Experimental Approaches in Computer Science

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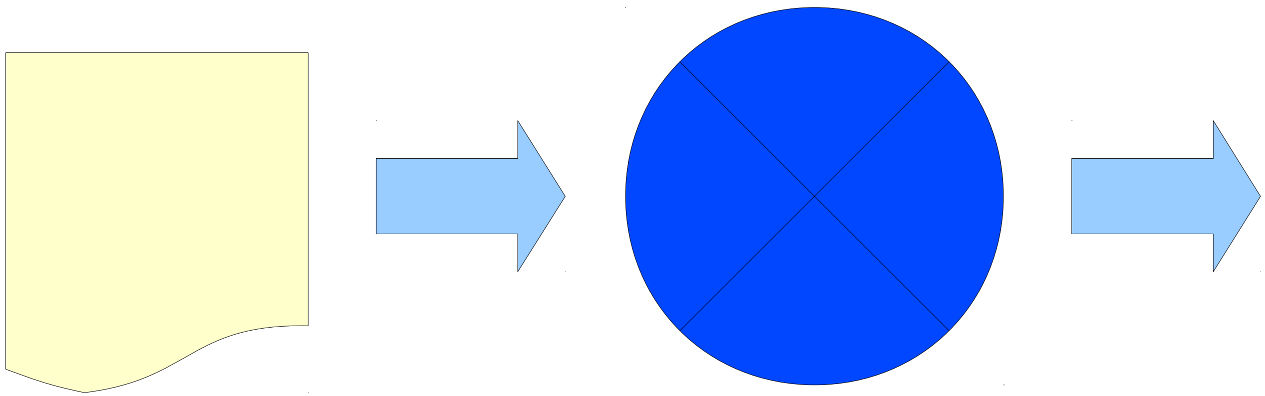
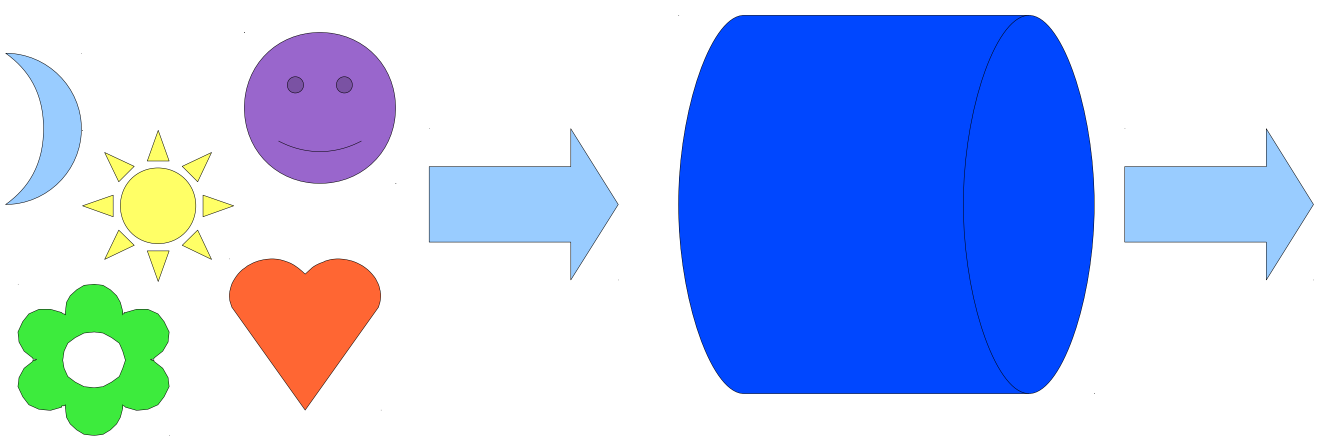
Lecture 7 – Observations about Workloads

In algorithm analysis, performance depends on the input



worst case over all possible inputs

In systems analysis, the input is the workload

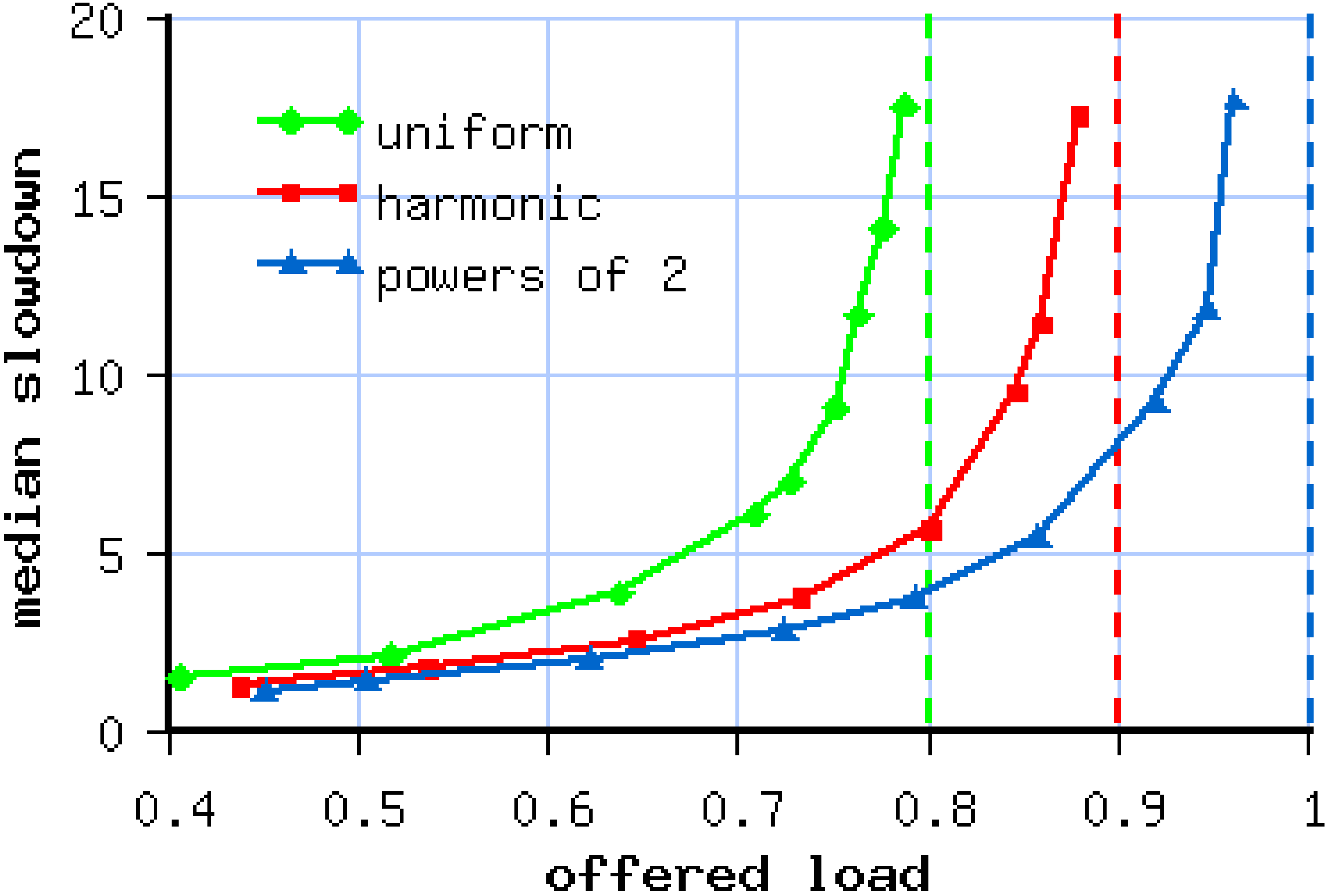


average case over all possible workloads

The main requirement from workloads is that they be representative

- Lead to *exactly the same* performance evaluation results as will occur with real production workloads
  - Include all and only the important features
  - Need iterative evaluations to find what is important
- Or lead to *qualitatively similar* performance evaluation results
  - Reliably conclude that approach A is better than B
- Or at least exhibit the same *general behavior*
  - Include known features because they might be important

Example: packing parallel jobs for execution depends on the distribution of sizes. A uniform distribution suffers the worst fragmentation



Sources of workload data

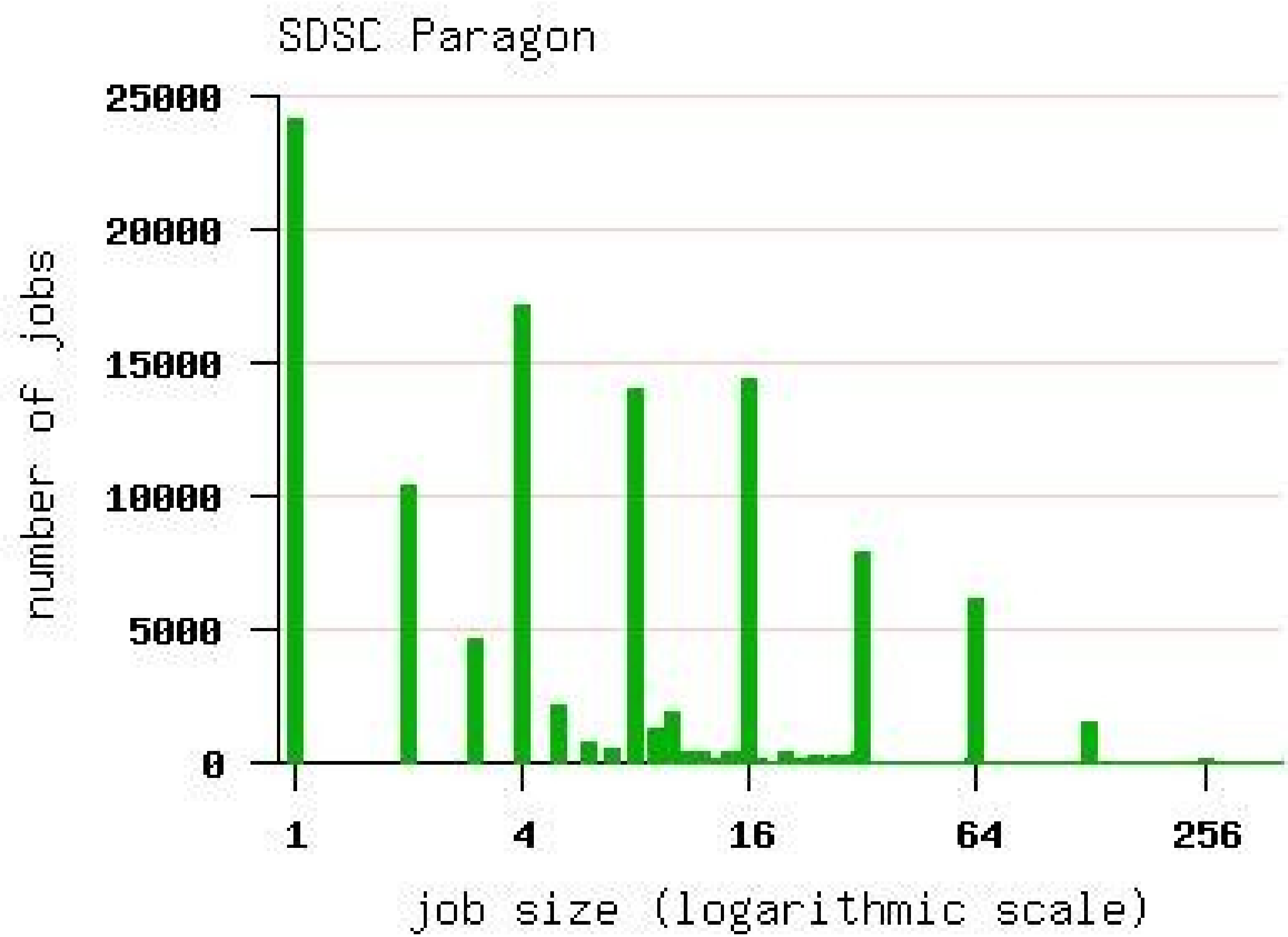
- Active instrumentation
  - Network sniffers to record packets
  - Instrument an I/O library to record operations
  - Collect data from architecture counters
- Use available data
  - Many systems collect data for accounting
  - Web server access logs
  - Parallel Workloads Archive
    www.cs.huji.ac.il/labs/parallel/workload/

