulation of ICT Systems – Step 1

- Model creation
  - Model the building elements of the system
    - Study the operation of the given building element
    - Model its properties important for our purposes
  - Model the traffic of the System
    - Either based on traffic measurements on the modelled system
    - Or by modelling the applications
  - Build the model of the system from the elements
    - Need to acquire the topology of the system, the exact types of the elements and their configuration data

Detour: Stakeholders of Model Building

- We suppose that a consultation company works for a company operating a large system
  - The one who knows the real system (e.g. its planner, builder or operator)
  - Simulation professional (knows the methodology of the simulation and the used modelling system)
  - The management of the companies involved
- Important: What can each stakeholder expect from the project?

Simulation of ICT Systems – Step 2

- Design of the experiments – depends on the purpose of the analysis, it can be
  - To find the bottleneck(s)
  - To find the root cause of anomalies
  - Preparations for the introduction of new services
  - Preparations for reconstruction, update, adding further elements, etc.
- Important
  - What input parameters to be used?
  - What should be observed?

Simulation of ICT Systems – Step 3

- Execution of the experiments
  - Collect “measurement” data
  - Continue/repeat the simulation, until the required statistical accuracy of the measurement data is achieved

Simulation of ICT Systems – Step 4

- Evaluation of the results
  - Machine processing of a high amount of data
  - Filter out events interesting for us
    - E.g. the utilization of a resource is > 90%
  - Presentation of the results
    - Using tables, graphs, perhaps on the network topology
- Draw conclusions
  - Refine the model, design/execute new experiments, if necessary
- Presentation to the customer (management)

Types of simulation

- According to the time of the model
  - Continuous: the state of the system changes continuously
    - E.g.: water flows in a pipeline
  - Discrete: the state of the system changes in well defined discrete time points or we take them into consideration in this way
    - E.g. digital circuit, computer network, telephone network

    Called: Discrete-Event Simulation (DES)

Types of Discrete-Event Simulation

- According to the operation of the algorithm
  - Time-driven: the time of the model is increased by fixed steps
    - E.g.: in digital telephony, sampling happens in every 125µs
  - Event-driven: the occurrence of the events drives the operation of the simulation
    - This is more general, we deal with this one

Operation of the event-driven DES

- Future Event Set (FES)
  - Stores the events to occur in the future

Timestamp	Event
0.000000	Transmission of frame #0 begins
0.000100	The head of frame #0 arrives to the receiver
0.000512	Transmission of frame #0 ends
0.000612	The tail of frame #0 arrives to the receiver

Algorithm of the event-driven DES

```
Initialization: put staring event(s)
 into the FES;
REPEAT
  Remove the event with the lowest
   timestamp from the FES;
  NOW := the timestamp of the removed
   event;
  Process the event and schedule new
   events, if necessary;
UNTIL (NOW > limit)OR(no more events)OR
 (we must stop for some reason)
```

Basic concepts of event-driven DES

- Virtual time (also called: model time)
  - The time measured in the model
- Execution time (also called: wall clock time)
  - The time measured by the real-time clock of the computer executing the simulation

  - Causality requires that virtual time as a function of execution time be non-decreasing.
    - It is allowed that multiple events have the same timestamp. Execution of events with equal timestamps happens in the order they were put into the FES (unless overridden by their priorities).

A few definitions to learn

- **Modelling** (or model creation) is a *human activity* that builds a kind of (typically simplified) variation of a real (existing or imagined) system, which can be handled by a toolset (called modelling system).
- **Simulation** is an *experiment* carried out using a computer executable model.

A few definitions to learn

- **Emulation** is the *replacement* of a software or hardware by another software or hardware, the operation of which as a black box is the same as that of the original one, but its internal operation may be totally different.
- Comparison:
  - Simulation: experimenting
    - A flight simulator can be used for pilot training, but we can not travel by it
  - Emulation: replacement for normal use
    - An emulated CPU must give the same result as the original

A few definitions to learn

- **Monte Carlo simulation** is a special case of simulation; it follows random events and neglects some precise timing.
- **Trace-driven simulation** uses the precise data set of events experienced in a real system as its input.

A few definitions to learn

- **Verification** checks if the model is well implemented in the simulator. (debugging)
  Question: “Does this program work correctly?”
- **Validation** checks if the given model represents the real system well, and if questions regarding the real system can be answered using the given model.
  Question: “Is this program the right one?”

How to Handle Measurement Results?

- Measurement results may come from
  - Measurements taken on a real system
  - Measurements taken during simulation
- The rule is the same
  - **Measurements MUST be executed multiple times!**
  - The necessary number of repetitions to achieve reliable results depends on the actual measurement.

