开源操作系统实践

Lecture 4: printk() - The most useful tool

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Outline

1. printk() in Linux v1.0

2. Multiprocessor Support from Linux 2.1.80
3. Scheduler, NMI and printk()
4. printk() within a printk()?
5. Choosing what printk()

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)
- Used to show panics (when all else fails)

课堂练习

请尝试对Linux内核v1.0版本中的printk()的54行的Linux代码进行分析，并形成分析文档。分析文档的内容建议：

1. 这个函数的流程图；
2. 函数涉及的全局变量和局部变量在函数执行过程中的变化情况；
3. 函数中调用的其他函数的功能；
4. 这个函数实现的不足；

如果有同学想接受进一步的挑战，可以在完成上述函数分析后，分析Linux内核v3.13.11版本中的printk()的源代码。

Linux v1.0 - /kernel/printk.c

Linux v1.0 - /kernel/printk.c - Line 142

```
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] != '<' ||
                                p[1] < '0' ||
                                p[1] > '7' ||
                                p[2] != '>'
                        ) {
                                p -= 3;
                                p[0] = '<';
                                p[1] = DEFAULT_MESSAGE_LOGLEVEL - 1 + '0';
```

save_flags() and cli()

Linux v1.0 - /kernel/printk.c - Line 150

```
144         va_list args;
145         int i;
146         char *msg, *p, *buf_end;
147         static char msg_level = -1;
148         long flags;
149
150         save_flags(flags);
151         cli();
152         va_start(args, fmt);
153         i = vsprintf(buf + 3, fmt, args); /* hopefully i < sizeof(buf)-4 */
154         buf_end = buf + 3 + i;
155         va_end(args);
```

Handle variable argument list

Linux v1.0 - /kernel/printk.c - Line 152

```
150         save_flags(flags);
151         cli();
152         va_start(args, fmt);
153         i = vsprintf(buf + 3, fmt, args); /* hopefully i < sizeof(buf)-4 */
154         buf_end = buf + 3 + i;
155         va_end(args);
156         for (p = buf + 3; p < buf_end; p++) {
157                 msg = p;
158                 if (msg_level < 0) {
```

sizeof(buf)

Linux v1.0 - /kernel/printk.c - Line 153

```
150         save_flags(flags);
151         cli();
152         va_start(args, fmt);
153         i = vsprintf(buf + 3, fmt, args); /* hopefully i < sizeof(buf)-4 */
154         buf_end = buf + 3 + i;
155         va_end(args);
156         for (p = buf + 3; p < buf_end; p++) {
157                 msg = p;
158                 if (msg_level < 0) {
159                         if (
```

msg

Linux v1.0 - /kernel/printk.c - Line 156

```
150         save_flags(flags);
151         cli();
152         va_start(args, fmt);
153         i = vsprintf(buf + 3, fmt, args); /* hopefully i < sizeof(buf)-4 */
154         buf_end = buf + 3 + i;
155         va_end(args);
156         for (p = buf + 3; p < buf_end; p++) {
157                 msg = p;
158                 if (msg_level < 0) {
159                         if (
160                                 p[0] != '<' ||
161                                 p[1] < '0' ||
162                                 p[1] > '7' ||
163                                 p[2] != '>'
164                         ) {
165                                 p -= 3;
166                                 p[0] = '<';
167                                 p[1] = DEFAULT_MESSAGE_LOGLEVEL - 1 + '0';
168                                 p[2] = '>';
169                         } else
```

msg_level

Linux v1.0 - /kernel/printk.c - Line 158

```
142  asmlinkage int printk(const char *fmt, ...)
143  {
144          va_list args;
145          int i;
146          char *msg, *p, *buf_end;
147          static char msg_level = -1;
148          long flags;
149
150          save_flags(flags);
151          cli();
152          va_start(args, fmt);
153          i = vsprintf(buf + 3, fmt, args); /* hopefully i < sizeof(buf)-4 */
154          buf_end = buf + 3 + i;
155          va_end(args);
156          for (p = buf + 3; p < buf_end; p++) {
157                  msg = p;
158                  if (msg_level < 0) {
159                          if (
160                                  p[0] != '<' ||
161                                  p[1] < '0' ||
162                                  p[1] > '7' ||
163                                  p[2] != '>'
164                          ) {
```