Workload Statistics

- Typical way to characterize or model a workload is using statistics
- Distributions of workload attributes
- Correlations among workload attributes
- All this is based on experimental observations

Distributions may be modal

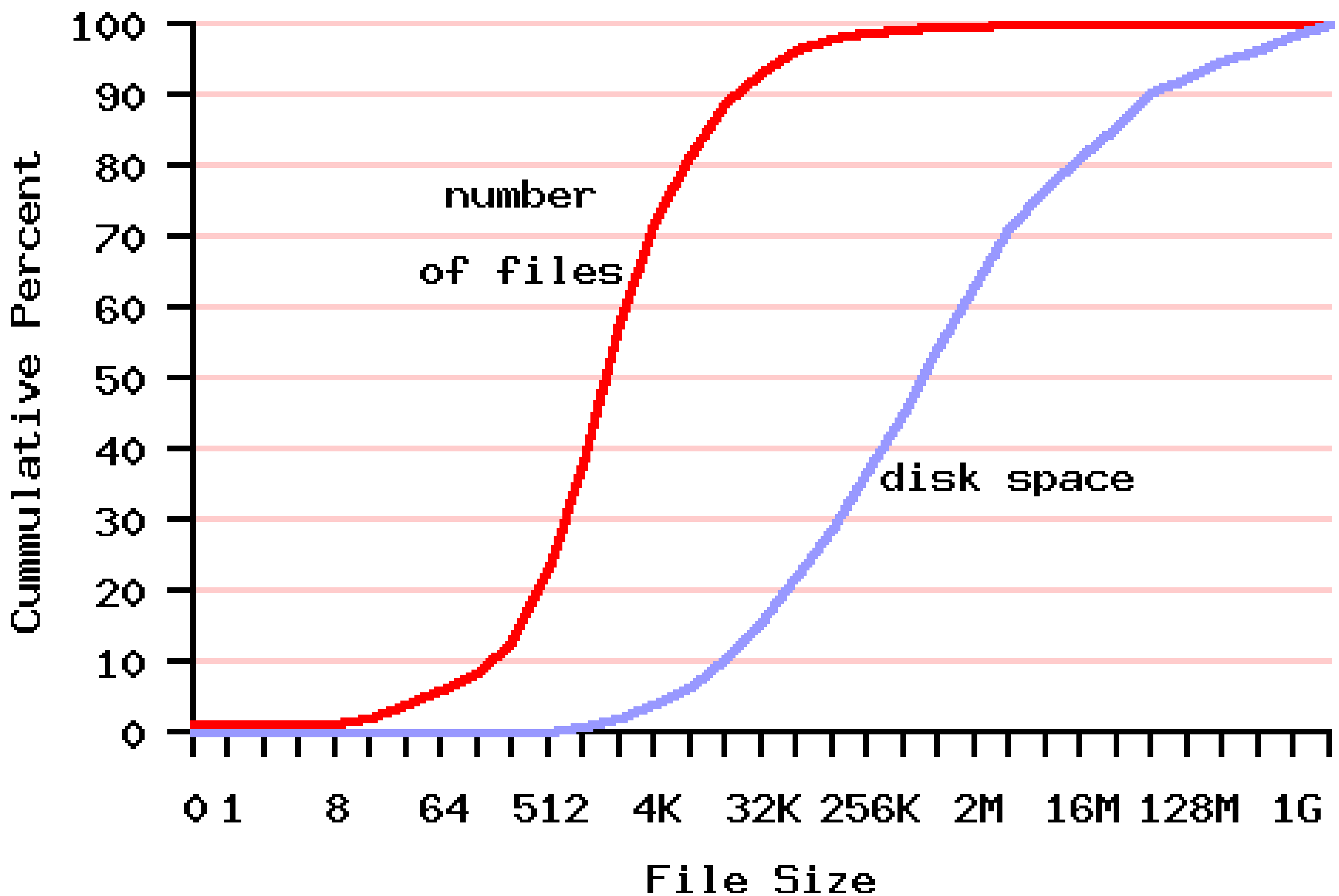
- File sizes
- Parallel job sizes
- Network packet sizes



Distributions may be heavy tailed

- File sizes
- Process runtimes
- Web page popularity

(more on this later)



Arrival processes tend to be bursty

- Not well-modeled by a Poisson process
- Do not average out when aggregated
- Fluctuations in load at many different time scales

(more on this later)

Many workloads tend to display locality

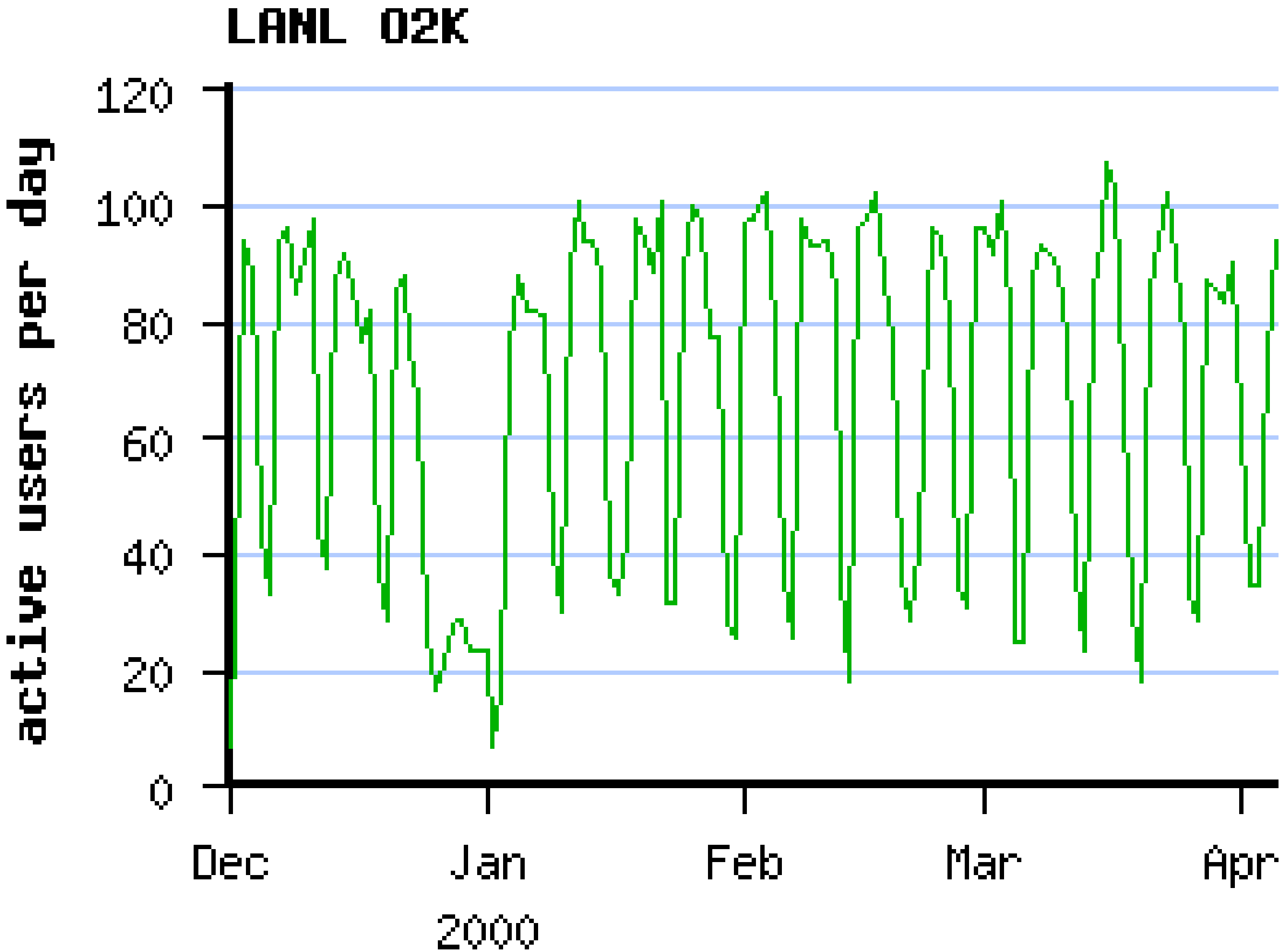
- Not well-modeled by a random sampling from a distribution
- Significant short-range correlations
  - Repetitions of the same activity
  - Repetitions of the same sequences
- Adaptation and evolution over longer ranges

(more on this later)

