IBM Linux Technology Center

Testing real-time Linux: What to test and how.

Sripathi Kodi

sripathik@in.ibm.com

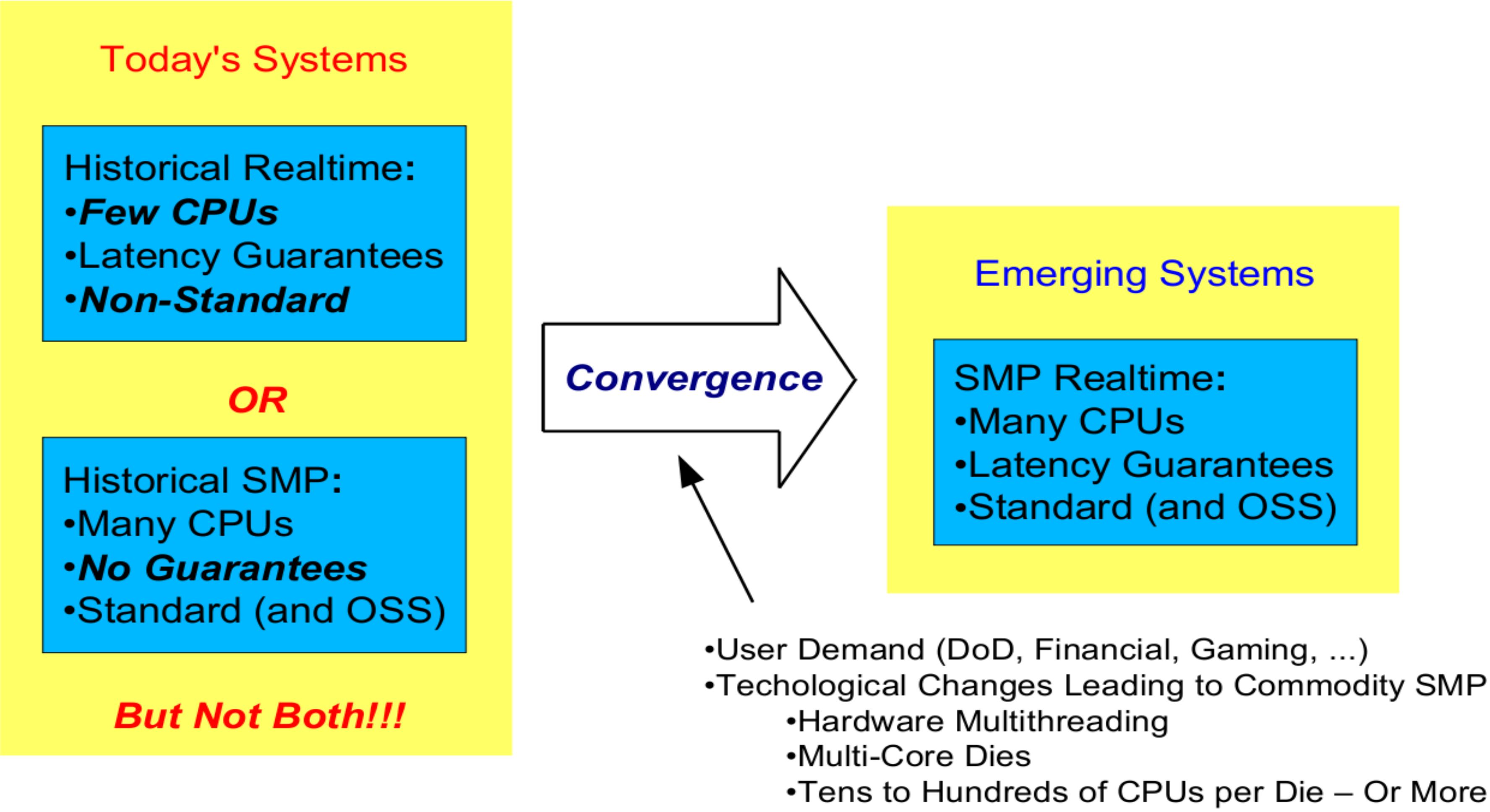
Agenda

- What is a real-time Operating System?
- Enterprise real-time
- Real-Time patches for Linux
- Testing real-time kernel: What to test
- Testing real-time kernel: Setup
- Tips for writing test cases for real-time kernel
- Existing real-time tests
- How can *you* contribute?
- References

What is a real-time Operating System (OS)?