Set msg_level Tag

Linux v1.0 - /kernel/printk.c - Line 160

```
158             if (msg_level < 0) {
159                     if (
160                             p[0] != '<' ||
161                             p[1] < '0' ||
162                             p[1] > '7' ||
163                             p[2] != '>'
164                     ) {
165                             p -= 3;
166                             p[0] = '<';
167                             p[1] = DEFAULT_MESSAGE_LOGLEVEL - 1 + '0';
168                             p[2] = '>';
169                     } else
170                             msg += 3;
171                     msg_level = p[1] - '0';
172             }
```

msg-start-position

Linux v1.0 - /kernel/printk.c - Line 170

```
156             for (p = buf + 3; p < buf_end; p++) {
157                     msg = p;
158                     if (msg_level < 0) {
159                             if (
160                                     p[0] != '<' ||
161                                     p[1] < '0' ||
162                                     p[1] > '7' ||
163                                     p[2] != '>'
164                             ) {
165                                     p -= 3;
166                                     p[0] = '<';
167                                     p[1] = DEFAULT_MESSAGE_LOGLEVEL - 1 + '0';
168                                     p[2] = '>';
169                             } else
170                                     msg += 3;
171                             msg_level = p[1] - '0';
172                     }
```

Set msg_level

Linux v1.0 - /kernel/printk.c - Line 171

```
156         for (p = buf + 3; p < buf_end; p++) {
157                 msg = p;
158                 if (msg_level < 0) {
159                         if (
160                                 p[0] != '<' ||
161                                 p[1] < '0' ||
162                                 p[1] > '7' ||
163                                 p[2] != '>'
164                         ) {
165                                 p -= 3;
166                                 p[0] = '<';
167                                 p[1] = DEFAULT_MESSAGE_LOGLEVEL - 1 + '0';
168                                 p[2] = '>';
169                         } else
170                                 msg += 3;
171                         msg_level = p[1] - '0';
172                 }
```

log_buf

Linux v1.0 - /kernel/printk.c - Line 173

```
173                 for (; p < buf_end; p++) {
174                         log_buf[(log_start+log_size) & (LOG_BUF_LEN-1)] = *p;
175                         if (log_size < LOG_BUF_LEN)
176                                 log_size++;
177                         else
178                                 log_start++;
179                         logged_chars++;
180                         if (*p == '\n')
181                                 break;
182                 }
```

LOG_BUF_LEN

Linux v1.0 - /kernel/printk.c - Line 174

```
173             for (; p < buf_end; p++) {
174                     log_buf[(log_start+log_size) & (LOG_BUF_LEN-1)] = *p;
175                     if (log_size < LOG_BUF_LEN)
176                             log_size++;
177                     else
178                             log_start++;
179                     logged_chars++;
180                     if (*p == '\n')
181                             break;
182             }
```

log_size

Linux v1.0 - /kernel/printk.c - Line 176

```
173                 for (; p < buf_end; p++) {
174                         log_buf[(log_start+log_size) & (LOG_BUF_LEN-1)] = *p;
175                         if (log_size < LOG_BUF_LEN)
176                                 log_size++;
177                         else
178                                 log_start++;
179                         logged_chars++;
180                         if (*p == '\n')
181                                 break;
182                 }
```

return

Linux v1.0 - /kernel/printk.c - Line 180

```
173             for (; p < buf_end; p++) {
174                     log_buf[(log_start+log_size) & (LOG_BUF_LEN-1)] = *p;
175                     if (log_size < LOG_BUF_LEN)
176                             log_size++;
177                     else
178                             log_start++;
179                     logged_chars++;
180                     if (*p == '\n')
181                             break;
182             }
```

console_loglevel

Linux v1.0 - /kernel/printk.c - Line 183

```
183             if (msg_level < console_loglevel && console_print_proc) {
184                     char tmp = p[1];
185                     p[1] = '\0';
186                     (*console_print_proc)(msg);
187                     p[1] = tmp;
188             }
```

console_print_proc

Linux v1.0 - /kernel/printk.c - Line 186

```
183             if (msg_level < console_loglevel && console_print_proc) {
184                     char tmp = p[1];
185                     p[1] = '\0';
186                     (*console_print_proc)(msg);
187                     p[1] = tmp;
188             }
```

