Achieving Faster Boot Time With Linux

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Agenda

- System Definitions
- Hardware Considerations
- Typical Embedded Linux System
  - Boot Sequence
- Measurement Methods
- Optimization Techniques
- Summary/Q&A

Define what "Fast Boot" Means

- Fast Boot is not a single technology or "product"
- Many techniques are architecture or platform dependent
- Product/application defines "fast boot"
- Your system requirements determine limits
  - CAN Bus in 50 ms
  - Rear view camera video in 2 seconds?
  - Partial HMI in 3 seconds?
  - Full multimedia plus networking in 4 seconds?
  - Do you need Secure Boot?

What takes so much time?

- Power/Clock Stabilization
  - usually negligible but should be considered
- Low Level CPU Initialization - ~ 100 ms
  - Bootloader (often multi-stage, ie secure boot)
- Loading images (kernel, u-boot, rootfs, dtb)
  - Usually these images live on NOR or NAND Flash
  - Even a small reduced kernel can be 1-2 MB (compressed)
  - Often stored compressed (kernel)
- Subsystem (Driver) initialization
- Mounting a root file system
- Userland – System Utilities and Applications

Typical Embedded Linux System

- Freescale i.MX6 SabreLite:
  - Quad-Core ARM® Cortex A9 1 GHz
  - Yocto core-image-sato (~90 MB rootfs)
  - Booting from Class 10 micro-SD

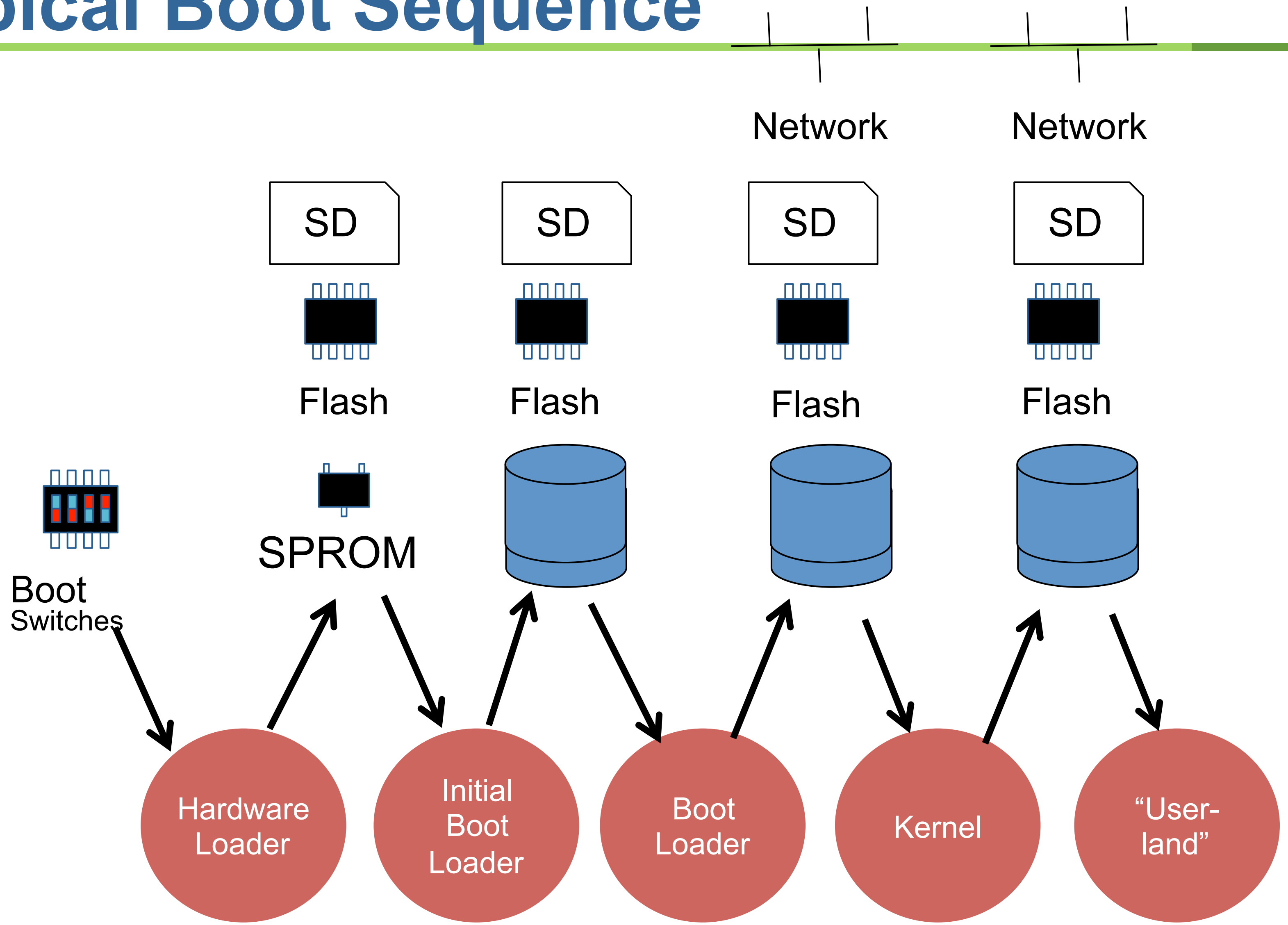
- Stopwatch analysis:

