MEASUREMENT: MONITORS & A FIRST LOOK AT INTERNET MEASUREMENTS

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Performance measurement

To measure the performance of a system you need at least two tools

- A tool to load the system: *load generator*
- A tool to measure the results: *monitor*

Monitor

- A monitor is a tool used to *observe the activities on a system*
- Monitors observe the performance of systems, collect performance statistics, analyze the data, and display results
- Reasons to monitor a system
- To optimize system performance
- To measure resource utilization
- To find the performance bottleneck
- To tune the system
- To characterize the workload

Terminolgy

- **Event**: a change in the system state (ex. Arrival of a packet)
- **Trace**: a log of events usually including the time of the event, the type of the event, and other important parameters associated with the event
- **Overhead**: consumption of system resources to run the monitor (ex. CPU or storage, additional packets)
- **Domain**: the set of activities observable by the monitor
- **Input rate**: the maximum frequency of events that a monitor can correctly observe
  - Burst mode: specifies the rate at which an event can occur for a short duration
  - Sustained mode: the rate that the monitor can tolerate for long durations
- **Resolution**: the coarseness of the information observed (ex. A monitor may be able to record time only in units of 16 milliseconds)
- **Input Width**: the number of bits of information recorded on a event

Monitor classification

Depending upon the mechanism that triggers the monitor into action:

- **Event driven**: is activated only by the occurrence of certain events
- **Timer driven** (**sampling** monitor): is activated at fixed time intervals by clock interrupts

Monitor classification (cont)

Depending upon the level at which a monitor is implemented:

1. **Software** monitors (used for networks)
   - Issues in buffer size (they record data in buffers and then into disk or other storage – the size of the buffer should be large),
   - Issues in data compression and analysis (the monitor can process the data as it is observed to save memory but adds overhead)
2. **Hardware** monitors: a separate piece of equipment attached to the system being monitored (no system resources are consumed)
3. **Firmware** monitors (network monitoring where existing network interfaces can be easily microprogrammed to monitor all traffic on the network)

Monitor classification (cont)

Depending upon the ability to display results

- **On-line** monitors display the system state either continuously or at frequent intervals
- **Batch** monitors collect data that can be analyzed later using a separate analysis program

- All three of the classifications can be used together to characterize a monitor
- Ex: a monitor may be classified as a firmware-event-driven-batch

