Debugging for production systems

February, 2013

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Embedded Linux Conference 2013

Who am I?

- Software engineer at Adeneo Embedded (Bellevue, WA)
  - Systems:
    - GNU/Linux
    - Android
  - Main activities:
    - BSP adaptation
    - Driver development
    - System integration

Production systems constraints

- Production systems have limited resources
- Production systems are secured
- Production systems are not connected
- Production systems are not accessible

Production systems constraints

- Production systems have limited resources
  - Limited CPU
    - Cannot do some heavy processing
  - Limited RAM
    - Cannot process huge files
  - Limited ROM
    - Cannot store all symbols, debug tools

Production systems constraints

- Production systems are secured
  - No external access to the filesystem
  - No automatic information reporting
  - No tools to perform in-depth analysis

Production systems constraints

- Production systems are not connected
  - No internet connection to send reports
  - No link to do remote debugging

Production systems constraints

- Production systems are not accessible
  - No UI for end users
  - Not in the developers' hands

Production systems constraints

- Some more constraints
  - A production system is not only “your software”
    - No full knowledge of all components
    - No control on other components
    - Build systems tend to give more control
  - ...

Purpose of this presentation

- Tim Bird did a very good presentation about debugging in production systems during ELC 2012 (Appropriate Crash Handling in Linux)
- This presentation focuses on
  - The same subject
  - Other key points
  - Further information

Purpose of this presentation

- This subject concerns everybody
- This is a key point in developing a product
- Not much information about it
- Sometimes postponed until last minute...

About this presentation

- Focus on stock systems
- Use of existing components
- Adding new components

Tools: Linux kernel coredumps

- Linux kernel offers a coredump feature
  - What is a coredump
  - How are they generated
  - What is the typical usage
  - How are coredumps designed
  - Why coredumps may not be suitable

Tools: Linux kernel coredumps

- What is a coredump
  - Process has a virtual memory space
  - Memory is divided in segment
    - Code: software / libraries
    - Stack
    - Heap
  - Segments are mapped in the process virtual address space

Tools: Linux kernel coredumps

- What is a coredump
  - Software runs in userspace
    - Linux kernel enforces permissions
  - When an error condition is detected, the kernel notify the software using unix signals.
    - SIGSEGV
    - SIGBUS
    - SIGABRT
    - SIGFPE
    - SIGTRAP
    - SIGILL
    - SIGBUS
    - SIGQUIT
    - SIGXCPU
    - SIGSYS
    - SIGXFSZ

Tools: Linux kernel coredumps

- Man 7 signal
  - All signals
  - Signum
  - Short description
  - Default actions
  - Much more...

Tools: Linux kernel coredumps

- How are they generated: user side
  - Need to activate the ELF_CORE option in kernel
  - Need to set the core_pattern
    - $> echo “core” > /proc/sys/kernel/core_pattern
  - Need to set ulimit
    - $> ulimit -c unlimited
  - Special care for busybox systems
    - Activate: FEATURE_INIT_COREDUMPS
    - A special file .init_enable_core must be present in /

Tools: Linux kernel coredumps

- How are they generated: kernel side
  - When delivering a signal: *get_signal_to_deliver()*
  - If signal matches the mask: *SIG_KERNEL_COREDUMP_MASK*
  - Kernel calls *do_coredump()* from the filesystem subsytem
    - Various checks (recursive crash, command format, ...)
    - Open the output descriptor (file or pipe)
  - Then calls *core_dump()* for the current binary format
    - *elf_core_dump()* is called for ELF
    - Collect all data and dump segments to the output descriptor (file or pipe)

Tools: Linux kernel coredumps

- What is the typical usage
  - Debugging with GDB
  - Using the symbols from debug binaries
  - Full access to backtrace, variables

Tools: Linux kernel coredumps

DEMO

GDB + coredump for post-mortem analysis

Tools: Linux kernel coredumps

- How are coredumps designed:
  - Coredumps are ELF files
  - The ELF e_type is ET_CORE (4)

