# printk() - The most useful tool

Now showing its age

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# What is printk()?

- Basically it is the printf() of the kernel
  - Writes text to the console (VGA screen, serial UART, network, etc)
- Does not use libc! (all code is implemented in the kernel)
- Used to display information (devices coming on line)
- Used to show stack  traces (Warnings, things going wrong)
- Used to show panics (when all else fails)

# History of printk() - Going down memory lane

## Linux v1.0

```
asmlinkage int printk(const char *fmt, ...)
{
        va_list args;
        int i;
        char *msg, *p, *buf_end;
        static char msg_level = -1;
        long flags;

        save_flags(flags);
        cli();
        va_start(args, fmt);
        i = vsprintf(buf + 3, fmt, args); /* hopefully i < sizeof(buf)-4 */
        buf_end = buf + 3 + i;
        va_end(args);
        for (p = buf + 3; p < buf_end; p++) {
                msg = p;
                if (msg_level < 0) {
                        if (
                                p[0] != '<' ||
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                        ) {
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                                log_start++;
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                        if (*p == '\n')
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## printk() basically does the same thing today

- Has log levels
- Has a fixed size ring buffer
- Sends to a console
- Wakes up a user space task (syslogd) if one is waiting

# Log Levels (back then through to today)

- Set how much verbosity you want to print
  - 8 different printk levels
    - KERN_EMERG “0”
    - KERN_ALERT “1”
    - KERN_CRIT “2”
    - KERN_ERR “3”
    - KERN_WARNING “4”
    - KERN_NOTICE “5”
    - KERN_INFO “6”
    - KERN_DEBUG “7”
  - Default level to print is < 7  (can be changed by config option)
    - Only levels less than the number will print
    - Lowest log level is 1 (EMERG is always printed)
  - Can set how much to print from kernel command line as well
  - Log levels are “prefixed” to the format string of the printk
    - printk(KERN_WARNING “Something bad happened\n”);
    - (old way) printk(“<4>” “Something bad happened\n”);
    - (new way) printk(“\001” “4” “Something bad happened\n”);

# The printk ring buffer

- Single fixed size ring buffer