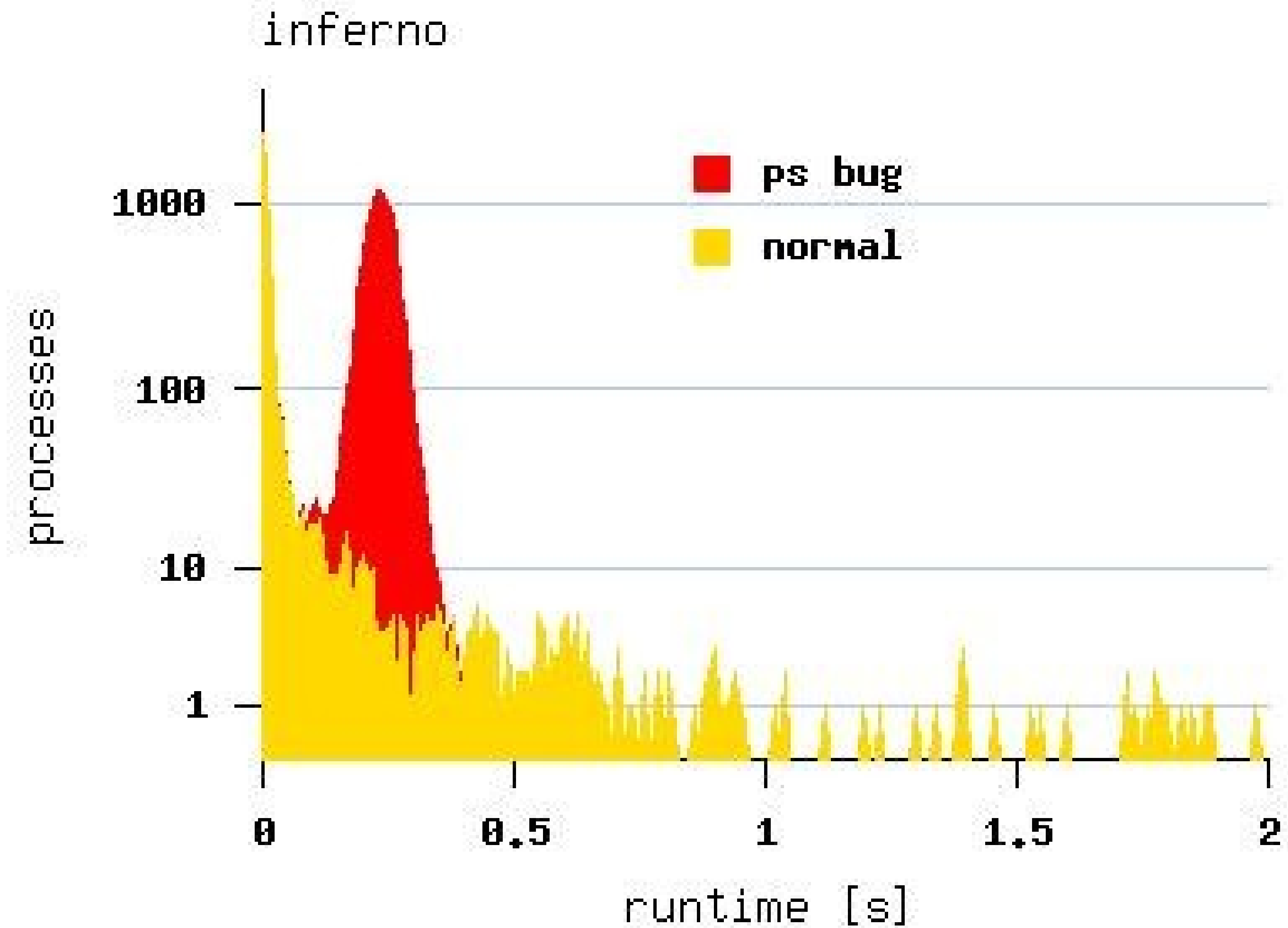
Data Cleaning

- Workload data may be multiclass
  - A mixture of different workloads
- We may be interested in only part of them
  - Real user work as opposed to system administrator activity
  - User applications as opposed to the OS
  - Human users as opposed to bots
- Especially if one class is actually junk
  - Errors in tabulating the data
  - Unique and unrepresentative activity
- Undesired data should be filtered out

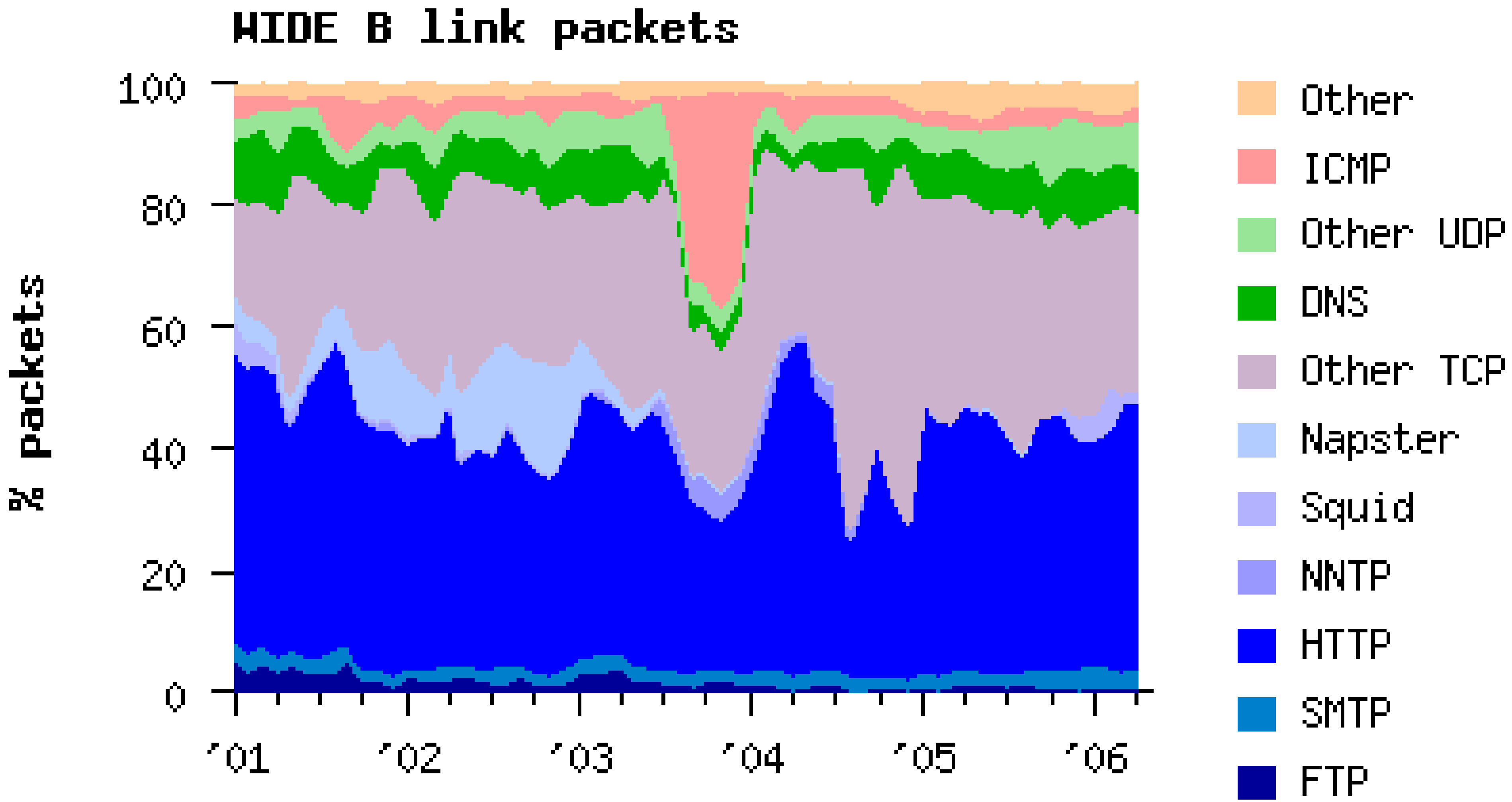
Example: weekends and holidays are different



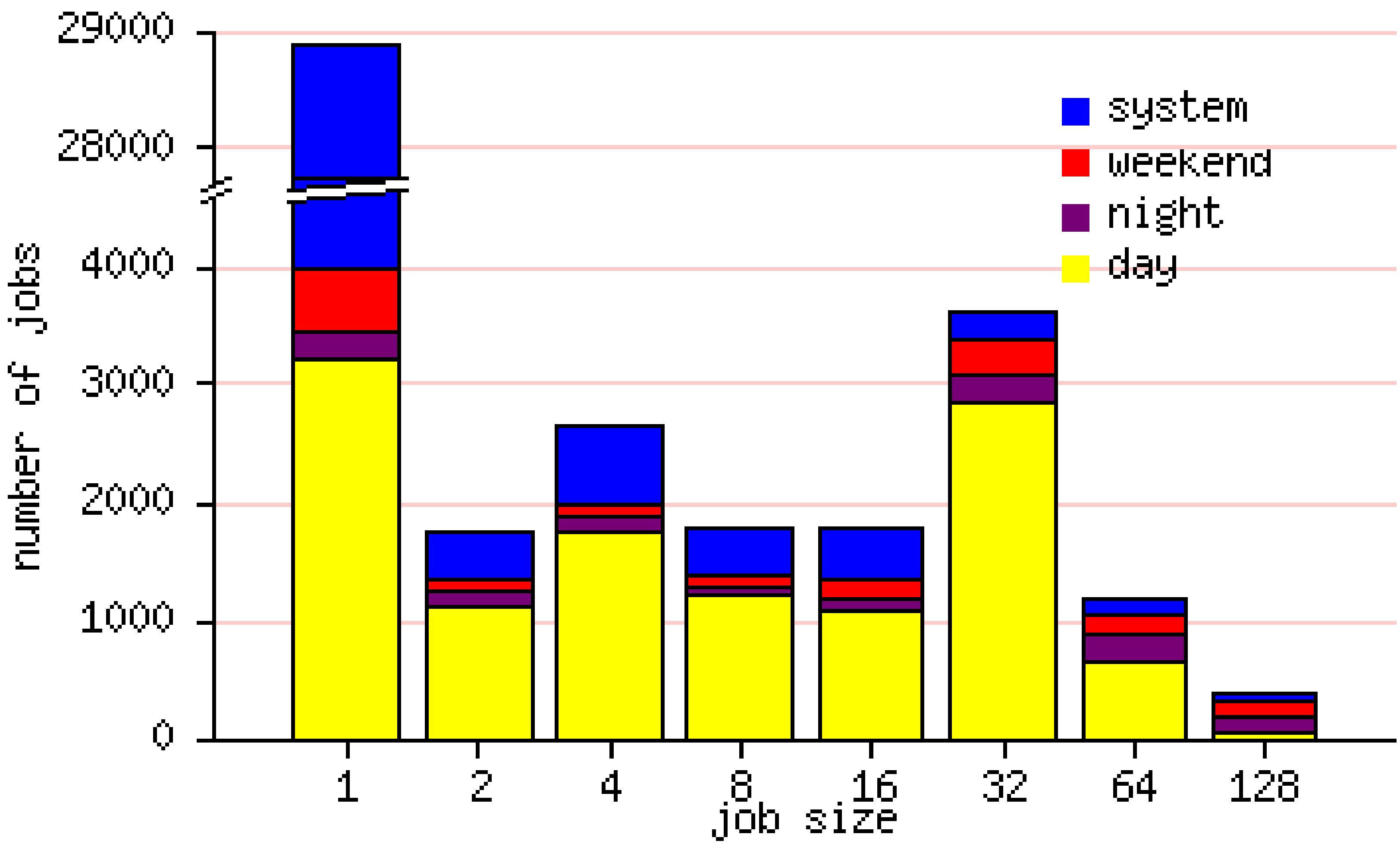
Example: process runtime data including multiple processes running ps as a result of a bug in an OS exercise



