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RAS Enhancement Activities for Mission-Critical Linux Systems

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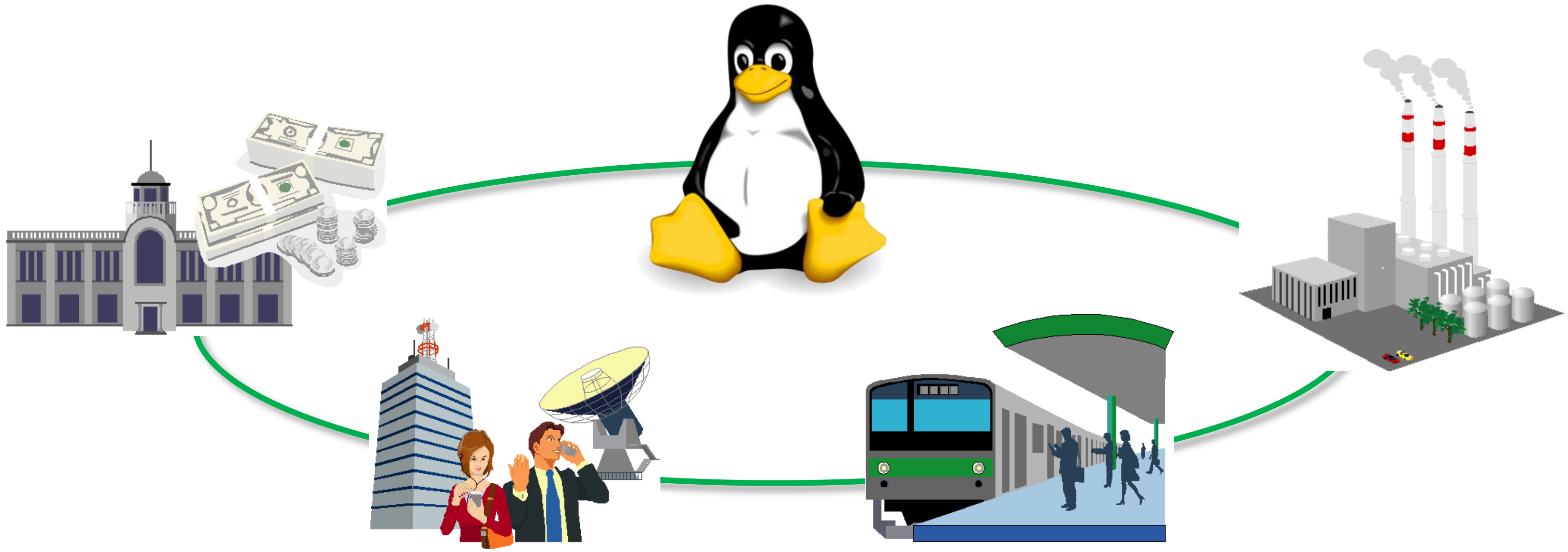
0-1 Mission-Critical Systems



- We apply Linux to mission-critical systems.
  - Banking systems/carrier backend systems/train management systems and more
  - People(consumers/providers) expect stable operation for long-term use.
    - Don't frequently change the system configuration
    - Changing the system introduces the risk for illegal operation.
  - "RAS" requirements are needed.

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0-2 RAS

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- Reliability
  - To identify problems before release
    e.g. Bug fixing, Testing
- Availability
  - To continue the operation even if a problem occurs
    e.g. HA cluster system
- Serviceability
  - To find out the root cause of the problem certainly in order to be able to solve it permanently
    e.g. Logging, Tracing, Memory dump

- Do the systems satisfy these requirements in current upstream kernel?
  - Will talk about 'R' and 'S'

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Activities

1. Fix a deadlock problem on NMI dump（R）
2. Improve data reception latency on serial devices（R）
3. Save names of more processes in ftrace（S）
4. Solve the printk message fragmentation problem（S）

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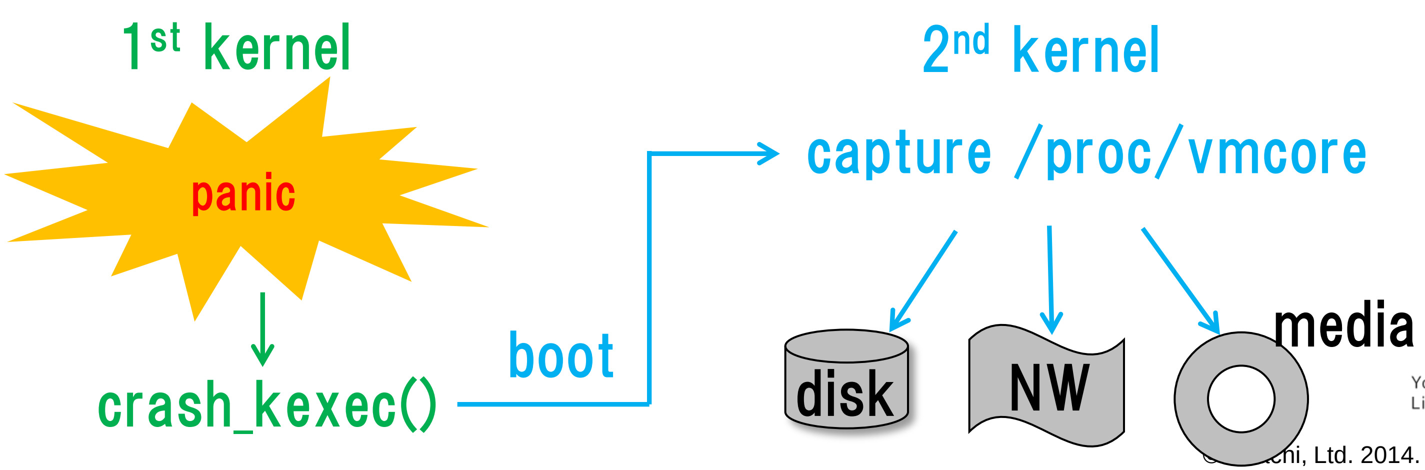
1-1 Memory dump deadlock – introduction

- We get memory dump via Kdump when serious problems, which induce panic or oops, occur.
- Kdump
  - Kernel crash dumping feature based on Kexec
    1. In 1st kernel , kernel panic occurs.
    2. Execute crash_kexec() in panic() and save the memory
    3. Boot 2nd kernel (capture kernel) and copy /proc/vmcore
- When kernel panic occurs via NMI, Kdump operation sometimes stops before booting 2nd kernel.



