Extending the swsusp Hibernation Framework to ARM

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Introduction

- Russ Dill of Texas Instruments
- swsusp/hibernation on ARM
  - Overview
  - Challenges
  - Implementation
  - Remaining work
  - Debugging
- swsusp restore from U-Boot
- Code at:
  - https://github.com/russdill/linux/commits/arm-hibernation-am33xx
  - https://github.com/russdill/commits/hibernation
- eLinux.org page: http://elinux.org/ARM_Hibernation

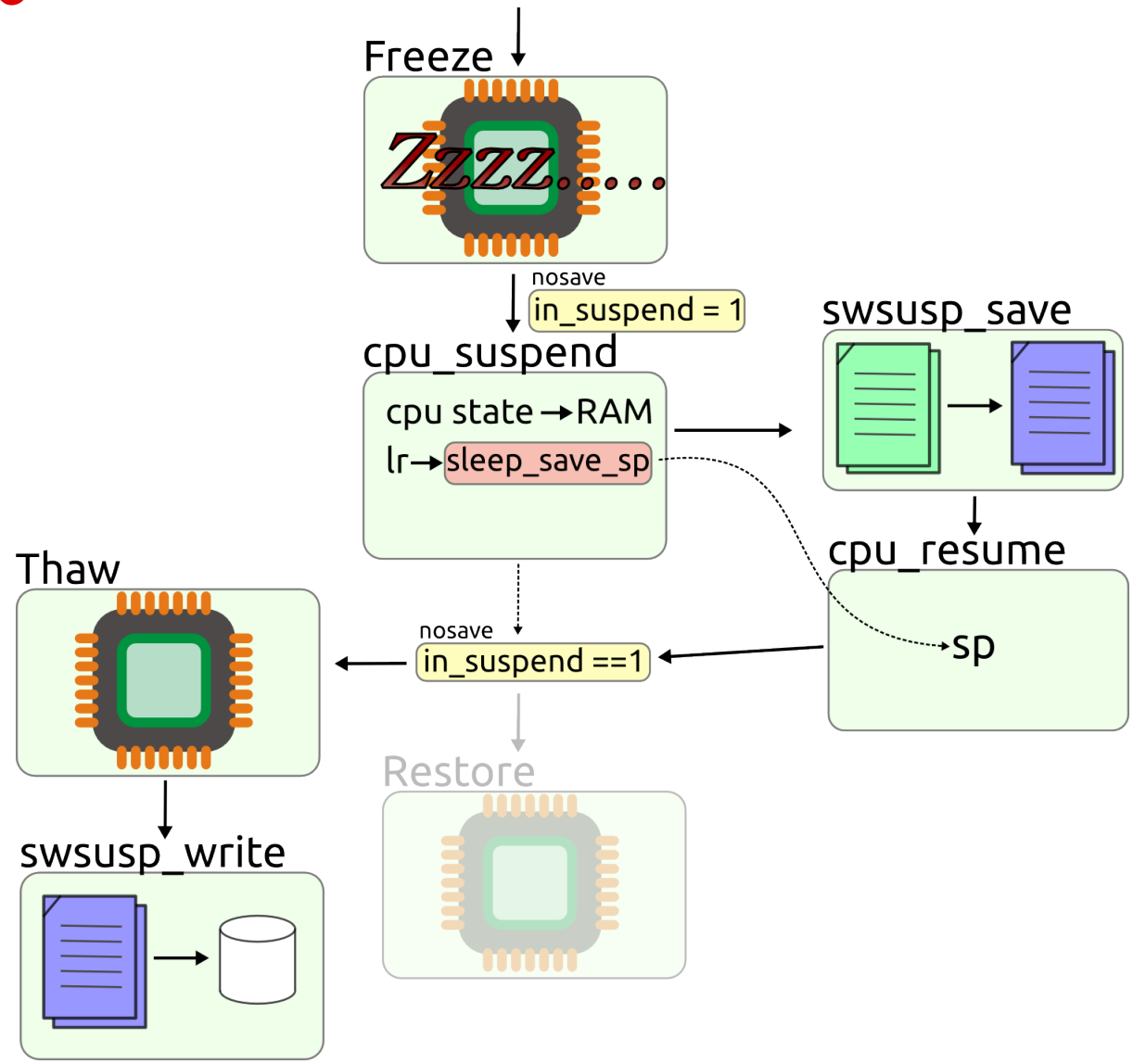
Motivation

- Hibernation provides zero power consumption sleep
- Allows for snapshot boot
- Shares requirements with self-refresh only sleep modes
  - RTC-Only+DDR self-refresh