From Power On to:	Time (seconds)
Kernel FB logo	5
Userland psplash	13
Full Mobile Desktop	23

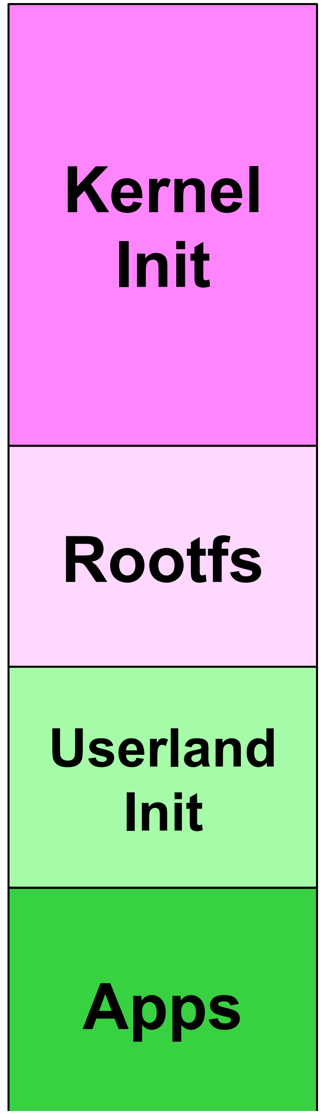
Hardware Considerations

- Hardware architecture makes a difference
  - Goes beyond just clock speeds, etc.
- Power and Clock stabilization should be very fast
- Design choices should support fast boot requirements
- Examples:
  - Loading u-boot and kernel from SPI NOR takes substantially longer than from parallel NOR or NAND
  - NAND flash or SD/MMC requires early software overhead but may be faster overall
  - Is your bootloader enabling caches early?