How to Handle Multiple Results?

- We use a summarizing function, usually either *average* or *median*.
  - Average is more inclusive and less sensitive to noise, but it is more sensitive to outliers.
- Using only a single number would result in oversimplification.
- To express indices of dispersion we can use
  - Standard deviation
  - Minimum and maximum
  - Percentiles, e.g. 1st percentile and 99th percentile

A Simple Example

minimum -------->	**1370**	1371	1100
10 percentile --->	**1390**	1389	1390
	1410	1411	1410
	1430	1429	1430
	1450	1451	1450
median ---------->	**1500**	1499	1500
	1550	1551	1550
	1570	1569	1570
	1590	1591	1590
90 percentile --->	**1610**	1609	1610
maximum ------->	**1630**	1631	1630
average:	1500	1500.09	1475.455
standard deviation:	94.34	94.35	150.16

Results of Measurement Series…

- In practice, we often use several input parameters in simulation. For example:
  - Number of clients
  - Number CPU cores used in the router
- They can have a few typical meaningful values
  - It is called “parameter study”, when all their possible combinations are used. Their results form…
    - A (single dimensional) table (1 parameter)
    - A matrix (2 parameters)
    - An N dimensional hypercube (N parameters)

Tips for Presentation of Results

- Graphs are easier to overview than tables, but graphs do not always substitute tables.
- Try to add all possible information to the figures.
- At the same time, require minimum effort from the readers to interpret the results.
- The validity of the results should also appear (in the Figure, or in its caption.)

Example 1

- Is there an easy to recognize trend?
- How many graphs are condensed into a single one?
- What could error bars mean?

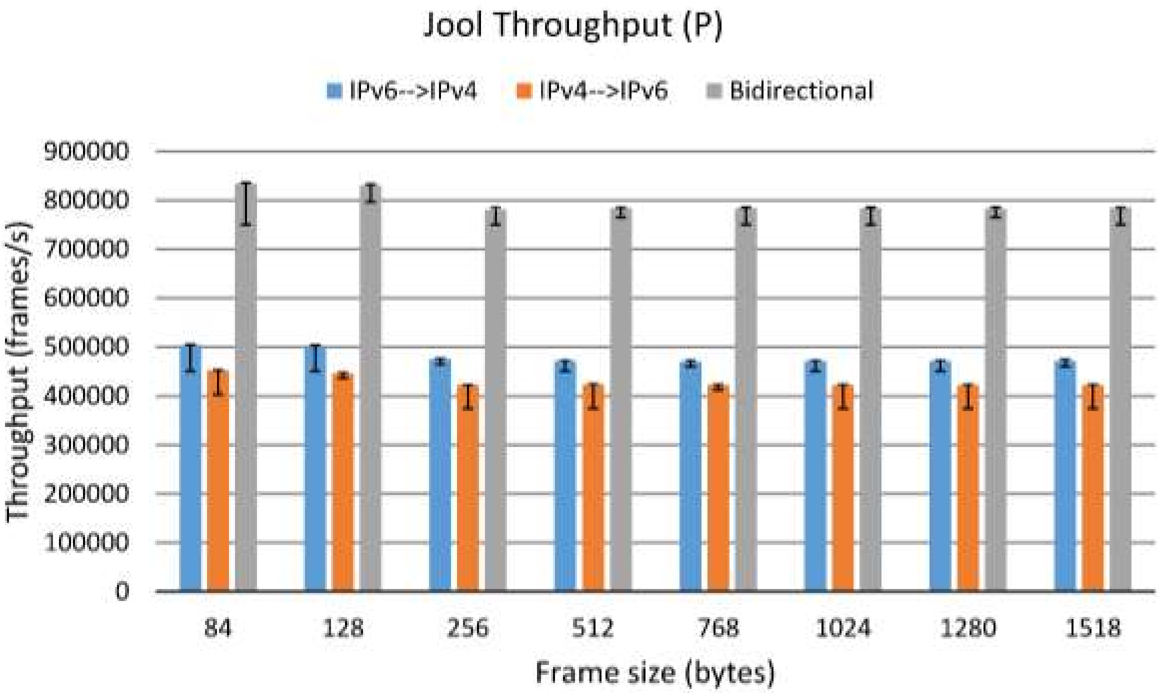


Fig. 4. Throughput results of Jool, TS2.

Source:

G. Lencse, K. Shima, "Performance Analysis of SIIT Implementations: Testing and Improving the Methodology“, *Computer Communications*, vol. 156, no. 1, pp. 54-67, April 15, 2020, DOI: 10.1016/j.comcom.2020.03.034

Example 2

- Is there an easy to recognize trend?
- How many input parameters can you observe?
- What other tip is demonstrated?