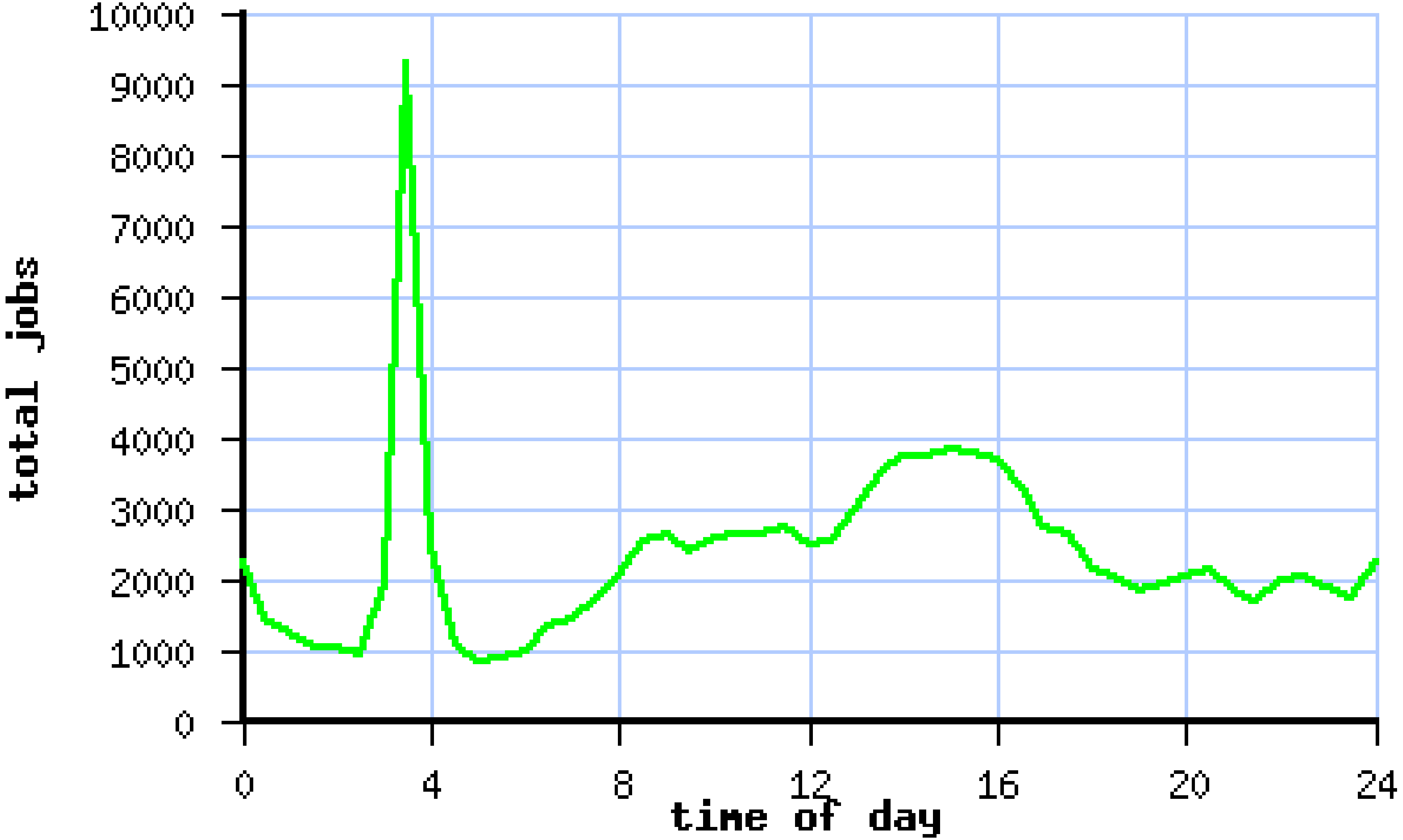
Example: the Welchia worm caused a change in Internet traffic composition that lasted 4 months



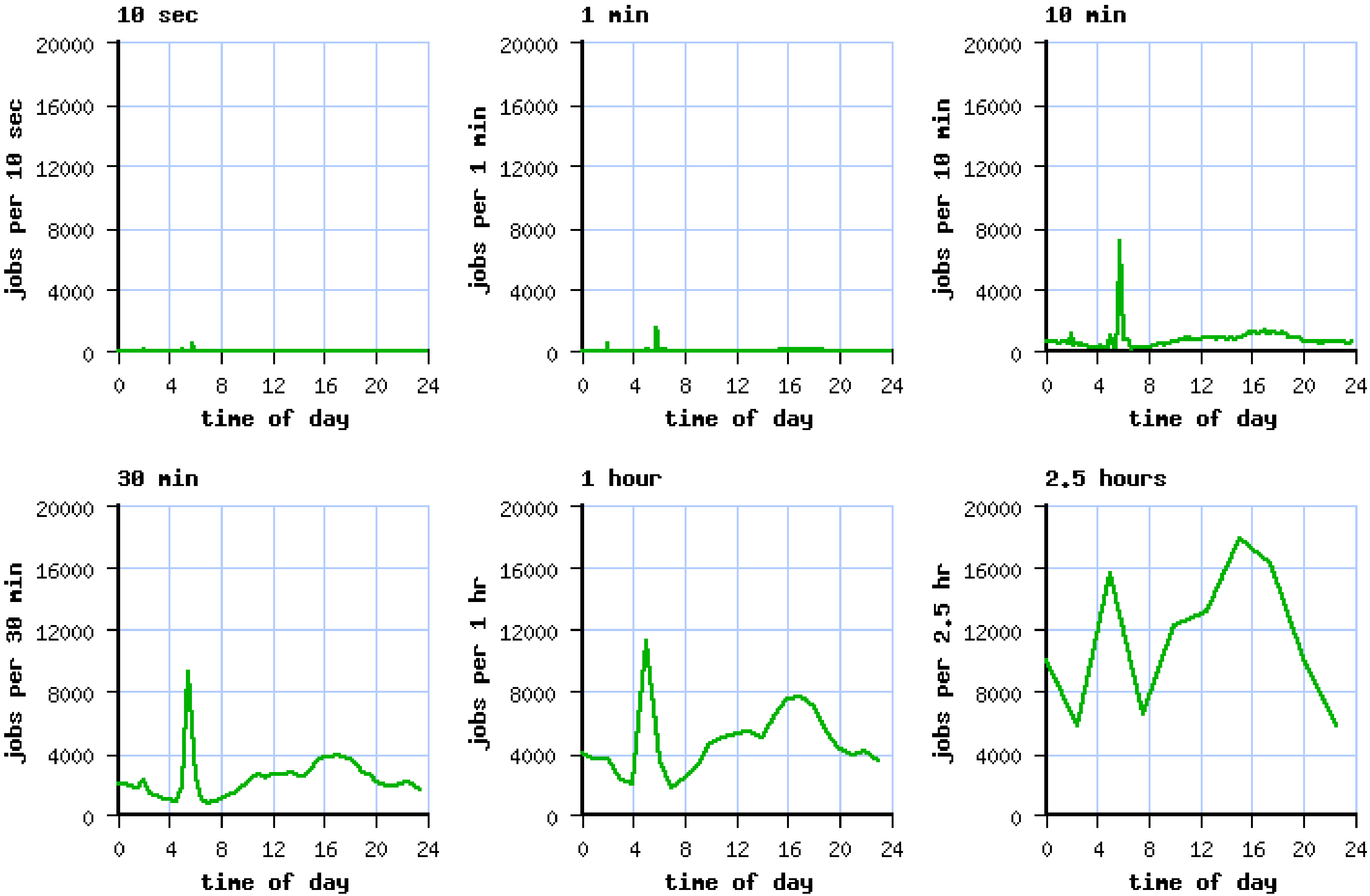
Example: half of NASA Ames iPSC workload was system administrators running pwd on one node to verify that the system was responsive



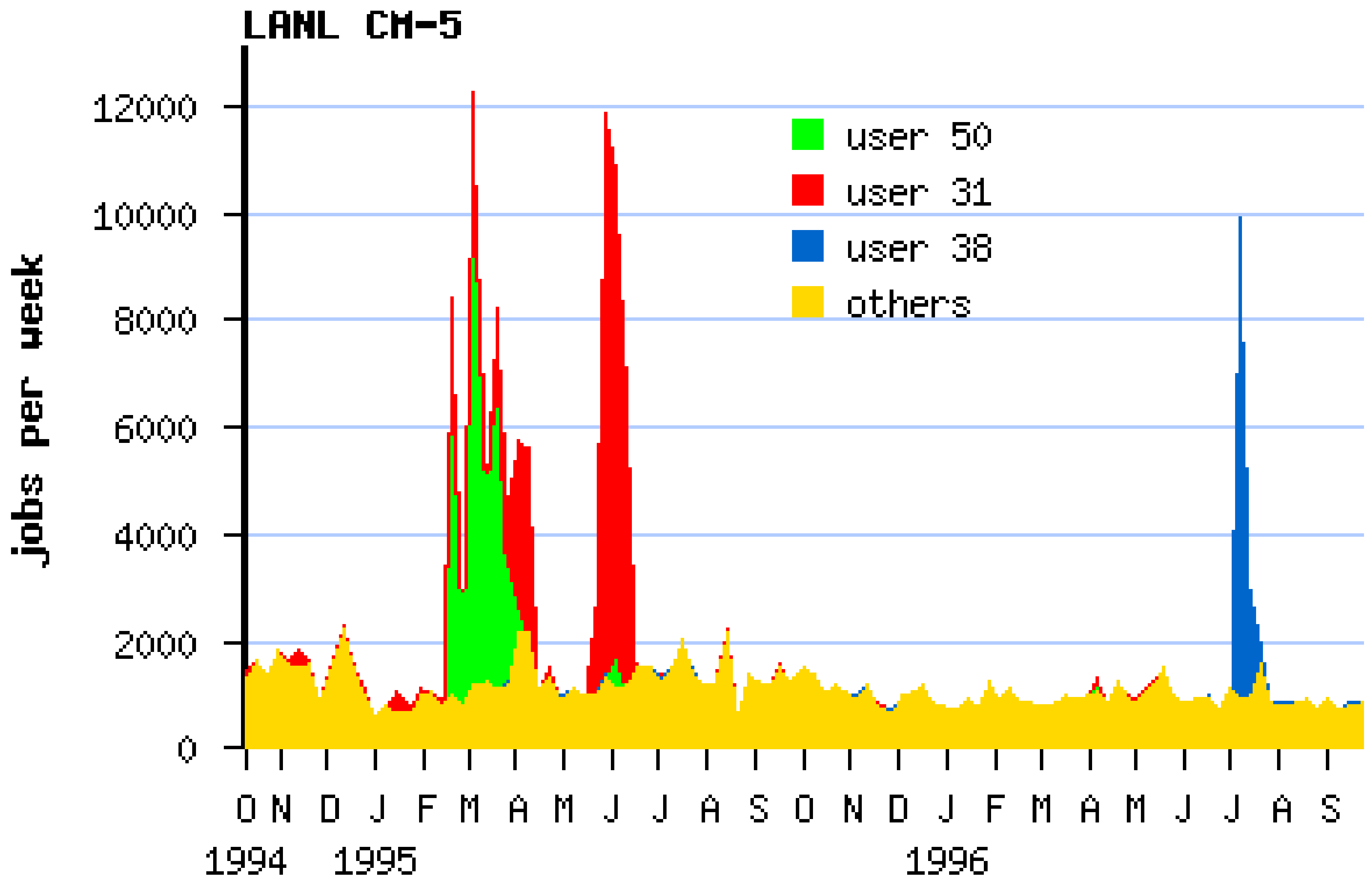
Example: SDSC Paragon has a suspicious peak of activity at 3:30 AM (probably daily cleanup)

