Performance Analysis:
The USE Method

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whoami

- **I work at the top of the performance support chain**
- **I also write open source performance tools out of necessity to solve issues**
  - http://github.com/brendangregg
  - http://www.brendangregg.com/#software
- **And books (DTrace, Solaris Performance and Tools)**
- **Was Brendan @ Sun Microsystems, Oracle, now Joyent**

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- **Cloud computing provider**
- **Cloud computing software**
- **SmartOS**
  - host OS, and guest via OS virtualization
- **Linux, Windows**
  - guest via KVM

Agenda

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- **Example Problem**
- **Performance Methodology**
    - Problem Statement
    - The USE Method
    - Workload Characterization
    - Drill-Down Analysis
- **Specific Tools**

Example Problem

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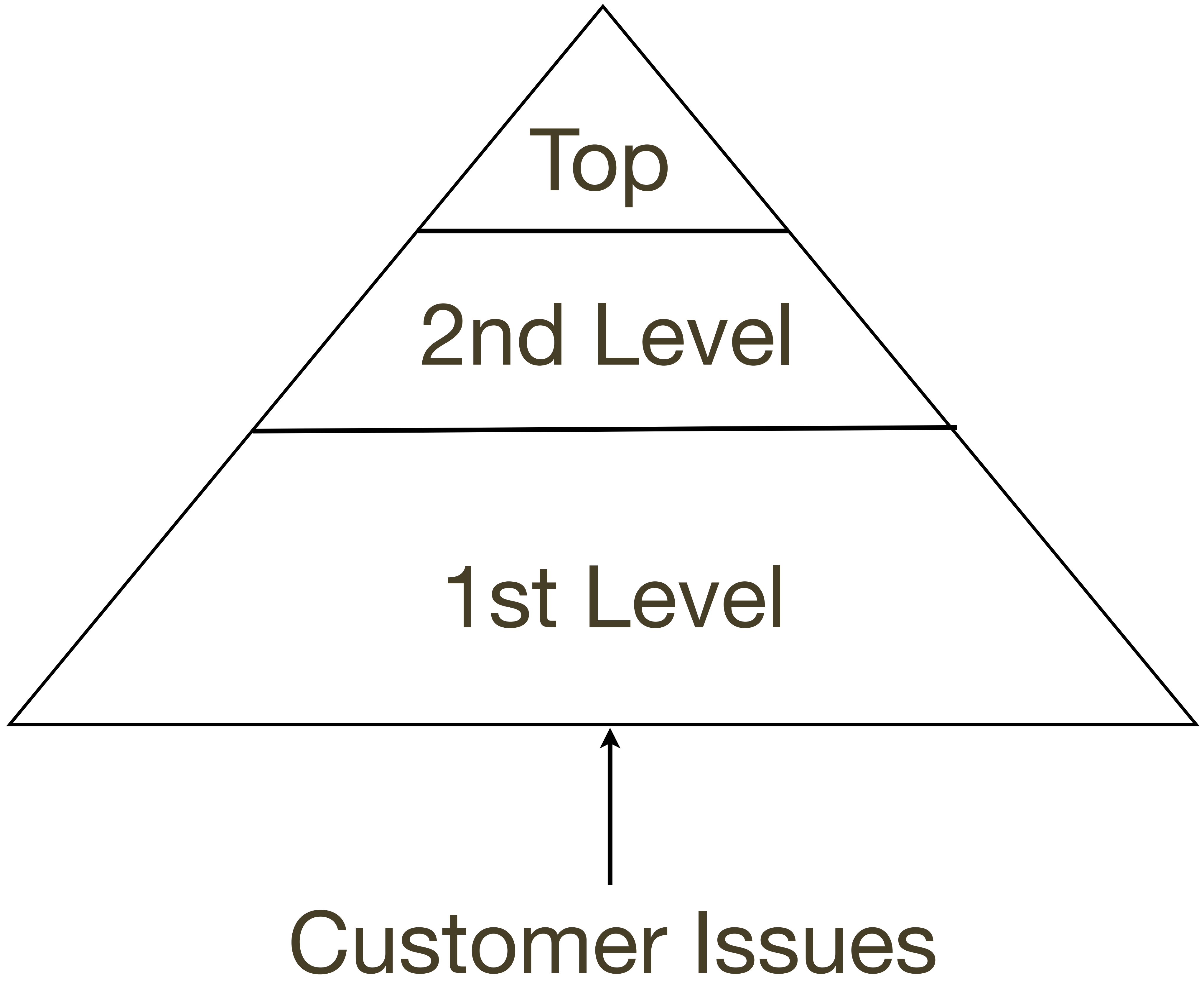
- **Recent cloud-based performance issue**
- **Customer problem statement:**
  - “Database response time sometimes take multiple seconds. Is the network dropping packets?”
  - Tested network using traceroute, which showed some packet drops