Typical Boot Sequence



Typical Linux Boot



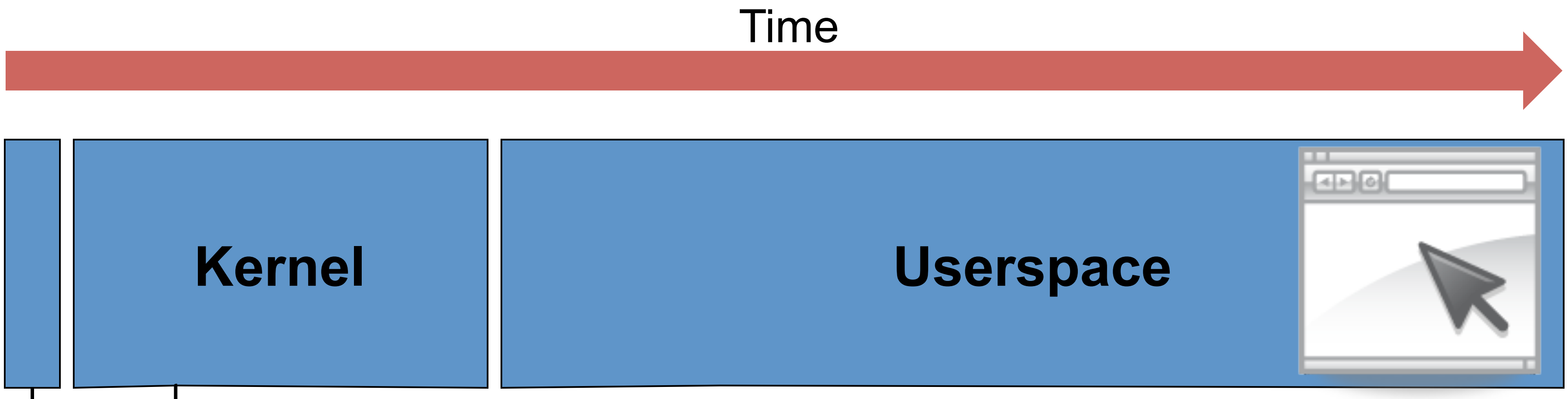
Hardware init
Core init
Loops per jiffy
Memory init
Driver init
Bus probing

Filesystem init
UBI scan
Rootfs mount

Init (systemd)
Subsystem init
Preload

Application Startup
Prelink
Optimize

The Bootup Phases (Relative Phase Lengths)



User-Space Initialization
- **Init scripts**
- **System processes**
- **Applications**

Kernel Startup
- Core init
- Module init

Bootloader
- Early h/w init
- Load/start kernel

Splash Screens – Make it look like it's booted!

- Indicates system is active, but still booting
- A splash screen can take place:
  - In the bootloader
    - Will get splash up sooner, but...
      - Usually require some porting to bootloader
      - May delay early kernel functionality
  - In the kernel
    - After initialization of the framebuffer driver
  - Early user-space init (psplash)
    - Before system apps initialized

Profiling and Measurement Tools

Boot Time Measurement Methods

- Techniques depend on context:
- Bootloader profiling often requires custom tools
- Several tools are helpful for Linux kernel profiling
  - Some are very easy to use (CONFIG_PRINTK_TIME, etc)
- Userland tools
  - Many tools to chose from
  - Some easy to use, some require investment in learning
- Some portions require custom techniques

Profiling U-Boot

- No clever "out-of-the-box" tools
- Whatever you do here will be custom
- First order: something similar to CONFIG_PRINTK_TIME
  - Enable timestamp values on each line of console output
  - May require architecture-specific timer
  - Can also use "grabserial"
- Second order:
  - Custom time checks around suspect areas
  - Hardware tracing on supported processors

Some Popular Measurement Tools

- CONFIG_PRINTK_TIME
- ftrace
- Bootchart (userspace)
- SystemTap
- LTTng

- initcall_debug
- oprofile (both)
- perf
- strace (userspace)
- uptime
- …

Timing Printk

- A simple method to put a timestamp on every printk
- Useful to identify lengthy init operations
- Activation (use one of the following):
  - Compile kernel with: CONFIG_PRINTK_TIMES=y (in Kernel Hacking)
  - Use “printk.time” on kernel command line
    - Both of these methods can be used during kernel boot
  - Or, dynamically in a run-time system (as root):
    - echo "Y" >/sys/module/printk/parameters/time
    - Obviously only useful after kernel is booted