1-2 Memory dump deadlock - reason

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- The cause of the stop is deadlock on ioapic_lock in NMI context.
  - panic()->crash_kexec()->…->disable_IOAPIC() -> …->ioapic_read_entry()

```
ioapic_read_entry()
{
        raw_spin_lock_irqsave(&ioapic_lock, flags);
        eu.entry = __ioapic_read_entry(apic, pin);
        raw_spin_unlock_irqstore(&ioapic_lock, flags);
}
```

- The scenario is …
  1. Get ioapic_lock for rebalancing IRQ (irq_set_affinity)
  2. Inject NMI while locking ioapic_lock
  3. Panic caused by NMI occurs
  4. Try to execute Kdump
  5. Deadlock in ioapic_read_entry()

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1-3 Memory dump deadlock - fixing

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- Fixed this problem by initializing ioapic_lock before disable_IO_APIC():

```
native_machine_crash_shutdown()
{
            …
#ifdef CONFIG_X86_IO_APIC
+           /* Prevent crash_kexec() from deadlocking on ioapic_lock. */
+           ioapic_zap_locks();
            disable_IO_APIC();
#endif
            …
}
```

- This problem has been already fixed in current kernel.
  (from kernel-3.11)

Activities

1. Fix a deadlock problem on NMI dump (R)
2. **Improve data reception latency on serial devices (R)**
3. Save names of more processes in ftrace (S)
4. Solve the printk message fragmentation problem (S)

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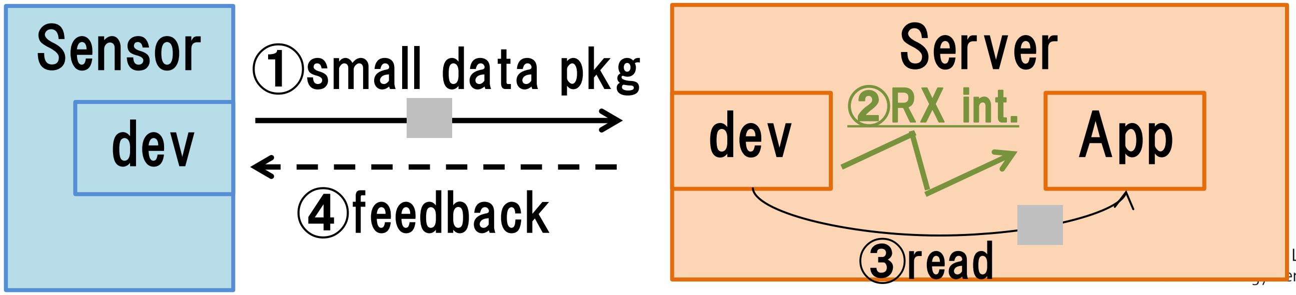
2-1 Serial RX interrupt frequency – introduction

- Serial devices are mainly used not only for embedded systems but also for mission-critical systems.
  - Maintenance
  - Sensor feedback
    - Serial communication has the specialty that it is resistant for noise.
    - For a control system(one of mission-critical systems), long-distance communication is needed.

- If we have a sensor which sends small data packages each time and must control a device based on the sensor feedback, the RX interrupt should be triggered for each packages.



2-2 Serial RX interrupt frequency - problem

- A test requirement of a system was that the serial communication time between send and receive has to be within *3msec*.
- When we measured the time on 16550A, it took *10msec*.
  - It did not change even if the receiver application was operated as a real time application.
  - We analyzed this by using event tracer of ftrace.
  - Hard IRQ of the serial device interrupts once each 10msec, so this is caused by a HW specification or the device driver.

```
                timestamp[sec]                                    ~10msec
<idle>-0 [001] 2689.160668: irq_handler_entry: irq=4 name=serial
<idle>-0 [001] 2689.170653: irq_handler_entry: irq=4 name=serial
<idle>-0 [001] 2689.180634: irq_handler_entry: irq=4 name=serial
<idle>-0 [001] 2689.190620: irq_handler_entry: irq=4 name=serial
```

2-3 Serial RX interrupt frequency - reason

- HW spec of 16550A
  - 16bytes FIFO buffer
  - Flow Control Register(FCR)
    - 2bit register
    - Changeable RX interrupt trigger of 1, 4, 8, or 14 bytes for the FIFO buffer
      (0b00=1byte, 0b01=4bytes, 0b10=8bytes, 0b11=14bytes)
- In Linux, the trigger is hard-coded as 8bytes.

```
[PORT_16550A] = {
        .name = "16550A",
        .fifo_size = 16,
        .tx_loadsz = 16,
        .fcr = UART_FCR_ENABLE_FIFO | UART_FCR_R_TRIG_10,
        .flags = UART_CAP_FIFO,
},
```

8bytes trigger

  - For 9600baud, an interrupt per 10msec is consistent.

(start + octet + stop * 2 + parity) / 9600(baud) = 1/800 (sec/byte) = 1.25(msec/byte)

start: 1bit, octet: 8bit, stop: 1bit * 2, parity: 1bit

1.25(msec/byte) * 8(byte) = **10msec**

2-4 Serial RX interrupt frequency - temporary fixing

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- Changed FCR as a test

```
[PORT_16550A] = {
        .name = "16550A",
        .fifo_size = 16,
        .tx_loadsz = 16,
        .fcr = UART_FCR_ENABLE_FIFO | UART_FCR_R_TRIG_00,
        .flags = UART_CAP_FIFO,
},
```

1byte trigger

- Result
  - The interrupt frequency is once each 1.25msec.

timestamp[sec]

1.25msec

```
<idle>-0 [001] 3216.436959: irq_handler_entry: irq=4 name=serial
<idle>-0 [001] 3216.438209: irq_handler_entry: irq=4 name=serial
<idle>-0 [001] 3216.439454: irq_handler_entry: irq=4 name=serial
<idle>-0 [001] 3216.440706: irq_handler_entry: irq=4 name=serial
```

- We need a configurable RX interrupt trigger.