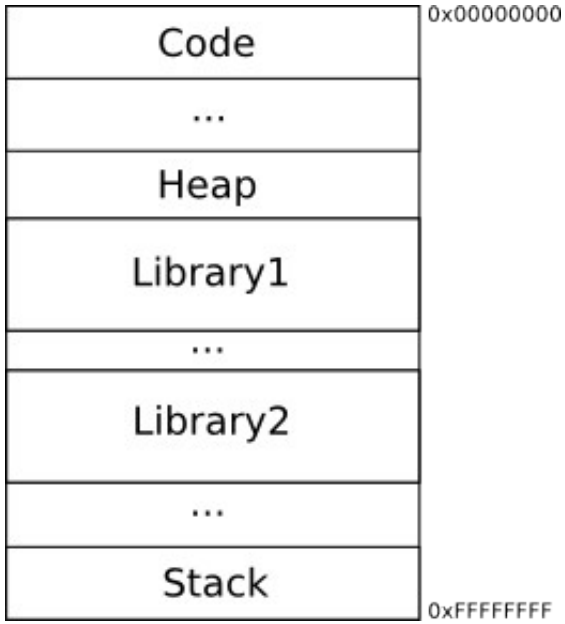
ELF file format

- **Executable** and **Linkable Format**
- Reference in UNIX systems since 1999
- Standardized structure:
  - Headers
  - Segments (physical view)
  - Sections (linker view)

ELF file format

- On GNU/Linux memory map are reachable:
  - /proc/<pid>/maps

```
$ cat /proc/32026/maps
08048000-08129000 r-xp 00000000 08:01 1088084    /bin/bash
08129000-0812a000 r--p 000e0000 08:01 1088084    /bin/bash
0812a000-0812f000 rw-p 000e1000 08:01 1088084    /bin/bash
0812f000-08134000 rw-p 00000000 00:00 0
09627000-0980e000 rw-p 00000000 00:00 0          [heap]
b7439000-b745b000 r--p 00000000 08:01 183354     /usr/share/locale/fr/LC_MESSAGES/bash.mo
b745b000-b7465000 r-xp 00000000 08:01 2265084    /lib/i386-linux-gnu/i686/cmov/libnss_files-2.13.so
...
b7490000-b7491000 rw-p 00006000 08:01 2265072    /lib/i386-linux-gnu/i686/cmov/libnss_compat-2.13.so
b7491000-b7609000 r--p 00000000 08:01 196268     /usr/lib/locale/locale-archive
b7609000-b760a000 rw-p 00000000 00:00 0
b760a000-b7760000 r-xp 00000000 08:01 2265083    /lib/i386-linux-gnu/i686/cmov/libc-2.13.so
...
b7763000-b7764000 rw-p 00158000 08:01 2265083    /lib/i386-linux-gnu/i686/cmov/libc-2.13.so
b7764000-b7768000 rw-p 00000000 00:00 0
b7768000-b776a000 r-xp 00000000 08:01 2265066    /lib/i386-linux-gnu/i686/cmov/libdl-2.13.so
...
b778b000-b778c000 rw-p 0001e000 08:01 542        /lib/i386-linux-gnu/libtinfo.so.5.9
b77a8000-b77af000 r--s 00000000 08:01 646575     /usr/lib/i386-linux-gnu/gconv/gconv-modules.cache
...
b77ce000-b77cf000 r--p 0001b000 08:01 655        /lib/i386-linux-gnu/ld-2.13.so
b77cf000-b77d0000 rw-p 0001c000 08:01 655        /lib/i386-linux-gnu/ld-2.13.so
bf868000-bf889000 rw-p 00000000 00:00 0          [stack]
```



ELF file format

- Man elf
  - Headers description
  - Segments and sections format
  - Description of all structures members
  - Listing / description of standard sections

Tools: Linux kernel coredumps

- How are coredumps designed
  - Generic ELF header
  - Description of all segments
  - No section / No symbol
  - One specific segment: PT_NOTE
  - Text segment
  - Stack segment (end of memory space)

Tools: Linux kernel coredumps

- Why coredumps may not be suitable
  - Coredumps are binaries: need tools to interpret
  - Coredumps are large
    - All segment dumped: main app + libraries
    - Multithread increases the overall size (8MB / thread)
  - Coredump does not contain debug symbols

Tools: binutils / objdump

- Specific to the architecture
- Part of the toolchain
- Contains useful tool for debugging
  - objdump

Tools: binutils / objdump

- Objdump parses an ELF file
  - Reads headers
  - Reads segments / sections tables
  - Dumps segments / sections
  - Disassembles code
  - Resolves symbols and debugging information

Tools: binutils / objdump

DEMO

structure of a coredump using objdump

Tools: Linux kernel coredumps

- The PT_NOTE segment is not a memory dump
  - It is generated by Linux kernel function *fill_note_info()*
  - It is then dumped as the first segment of coredump
  - It contains generic process info