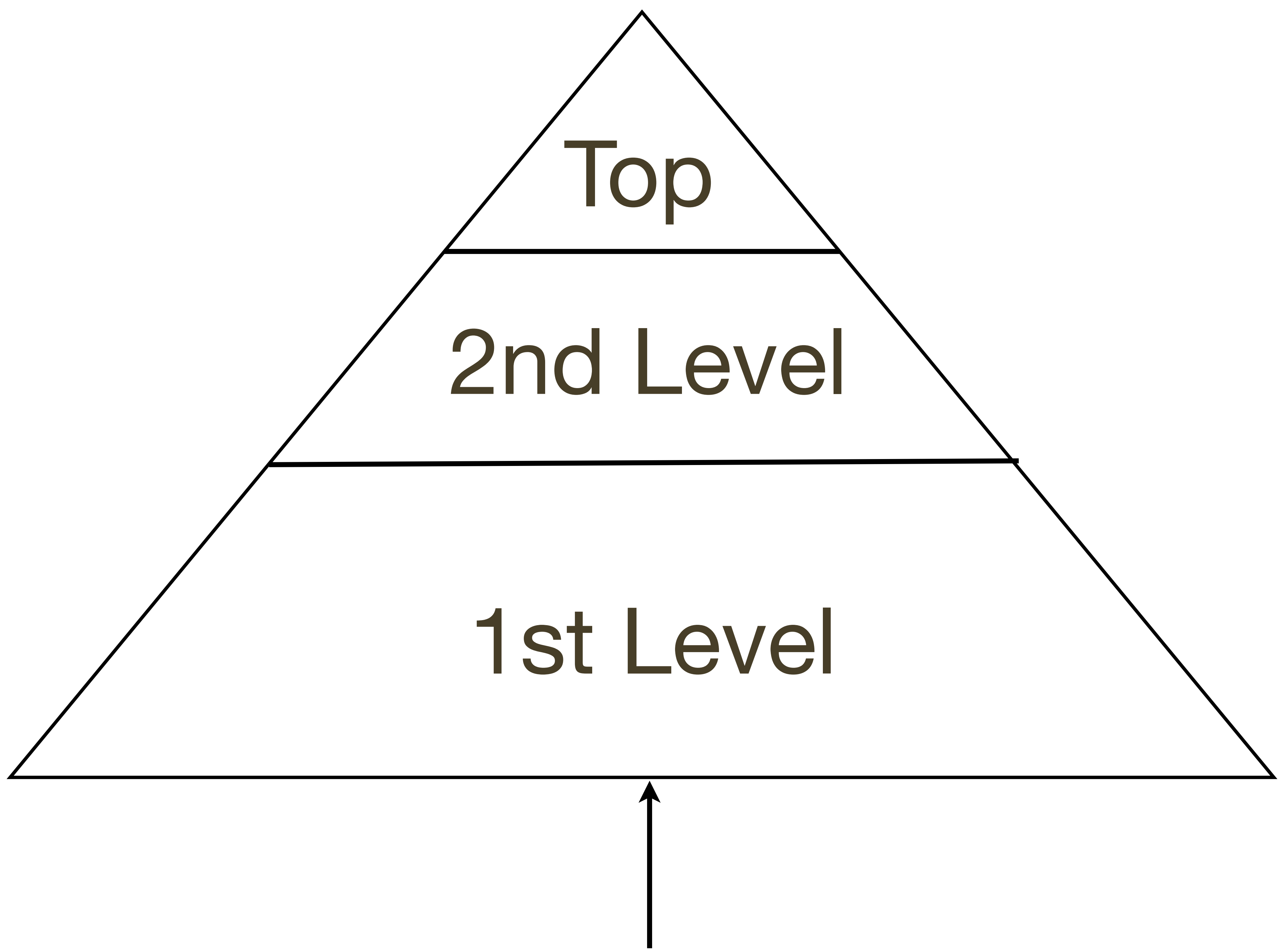
Example: Support Path

- **Performance Analysis**



Example: Support Path

- **Performance Analysis**



my turn

"network looks ok, CPU also ok"

"ran traceroute, can't reproduce"

Customer: "network drops?"