Next msg

Linux v1.0 - /kernel/printk.c - Line 190

```
183             if (msg_level < console_loglevel && console_print_proc) {
184                     char tmp = p[1];
185                     p[1] = '\0';
186                     (*console_print_proc)(msg);
187                     p[1] = tmp;
188             }
189             if (*p == '\n')
190                     msg_level = -1;
```

wake_up_interruptible

Linux v1.0 - /kernel/printk.c - Line 193

```
189                     if (*p == '\n')
190                             msg_level = -1;
191             }
192             restore_flags(flags);
193             wake_up_interruptible(&log_wait);
194             return i;
195     }
```

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

8 printk Log Levels: Set how much verbosity you want to print

- KERN_EMERG “0”
- KERN_ALERT “1”
- KERN_CRIT “2”
- KERN_ERR “3”
- KERN_WARNING “4”
- KERN_NOTICE “5”
- KERN_INFO “6”
- KERN_DEBUG “7”

Log Levels (back then through to today)

- Set how much verbosity you want to print
  - 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
  - New printk_safe() mode 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

Sending to the 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)

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2. Multiprocessor Support from Linux 2.1.80

3. Scheduler, NMI and printk()
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5. Choosing what printk()

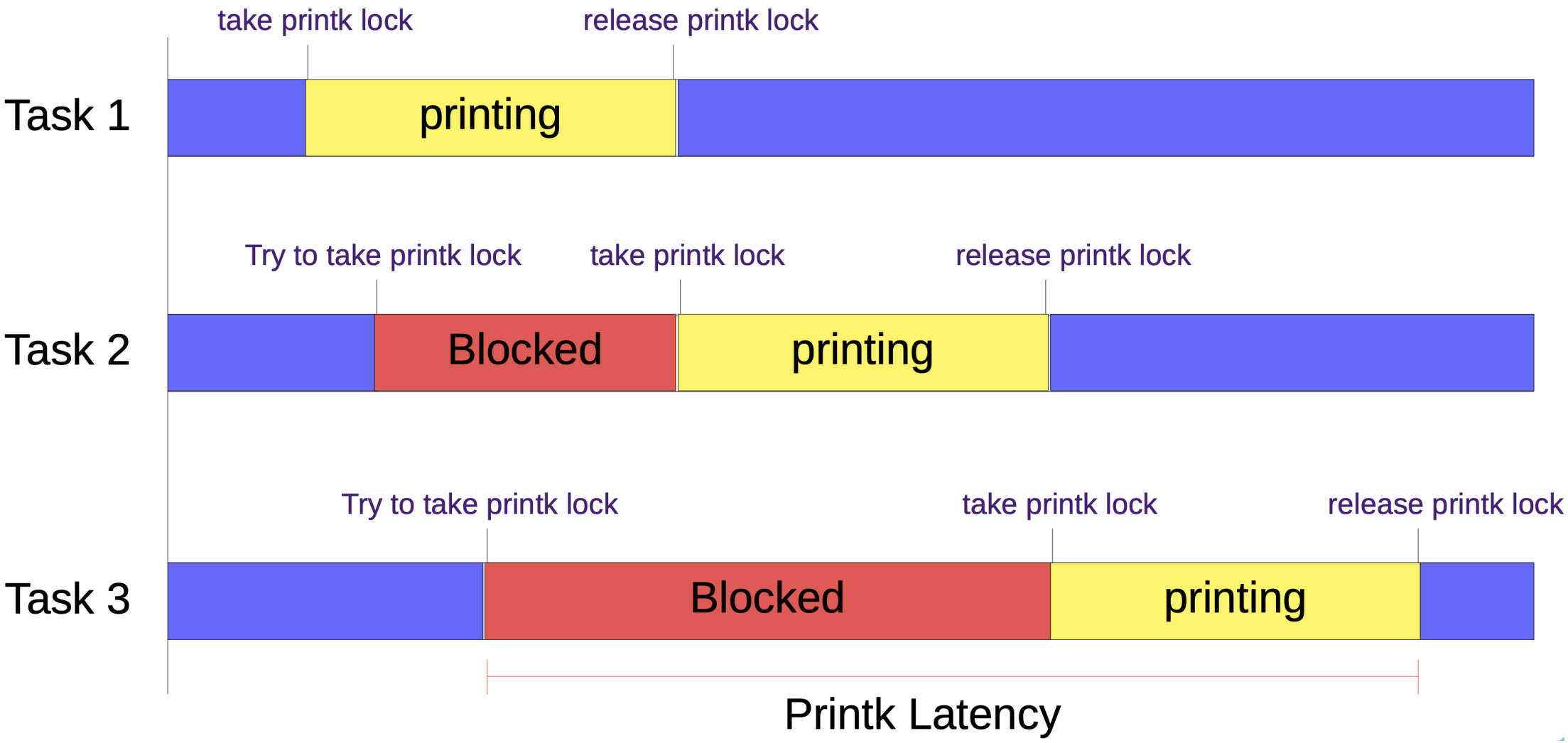
Then multiprocessors happened

- 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!

课堂练习

使用办公室的**公用打印机**有哪些限制？如何提高打印机的利用效率?

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 console_lock semaphore

- 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 (Con't)

- 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()

Linux v3.13.11 - /kernel/printk/printk.c - Line 2012

```
1998  /**
1999   * console_unlock - unlock the console system
2000   *
2001   * Releases the console_lock which the caller holds on the console system
2002   * and the console driver list.
2003   *
2004   * While the console_lock was held, console output may have been buffered
2005   * by printk().  If this is the case, console_unlock(); emits
2006   * the output prior to releasing the lock.
2007   *
2008   * If there is output waiting, we wake /dev/kmsg and syslog() users.
2009   *
2010   * console_unlock(); may be called from any context.
2011   */
2012  void console_unlock(void)
2013  {
2014          static char text[LOG_LINE_MAX + PREFIX_MAX];
2015          static u64 seen_seq;
2016          unsigned long flags;
2017          bool wake_klogd = false;
2018          bool retry;
2019
2020          if (console_suspended) {
2021                  up(&console_sem);
2022                  return;
2023          }
```

console_unlock() - up_console_sem

Linux v3.13.11 - /kernel/printk/printk.c - Line 2020

```
2012  void console_unlock(void)