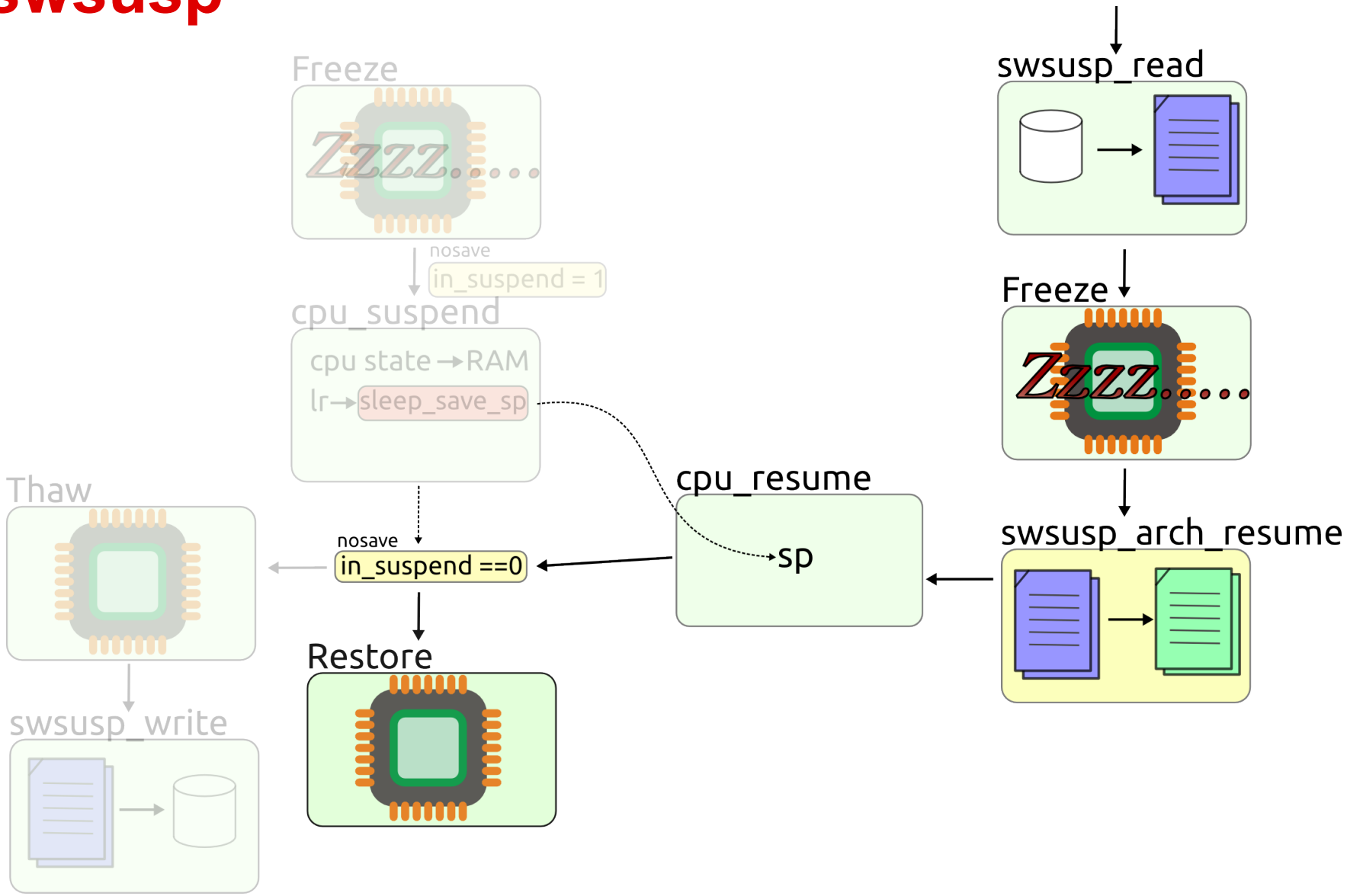
swsusp

- Mainline hibernation implementation since 2.6.0
  - TuxOnIce (Suspend2)
- Uses swap device to store image
- Can be used with uswsusp to support additional features
  - Encryption
  - Limitless storage options
  - Graphical progress
- Limited to snapshotting 1/2 of system RAM

swsusp


Freeze
Zzzz....
nosave
in_suspend = 1
cpu_suspend
cpu state → RAM
lr → sleep_save_sp
swsusp_save
cpu_resume
sp
Thaw
nosave
in_suspend ==1
Restore
swsusp_write

swsusp


swsusp_read
Freeze
Zzzz.....
Freeze
Zzzz.....
swsusp_arch_resume
cpu_resume
sp
nosave
in_suspend ==0
Thaw
swsusp_write
Restore
nosave
in_suspend = 1
cpu_suspend
cpu state → RAM
lr → sleep_save_sp

OMAP PM

- Clocks
  - Clock gating
  - Clock domains
  - Clock scaling
- Power
  - Power domains
    - Logic
    - Retention
  - Voltage scaling
- PRCM Controls these features