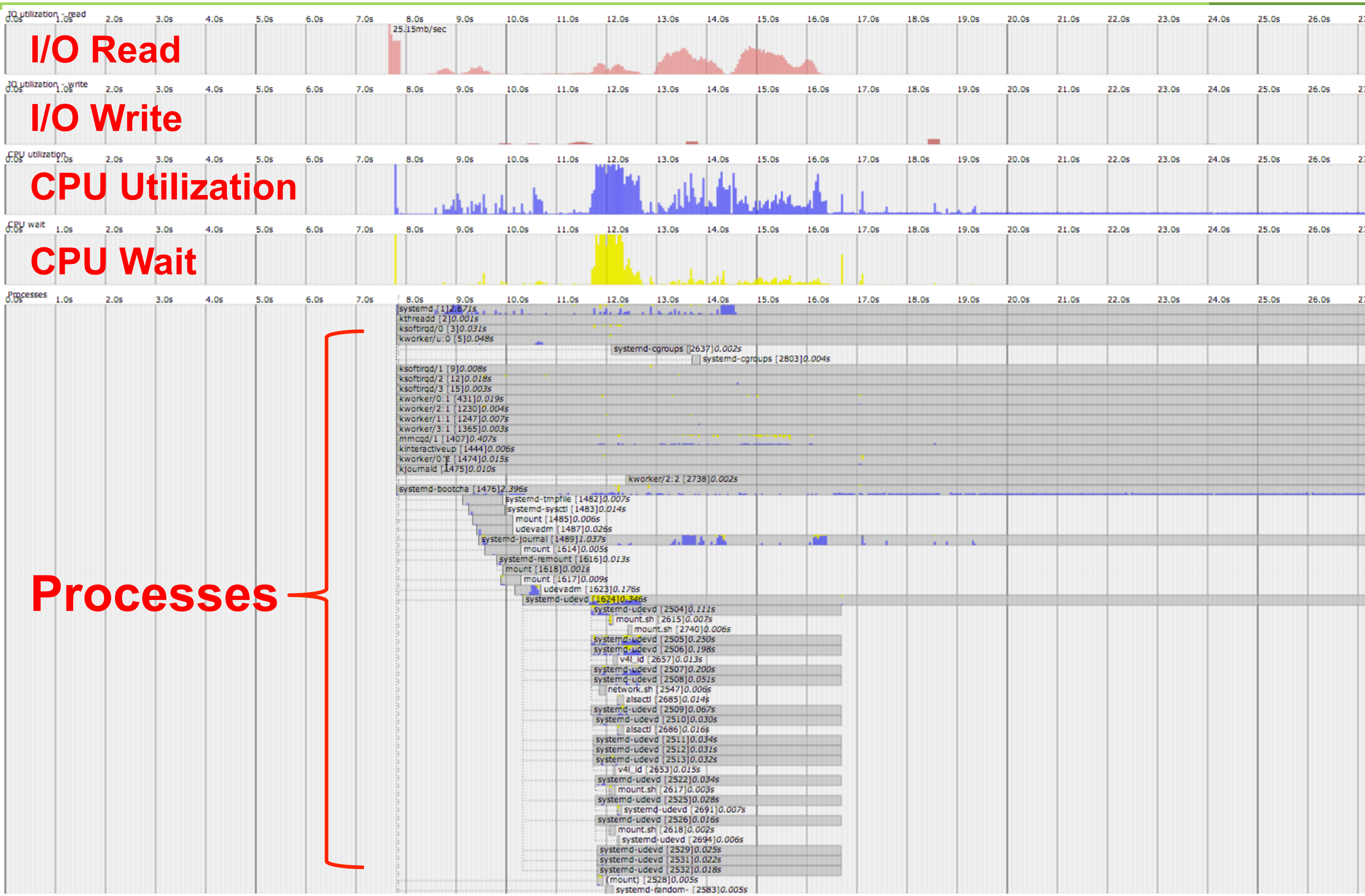
Using ftrace for profiling

- Requires some "investment" (learning curve)
- Analyze and debug latency and performance issues inside the kernel
- Profile execution time of functions, events, more
- A “framework” of several assorted trace and event utilities
  - Lots of filters and options for fine tuning your measurement
  - Over 800 events in 26 categories (syscalls, sched, irq, module, etc)
- Controlled via `/sys/kernel/debug/tracing`
- Can be enabled on kernel command line to facilitate early boot profiling. Ex:
  - ftrace=function_graph tracing_thresh=5000
- See …/Documentation/trace/ftrace.txt for more information