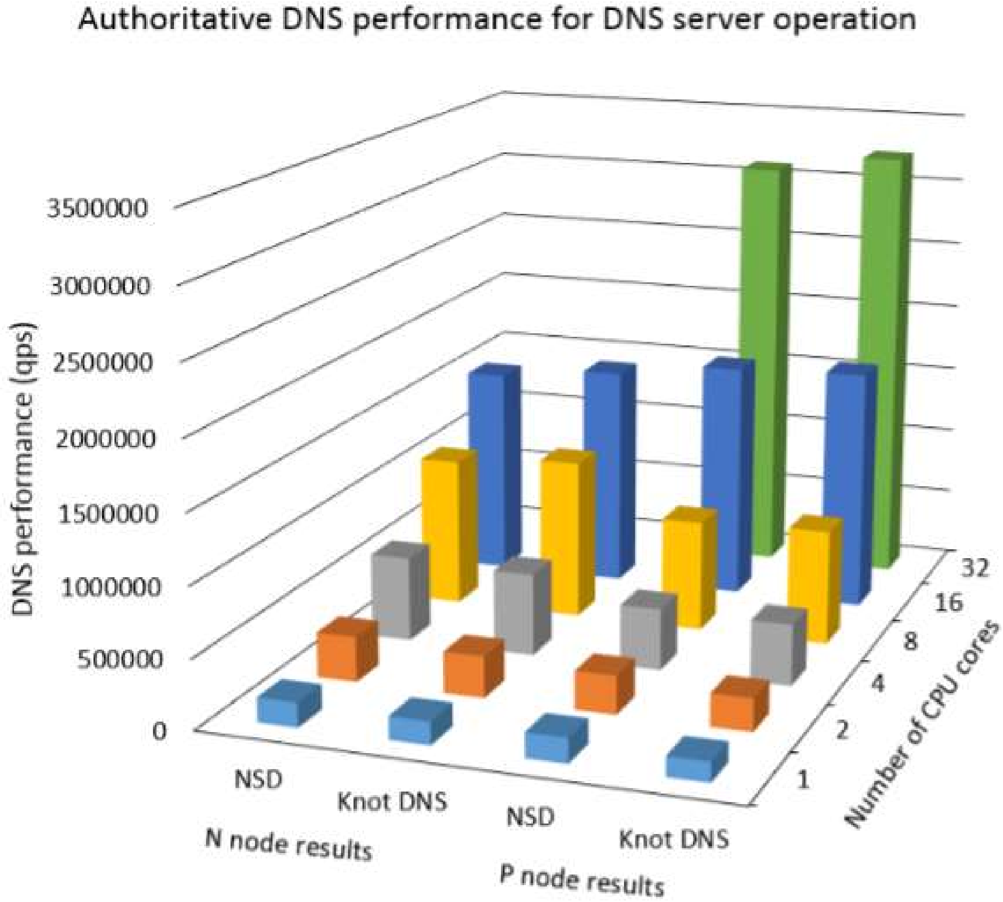


FIGURE 3. Comparison of NSD and Knot DNS for DNS server operation. (The N node result of Knot DNS at 16 cores are limited by Tester performance.)

Source:

G. Lencse, "Benchmarking Authoritative DNS Servers“, *IEEE Access*, vol. 8. pp. 130224-130238, July 2020. DOI: 10.1109/ACCESS.2020.3009141

Example 3

- Can you see a valid reason for using a table (and not a graph)?

