InterConnect 2016

The Premier Cloud & Mobile Conference

7393: Using Linux with WebSphere Application Server in the Enterprise

Tips

IBM

February 21 – 25

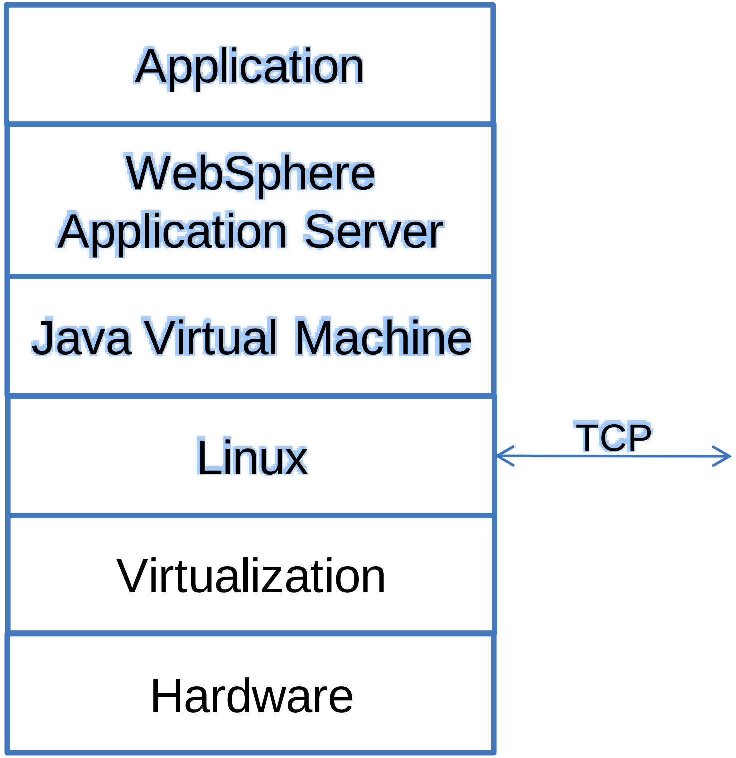
MGM Grand & Mandalay Bay

Las Vegas, Nevada

Agenda

- Where to Look?
- How to Look?
- Tips for Common Things You'll Find

Where to Look?



Linux

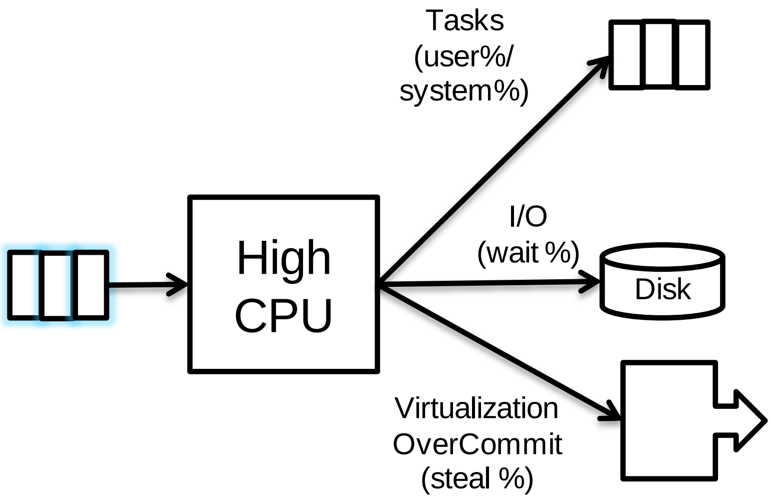
InterConnect 2016
The Premier Cloud & Mobile Conference

IBM

February 21 – 25
MGM Grand & Mandalay Bay
Las Vegas, Nevada

Linux

- High CPU: Tasks waiting in line



- Monitor:
  - 100 - Idle CPU % > ~80%
  - Run queue > # Core Threads
- Know your interval
  - Example: If a monitoring product interval is 15 minutes, spikes might be averaged out
- Monitor per-CPU utilization

top -H

- Don’t use `top`; use `top -H`: CPU usage by thread

```
top - 16:58:14 up 2 min,  5 users,  load average: 1.34, 0.50, 0.18
Tasks: 799 total,   5 running, 792 sleeping,   0 stopped,   2 zombie
Cpu(s): 37.8%us,  0.2%sy,  0.0%ni, 61.9%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Mem:  15943268k total,  3366124k used, 12577144k free,    87824k buffers
Swap:    65532k total,        0k used,    65532k free,  1715160k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
 6607 user1     20   0 1992m  18m 9164 R 100.1  0.1   0:20.67 WebContainer :
 6730 user1     20   0 1992m  19m 9144 R 100.1  0.1   0:12.40 WebContainer :
 6806 user1     20   0 1992m  27m 8900 R 99.8   0.2   0:07.38 WebContainer :
```

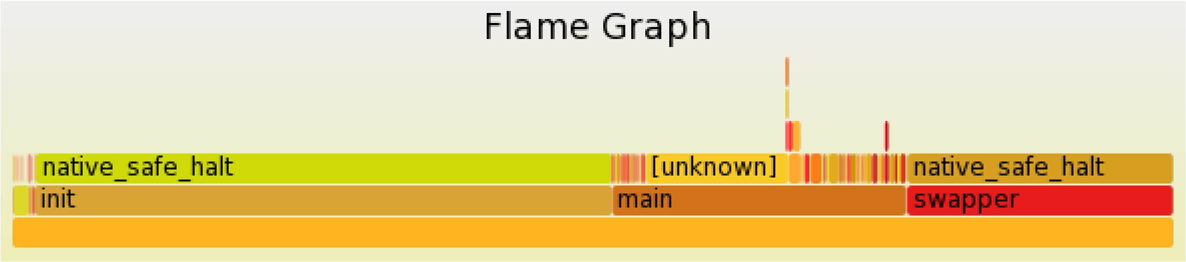
- Thread names may be cut off, but still often give a good idea
- Use `ps -eLf` to find the parent PID (or type `f` then `b`)
- Type `1` to see per-CPU utilization
- Use `-b` to write to a file with `-d SECONDS` for interval

perf

- `perf top -z` gives a perspective from the kernel

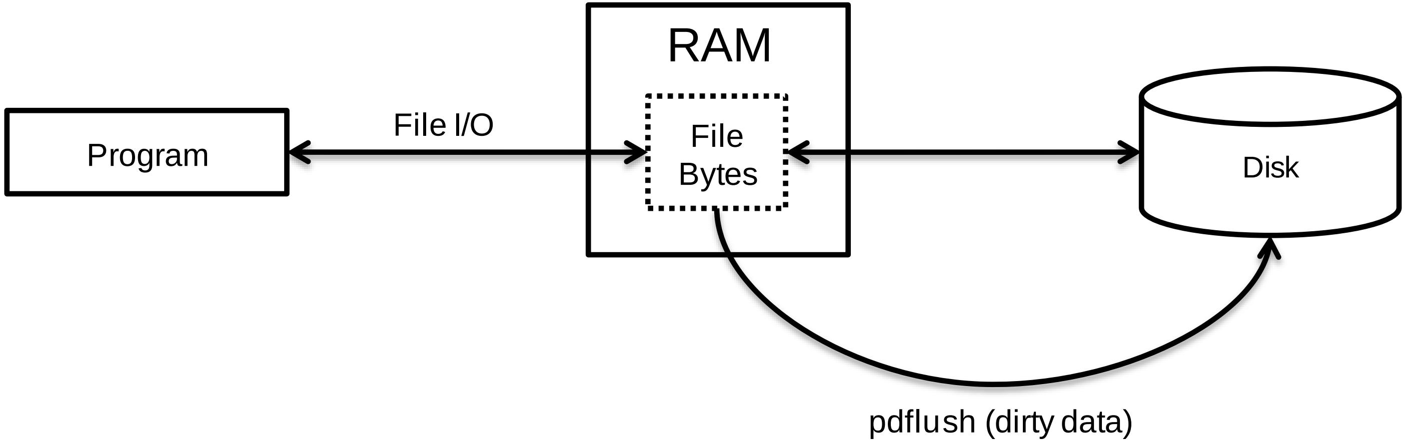
```
–   35.60%  perf-9978.map                    [.] 0x00007fa3093c27db
    20.64%  perf-9978.map                    [.] 0x00007fa3093c27d4
     3.71%  [kernel]                         [k] module_get_kallsym
     2.30%  perf                             [.] symbols__insert
     1.26%  [kernel]                         [k] kallsyms_expand_symbol
```

- Great for investigating if your “system %” CPU is high
- Requires kernel symbols
  - Install at least kernel and glibc symbols on all machines (and perf, gdb, and stap while you’re at it)
- Flame Graphs
  - Brendan Gregg



Page Cache

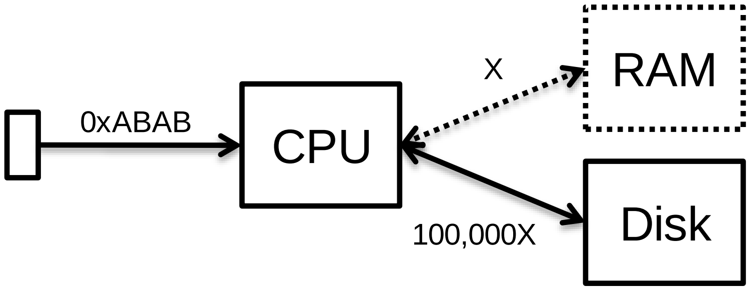
- Linux aggressively uses RAM to accelerate file I/O using the page cache (a.k.a. filecache)



- When benchmarking, flush the cache before a run:
  - sudo sync; echo 1 | sudo tee /proc/sys/vm/drop_caches

Linux

- Paging: RAM Overcommitted



- /proc/sys/vm/swappiness: 0-100
  - Default 60
  - Higher value: Prefer filecache
  - Lower value: Prefer programs
  - This means Linux may page even with plenty of RAM potentially available

- Monitor: Swap Space Usage
- Consider reducing swappiness for Java workloads
- Monitor: Kernel messages for OOM killer