Bootchart

- Bootchart
  - Very useful for correlating CPU utilization with initialization process
  - Helps identify opportunities for parallel init
  - Limited to userland initialization profiling
  - Very easy to use: init=<path-to-systemd-bootchart>
  - Also works with systemd

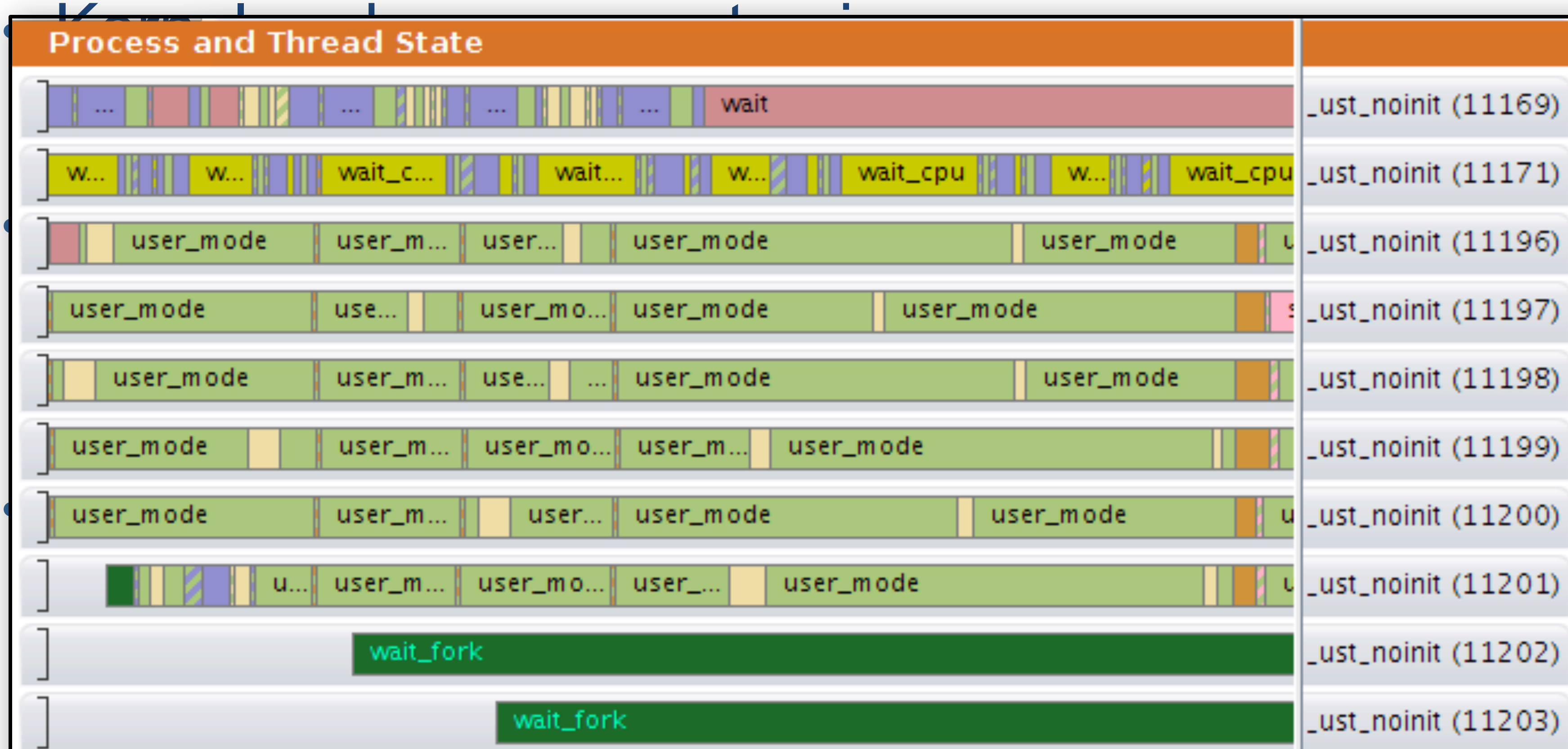
Typical Bootchart Output – i.mx6 startup