Example: Network Drops

- **Old fashioned: network packet capture (sniffing)**
  - Performance overhead during capture (CPU, storage) and post-processing (wireshark)
  - Time consuming to analyze: not real-time

Example: Network Drops

- **New: dynamic tracing**
  - Efficient: only drop/retransmit paths traced
  - Context: kernel state readable
  - Real-time: analysis and summaries

```
# ./tcplistendrop.d
TIME                    SRC-IP              PORT     DST-IP               PORT
2012 Jan 19 01:22:49  10.17.210.103      25691 -> 192.192.240.212     80
2012 Jan 19 01:22:49  10.17.210.108      18423 -> 192.192.240.212     80
2012 Jan 19 01:22:49  10.17.210.116      38883 -> 192.192.240.212     80
2012 Jan 19 01:22:49  10.17.210.117      10739 -> 192.192.240.212     80
2012 Jan 19 01:22:49  10.17.210.112      27988 -> 192.192.240.212     80
2012 Jan 19 01:22:49  10.17.210.106      28824 -> 192.192.240.212     80
2012 Jan 19 01:22:49  10.12.143.16       65070 -> 192.192.240.212     80
[...]
```

Example: Methodology

- Instead of network drop analysis, I began with the USE method to check system health

Example: Methodology

- **Instead of network drop analysis, I began with the USE method to check system health**
- **In < 5 minutes, I found:**
    - **CPU**: ok (light usage)
    - **network**: ok (light usage)
    - **memory**: available memory was exhausted, and the system was paging
    - **disk**: periodic bursts of 100% utilization
- **The method is simple, fast, directs further analysis**

Example: Other Methodologies

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- **Customer was surprised (are you sure?) I used latency analysis to confirm. Details (if interesting):**
  - **memory**: using both microstate accounting and dynamic tracing to confirm that anonymous pagins were hurting the database; worst case app thread spent 97% of time waiting on disk (data faults).
  - **disk**: using dynamic tracing to confirm latency at the application / file system interface; included up to 1000ms fsync() calls.
- **Different methodology, smaller audience (expertise), more time (1 hour).**

Example: Summary

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- **What happened:**
  - customer, 1st and 2nd level support spent much time chasing network packet drops.
- **What could have happened:**
  - customer or 1st level follows the USE method and quickly discover memory and disk issues
    - memory: fixable by customer reconfig
    - disk: could go back to 1st or 2nd level support for confirmation
  - Faster resolution, frees time

Performance Methodology

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- Not a tool
- Not a product
- Is a procedure (documentation)

Performance Methodology

- Not a tool -> but tools can be written to help
- Not a product -> could be in monitoring solutions
- Is a procedure (documentation)

Why Now: past

- **Performance analysis circa '90s, metric-orientated:**
  - Vendor creates metrics and performance tools
  - Users develop methods to interpret metrics
- **Common method: "Tools Method"**
  - List available performance tools
  - For each tool, list useful metrics
  - For each metric, determine interpretation
- Problematic: vendors often don't provide the best metrics; can be blind to issue types

Why Now: changes

- **Open Source**
- **Dynamic Tracing**
  - See <u>anything</u>, not just what the vendor gave you
  - Only practical on *open source* software
  - Hardest part is knowing what *questions* to ask

Why Now: present

- **Performance analysis now (post dynamic tracing), question-orientated:**
  - Users pose questions
  - Check if vendor has provided metrics
  - Develop custom metrics using dynamic tracing
- **Methodologies pose the questions**
  - What would previously be an academic exercise is now practical

Methology Audience

- Beginners: provides a starting point
- Experts: provides a checklist/reminder

Performance Methodolgies

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- **Suggested order of execution:**