OOM Killer

- “By default [/proc/sys/vm/overcommit_memory=0], Linux follows an optimistic memory allocation strategy. This means that when malloc() returns non-NULL there is no guarantee that the memory really is available. In case it turns out that the system is out of memory, one or more processes will be killed by the OOM killer” (`man 3 malloc`).
- Watch your system logs for messages such as:
  - kernel: Out of Memory: Killed process 123 (someprocess).
- Or set /proc/sys/vm/panic_on_oom=1 to cause a kernel panic instead
  - Then use the `bt` command to see who requested memory and how much and the `ps` command to see what is using memory

top -H

- `top -H` shows Swap usage:
  - ```
    top - 16:58:14 up 2 min,  5 users,  load average: 1.34, 0.50, 0.18
    Tasks: 799 total,   5 running, 792 sleeping,   0 stopped,   2 zombie
    Cpu(s): 37.8%us,  0.2%sy,  0.0%ni, 61.9%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
    Mem:  15943268k total,  3366124k used, 12577144k free,    87824k buffers
    Swap:     65532k total,        0k used,    65532k free,  1715160k cached

      PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
     6607 user1     20   0 1992m  18m 9164 R 100.1  0.1   0:20.67 WebContainer :
     6730 user1     20   0 1992m  19m 9144 R 100.1  0.1   0:12.40 WebContainer :
     6806 user1     20   0 1992m  27m 8900 R 99.8   0.2   0:07.38 WebContainer :
    ```
- If `Mem free` is low, that might be okay as `buffers` and `cached` can be used if needed (depending on swappiness)
- If `used` is greater 0, then monitor `si/so` columns in `vmstat`
- Type `M` to sort processes by memory used (RES)
- VmSwap in /proc/$PID/status to see swap usage by process
    ```

Networking

- Use `netstat` for interface statistics and listing sockets
  - $ netstat -i

```
Iface          MTU Met     RX-OK RX-ERR RX-DRP RX-OVR      TX-OK TX-ERR TX-DRP TX-OVR Flg
eth0          1500   0         0      0      0      0          0      0      0      0 BMU
```

  - $ sudo netstat -antop

```
Proto Recv-Q Send-Q Local Address      Foreign Address      State     PID/Program name     Timer
tcp        0      0 0.0.0.0:6000           0.0.0.0:*        LISTEN       3646/Xorg
tcp        0      0 1.2.3.4:46238          1.2.3.4:80     ESTABLISHED    4140/firefox
tcp        0      0 1.2.3.4:35370          1.2.3.4:443     TIME_WAIT          -          timewait..
```

- TIME_WAIT=60 seconds – required by TCP to reduce probability of collisions. Use persistent connection pooling if possible.
- Use `nfsstat` for NFS statistics

Networking

- The kernel auto-tunes TCP memory buffers. Test constraints based on expected average bandwidth delay product
- Example in sysctl.conf
  - ```
    net.core.rmem_default=1048576
    net.core.wmem_default=1048576
    net.core.rmem_max=16777216
    net.core.wmem_max=16777216
    net.ipv4.tcp_rmem=4096 1048576 16777216
    net.ipv4.tcp_wmem=4096 1048576 16777216
    ```
- Running tcpdump:
  - nohup tcpdump -nn -v -i any -B 4096 -s 0 -C 100 -W 10 -Z root -w capture`hostname`_`date +"%Y%m%d_%H%M"`.pcap &
- Different TCP congestion control algorithms (default cubic) set with net.ipv4.tcp_congestion_control
    ```

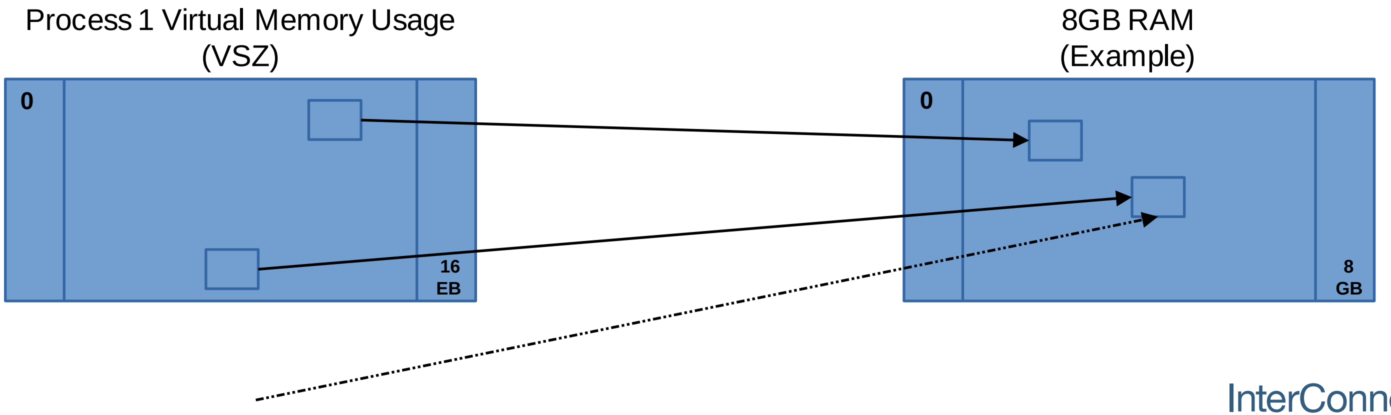
Other Linux Tips

- SystemTap is a wonderful, low-overhead kernel diagnostic tool:
  - Take the time to learn it and try it
- Use `iostat` to investigate I/O performance
- Pin processes to subsets of CPUs with `taskset`
- You might see programs with massive virtual sizes (VIRT/VSZ). This is often caused by glibc malloc's aggressive "arena" allocation since 2.11
  - Performance implications inconclusive but should be small & positive
  - Limit this with envar MALLOC_ARENA_MAX=N (e.g. 1 or 4)

How much virtual memory is used?

- Use `ps` or similar tools to query user process virtual memory usage (in KB):
  - $ ps -o pid,vsz,rss -p 14062

PID	VSZ	RSS
14062	44648	42508

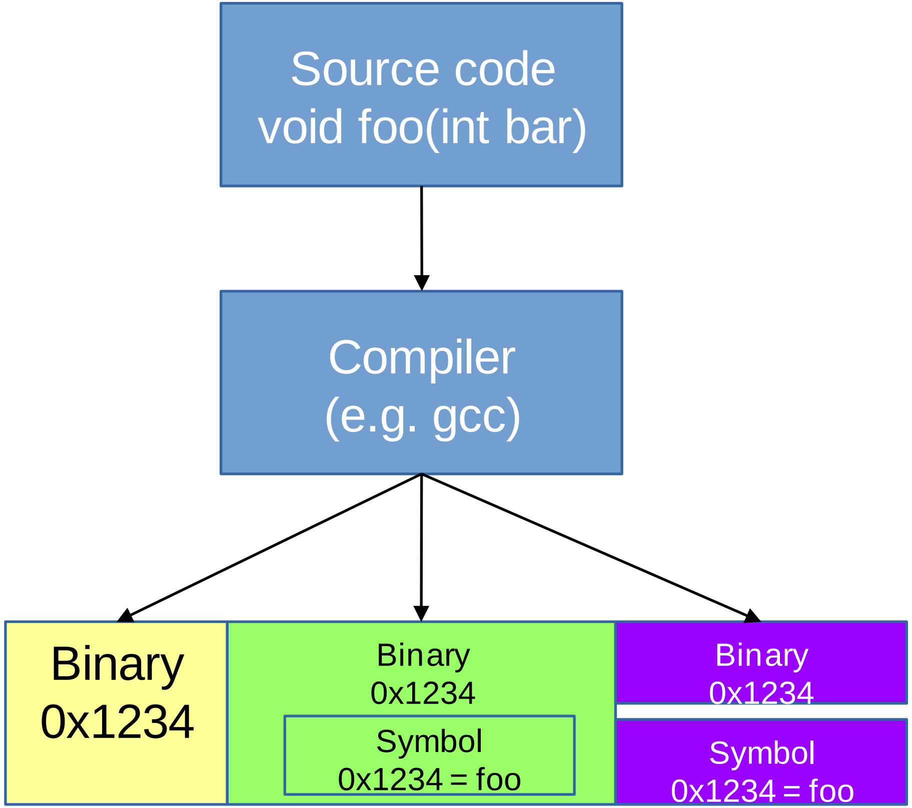


How much virtual memory is used?

- Virtual memory is broken up into virtual memory areas (VMAs), the sum of which equal VSZ and may be printed with:
  - $ cat /proc/${PID}/smaps
    ```
    00400000-0040b000 r-xp 00000000 fd:02 22151273    /bin/cat
    Size:           44 kB
    Rss:            20 kB
    Pss:            12 kB...
    ```
    - The first column is the address range of the VMA.
    - The second column is the set of permissions (read, write, execute, private copy on write).
    - The final column is the pathname if the VMA is a file mapping. If it's [heap], that's the data segment (primary malloc arena).
    - The Rss value shows how much of the VMA is resident in RAM.
    - The Pss value divides Rss by the total number of processes sharing this VMA.

Symbols

- Symbols map virtual addresses to human-understandable names (functions, structures, etc.)
- Without symbols, you'll just get a bunch of addresses
- “We recommend that you always use ‘-g’ whenever you compile a program." https://www.sourceware.org/gdb/current/onlinedocs/gdb.html



User coredump ulimits

- Ensure process ulimits for coredumps (-c) and files (-f) are unlimited
  - The coredump ulimit (-c) often defaults to 0, suppressing cores
  - A coredump is a file so the file ulimit (-f) also applies
- Ulimits may be soft or hard
  - Hard: the maximum value a non-root user can set
  - Soft: Sets the current limit (must be <= hard for non-root)
- Ulimits for the current shell may be queried:
  - ```
    $ ulimit -c -f
    core file size          (blocks, -c) 0
    file size               (blocks, -f) unlimited
    ```
- Or by process:
  - ```
    $ cat /proc/${PID}/limits | grep -e Limit -e core -e "Max file size"
    Limit                   Soft Limit     Hard Limit     Units
    Max file size           unlimited      unlimited      bytes
    Max core file size      0              unlimited      bytes
    ```

User Coredump Ulimits

- Ulimits may be set in limits.conf on a user or group basis.
- Commonly set in /etc/security/limits.conf or /etc/security/limits.d/99-cores.conf
- The following example sets file and core soft and hard ulimits to unlimited for all users
  - * - core unlimited
    * - file unlimited
- Alternatively, run the command `ulimit -c unlimited -f unlimited` in the shell that launches the program
- systemd-started processes use LimitCORE/LimitFSIZE

Where is the user coredump?

