How to Surprise by being a Linux Performance “know-it-all”

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IBM Lab Böblingen, Germany
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NOTES: Linux penguin image courtesy of Larry Ewing (lewing@isc.tamu.edu) and The GIMP

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Agenda (what it used to be)

- **Tools are your swiss army knife**
  - ps
  - top
  - sadc/sar
  - iostat
  - vmstat
  - netstat
Agenda (what it used to be)

- Tools are your swiss army knife
  - ps
  - top
  - sadc/sar
  - iostat
  - vmstat
  - netstat
Ready for take-off
Agenda

- **Tools are your swiss army knife**
  - htop
  - dstat
  - pidstat
  - irqstats
  - strace/ltrace
  - blktrace
  - hyptop
  - profiling
  - valgrind
  - iptraf
  - tracepoints
General thoughts on performance tools

- **Things that are always to consider**
  - Monitoring can impact the system
  - Most data gathering averages over a certain period of time → this flattens peaks
  - Start with defining the problem
    - which parameter(s) from the application/system indicates the problem
    - which range is considered as bad, what is considered as good
  - monitor the good case and save the results
    - comparisons when a problem occurs can save days and weeks

- **Staged approach saves a lot of work**
  - Try to use general tools to isolate the area of the issue
  - Create theories and try to quickly verify/falsify them
  - Use advanced tools to debug the identified area
# Orientation - where to go

<table>
<thead>
<tr>
<th>Tool</th>
<th>1st overview</th>
<th>CPU consumption</th>
<th>latencies</th>
<th>Hot spots</th>
<th>Disk I/O</th>
<th>Memory</th>
<th>Network</th>
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DSTAT

- Characteristics: Live easy to use full system information
- Objective: Flexible set of statistics
- Usage:
  ```
  dstat -tv -aio -disk-util -n -net-packets -i -ipc -D total, [diskname] -top-io [...] [interval]
  dstat -tinv
  ```
- Shows
  - Throughput and utilization
  - Summarized and per Device queue information
  - Much more, it more or less combines several classic tools like iostat and vmstat
- Hints
  - Powerful plugin concept
  - "--top-io" for example identifies the application causing the most I/Os
  - Colorization allows fast identification of deviations
DSTAT – the limit is your screen width

similar to vmstat

similar to iostat
(also per device)

new in live tool
HTOP

- Characteristics: Process overview with extra features
- Objective: Get a understanding about your running processes
- Usage:

  htop

- Shows
  - Running processes
  - CPU and memory utilization
  - Accumulated times
  - I/O rates
  - System utilization visualization

- Hints
  - Htop can display more uncommon fields (in menu)
  - Able to send signals out of its UI for administration purposes
  - Processes can be sorted/filtered for a more condensed view
**HTOP**

Configurable utilization visualization

Common process info

Accumulated Usage and IO rates

Hierarchy

<table>
<thead>
<tr>
<th>PID</th>
<th>USER</th>
<th>PRI</th>
<th>NI</th>
<th>VIRT</th>
<th>RES</th>
<th>SHR</th>
<th>S</th>
<th>CPU%</th>
<th>MEM%</th>
<th>UTIME+</th>
<th>STIME+</th>
<th>IORR</th>
<th>IOWR</th>
<th>TIME+</th>
<th>Command</th>
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<td>142M</td>
<td>140M</td>
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<td>1.2</td>
<td>0:00.47</td>
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<td>0</td>
<td>0:00.59</td>
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</tbody>
</table>
PIDSTAT

- Characteristics: Easy to use extended per process statistics
- Objective: Identify processes with peak activity
- Usage:

  \[ \text{pidstat} \ [-\text{w} \mid -\text{r} \mid -\text{d}] \]

- Shows
  - \(-\text{w}\) context switching activity and if it was voluntary
  - \(-\text{r}\) memory statistics, especially minor/major faults per process
  - \(-\text{d}\) disk throughput per process

- Hints
  - Also useful if run as background log due to its low overhead
    - Good extension to sadc in systems running different applications/services
  - \(-\text{p} <\text{pid}>\) can be useful to track activity of a specific process
## PIDSTAT examples

<table>
<thead>
<tr>
<th>Time</th>
<th>PID</th>
<th>cswch/s</th>
<th>nvcswch/s</th>
<th>Command</th>
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<td>12:46:18 PM</td>
<td>3</td>
<td>2.39</td>
<td>0.00</td>
<td>ksoftirqd/0</td>
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<tr>
<td>12:46:18 PM</td>
<td>4</td>
<td>0.04</td>
<td>0.00</td>
<td>migration/0</td>
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<tr>
<td>12:46:18 PM</td>
<td>1073</td>
<td>123.42</td>
<td>180.18</td>
<td>Xorg</td>
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</tbody>
</table>

