Greening the OpenSolaris Kernel

OSDevCon 2009, Dresden

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Solaris Kernel Development
Sun Microsystems, Inc.
http://www.opensolaris.org/os/project/tickless

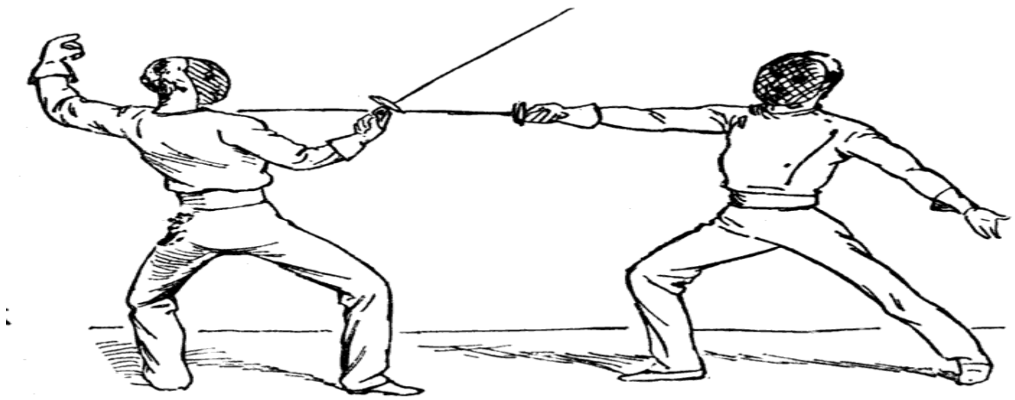
Intro and Overview

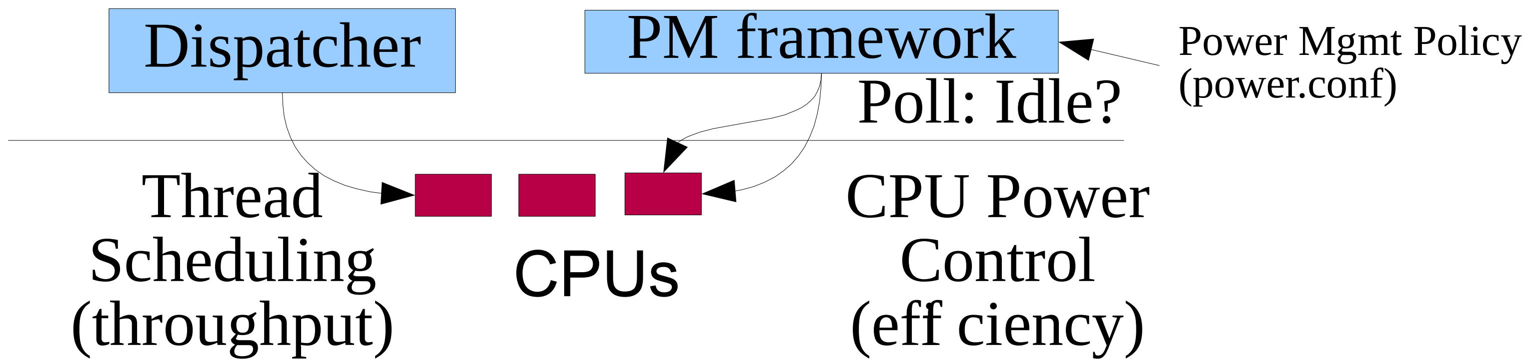
- Power Management Feature Background
- Greening the System
  - Power Efficient Resource Management
  - Efficient Resource Consumption
- Tickless Kernel Project
  - Overview
  - Progress
- Getting Involved

Resource Power Management

- Active Resource Power States
  - Trade off: performance vs. power
    - CPUs: Dynamic Frequency, Voltage Scaling (DVFS)
    - Memory, CPUs: Clock Throttling
    - CPUs: Dynamic Frequency Overclocking
- Idle Resource Power States
  - Trade off: power vs. recovery latency
    - CPUs: ACPI C-states
    - Memory: Self-Refresh
    - Systems: Suspend to RAM, Suspend to Disk