Figure 8-1. Functional and Interface Clocks

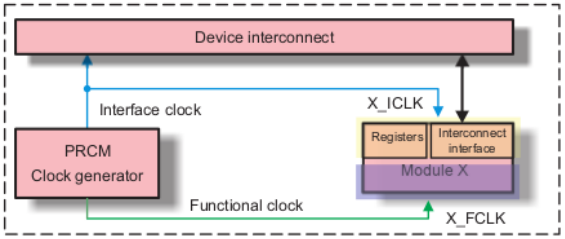


Figure 8-2. Generic Clock Domain

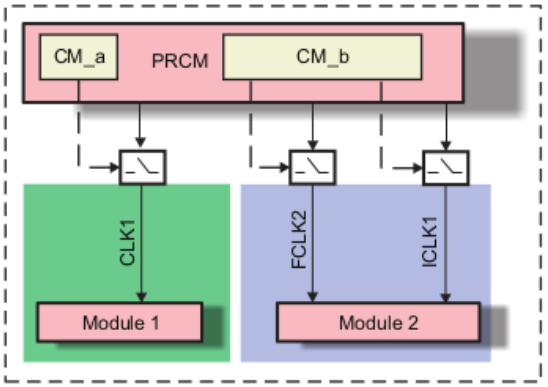
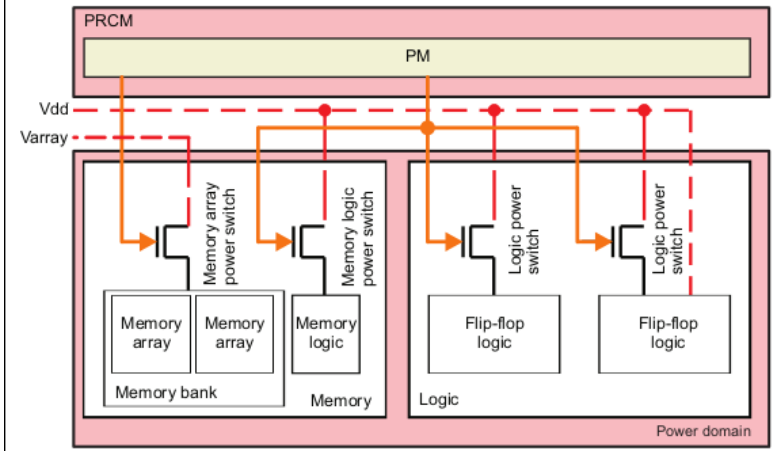
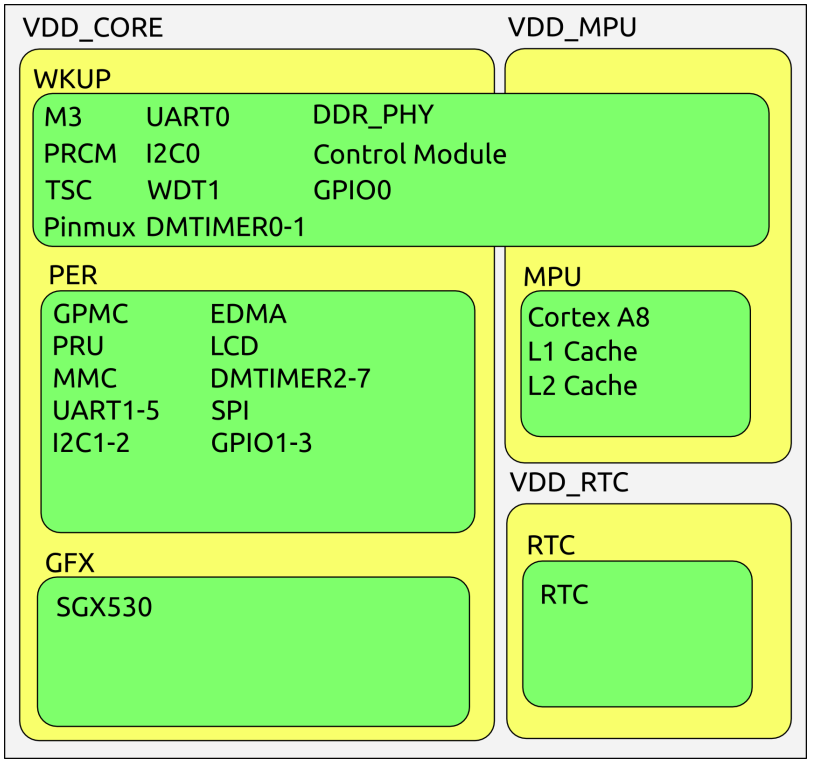


Figure 8-4. Generic Power Domain Architecture



AM33xx PM Overview

- MPU, PER, and GFX power domains can be turned off during suspend
- Current OMAP PM core assumes WKUP domain will always have power



WKUP Context

- Used for:
  - Power, reset, and clock management (PRCM)
  - Pin mux configuration
  - modules that wake up the processor from suspend
- After hibernation, we need to restore this state

PRCM

- Power domains
  - Represented by arch/arm/mach-omap2/powerdomain.c

```
static void am33xx_pwrdm_save_context(struct powerdomain *pwrdm)
{
        pwrdm->context = am33xx_prm_read_reg(pwrdm->prcm_offs,
                                             pwrdm->pwrstctrl_offs);
        /*
         * Do not save LOWPOWERSTATECHANGE, writing a 1 indicates a request,
         * reading back a 1 indicates a request in progress.
         */
        pwrdm->context &= ~AM33XX_LOWPOWERSTATECHANGE_MASK;
}

static void am33xx_pwrdm_restore_context(struct powerdomain *pwrdm)
{
        am33xx_prm_write_reg(pwrdm->context, pwrdm->prcm_offs,
                                             pwrdm->pwrstctrl_offs);
        am33xx_pwrdm_wait_transition(pwrdm);
}
```