### Voluntarily / Involuntary

<table>
<thead>
<tr>
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<th>PID</th>
<th>minflt/s</th>
<th>majflt/s</th>
<th>VSZ</th>
<th>RSS</th>
<th>%MEM</th>
<th>Command</th>
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</thead>
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<tr>
<td>12:47:51 PM</td>
<td>985</td>
<td>0.06</td>
<td>0.00</td>
<td>15328</td>
<td>3948</td>
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<td>12:47:51 PM</td>
<td>992</td>
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<td>0.00</td>
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</table>

### Faults per process

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<th>PID</th>
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<th>kB_wr/s</th>
<th>kB_ccwr/s</th>
<th>Command</th>
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<td>12:49:18 PM</td>
<td>330</td>
<td>0.00</td>
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<td>kjournald</td>
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<td>12:49:18 PM</td>
<td>2899</td>
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<td>3045</td>
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</table>

### How much KB disk I/O per process
**IRQ Statistics**

- **Characteristics:** Low overhead IRQ information
- **Objective:** Condensed overview of IRQ activity
- **Usage:**
  - Shows
    - Which interrupts happen on which cpu
  - Hints
    - Recent Versions (SLES11-SP2) much more useful
    - If interrupts are unintentionally unbalanced
    - If the amount of interrupts matches I/O
      - This can point to non-working IRQ avoidance

**cat / proc/interrupts**
IRQ Statistics

- Example
  - Network focus on CPU zero (in this case unwanted)
  - Scheduler covered most of that avoiding idle CPU 1-3
  - But caused a lot migrations, IPI's and cache misses

<table>
<thead>
<tr>
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<td>DAS:</td>
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<td>909</td>
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[Ext] Clock Comparator
[Ext] External Call
[Ext] Emergency Signal
[Ext] CPU Timer
[Ext] Timing Alert
[Ext] Pseudo Page Fault
[Ext] DASD Diag
[Ext] Virtio
[Ext] Service Call
[Ext] IUCV
[Ext] CPU Measurement
[I/O] Common I/O Layer Interrupt
[I/O] QDIO Adapter Interrupt
[I/O] DASD

[...] 3215, 3270, Tape, Unit Record Devices, LCS, CLAW, CTC, AP Bus, Machine Check
STRACE

- Characteristics: High overhead, high detail tool
- Objective: Get insights about the ongoing system calls of a program
- Usage:

  ```
  strace -p [pid of target program]
  ```

- Shows
  - Identify kernel entries called more often or taking too long
    - Can be useful if you search for increased system time
  - Time in call (\(-T\))
  - Relative time-stamp (\(-r\))

- Hints
  - The option “\(-c\)” allows medium overhead by just tracking counters and durations
STRACE - example

```
strace -cf -p 26802
Process 26802 attached - interrupt to quit
^CProcess 26802 detached

% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
 58.43    0.007430          17       450           read
 24.33    0.003094           4       850       210 access
  5.53    0.000703           4       190        10 open
  4.16    0.000529           3       175           write
  2.97    0.000377           2       180           munmap
  1.95    0.000248           1       180           close
  1.01    0.000128           1       180           mmap
  0.69    0.000088          18         5           fdatasync
  0.61    0.000078           0       180           fstat
  0.13    0.000017           3       180           pause

------ ----------- ----------- --------- --------- ----------------
100.00    0.012715                  2415       225 total
```

shares to rate importance

name (see man pages)

a lot or slow calls?
LTRACE

- Characteristics: High overhead, high detail tool
- Objective: Get insights about the ongoing library calls of a program
- Usage:

```
ltrace -p [pid of target program]
```

- Shows
  - Identify library calls that are too often or take too long
  - Good if you search for additional user time
  - Good if things changed after upgrading libs
  - Time in call (-T)
  - Relative time-stamp (-r)

- Hints
  - The option “-c” allows medium overhead by just tracking counters and durations
  - The option -S allows to combine ltrace and strace
# LTRACE - example

The LTRACE tool provides detailed timing information for a running program. Here's an example:

```bash
ltrace -cf -p 26802
```

