Debugging embedded Linux power management

Kernel developer point of view

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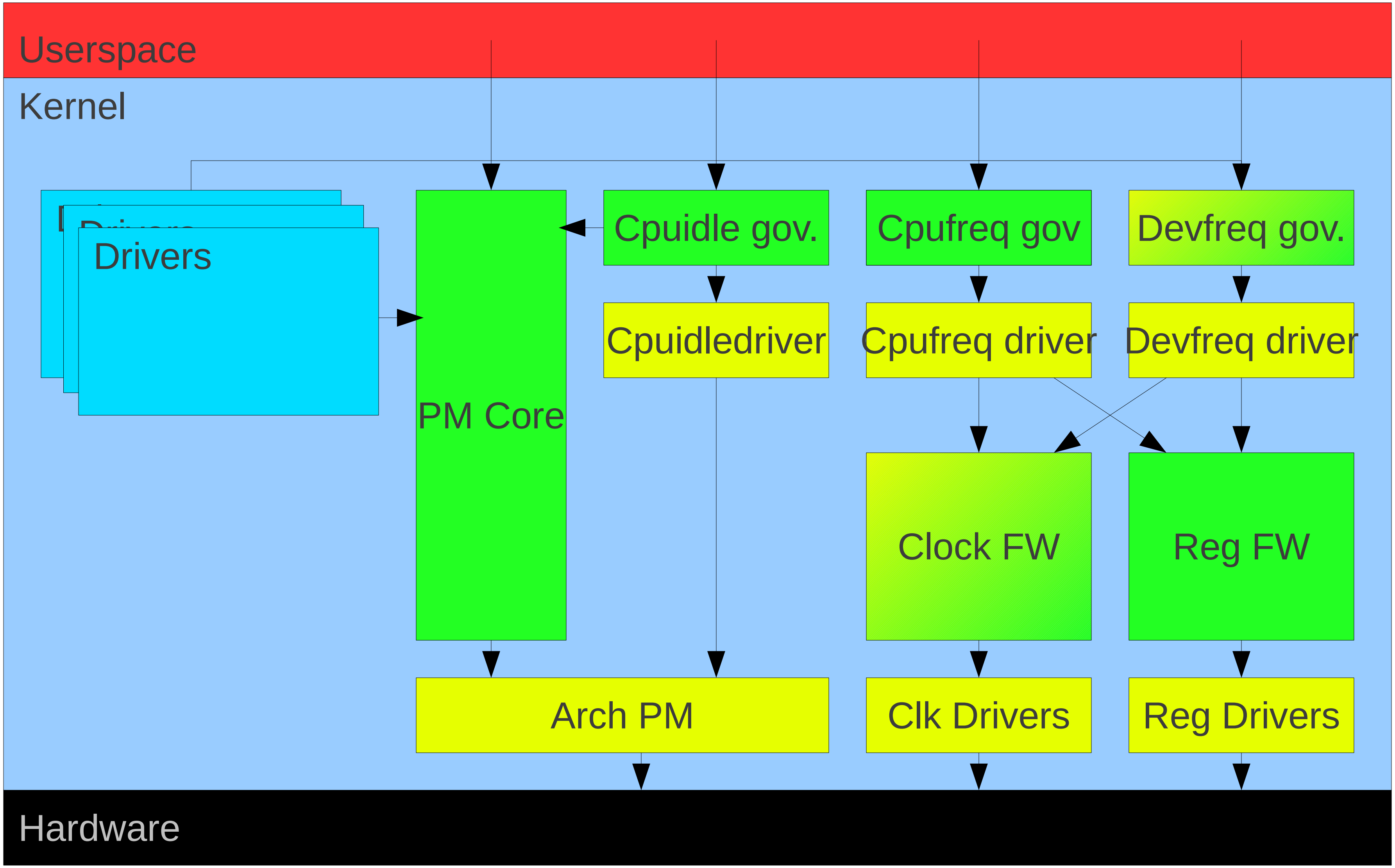
Common PM architecture



Debugging tools / methods for PM

Disabling kernel features

- Disable CONFIG_PM
  - If bug remains, complain to someone else!
- Disable unnecessary drivers
  - Only enable minimal set like timers, console, I2C, etc., depends on arch which are needed
- Disable PM features
  - Only enable a single PM feature at a time and attempt to reproduce the problem
- Pros:
  - Good for isolating a PM related problem if don't have any kind of clue about what is wrong
- Cons:
  - Rather slow and difficult to use