Table 13 DNS64 Performance: BIND, Forwarder, Opteron

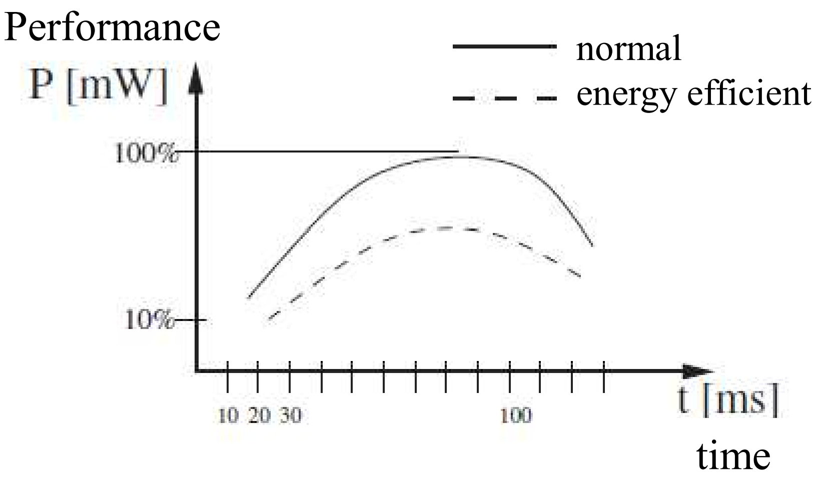
1	**Operating System**		**Linux**				**OpenBSD**				**FreeBSD**			
2	**Number of clients**		**1**	**2**	**4**	**8**	**1**	**2**	**4**	**8**	**1**	**2**	**4**	**8**
3	**Exec. time of**	average	0.067	0.098	0.213	0.409	0.094	0.188	0.382	0.783	0.082	0.121	0.239	0.479
4	**256 DNS**	std. dev.	0.005	0.007	0.017	0.018	0.006	0.005	0.007	0.015	0.010	0.005	0.008	0.012
5	**queries (s)**	maximum	0.140	0.170	0.290	0.530	0.180	0.260	0.440	0.860	0.490	0.160	0.290	0.540
6	**CPU utiliza-**	average	57.91	72.20	63.00	69.92	26.15	27.22	27.42	27.28	66.88	87.82	88.68	89.52
7	**tion (%)**	std. dev.	0.95	1.38	3.02	2.45	0.85	0.87	0.98	0.93	2.10	1.76	1.76	1.74
8	**Memory cons. (MB)**		49.992	80.691	147.262	277.242	38.324	67.652	123.117	233.848	62.609	94.406	169.414	303.613
9	**Number of requests served in a second (req./s)**		3838	5208	4816	5003	2721	2724	2682	2615	3130	4215	4290	4272

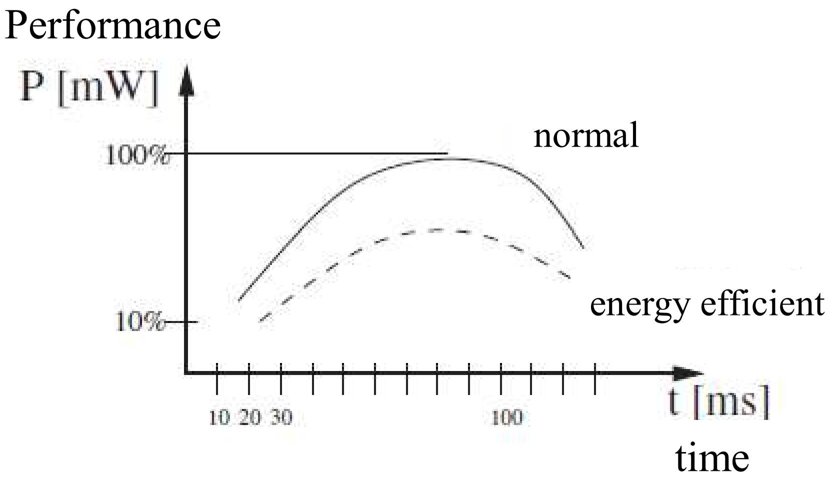
Source:

G. Lencse and S. Répás, "Performance Analysis and Comparison of Four DNS64 Implementations under Different Free Operating Systems“, *Telecommunication Systems* (Springer), vol 63, no 4, pp. 557-577, DOI: 10.1007/s11235-016-0142-x