<table>
<thead>
<tr>
<th>% time</th>
<th>seconds</th>
<th>usecs/call</th>
<th>calls</th>
<th>function</th>
</tr>
</thead>
<tbody>
<tr>
<td>98.33</td>
<td>46.765660</td>
<td>5845707</td>
<td>8</td>
<td>pause</td>
</tr>
<tr>
<td>0.94</td>
<td>0.445621</td>
<td>10</td>
<td>42669</td>
<td>strcmp</td>
</tr>
<tr>
<td>0.44</td>
<td>0.209839</td>
<td>25</td>
<td>8253</td>
<td>fgets</td>
</tr>
<tr>
<td>0.08</td>
<td>0.037737</td>
<td>11</td>
<td>3168</td>
<td>__isoc99_sscanf</td>
</tr>
<tr>
<td>0.07</td>
<td>0.031786</td>
<td>20</td>
<td>1530</td>
<td>access</td>
</tr>
<tr>
<td>0.04</td>
<td>0.016757</td>
<td>10</td>
<td>1611</td>
<td>strchr</td>
</tr>
<tr>
<td>0.03</td>
<td>0.016479</td>
<td>10</td>
<td>1530</td>
<td>snprintf</td>
</tr>
<tr>
<td>0.02</td>
<td>0.010467</td>
<td>1163</td>
<td>9</td>
<td>fdatasync</td>
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<td>324</td>
<td>fclose</td>
</tr>
<tr>
<td>0.02</td>
<td>0.007218</td>
<td>21</td>
<td>342</td>
<td>fopen</td>
</tr>
<tr>
<td>0.01</td>
<td>0.006239</td>
<td>19</td>
<td>315</td>
<td>write</td>
</tr>
<tr>
<td>0.00</td>
<td>0.000565</td>
<td>10</td>
<td>54</td>
<td>strncpy</td>
</tr>
</tbody>
</table>

**Shares to rate importance**

- **a lot or slow calls?**

- **name (see man pages)**

**Total:**

- **% time:** 100.00
- **seconds:** 47.560161
- **total calls:** 59948

Note: The tool helps identify critical functions that consume a significant amount of time in the program.
STRACE / LTRACE – full trace

- Without -c both tools produce a full detail log
  - Via -f child processes can be traced as well
  - Extra options “-Tr” are useful to search for latencies
    follow time in call / relative time-stamp
  - Useful to “read” what exactly goes on when

Example strace'ing a sadc data gatherer

```
0.000028 write(3, "\0\0\0\0\0\17\0\0\0\0\0\0\0\0\17\0\0\0\0\0\0\0\0\0\0\0\0\0\0\0\0", 680) = 680 <0.000007>
0.000027 write(3, "\0\0\0\0\0\17\0\0\0\0\0\0\0\0\0\0\0\0\0\0\0\0", 680) = 680 <0.000007>
0.000026 fdatasync(3) = 0 <0.002673>
0.002688 pause() = 0 <3.972935>
3.972957 --- SIGALRM (Alarm clock) @ 0 (0) ---
0.000051 rt_sigaction(SIGALRM, {0x8000314c, [ALRM], SA_RESTART}, {0x8000314c, [ALRM], SA_RESTART}, 8) = 0 <0.000005>
0.000038 alarm(4) = 0 <0.000005>
0.000031 sigreturn() = ? (mask now []) <0.000005>
0.000024 stat("/etc/localtime", {st_mode=S_IFREG|0644, st_size=2309, ...}) = 0 <0.000007>
0.000034 open("/proc/uptime", O_RDONLY) = 4 <0.000009>
0.000024 fstat(4, {st_mode=S_IFREG|0444, st_size=0, ...}) = 0 <0.000005>
0.000029 mmap(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0x3fffd20a000 <0.000006>
0.000028 read(4, "11687.70 24836.04\n", 1024) = 18 <0.000010>
0.000027 close(4) = 0 <0.000006>
0.000020 munmap(0x3fffd20a000, 4096) = 0 <0.000009>
```
BLKTRACE

- Characteristics: High detail info of the block device layer actions
- Objective: Understand what's going with your I/O in the kernel and devices
- Usage:
  - `blktrace -d [device(s)]`
  - `blkparse -st [commontracefilepart]`

- Shows
  - Events like merging, request creation, I/O submission, I/O completion, ...
  - Timestamps and disk offsets for each event
  - Associated task and executing CPU
  - Application and CPU summaries

- Hints
  - Filter masks allow lower overhead if only specific events are of interest
  - Has an integrated client/server mode to stream data away
    - Avoids extra disk I/O on a system with disk I/O issues
BLKTRACE – when is it useful

- Often its easy to identify that I/O is slow, but
  → Where?
  → Because of what?