  1. Problem Statement
  2. The USE Method
  3. Workload Characterization
  4. Drill-Down Analysis (Latency)

Problem Statement

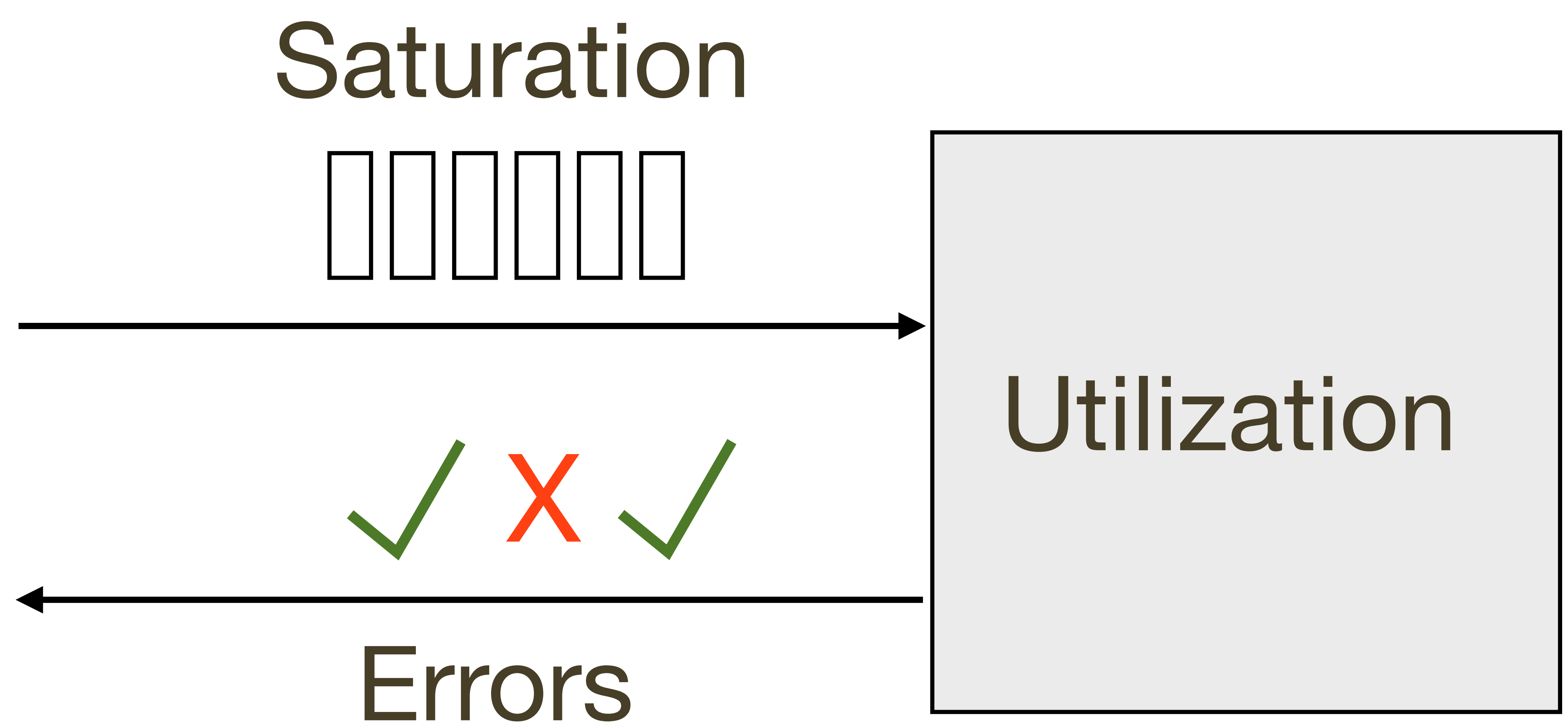
- **Typical support procedure (1st Methodology):**
  1. What makes you think there is a problem?
  2. Has this system ever performed well?
  3. What changed? Software? Hardware? Load?
  4. Can the performance degradation be expressed in terms of latency or run time?
  5. Does the problem affect other people or applications?
  6. What is the environment? What software and hardware is used? Versions? Configuration?

The USE Method

- **Quick System Health Check (2nd Methodology):**
- **For every resource, check:**
    - Utilization
    - Saturation
    - Errors

The USE Method

- **Quick System Health Check (2nd Methodology):**
- **For every resource, check:**
  - Utilization: time resource was busy, or degree used
  - Saturation: degree of queued extra work
  - Errors: any errors