- The coredump goes to core_pattern (see `man 5 core`):
  - $ sysctl kernel.core_pattern
    kernel.core_pattern = |/usr/lib/systemd/systemd-coredump %p %u %g %s %t %e
- The default is `core` (sometimes with %p) which writes a file named `core` to the current directory of the PID
  - May include a path to use a dedicated coredump directory
- If the value starts with a `|`, then the coredump bytes are piped to that program
- Often specified in /etc/sysctl.conf or {/etc/sysctl.d|/usr/lib/sysctl.d|/run/sysctl.d}/*.conf

systemd-coredump

- systemd-coredump is a common user coredump handler which handles coredumps
- Configured in /etc/systemd/coredump.conf
- Defaults:
  - Store coredumps in /var/lib/systemd/coredump/
  - Use no more than 10% of that disk's space
  - Ensures cores don't cause that disk's free space to go below 15%
- systemd-tmpfiles may remove old cores

abrtd

- abrtd is an older user coredump handler
- Like systemd-coredump, modified core_pattern to something like:
  - |/usr/libexec/abrt-hook-ccpp %s %c %p %u %g %t e
- Configured in /etc/abrt/abrt.conf
- Defaults:
  - DumpLocation=/var/spool/abrt/
  - MaxCrashReportsSize=1000M

Configure Kernel Coredumps

- Install `kexec-tools`
- Add `crashkernel=256M` to the kernel cmdline – This amount of RAM is no longer available to your live kernel
  - grub2 example:
    - Edit /etc/default/grub
      - Add `crashkernel=256M` to GRUB_CMDLINE_LINUX
    - # grub2-mkconfig -o /boot/grub2/grub.cfg
    - Reboot and verify with `cat /proc/cmdline`
- To customize kdump, edit /etc/kdump.conf
  - For example, often useful to get user process data:
    - core_collector makedumpfile -l --message-level 1 -d 23,31
- Enable and start the kdump service
  - # systemctl enable kdump.service
  - # systemctl start kdump.service

How to Create a Kernel Coredump?

- Once the kdump service is running, a kernel panic will automatically produce a kernel coredump
- To manually produce a kernel coredump:
  - Enable sysrq (`man 5 proc`):
    - # echo 1 > /proc/sys/kernel/sysrq
  - Emulate a crash:
    - # echo c > /proc/sysrq-trigger
- kdump will dump the vmcore and reboot

Reading a Kernel Coredump

- Switch to the root user
- Kernel coredumps normally in /var/crash/
  - Check the version of the core:
  - # cd /var/carsh/${VMCORE_DIRECTORY}/
  - # strings vmcore | grep "Linux version"
    - Linux version 4.2.3-200.local.fc22.x86_64
- Install the kernel debuginfo/dbgsym packages matching the version of the vmcore

Reading a Kernel Coredump

- You may install the `crash` package, but best to compile from source:
  - https://github.com/crash-utility/crash/releases
  - $ tar xzf crash* && cd crash*
  - Recent vmcores may be compressed with lzop so best to compile in that support:
    - Install lzo, lzo-devel and lzo-minilzo packages
    - echo '-DLZO' > CFLAGS.extra
    - echo '-llzo2' > LDFLAGS.extra
  - $ make
  - # make install

Reading a Kernel Coredump

- Run crash on the matching vmlinux file and vmcore
  - crash ${PATH_TO_VMLINUX} ${PATH_TO_VMCORE}
  - Example:
    - $ crash /usr/lib/debug/lib/modules/4.2.3-200.local.fc22.x86_64/vmlinux /var/crash/*/vmcore

      ```
      CPUS: 4
      LOAD AVERAGE: 1.45, 0.72, 0.27
      TASKS: 444
      RELEASE: 4.2.3-200.local.fc22.x86_64
      PANIC: "sysrq: SysRq : Trigger a crash"
      PID: 12868
      COMMAND: "bash"
      CPU: 3
      ```
    - Last few lines are the current context

Crash Commands

- Type `help` for command list. `alias` to list aliases. `quit` to exit.
- Print the kernel log
  - ```
    crash> dmesg
    [   90.266362] sysrq: SysRq : Trigger a crash
    ```
- Print processes
  - ```
    crash> ps
       PID    PPID  CPU       TASK        ST  %MEM     VSZ    RSS  COMM
    >     0      0      0   ffffffff81c124c0  RU   0.0       0      0  [swapper/0]
    ```
- Change current context to another PID:
  - ```
    crash> set 10042
        PID: 10042
    COMMAND: "gnome-terminal-"
       TASK: ffff8800482c3b00  [THREAD_INFO: ffff880044d24000]
        CPU: 3
      STATE: TASK_RUNNING
    ```
- Change context to the task executing on CPU #N (0-based), or the panic'ed task:
  - `crash> set -c 0`
  - `crash> set -p`
    ```

Crash Commands

- Print the stack trace of the current context:
  - crash> bt -l
    PID: 12868 TASK: ffff88007a0a0000 CPU: 3   COMMAND: "bash"
     #0 [ffff88004832f9f0] machine_kexec at ffffffff8105802b
        /usr/src/debug/kernel-4.2.fc22/linux-4.2.3-200.local.fc22.x86_64/arch/x86/kernel/machine_kexec_64.c: 322
     #1 [ffff88004832fa60] crash_kexec at ffffffff81127f42
        /usr/src/debug/kernel-4.2.fc22/linux-4.2.3-200.local.fc22.x86_64/kernel/kexec.c: 1500
     #2 [ffff88004832fb30] oops_end at ffffffff810180e6
        /usr/src/debug/kernel-4.2.fc22/linux-4.2.3-200.local.fc22.x86_64/arch/x86/kernel/dumpstack.c: 232
    ...

Crash Commands

- Print virtual memory areas of the current context
  - crash> vm

```
PID: 12868  TASK: ffff88007a0a0000  CPU: 3   COMMAND: "bash"
      MM               PGD          RSS    TOTAL_VM
ffff880044d5d800  ffff88007b15b000  4816k   118400k
      VMA           START       END     FLAGS FILE
ffff880060b3eda8 55c1a01eb000 55c1a02e3000 8000875 /usr/bin/bash
```

- Print open files of the current context:
  - crash> files