PRCM

- Reset state and module state
  - Represented by omap_hwmod, leverage it

```
for (i = 0; i < oh->rst_lines_cnt; i++)
        if (oh->rst_lines[i].context)
                _assert_hardreset(oh, oh->rst_lines[i].name);
        else if (oh->_state == _HWMOD_STATE_ENABLED)
                _deassert_hardreset(oh, oh->rst_lines[i].name);

if (oh->_state == _HWMOD_STATE_ENABLED) {
        if (soc_ops.enable_module)
                soc_ops.enable_module(oh);
} else {
        if (soc_ops.disable_module)
                soc_ops.disable_module(oh);
}
```

PRCM

- Clocks domains
  - Represented by arch/arm/mach-omap2/clockdomain.c

```
static int am33xx_clkdm_save_context(struct clockdomain *clkdm)
{
        clkdm->context = am33xx_cm_read_reg_bits(clkdm->cm_inst,
                                clkdm->clkdm_offs, AM33XX_CLKTRCTRL_MASK);

        return 0;
}

static int am33xx_clkdm_restore_context(struct clockdomain *clkdm)
{
        switch (clkdm->context) {
        case OMAP34XX_CLKSTCTRL_DISABLE_AUTO:
                am33xx_clkdm_deny_idle(clkdm);
                break;
        case OMAP34XX_CLKSTCTRL_FORCE_SLEEP:
                am33xx_clkdm_sleep(clkdm);
                break;
        case OMAP34XX_CLKSTCTRL_FORCE_WAKEUP:
                am33xx_clkdm_wakeup(clkdm);
                break;
        case OMAP34XX_CLKSTCTRL_ENABLE_AUTO:
                am33xx_clkdm_allow_idle(clkdm);
                break;
        }
        return 0;
}
```

PRCM

- Clocks
  - Leverage the clock tree by adding context save/restore callbacks

```
static int clk_save_context(struct clk *clk)
{
        struct clk *child;
        struct hlist_node *tmp;
        int ret = 0;

        hlist_for_each_entry(child, tmp, &clk->children, child_node) {
                ret = clk_save_context(child);
                if (ret < 0)
                        return ret;
        }

        if (clk->ops && clk->ops->save_context)
                ret = clk->ops->save_context(clk->hw);

        return ret;
}

static void clk_restore_context(struct clk *clk)
{
        struct clk *child;
        struct hlist_node *tmp;

        if (clk->ops && clk->ops->restore_context)
                clk->ops->restore_context(clk->hw);

        hlist_for_each_entry(child, tmp, &clk->children, child_node)
                clk_restore_context(child);
}
```

```
int clk_divider_save_context(struct clk_hw *hw)
{
        struct clk_divider *divider = to_clk_divider(hw);
        u32 val;

        val = readl(divider->reg) >> divider->shift;
        divider->context = val & div_mask(divider);

        return 0;
}

void clk_divider_restore_context(struct clk_hw *hw)
{
        struct clk_divider *divider = to_clk_divider(hw);
        u32 val;

        val = readl(divider->reg);
        val &= ~(div_mask(divider) << divider->shift);
        val |= divider->context << divider->shift;
        writel(val, divider->reg);
}
```

pinctrl

- Controls how internal signals are routed to external pins
- Contains memory map of register area, but no complete description of registers
- AM335X errata complicates the situation, certain registers lose context when the PER domain powers during suspend
- The pinctrl subsystem needs knowledge of which registers are available, and which domain they are in.