Stress testing

- Scripts that do some PM related operations in a tight loop
  - Example: suspend loop with a wakeup from suspend every 100ms
- Should be random enough so that the bug producing pattern is executed
- Pros:
  - Can be very useful in reproducing some problems that take typically a long time to occur with normal use
- Cons:
  - Difficult to figure out what operations to actually execute in the stress testing script

Tracing (printk / low level UART)

- Populate enough debug printks to the code being examined
- If possible, can also dedicate a custom interface for debug traces
- Pros:
  - Easy / quick to use
- Cons:
  - Typically alters code execution time (especially if using serial port), and may hide the actual problem
  - Not usable from very low level code (printk)
  - Printk:s are cached and may not be printed out before a crash happens (e.g. during suspend)

GPIO / LED trace

- Add control to some GPIO / LED signal from certain points in code
  - Example: LED is turned on when CPU is running, disabled when idle
- If possible to use multiple signals, can provide a binary coded trace value from kernel
- Pros:
  - Single GPIO / LED control typically does not consume so much time as to alter execution times drastically (vs. UART)
  - Can even use multiple devices with LEDS, and if using stress testing script, can immediately see if some devices have crashed or not
  - Useful in case debugging code areas where debugger / printk is not usable
- Cons:
  - Most likely only a few available (what to trace?)

Debugger

- Useful in developing new code, and sometimes can see where kernel has crashed
- With PM code, typically need breakpoints
  - Static / dynamic
  - Fake breakpoint (infinite loop in code, re-program PC after stopped)
- Real hackers don't use/need debugger though
- Pros:
  - Well, debugger is always a debugger
- Cons:
  - Communication with CPU is probably blocked during low power operating modes

Buffered traces / statistics

- Trace information collected from kernel side into a ring buffer
- Dumped out with a console operation through e.g. debugfs
- Typical uses: cpuidle tracing, power state usage statistics
- Kernel tracepoints seem to be a good tool for this, and it is easy to add new tracepoints in case something is missing
- Pros:
  - Minor impact to execution times (no slow HW components accessed)
- Cons:
  - Only useful in debugging misbehavior (crash prevents later dump)