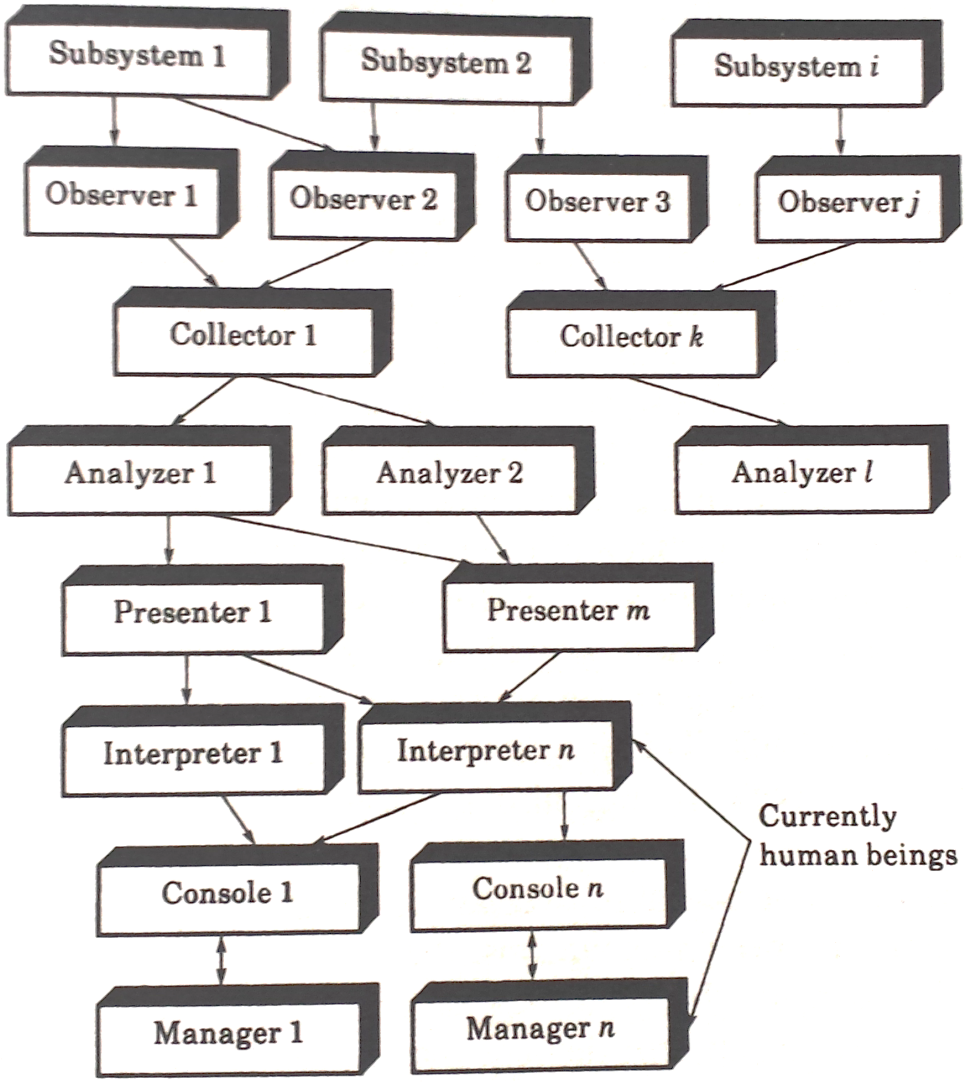
Distributed-system monitors

- Computer networks consist of many hardware and software components that work together separately and concurrently
- Monitoring a **distributed system** is more difficult than monitoring a centralized system
- The **monitor** itself must be **distributed** and should consist of several components that work separately and concurrently
- Ex. To determine the link with the highest error rate, the errors at each and every link in a network should be observed.
- The easiest way to understand various components of a distributed-system monitor is to divide various functions in the monitor into a number of layers
- Each layer makes use of the services provided by the lower layers and extends the available facilities to the upper layer

Distributed-system monitors (cont)

Management	The entity that makes the decision to set or change system parameters
Console	Interface to control the system parameters and states
Interpretation	Human being or expert system
Presentation	Interface to human user. It produces reports, alarms, etc.
Analysis	Analyzes the data gathered at various collectors
Collection	Collects data from various observer
Observation	Gathers raw data on individual components of the system

Distributed-system monitors (cont)



Distributed-system monitors (cont)

- *Observation*: raw data gathering
  - **Implicit spying**: the first and least intrusive monitoring technique
    - promiscuously observing the activity of the system bus or network link (packet sniffer)
    - Used to monitor local-area networks in which all stations can hear all conversations, and one station is designated to be the observed
    - Advantage: there is no impact on the performance of the system being monitored
    - Implicit-spying observer are often accompanied by one or more filters that allow the monitor to decide which activities to record
  - **Explicit instrumenting**: incorporating trace points, probe points, hooks, or counters in the system
  - **Probing**: making requests on the system to sense its current performance
    - A specially marked packet sent to a given destination and looped back by the destination may provide information about queueing at the source, at intermediate bridges, the destination station and back

Distributed-system monitors (cont)

- *Observation*: raw data gathering
  - There are activities that can be observed only by one of the three mechanisms
  - Ex: request to nonexistent devices may be observed only by implicit spying
  - Probing provides cumulative information about a number of components
- *Collection*: data gathering (from a group of observer)
  - Synchronization issues: time stamp from different observer cannot be compared unless the observers' clocks are close to each other within some tolerance
- *Analysis*: can be performed in the observer or the analyzer depending on the specific case (highest error rate => analyzer)

Measurement

Performance evaluation technique which can be applicable to any existing network or prototype

- Internet
- Sensor network (terrestrial & underwater)
- RFID systems
- …

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Internet measurement

Internet measurement

Motivation

- Many quantitative measures of the internet are absent
  - Internet is not the result of a centralized design
  - It is constantly changing in size, configuration, traffic, and applications mix
- How big is the Internet?
- How much traffic flows over the Internet?
- What is the structure of the Internet?
- What are the statistical properties of network traffic?
- What demands do different applications place on the network?
- What is the capacity of the path to my server?