2013  {
2014          static char text[LOG_LINE_MAX + PREFIX_MAX];
2015          static u64 seen_seq;
2016          unsigned long flags;
2017          bool wake_klogd = false;
2018          bool retry;
2019
2020          if (console_suspended) {
2021                  up(&console_sem);
2022                  return;
2023          }
```

console_unlock() - console_may_schedule

Linux v3.13.11 - /kernel/printk/printk.c - Line 2025

```
2025        console_may_schedule = 0;
2026
2027        /* flush buffered message fragment immediately to console */
2028        console_cont_flush(text, sizeof(text));
2029 again:
2030        for (;;) {
2031                struct printk_log *msg;
2032                size_t len;
2033                int level;
2034
2035                raw_spin_lock_irqsave(&logbuf_lock, flags);
2036                if (seen_seq != log_next_seq) {
2037                        wake_klogd = true;
2038                        seen_seq = log_next_seq;
2039                }
2040
2041                if (console_seq < log_first_seq) {
2042                        /* messages are gone, move to first one */
2043                        console_seq = log_first_seq;
2044                        console_idx = log_first_idx;
2045                        console_prev = 0;
2046                }
2047 skip:
2048                if (console_seq == log_next_seq)
2049                        break;
2050
2051                msg = log_from_idx(console_idx);
2052                if (msg->flags & LOG_NOCONS) {
2053                        /*
2054                         * Skip record we have buffered and already printed
2055                         * directly to the console when we received it.
2056                         */
2057                        console_idx = log_next(console_idx);
2058                        console_seq++;
2059                        /*
2060                         * We will get here again when we register a new
2061                         * CON_PRINTBUFFER console. Clear the flag so we
2062                         * will properly dump everything later.
2063                         */
2064                        msg->flags &= ~LOG_NOCONS;
2065                        console_prev = msg->flags;
2066                        goto skip;
2067                }
2068
2069                level = msg->level;
2070                len = msg_print_text(msg, console_prev, false,
2071                                     text, sizeof(text));
2072                console_idx = log_next(console_idx);
2073                console_seq++;
2074                console_prev = msg->flags;
2075                raw_spin_unlock(&logbuf_lock);
2076
2077                stop_critical_timings();        /* don't trace print latency */
2078                call_console_drivers(level, text, len);
2079                start_critical_timings();
2080                local_irq_restore(flags);
2081        }
```