- Size can be changed by “log_buf_len” on kernel command line
- No longer a simple buffer
  - Made up of “messages”
  - Messages contain timestamp, loglevel, other meta data, and the print output
- Protected by a spinlock (must not be called from NMI)
  - Can happen but it can deadlock if it happens during a printk
  - There’s a new printk_safe() mode that can be used (explained later)

# Sending to the console

- Needs to go over some output medium
  - The monitor
  - Frame Buffers
  - UART / Serial console
  - Network console
  - Braille console
- Uses a different locking mechanism
  - The console_lock
  - It is not a spinlock, but a weird semaphore (mutex)
  - The owner of the lock will print all remaining data in the ring buffer
  - The owner of the lock will print new data that comes in while held
- Consoles can have their own lock too!

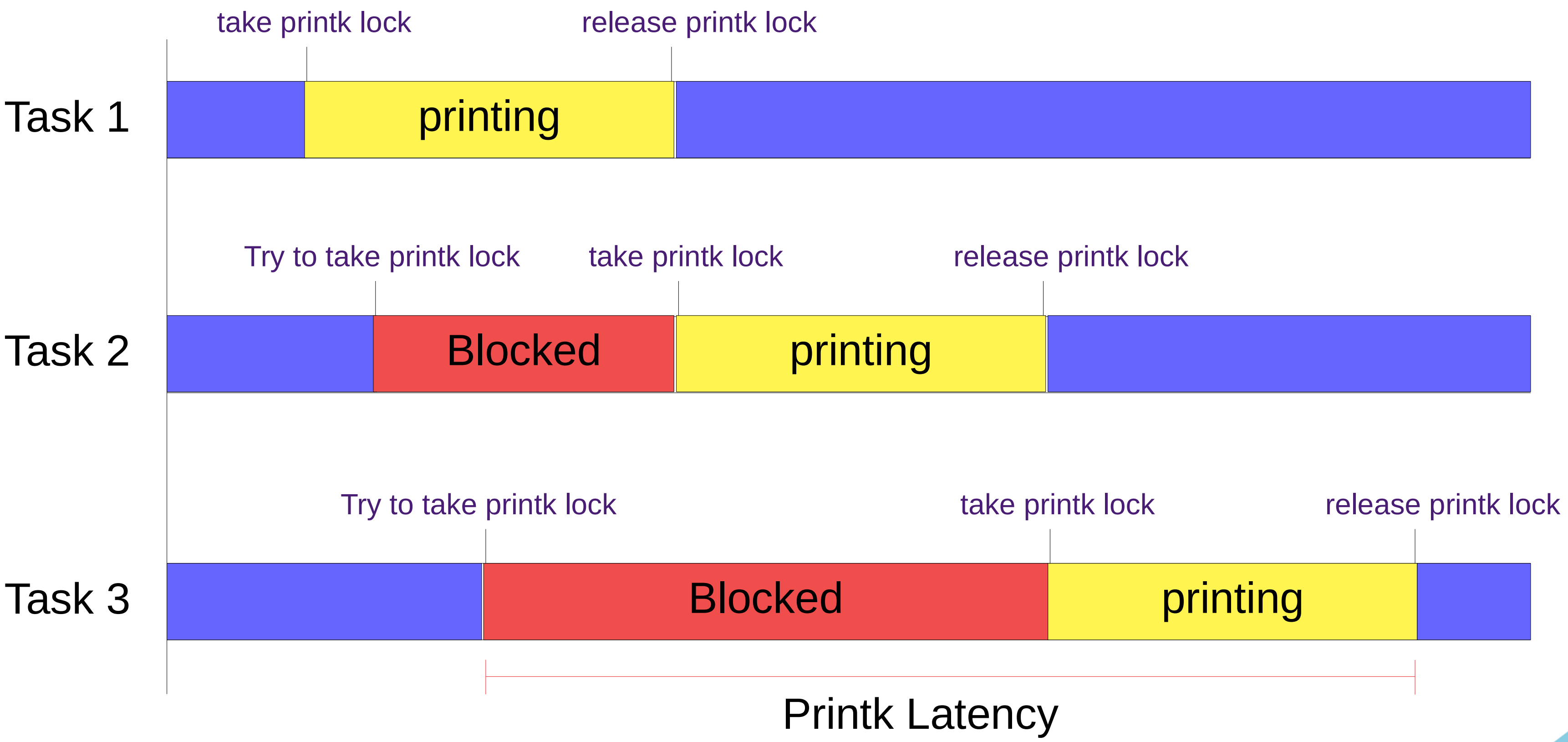
# syslogd (or other task waiting to read dmesg)

- If a task is waiting to record kernel messages it needs to be woken up
- Something like syslogd (or journald)
- When a print occurs a wake up must happen
- This task writes to the journal or syslog (/var/log/syslog)

# Then multiprocessors happened

- In January 1998 - Linux 2.1.80
  - spin_lock was introduced to printk()
- All prints were serialized
  - If two CPUs called printk at the same time
  - The second one has to wait for the first one to finish
  - This does not scale
  - All CPUs can be halted waiting its turn to print
- Remember, printk can be very slow!

# Sharing the printk lock



# The console_lock semaphore

- In September of 2001 - Linux 2.4.10
  - The console_lock semaphore was added
  - A logbuf_lock spinlock was added
- The logbuf_lock spinlock
  - Used to add data to the ring buffer
  - Then perform a trylock on the console_lock semaphore
  - Then release the logbuf_lock spinlock
- The first holder would do all the printing
  - Tasks would grab logbuf_lock, write into log
  - Try to take the console_lock, if it fails, then just exit printk()
    - Someone else will finish
  - The console_lock owner would finish all the printing

# The console_lock semaphore

- This is where the magic happens to get to the consoles
- printk() tries to do a console_trylock()
  - If it fails, it just exits (someone else is doing the print)
  - If it gets the lock, others will not print