Tips for Presentation of Results

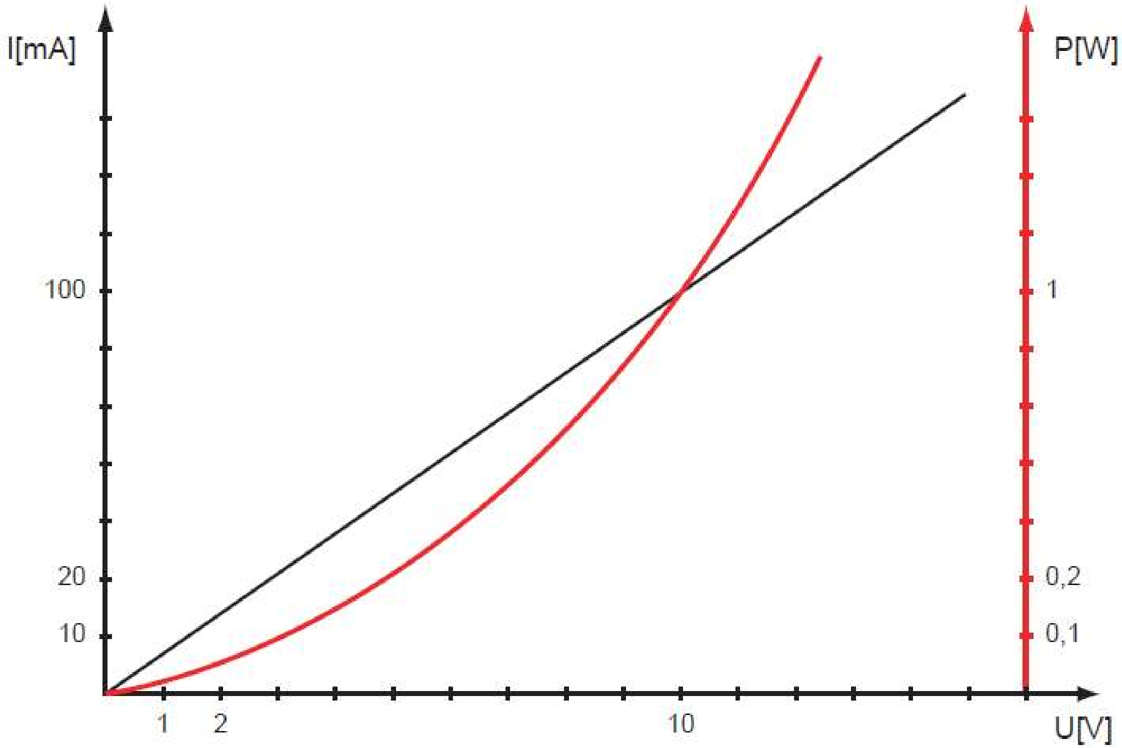
- Use a legend, or if possible, write in the meaning of the graphs into the figure





Tips for Presentation of Results

- Multiple quantities may be displayed as a function of the same independent variable (on the horizontal axis), but no more than two scales should appear on the vertical axis.



