Real Life Examples of Solving Performance Problems Using SystemTap

IBM Linux Technology Center
Vara Prasad
varap@us.ibm.com
Agenda

- Common Performance Questions
- What is SystemTap?
- What can SystemTap do for you?
- SystemTap GUI
- Real Life Examples
- Conclusions
- Q&A
Common performance questions

- Occasionally jobs take significantly longer than usual to complete, or don’t complete. Why?
- An application seems to always take a long time to complete. Where is the problem?
- Is my system capable of handling additional workloads?

- **Answering these questions is often disruptive, time-consuming, and requires a high degree of OS knowledge and expertise.**
Current performance tools: Drawbacks

- Tuning high performance systems is complex
- System wide performance problems are difficult to identify
  - many complex moving parts
  - Standard tools are limited in capabilities
  - Expert tools require customization not feasible for production systems
- Some tools have overhead even when not in use, not ideal for production systems
- Some tools need modifying operating system
- Often, different tools are used on different hardware
  - Many different tools and data sources but no easy way to integrate the information
Characteristics of the ideal tool

- Available: Integrated into the OS and available on demand
- Low overhead: Has zero impact when disabled; insignificant overhead when in use
- Safe: Safe to use in a production environment
- Top to bottom: A tool that helps to solve problems from application layer to the hardware interface
- Versatile: Easy to learn and use effectively by both novices and experts
SystemTap

- One tool to analyze systemic problems all the way from applications to Operating System
- Tool for real time performance analysis
- Designed to be safe to use in production environments, no need to reproduce the problems in test environment
- Open source community project with active contributions from IBM, Intel, Hitachi, Red Hat and various community members.
- A rich set of tracing applications are bundled with OS releases for common problems
- Custom applications can be developed quickly using a familiar scripting language.
- **Native code**, no interpreter and highly parallel execution.
- An extensible platform and enabler for developing lots of new tools
- Enhanced through customer and development-community involvement.
SystemTap

- Realtime performance analysis
- Capacity planning
- Functional problem analysis (debugging)
- Low overhead and safe for production systems
- Continuous Performance monitoring
- Easy to use by system administrators
- On Demand probing
SystemTap Safety features

- Leverages well tested tool chain, no new compiler or interpreter
- Reuse well tested kernel features
- Language Safety features:
  - No dynamic memory allocation
  - Types and type conversions limited
  - Limited pointer operations
- Builtin safety checks
  - Infinite loops and recursion
  - Invalid variable access
  - Division by zero
  - Restricted access to kernel memory
  - Array bound checks
  - Version compatibility checks
SystemTap Availability
What can SystemTap do for you TODAY?

- **VMM**
- **Scheduler**
- **Kernel**
- **Platforms**
- **Filesystems**
- **Loadable modules**
- **Networking**
- **Systemcalls**
- **Device Drivers/ISR**
- **I/O subsystem**
- **Process**
- **Locking**

Architectures supported:
- IA 32
- X86_64
- IA64
- PPC 64
- S390
What will SystemTap do for you by 2007?

Architectures supported

- IA 32
- X86_64
- IA64
- PPC 64
- S390

Application Space

- Perl/Python Apps
- Java Apps
- PHP
- Other interpreted apps
- Popular enterprise apps in C/C++
- C/C++ apps
- User Libs/shared libraries/libc

Kernel Space

- Systemcalls
- Other Kernel Subsystems
- Filesystems
- Device Drivers/ISR
- Networking
- Loadable modules
- VMM
- Scheduler
- I/O subsystem
- Process
- Locking

Platforms
Example End User Script

global reads
probe begin {
    printf(“probe beginning\n”)
}

probe syscall.read {
    reads[execname()] <<< count
}

probe end {
    foreach (prog_name in reads) {
        printf("Name: %s, # Reads: %d, Total Bytes: %d, Avg: %d\n", 
            prog_name, @count(reads[prog_name]), 
            @sum(reads[prog_name]), @avg(reads[prog_name]))
    }
}

Language features:
- Global variables and builtin functions
- Associative arrays
- Aggregation operations and functions
- Pre-defined probe library or tapsets for common probe points
- Familiar hierarchical “dot” notation for probe specification
- Probe entry and termination call-backs
TapSets

- A TapSet defines:
  - Probe Points: a set of instrumentation points for a particular subsystem
  - Data values that are available at each probe point.
- Written by experts
- Tested and packaged with SystemTap
- Tapsets are currently available for major areas of the kernel like systemcalls, process, scheduler, filesystem, networking etc.
- Currently Tapsets define thousands of probe points
How SystemTap works?