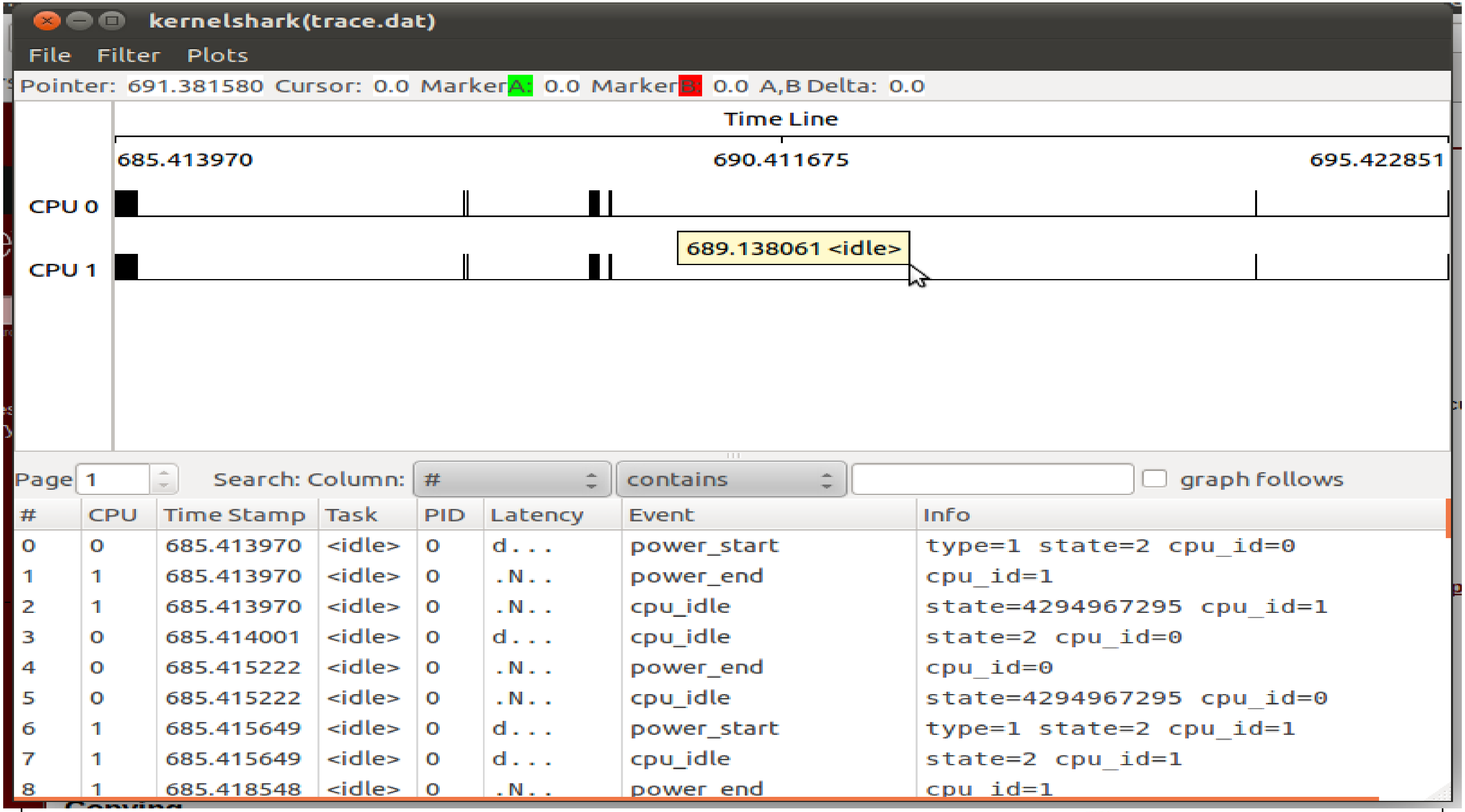
Example: tracepoints with idle 1/2

- Execute following script in target device:

```
#!/bin/sh
trace-cmd reset
sleep 10
trace-cmd start -e power
sleep 10
trace-cmd stop
trace-cmd extract
```

Example: tracepoints with idle 2/2

- Copy resulting trace.dat over to host and process it with kernelshark



Pointer: 691.381580 Cursor: 0.0 Marker A: 0.0 Marker B: 0.0 A,B Delta: 0.0

#	CPU	Time Stamp	Task	PID	Latency	Event	Info
0	0	685.413970	<idle>	0	d...	power_start	type=1 state=2 cpu_id=0
1	1	685.413970	<idle>	0	.N..	power_end	cpu_id=1
2	1	685.413970	<idle>	0	.N..	cpu_idle	state=4294967295 cpu_id=1
3	0	685.414001	<idle>	0	d...	cpu_idle	state=2 cpu_id=0
4	0	685.415222	<idle>	0	.N..	power_end	cpu_id=0
5	0	685.415222	<idle>	0	.N..	cpu_idle	state=4294967295 cpu_id=0
6	1	685.415649	<idle>	0	d...	power_start	type=1 state=2 cpu_id=1
7	1	685.415649	<idle>	0	d...	cpu_idle	state=2 cpu_id=1
8	1	685.418548	<idle>	0	.N..	power_end	cpu_id=1

Exporting debug functionality to userspace

- Provide a testing API to userspace to read / write hardware registers directly (on memory mapped registers can use /dev/mem)
- Enhance existing debug interfaces by adding write functionality in addition to existing read-only APIs
  - Example: regulator fw microvolt nodes
- Add completely new interfaces where nothing exists currently
- Pros:
  - Having as much of the functionality available to userspace as possible makes it easy to write test scripts
  - Can dynamically create new test cases
- Cons:
  - Might not be possible to upstream these

Kernel PM features

Suspend

- Executed from command line (echo mem > /sys/power/state)
- Disables all drivers manually
  - Disables also trace!
- Tools for debugging:
  - Trace (limited)
  - Gpios
  - Debugger (with breakpoints)
- Tricks:
  - Prevent low level PM entry so that hardware is mostly taken out from debug process, re-enable once SW works