- Block trace allows to
  - Analyze Disk I/O characteristics like sizes and offsets
    - Maybe your I/O is split in a layer below
  - Analyze the timing with details about all involved Linux layers
    - Often useful to decide if HW or SW causes stalls
  - Summaries per CPU / application can identify imbalances
BLKTRACE - events

Common
A -- remap For stacked devices, incoming i/o is remapped to device below it in the i/o stack. The remap action details what exactly is being remapped to what.
Q -- queued This notes intent to queue i/o at the given location. No real requests exists yet.
G -- get request To send any type of request to a block device, a struct request container must be allocated first.
I -- inserted A request is being sent to the i/o scheduler for addition to the internal queue and later service by the driver. The request is fully formed at this time.
D -- issued A request that previously resided on the block layer queue or in the i/o scheduler has been sent to the driver.
C -- complete A previously issued request has been completed. The output will detail the sector and size of that request, as well as the success or failure of it.

Plugging & Merges:
P -- plug When i/o is queued to a previously empty block device queue, Linux will plug the queue in anticipation of future I/Os being added before this data is needed.
U -- unplug Some request data already queued in the device, start sending requests to the driver. This may happen automatically if a timeout period has passed (see next entry) or if a number of requests have been added to the queue. Recent kernels associate the queue with the submitting task and unplug also on a context switch.
T -- unplug due to timer If nobody requests the i/o that was queued after plugging the queue, Linux will automatically unplug it after a defined period has passed.
M -- back merge A previously inserted request exists that ends on the boundary of where this i/o begins, so the i/o scheduler can merge them together.
F -- front merge Same as the back merge, except this i/o ends where a previously inserted requests starts.

Special
B -- bounced The data pages attached to this bio are not reachable by the hardware and must be bounced to a lower memory location. This causes a big slowdown in i/o performance, since the data must be copied to/from kernel buffers. Usually this can be fixed with using better hardware -- either a better i/o controller, or a platform with an IOMMU.
S -- sleep No available request structures were available, so the issuer has to wait for one to be freed.
X -- split On raid or device mapper setups, an incoming i/o may straddle a device or internal zone and needs to be chopped up into smaller pieces for service. This may indicate a performance problem due to a bad setup of that raid/dm device, but may also just be part of normal boundary conditions. dm is notably bad at this and will clone lots of i/o.
BLKTRACE - events

Common
A -- remap  For stacked devices, incoming i/o is remapped to device below it in the i/o stack. The remap action details what exactly is being remapped to what.
Q -- queued  This notes intent to queue i/o at the given location. No real requests exists yet.
G -- get request  To send any type of request to a block device, a struct request container must be allocated first.
I -- inserted  A request is being sent to the i/o scheduler for addition to the internal queue and later service by the driver. The request is fully formed at this time.
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U -- unplug  Some request data already exists in the device, start sending requests to the driver. This may happen automatically if a timeout period has passed or it may happen with a plug since added data has been added to the queue. Recent kernels associate the queue with the submitting task, so unplug is also called when unplug a context switch.
T -- unplug due to timer  If nobody requests the i/o that was queued after plugging the queue, Linux will automatically unplug it after a defined period has passed.
M -- back merge  A previously inserted request exists that ends on the boundary of where this i/o begins, so the i/o scheduler can merge them together.
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**Block device layer – events (simplified)**

- **App / A / X**
  - **Q**
    - **G**
      - **I** (Need to Generate a new request)
      - **P**
        - **U** (Plug queue and wait a bit if following requests can be merged)
        - **D**
          - **C** (Time from Dispatch to Complete)
          - **M / F** (Merge with an existing request)
    - **mergeable**
      - **N** (Plug queue and wait a bit if following requests can be merged)
      - **Y**
        - **M / F** (Unplug on upper limit (stream) or Time reached / submitting task ctx switch)
        - **Dispatch from block device layer to device driver**
BLKTRACE - example

- Example Case
  - The snippet shows a lot of 4k requests (8x512 byte sectors)
    - We expected the I/O to be 32k
  - Each one is dispatched separately (no merges)
    - This caused unnecessary overhead and slow I/O