```
PID: 12868  TASK: ffff88007a0a0000  CPU: 3   COMMAND: "bash"
ROOT: /    CWD: /root
 FD       FILE            DENTRY           INODE       TYPE PATH
  0 ffff88005518ba00 ffff88005170a000 ffff88007c6a1f10 CHR  /dev/pts/0
```

Crash Commands

- Print general memory information:
  - crash> **kmem -i**

	PAGES	TOTAL	PERCENTAGE
TOTAL MEM	479480	1.8 GB	----
FREE	218470	853.4 MB	45% of TOTAL MEM
USED	261010	1019.6 MB	54% of TOTAL MEM
BUFFERS	8096	31.6 MB	1% of TOTAL MEM
CACHED	93047	363.5 MB	19% of TOTAL MEM
TOTAL SWAP	64511	252 MB	----
SWAP USED	0	0	0% of TOTAL SWAP
SWAP FREE	64511	252 MB	100% of TOTAL SWAP
COMMIT LIMIT	304251	1.2 GB	----
COMMITTED	828252	3.2 GB	272% of TOTAL LIMIT

- Print kernel memory slab information:
  - crash> **kmem -s**

CACHE	NAME	OBJSIZE	ALLOCATED	TOTAL	SLABS	SSIZE
ffff88007d3c5e00	TCP	1984	30	32	2	32k

Crash Commands

- Print each CPU's run queue:
  - crash> runq
    ```
    CPU 0 RUNQUEUE: ffff88007fd967c0
      CURRENT: PID: 12868  TASK: ffff88007a0a0000  COMMAND: "bash"
      RT PRIO_ARRAY: ffff88007fd96960
         [no tasks queued]
      CFS RB_ROOT: ffff88007fd96860
         [120] PID: 224    TASK: ffff880036939d80  COMMAND: "kworker/3:2"
         [120] PID: 10042  TASK: ffff8800482c3b00  COMMAND: "gnome-terminal-"
    ```
- Print swap information:
  - crash> swap
    ```
    SWAP_INFO_STRUCT   TYPE       SIZE      USED    PCT  PRI  FILENAME
    ffff880036629400  PARTITION   258044k     0k      0%   -1  /dev/dm-0
    ```
- Display X bytes from a start address (in this example, 32 bytes):
  - crash> rd -8 0xffffffff814821f6 32
    ```
    ffffffff814821f6:  c6 04 25 00 00 00 00 01 5d c3 0f 1f 44 00 00  55   ..%.....]...D..U
    ffffffff81482206:  48 89 e5 53 8d 5f d0 48 c7 c7 60 48 a9 81 48 83   H..S._.H..`H..H.
    ```

Crash Commands

- Print stack contents for each frame:
  - crash> bt -f
    #11 [ffff880079d03de0] write_sysrq_trigger at ffffffff81482e98...
    #12 [ffff880079d03e00] proc_reg_write at ffffffff81286f62
    ffff880079d03e08: ffff8800420e3800 ffff880079d03f18
    ffff880079d03e18: ffff880079d03ea8 ffffffff8121d8d7
- Print definition of something like a stack frame method:
  - crash> whatis write_sysrq_trigger
    ssize_t write_sysrq_trigger(struct file *, const char *, size_t, loff_t *);
- In this case, the four arguments to write_sysrq_trigger will be the four addresses at the top of the stack of the lower frame (respectively, ffff8800420e3800, ffff880079d03f18, etc.)
- Since we know the first argument is a file, let's print its dentry struct and then from that its name:
  - crash> struct file.f_path.dentry ffff8800420e3800
    f_path.dentry = 0xffff880060a2d0c0
    crash> struct dentry.d_name.name 0xffff880060a2d0c0
    d_name.name = 0xffff880060a2d0f8 "sysrq-trigger"

InterConnect 2016
The Premier Cloud & Mobile Conference

Java Virtual Machine

IBM

February 21 – 25
MGM Grand & Mandalay Bay
Las Vegas, Nevada

Thread Dumps

- Always take thread dumps:
  - kill -3 $PID
- If you know a unique string in the command line (e.g. server1):
  - pkill -3 -f server1
- IBM Java: thread dumps are written to the current working directory
  - cd /proc/$PID/cwd
  - Oracle Java: thread dumps written to stdout
- Take multiple thread dumps and review in the IBM Thread and Monitor Dump Analyzer

Other Java Tips

- For Java processes, ensure large ulimit for:
  - processes/threads (-u): 131072
- Set in limits.conf, limits.d/*, or startNode.sh
- Consider disabling core processing programs such as ABRTD, systemd-coredump
  - Often managed poorly, unmonitored, constrained
- Use core dumps instead of heapdumps. Jextract not needed on recent versions – just rename to .dmp and load in IBM Memory Analyzer

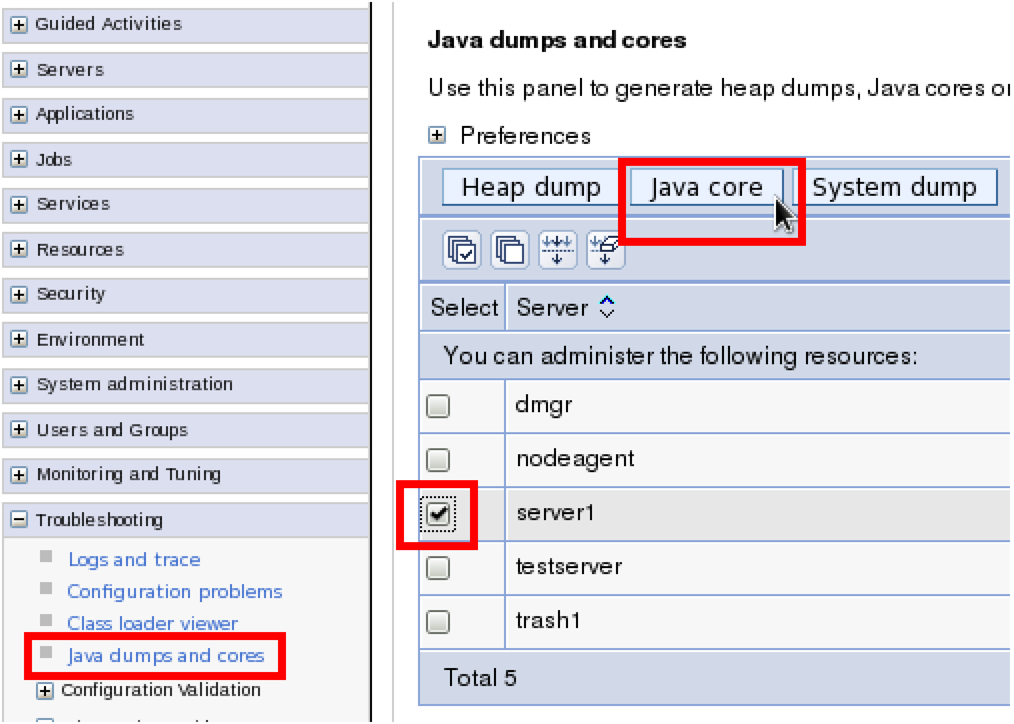
Other Java Tips

- Execute Linux commands on JVM events:
  - -Xdump:tool:events=systhrow,filter=java/lang/OutOfMemoryError,request=serial+exclusive+prepwalk,range=1..0,priority=999,exec="cat /proc/%pid/smaps > smaps.%Y%m%d.%H%M%S.%pid.%seq.txt; cat /proc/meminfo > meminfo.%Y%m%d.%H%M%S.%pid.%seq.txt“
- The Linux kernel does not provide an API to request a core dump, so IBM Java forks itself and kills the forked process. Some things (like all thread stacks) will be missing by IBM Java produced core dumps.

WebSphere Application Server

WAS Tips

- WAS Traditional can generate various diagnostics from the GUI:



WAS Tips

- From wsadmin:
  - AdminControl.invoke(AdminControl.completeObjectName("type=JVM,process=server1,*"), "dumpThreads")
  - AdminControl.invoke(AdminControl.completeObjectName("type=JVM,process=server1,*"), "generateSystemDump")

WAS product family – positioning summary

1 PVU of Family Edition entitles:

1 PVU ND *or*
4 PVUs Base *or*
8 PVUs Liberty Core

OR mix & match

AND can redeploy new mix over time

8x Liberty Core

- ✓ Web, mobile, OSGi apps (Web profile specification)
- ✓ Subset of Liberty profile

4x Base
Full profile

- ✓ Web, Java EE apps and extensions
- ✓ Secure, high performance transaction engine

1x ND
Full profile

+ High availability
+ Intelligent mgmt
+ High scalability

and more…

WAS Family Edition

Notices and Disclaimers

Notices and Disclaimers Con't.

Information concerning non-IBM products was obtained from the suppliers of those products, their published announcements or other publicly available sources. IBM has not tested those products in connection with this publication and cannot confirm the accuracy of performance, compatibility or any other claims related to non-IBM products. Questions on the capabilities of non-IBM products should be addressed to the suppliers of those products. IBM does not warrant the quality of any third-party products, or the ability of any such third-party products to interoperate with IBM's products. IBM EXPRESSLY DISCLAIMS ALL WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

The provision of the information contained herein is not intended to, and does not, grant any right or license under any IBM patents, copyrights, trademarks or other intellectual property right.

IBM, the IBM logo, ibm.com, Aspera®, Bluemix, Blueworks Live, CICS, Clearcase, Cognos®, DOORS®, Emptoris®, Enterprise Document Management System™, FASP®, FileNet®, Global Business Services®, Global Technology Services®, IBM ExperienceOne™, IBM SmartCloud®, IBM Social Business®, Information on Demand, ILOG, Maximo®, MQIntegrator®, MQSeries®, Netcool®, OMEGAMON, OpenPower, PureAnalytics™, PureApplication®, pureCluster™, PureCoverage®, PureData®, PureExperience®, PureFlex®, pureQuery®, pureScale®, PureSystems®, QRadar®, Rational®, Rhapsody®, Smarter Commerce®, SoDA, SPSS, Sterling Commerce®, StoredIQ, Tealeaf®, Tivoli®, Trusteer®, Unica®, urban{code}®, Watson, WebSphere®, Worklight®, X-Force® and System z® Z/OS, are trademarks of International Business Machines Corporation, registered in many jurisdictions worldwide. Other product and service names might be trademarks of IBM or other companies. A current list of IBM trademarks is available on the Web at "Copyright and trademark information" at: www.ibm.com/legal/copytrade.shtml.

Thank You

InterConnect 2016
The Premier Cloud & Mobile Conference

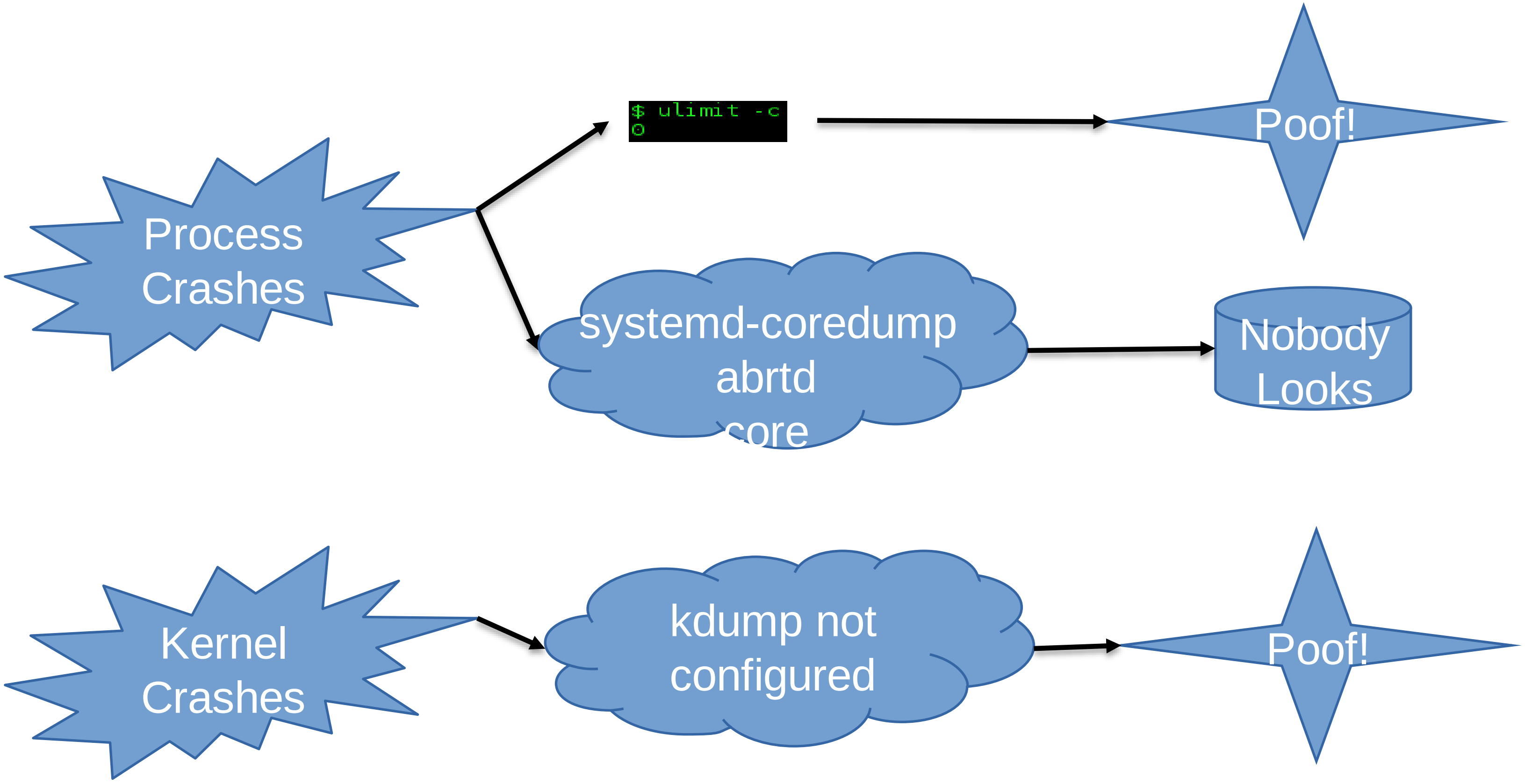
Your Feedback is Important!

Access the InterConnect 2016 Conference Attendee Portal to complete your session surveys from your smartphone,
laptop or conference kiosk.

February 21 – 25
MGM Grand & Mandalay Bay
Las Vegas, Nevada

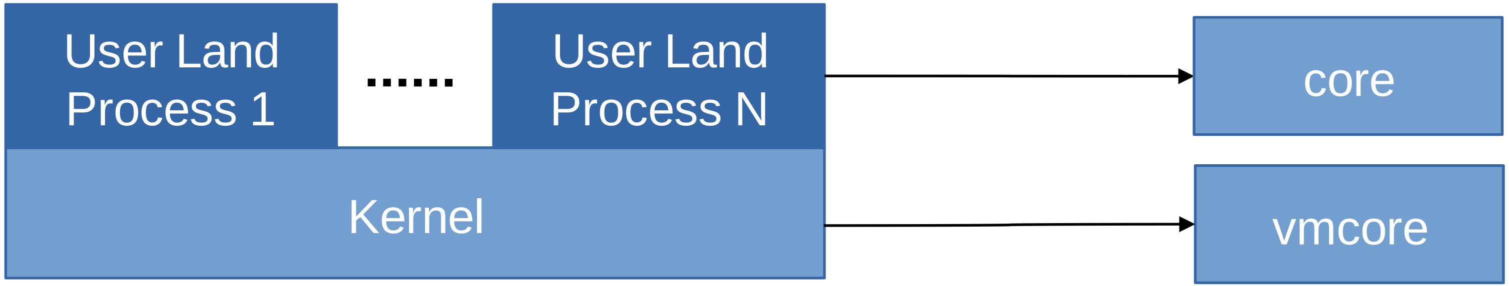
Backup

Most Interactions with Core Dumps



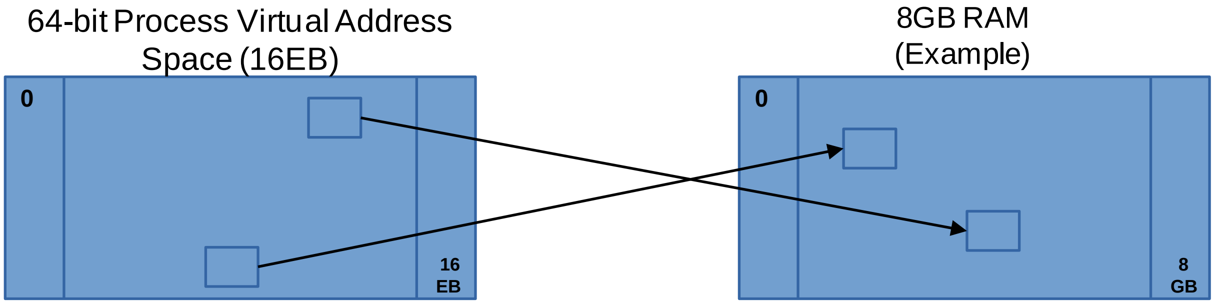
What is a core dump?

- It's just a file that contains virtual memory contents, register values, and other meta-data.
  - User land core dump: Represents state of a particular process (e.g. from crash)
  - Kernel core dump: Represents state of the kernel (e.g. from panic) and process data
- ELF-formatted file (like a program)



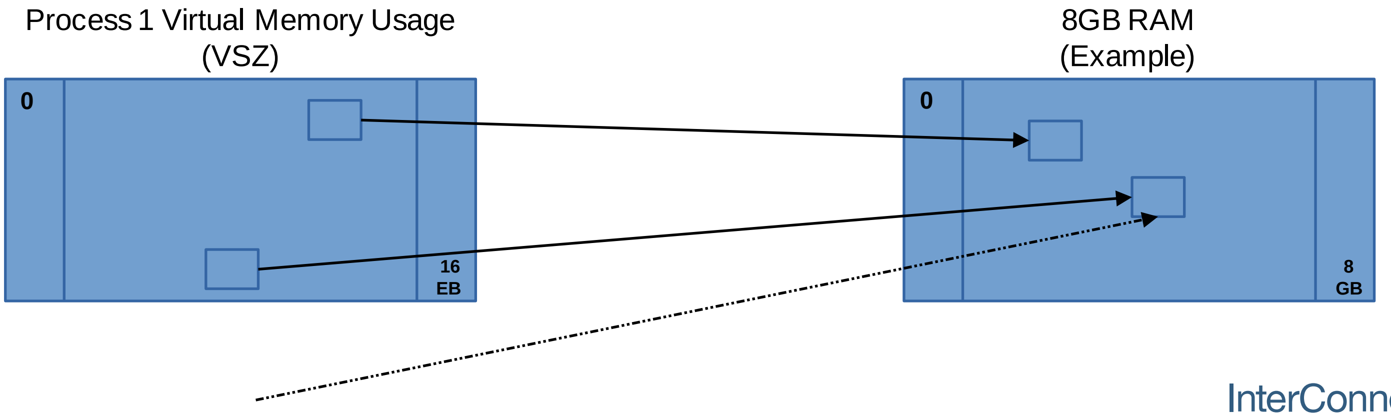
What is Virtual Memory?

- Virtual Memory is an abstraction over physical memory (RAM/swap)
  - Simplifies programming
  - User land: process isolation
  - Kernel/processor translate virtual address references to physical memory locations



How much virtual memory is used?

- Use `ps` or similar tools to query user process virtual memory usage (in KB):
  - $ ps -o pid,vsz,rss -p 14062
    PID VSZ RSS
    14062 44648 42508

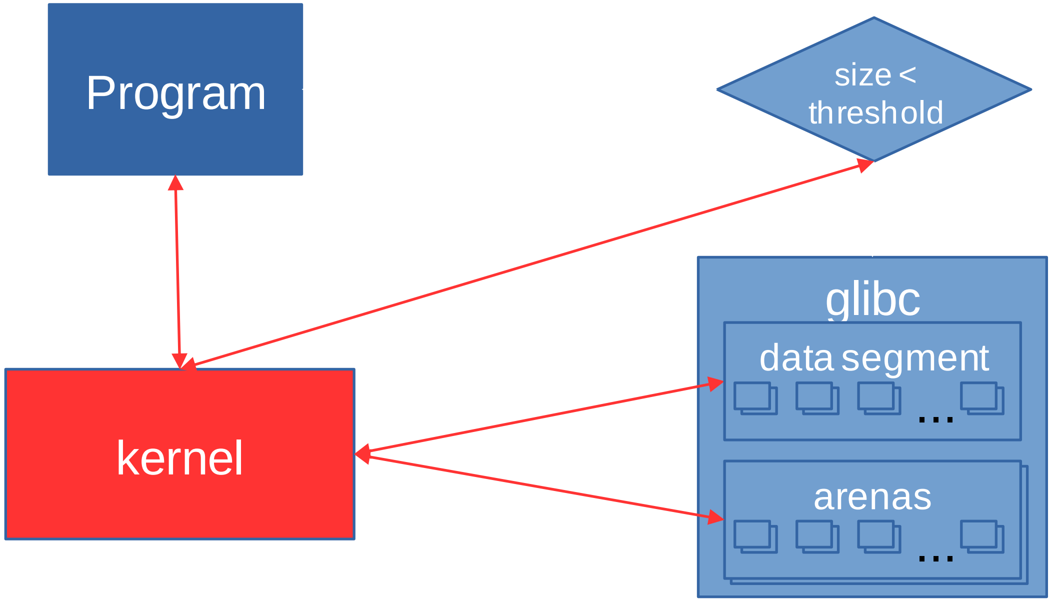


How much virtual memory is used?

- Virtual memory is broken up into virtual memory areas (VMAs), the sum of which equal VSZ and may be printed with:
  - $ cat /proc/${PID}/smaps
    ```
    00400000-0040b000 r-xp 00000000 fd:02 22151273    /bin/cat
    Size:                 44 kB
    Rss:                  20 kB
    Pss:                  12 kB...
    ```
    - The first column is the address range of the VMA.
    - The second column is the set of permissions (read, write, execute, private copy on write).
    - The final column is the pathname if the VMA is a file mapping. If it's [heap], that's the data segment (primary malloc arena).
    - The Rss value shows how much of the VMA is resident in RAM.
    - The Pss value divides Rss by the total number of processes sharing this VMA.

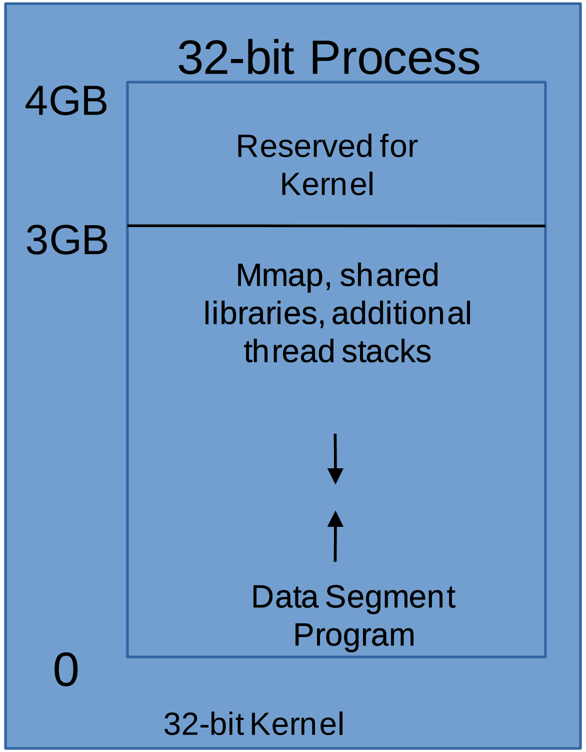
How to request virtual memory?

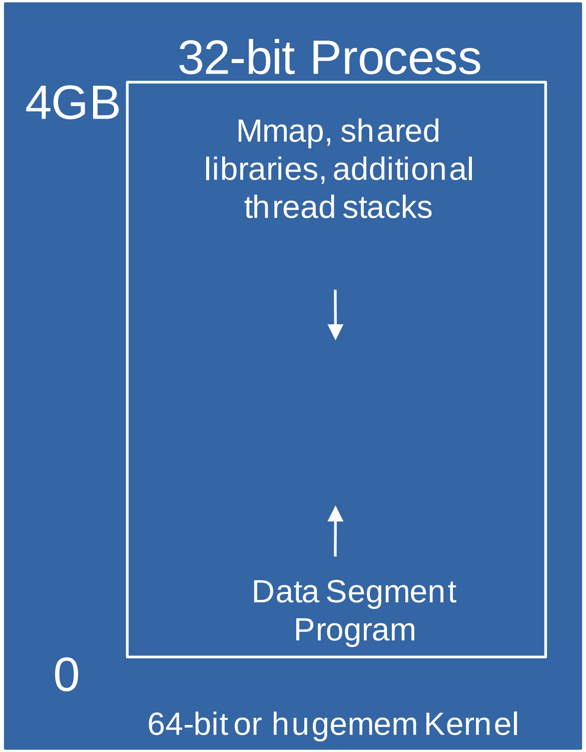
- malloc: request process virtual address space
  - May suffer fragmentation
- mmap (syscall): size rounded up to page size and zero'd



Linux 32-bit Virtual Memory Layout

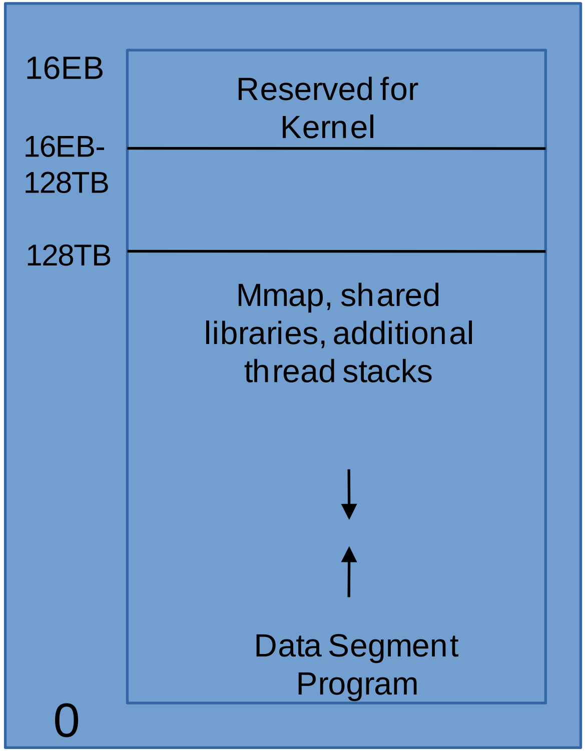
- 3GB user space (2^^32), or 4GB if:
  - 32-bit process on 64-bit kernel
  - 32-bit hugemem kernel





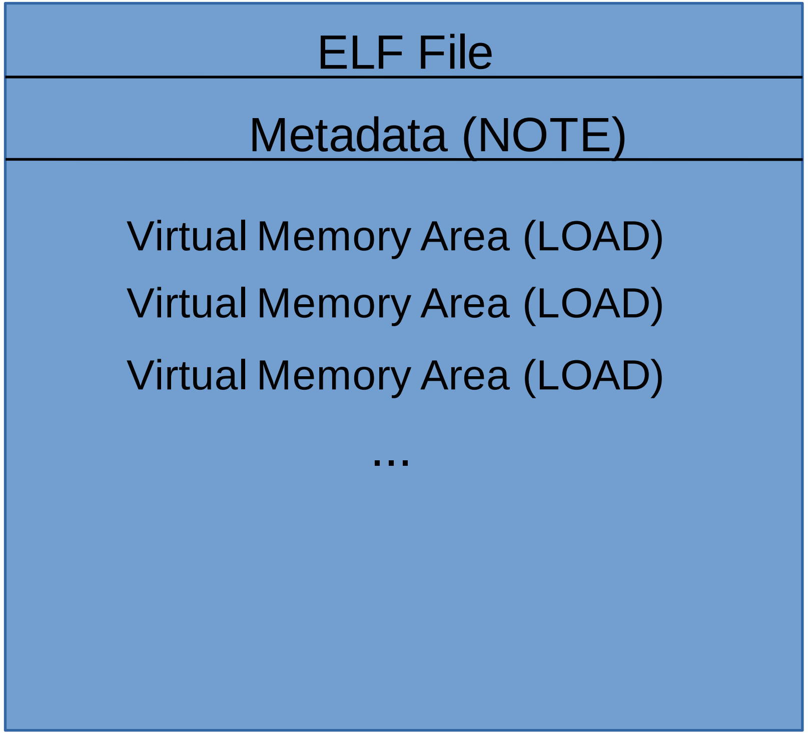
Linux 64-bit Virtual Memory Layout

- The x86_64 processor memory management unit supports up to 48-bit virtual addresses (256TB).
  - https://www.kernel.org/doc/ols/2001/x86-64.pdf
- 128TB for the program
  - 0x through 0x00007FFF'FFFFFFFF
- 128TB for the kernel
  - 0xFFFF8000'00000000 through 0xFFFFFFFF'FFFFFFFF
  - $ sudo ls -lh /proc/kcore
    -r-------- 1 root root 128T /proc/kcore



Diving in!

- Before going through the boring details of how to produce coredumps, let's assume we have one.
- Since it's an ELF-formatted file, let's see the details:
- $ readelf -h core.14391.dmp
  Class: ELF64
  Type: CORE (Core file)...
- This confirms we've got a coredump from a 64-bit process.



User Coredumps

- Next, we'll need to know which program crashed. This may be in logs, but let's just read the notes:
- $ readelf -n core.14391.dmp