- Real-time OSes provide *predictable* performance
- They don't necessarily provide the best *throughput*
  - Real-time OSes often sacrifice throughput for predictability
- Used in environments where timely action is critical
  - Defense, medical systems, embedded devices
- Applications to run are carefully chosen
- Hard vs soft real-time

Enterprise real-time systems: The convergence



Today's Systems

Historical Realtime:
- ***Few CPUs***
- Latency Guarantees
- ***Non-Standard***

OR

Historical SMP:
- Many CPUs
- ***No Guarantees***
- Standard (and OSS)

But Not Both!!!

Convergence

Emerging Systems

SMP Realtime:
- Many CPUs
- Latency Guarantees
- Standard (and OSS)

- User Demand (DoD, Financial, Gaming, ...)
- Techological Changes Leading to Commodity SMP
  - Hardware Multithreading
  - Multi-Core Dies
  - Tens to Hundreds of CPUs per Die – Or More

Source: Paul McKenney

Real-time patches for Linux

- Various approaches
- CONFIG_PREEMPT_RT (RT) patch by Ingo Molnar
- Soft real-time
- Is a patch on top of Linux mainline kernel
- All APIs remain same, hence apps work as-is
- Concentrates on some areas of the kernel
  - Process subsystem, scheduling, Interrupt handling, synchronization
  - Cannot cater to all parts of the kernel. Example: disk IO

Major Components of RT patch

- High Resolution Timers
- Priority Inheritance
- Threaded Interrupts
  - Some interrupts are not threaded
- Threaded softirqs
- Preemptible spin locks
  - *raw* spin locks
- Read-write locks

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- Latency
  - Most important category
  - Measure latency and variation in latency over various conditions

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  - Size of RAM
  - SMIs
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- Kernel
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  - Configuration options
    - HZ, NO_HZ, CPU_FREQ, Debug options under “Kernel Hacking”

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- Priorities of IRQs and softirqs
  - chrt command
  - rtctl, set_kthread_prio

Output of 'ps' showing IRQs and softirqs

```
# ps -eo comm,pid,class,rtprio | grep -i irq
   sirq-high/0        5 FF     30
   sirq-timer/0       6 FF     30
   sirq-net-tx/0      7 FF     90
   sirq-net-rx/0      8 FF     90
   sirq-block/0       9 FF     30
   sirq-tasklet/0    10 FF     30
   sirq-sched/0      11 FF     30
   sirq-hrtimer/0    12 FF     92
   sirq-rcu/0        13 FF     30
   sirq-high/1       18 FF     30
   ...
   ...
   IRQ-11           119 FF     95
   IRQ-12           408 FF     95
   IRQ-1            409 FF     95
   IRQ-8            420 FF     95
   IRQ-19           438 FF     95
   IRQ-26           489 FF     95
   IRQ-6           1079 FF     95
   IRQ-24          8230 FF     95
   IRQ-4          10449 FF     95
   IRQ-3          10451 FF     95
```

Tips for writing test cases for real-time kernel

- Run as SCHED_FIFO
- Limit to available memory
- Page faults
  - Can't be prevented during application start-up
  - Methods to prevent page faults in critical code paths
    - mlockall()
    - Don't create threads
    - Don't allocate dynamic memory
    - Avoid IO
- Take the number of cpus into account
- Interrupt shielding
  - /proc/irq/<n>/smp_affinity

Tips for writing test cases: continued

- Use proper calls to record time
  - clock_gettime (CLOCK_MONOTONIC)
- Understand PI mechanism
- Run large number of iterations
  - Find statistics like max, min, average and percentiles
  - Worst case behavior more important than average
- Use proper priorities
  - Possibility of hung system
  - User space now has power. Power imparts responsibility!
- Avoid sched_yield()

What happens?