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2-5 Serial RX interrupt frequency – tunable patch

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- Added new I/F to the serial driver
  - Tunable RX interrupt trigger frequency
    - High frequency(1byte trigger) → low latency
    - Low frequency(14byte trigger) → low CPU overhead
  - Usability problems of 1st/2nd patch:
    - ✓ Using ioctl(2) (c.f. using echo command is better)
    - ✓ Interrupt frequency can be changed only **after** opening serial fd
    - ✓ Cannot read FCR value (FCR is a write-only register)
  - Change the ioctl(2) to sysfs I/F after discussion in a Linux community
    - Set the interrupt trigger byte (if val is invalid, nearest lower val is set.)

```
# echo  1  > rx_trig_byte                    /* 1byte trigger*/
```

    - User can read/write the trigger any time.
      - The driver keeps FCR value if user changes interrupt trigger.

- This new feature will be able to be used from kernel-3.17.

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Activities

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4. Solve the printk message fragmentation problem (S)

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3-1 PID-process name table in ftrace - introduction

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- ftrace is in-kernel tracer for debugging and analyzing problems.
- ftrace records PIDs and process names in order to specify process context of an operation.
  - If process name is indicated in a trace result, a user can understand who executed the program by doing grep with the process name.

- In the trace file, process names are sometimes output as <…>:

name-PID

```
<...>-2625 [002] .... 209630.888186: sys_write(fd: 8, buf: 7fd0ef836968, count: 8)
<...>-2625 [002] .... 209630.888186: sys_enter: NR 1 (8, 7fd0ef836968, 8, 20, 0, a41)
<...>-2625 [002] .... 209630.888186: kfree: call_site=ffffffff810e410c ptr= (null)
<...>-2625 [002] .... 209630.888187: sys_write -> 0x8
```

3-2 PID-process name table in ftrace – reason

- ftrace has saved_cmdlines file storing the PID-process name mapping table.
  - It stores the list of **128** processes that hit a tracepoint.

```
# cat saved_cmdlines
13 ksoftirqd/1
10009 python
1718 gnome-panel
500 jbd2/sda5-8
…
```

  - If the number of processes that hit a tracepoint exceeds 128, the oldest process name is overwritten.
  - How does ftrace manage this table?

3-3 PID-process name table in ftrace - current

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- Read trace file (get process name from PID)

```
struct trace_entry{
…
            int pid;
}
```