```
CORE                0x000001de      NT_FILE (mapped files)
    Start           End             Page            Offset
  0x400000  0x401000  0x00000000      /work/program/a.out …
```

- In this case, the program is /work/program/a.out

Debugging User Coredumps

- Now that we know the program that produced the coredump, simply load `gdb` with the program and the coredump. For example:
  - $ gdb /work/program/a.out core.14391.dmp
    Program terminated with signal SIGSEGV, Segmentation fault.
    #0 0x00007f6526f1ec8a in strlen () from /lib64/libc.so.6
    Missing separate debuginfos, use: debuginfo-install glibc-2.20-8.fc21.x86_64
- The (gdb) prompt awaits instructions. Type `help` for a list of commands. Type `quit` to exit.

Debugging User Coredumps

If you're not a developer of the program, you'll just need to send them the coredump, libraries, and a stacktrace

(gdb) bt

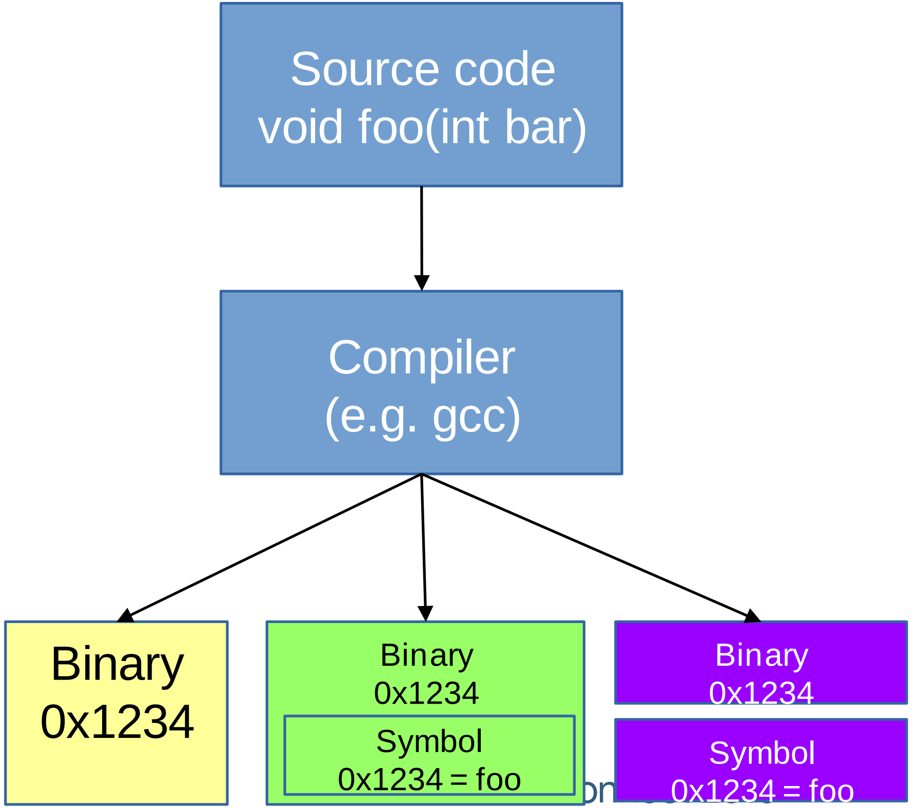
```
#0  0x00007f6526f1ec8a in strlen () from /lib64/libc.so.6
#1  0x00007f6526f03d3c in puts () from /lib64/libc.so.6
#2  0x0000000000400563 in main (argc=1, argv=0x7ffebc36a128)
at test.c:6
```

Even better: all stacks

(gdb) thread apply all bt

Symbols

- Symbols map virtual addresses to human-understandable names (functions, structures, etc.)
- Without symbols, you'll just get a bunch of addresses
- -g doesn't affect optimizations. “We recommend that you always use ‘-g’ whenever you compile a program." https://www.sourceware.org/gdb/current/onlinedocs/gdb.html



Debugging User Coredumps

- It's best to load the coredump on the same machine where it was produced since gdb will find the loaded shared libraries and any installed debuginfo symbols.
- If copying the coredump for processing on another machine, also copy the program, all shared libraries in the NOTE section and expand those files into a similar folder structure and point to that:
  - $ gdb   # no parameters
    (gdb) set solib-absolute-prefix ./
    (gdb) set solib-search-path .
    # (gdb) set debug-file-directory ./path_to_debug
    (gdb) file ./path_to_program
    (gdb) core-file ./path_to_coredump

GDB: Querying virtual memory

- gdb can query a core file and produce output about the virtual address space which is similar to /proc/${PID}/smaps, although it is normally a subset of all of the VMAs:
  - (gdb) info files
    Local core dump file:
    `core.16721.dmp', file type elf64-x86-64.
    0x0000000000400000 - 0x0000000000401000 is load1
    0x0000000000600000 - 0x0000000000601000 is load2
    0x0000000000601000 - 0x0000000000602000 is load3
    0x00007fe288ca5000 - 0x00007fe288ca6000 is load4a
    0x00007fe288ca6000 - 0x00007fe288ca6000 is load4b
    0x00007fe288e58000 - 0x00007fe288e58000 is load5...

GDB Details

- Switch to a frame (list threads with `info thread` and switch threads with `thread N`):
  - (gdb) frame 2
    #2 0x0000000000400563 in main (argc=3, argv=0x7ffd47508d18) at test.c:6
    6   printf("%s\n", p);
- Check why the printf crashed:
  - (gdb) print p
    $10 = 0x0
- Understand the type of argv and then print string contents:
  - (gdb) ptype argv
    type = char **
    (gdb) print argv[0]
    $7 = 0x7ffd4750a17c "./a.out"
    (gdb) print argv[1]
    $8 = 0x7ffd4750a184 "arg1"

User coredump ulimits

- Ensure process ulimits for coredumps (-c) and files (-f) are unlimited
  - The coredump ulimit (-c) often defaults to 0, suppressing cores
  - A coredump is a file so the file ulimit (-f) also applies
- Ulimits may be soft or hard
  - Hard: the maximum value a non-root user can set
  - Soft: Sets the current limit (must be <= hard for non-root)
- Ulimits for the current shell may be queried:
  - ```
    $ ulimit -c -f
    core file size          (blocks, -c) 0
    file size               (blocks, -f) unlimited
    ```
- Or by process:
  - ```
    $ cat /proc/${PID}/limits | grep -e Limit -e core -e "Max file size"
    Limit                Soft Limit     Hard Limit     Units
    Max file size        unlimited      unlimited      bytes
    Max core file size   0              unlimited      bytes
    ```

User Coredump Ulimits

- Ulimits may be set in limits.conf on a user or group basis.
- Commonly set in /etc/security/limits.conf or /etc/security/limits.d/99-cores.conf
- The following example sets file and core soft and hard ulimits to unlimited for all users
  - * - core unlimited
    * - file unlimited
- Alternatively, run the command `ulimit -c unlimited -f unlimited` in the shell that launches the program
- systemd-started processes use LimitCORE/LimitFSIZE

What produces a user coredump?

- When the kernel handles certain signals (`man 7 signal`):
  - SIGQUIT (kill -3)
  - SIGILL (kill -4)
  - SIGABRT (kill -6)
  - SIGGFPE (kill -8)
  - SIGSEGV (kill -11)
    - This is one of the most common causes of a crash when a program references invalid memory (e.g. NULL)
  - Others: SIGBUS, SIGSYS, SIGTRAP, SIGXCPU, SIGXFSZ, SIGUNUSED
- Outside the kernel: use `gcore $PID` (part of gdb)
  - Different code than the kernel: attaches gdb and dumps memory
  - Non-destructive (i.e. process continues after detach)

Where is the user coredump?

- The coredump goes to core_pattern (see `man 5 core`):
  - $ sysctl kernel.core_pattern
    kernel.core_pattern = |/usr/lib/systemd/systemd-coredump %p %u %g %s %t %e
- The default is `core` (sometimes with %p) which writes a file named `core` to the current directory of the PID
  - May include a path to use a dedicated coredump directory
- If the value starts with a `|`, then the coredump bytes are piped to that program
- Often specified in /etc/sysctl.conf or {/etc/sysctl.d|/usr/lib/sysctl.d|/run/sysctl.d}/*.conf

What's in a user coredump?

- The memory dumped is controlled with a bit mask in /proc/$PID/coredump_filter (see `man 5 core`)
  - Inherited from parent process, so you may set in the script/shell that starts the process. Example:
    - $ echo 0x7F > /proc/self/coredump_filter
- Never dumped:
  - Anything madvise'd with MADV_DONTDUMP
  - Memory the process can't read (see the `r` permission in `cat /proc/$PID/smaps`)
  - Memory-mapped I/O pages such as frame buffers

systemd-coredump

- systemd-coredump is a common user coredump handler which handles coredumps
- Configured in /etc/systemd/coredump.conf
- Defaults:
  - Store coredumps in /var/lib/systemd/coredump/
  - Use no more than 10% of that disk's space
  - Ensures cores don't cause that disk's free space to go below 15%
- systemd-tmpfiles may remove old cores

abrtd

- abrtd is an older user coredump handler
- Like systemd-coredump, modified core_pattern to something like:
  - |/usr/libexec/abrt-hook-ccpp % s % c % p % u % g % t e
- Configured in /etc/abrt/abrt.conf
- Defaults:
  - DumpLocation=/var/spool/abrt/
  - MaxCrashReportsSize=1000M

Read Memory in GDB

- Virtual memory may be printed with the `x` command:
  - (gdb) x/32xc 0x00007f3498000000
    0x7f3498000000: 32 ' ' 0 '\000' 0 '\000' 28 '\034' 54 '6' 127 '\177' 0 '\000' 0 '\000'
    0x7f3498000008: 0 '\000' 0 '\000' 0 '\000' -92 '\244' 52 '4' 127 '\177' 0 '\000' 0 '\000'...
- Another option is to dump memory to a file and then spawn an xxd process from within gdb to dump that file which is easier to read (install package vim-common):
  - (gdb) define xxd
    >dump binary memory dump.bin $arg0 $arg0+$arg1
    >shell xxd dump.bin
    >shell rm -f dump.bin
    >end
    (gdb) xxd 0x00007f3498000000 32
    0000000: 2000 001c 367f 0000 0000 00a4 347f 0000 ...6.......4...
    0000010: 0000 0004 0000 0000 0000 0004 0000 0000 ....
- For large chunks, these may be dumped to a file directly:
  - (gdb) dump binary memory dump.bin 0x00007f3498000000 0x00007f34a0000000
- Large VMAs often have a lot of zero'd memory. A simple trick to filter those out is to remove all zero lines:
  - $ xxd dump.bin | grep -v "0000 0000 0000 0000 0000 0000 0000 0000" > dump.bin.txt

Eye catchers

- Well written programs put eye catchers at the start of structures to make finding problems easiers
  - (gdb) xxd 0xF2E010 128