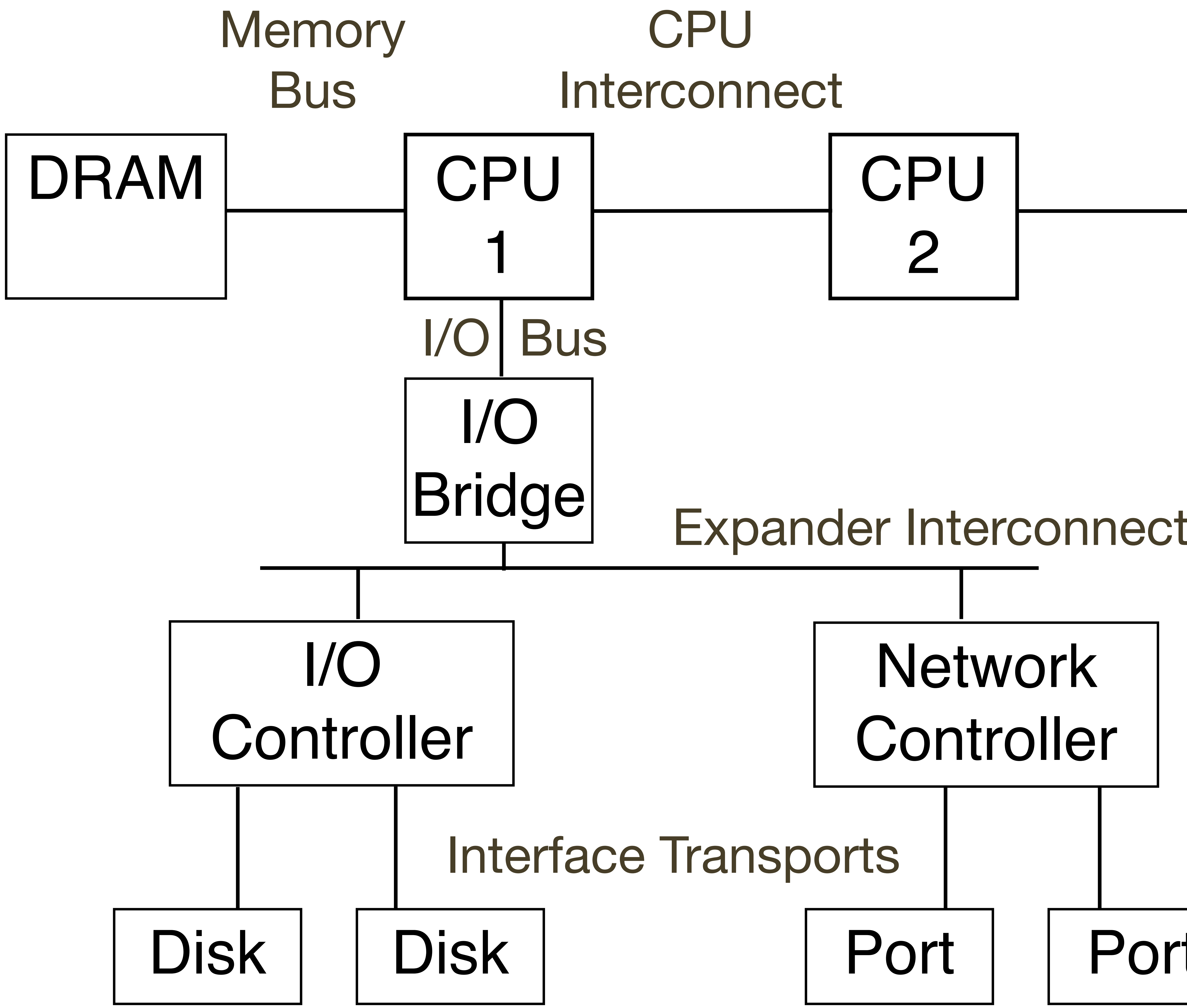
The USE Method: Hardware Resources

- CPUs
- Main Memory
- Network Interfaces
- Storage Devices
- Controllers
- Interconnects

The USE Method: Hardware Resources

- **A great way to determine resources is to find (or draw) the server *functional diagram***
  - The hardware team at vendors should have these
- **Analyze every component in the data path**