- **parse**
- **elaborate**
- **translate to C, compile**
- **load module, start probe**
- **extract output, unload**

Flowchart:
- Probe script
- TapSet library
- Probe kernel module
- Probe output
SystemTap GUI

- An Eclipse-based application intended to ease the use of SystemTap.
- Both an Integrated Development Environment for the SystemTap, as well as a data visualization and analysis tool.
- Contains three unique perspectives, each with a different purpose – IDE, Graphing and Dashboard.
SystemTap GUI – IDE Perspective

- Editor for creating, editing and testing SystemTap scripts, including code assist, syntax highlighting, and script execution.
- Browsers:
  1. Tapset Browser – Browse and insert skeleton probes, learn available parameters.
  2. Builtin Function – Browse tapset functions/return types.
  3. Source Browser – Navigate and view source files, and using those files, place probes at arbitrary code locations.
SystemTap GUI – IDE Perspective
SystemTap GUI – Graphing Perspective

- Allows users to view the output of their SystemTap scripts in graph form.
- Users can run an open script, import existing data from a previous run, export data from a new run, or save the graph as an image.
- Features include zooming, scrolling along the timeline, and optional legends, gridlines, etc.
SystemTap GUI – Graphing Perspective

![SystemTap GUI Graph](image)

**Time vs Read, Write**

```
/home/biggsje/chart.stp
1155232066 1179814 360846
1155232067 4897897 482319
1155232068 2007618 178105
1155232069 646618 26944
1155232070 677455 35726
1155232071 691687 86032
1155232072 2196376 90279
1155232073 317846 20184
```
SystemTap GUI – Dashboard Perspective

- Enables users to import, load, and run predefined scripts.
- Allows the execution and viewing of 1 to 8 different graphs at one time, gives ideal perspective for entire system analysis.
SystemTap GUI – Dashboard Perspective
Real Life Uses of SystemTap

- SCSI request size mismatch
- UDP datagram loss
- Top I/O by users and processes
SCSI Request Sizes

Problem
In a benchmark run, we observed a mismatch between expected and actual SCSI I/O counts.

Solution
Create a simple SystemTap script to track the counts and sizes of SCSI requests to a specific device.
SCSI Request Sizes – scsi_req.stp

# Thanks to Allan Brunelle from HP
global rqs, host_no, channel, id, lun, direction

probe begin
{
    host_no   = 0
    channel   = 1
    id        = 1
    lun       = 0
    direction = 1 /* write */
}

probe scsi.iodispatching
{
    if (data_direction != direction) next
    if (lun            != lun) next
    if (id             != dev_id) next
    if (channel        != channel) next
    if (host_no        != host_no) next

    rqs[req_bufflen / 1024]++
}

probe end
{
    printf("ReqSz(KB)	#Reqs\n")
    foreach (rec+ in rqs)
        printf("%8d	%5d\n", rec, rqs[rec])
}
### SCSI Request Sizes – output

```
# stap scsi_req.stp

<table>
<thead>
<tr>
<th>ReqSz (KB)</th>
<th>#Reqs</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>44</td>
<td>1</td>
</tr>
<tr>
<td>88</td>
<td>1</td>
</tr>
<tr>
<td>164</td>
<td>1</td>
</tr>
<tr>
<td>204</td>
<td>1</td>
</tr>
<tr>
<td>216</td>
<td>1</td>
</tr>
<tr>
<td>308</td>
<td>1</td>
</tr>
<tr>
<td>448</td>
<td>1</td>
</tr>
<tr>
<td>508</td>
<td>1</td>
</tr>
<tr>
<td>512</td>
<td>36</td>
</tr>
</tbody>
</table>
```
UDP Datagram Loss

Problem
A customer wanted to see UDP statistics for both the sending and receiving sides and how many UDP datagrams were dropped. Existing tools don't provide all of this data:
- netstat -su doesn't show how many datagrams are dropped when sending.
- iptraf doesn't show statistics on datagram loss.

Solution
Create a SystemTap script that records how many UDP datagrams have been sent and received and how many were dropped.
# Thanks to Eugene Teo from Red Hat

global udp_out, udp_outerr, udp_in, udp_inerr, udp_noport

probe begin {
    /* print header */
    printf("%11s %10s %10s %10s %10s\n",
            "UDP_out", "UDP_outErr", "UDP_in", "UDP_inErr", "UDP_noPort")
}

probe kernel.function("udp_sendmsg") .return {
    $return >= 0 ? udp_out++ : udp_outerr++
}

probe kernel.function("udp_queue_rcv_skb") .return {
    $return == 0 ? udp_in++ : udp_inerr++
}

probe kernel.function("icmp_send") {
    /* destination not reachable and port not reachable */
    if ($type == 3 && $code == 3) {
        /* UDP Protocol = 17 */
        if ($skb_in->nh->iph->protocol == 17)
            udp_noport++
    }
}

/* print data every sec */
probe timer.ms(1000) {
    printf("%11d %10d %10d %10d %10d\n",
            udp_out, udp_outerr, udp_in, udp_inerr, udp_noport)
}
### UDP Datagram Loss - udpstat.stp output

<table>
<thead>
<tr>
<th>UDP_out</th>
<th>UDP_outErr</th>
<th>UDP_in</th>
<th>UDP_inErr</th>
<th>UDP_noPort</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>9</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>
Top IO Users by User ID

Problem
Which user is doing the most IO on the system? iostat does not provide statistics on a per user basis.