<table>
<thead>
<tr>
<th>Maj/Min</th>
<th>CPU</th>
<th>Seq-nr</th>
<th>sec.nsec</th>
<th>pid</th>
<th>Action</th>
<th>RWBS</th>
<th>sect + size</th>
<th>map</th>
<th>source</th>
<th>task</th>
</tr>
</thead>
<tbody>
<tr>
<td>94,4</td>
<td>27</td>
<td>21</td>
<td>0.059363692</td>
<td>18994</td>
<td>A</td>
<td>R</td>
<td>20472832 + 8</td>
<td>&lt;- (94,5) 20472640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>94,4</td>
<td>27</td>
<td>22</td>
<td>0.059364630</td>
<td>18994</td>
<td>Q</td>
<td>R</td>
<td>20472832 + 8 [qemu-kvm]</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>94,4</td>
<td>27</td>
<td>23</td>
<td>0.059365286</td>
<td>18994</td>
<td>G</td>
<td>R</td>
<td>20472832 + 8 [qemu-kvm]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>94,4</td>
<td>27</td>
<td>24</td>
<td>0.059365598</td>
<td>18994</td>
<td>I</td>
<td>R</td>
<td>20472832 + 8 ( 312) [qemu-kvm]</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>25</td>
<td>0.059366255</td>
<td>18994</td>
<td>D</td>
<td>R</td>
<td>20472832 + 8 ( 657) [qemu-kvm]</td>
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<td></td>
</tr>
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<td>0.059370223</td>
<td>18994</td>
<td>A</td>
<td>R</td>
<td>20472840 + 8 &lt;- (94,5) 20472648</td>
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<td></td>
<td></td>
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<td>94,4</td>
<td>27</td>
<td>27</td>
<td>0.059370442</td>
<td>18994</td>
<td>Q</td>
<td>R</td>
<td>20472840 + 8 [qemu-kvm]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>94,4</td>
<td>27</td>
<td>28</td>
<td>0.059370880</td>
<td>18994</td>
<td>G</td>
<td>R</td>
<td>20472840 + 8 [qemu-kvm]</td>
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<td>R</td>
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<td>18994</td>
<td>D</td>
<td>R</td>
<td>20472840 + 8 ( 406) [qemu-kvm]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BLKTRACE - example

Example Case

- Analysis turned out that the I/O was from the swap code
- Same offsets were written by kswapd
- A recent code change there disabled the ability to merge
- The summary below shows the difference after a fix

Total initially

<table>
<thead>
<tr>
<th></th>
<th>Initially</th>
<th>After Fix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reads Queued</td>
<td>560,888, 2,243MiB</td>
<td>734,315, 2,937MiB</td>
</tr>
<tr>
<td>Read Dispatches</td>
<td>544,701, 2,243MiB</td>
<td>214,972, 2,937MiB</td>
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<tr>
<td>Reads Requeued</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reads Completed</td>
<td>544,716, 2,243MiB</td>
<td>214,971, 2,937MiB</td>
</tr>
<tr>
<td>Read Merges</td>
<td>16,187, 64,748KiB</td>
<td>519,343, 2,077MiB</td>
</tr>
<tr>
<td>IO unplugs</td>
<td>149,614</td>
<td>337,130</td>
</tr>
<tr>
<td>Writes Queued</td>
<td>226,242, 904,968KiB</td>
<td>300,188, 1,200MiB</td>
</tr>
<tr>
<td>Write Dispatches</td>
<td>159,318, 904,968KiB</td>
<td>215,176, 1,200MiB</td>
</tr>
<tr>
<td>Writes Requeued</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Writes Completed</td>
<td>159,321, 904,980KiB</td>
<td>215,177, 1,200MiB</td>
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<tr>
<td>Write Merges</td>
<td>61,744, 246,976KiB</td>
<td>73,325, 293,300KiB</td>
</tr>
<tr>
<td>Timer unplugs</td>
<td>149,614</td>
<td>337,130</td>
</tr>
</tbody>
</table>
HYPTOP

- Characteristics: Easy to use Guest/LPAR overview
- Objective: Check CPU and overhead statistics of your own and sibling images
- Usage:
  - Shows
    - CPU load & Management overhead
    - Memory usage
    - Can show image overview or single image details
- Hints
  - Good “first view” tool for linux admins that want to look “out of their linux”
  - Requirements:
    - For z/VM the Guest needs Class B
    - For LPAR “Global performance data control” check-box in HMC

hyptop
### HYPTOP

#### Why are exactly 4 CPUs used in all 6 CPU guests
- All these do not fully utilize their 2 CPUs
- No peaks in service guests
- LPAR images would see other LPARs

