Strategies for sound Internet measurement

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Paxson’s disclaimer …
There are no new research results
Some points apply to large scale systems in general
Unfortunately, all strategies involve extra work (“discipline”)
No easy answer to “how much extra work is merited?”
Why simulations are not enough?

- Constructed, abstracted model of the real world?
- Simulations are only as good as the simulator
- Danger of oversimplification
- Can model only foreseen properties
Why measurements are important

- Measurements are a “reality check”
- Question implicit assumptions
- But …
  - Conducting sound Internet measurements is difficult
  - Soundness in measurement process and quality of analysis
- Emphasis on general principles as opposed to particular techniques and tools
Difficulties of measurements

- To measure the global Internet, need wide cooperation
  - Designing meaningful experiments
  - Securing permission
  - Testing that the tools work correctly
  - Reducing raw data
  - Exploring the data and presenting results
- ISPs are reluctant to coordinate their efforts
- Tremendous growth of Internet
  - Results get obsolete very rapidly
  - Conducting scalable measurements is difficult
Dealing with errors and imperfections

- **Precision** – Errors inherent in the basic design of a tool
- **Meta-data**
- **Accuracy** – Errors incurred during application of a tool
- **Misconception** – Are we measuring what we believe we are?
- **Calibration** – Strategy to detect and correct errors
Precision

- Maximum exactness that a tool’s design permits
  Consider a tcpdump timestamp:
  1092704424.276251 IP 192.168.0.122.22 >
  192.168.0.1 16.1213:
  - How precise is it?
  - Answer: at most to 1 μsec. But perhaps much less.

- When reporting measurements, indicate the tool’s precision

- Formulate error bars
Precision (cont’d)

- Notion applies to discrete measurements too
  Ex: Copies of packets, web server logs etc

- Depends:
  - Snapshot length limits total data
  - Filtering does too

- Pitfalls
  - Reporting simplistic precisions

- When does extra effort matter?
  - Unfortunately no crisp rules
  - Discuss whether or not it matters
Strategy #1: Meta-data

- Preserving the information during the course of analysis
- Many convenient data formats lack a way to annotate measurements,
  - E.g., today’s web server log, tcpdump
    - Simple, line oriented structure
    - No API available for retrieving or setting the value

```
$ sudo tcpdump 'tcp[13] & 4I=0'
tcpdump: data link type PKTAP
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on pktap, link-type PKTAP (Apple DLT_PKTAP), capture size 262144 bytes
16:43:38.903107 IP 10.238.47.59.52293 > a104-98-91-191.deploy.static.akamaitechnologies.com.https: Flags [R], seq 691040919, win 0, length 0
16:43:38.927288 IP 10.238.47.59.52293 > a104-98-91-191.deploy.static.akamaitechnologies.com.https: Flags [R], seq 691041654, win 0, length 0
16:43:38.934845 IP 10.238.47.59.52293 > a104-98-91-191.deploy.static.akamaitechnologies.com.https: Flags [R], seq 691041654, win 0, length 0
16:43:44.104708 IP 10.238.47.59.52195 > hinckley.cs.northwestern.edu.http: Flags [R], seq 3290639839, win 0, length 0
16:43:50.23693 IP 10.238.47.59.52302 > jb-in-f108.1e100.net.imaps: Flags [R], seq 2332392575, win 0, length 0
16:43:50.23693 IP 10.238.47.59.52302 > jb-in-f108.1e100.net.imaps: Flags [R], seq 2332392575, win 0, length 0
16:43:50.251439 IP 10.238.47.59.52302 > jb-in-f108.1e100.net.imaps: Flags [R], seq 2332392575, win 0, length 0
```
Key consideration for meta-data

- Uniform format for the meta-data is needed
- Data have a lifetime beyond what the researcher initially envisions
  - Good data is hard to gather
  - Revisiting datasets in new contexts
- It is beneficial to retain meta-data information even when doing so is not of immediate benefit
Accuracy

- How well does the measured abstraction indeed match the actual phenomenon?
- Much broader problem than precision
  - E.g. clocks can
    - Arbitrarily off from true time
    - Jump backward or forward
    - Run arbitrarily fast or slow
    - Fail to move
  - E.g.) Packet filters can:
    - Fail to record packets (“drops”)
    - Fail to report drops
    - Report drops that did not occur
    - Reorder packets
    - Duplicate packets
    - Record wrong packets
Inaccuracy rises meta-data problem??