console_unlock() - console_locked

Linux v3.13.11 - /kernel/printk/printk.c - Line 2082

```
2082            console_locked = 0;
2083            mutex_release(&console_lock_dep_map, 1, _RET_IP_);
2084
2085            /* Release the exclusive_console once it is used */
2086            if (unlikely(exclusive_console))
2087                    exclusive_console = NULL;
2088
2089            raw_spin_unlock(&logbuf_lock);
```

console_unlock() - exclusive_console

Linux v3.13.11 - /kernel/printk/printk.c - Line 2086

```
2082        console_locked = 0;
2083        mutex_release(&console_lock_dep_map, 1, _RET_IP_);
2084
2085        /* Release the exclusive_console once it is used */
2086        if (unlikely(exclusive_console))
2087                exclusive_console = NULL;
2088
2089        raw_spin_unlock(&logbuf_lock);
```

console_unlock() - logbuf_lock

Linux v3.13.11 - /kernel/printk/printk.c - Line 2099

```
2093        /*
2094         * Someone could have filled up the buffer again, so re-check if there's
2095         * something to flush. In case we cannot trylock the console_sem again,
2096         * there's a new owner and the console_unlock() from them will do the
2097         * flush, no worries.
2098         */
2099        raw_spin_lock(&logbuf_lock);
2100        retry = console_seq != log_next_seq;
2101        raw_spin_unlock_irqrestore(&logbuf_lock, flags);
2102
2103        if (retry && console_trylock())
2104                goto again;
2105
2106        if (wake_klogd)
2107                wake_up_klogd();
```