Solution
Write a simple SystemTap script that probes file system read() and write() and records the bytes of IO for each user.
uid-iotop.stp

# Thanks to Mike Grundy and Mike Mason from IBM

global reads, writes

function print_top () {
  cnt=0
  printf("%-10s\t%10s\t%15s\n", "User ID", "KB Read", "KB Written")
  foreach (id in reads-) {
    printf("%-10s\t%10d\t%15d\n", id, reads[id]/1024, writes[id]/1024)
    if (cnt++ == 5)
      break
  }
  delete reads
  delete writes
}

probe kernel.function("vfs_read") {
  reads[sprintf("%d", uid())] += $count
}

probe kernel.function("vfs_write") {
  writes[sprintf("%d", uid())] += $count
}

# print top 5 IO users by uid every 5 seconds
probe timer.ms(5000) {
  print_top ()
}
uid-iottop.stp output

<table>
<thead>
<tr>
<th>User ID</th>
<th>KB Read</th>
<th>KB Written</th>
</tr>
</thead>
<tbody>
<tr>
<td>504</td>
<td>14237</td>
<td>3163</td>
</tr>
<tr>
<td>505</td>
<td>11208</td>
<td>929</td>
</tr>
<tr>
<td>502</td>
<td>11175</td>
<td>889</td>
</tr>
<tr>
<td>503</td>
<td>12469</td>
<td>866</td>
</tr>
<tr>
<td>0</td>
<td>1778</td>
<td>183</td>
</tr>
</tbody>
</table>
Top IO Users by Process ID

**Problem**
Which process is doing the most IO on the system?

**Solution**
Convert the uid-iotop.stp script to record IO for each process instead of each user. Changes shown on next slide in **bold italics**. Ease of changes demonstrate the flexibility of SystemTap.
# Thanks to Mike Grundy and Mike Mason from IBM

global reads, writes

function print_top () {
    cnt=0
    printf ("%-10s	%10s	%15s\n", "Process ID", "KB Read", "KB Written")
    foreach (id in reads-) {
        printf("%-10s	%10d	%15d\n", id, reads[id]/1024, writes[id]/1024)
        if (cnt++ == 5)
            break
    }
    delete reads
    delete writes
}

probe kernel.function("vfs_read") {
    reads[sprintf("%d", pid())] += $count
}

probe kernel.function("vfs_write"){
    writes[sprintf("%d", pid())] += $count
}

# print top 5 IO users by pid every 5 seconds
probe timer.ms(5000) {
    print_top ()
}
### pid-iotop.stp output

<table>
<thead>
<tr>
<th>Process ID</th>
<th>KB Read</th>
<th>KB Written</th>
</tr>
</thead>
<tbody>
<tr>
<td>13839</td>
<td>2827</td>
<td>25</td>
</tr>
<tr>
<td>10608</td>
<td>1318</td>
<td>303</td>
</tr>
<tr>
<td>10587</td>
<td>1298</td>
<td>314</td>
</tr>
<tr>
<td>10627</td>
<td>1219</td>
<td>454</td>
</tr>
<tr>
<td>10633</td>
<td>1219</td>
<td>438</td>
</tr>
</tbody>
</table>
Conclusions

- **One tool**: SystemTap is a new performance tool for analyzing systemwide performance problems
- **Safe**: Safety is built-in to use in production systems
- **Realtime**: Low overhead suitable for continuous performance monitoring production systems
- **Easy**: Easy to use by all levels of users with its familiar scripting language and intuitive GUI
- **Effective**: Identify bottlenecks all the way from applications to OS in hours vs days to weeks
- **On Demand**: New probe points can be added on demand, not limited to what is shipped
- **Available**: Available on most common h/w platforms and enterprise distributions
References

- SystemTap Project http://sourceware.org/systemtap/
- SystemTap GUI http://stapgui.sourceforge.net/
- SystemTap Wiki http://sourceware.org/systemtap/wiki
Disclaimers and Trademarks

- This work represents the view of the author and does not necessarily represent the view of IBM.
- IBM and the IBM logo are registered trademarks of International Business Machines Corporation in the United States and/or other countries.
- Linux is a registered trademark of Linus Torvalds.
- Other company, product, and service names may be trademarks or service marks of others.
Q & A