```
00000000: 4445 4144 4641 4444 0000 0000 0000 0000  DEADFADD........
00000010: 0000 0000 0000 0000 2100 0000 0000 0000  ........!.......
00000020: 4445 4144 4641 4444 0000 0000 7b00 0000  DEADFADD....{...
00000030: 0000 0000 0000 0000 2100 0000 0000 0000  ........!.......
00000040: 4445 4144 4641 4444 0000 0000 f600 0000  DEADFADD........
00000050: 0000 0000 0000 0000 2100 0000 0000 0000  ........!.......
00000060: 4445 4144 4641 4444 0000 0000 7101 0000  DEADFADD....q...
00000070: 0000 0000 0000 0000 2100 0000 0000 0000  ........!.......
```

Debugging glibc malloc

- (gdb) p mp_
  - $5 = {trim_threshold = 4202496, top_pad = 131072, mmap_threshold = 2101248, arena_test = 0, arena_max = 1, n_mmaps = 14, n_mmaps_max = 65536, max_n_mmaps = 16, no_dyn_threshold = 0, pagesize = 4096, mmapped_mem = 18333696, max_mmapped_mem = 22536192, max_total_mem = 0, sbrk_base = 0xd83000 ""}
- (gdb) p main_arena
  - $4 = {mutex = 0, flags = 3, fastbinsY = {...}, top = 0x7f650e165000, last_remainder = 0x7f65952d4740, bins = {...}, binmap = {...}, next = 0x368e58ee80, next_free = 0x368e58ee80, system_mem = 3022028800, max_system_mem = 3022028800}
- (gdb) p &main_arena
  - $2 = (struct malloc_state *) 0x368e58ee80
- (gdb) p main_arena.next
  - $3 = (struct malloc_state *) 0x368e58ff80
- (gdb) p *((struct malloc_state *) 0x368e58ff80)
  - $4 = (struct malloc_state *) 0x368e58ee80
- (gdb) p *(mchunkptr) 0x10c5c90
  - $5 = {prev_size = 0, size = 145, fd = 0x10c4030, bk = 0x312258fed8, fd_nextsize = 0x7fd3f0d5b000, bk_nextsize = 0x7fd3f0d5b4e8}

Configure Kernel Coredumps

- Install `kexec-tools`
- Add `crashkernel=256M` to the kernel cmdline – This amount of RAM is no longer available to your live kernel
  - grub2 example:
    - Edit /etc/default/grub
      - Add `crashkernel=256M` to GRUB_CMDLINE_LINUX
    - # grub2-mkconfig -o /boot/grub2/grub.cfg
    - Reboot and verify with `cat /proc/cmdline`
- To customize kdump, edit /etc/kdump.conf
  - For example, often useful to get user process data:
    - core_collector makedumpfile -l --message-level 1 -d 23,31
- Enable and start the kdump service
  - # systemctl enable kdump.service
  - # systemctl start kdump.service

How to Create a Kernel Coredump?

- Once the kdump service is running, a kernel panic will automatically produce a kernel coredump
- To manually produce a kernel coredump:
  - Enable sysrq (`man 5 proc`):
    - # echo 1 > /proc/sys/kernel/sysrq
  - Emulate a crash:
    - # echo c > /proc/sysrq-trigger
- kdump will dump the vmcore and reboot

Reading a Kernel Coredump

- Switch to the root user
- Kernel coredumps normally in /var/crash/
  - Check the version of the core:
  - # cd /var/carsh/${VMCORE_DIRECTORY}/
  - # strings vmcore | grep "Linux version"
    - Linux version 4.2.3-200.local.fc22.x86_64
- Install the kernel debuginfo/dbgsym packages matching the version of the vmcore

Reading a Kernel Coredump

- You may install the \`crash\` package, but best to compile from source:
  - https://github.com/crash-utility/crash/releases
  - $ tar xzf crash* && cd crash*
  - Recent vmcores may be compressed with lzop so best to compile in that support:
    - Install lzo, lzo-devel and lzo-minilzo packages
    - echo '-DLZO' > CFLAGS.extra
    - echo '-llzo2' > LDFLAGS.extra
  - $ make
  - # make install

Reading a Kernel Coredump

- Run crash on the matching vmlinux file and vmcore
  - crash ${PATH_TO_VMLINUX} ${PATH_TO_VMCORE}
  - Example:
    - $ crash /usr/lib/debug/lib/modules/4.2.3-200.local.fc22.x86_64/vmlinux /var/crash/*/vmcore