- Measurement tools are in adequately recording failure information, e.g.
- Tcpdump
  - produces an end-of-run summary of the total number of drops
  - No report on the drops by the tap itself
  - Cannot associate drops with the time of occurrence
  - Records them separately, requires association
Misconception

Errors in equating what we are actually measuring with what we wish to measure

Examples
  – Measuring TCP packet loss
    • By counting retransmitted packets
    • Risks overlooking the problem
      – Unnecessary retransmissions
      – Packets replicated by the network
  – Computing the distribution of TCP connection sizes
    • By capturing SYN and FIN packets
      – Using the difference between the sequence numbers
      – Miss/fail to include packets SYNs or FINs
        » Very large connections started before we start tracing
        » Not terminated when we finish
Significant misconceptions

- **Vantage point**
  - The location of exactly where a measurement is performed can significantly skew the interpretation of the measurement

- **Representativeness**
  - Internet properties vary a great deal across different points and different times

- **General strategy against misconceptions**
  - To gather more than one type of dataset
    - From a different location
    - From a different time
  - Seek out early peer review
Calibration

- A set of techniques that help with detecting problems of inaccuracy, misconception, errors in analysis
  - Examining outliers and spikes
  - Employing self-consistency checks
  - Measuring facets of the same phenomenon different ways and comparing
  - Evaluating synthetic data

Not achieve perfection but achieve confidence
Examining outliers and spikes

- **Outliers**
  - Unusually low or high values

- **Spikes**
  - Values that repeat a great deal

- Represent “corner cases” at the extremes of measurements where problems often manifest

- Reflect measurement errors, analysis errors, misconceptions
Employing self-consistency checks

- Testing whether properties that must hold do in fact hold

- E.g., How to find evidence of packet filter drops
  - Use cumulative TCP ACK properties
    - To see whether each ACK present in a trace at the point in time it was sent
    - All of the data up to the sequence number of ACK has to have been seen previously in the trace
Comparing multiple measurements

- Measuring the same phenomenon different ways and comparing the results
- Conducting additional measurements
- Multiple versions of analysis
Evaluating synthetic data

- Hand-edit some measurements to introduce changes
- Test whether software processes it correctly
- Monte Carlo simulations
  - Simulate multiple random instances
Dealing with large volume of data

- Large scale leads to a number of potential difficulties
- System limitations such as disk space, max file sizes, number of files on a volume, ....
- Many systems for statistical analysis have upper bounds on the amount of data they can process

- Strategy: In-depth analysis of small subsets
Ensuring reproducible analysis

- The analysis derived from the data is reproducible

- **Strategy: Structured analysis**
  - Single master script
  - Cataloging notebook

- **Benefits of structuring analysis**
  - Reproduce the results, Minimizing the headaches
  - Explore the analysis of the data in a consistent fashion
Making datasets publicly available

- Dearth of publicly available datasets
- Strategy: periodically analyze ongoing measurements
  - let’s you discover when data acquisition broken
  - ensures you’re collecting (some) meta-data

- Problems
  - Reluctance, legal impediments
  - Privacy, security and business sensitivities – anonymization

- Strategy: package analysis for “data reduction requests”
  - send data analysis software to dataset holder
  - they run it, inspect results, & return them
Summary – strategies for soundness

- #1: Maintain meta-data
- #2: Run your intended methodology by colleagues
- #3a: Examine outliers and spikes
- #3b: Employ self-consistency checks
- #3c: Compare multiple measurements/computations
- #4: Structure for reproducible analysis
- #5: Periodically analyze ongoing measurements
- #6: Package analysis for “data reduction requests”
- #7: Subsample large datasets, assess variability
Today

- Internet design principles and measurements
- Standards and strategies

**Experimental approaches**

- Ethical considerations