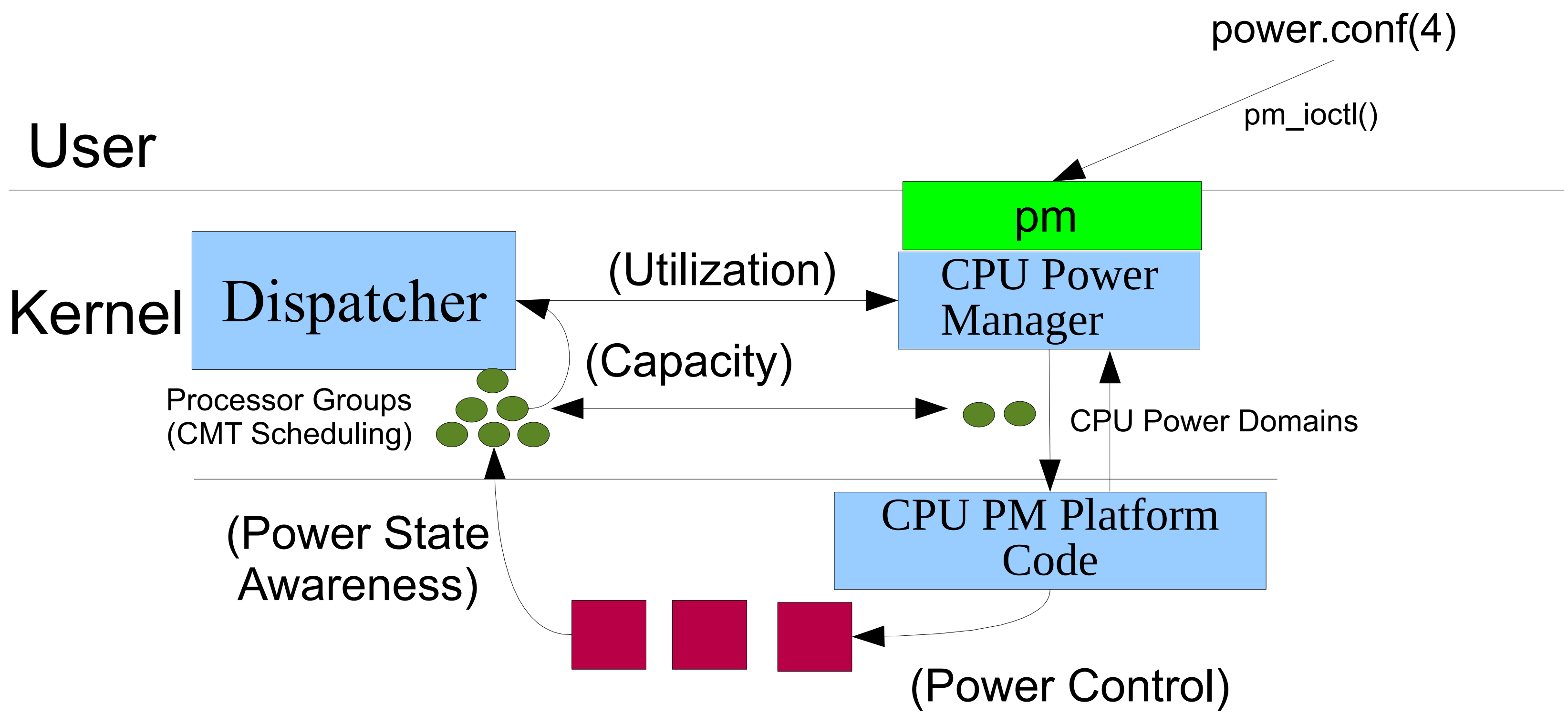
CPU Power Management (then)





- The CPUPM Subsystem and the dispatcher don't necessarily get along.
- Architecture relies on polling, need to periodically look at CPU utilization statistics, even on an idle system.