The USE Method: Functional Diagrams, Generic Example



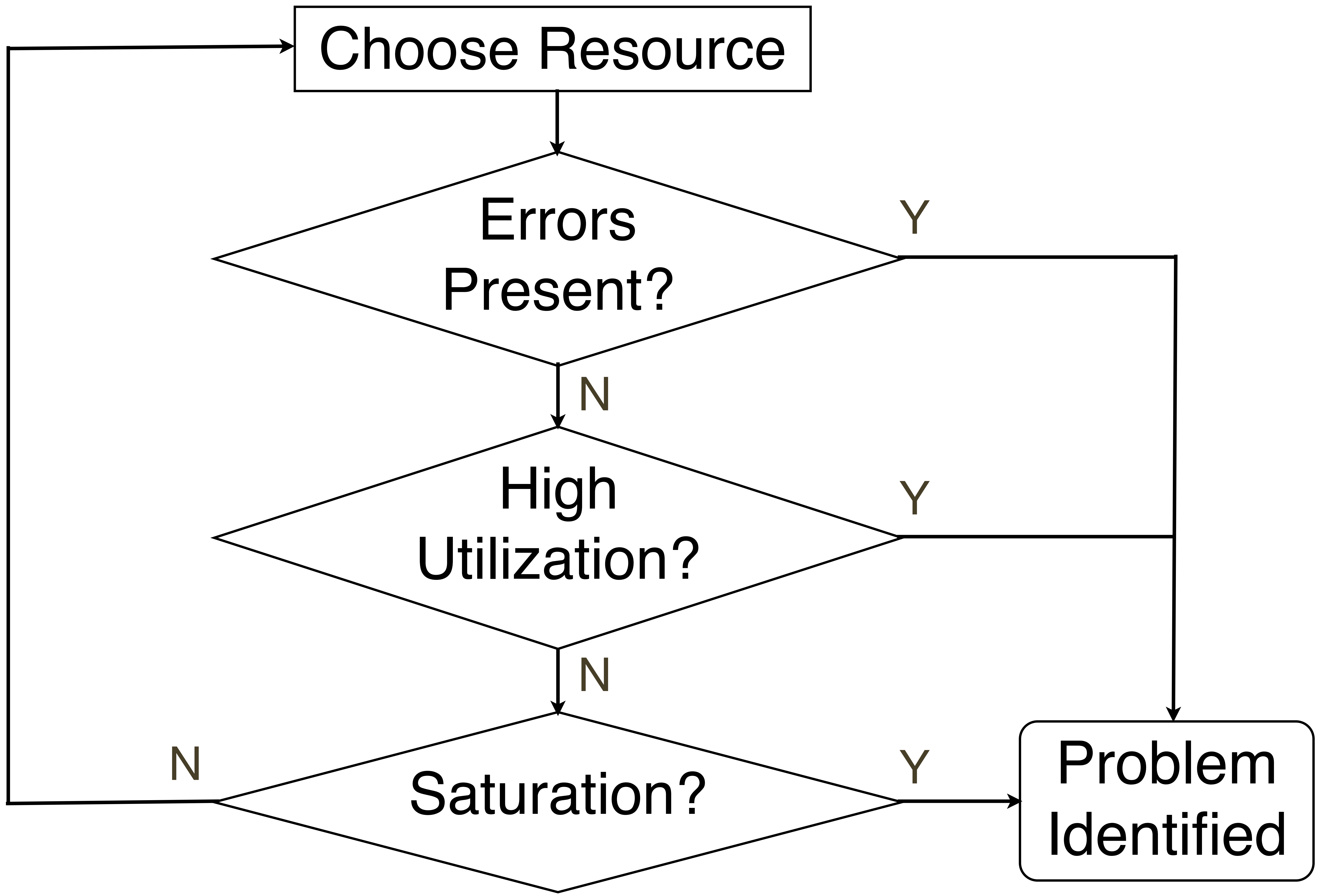
The USE Method: Resource Types

- **There are two different resource types, each define utilization differently:**
  - **I/O Resource**: eg, network interface
    - utilization: time resource was busy.
      current IOPS / max or current throughput / max can be used in some cases
  - **Capacity Resource**: eg, main memory
    - utilization: space consumed
- **Storage devices act as both resource types**

The USE Method: Software Resources

- Mutex Locks
- Thread Pools
- Process/Thread Capacity
- File Descriptor Capacity

The USE Method: Flow Diagram



The USE Method: Interpretation

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- **Utilization**
  - 100% usually a bottleneck
  - 70%+ often a bottleneck for I/O resources, especially when high priority work cannot easily interrupt lower priority work (eg, disks)
  - Beware of time intervals. 60% utilized over 5 minutes may mean 100% utilized for 3 minutes then idle
  - Best examined per-device (unbalanced workloads)

The USE Method: Interpretation

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- **Saturation**
    - Any non-zero value adds latency
- **Errors**
    - Should be obvious

The USE Method: Easy Combinations

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Resource	Type	Metric
CPU	utilization	
CPU	saturation	
Memory	utilization	
Memory	saturation	
Network Interface	utilization	
Storage Device I/O	utilization	
Storage Device I/O	saturation	
Storage Device I/O	errors	

The USE Method: Easy Combinations

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Resource	Type	Metric
CPU	utilization	CPU utilization
CPU	saturation	run-queue length
Memory	utilization	available memory
Memory	saturation	paging or swapping
Network Interface	utilization	RX/TX tput/bandwidth
Storage Device I/O	utilization	device busy percent
Storage Device I/O	saturation	wait queue length
Storage Device I/O	errors	device errors

The USE Method: Harder Combinations

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Resource	Type	Metric
CPU	errors	
Network	saturation	
Storage Controller	utilization	
CPU Interconnect	utilization	
Mem. Interconnect	saturation	
I/O Interconnect	saturation	

The USE Method: Harder Combinations

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Resource	Type	Metric
CPU	errors	eg, correctable CPU cache ECC events
Network	saturation	“nocanputs”, buffering
Storage Controller	utilization	active vs max controller IOPS and tput
CPU Interconnect	utilization	per port tput / max bandwidth
Mem. Interconnect	saturation	memory stall cycles
I/O Interconnect	saturation	bus throughput / max bandwidth