#### Weights are equal

#### Service guest weights

<table>
<thead>
<tr>
<th>System</th>
<th>CPU (str)</th>
<th>CPU (%)</th>
<th>CPU+ (hm)</th>
<th>Online mem (GiB)</th>
<th>Mem (GiB)</th>
<th>Wcpu (%)</th>
</tr>
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<tbody>
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<td>399.11</td>
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<td>11.94</td>
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<td>0:03:05</td>
<td>11.94</td>
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<td>398.99</td>
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<td>0.25</td>
<td>2.00</td>
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<td>0:03:05</td>
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<td>0:00</td>
<td>0:03:10</td>
<td>0.01</td>
<td>0.03</td>
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<td>0:00</td>
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<td>0.01</td>
<td>0.02</td>
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<td>0:03:10</td>
<td>0.01</td>
<td>0.03</td>
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<tr>
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<td>0.00</td>
<td>0:00</td>
<td>0:03:10</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>VMSERVV</td>
<td>1</td>
<td>0.00</td>
<td>0:00</td>
<td>0:03:10</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>VMSERVV</td>
<td>1</td>
<td>0.00</td>
<td>0:00</td>
<td>0:03:10</td>
<td>0.01</td>
<td>0.03</td>
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<tr>
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<td>0:00</td>
<td>0:03:10</td>
<td>0.01</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Profiling

- Characteristics: Easy to use profiling and kernel tracing
- Objective: Get detailed information where & why CPU is consumed
- Usage:

  - perf top

- Shows
  - Sampling for CPU hotspots
  - Annotated source code along hotspot
  - CPU event counters
  - Further integrated non-sampling tools

- Hints
  - Without HW support only userspace can be reasonably profiled
  - “successor” of oprofile that is available with HW support (SLES11-SP2)
  - Perf HW support code upstream, wait for next distribution releases
Profiling

- What profiling can and what it can't
  - + Search hot-spots of CPU consumption worth to optimize
  - + List functions according to their usage
  - - Search where time is lost (I/O, Stalls)

- Perf is not just a sampling tool
  - Integrated tools to evaluate tracepoints like "perf sched", "perf timechart", …
  - Opposite to real sampling this can help to search for stalls
Profiling

- Perf example howto
  - We had a case where new code caused cpus to scale badly
  - `perf record "workload"`
    - Creates a file called perf.data that can be analyzes
  - We used "`perf diff`" on both data files to get a comparison

- “Myriad” of further options/modules
  - Live view with perf top
  - Perf sched for an integrated analysis of scheduler tracepoints
  - Perf annotate to see samples alongside code
  - Perf stat for a counter based analysis
  - [...]
Profiling

- Perf example (perf diff)
  - found a locking issue causing increased cpu consumption

<table>
<thead>
<tr>
<th># Baseline</th>
<th>Delta</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.14%</td>
<td>+8.07%</td>
<td>[kernel.kallsyms] lock_acquire</td>
</tr>
<tr>
<td>8.96%</td>
<td>+5.50%</td>
<td>[kernel.kallsyms] lock_release</td>
</tr>
<tr>
<td>4.83%</td>
<td>+0.38%</td>
<td>reaim add_long</td>
</tr>
<tr>
<td>4.22%</td>
<td>+0.41%</td>
<td>reaim add_int</td>
</tr>
<tr>
<td>4.10%</td>
<td>+2.49%</td>
<td>[kernel.kallsyms] lock_acquired</td>
</tr>
<tr>
<td>3.17%</td>
<td>+0.38%</td>
<td>libc-2.11.3.so msort_with_tmp</td>
</tr>
<tr>
<td>3.56%</td>
<td>-0.37%</td>
<td>reaim string_rtns_1</td>
</tr>
<tr>
<td>3.04%</td>
<td>-0.38%</td>
<td>libc-2.11.3.so strncat</td>
</tr>
</tbody>
</table>
Valgrind

- Characteristics: In depth memory analysis
- Objective: Find out where memory is leaked, sub-optimally cached, ...
- Usage:

  valgrind [program]

- Shows
  - Memory leaks
  - Cache profiling
  - Heap profiling

- Hints
  - Runs on binaries, therefore easy to use
  - Debug Info not required but makes output more useful
Valgrind Overview

- Technology is based on a JIT (Just-in-Time Compiler)
- Intermediate language allows debugging instrumentation
Valgrind – sample output of “memcheck”

# valgrind buggy_program
==2799== Memcheck, a memory error detector
==2799== Copyright (C) 2002-2010, and GNU GPL'd, by Julian Seward et al.
==2799== Using Valgrind-3.6.1 and LibVEX; rerun with -h for copyright info
==2799== Command: buggy_program
==2799==
==2799== HEAP SUMMARY:
==2799==     in use at exit: 200 bytes in 2 blocks
==2799==     total heap usage: 2 allocs, 0 frees, 200 bytes allocated
==2799==
==2799== LEAK SUMMARY:
==2799==    definitely lost: 100 bytes in 1 blocks
==2799==    indirectly lost: 0 bytes in 0 blocks
==2799==    possibly lost: 0 bytes in 0 blocks
==2799==    still reachable: 100 bytes in 1 blocks
==2799==    suppressed: 0 bytes in 0 blocks
==2799== Rerun with --leak-check=full to see details of leaked memory
[...]