Measurement issues

- Internet devices do not always provide the kind of measurements that are most useful for understanding the network
- Collecting measurements of the Internet can result in *huge datasets* that are difficult to store, transfer, process, and analyze
- Commercial service providers often *do not s*hare information about the internal details of their networks
- No possibility for remote monitoring
- Some forms of internet measurement can *violate privacy* and *raise security concerns*
- *Synchronization* is an important issue

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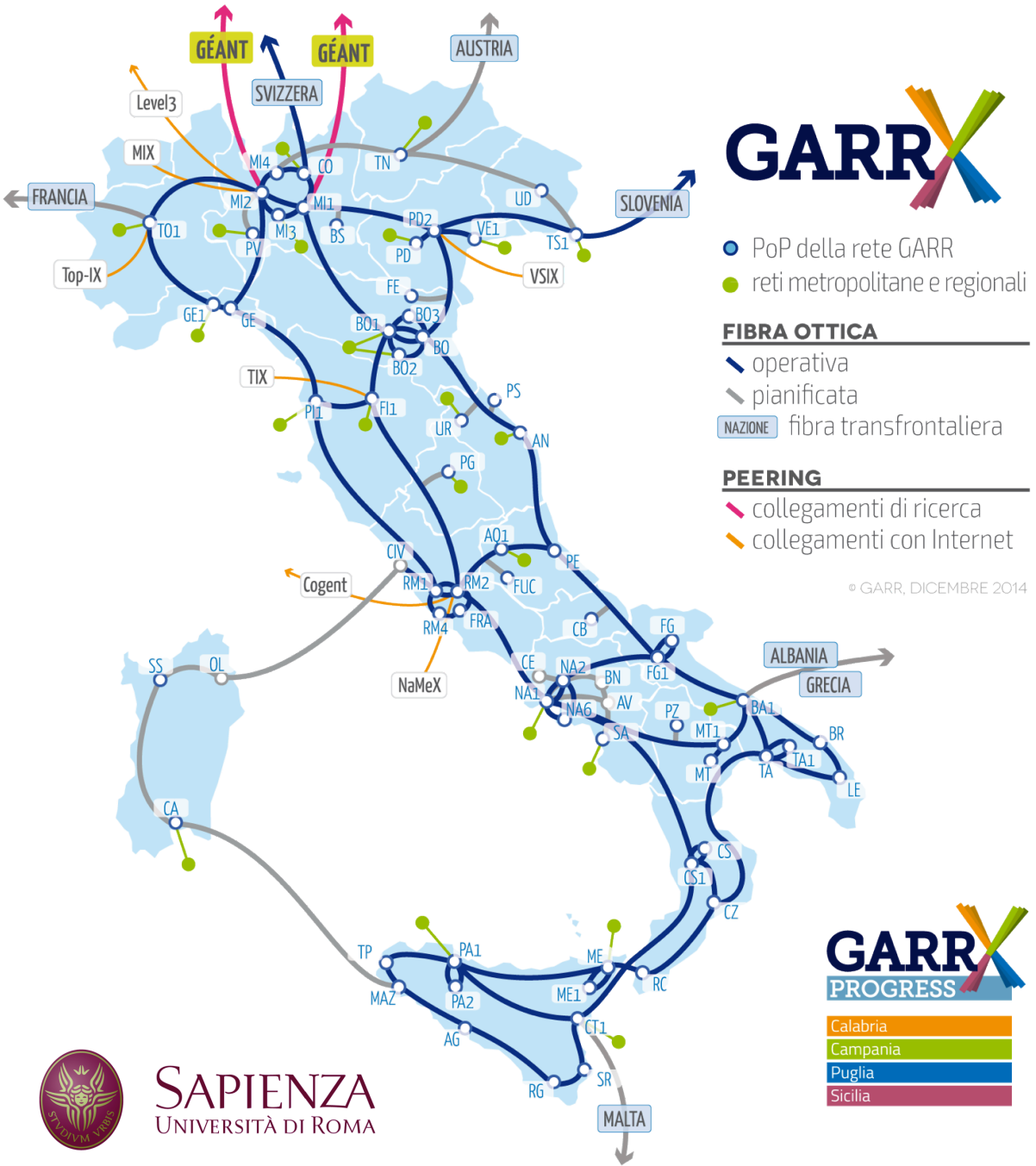
Where can measurements be made?