1. Get a pid member in trace_entry structure of each trace event

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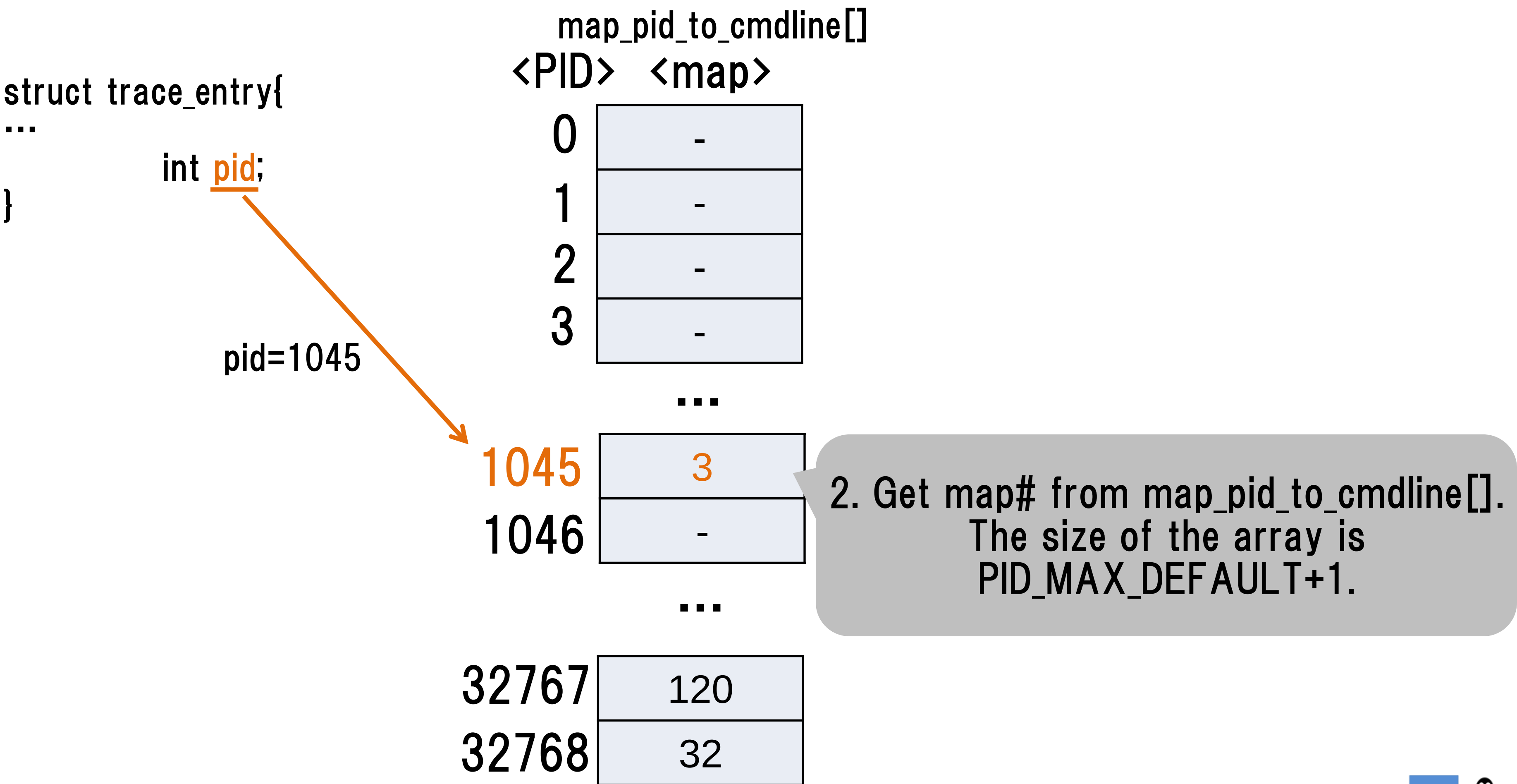
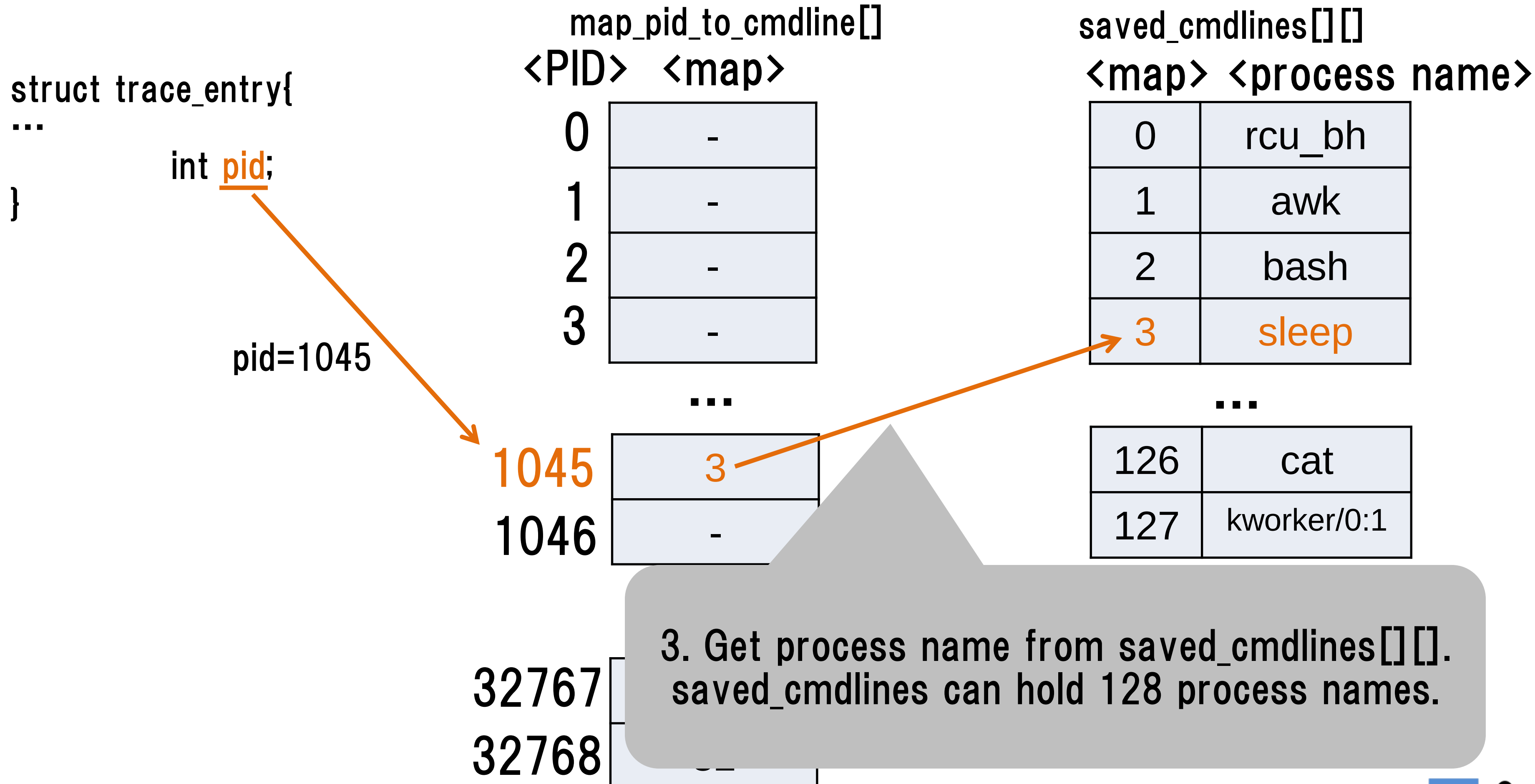
3-4 PID-process name table in ftrace - current

- Read trace file (get process name from PID)