pinctrl

- Temporary measure, list each power domain register set as a pinconf function

```
am33xx_pinmux: pinmux@44e10800 {
        compatible = "pinctrl-single";
        reg = <0x44e10800 0x0238>;
        #address-cells = <1>;
        #size-cells = <0>;
        pinctrl-single,register-width = <32>;
        pinctrl-single,function-mask = <0x7f>;

        pinctrl-names = "default", "context";
        pinctrl-0 = <>;
        pinctrl-1 = <&am33xx_pmx_wkup &am33xx_pmx_per>;

        am33xx_pmx_wkup: am33xx_pmx_wkup {
                pinctrl-single,pins = <
                        0x000 0x00 /* GPMC_AD0 */
                        0x004 0x00 /* GPMC_AD1 */
                        0x008 0x00 /* GPMC_AD2 */
                        0x00c 0x00 /* GPMC_AD3 */
                        0x010 0x00 /* GPMC_AD4 */
                        0x014 0x00 /* GPMC_AD5 */

                        0x1e8 0x00 /* EMU1 */
                        0x1f8 0x00 /* RTC_PWRONRSTN */
                        0x1fc 0x00 /* PMIC_POWER_EN */
                        0x200 0x00 /* EXT_WAKEUP */
                        0x204 0x00 /* RTC_KALDO_ENN */
                        0x21c 0x00 /* USB0_DRVVBUS */
                        0x234 0x00 /* USB1_DRVVBUS */
                >;
        };
```

```
        am33xx_pmx_per: am33xx_pmx_per {
                pinctrl-single,pins = <
                        0x040 0x00 /* GPMC_A0 */
                        0x044 0x00 /* GPMC_A1 */
                        0x048 0x00 /* GPMC_A2 */
                        0x04c 0x00 /* GPMC_A3 */
                        0x050 0x00 /* GPMC_A4 */
                        0x054 0x00 /* GPMC_A5 */
                        0x058 0x00 /* GPMC_A6 */

                        0x134 0x00 /* MII1_RXD3 */
                        0x138 0x00 /* MII1_RXD2 */
                        0x13c 0x00 /* MII1_RXD1 */
                        0x140 0x00 /* MII1_RXD0 */
                        0x144 0x00 /* MII1_REFCLK */
                        0x148 0x00 /* MDIO_DATA */
                        0x14c 0x00 /* MDIO_CLK */
                >;
        };
};
```

pinctrl

- Code added to pinctrl to save/restore a pinctrl function group

```
int pinmux_save_context(struct pinctrl_dev *pctldev, const char *function)
{
        const struct pinmux_ops *pmxops = pctldev->desc->pmxops;
        int ret;

        ret = pinmux_func_name_to_selector(pctldev, function);
        if (ret < 0) {
                dev_err(pctldev->dev, "invalid function %s\n", function);
                return ret;
        }

        if (!pmxops || !pmxops->save_context)
                return -EINVAL;

        return pmxops->save_context(pctldev, ret);
}
EXPORT_SYMBOL(pinmux_save_context);

void pinmux_restore_context(struct pinctrl_dev *pctldev, const char *function)
{
        const struct pinmux_ops *pmxops = pctldev->desc->pmxops;
        int ret;

        ret = pinmux_func_name_to_selector(pctldev, function);
        if (ret < 0) {
                dev_err(pctldev->dev, "invalid function %s\n", function);
                return;
        }

        if (!pmxops || !pmxops->restore_context)
                return;

        pmxops->restore_context(pctldev, ret);
}
EXPORT_SYMBOL(pinmux_restore_context);
```

```
static int pcs_save_context(struct pinctrl_dev *pctldev, unsigned fselector)
{
        struct pcs_device *pcs;
        struct pcs_function *func;
        int i;

        pcs = pinctrl_dev_get_drvdata(pctldev);
        func = radix_tree_lookup(&pcs->ftree, fselector);
        if (!func) {
                dev_err(pcs->dev, "%s could not find function%i\n",
                        __func__, fselector);
                return -ENODEV;
        }

        for (i = 0; i < func->nvals; i++) {
                struct pcs_func_vals *vals;

                vals = &func->vals[i];
                vals->val = pcs->read(vals->reg);
        }

        return 0;
}

static void pcs_restore_context(struct pinctrl_dev *pctldev, unsigned fselector)
{
        struct pcs_device *pcs;
        struct pcs_function *func;
        int i;

        pcs = pinctrl_dev_get_drvdata(pctldev);
        func = radix_tree_lookup(&pcs->ftree, fselector);
        if (!func) {
                dev_err(pcs->dev, "%s could not find function%i\n",
                        __func__, fselector);
                return;
        }

        for (i = 0; i < func->nvals; i++) {
                struct pcs_func_vals *vals;
                unsigned val, mask;

                vals = &func->vals[i];
                val = pcs->read(vals->reg);
                if (!vals->mask)
                        mask = pcs->fmask;
                else
                        mask = pcs->fmask & vals->mask;

                val &= ~mask;
                val |= (vals->val & mask);
                pcs->write(val, vals->reg);
        }
}
```