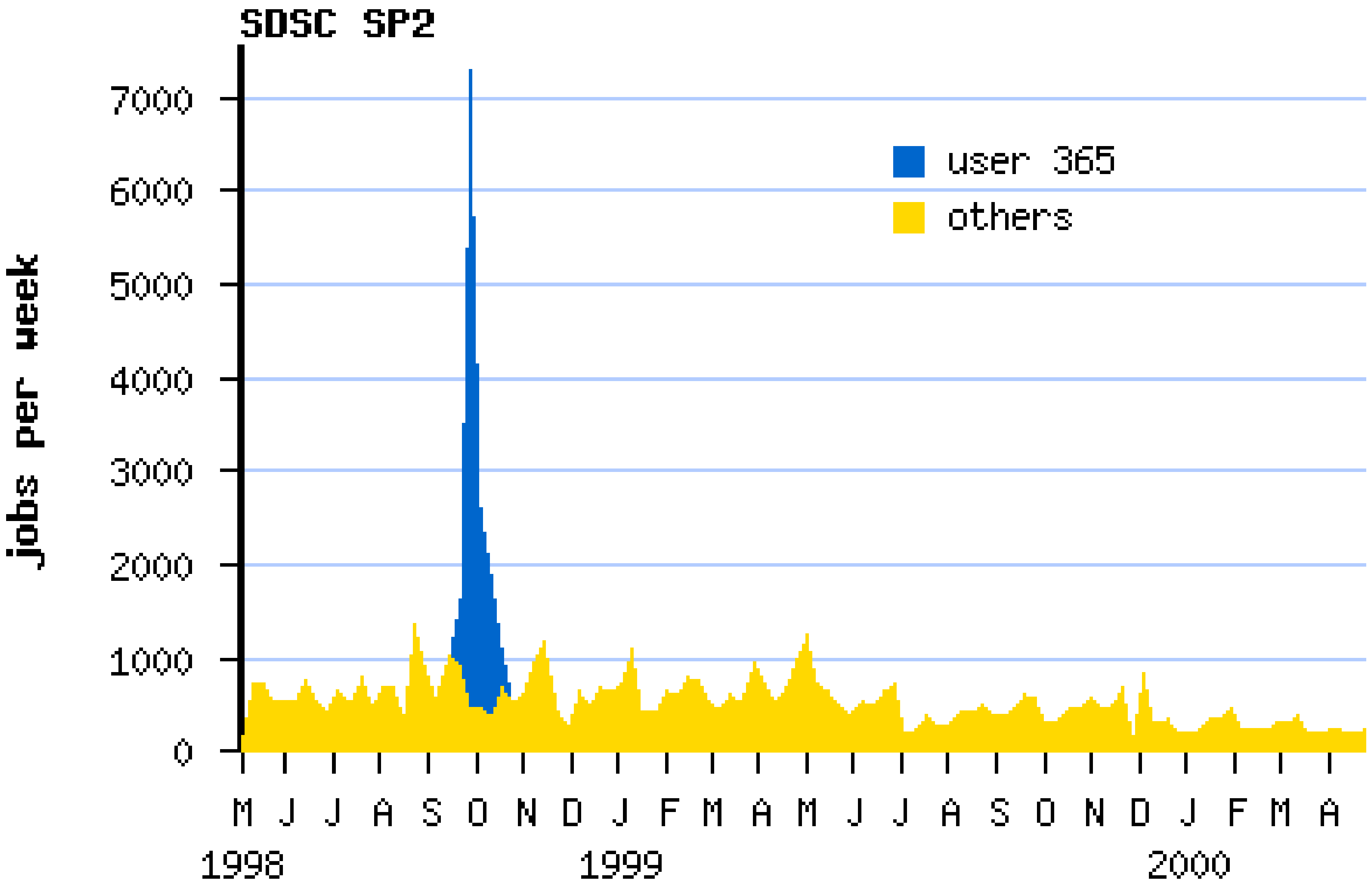


Need to set the resolution right to see this

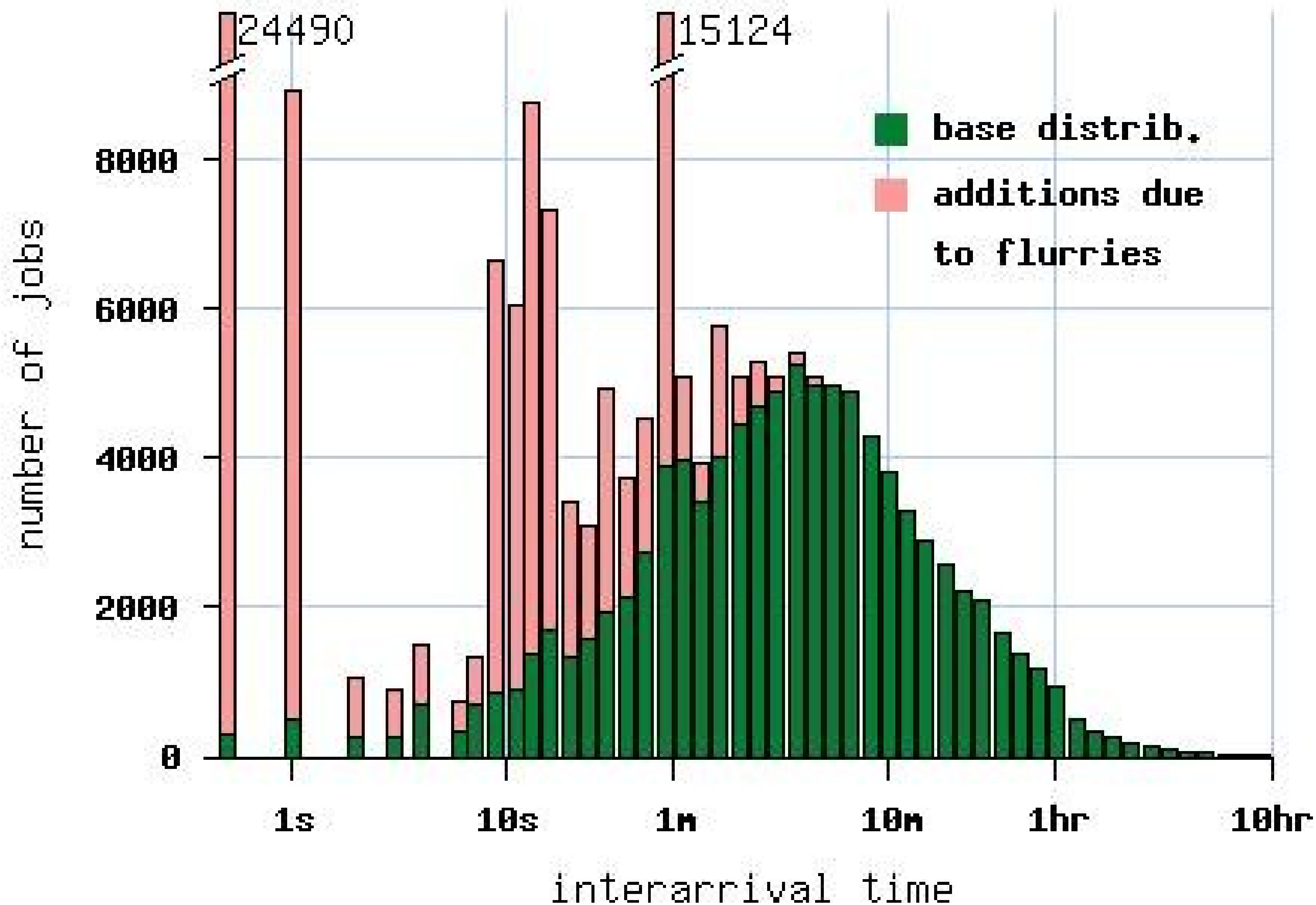


Example: workload may include flurries of intense activity by specific users

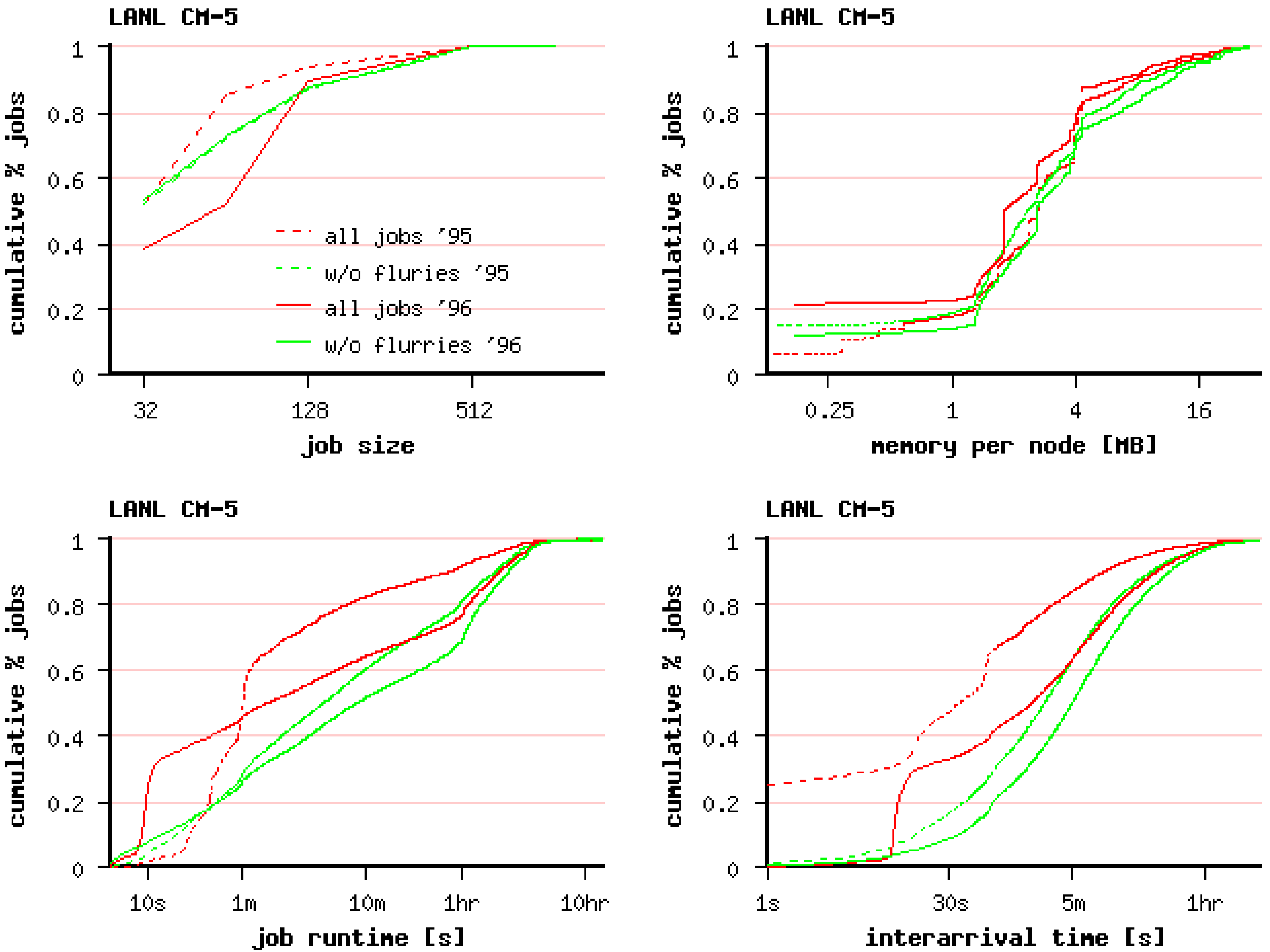



SDSC SP2
jobs per week
7000
6000