```
if (console_trylock())
    console_unlock();
```

- console_unlock() is where the real work happens

# console_unlock()

```
void console_unlock(void)
{
        unsigned long flags;
        bool wake_klogd = false;
        bool do_cond_resched, retry;

        if (console_suspended) {
                up_console_sem();
                return;
        }
        do_cond_resched = console_may_schedule;
again:
        console_may_schedule = 0;
        if (!can_use_console()) {
                console_locked = 0;
                up_console_sem();
                return;
        }
        for (;;) {
                /* Print from ring buffer into consoles */
                if (/* printed something */)
                        wake_klogd = true;
                if (do_cond_resched)
                        cond_resched();
        }
        console_locked = 0;
        if (unlikely(exclusive_console))
                exclusive_console = NULL;
        raw_spin_unlock(&logbuf_lock);
        up_console_sem();
        raw_spin_lock(&logbuf_lock);
        retry = console_seq != log_next_seq;
        raw_spin_unlock(&logbuf_lock);
        printk_safe_exit_irqrestore(flags);
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        if (wake_klogd)
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        raw_spin_unlock(&logbuf_lock);
        up_console_sem();
        raw_spin_lock(&logbuf_lock);
        retry = console_seq != log_next_seq;
        raw_spin_unlock(&logbuf_lock);
        printk_safe_exit_irqrestore(flags);
        if (retry && console_trylock())
                goto again;
        if (wake_klogd)
                wake_up_klogd();
}
```

# console_unlock()

```
void console_unlock(void)
{
        unsigned long flags;
        bool wake_klogd = false;
        bool do_cond_resched, retry;