Tools: Linux kernel coredumps

- PT_NOTE segment:
  - prstatus: NT_PRSTATUS (for each thread)
    - Signals / pids / time / registers
  - psinfo: NT_PRPSINFO
    - Process state / UID / GID / name / args
  - auxv: NT_AUXV
  - fpu: NT_PRFPREG
  - xfpu: ELF_CORE_XFPREG_TYPE

Tools: libc

- Libc offers an unwinding function:
  - *backtrace()*
- It can even resolve addresses to symbols
  - *backtrace_symbols(), backtrace_symbols_fd()*
- Work only inside the current process
  - Useful for error logs in your software

Tools: ptrace

UNIX®

- ptrace is a system call in unix systems
  - IRIX, AIX, NetBSD, FreeBSD, OpenBSD, Linux...
- Access to another process memory space
  - Registers, data, code
- Very powerful
  - For debugging
  - For profiling
  - For on the fly patching

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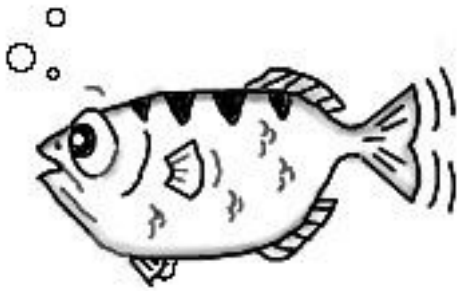
Tools: libunwind

- Libunwind project
  - Aims at providing a common API to determine the call chain of a program.
  - Works locally and remotely (need to use accessors).
  - Works with several architectures:
    - x86, x86_64, ppc (32/64), mips, ia64, hppa, arm, superH
- Since release 1.1 (oct 2012): can unwind coredumps
  - Still need the full coredump file

Tools: gdb



- GNU debugger
- Really powerful
  - Remote debugging
  - Scripting for auto debugging

Tools: debuggerd

- Android debugging service
  - Debuggerd is running in background
  - Uses a custom libc: android bionic to hook signal reception
  - Uses ptrace to access process information
  - Good unwinding but working only for ARM

Tools: crash_handler

- Tim Bird crash handler
- Works for ARM architecture
- Hooks on core generation: core_pattern
- Uses ptrace and /proc for information extraction
- Unwinding:
  - Best guess
  - Based on unwinding tables
  - McTernan: modeling an ARM processor

Tools: cortex

- Author: Tristan Lelong
- Started in 2011
- Objective was to have a userland equivalent to kernel oopses
  - Generate crash report with relevant informations in a simple and human (developer) readable format.

Tools: cortex

- The name come from the contraction of coredump and textreport: **COR**e**TEX**t
- Cortex aims at converting binary cores to text reports.

Tools: cortex

- Dependency on binutils for code disassembly
- No dependency on libelf
  - Use only standard elf.h header libc
  - Easy raw access to the segments
  - Parsing of core is done on-the-fly to comply with the core_pattern streaming feature: not seekable stream.

Tools: cortex

- Easily integrated in the target system
  - Installed as a core handler in core_pattern proc file
  - Can be integrated in a core handling chain
  - No system source code modification required

Tools: cortex

- Architectures are handled in separate modules
- Makefile selects the architecture to include depending on configure variables
- New architectures can be added by following a standardized API
  - declared in arch/cortex_arch.h
  - 7 functions exported in struct cortex_arch_ops

Tools: cortex

DEMO

cortex text report generation

Tools: cortex

- Constraints when using cortex
  - The unwinding is relying on frame pointers (option -fno-omit-framepointer required for accurate results)
  - Equivalent production binaries with symbols must be generated and kept.

Tools: cortex

- Another feature recently added is the coredump stripping:
  - Remove all text sections except the current one
  - Keep only the top part of the stack segment
- Stripped coredumps are compatible with gdb even though less information is available

Tools: cortex

DEMO

cortex stripped coredump

Tools: cortex

- Google project already online
  - http://cortex-tool.googlecode.com
  - Sources on git
  - GPLv2 licensed
- First release: cortex-0.1 is available
  - Handle ARM, x86 architectures
  - Basic unwinding based on frame pointers

Tools: cortex

- Next steps:
  - Improve unwinding
  - Add new architectures
  - Include it in build systems

Debugging for production systems

Thank you for your attention

Questions?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