Dispatcher Integrated CPUPM (now)



- Event based architecture driven by thread scheduling activity (no polling)
- Enables power aware thread placement, and thread aware CPU power management
  - Dynamic Frequency and Voltage Scaling, and multi-level C-states

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  - “throttling” requests (where possible) generally detrimental to performance
  - Imposing “active PM” residency at the expense of “idle PM” residency generally not good trade-off

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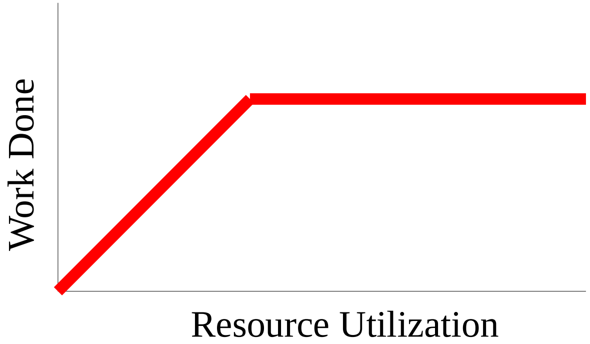
  - Imposing “active PM” residency at the expense of “idle PM” residency generally not good trade-off
- Good resource management ultimately cannot compensate for wasteful resource consumption.

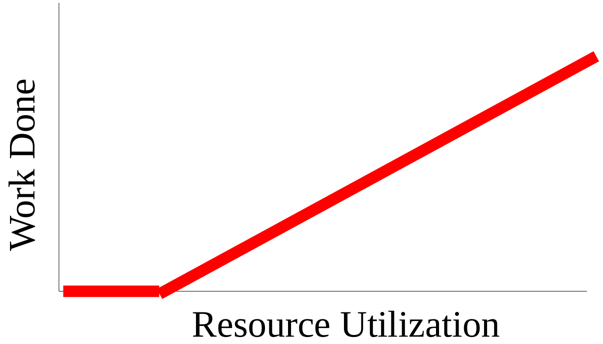
Profiles of Inefficient Software

- Resource consumption non proportional with respect to useful work performed...

Poor Scalability



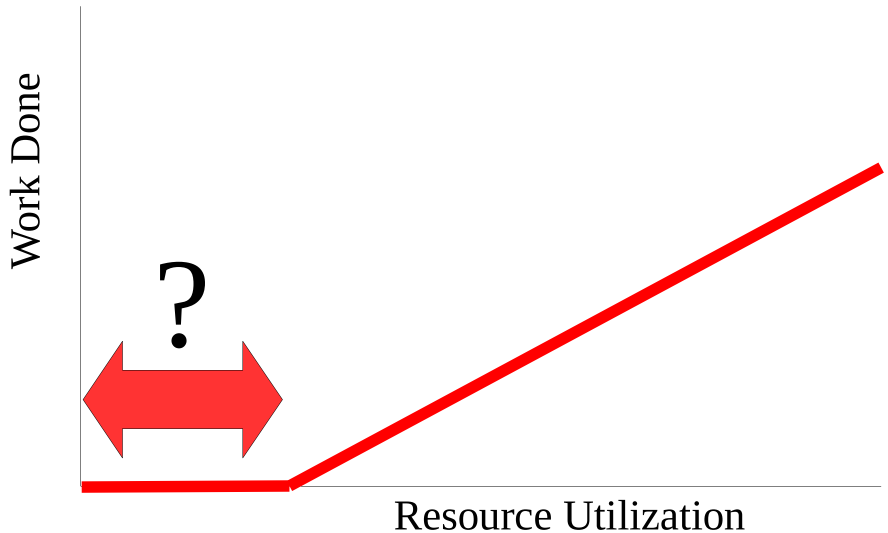
Poor Reverse Scalability



- At higher utilizations with poor scaling...
  - Too many threads, memory leaks, etc.
- At low/zero utilization, by not yielding (or continuing to use) resources
  - e.g. periodic “polling” for a condition

Observing Inefficiency

- A simple approach for the low utilization case...
  - At system idle no useful work is being performed...
  - So watch who's using resources (they are being bad).