```
CPUS: 4
LOAD AVERAGE: 1.45, 0.72, 0.27
TASKS: 444
RELEASE: 4.2.3-200.local.fc22.x86_64
PANIC: "sysrq: SysRq : Trigger a crash"
PID: 12868
COMMAND: "bash"
CPU: 3
```

    - Last few lines are the current context

Crash Commands

- Type `help` for command list. `alias` to list aliases. `quit` to exit.
- Print the kernel log
  - crash> dmesg
    [90.266362] sysrq: SysRq : Trigger a crash
- Print processes
  - crash> ps
    ```
       PID    PPID  CPU       TASK        ST  %MEM     VSZ    RSS  COMM
    >     0      0      0   ffffffff81c124c0  RU   0.0       0      0  [swapper/0]
    ```
- Change current context to another PID:
  - crash> set 10042
    ```
        PID: 10042
    COMMAND: "gnome-terminal-"
       TASK: ffff8800482c3b00  [THREAD_INFO: ffff880044d24000]
        CPU: 3
      STATE: TASK_RUNNING
    ```
- Change context to the task executing on CPU #N (0-based), or the panic'ed task:
  - crash> set -c 0
  - crash> set -p

Crash Commands

- Print the stack trace of the current context:
  - crash> bt -l
    PID: 12868 TASK: ffff88007a0a0000 CPU: 3   COMMAND: "bash"
     #0 [ffff88004832f9f0] machine_kexec at ffffffff8105802b
        /usr/src/debug/kernel-4.2.fc22/linux-4.2.3-200.local.fc22.x86_64/arch/x86/kernel/machine_kexec_64.c: 322
     #1 [ffff88004832fa60] crash_kexec at ffffffff81127f42
        /usr/src/debug/kernel-4.2.fc22/linux-4.2.3-200.local.fc22.x86_64/kernel/kexec.c: 1500
     #2 [ffff88004832fb30] oops_end at ffffffff810180e6
        /usr/src/debug/kernel-4.2.fc22/linux-4.2.3-200.local.fc22.x86_64/arch/x86/kernel/dumpstack.c: 232
    ...

Crash Commands

- Print virtual memory areas of the current context
  - crash> vm