5000
4000
3000
2000
1000
0
user 365
others
M J J A S O N D J F M A M J J A S O N D J F M A
1998
1999
2000

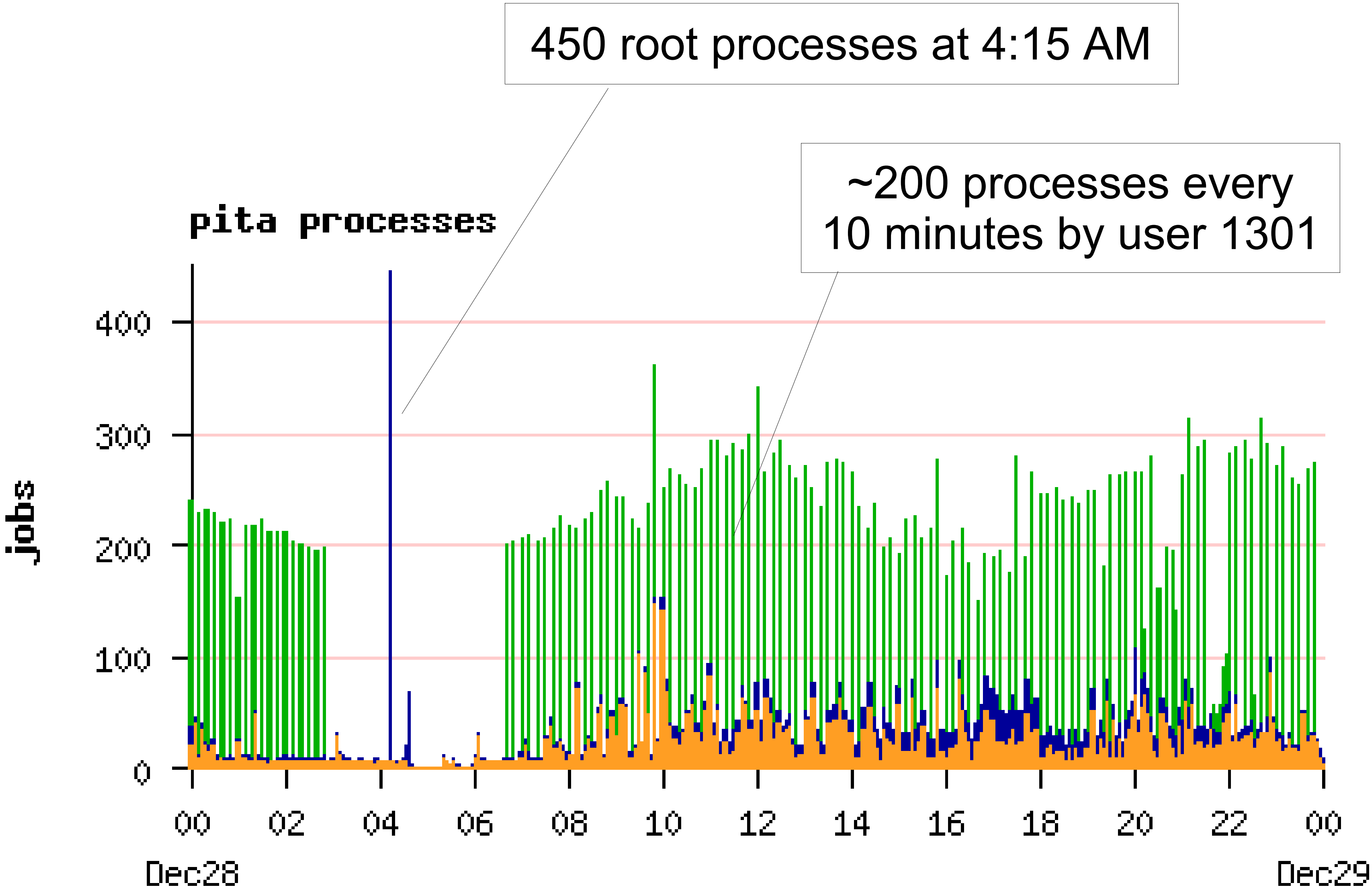
Flurries affect distributions of workload attributes



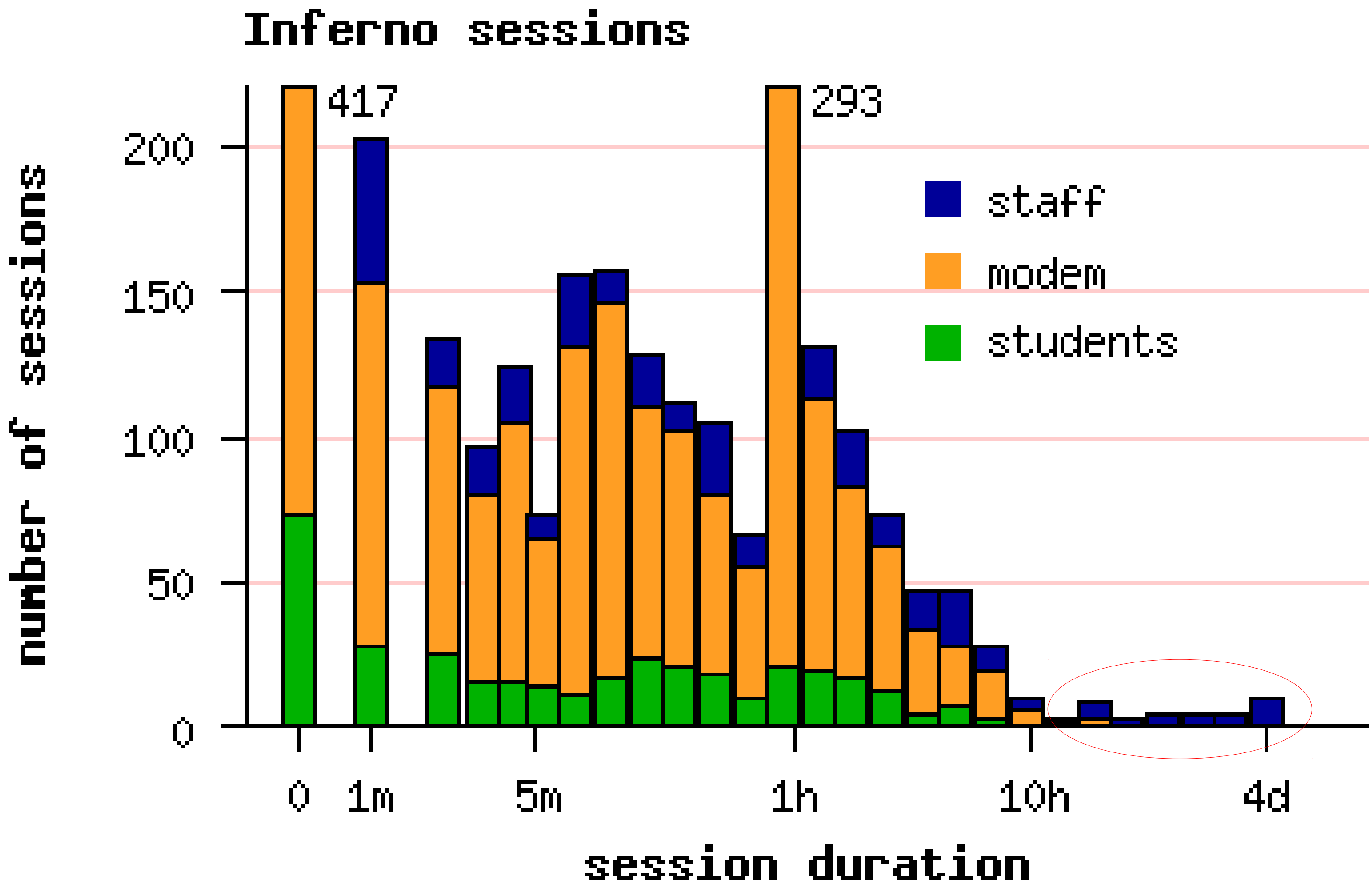
Different flurries cause different effects