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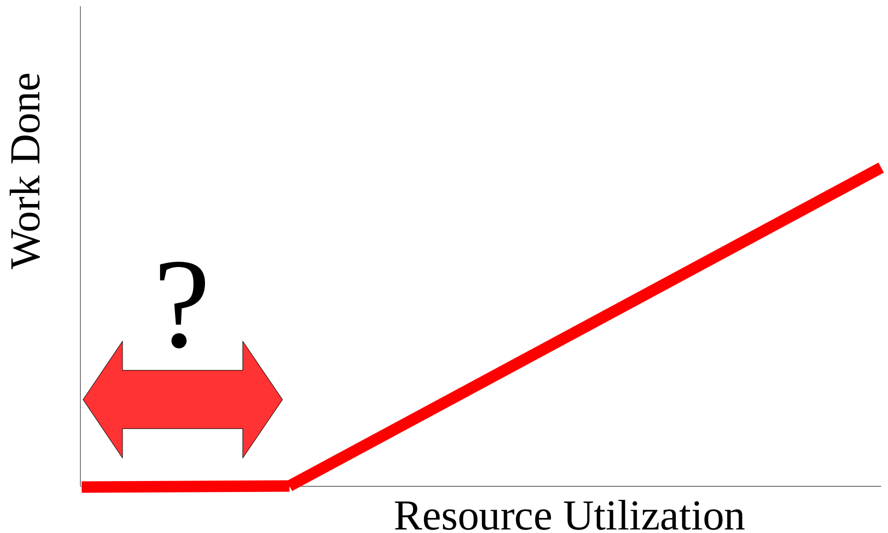

- Optimizing for the low utilization case makes sense, due to effectiveness of idle power management features.
  - In many ways, high utilization case already pursued though performance (scalability) efforts.

PowerTOP(1M)

```
PowerTOP for OpenSolaris v1.1
File  Edit  View  Terminal  Tabs  Help
   OpenSolaris PowerTOP version 1.1     (C) 2007 Intel Corporation

Cn                        Avg     residency       P-states (frequencies)
C0 (cpu running)                  (59.9%)         1998 Mhz        100.0%
C1                        0.1ms   (40.1%)         2997 Mhz        0.0%

Wakeups-from-idle per second: 3477.2    interval: 1.0s
no ACPI power usage estimate available

Top causes for wakeups:
86.3% (3000.0)          <interrupt> :  hdaudio#0
 4.3% (148.5)              <kernel> :  uhci`uhci_handle_root_hub_status_change
 3.5% (121.8)           <interrupt> :  nvidia#0
 3.4% (116.8)                 sched :  <cross calls>
 3.1% (107.9)           <interrupt> :  e1000g#0
 2.9% (100.0)              <kernel> :  genunix`clock
 2.8% ( 96.0)          realplay.bin :  <scheduled timeout expiration>
 1.9% ( 66.3)              <kernel> :  ehci`ehci_handle_root_hub_status_change
 1.5% ( 53.5)                 sched :  <scheduled timeout expiration>
 0.5% ( 16.8)                  java :  <scheduled timeout expiration>
 0.3% ( 10.9)           firefox-bin :  <scheduled timeout expiration>
 0.3% (  9.9)              <kernel> :  ata`ghd_timeout
 0.3% (  9.9)         mixer_applet2 :  <scheduled timeout expiration>
 0.2% (  7.9)              <kernel> :  genunix`realitexpire
 0.2% (  7.9)            gam_server :  <scheduled timeout expiration>
 0.2% (  5.9)              <kernel> :  uhci`uhci_cmd_timeout_hdlr
 0.1% (  5.0)       thunderbird-bin :  <scheduled timeout expiration>
 0.1% (  4.0)              <kernel> :  genunix`schedpaging
 0.1% (  4.0)           xscreensaver :  <scheduled timeout expiration>
 0.1% (  3.0)              <kernel> :  ip`tcp_timer_callback
 0.1% (  3.0)        gnome-terminal :  <scheduled timeout expiration>

Suggestion: run as root to get suggestions for reducing system power consumption

 Q - Quit   R - Refresh
```

Greening the System
Starting with the Kernel...