        if (console_suspended) {
                up_console_sem();
                return;
        }
        do_cond_resched = console_may_schedule;
again:
        console_may_schedule = 0;
        if (!can_use_console()) {
                console_locked = 0;
                up_console_sem();
                return;
        }
        for (;;) {
                /* Print from ring buffer into consoles */
                if (/* printed something */)
                        wake_klogd = true;
                if (do_cond_resched)
                        cond_resched();
        }
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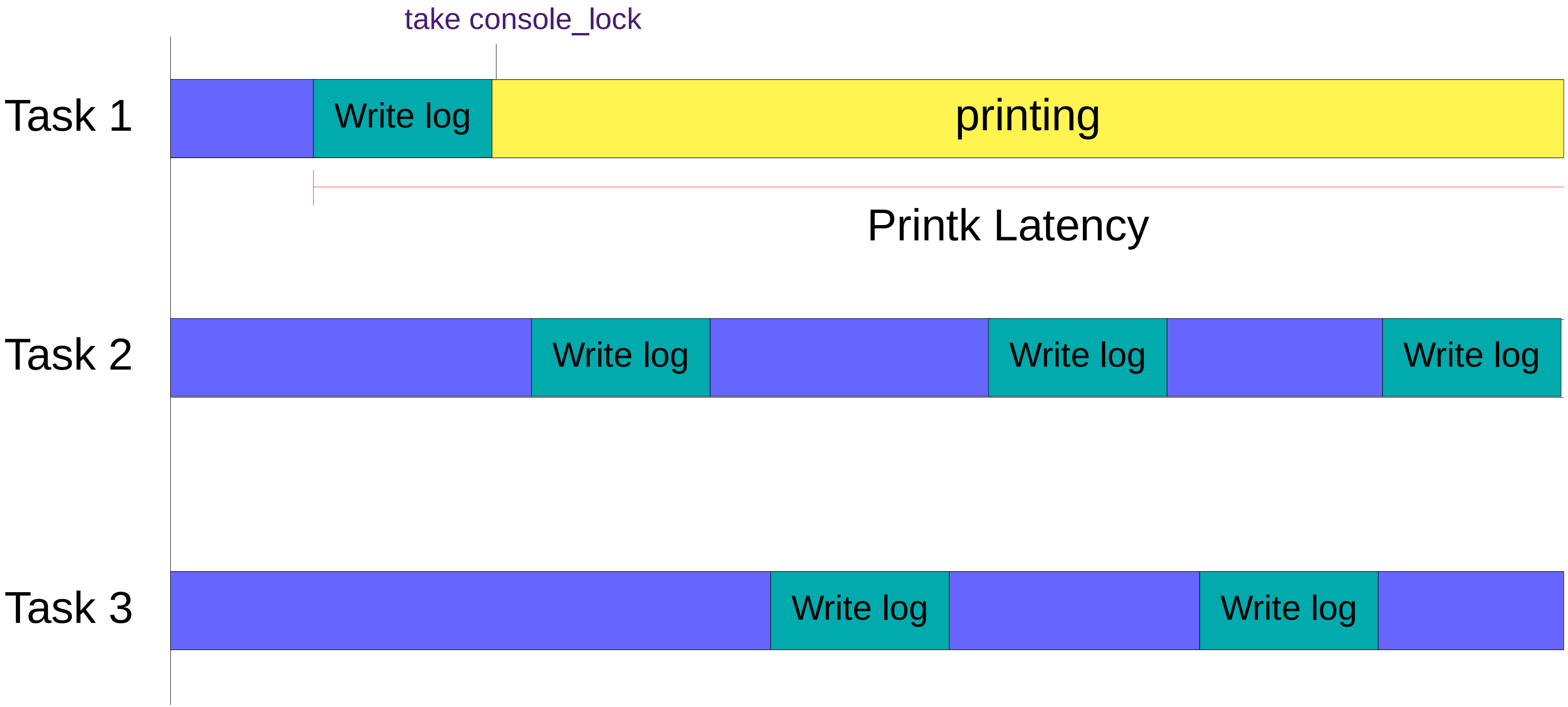
}
```

# the console_lock



# exclusive_console (Added March 2011)

- console=tty1 console=ttyMFD2 console=ttyS0 earlyprintk=mrst
- Each console registered would cause a reprint of the logbuf on other consoles
- The console “start” location would get reset when new console is registered
  - When sending to all consoles would send repeated data
- exclusive_console set to registered console
  - Only this console will do the print on the next console_unlock()
  - (Note, new printks, wont go over other consoles here!)
- printk message rewrite (for journald) (May 2012)
  - caused excluse_console to be obsolete
  - why is it still there?

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- printk message rewrite (for journald) (May 2012)
  - caused excluse_console to be obsolete
  - why is it still there?
  - Nobody noticed it was obsolete
    - I noticed this while reviewing these slides (today!)

# Printk and the scheduler

- We want printk to work most everywhere
- Now printk has locks
  - This is an issue with NMIs
- Printk now takes a semaphore
  - There are callers of the console_lock that blocks (does not use trylock)
  - Releasing the console lock may require to do a wake up
  - A wake up grabs the scheduler runqueue locks
  - A printk may happen in the scheduler!

```
schedule() {
  raw_spin_lock_irq(&rq->lock);
    printk() {
      console_unlock() {
        up() {
          wake_up_process() {
            raw_spin_lock_irq(&rq->lock);
```

**DEADLOCK**

# Printk and the scheduler

- originally called printk_sched()
  - now called printk_deferred()
- Originally wrote to separate per_cpu buffers
  - now writes directly into the printk ring buffer (taking the logbuf_lock)
- Originally waited for the next jiffy tick to trigger to print
  - now uses irq_work to do the print (on some archs, that is still the jiffy tick)
- Still can not do output while holding a scheduler runqueue lock

# NMI - Non-Maskable Interrupt

- Printk can happen in an NMI
- NMI watchdog can detect a lockup (deadlock)
- echo ‘l’ > /proc/sysrq-trigger
  - Dumps a back trace of all active CPUs (via NMI)
- Remember, printk takes a spinlock
  - If NMI tries to do a printk when it interrupted a printk
  - Can cause a deadlock to the system
- For years it was mostly a crap shoot that it would work

# BUST Spinlocks!

- From v2.4 through to 4.11
- Also called “zap_locks()”
- Sets oops_in_progress = 1
  - Lets the system know it is dieing
  - Try to get output to the screen as best as possible