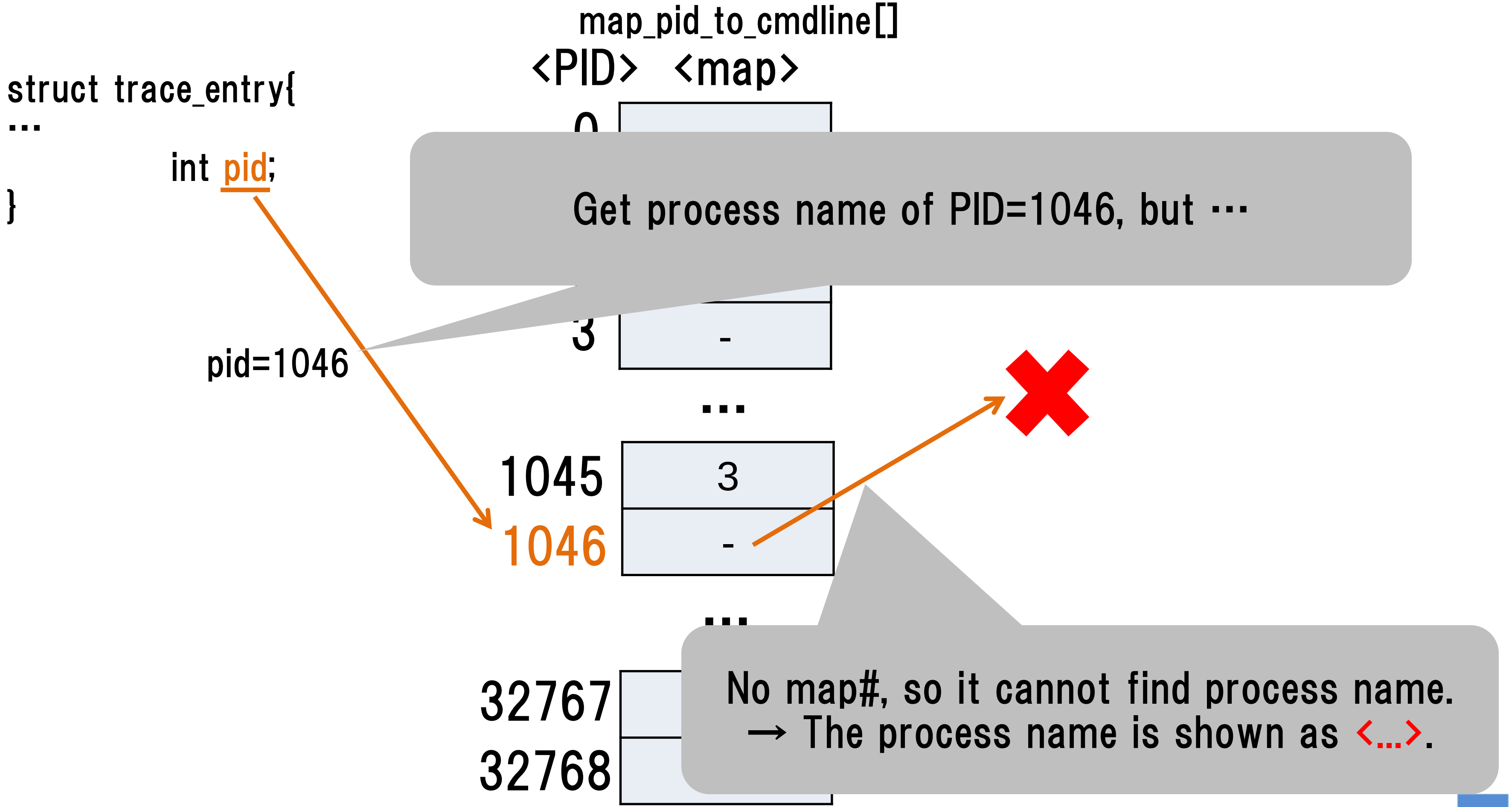
3-5 PID-process name table in ftrace - current

- Read trace file (get process name from PID)



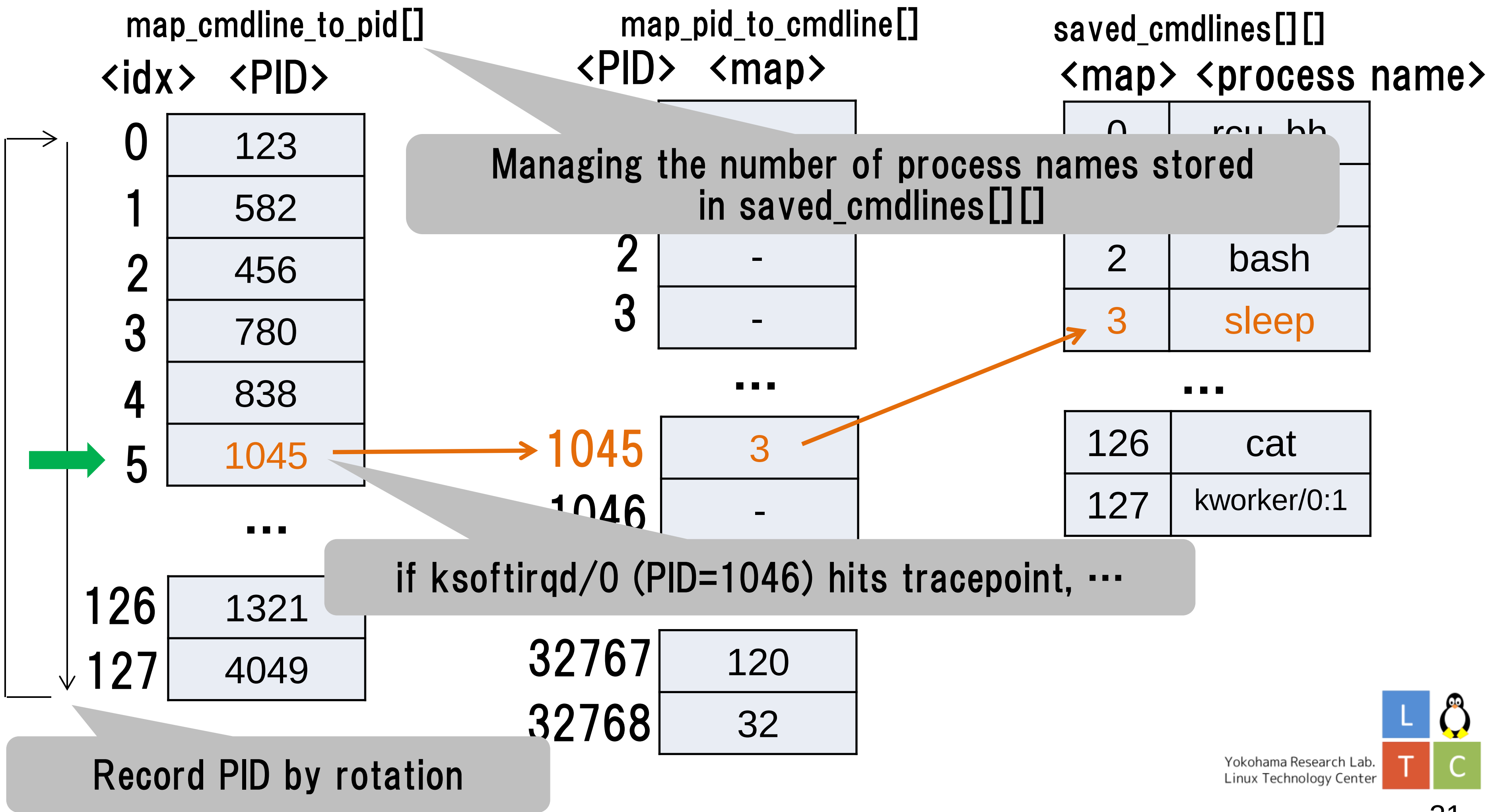
3-6 PID-process name table in ftrace – current