The USE Method: tools

- **To be thorough, you will need to use:**
  - CPU performance counters
    - For bus and interconnect activity; eg, perf events, cpustat
  - Dynamic Tracing
    - For missing saturation and error metrics; eg, DTrace
- **Both can get tricky; tools can be developed to help**
  - Please, no more top variants! ... unless it is *interconnect*-top or *bus*-top
  - I've written dozens of open source tools for both CPC and DTrace; much more can be done

Workload Characterization

- **May use as a 3rd Methodology**
- **Characterize workload by:**
  - **who** is causing the load? PID, UID, IP addr, ...
  - **why** is the load called? code path
  - **what** is the load? IOPS, tput, type
  - **how** is the load changing over time?
- **Best performance wins are from *eliminating unnecessary work***
- **Identifies class of issues that are load-based, not architecture-based**

Drill-Down Analysis

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- May use as a 4th Methodology
- Peel away software layers to drill down on the issue
- Eg, software stack I/O latency analysis:

Application
System Call Interface
File System
Block Device Interface
Storage Device Drivers
Storage Devices

Drill-Down Analysis: Open Source

- With Dynamic Tracing, all function entry & return points can be traced, with nanosecond timestamps.
- One Strategy is to measure latency pairs, to search for the source; eg, A->B & C->D:

```
 static int
 arc_cksum_equal(arc_buf_t *buf)
A{
         zio_cksum_t zc;
         int equal;

         mutex_enter(&buf->b_hdr->b_freeze_lock);
       C fletcher_2_native(buf->b_data, buf->b_hdr->b_size, &zc); D

         equal = ZIO_CHECKSUM_EQUAL(*buf->b_hdr->b_freeze_cksum, zc);
         mutex_exit(&buf->b_hdr->b_freeze_lock);

         return (equal);
B}
```

Other Methodologies

- **Method R**
  - A latency-based analysis approach for Oracle databases. See “Optimizing Oracle Performance" by Cary Millsap and Jeff Holt (2003)
- **Experimental approaches**
  - Can be very useful: eg, validating network throughput using iperf

Specific Tools for the USE Method

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illumos-based

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- **http://dtrace.org/blogs/brendan/2012/03/01/the-use-method-solaris-performance-checklist/**

Resource	Type	Metric
CPU	Utilization	per-cpu: `mpstat 1`, "idl"; system-wide: `vmstat 1`, "id"; per-process:`prstat -c 1` ("CPU" == recent), `prstat -mLc 1` ("USR" + "SYS"); per-kernel-thread: `lockstat -Ii` *`rate`*, DTrace profile stack()
CPU	Saturation	system-wide: `uptime`, load averages; `vmstat 1`, "r"; DTrace dispqlen.d (DTT) for a better "vmstat r"; per-process: `prstat -mLc 1`, "LAT"
CPU	Errors	`fmadm faulty`; `cpustat` (CPC) for whatever error counters are supported (eg, thermal throttling)
Memory	Saturation	system-wide: `vmstat 1`, "sr" (bad now), "w" (was very bad); `vmstat -p 1`, "api" (anon page ins == pain), "apo"; per-process: `prstat -mLc 1`, "DFL"; DTrace anonpgpid.d (DTT), vminfo:::anonpgin on execname