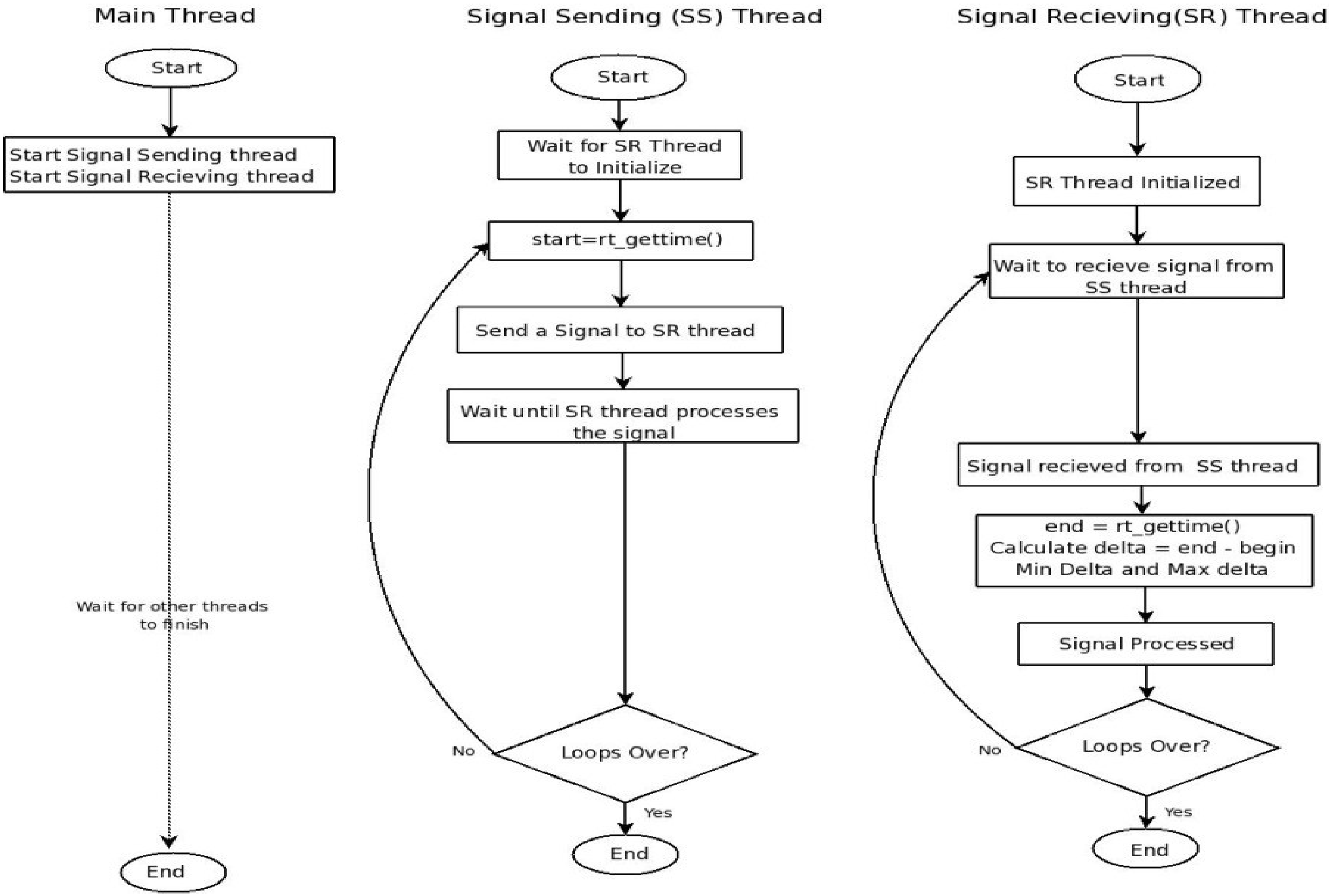
```
while (1) {
   if (check_something())
     break;
   sched_yield();
 }
```