- Important parameters:
  - --leak-check=full
  - --track-origins=yes
Valgrind - Tools

- Several tools
  - Memcheck (default): detects memory and data flow problems
  - CacheGrind: cache profiling
  - Massif: heap profiling
  - Helgrind: thread debugging
  - DRD: thread debugging
  - None: no debugging (for valgrind JIT testing)
  - Callgrind: codeflow and profiling

- Tool can be selected with –tool=xxx

- System z support since version 3.7 (SLES-11-SP2)
- Backports into 3.6 (SLES-10-SP4, RHEL6-U1)
IPTRAf

- Characteristics: Live information on network devices / connections
- Objective: Filter and format network statistics
- Usage:
  - Shows
    - Details per Connection / Interface
    - Statistical breakdown of ports / packet sizes
    - LAN station monitor
  - Hints
    - Can be used for background logging as well
      - Use SIGUSR1 and logrotate to handle the growing amount of data
    - Knowledge of packet sizes important for the right tuning
**IPTRAF**

- Questions that usually can be addressed
  - Connection behavior overview
  - Do you have peaks in your workload characteristic
  - With whom does your host really communicate

- Comparison to wireshark
  - Not as powerful, but much easier and faster to use
  - Lower overhead and no sniffing needed (often prohibited)

---

**Packet sizes**

<table>
<thead>
<tr>
<th>Packet Size</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 75</td>
<td>2274</td>
</tr>
<tr>
<td>76 to 150</td>
<td>37</td>
</tr>
<tr>
<td>151 to 225</td>
<td>25</td>
</tr>
<tr>
<td>226 to 300</td>
<td>84</td>
</tr>
<tr>
<td>301 to 375</td>
<td>10</td>
</tr>
<tr>
<td>376 to 450</td>
<td>27</td>
</tr>
<tr>
<td>451 to 525</td>
<td>16</td>
</tr>
<tr>
<td>526 to 600</td>
<td>38</td>
</tr>
<tr>
<td>601 to 675</td>
<td>5</td>
</tr>
<tr>
<td>676 to 750</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total:**

- **Total:** 286
- **IP:** 44
- **TCP:** 19
- **UDP:** 25
- **ICMP:** 0
- **Other IP:** 0
- **Non-IP:** 0

**Interface MTU is 1500 bytes, not counting the data-link header. Maximum packet size is the MTU plus the data-link header length. Packet size computations include data-link headers, if any.**

**IF details**

<table>
<thead>
<tr>
<th>Total rates</th>
<th>1.0 kbits/sec</th>
<th>Broadcast packets: 71</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.2 packets/sec</td>
<td>Broadcast bytes: 5492</td>
</tr>
<tr>
<td>Incoming rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.7 kbits/sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.6 packets/sec</td>
<td></td>
</tr>
<tr>
<td>Outgoing rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.3 kbits/sec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.6 packets/sec</td>
<td></td>
</tr>
<tr>
<td>IP checksum errors:</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

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Tracepoints (Events)

- Characteristics: Complex interface, but a vast source of information
- Objective: In kernel latency and activity insights
- Usage: Access debugfs mount point /tracing
- Shows
  - Time-stamp and activity name
  - Tracepoints can provide event specific context data
  - Infrastructure adds extra common context data like cpu, preempts depth, ...
- Hints
  - Very powerful and customizable, there are hundreds of tracepoints
    - Some tracepoints have tools to be accessed “perf sched”, “blktrace” both base on them
    - Others need custom post processing
  - There are much more things you can handle with tracepoints check out Kernel Documentation/trace/tracepoint-analysis.txt (via perf stat) and Kernel Documentation/trace/events.txt (custom access)
Tracepoints – example I/III

- Here we use custom access since there was tool
  - We searched for 1.2ms extra latency
    - Target is it lost in HW, User-space, Kernel or all of them
  - Workload was a simple 1 connection 1 byte ←→ 1 byte load
  - Call “perf list” for a list of currently supported tracepoints
  - We used the following tracepoints

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Tracepoint</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>netif_receive_skb</td>
<td>low level receive</td>
</tr>
<tr>
<td>P</td>
<td>napi_poll</td>
<td>napi work related to receive</td>
</tr>
<tr>
<td>Q</td>
<td>net_dev_queue</td>
<td>enqueue in the stack</td>
</tr>
<tr>
<td>S</td>
<td>net_dev_xmit</td>
<td>low level send</td>
</tr>
</tbody>
</table>
Tracepoints – example II/III