```
static void zap_locks(void)
{
        static unsigned long oops_timestamp;

        if (time_after_eq(jiffies, oops_timestamp) &&
            !time_after(jiffies, oops_timestamp + 30 * HZ))
                return;

        oops_timestamp = jiffies;

        debug_locks_off();
        /* If a crash is occurring, make sure we can't deadlock */
        raw_spin_lock_init(&logbuf_lock);
        /* And make sure that we print immediately */
        sema_init(&console_sem, 1);
}
```

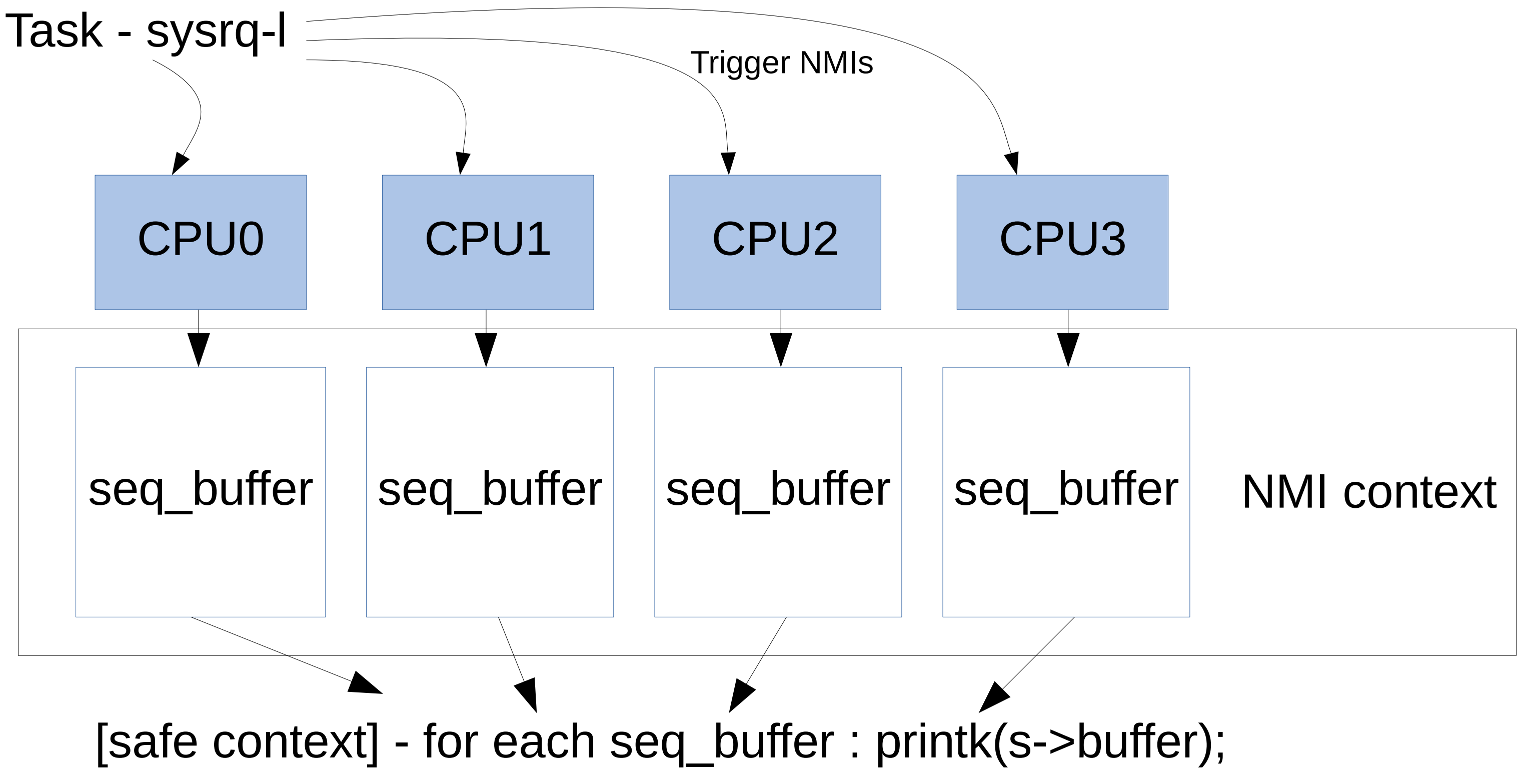
# Introduction of seq_buffer (v3.19)

- Used by the tracing facility
- Allows to pass a buffer descriptor between functions
- Can use any allocated buffer
- Can be used by NMI printk
  - A buffer per CPU
  - NMI printk writes to the seq_buffer and not to console
  - A “safe” place reads NMI seq_buffers and prints to console
  - Unfortunately, if system dies no output will come from NMIs
  - Used by sysrq-’l’ - stable output (not for system crashes)
- Printk now is determined by per CPU what it will do