Example: robot activity has different characteristics than humans



Example: impossibly long sessions created by staff that leave windows connected to a server open for several days



Heavy Tails

- Distributions of workload attributes are typically positive
  - No negative file sizes, runtimes, etc.
- There are typically many small items and few large ones
- The large ones can be very large
  - And therefore important in terms of resource usage
- This is the tail of the distribution
  - Technically, the "right" tail

The large items can be **so large** that they dominate the whole distribution

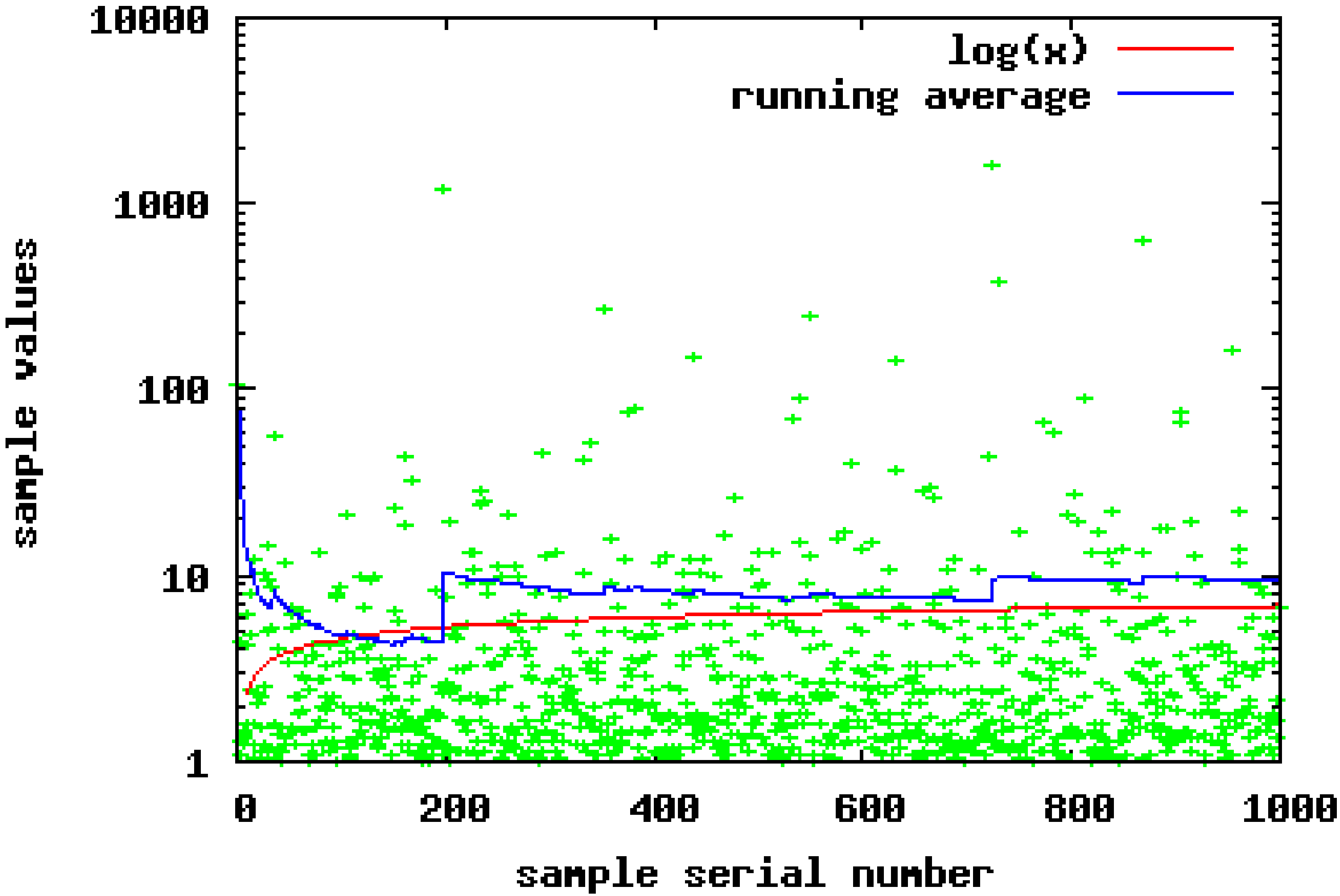
Consider the following discrete distribution:

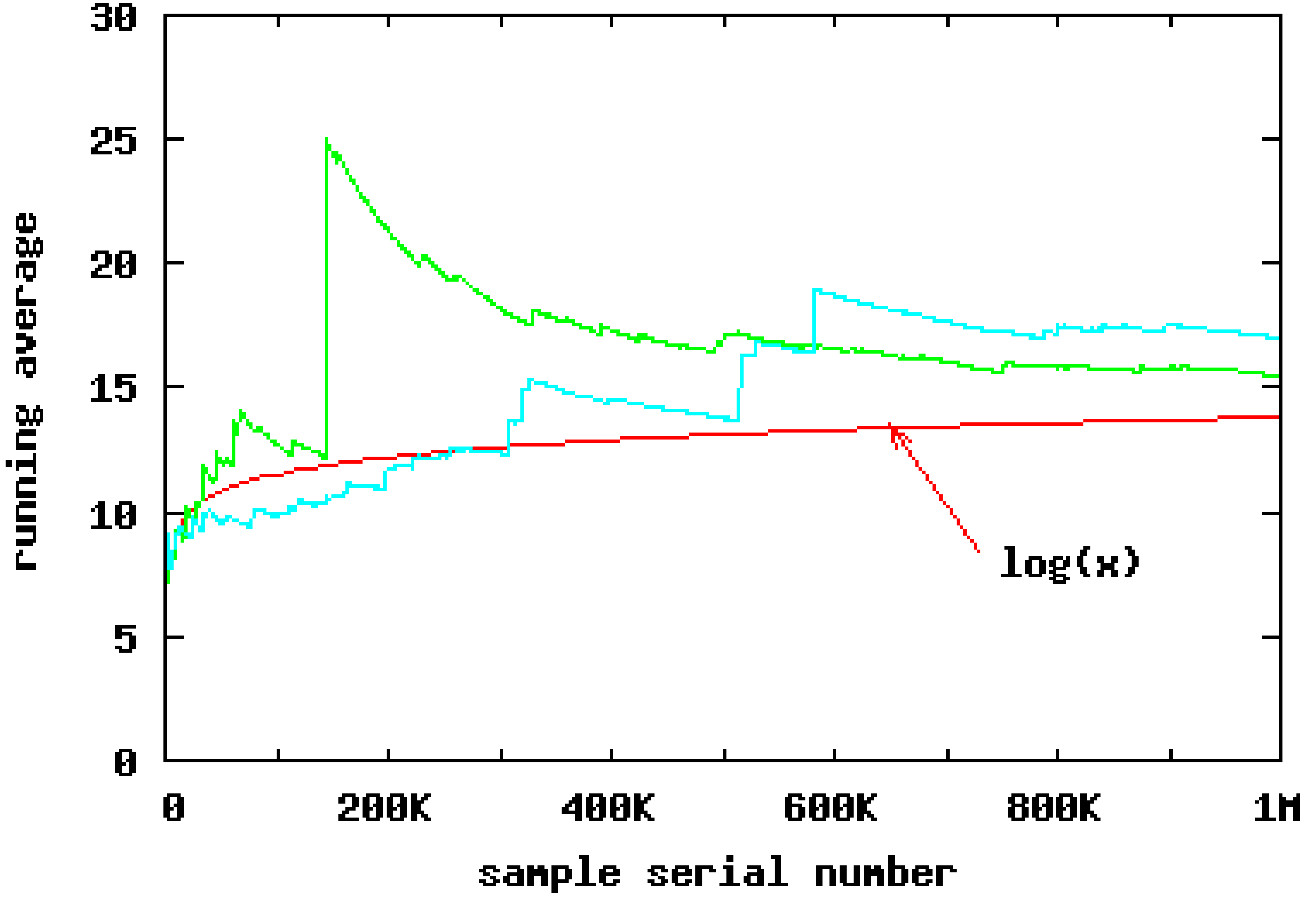
- 2 with probability of 1/2
- 4 with probability of 1/4
- 8 with probability of 1/8
- 16 with probability of 1/16

and so on

...The mean of this distribution is ∞

If we look at the running average of samples from a Pareto distribution, it grows in jumps whenever a large sample is seen



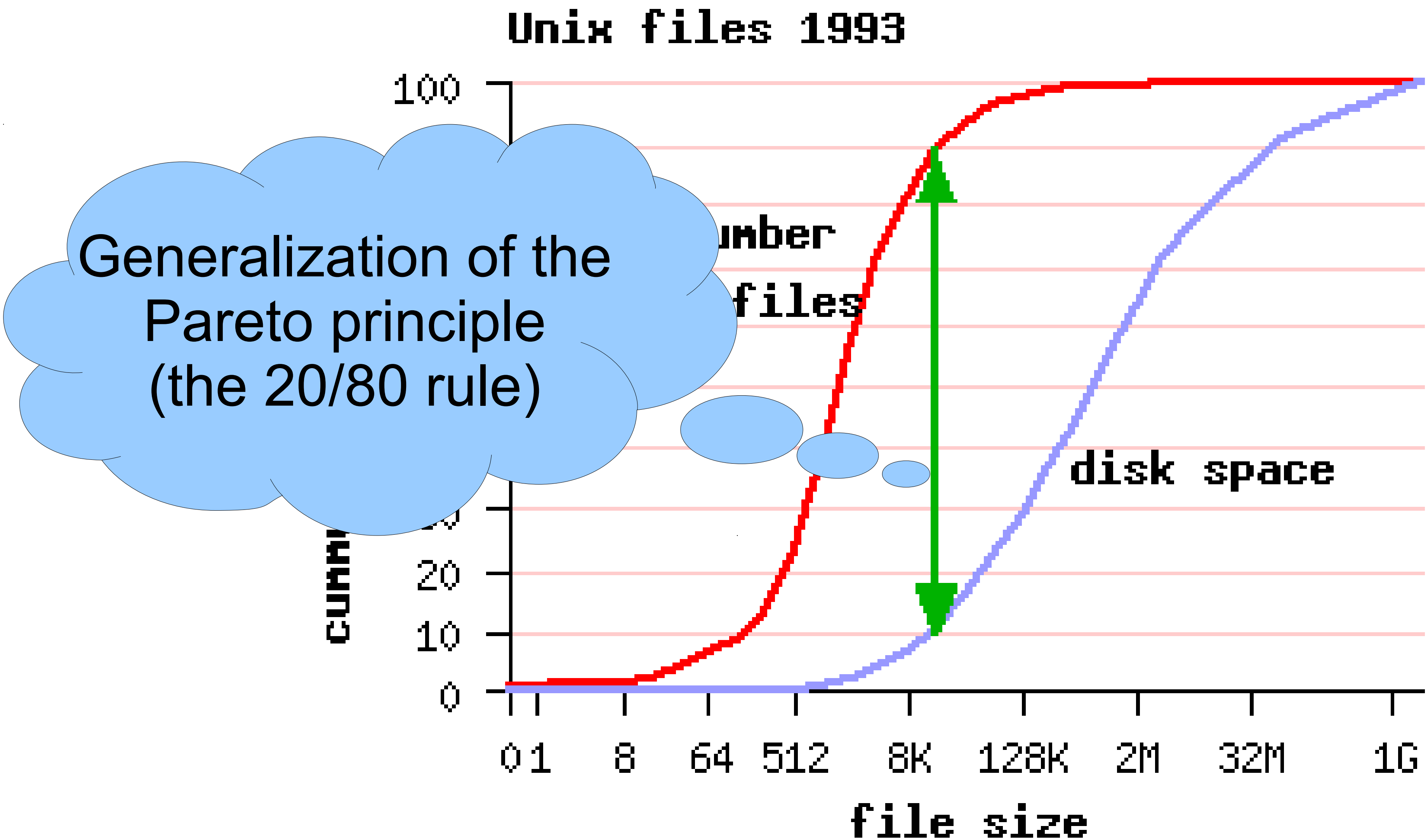


running average
30
25
20
15
10
5
0
0
200K
400K
600K
800K
1M
sample serial number
log(x)