console_unlock() - log_next_seq

Linux v3.13.11 - /kernel/printk/printk.c - Line 2100

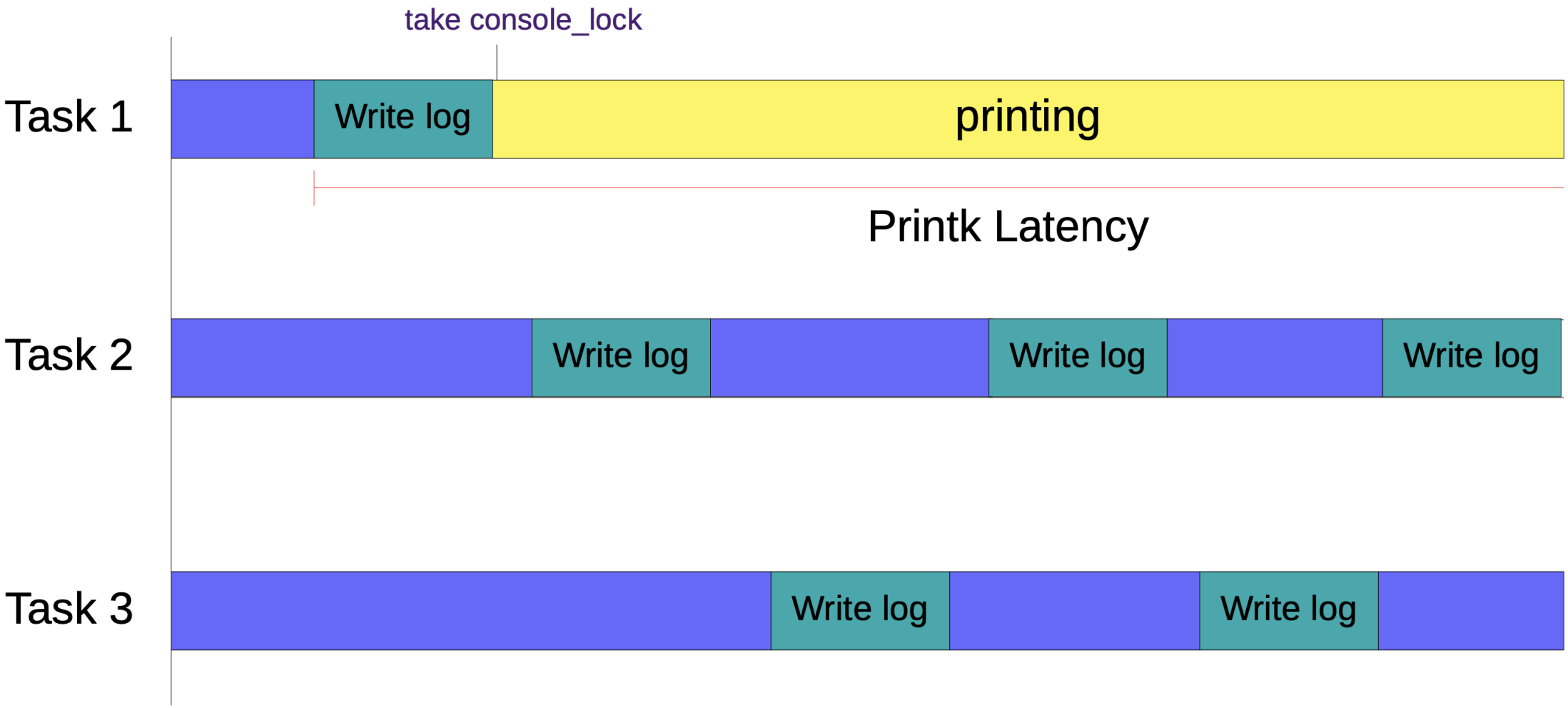
```
2093            /*
2094             * Someone could have filled up the buffer again, so re-check if there's
2095             * something to flush. In case we cannot trylock the console_sem again,
2096             * there's a new owner and the console_unlock() from them will do the
2097             * flush, no worries.
2098             */
2099            raw_spin_lock(&logbuf_lock);
2100            retry = console_seq != log_next_seq;
2101            raw_spin_unlock_irqrestore(&logbuf_lock, flags);
2102
2103            if (retry && console_trylock())
2104                    goto again;
2105
2106            if (wake_klogd)
2107                    wake_up_klogd();
```

console_unlock() - wake_klogd

Linux v3.13.11 - /kernel/printk/printk.c - Line 2107

```
2093            /*
2094             * Someone could have filled up the buffer again, so re-check if there's
2095             * something to flush. In case we cannot trylock the console_sem again,
2096             * there's a new owner and the console_unlock() from them will do the
2097             * flush, no worries.
2098             */
2099            raw_spin_lock(&logbuf_lock);
2100            retry = console_seq != log_next_seq;
2101            raw_spin_unlock_irqrestore(&logbuf_lock, flags);
2102
2103            if (retry && console_trylock())
2104                    goto again;
2105
2106            if (wake_klogd)
2107                    wake_up_klogd();
2108    }
```

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!)

exclusive_console (Added March 2011)

- 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!)

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3. Scheduler, NMI and printk()

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5. Choosing what printk()

Printk and the scheduler

- We want printk to work most everywhere
- Now printk has locks
  - This is an issue with NMIs