- Why?
  - Improve ability to leverage idle power management features (especially on small systems).
  - Lessen guest performance overhead at zero utilization (when sharing system with other guests).
  - Lessen jitter, to improve RT latency/determinism and barrier synchronization performance (HPC)
  - Improve kernel service scalability
  - Set the example for all software in the ecosystem, and learn (while providing missing mechanism) along the way...

Greening the System
Approach

- Consider PowerTOP(1M) an “todo” list.
  - Being “tickless” is a matter of degree (not binary)
    - e.g. average duration of system quiescence
- Begin by eliminating the 100 Hz clock() cyclic
  - Decompose it into component tick based services. For each service:
    - Provide an event based (tickless) implementation
    - Where this isn't possible, make it less painful.
- Provide the architecture / interfaces needed to facilitate event based programming practices (and more efficient polling) throughout the system.

Tickless clock() Overview

- Core tick-based clock() services
  - Expire callouts / timeouts (timers)
  - Perform CPU utilization accounting for running threads, and expire time slices
  - Bump lbolt variable (tick resolution time source)
  - Time-of-day / hires time sync up
  - ...and other stuff that's crept in.

Tickless Timeouts / Callouts

- Historical Implementation
  - clock() invoked a routine that would inspect callout table heaps, expiring due timers.
  - Inherently non-scalable and inefficient (as tables frequently empty on idle systems)

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  - clock() invoked a routine that would inspect callout table heaps, expiring due timers.
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- Tickless Implementation
  - Re-programmable cyclics introduced
  - Per CPU timer heap(s), driven by a re-programmable cyclic who's firing is set for when the next timer is due.
  - Status: Integrated into Nevada build 103

Tickless lbolt

- lbolt - “lightning bolt”
  - “tick” counter (global kernel variable) incremented by clock()
  - Used extensively throughout the kernel
    - as a low resolution, yet cheap to read (and convenient) time source
    - as arguments for cv_timedwait() and friends
  - Likely used in 3rd party kernel modules
- Approach
  - Replace the variables with a routine backed by a hardware time source
    - Leverage existing ddi_get_lbolt()
  - Change *where* lbolt comes from, not *how* it is used
- Status
  - Preparing to integrate (next few builds)