- At every point of the Internet network
- Inside LAN
- In and around an Internet Service Provider (organization controlling one or multiple autonomous systems)
  - At backbone routers, access routers, gateway routers, peering routers
- At network access points (NAP) - exchange points of multiple ISP

Inside LAN

- Carried out for local test-beds
- Typically not of significant interest in the “Internet” measurement sense
- Measurements of local latency and hardware related measurements are done on a LAN
- Security reasons

Inside a backbone



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Inside a backbone

- ISPs constantly monitor the network for a variety of purposes
  - Ensuring availability
  - Scanning for outages or attacks
  - Topology changes
  - Compliance with service level agreements
  - Traffic trends (diurnal, weekday, and other periodicities)
- Measurements inside the backbone are done from an *intra-organizational point of view*
  - Help in proper provisioning of resources
  - Indicate whether router and link upgrades may be warranted
- Tools:
  - SNMP: provides the basic information needed to measure packet loss, delay, and throughput
  - packet tracing: provides time stamps at high precision

Key objectives of backbone measurements

- Capacity planning
  - To see if additional points of presence (PoPs) are needed
  - To see if existing PoPs in a network need additional capacity
  - Requires packet loss, delay and throughput measurements

- Provisioning (proper allocation of bandwidth to various links inside an ISP)
  - Different applications have varying degrees of sensitivity to latency (consider email vs. multimedia streaming)
  - Typically ISP over-provision the network, but the appropriate degree of over-provisioning has to be computed
  - Requires measurements of changes in traffic patterns at small scale and traffic across all pairs of PoPs

Key objectives of backbone measurements (cont)

- Link utilization
  - Long term information on link utilization help to identify PoP that need more capacity
  - Understanding the traffic associated to a set of costumers, an organization can provide tailored service to them
  - Requires packet delay measurement with high speed monitors
- Proper tuning of interior gateway protocol (balance traffic)
  - Monitor links and routing information to get a view of eventual traffic shifts (sudden growth in a particular protocol)
  - Requires combining traffic matrix and routing data

Key objectives of backbone measurements (cont)

- Security
  - Attacks and anomalies
  - Requires monitoring significant changes in traffic patterns between PoPs
  - Requires examine link utilizations periodically and notice significant increases
- Identify failures
  - Failures that are not related to attacks may affect availability
  - Path failures trigger rerouting

Entry points into a network: *gateway* routers

- Access control
  - Entry points of the network are the first line of defense and the best place to filter out unwanted traffic
- Overall statistics
  - The *netflow* tool allows to export *per-flow summaries* of traffic which includes information about
    - start and ending time of flows,
    - duration,
    - source and destination IP and ports
    - autonomous systems
    - Fraction of traffic destined to customers inside the network
    - Portion of traffic that is transiting through the network

Entry points into a network: *peering* router

- Monitoring inter-domain connectivity
- Ensure balanced traffic exchange
  - Traffic volumes exchanged between private peers has be approximately equal
  - Deviations from expectation can trigger policy decisions (peering at other points) or require the exceeding peer to pay for the surplus traffic
- Monitoring BGP
  - Examining convergence
  - Fixing problems
  - Locating routing loops
  - Faults can be deliberately injected to examine their impact, such as how long before the route is repaired, a better path is discovered, etc.