```
PID: 12868  TASK: ffff88007a0a0000  CPU: 3   COMMAND: "bash"
       MM               PGD          RSS    TOTAL_VM
ffff880044d5d800  ffff88007b15b000  4816k   118400k
      VMA           START       END     FLAGS FILE
ffff880060b3eda8 55c1a01eb000 55c1a02e3000 8000875 /usr/bin/bash
```

- Print open files of the current context:
  - crash> files

```
PID: 12868  TASK: ffff88007a0a0000  CPU: 3   COMMAND: "bash"
ROOT: /    CWD: /root
 FD       FILE            DENTRY           INODE       TYPE PATH
  0 ffff88005518ba00 ffff88005170a000 ffff88007c6a1f10 CHR  /dev/pts/0
```

Crash Commands

- Print general memory information:
  - crash> kmem -i

```
                 PAGES      TOTAL      PERCENTAGE
  TOTAL MEM     479480      1.8 GB       ----
       FREE     218470    853.4 MB    45% of TOTAL MEM
       USED     261010   1019.6 MB    54% of TOTAL MEM
    BUFFERS       8096     31.6 MB     1% of TOTAL MEM
     CACHED      93047    363.5 MB    19% of TOTAL MEM
 TOTAL SWAP      64511      252 MB       ----
  SWAP USED          0          0      0% of TOTAL SWAP
  SWAP FREE      64511      252 MB   100% of TOTAL SWAP
COMMIT LIMIT    304251      1.2 GB       ----
  COMMITTED     828252      3.2 GB   272% of TOTAL LIMIT
```

- Print kernel memory slab information:
  - crash> kmem -s

```
CACHE             NAME   OBJSIZE  ALLOCATED  TOTAL  SLABS  SSIZE
ffff88007d3c5e00  TCP       1984         30     32      2    32k
```

Crash Commands

- Print each CPU's run queue:
  - crash> runq
```
CPU 0 RUNQUEUE: ffff88007fd967c0
  CURRENT: PID: 12868  TASK: ffff88007a0a0000  COMMAND: "bash"
  RT PRIO_ARRAY: ffff88007fd96960
     [no tasks queued]
  CFS RB_ROOT: ffff88007fd96860
     [120] PID: 224    TASK: ffff880036939d80  COMMAND: "kworker/3:2"
     [120] PID: 10042  TASK: ffff8800482c3b00  COMMAND: "gnome-terminal-"
```
- Print swap information:
  - crash> swap
```
SWAP_INFO_STRUCT   TYPE       SIZE       USED     PCT  PRI  FILENAME
ffff880036629400  PARTITION   258044k      0k       0%   -1  /dev/dm-0
```
- Display X bytes from a start address (in this example, 32 bytes):
  - crash> rd -8 0xffffffff814821f6 32
```
ffffffff814821f6:  c6 04 25 00 00 00 00 01 5d c3 0f 1f 44 00 00 55   ..%.....]...D..U
ffffffff81482206:  48 89 e5 53 8d 5f d0 48 c7 c7 60 48 a9 81 48 83   H..S._.H..`H..H.
```

Crash Commands

- Print stack contents for each frame:
  - crash> bt -f
    #11 [ffff880079d03de0] write_sysrq_trigger at ffffffff81482e98...
    #12 [ffff880079d03e00] proc_reg_write at ffffffff81286f62
    ffff880079d03e08: ffff8800420e3800 ffff880079d03f18
    ffff880079d03e18: ffff880079d03ea8 ffffffff8121d8d7
- Print definition of something like a stack frame method:
  - crash> whatis write_sysrq_trigger
    ssize_t write_sysrq_trigger(struct file *, const char *, size_t, loff_t *);
- In this case, the four arguments to write_sysrq_trigger will be the four addresses at the top of the stack of the lower frame (respectively, ffff8800420e3800, ffff880079d03f18, etc.)
- Since we know the first argument is a file, let's print its dentry struct and then from that its name:
  - crash> struct file.f_path.dentry ffff8800420e3800
    f_path.dentry = 0xffff880060a2d0c0
    crash> struct dentry.d_name.name 0xffff880060a2d0c0
    d_name.name = 0xffff880060a2d0f8 "sysrq-trigger"

Live Kernel Debugging

- If proper symbols are installed, simply run the `crash` command without arguments to debug the live kernel
- # crash

OOM Killer

- “By default [/proc/sys/vm/overcommit_memory=0], Linux follows an optimistic memory allocation strategy. This means that when malloc() returns non-NULL there is no guarantee that the memory really is available. In case it turns out that the system is out of memory, one or more processes will be killed by the OOM killer” (`man 3 malloc`).
- Watch your system logs for messages such as:
  - kernel: Out of Memory: Killed process 123 (someprocess).
- Or set /proc/sys/vm/panic_on_oom=1 to cause a kernel panic instead
  - Then use the `bt` command to see who requested memory and how much and the `ps` command to see what is using memory

swappiness

- Linux aggressively uses physical memory for transient data such as file cache.
  - $ free -m

	total	used	free	shared	buffers	cached
Mem:	15699	4573	11126	0	86	1963
-/+ buffers/cache:		2523	13176			

- However, /proc/sys/vm/swappiness (default 60) controls how much the kernel will prefer to page programs out rather than filecache
- Set lower (e.g. 0) to avoid paging out programs

Memory Leaks

- "Currently debugging native-memory leaks on Linux with the freely available tools is more challenging than doing the same on Windows. Whereas UMDH allows native leaks on Windows to be debugged in situ, on Linux you will probably need to do some traditional debugging rather than rely on a tool to solve the problem for you." http://www.ibm.com/developerworks/library/j-nativememory-linux/
- ltrace might help, but no stacks:
  - $ ltrace -f -tt -p ${PID} -e malloc,free -o ltrace.out
- valgrind might work in a test environment, but not production
- mtrace overhead too high. SystemTap good option
- Find largest Rss VMAs in smaps and dump them in gdb

Summary

- Set `core` (-c) and `file` (-f) ulimits to unlimited for users or groups that run programs you're concerned about.
  - Either run `ulimit -c unlimited -f unlimited` in the shell or script that starts the process, or set it globally in /etc/security/limits.conf or /etc/security/limits.d/
  - Confirm the ulimits are set correctly by running `cat /proc/$PID/limits`
- If using systemd-coredump, ensure enough disk space is available or modify the configuration
- If using abrtd, increase MaxCrashReportsSize or set to unlimited
- Install debuginfo/dbgsym packages for kernel* packages and all the programs you're concerned about

Summary

- Monitor for coredumps
- Enable kdump and monitor for vmcores
- Don't be afraid to load cores and vmcores and review the stack traces
  - Otherwise, report the issues to the owner(s) of the code

Tips

- Review the size of thread stacks when investigating memory usage
- If using gcore, also gather /proc/$PID/smaps beforehand
- Creating coredumps is mostly disk I/O time, so if performance is important, allocate additional RAM so that coredumps are written to filecache and written out asynchronously
- If no memory leak, but RSS increases, may be fragmentation. Consider MALLOC_MMAP_THRESHOLD_/MALLOC_MMAP_MAX_ and/or MALLOC_ARENA_MAX=1