```
static int nmi_vprintk(const char *fmt, va_list args)
{
     struct nmi_seq_buf *s = this_cpu_ptr(&nmi_print_seq);
     unsigned int len = seq_buf_used(&s->seq);

     seq_buf_vprintf(&s->seq, fmt, args);
     return seq_buf_used(&s->seq) - len;
}
```

# seq_buffers and NMIs



Task - sysrq-l

Trigger NMIs

CPU0

CPU1

CPU2

CPU3

seq_buffer

seq_buffer

seq_buffer

seq_buffer

NMI context

[safe context] - for each seq_buffer : printk(s->buffer);

# What about other NMI code?

- The seq_buffer method worked for sysrq-t for simple back traces
- What about panics
- What about WARN() calls?
- None of these are safe
- Need another Method

# nmi_vprintk (v4.7)

- printk_nmi_enter/exit() functions
  - Called when an NMI starts and exits
  - Switches printk to use vprintk_nmi()
- Flushes the nmi buffer via a irq_work
  - When interrupts are enabled again, the print will happen
  - Unfortunately, this makes NMI hard lockup detector no longer work
    - works if not all CPUs are locked up hard (infinite loop with interrupts disabled)

```
avoid printk_nmi_enter(void)
{
    this_cpu_write(printk_func, vprintk_nmi);
}

void printk_nmi_exit(void)
{
    this_cpu_write(printk_func, vprintk_default);
}
```

# Printk within a Printk?

- printk() does a console_unlock which wakes up pending tasks
- the scheduler code can warn (scheduling while atomic, etc)
- What happens if the scheduler does a printk when waking up printk?

```
printk() {
  console_unlock() {
    up(sem) {
      raw_spin_lock(sem->lock);
      wake_up_process(sem->waiter->task) {
        WARN() {
          printk() {
            console_trylock() {
              down_trylock(sem) {
                raw_spin_lock(sem->lock)
```

**DEADLOCK**

# lockdep

- Lock validator in Linux
- Would catch possible deadlock situations
  - lock A taken before lock B where someplace else takes lock B first
- When it detects a possible deadlock, it would print the problem
- printk() has three types of locks
  - logbuf_lock
  - console_lock
  - the consoles have their own locks
- If printk() causes a deadlock, and lockdep reports it
  - It will cause its own deadlock!

# printk_safe (v4.11)

- Similar to the NMI printk
- Manually mark areas in printk that can recurse
- Add a counter
  - incremented before “unsafe” regions of printk
  - decremented after “unsafe” regions of printk
  - When > 0, it uses a separate buffer
  - Uses irq_work to flush out the buffer

# printk_safe (v4.11)

- printk_func() no longer a function pointer, but a multiplexer
- Uses per-CPU context flags and counter to know what function to use
  - Whenever the logbuf spinlock is held, increment the counter, decrement when released
  - Increment the counter when releasing the console_lock
- Knows if NMI can write to the printk ring buffer directly
  - If the per-CPU context counter is zero, the current CPU does not have the logbuf lock
  - If the per-CPU context counter is not zero, check if the logbuf_lock is held