SystemTap

- Powerful instrumentation framework for tracing, profiling and evaluating kernel behavior
- Command line interface and scripting language
- Ideal for complex tasks that require live analysis without having to recompile the kernel
- Primarily designed for users with in-depth kernel knowledge and experience
- Can provide insight that no other tool can
- Significant learning curve
- Plenty of documentation on-line
- May not be available on every platform

LTTng (Linux Trace Toolkit next gen)



- For most modern kernels, LTTng is easy to integrate into your kernel
  - As always, YMMV depending on version and architecture

Using initcall_debug

- Driver initialization calls (initcalls) spend considerable time on kernel bootup
- A kernel flag enables initcall information during startup
  - On the command line, add “initcall_debug=1”
- Notes:
  - Increase the printk log buffer size in kernel config:
    - LOG_BUF_SHIFT=18 (256KB)
  - Enable CONFIG_KALLSYMS (to see function names)
- After booting info is found in bootlog (dmesg)
- May identify:
  - Opportunities for parallelism
  - Opportunities for removing functionality
  - Opportunities for deferring init

Using initcall_debug

```
root@mx6q:~# journalctl | egrep 'calling|initcall' | egrep 'ubifs|
ip_auto'
calling  ubifs_init+0x0/0xd0 @ 1
initcall ubifs_init+0x0/0xd0 returned 0 after 530 usecs
calling  ip_auto_config+0x0/0x1048 @ 1
initcall ip_auto_config+0x0/0x1048 returned 0 after 2777329 usecs
```

Oprofile

- Oprofile
  - Statistical profiler which records PC of currently executing program when specified events occur
  - Events include: (machine/processor dependent)
    - Timer, cache refills, interrupts while masked, many more
    - Varies by architecture
  - Useful for finding “hotspots” in kernel and application code
    - Not available on every platform
    - Often requires some customization

Perf

- Much more functionality than oprofile
  - Generally lower overhead, no daemon required
- Statistical profiling of entire system
  - Kernel and userspace
- Integrates hardware performance counters, tracepoints and dynamic probes for advanced profiling
- Userspace app which controls operations
  - `perf`
- Several subcommands: stat, top, record, report, sched…
- Does not work on all platforms
  - May need porting/patching to your particular platform

Using `strace` to profile applications

- Strace can be used to collect timing information for a process
  - strace –tt 2>/tmp/strace.log thttpd …
- Determine where time is being spent in application startup
- Can also collect system call counts (-c)
- Can see time spent in each system call (-T)
- Great for finding extraneous operations (ubiquitous)
  - scanning invalid paths for files (e.g.dynamic libs, fonts, etc),
  - opening a file multiple times, etc.
- Strace can follow children (-o -ff)
- Strace adds SIGNIFICANT overhead to the execution of the program
  - Good for relative timings, not absolute
  - May slow execution so much that it “breaks” interaction with other processes

Optimization Techniques

Optimization Techniques

- There are numerous ways to speed up boot time
- Your mileage may vary depending on many factors
- Identify the longest bootup paths and select these for optimization
- Some techniques are obvious, others not so
- Some are aggressive and intrusive
- Many are simply tweaks and easy to apply
  - Turn off unneeded options, etc.