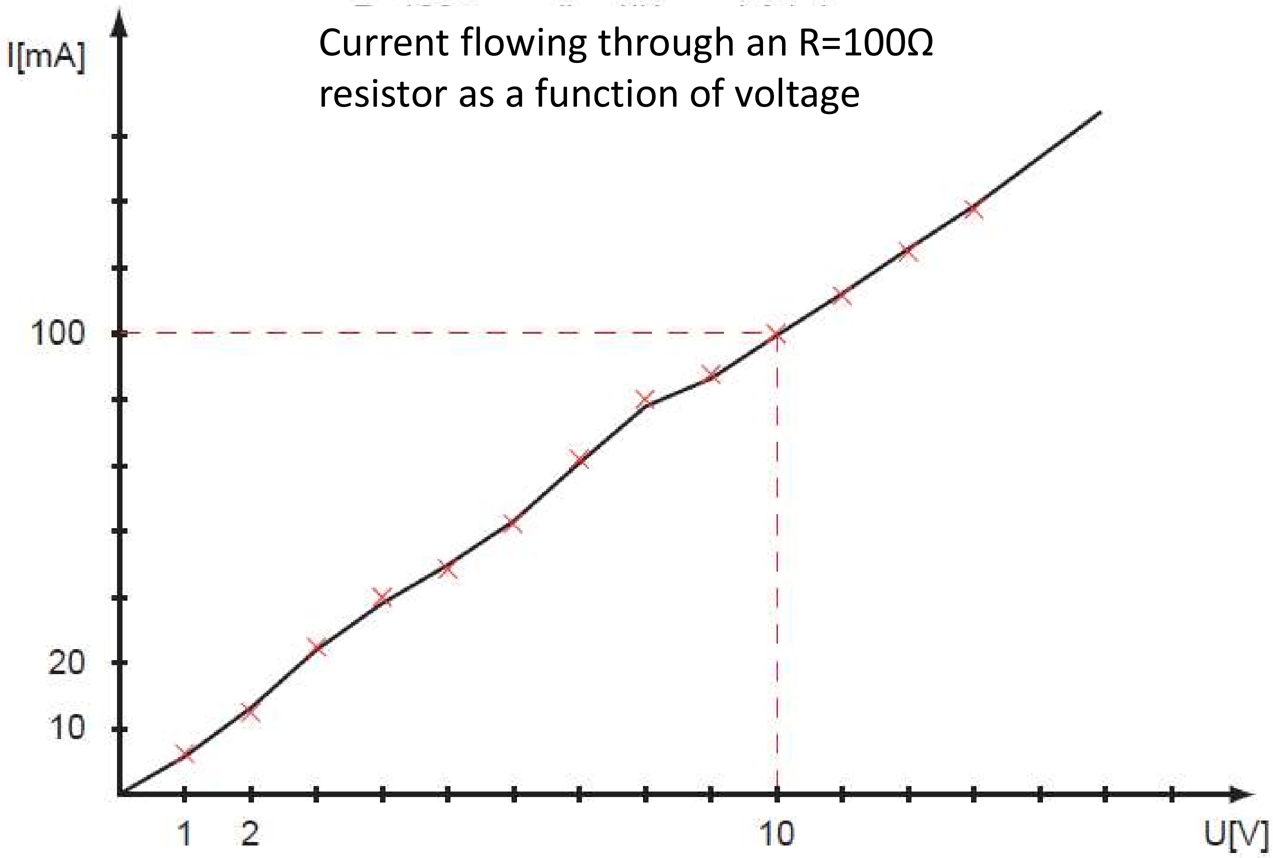
Tips for Presentation of Results

- It is worth using colors, if possible
- Choice of colors
  - Dark on white or vice versa is good

    But this is hardly readable on a projector
  - Select colors that look good together
    - Let us prepare beautiful presentations and papers. ☺
  - Our work should remain recognizable in black and write printing, too
    - We can use different line widths, different line styles (e.g. dashed, dotted lines, etc.)

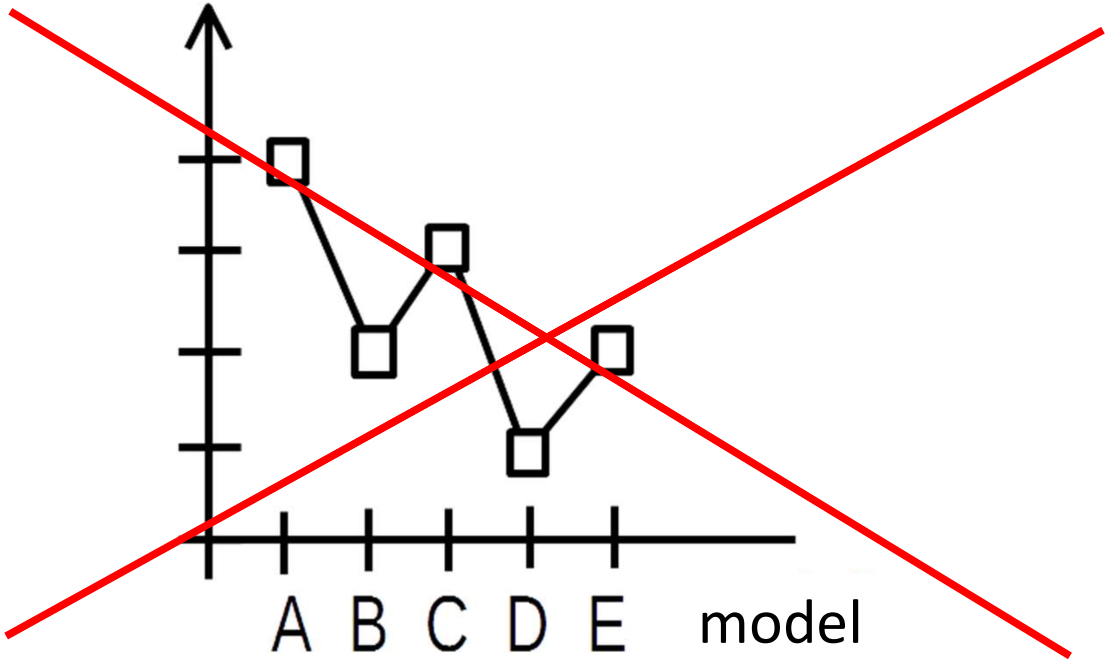
Tips for Presentation of Results

- If measurement results belong to a continuous function, they can be connected



Tips for Presentation of Results

- If measurement results do not belong to a continuous function, they should not be connected!