- Read trace file (get process name from PID)



3-7 PID-process name table in ftrace – current

- Store map information in saved_cmdlines



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3-8 PID-process name table in ftrace – current

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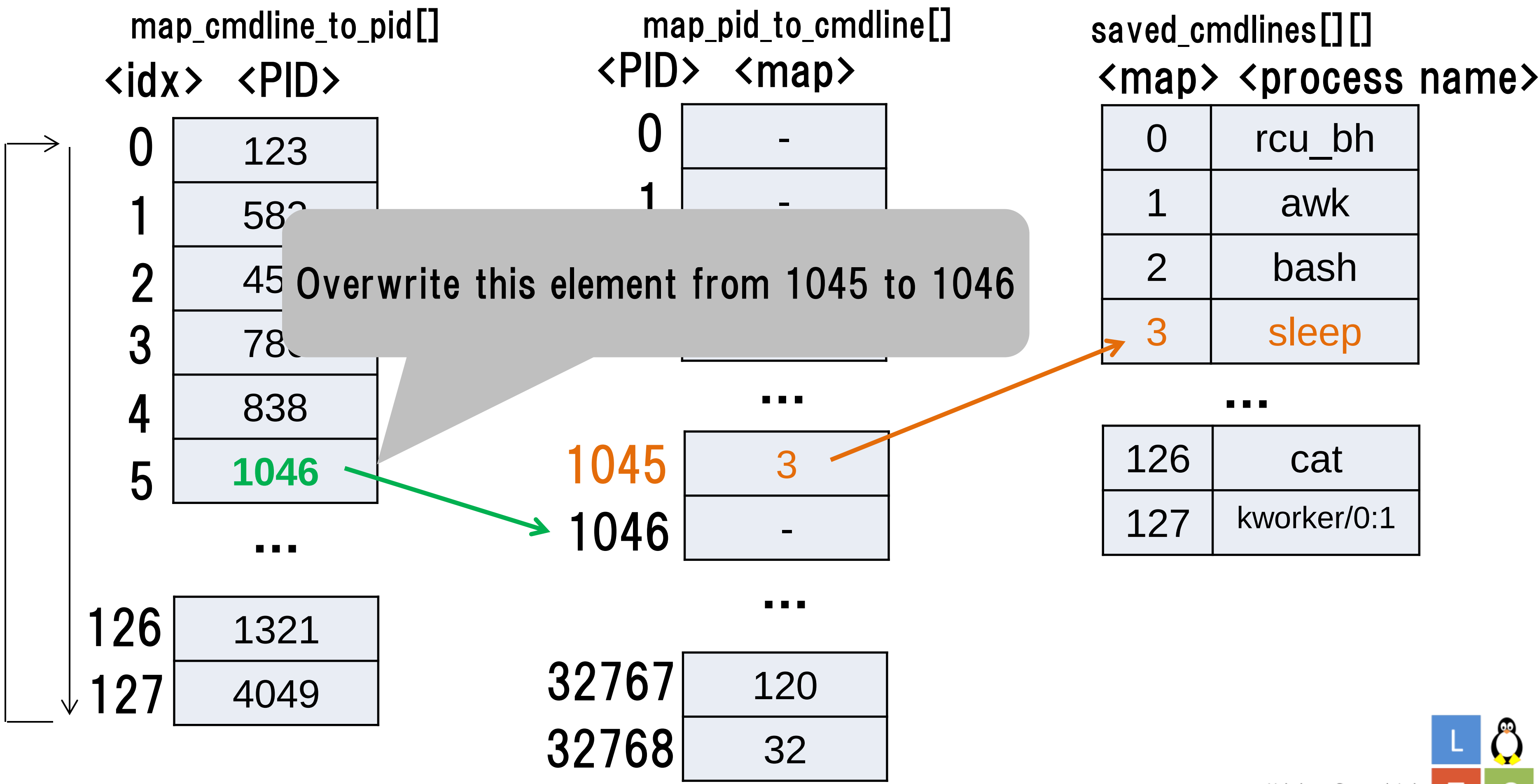
- Store map information in saved_cmdlines



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3-9 PID-process name table in ftrace - current