Optimizing U-Boot

- U-Boot must be relocated from Flash into DRAM
  - Reducing the image size reduces relocation time
- Lots of useful development functionality
  - tftp, pci scan, mem utils, disk utils, load*, dhcp, etc
  - In a production system, many of these features are unnecessary
  - Disabling these features can have a significant impact on boot time
- You want the bootloader to do it's work and get out of the way as fast as possible
- Look at every CONFIG_* option in your board configuration header
  - include/configs/<board_name>.h

Optimizing the Linux Kernel

- Size matters
  - The kernel needs to be loaded from FLASH into RAM
  - Smaller == faster
- Consider using an uncompressed kernel
  - Decompression can take dozens to hundreds of milliseconds
- Configure as many drivers as possible as modules
  - Mostly a "brute force" approach – trial and error, time consuming
- Consider using deferred initcall patch
  - Defer module init until much later in boot cycle
  - Initcalls deferred until triggered in userspace

Optimization Techniques

- XIP (Your mileage may vary)
- Limit console printk()
- Pre-configure or eliminate udev
- Kernel modules/deferred initcalls
- RTC_nosync
- Checkpoint restart
- Use parallelism for multi-core
- Cache systemd config
- Minimize rootfs size
- …

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Userspace – Optimize `init`

- Use BusyBox – Very popular in embedded systems
- Consider a custom `init` for very aggressive boot times
  - Can configure init=myinit on kernel command line
  - Allows complete customization of userland initialization
  - It is always faster to run native code than scripts
    - In general, every line of a script causes fork()/exec()
  - Often used in fixed function types of devices
- If you're using ready-made startup scripts
  - Eliminate unnecessary stuff (set -x)
  - Run multiple scripts in parallel wherever possible
  - May require adding some synchronization between services you start in parallel if there are dependencies.
- Use SystemD instead of SysV init

Using systemd

- Alternative to SysV Init
- Avoids much fork/exec of typical start up scripts
- Compatible with SysV Init scripts, but
  - Translate to systemd config files for best results
- Solves many of the startup dependencies quite nicely
- Parallelizes as much as it can
  - Big win on multicore
- See http://0pointer.de/blog/projects/systemd.html for an interesting introduction by the author

Application Prelink

- A good portion of application initialization time is spent resolving symbols to dynamic libraries
- Using Prelinking you can cut off a significant portion of application startup time if you have a large/complicated userland
- Tries to assign a preferred address space to each library used by an application – ahead of time
- Prelink is essential to rapid application startup

Designing your Applications - Considerations

- Keep it small
- Prelink
- Be careful adding dependencies on new libraries
  - it can snowball
- Keep fork/exec to minimum
- Some multithreading can help esp. with multicore
- Use Analysis tools – profiling, strace, etc.
- Use only Fast-path I/O Peripherals (e.g. – no Wifi)
- Avoid “discovery” code if possible

Achieving Sub-1 Second Boot

Aggressive Boot Time Reduction

- Mentor's Adaptive Preloading File System*
  - Profiles boot, stores read block list for faster playback
- U-Boot DMA
  - SPL or KL configuration
- Consider Read Only FS for root - YMMV
  - CRAMFS/SquashFS
- UBI Fastmap
- Avoid Initramfs
  - Apps that require shared libs require the entire lib in initramfs
  - Kernel drivers are more optimized than u-boot
  - Use a preloading FS instead
- Tiny kernel -> kexec full Linux kernel

*This is a technology, not a product

Linux Fast Boot – Mentor Projects

- Lesson Learned
  - Boot time is highly dependent on choices made in HW
  - Hardware architecture and system architecture matter
  - Individual requirements vary
- Mentor has significant experience
  - Kernel optimizations for custom boards in automotive space
  - Architecture analysis for system trade-offs in boot time performance
- Sample Benchmarks Mentor Graphics has met in the past
  - 100 msec boot loader to start kernel loading
  - 750 msec for Linux kernel start
    - *Rootfs and read/write filesystem mounted*
    - *First user process running*
  - Audio on within 1.25 sec
  - Safety-critical Camera feeds within 2 sec
  - Home screen available within 10 sec

Thank you!
Your Questions are Welcome

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