```
void printk_nmi_enter(void)
{
        if ((this_cpu_read(printk_context) & PRINTK_SAFE_CONTEXT_MASK) &&
            raw_spin_is_locked(&logbuf_lock)) {
                this_cpu_or(printk_context, PRINTK_NMI_CONTEXT_MASK);
        } else {
                this_cpu_or(printk_context, PRINTK_NMI_DEFERRED_CONTEXT_MASK);
        }
}

void printk_nmi_exit(void)
{
        this_cpu_and(printk_context,
                     ~(PRINTK_NMI_CONTEXT_MASK |
                       PRINTK_NMI_DEFERRED_CONTEXT_MASK));
}
```

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```
void printk_nmi_enter(void)
{
        If printk_safe is active (CONTEXT_MASK > 0) and logbuf_lock is locked
                then use the vprintk_nmi() function
        else
                Use the vprintk_deferred() function

}
```

# Choosing what printk() should do

```
 int vprintk_func(const char *fmt, va_list args)
{
        /* Use extra buffer in NMI when logbuf_lock is taken or in safe mode. */
        if (this_cpu_read(printk_context) & PRINTK_NMI_CONTEXT_MASK)
                return vprintk_nmi(fmt, args);

        /* Use extra buffer to prevent a recursion deadlock in safe mode. */
        if (this_cpu_read(printk_context) & PRINTK_SAFE_CONTEXT_MASK)
                return vprintk_safe(fmt, args);

        /*
         * Use the main logbuf when logbuf_lock is available in NMI.
         * But avoid calling console drivers that might have their own locks.
         */
        if (this_cpu_read(printk_context) & PRINTK_NMI_DEFERRED_CONTEXT_MASK)
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        /* No obstacles. */
        return vprintk_default(fmt, args);
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}
```

# In the mean time...

- systemd can write to the printk ring buffer
  - To store prints between init ramdisk and normal boot
- The interface is via /proc/kmsg
- The limited size of the ring buffer can overflow
  - due to user space writes
  - Loss of important kernel information can result

# early_printk

- Printk doesn’t print to consoles until consoles are set up
  - happens relatively late in the boot up sequence
  - If the kernel crashes before then, you will see no output
- Add to kernel command line: earlyprintk=ttyS0,1152008n
  - or serial,0x3F8,115200
  - or other types: vga, efi, usb, etc (See Documentation/admin-guide/kernel-parameters.txt)
- Serial port is rather easy to set up
  - That’s what is commonly used
- early printk stops when consoles are set up
- Add “,keep” to command line to keep the early printk going after consoles set up
- Code out there that has “force_early_printk” to replace printk to always use it

# Death of the UART

- Serial ports is sadly a thing of the past (for the desktop)
  - Hard to find even mother boards with a UART
- Simplest way to get crash data out
  - Especially if you have X running (will not see the output from the screen)
- Other methods:
  - network console - If you can get it working
  - delay print (to slowly see what’s on the screen)
  - kexec / kdump
    - Really great if you can get it to work
    - Uses “crash” utility as a gdb that knows how to parse kernel cores (can read the printk buffer)

## Summary

- A way to display data to the screen (especially for a kernel oops)
- Log kernel events (drivers coming on line, etc)
- Output in all context (normal, interrupt, NMI)
- Must retain serial order of events
- Ideally, get as much info out as possible before the machine dies

# Thank You

Steven Rostedt

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