Printk with semaphore and the scheduler

- 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

BUST Spinlocks!

```
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)

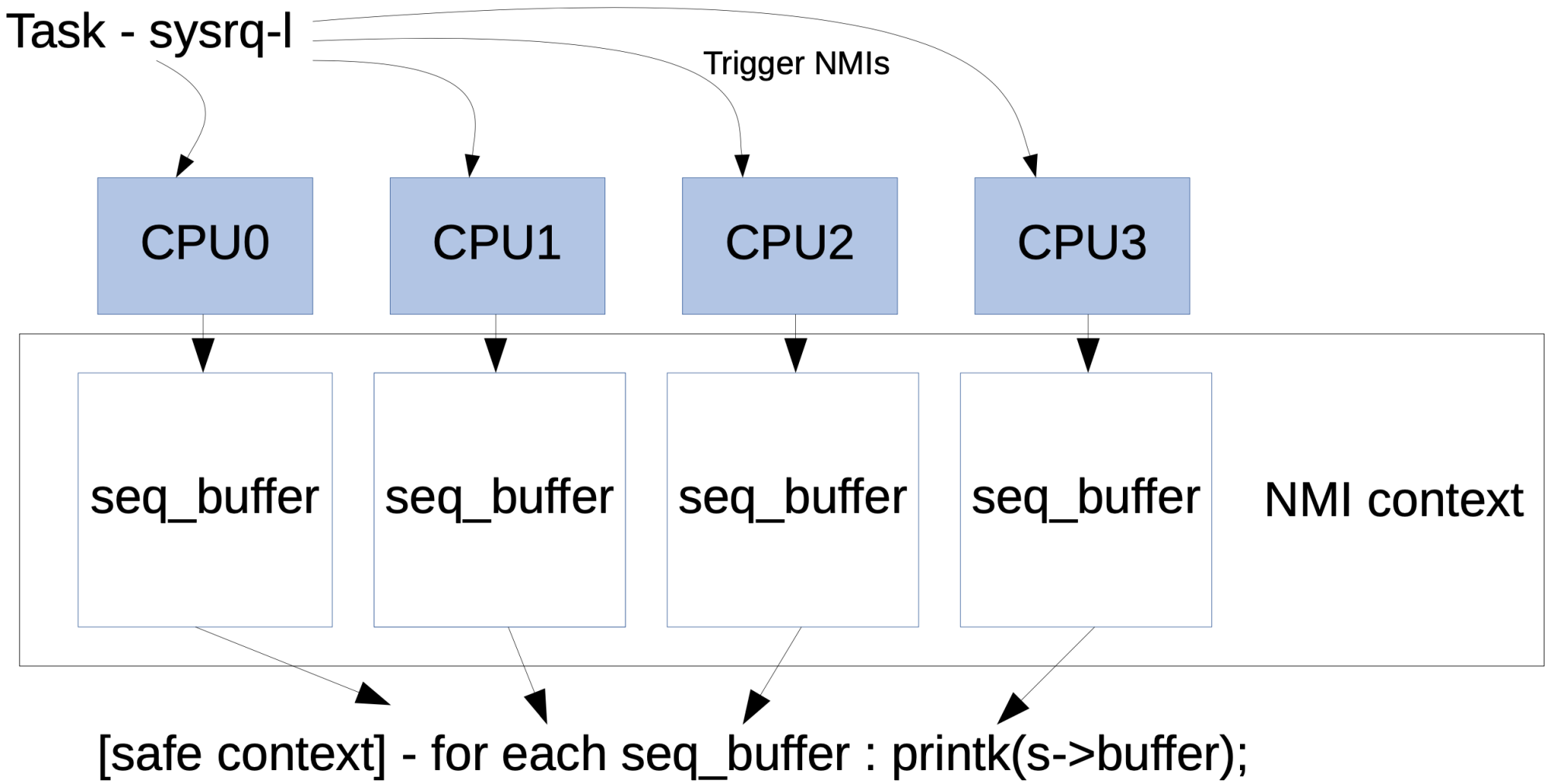
- Used by the tracing facility
- Allows to pass a buffer descriptor between functions
- Can use any allocated buffer
- Can be used by NMI printk
  - A buffer per CPU
  - NMI printk writes to the seq_buffer and not to console
  - A “safe” place reads NMI seq_buffers and prints to console
  - Unfortunately,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

Introduction of seq_buffer (v3.19)

- 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



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)

nmi_vprintk (v4.7)

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

Outline

1. printk() in Linux v1.0
2. Multiprocessor Support from Linux 2.1.80
3. Scheduler, NMI and printk()

4. printk() within a printk()?

5. Choosing what printk()

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

lockdep

- 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
- 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

printk_safe (v4.11)

```
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));
}
```

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

printk_safe (v4.11)

- 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 logbuf_lock

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

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Choosing what printk() should do

```c
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)
        return vprintk_deferred(fmt, args);
    /* No obstacles. */
    return vprintk_default(fmt, args);
}
```

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

- 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)

Methods for crash data out

- 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

谢谢！