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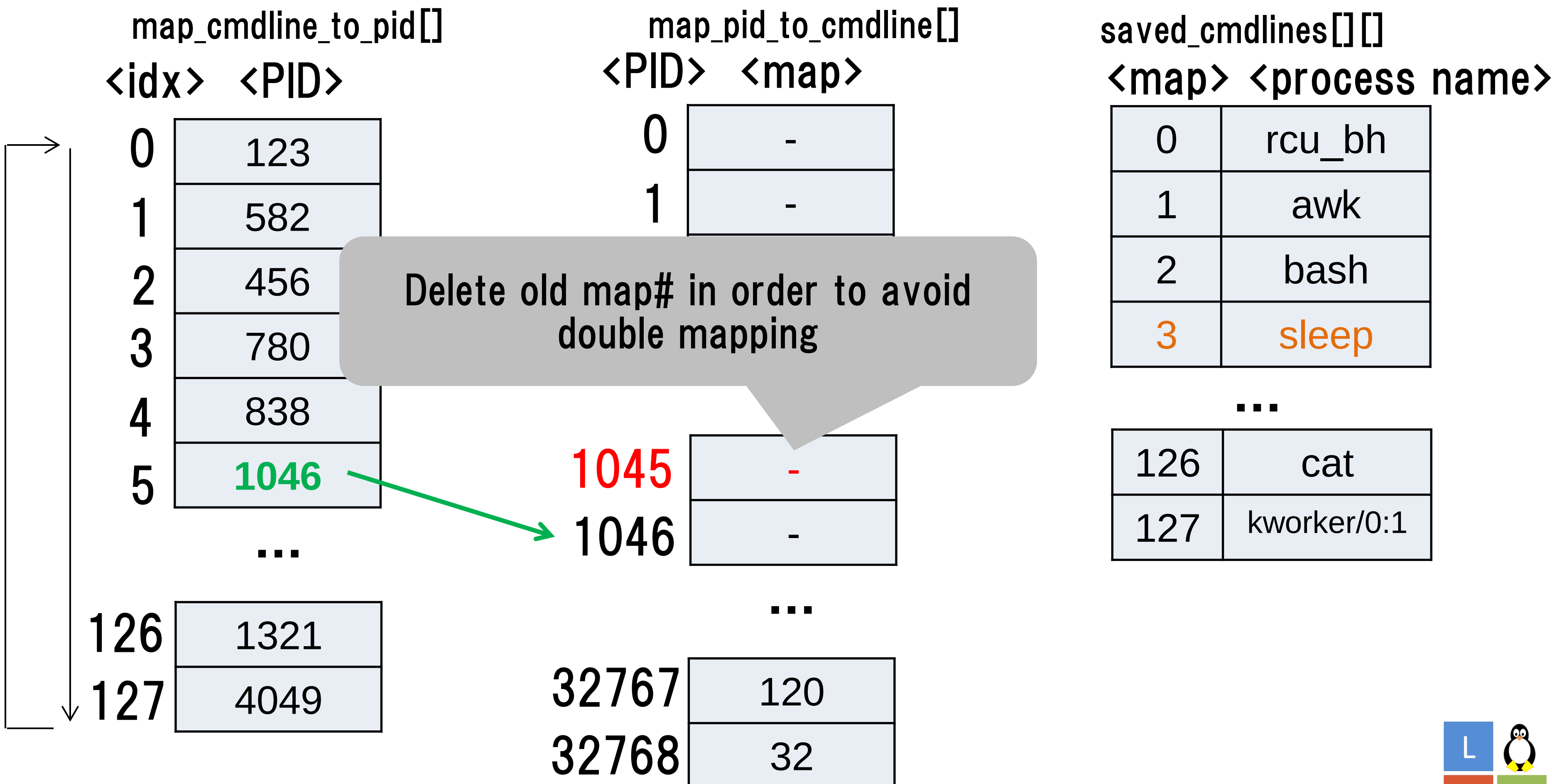
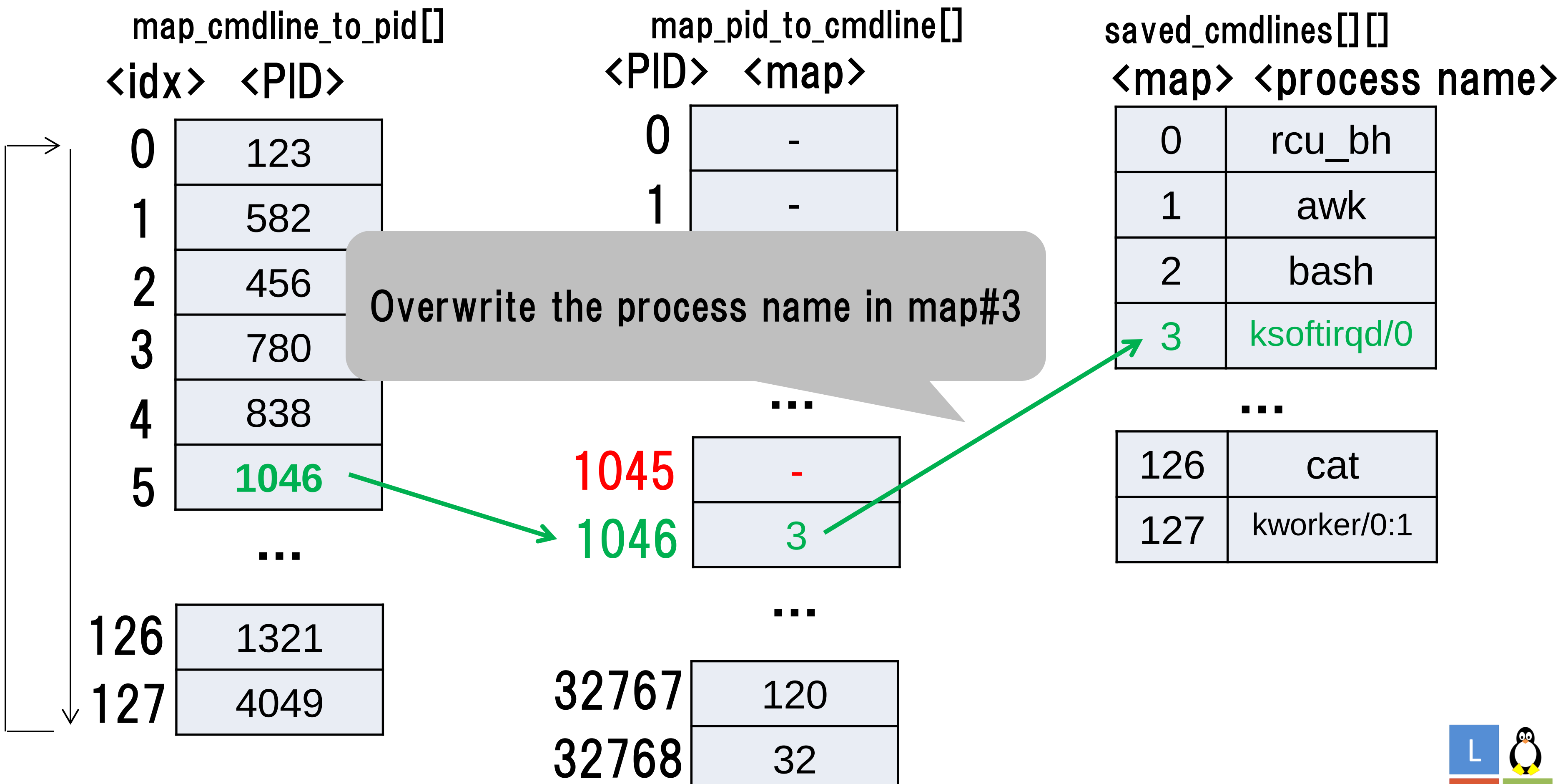
- Store map information in saved_cmdlines