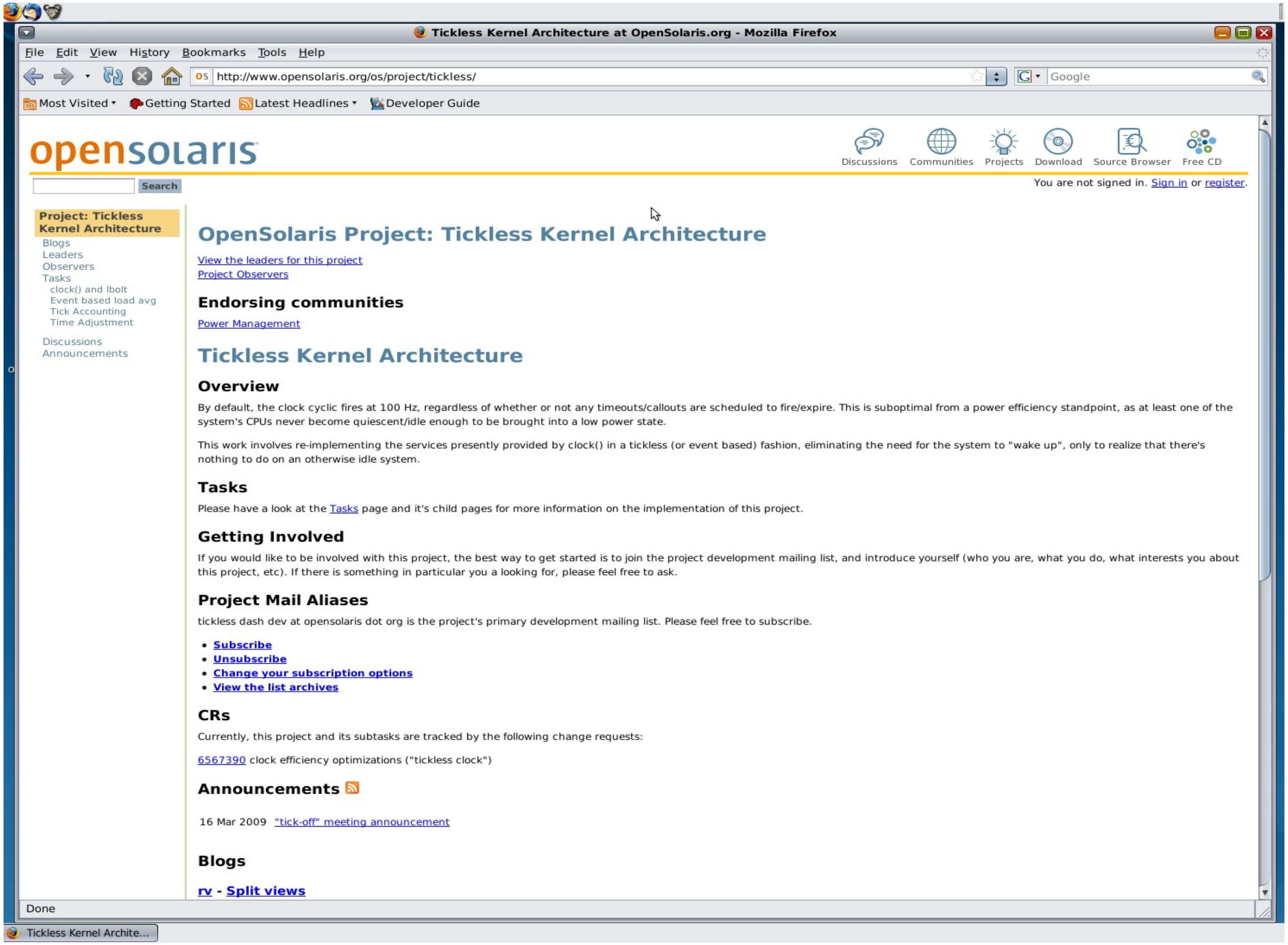
Tickless Thread Accounting (TAC)

- Approach
  - Per thread heap of timers maintained that fire when various amounts of thread CPU time have elapsed
    - time slice expiration, CPU time resource limits, etc.
  - Builds upon “reprogramable cyclics” feature
- Implementation
  - A TAC omni-cyclic processes the per CPU timer heaps.
  - Each CPUs cyclic is programmed at context switch time to the earliest timer in the heap
  - On cyclic expire, accounting is done and the cyclic is reprogrammed to the next timer
  - If the cyclic detects a kernel thread, it switches itself off
- Status
  - In development. Design document available for review.

Tickless OpenSolaris Project
Getting Involved

- Primary mailing list: tickless-dev@opensolaris.org
- Source repositories hosted on hg.opensolaris.org
  - One “gate” per clock() sub project
  - Will likely maintain a repo that is also the merge of the sub-projects
- Bug Tracking
  - Bugzilla: http://defect.opensolaris.org/
    - Track bugs under: Development/power-mgmt/tickless*
      - tickless tick accounting, tickless lbolt, tickless time sync, tickless clock misc
    - All bug updates currently go to tickless-dev as well
- Dev Team Meetings
  - Tuesdays 10:30AM Pacific
  - Concall info on project page

Tickless OpenSolaris Project



References

- Tickless Project Page
  - http://www.opensolaris.org/os/project/tickless
- Power Management Community
  - http://www.opensolaris.org/os/community/pm

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