- **... etc for all combinations (would span a dozen slides)**

Linux-based

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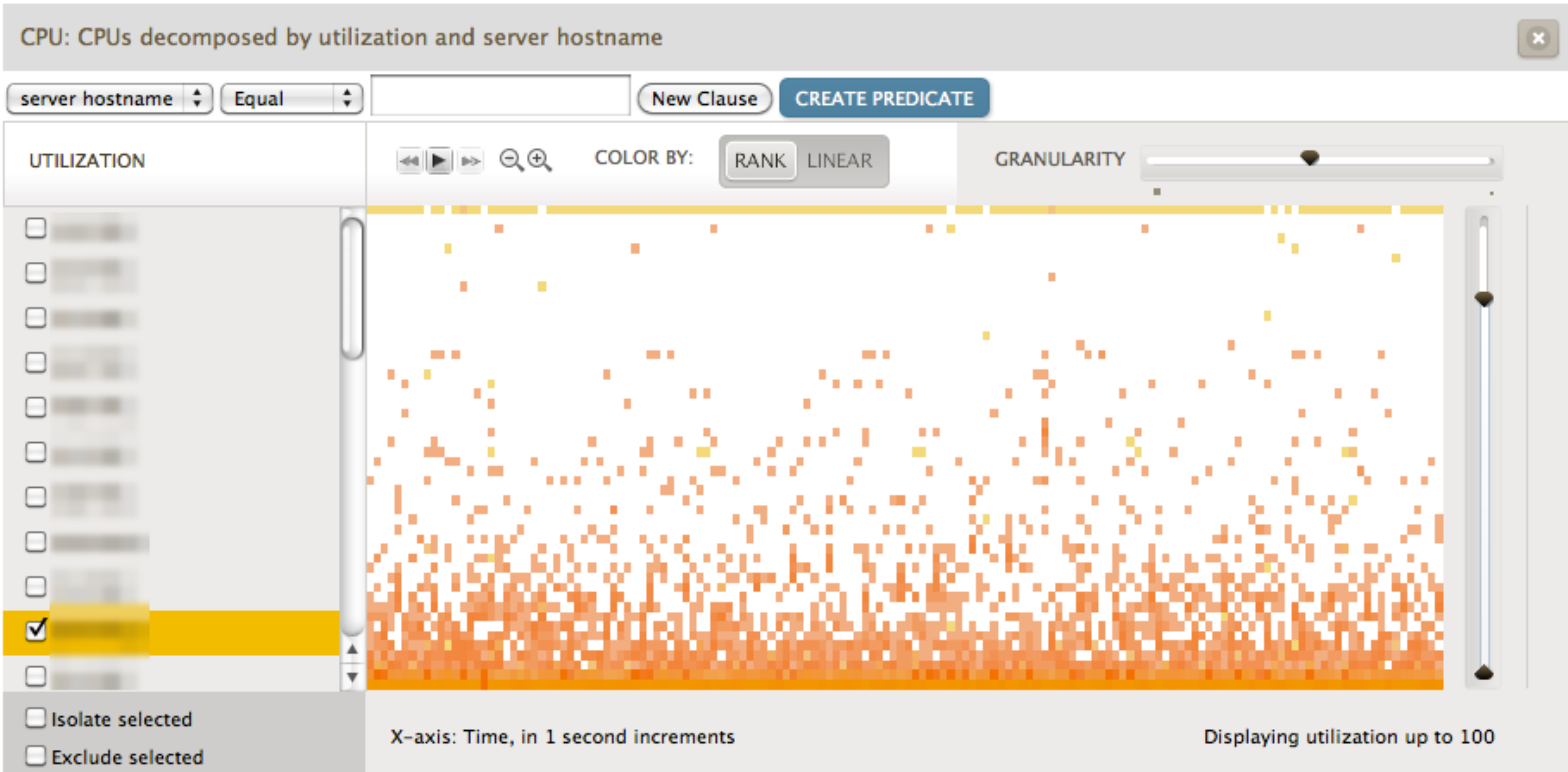
- **http://dtrace.org/blogs/brendan/2012/03/07/the-use-method-linux-performance-checklist/**

Resource	Type	Metric
CPU	Utilization	per-cpu: `mpstat -P ALL 1`, "%idle"; `sar -P ALL`, "%idle"; system-wide: `vmstat 1`, "id"; `sar -u`, "%idle"; `dstat -c`, "idl"; per-process:`top`, "%CPU"; `htop`, "CPU%"; `ps -o pcpu`; `pidstat 1`, "%CPU"; per-kernel-thread: `top/htop` ("K" to toggle), where VIRT == 0 (heuristic). [1]
CPU	Saturation	system-wide: `vmstat 1`, "r" > CPU count [2]; `sar -q`, "runq-sz" > CPU count; `dstat -p`, "run" > CPU count; per-process: /proc/PID/schedstat 2nd field (sched_info.run_delay); `perf sched latency` (shows "Average" and "Maximum" delay per-schedule); dynamic tracing, eg, SystemTap schedtimes.stp "queued(us)" [3]
CPU	Errors	`perf` (LPE) if processor specific error events (CPC) are available; eg, AMD64's "04Ah Single-bit ECC Errors Recorded by Scrubber" [4]

- **... etc for all combinations (would span a dozen slides)**

Products

- Earlier I said methodologies could be supported by monitoring solutions
- At Joyent we develop Cloud Analytics:



Future

- **Methodologies for advanced performance issues**
    - I recently worked a complex KVM bandwidth issue where no current methodologies really worked
- **Innovative methods based on open source + dynamic tracing**
- **Less performance mystery. Less guesswork.**
- **Better use of resources (price/performance)**
- **Easier for beginners to get started**

Thank you

- **Resources:**
  - http://dtrace.org/blogs/brendan
    - http://dtrace.org/blogs/brendan/2012/02/29/the-use-method/
    - http://dtrace.org/blogs/brendan/tag/usemethod/
    - http://dtrace.org/blogs/brendan/2011/12/18/visualizing-device-utilization/ - ideas if you are a monitoring solution developer
  - brendan@joyent.com