Existing real-time tests

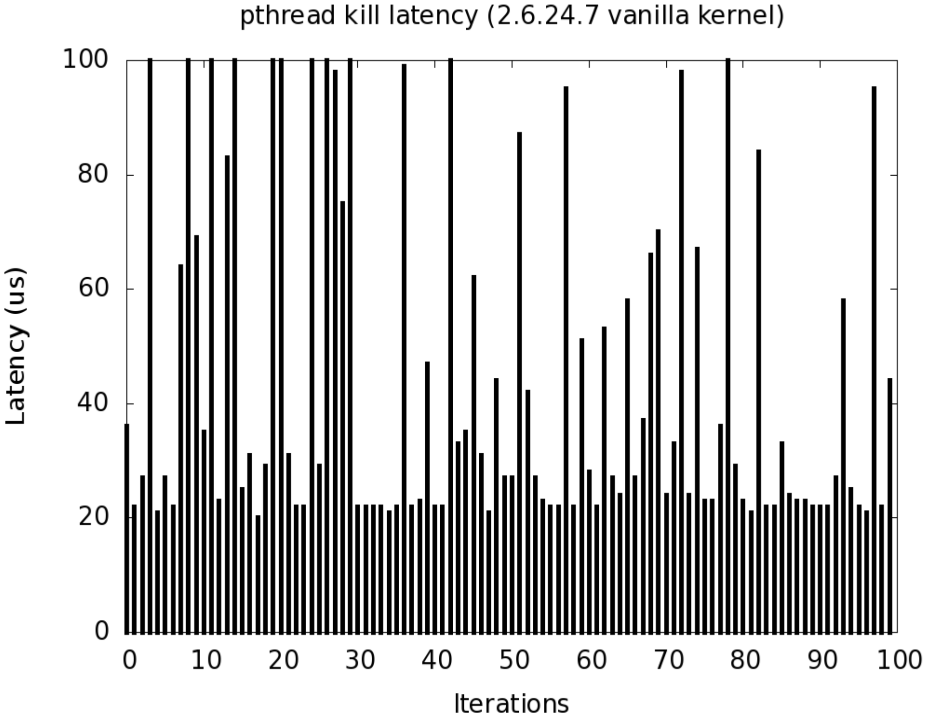
- LTP contains a real-time test suite
- testcases/realtime directory in LTP
  - Functional tests under testcases/realtime/func
  - Utility functions under testcases/realtime/lib
  - Stress tests under testcases/realtime/stress
  - ...
- Some of these tests were written to test functionality while RT patches were being stabilized
- Some were written to analyze specific latency problems
  - Regression test bucket

- rt-tests by Thomas Gleixner: Outside the LTP

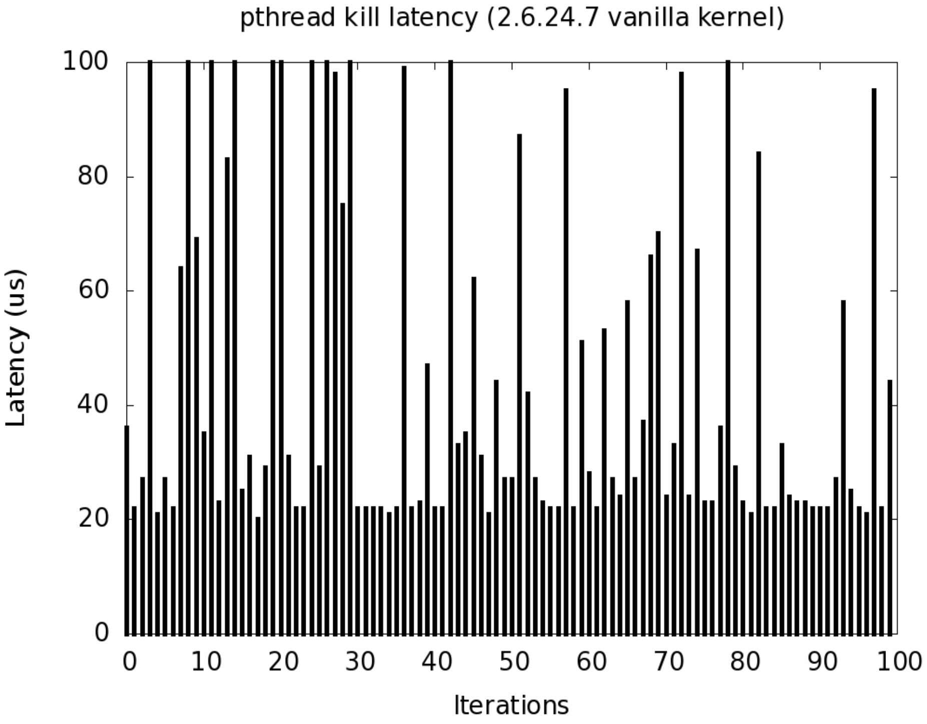
Example of a real-time test: pthread_kill_latency