Cpuidle

- Bit complicated as can execute multiple different C states based on system status
- Tools for debugging:
  - Traces (limited) / gpios / ring buffer
  - Debugger can be used with breakpoints
- Debug information from userspace:
  - /sys/devices/system/cpu/*/cpuidle/*
- Tricks:
  - Export API to userspace to “force” a certain C state always

Regulators

- Userspace API available at /sys/class/regulator
- Easy to check the status of regulator framework against hardware status by using multimeter etc.
- Tricks:
  - Export write capability for microvolt nodes to userspace
  - Export regulator enable / disable to userspace

Clock framework

- Ongoing work within Linaro to get a common clock framework into the kernel
- Part of the code exists already but integration missing to most of the platforms
- Tools for debugging:
  - Traces
  - Register dumps vs. clock framework status
- Userspace interface:
  - /sys/kernel/debug/clk/*
  - Provides info for clock rates, usecounts, flags etc.
  - Easy to tweak to allow manual enable of clocks from userspace

Cpufreq

- Pretty easy to debug, as typically does not block any kernel functionality, and has nice APIs readily available from userspace
- Can usually trace through everything
  - May have a critical section that requires more complex debugging
- Debug information from userspace:
  - /sys/devices/system/cpu/*/cpufreq/*
  - /sys/class/regulator/*
  - /sys/kernel/debug/clk/* if available
- Tricks:
  - Select clock frequency manually with 'ondemand' governor by writing to 'scaling_min/max_freq' nodes

Devfreq

- Device specific DVFS, relatively similar to cpufreq
- Should also be possible to trace through everything
- Adds extra 'devfreq' directory under device sysfs node

Typical PM problems

Bootloader ~~madness~~ insanity

- Everybody uses a different bootloader
- Lots of features inside the bootloaders, which typically leave hardware enabled after use => prevents PM
- Quite often it might not be evident that bootloader is causing PM problems
- First thing to do when someone complains to you about PM issues, ask them what bootloader they are using
  - If not the same you have => its their problem

Device crash

- Device dies completely, either with or without a crash dump
- If with dump, just decipher the crash dump to figure out what happened
- If silent hang, try to pinpoint where the crash happens
  - Disable CONFIG_PM
  - Disable PM options one by one
  - Disable drivers to get a 'minimal kernel'
  - Add traces to code
  - Add breakpoints to potential crash locations etc.

Device malfunction

- Some driver starts misbehaving after a while
- Can take a long time to reproduce
- Maybe difficult to pinpoint the actual problem
- If you are lucky, might provide mysterious crash dumps related to the component in question
- Stress testing scripts might be useful
- Example problems:
  - Device stops responding to serial console after a while, but the kernel / interrupts still work
  - Memory corruption

Increased power consumption (1/3)

- Power source good initial indicator
  - e.g. battery dies too quickly compared to what it should be
- Check if cpuidle / suspend work properly and set the device to proper state
  - Sysfs status for cpuidle
  - timer_stats
  - Regulator status
  - Whatever else is exported to userspace from HW point of view
- Good if you have a working / non-working case where you can compare the system state

Increased power consumption – hardware (2/3)

- Hardware problems usually force higher power use than planned
  - May need to disable some power saving techniques
    - e.g. some regulator must always be 'enabled'
  - Some HW pulls are incorrectly designed and consume extra power
- Might be possible to reduce impact in some cases with software tweaks
  - E.g. align external pull vs. SoC configurable pull config
- May need to re-design hardware

Increased power consumption - userspace (3/3)

- Typical culprit for consuming too much power
- Some process is using too much resources for execution
  - Prevents cpuidle completely (cpu load) or partially (timer usage)
- Check out 'top' or something similar for CPU load
- /proc/timer_stats is good for figuring out timers that are used too often

Some references

- Powertop
  - Parses timer + process + interrupt info
  - https://01.org/powertop/
- Powerdebug
  - Parses regulator + clock framework + sensor data
  - https://wiki.linaro.org/WorkingGroups/PowerManagement/Doc/PowerDebug
- Tracepoints
  - Kernel source: include/trace/events/power.h
  - Debugfs: /sys/kernel/debug/tracing/README
    - Parsers: (target) trace-cmd => (host) kernelshark, pytimechart

Thank you!