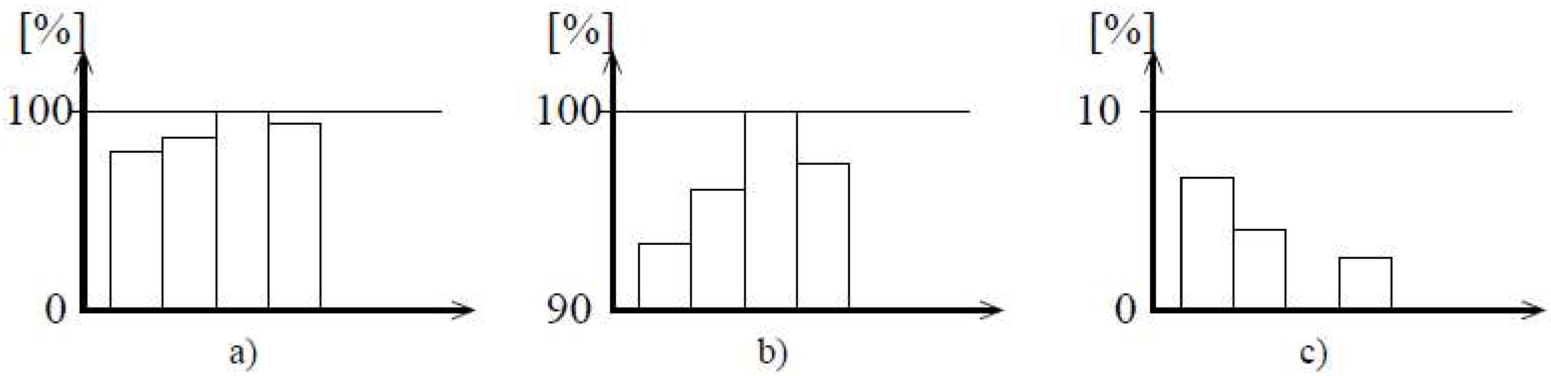


Tricks for Presentation of Results

- Tricks can be used for
  - emphasizing real facts, making things easier to observe
  - cheating
    - Please, do not do it!
    - But please be aware of it, especially when viewing ads!

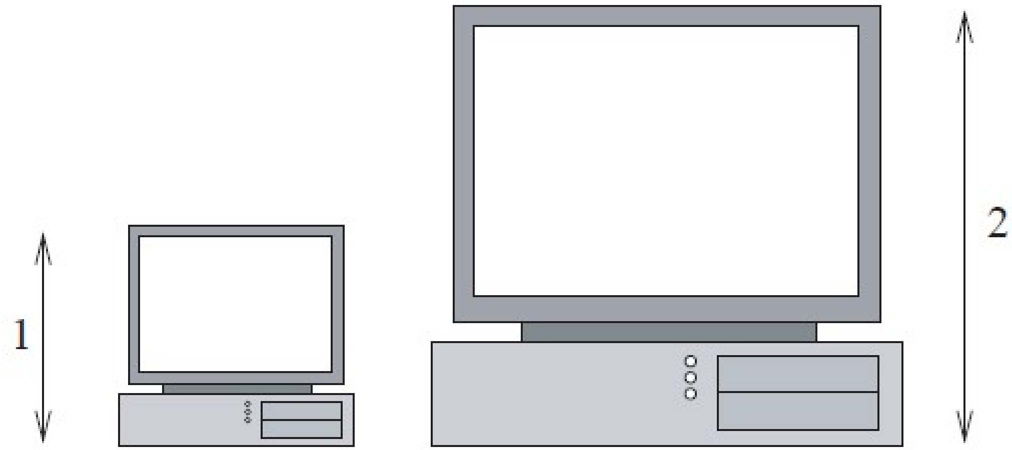
Tricks for Presentation of Results

- Gaming with the scale
  - We have exam results between 90% and 100%.
    a) expresses that all students are good
    b) shows the differences
    c) shows their mistakes



Tricks for Presentation of Results

- Instead of columns having equal widths, *two dimensional pictograms* are used
  - This is cheating: our vision senses their area: the twice as large icon seems to be four times as large!

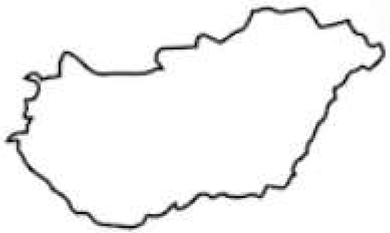


Tricks for Presentation of Results

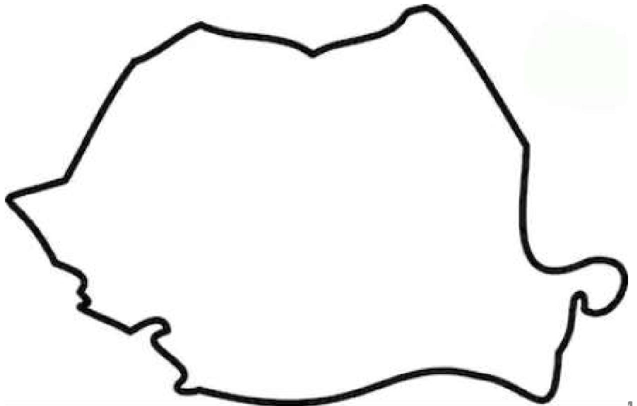
- Usage of certain *relative characteristics* is also suitable for <u>cheating</u>!
  - Number of wheels / Number of engine stokes
    - → An old East German car “Trabant” is better than a Lamborghini