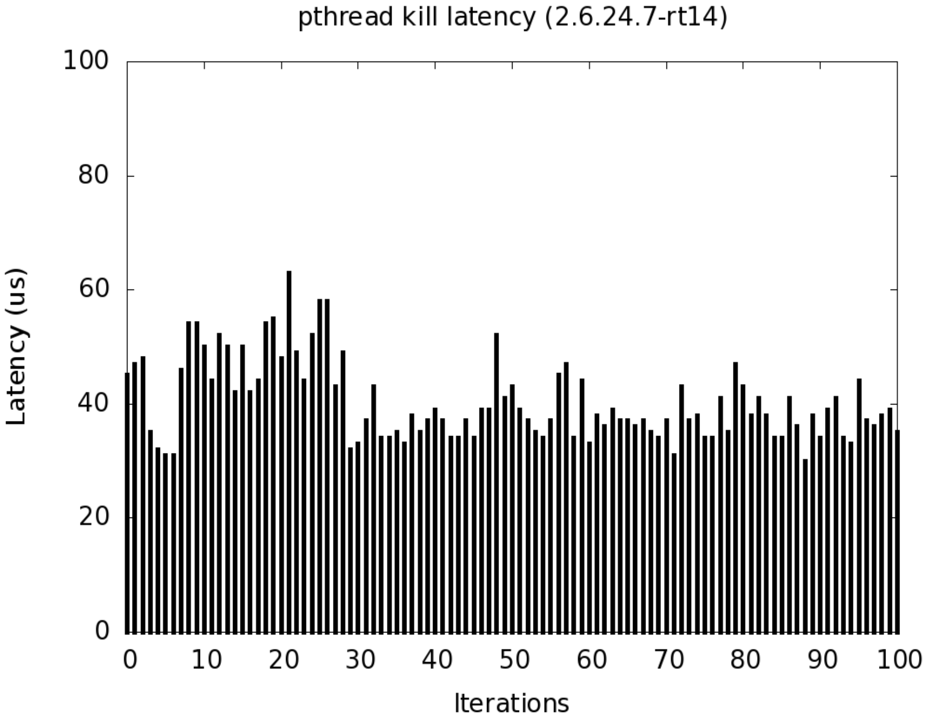

Main Thread
Start
Start Signal Sending thread
Start Signal Recieving thread
Wait for other threads
to finish
End
Signal Sending (SS) Thread
Start
Wait for SR Thread
to Initialize
start=rt_gettime()
Send a Signal to SR thread
Wait until SR thread processes
the signal
Loops Over?
No
Yes
End
Signal Recieving(SR) Thread
Start
SR Thread Initialized
Wait to recieve signal from
SS thread
Signal recieved from SS thread
end = rt_gettime()
Calculate delta = end - begin
Min Delta and Max delta
Signal Processed
Loops Over?
No
Yes
End

Performance vs predictability



Performance vs predictability





How can *you* contribute?

- Use existing test cases in LTP to test the real-time kernel
  - Share test results, learning
- Procedure to report bugs is same as that on mainline kernel
  - Report bugs on linux-rt-users ML as well as LKML
- Contribute to tests in LTP
  - Improve existing test cases. They are far from perfect
  - Write new tests for missing functionality
  - Submit patches to LTP mailing list
- Improve stress tests on real-time kernel
- Help debug latency problems on real-time kernel
  - Latency tracer, Logdev

References

- Real-time patches: http://www.kernel.org/pub/linux/kernel/projects/rt/
- Real-time kernel howto on the RT wiki

  http://rt.wiki.kernel.org/index.php/RT_PREEMPT_HOWTO
- Thomas Gleixner's real-time tests

  http://www.kernel.org/pub/linux/kernel/people/tglx/rt-tests/
- linux-rt-users mailing list:

  http://vger.kernel.org/vger-lists.html#linux-rt-users
- Linux Test Project: http://ltp.sourceforge.net/
- LTP mailing list: https://lists.sourceforge.net/lists/listinfo/ltp-list
- IBM's press release:

  http://www-03.ibm.com/press/us/en/pressrelease/21033.wss

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