• Simplified script (full versions might tune buffer sizes, check files, and so on)

```bash
echo latency-format > /sys/kernel/debug/tracing/trace_options            # enable tracing type
echo net:* >> /sys/kernel/debug/tracing/set_event                        # select specific events
echo napi:* >> /sys/kernel/debug/tracing/set_event
echo "name == ${dev}" > /sys/kernel/debug/tracing/events/net/filter      # set filters
echo "dev_name == ${dev}" > /sys/kernel/debug/tracing/events/napi/filter

cat /sys/kernel/debug/tracing/trace >> ${output}                         # synchronous
echo !*:* > /sys/kernel/debug/tracing/set_event                           # disable tracing
```

• Output

```
#                _------=>
#               / _-----=> irqs-off
#              | / _----=> need-resched
#              || / _---=> hardirq/softirq
#              ||| / _--=> preempt-depth
#              |||| /     delay
#     cmd     pid |||||  
#     \   /    |||||  
#     <...>-24116 0..s. 486183281us+:
#<idle>-0     0..s. 486183303us+:
#<idle>-0     0.Ns. 486183306us+:
```

486183288us+: net_dev_xmit: dev=eth5 skbaddr=000000075b7e3e8 len=67 rc=0

<idle>-0 0..s. 486183303us+: netif_receive_skb: dev=eth5 skbaddr=00000007ecc6e00 len=53

<idle>-0 0.Ns. 486183306us+: napi_poll: napi poll on napi struct 0000000007d2479a8 for device eth

<...>-24116 0..s. 486183311us+: net_dev_queue: dev=eth5 skbaddr=0000000075b7e3e8 len=67

<...>-24116 0..s. 486183317us+: net_dev_xmit: dev=eth5 skbaddr=0000000075b7e3e8 len=67 rc=0
Tracepoints – example III/III

- Example postprocessed

<table>
<thead>
<tr>
<th>SUM</th>
<th>COUNT</th>
<th>AVERAGE</th>
<th>MIN</th>
<th>MAX</th>
<th>STD-DEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2Q:</td>
<td>8478724</td>
<td>1572635</td>
<td>5.39</td>
<td>4</td>
<td>2140</td>
</tr>
<tr>
<td>Q2S:</td>
<td>12188675</td>
<td>1572638</td>
<td>7.65</td>
<td>3</td>
<td>71</td>
</tr>
<tr>
<td>S2R:</td>
<td>38562294</td>
<td>1572636</td>
<td>24.42</td>
<td>1</td>
<td>2158</td>
</tr>
<tr>
<td>R2P:</td>
<td>4197486</td>
<td>1572633</td>
<td>2.57</td>
<td>1</td>
<td>43</td>
</tr>
<tr>
<td>SUM:</td>
<td>63427179</td>
<td>1572635</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SUM</th>
<th>COUNT</th>
<th>AVERAGE</th>
<th>MIN</th>
<th>MAX</th>
<th>STD-DEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2Q:</td>
<td>7191885</td>
<td>1300897</td>
<td>5.53</td>
<td>4</td>
<td>171</td>
</tr>
<tr>
<td>Q2S:</td>
<td>10622270</td>
<td>1300897</td>
<td>8.17</td>
<td>3</td>
<td>71</td>
</tr>
<tr>
<td>S2R:</td>
<td>32078550</td>
<td>1300898</td>
<td>24.66</td>
<td>2</td>
<td>286</td>
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<td>R2P:</td>
<td>3707814</td>
<td>1300897</td>
<td>2.85</td>
<td>1</td>
<td>265</td>
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<tr>
<td>SUM:</td>
<td>53600519</td>
<td>1300897</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- Confirmed that most of the 1.2 ms were lost in our image
- Confirmed that it was not at/between a specific function
  - Eventually it was an interrupt locality issue causing bad caching
## Orientation – where to go

<table>
<thead>
<tr>
<th>Tool</th>
<th>1st overview</th>
<th>CPU consumption</th>
<th>latencies</th>
<th>Hot spots</th>
<th>Disk I/O</th>
<th>Memory</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>top / ps</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>sysstat</td>
<td>x</td>
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<td>vmstat</td>
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<td>htop / dstat / pidstat</td>
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<td>irqstats</td>
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<td>strace / ltrace</td>
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<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
Questions?

- Further information is available at
  - Live Virtual Classes for z/VM and Linux
    http://www.vm.ibm.com/education/lvc/
  - Linux on System z – Tuning hints and tips

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Linux on System z
Development
Please Evaluate!