3-10 PID-process name table in ftrace - current

- Store map information in saved_cmdlines



3-10 PID-process name table in ftrace - current

- Store map information in saved_cmdlines

map_cmdline_to_pid[]

<idx>	<PID>
0	123
1	582
2	456
3	780
4	838
5	1046
...	...
126	1321
127	4049

map_pid_to_cmdline[]

<PID>	<map>
0	-
1	-
2	-
3	-
...	...
1045	-
1046	3
...	...

saved_cmdlines[][]

<map>	<process name>
0	rcu_bh
1	awk
2	bash
3	ksoftirqd/0
...	...
126	cat
127	kworker/0:1

Develop tunable I/F

3-11 PID-process name table in ftrace – tunable patch

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- We added the changeable I/F 'saved_cmdlines_size' to expand the max number of saved process names.
  - Read/write saved_cmdlines_size
    - For write, all saved_cmdlines information are cleared.
  - Max size: PID_MAX_DEFAULT(32768)
    - If we set 32768, all process names can be stored.

```
# cat saved_cmdlines_size
  128      /* defalut value*/

// Switch to new saved_cmdlines buffers
# echo  1024  > saved_cmdlines_size

# cat saved_cmdlines_size
  1024    /* Store 1024 process names */
```

- This new feature can be used from kernel-3.16.

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Activities

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4. **Solve the printk message fragmentation problem（S）**

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4-1 printk fragmentation problem – introduction

- printk message outputs error logging or debugging information in kernel.
  - We handle automatically printk messages in user space in order to detect that the system has became unstable.
  - We want the kernel to output printk as expected.
  - printk messages are sometimes **mixed with similar messages**.
    - It is difficult to automatically handle an event from mixed messages.
- **mixed** kernel error messages in SCSI layer

Which process does this message belong to?

```
[110781.736171] sd 2:0:0:0: [sdb]
[110781.736170] sd 3:0:0:0: [sdc] Unhandled sense code
[110781.736172] sd 3:0:0:0: [sdc]
[110781.736175] Result: hostbyte=DID_OK driverbyte=DRIVER_SENSE
[110781.736177] sd 3:0:0:0: [sdc]
[110781.736178] Sense Key : Medium Error [current]
[110781.736187] Sense Key : Recovered Error
[110781.736189] [current]
```

4-2 printk fragmentation problem – introduction

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- Mixed messages can occur when multiple printk() are executed at the same time.

<CPU0>

```
printk("sd 2:0:0:0: [sdb]¥n");

printk("Sense Key : Medium Error¥n");
```

break into

<CPU1>

```
printk("sd 3:0:0:0: [sdc]¥n");

printk("Sense Key :
        Recovered Error¥n");
```

```
[110781.736171] sd 2:0:0:0: [sdb]
[110781.736177] sd 3:0:0:0: [sdc]
[110781.736178] Sense Key : Medium Error [current]
[110781.736187] Sense Key : Recovered Error
```

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4-3 printk fragmentation problem - Solution

- How to solve
  1. Store all continuous messages in local buffer as temporary, and execute printk
     - This idea is rejected by SCSI community.
       – https://lkml.org/lkml/2014/5/20/742
     - To store continuous messages, we need big buffer.
     - This can induce buffer overflow for deep nesting.
     - Of course, memory allocation is invalid.
  2. Add information necessary to merge all fragmented printk messages
     - This idea is also rejected.
       – https://lkml.org/lkml/2014/5/19/285
     - The community said this problem should be fixed for each subsystem.
  3. Use traceevents of ftrace to output atomically only for SCSI layer
     - This is not for all printk messages.

4-4 printk fragmentation problem - Key idea

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- traceevents can be atomically stored to ring buffer.
  - Kernel preemption is disabled.
  - A ring buffer a CPU

  ➔ We don't need to concern about mixed traceevent.

- Use trace_seq_printf() for traceevent
  - Add event information using not only macros but functions
  - scsi-trace.c has already used this, but it does not have error messages.

  ➔ We added new three traceevents for SCSI error messages.

      - scsi_show_result: output driverbyte, hostbyte
      - scsi_print_sense: output sense key with asc and ascq
      - scsi_print_command: output SCSI command

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4-5 printk fragmentation problem – Result

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- A result of dmesg in current kernel

```
[ 6379.535874] sd 2:0:0:0: [sda]
[ 6379.538376] Result: hostbyte=DID_OK driverbyte=DRIVER_SENSE
[ 6379.542083] sd 2:0:0:0: [sda]
[ 6379.544556] Sense Key : Medium Error [current]
[ 6379.549988] sd 2:0:0:0: [sda]
[ 6379.552408] Add. Sense: Unrecovered read error
[ 6379.574040] sd 3:0:0:0: [sdb]
[ 6379.576576] Result: hostbyte=DID_OK driverbyte=DRIVER_SENSE
[ 6379.580299] sd 3:0:0:0: [sdb]
[ 6379.582727] Sense Key : Medium Error [current]
```

- A result of ftrace with our patch

```
scsi_show_result: …[sda] result=(driver=DRIVER_SENSE host=DID_OK)   } atomic
scsi_print_sense: …[sda] Sense Key (Medium Error [current]) \        } atomic
                         Add. Sense (Unrecovered read error)
scsi_show_result: …[sdb] result=(driver=DRIVER_SENSE host=DID_OK)
scsi_print_sense: …[sdb] Sense Key (Medium Error [current]) \
                         Add. Sense (Unrecovered read error)
```

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4-6 printk fragmentation problem - current status

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- Current patch
  - https://lkml.org/lkml/2014/8/8/221
  - Any comments are welcome!

5 Summary

- We are doing community activities for realizing Linux which satisfies RAS requirements for mission-critical systems.
  - Bug fixing (avoid the deadlock on Kdump)
  - Add features (tunable serial RX trigger, tunable saved_cmdlines, and SCSI traceevents)
  - These activities can be used for not only mission-critical systems but also other systems. For example, fragmented printk is a big problem for a support division of system integrators.

Any questions?

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