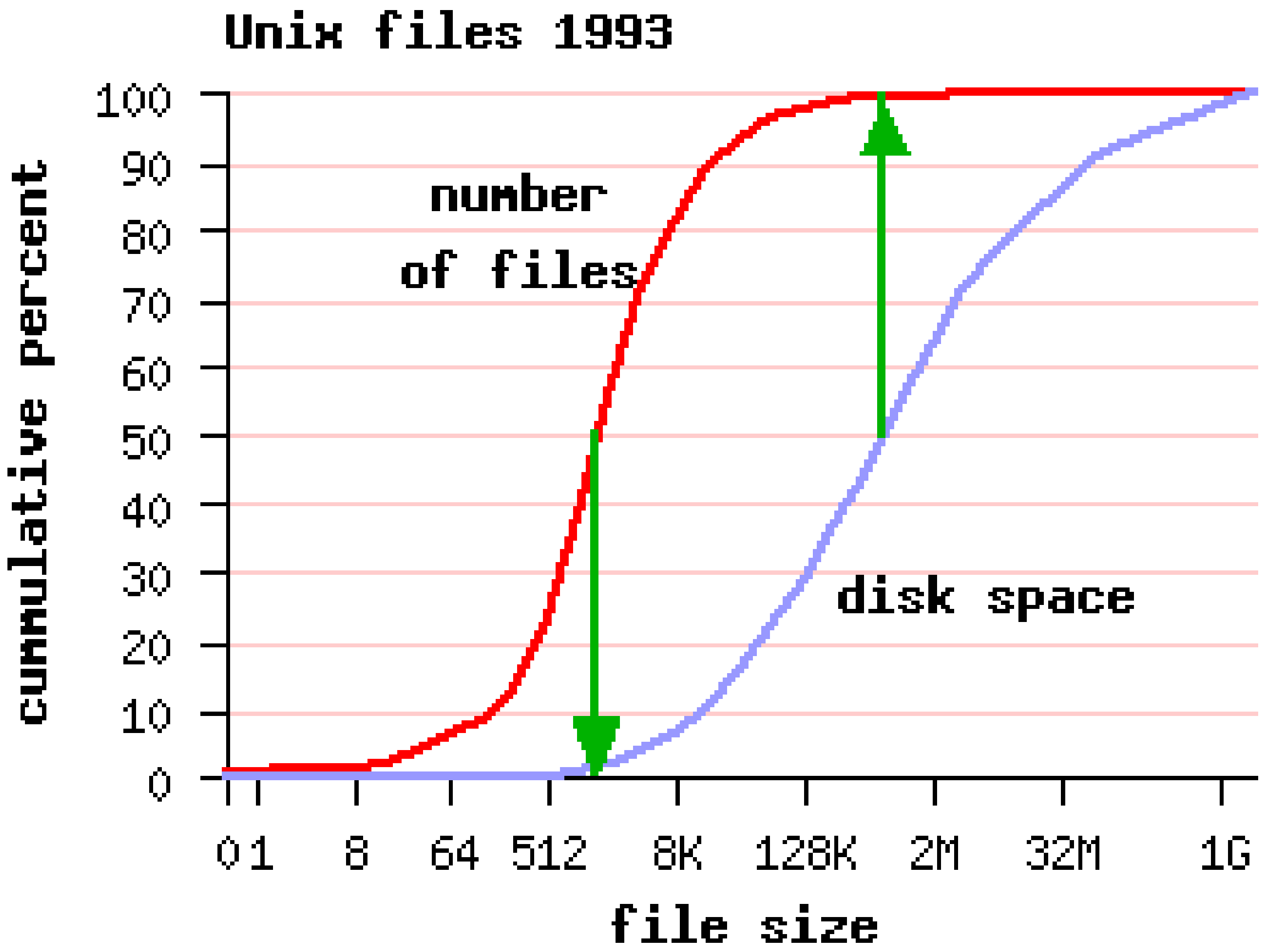
Perhaps the most important attribute of heavy-tail distributions is mass-count disparity: most of the items are small, but most of the mass is concentrated in a few items

- Most processes are short, but most CPU seconds are used by long processes
- Most files are small, but most disk space is used to store large files
- Most files on a web server are seldom requested, while most requests target a small subset of the files

Mass-count disparity can be quantified by the joint ratio: here 11% of the files account for 89% of the disk space, and 89% of files are only 11% of space



Also quantified by the 0-50 rule: 50% of the items together are practically 0 of the mass, and 50% of the mass comes from essentially 0 items



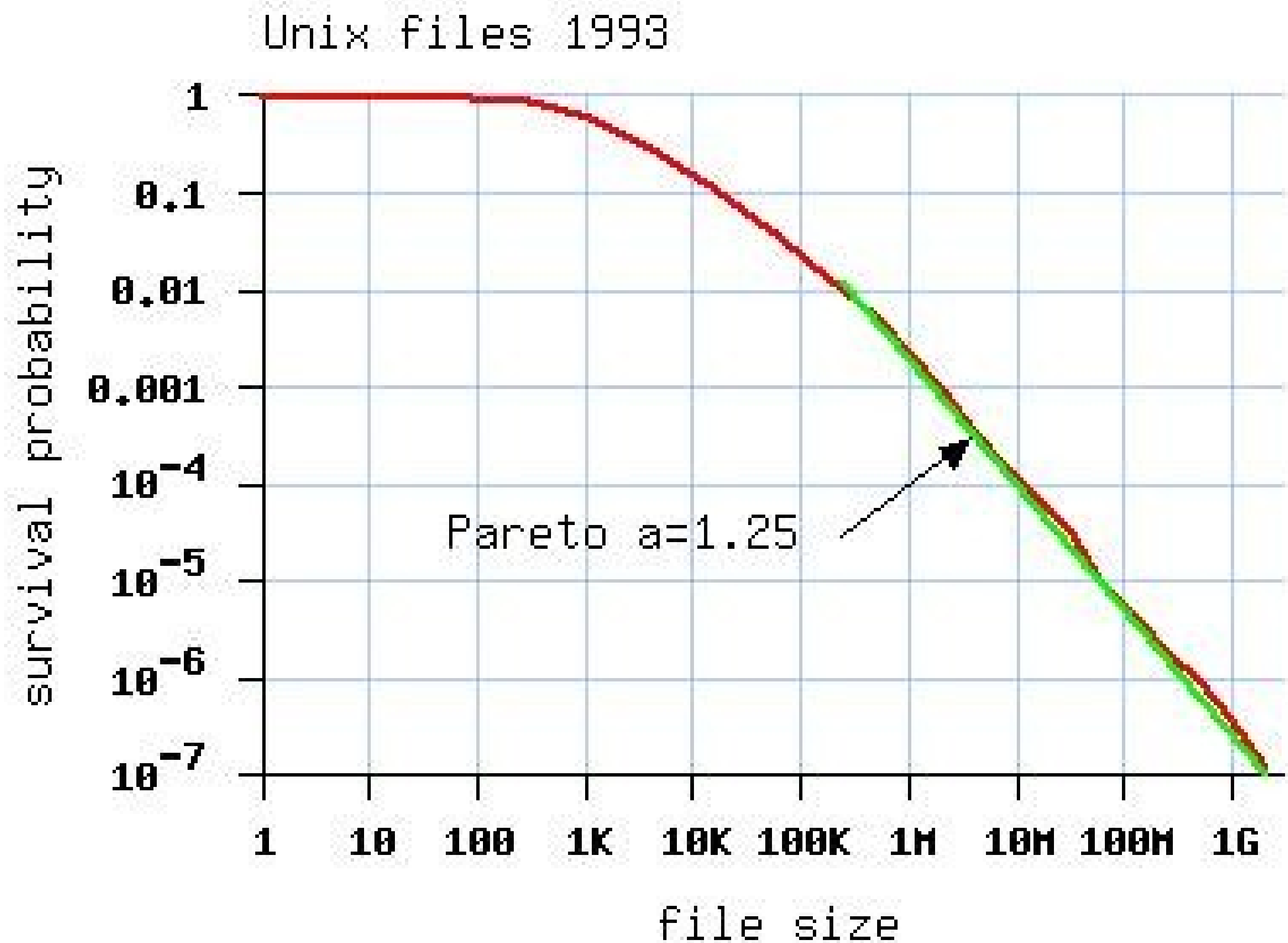
The formal definition of a heavy tail is that the survival function decay according to a power law

$$\bar{F}(x) = Pr(X > x) = x^{-\alpha}$$

By taking the log from both sides, we get

$$\begin{aligned} \ln(\bar{F}(x)) &= \ln(x^{-\alpha}) \\ &= -\alpha \ln(x) \end{aligned}$$

This serves both to identify heavy tails and to assess the tail index α



Unix files 1993
survival probability
1
0.1
0.01
0.001
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Pareto a=1.25
1
10
100
1K
10K
100K
1M
10M
100M
1G
file size

- There are alternative models too
  - Lognormal distribution
  - Weibull distribution
- Choice can be based on fitting data
- Or on a generative model
  - Multiplicative file-size model suggests a lognormal distribution
  - Preferential attachment models (e.g. popular web pages are more visible and therefore become even more popular) suggest a Pareto model
  - The boundaries may depend on details of the model