4/2=2 > 4/4=1

  - Number of astronauts / number of inhabitants
    - → Hungary is better than Romania

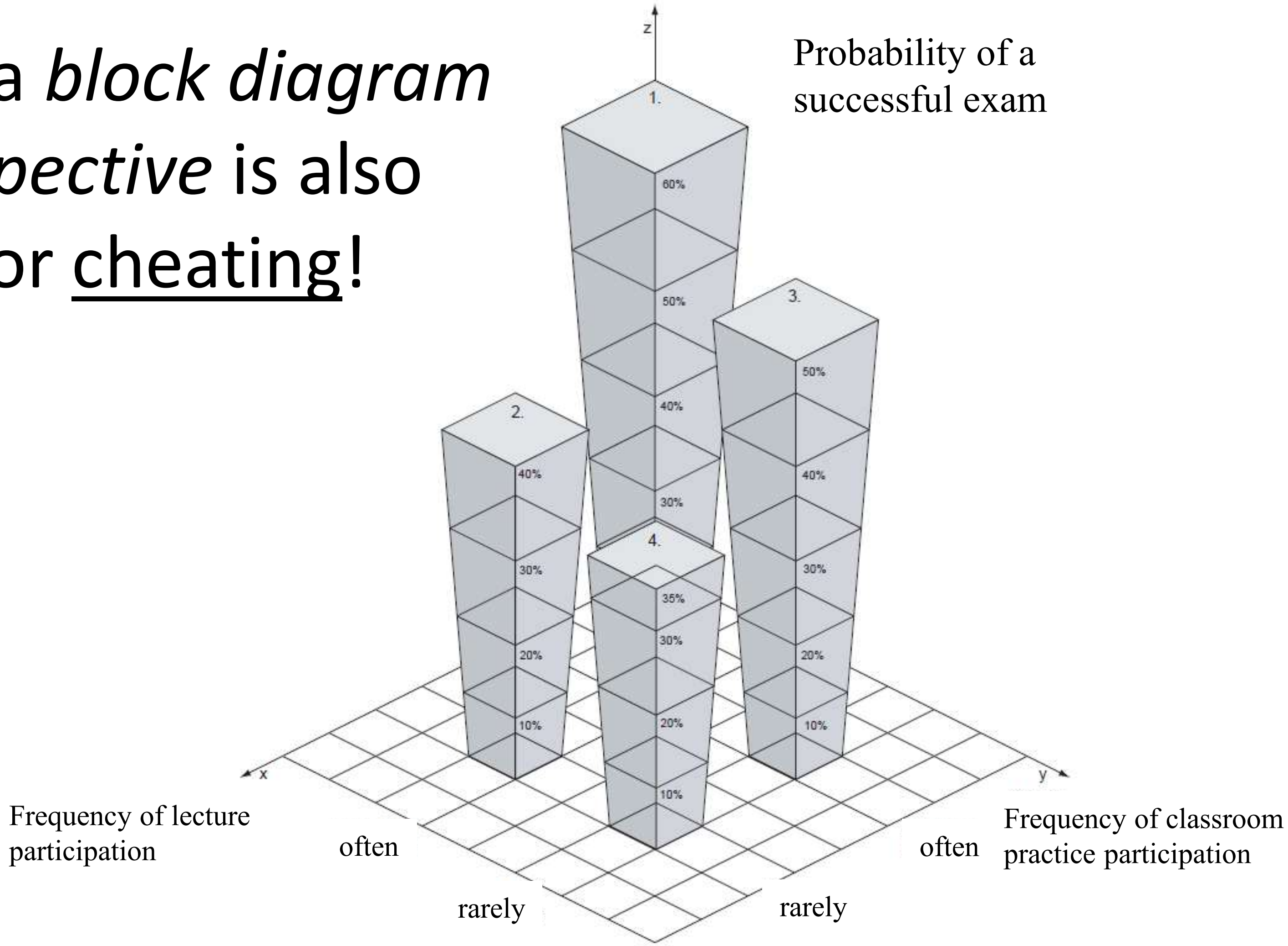


1/1,000,000 > 1/20,000,000



Tricks for Presentation of Results

- Usage of a *block diagram with perspective* is also suitable for cheating!



Sources

- Ray Jain, “The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling”, Wiley-Interscience, New York, 1991.
- György Pongor, “Kommunikációs rendszerek szimulációja”, an MSc course about simulation of ICT systems (in Hungarian), BME, VIK, 1993.

Thank you for your attention!

Questions?

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