Entry points into a network: *access* router

- Access router connect the backbone to the set of customers
- Access routers are also the routers used to connect to web and mail server
- Availability is crucial (failure rate must be low or non-existent)
- Some customers may require packet filtering
- Some customers may require periodic statistics and constant performance monitoring to ensure that anomalous events are kept to a minimum
- Many customers expect the access provider to look for attacks and sudden fluctuations in network traffic in a pro-active manner

Entry points into a network: *exchange points*

- An Internet Exchange Point permits various ISPs to exchange traffic
- There are commercial, government and research/ education exchange points
- One of the primary purposes of a network exchange point is to keep traffic local, i.e., move traffic between two participants without having to route it through long distance routes
- Measuring at exchange points allows to get a broader idea of shifts in traffic patterns (increasing online gaming, etc.)

Wide area network

- The measurement sites examined so far are restricted to a single location or point of presence
- The amount of traffic at each of these places may differ significantly
- Any internet topology related measurement has to carried out in the wide area
- Measurements on a wide area network: across the Internet on multiple locations
  - Coordinated and carried out simultaneously
  - Separately over a period of time

WAN: various places in the network

- WAN measurements are done by researchers and measurement companies
- Typical locations: all the ones listed in the previous slides but across a wider area: at multiple point of presence on the Internet

WAN: multi-site measurements

- A collection of nodes are used for simultaneous and cooperative measurement
- Example: to obtain a measure of how typical users might experience a Web site, measurements might be carried out on several locations on the Internet corresponding to different user populations
- Carrying out multi-site measurements in a coordinated fashion may require
  - clock synchronization
  - Execution serialization
  - A command and control mechanism capable of handling access and resource control
- Available platforms: NIMI and PlanetLab
- Representativeness: user populations, choices of clients, servers, etc. are reasonably well represented so that proper inferences can be made

Role of time

- *Synchronization* is the process of ensuring that physically distributed processor have a common notion of time
- Many measurement tasks require accurate time measurement
  - Packet round trip time
  - Packet delay across routers and over links
  - Producing a time-ordered view of measurements taken at different places in the network
  - Response time and throughput
- Synchronization is a challenging issue as the Internet is a distributed system with components often separated by considerable distances
- In the case an accurate clock exists, the distance between component induces communication latency which can make clock readings stale by the time they arrive

Definition

- t: **true time** at any instant
- $C(t)$: **apparent time** reported by a clock at time t
- ***Offset*** of a clock $\theta(t)=C(t)-t$: the difference between the time it reports and the true time.

  An accurate clock has always $\theta(t)=0$
- ***Rate*** of a *clock* $\gamma(t) = dC(t)/dt$: the first derivative of its apparent time with respect to true time.

  An accurate clock has $\gamma(t)$ close to 1
- ***Skew*** = $\gamma-1$ is the difference between its rate and the correct rate

Observations

- Accuracy is a more stringent requirement than zero skew
- A clock that has large offset (is inaccurate) but has **zero skew** is still useful for certain type of measurement
  - Packet round trip time
  - Packet inter arrival time
- Measurement with one-way packet delay or time ordering of events occurring in different places requires clocks with **zero offset**

Sources of time information

External time sources

- Radio services that disseminate time information

1. Radio clocks
2. Global Positioning System (GPS): a constellation of 32 satellites in 12-hour orbit, available worldwide
   - Requires large antennas
   - outdoor
3. CDMA cellular phone system
   - Indoor and outdoor
   - Available in areas having CDMA telephony providers (not in Europe)

Sources of time information

PC-based clocks

- Standard PCs have two clocks

1. A battery-powered *hardware clock* keeps track of time when the system is turned off, and is not typically used when the system is running
2. *Software clock* is the usual source of time while the system is running
   - To read it: gettimeofday() or GetsystemTime()
3. Time Stamp Counter (TSC) register which is incremented every processor cycle

Synchronized time

- Many Internet measurement tasks involve measurements taken using different clocks.
- Ex. One way packet delay measurements involve measuring the departure time of a packet in one location and the arrival time of the packet at another point.
- Accurate determination of the true delay can be obtained in one of two ways:

1. Using synchronized clocks => Network Time Protocol (NTP)
2. Inferring clock offsets and removing their effects after measurements are made (see Paxson ACM SIGMETRICS 98)