pinctrl

- Current solution is a bit of a hack and likely not upstreamable.
- Possible solution?
  - New type of pinctrl register grouping
  - Would contain reference to power domain register group is contained in
  - Code could use syscore suspend/resume callbacks to save and restore context
- Problem
  - omap2+ power domains are currently arch specific

clocksource/clockevent

- Clockevent is already handled properly, disabling on suspend and reprogramming on resume
- Clocksource is assumed to be always running and within a domain that does not lose power
- Clocksource is also required for many kernel delay calculations. Must be restored before most other kernel code

```
static cycle_t clksrc_suspend_cyc;

static void omap_clksrc_suspend(struct clocksource *cs)
{
        char name[10];
        struct omap_hwmod *oh;

        sprintf(name, "timer%d", clksrc.id);
        oh = omap_hwmod_lookup(name);
        if (!oh)
                return;

        clksrc_suspend_cyc = (cycle_t)__omap_dm_timer_read_counter(&clksrc, 1);
        clksrc.ctx_loss_count = omap_hwmod_get_context_loss_count(oh);
}
```

```
static void omap_clksrc_resume(struct clocksource *cs)
{
        char name[10];
        struct omap_hwmod *oh;
        u32 ctx_loss_cnt_after;

        sprintf(name, "timer%d", clksrc.id);
        oh = omap_hwmod_lookup(name);
        if (!oh)
                return;

        ctx_loss_cnt_after = omap_hwmod_get_context_loss_count(oh);
        if (ctx_loss_cnt_after != clksrc.ctx_loss_count) {
                omap2_dflt_clk_restore_context(__clk_get_hw(clksrc.fclk));
                omap_hwmod_reset(oh);
                __omap_dm_timer_load_start(&clksrc,
                                OMAP_TIMER_CTRL_ST | OMAP_TIMER_CTRL_AR,
                                clksrc_suspend_cyc, 1);
                __omap_dm_timer_int_enable(&clksrc, OMAP_TIMER_INT_OVERFLOW);
        }
}
```

SRAM

- Internal memory on many OMAP processors used to run suspend resume code or code that modifies memory controller registers or clocking
- Currently restored for OMAP3, but in an OMAP3 specific way – Make it more general instead

```
void omap_sram_save_context(void)
{
        if (omap_sram_backup) {
                unsigned long start = omap_sram_ceil - omap_sram_base;
                memcpy(omap_sram_backup, omap_sram_base, omap_sram_skip);
                memcpy(omap_sram_backup + start, omap_sram_ceil,
                                                        omap_sram_size - start);
        }
}

void omap_sram_restore_context(void)
{
        if (omap_sram_backup) {
                unsigned long start = omap_sram_ceil - omap_sram_base;
                memcpy(omap_sram_base, omap_sram_backup, omap_sram_skip);
                memcpy(omap_sram_ceil, omap_sram_backup + start,
                                                        omap_sram_size - start);
        }
}
```

Other Devices

- Many devices just need to know that their power domain lost context
- Teach arch/arm/mach-omap2/powerdomain.c about hibernation induced off modes.

```
static int pwrdm_lost_power(struct powerdomain *pwrdm, void *unused)
{
        enum pwrdm_func_state fpwrst;

        /*
         * Power has been lost across all powerdomains, increment the
         * counter.
         */
        if (pwrdm->fpwrst == PWRDM_FUNC_PWRST_OFF)
                return 0;

        pwrdm->fpwrst_counter[PWRDM_FUNC_PWRST_OFF - PWRDM_FPWRST_OFFSET]++;

        fpwrst = _pwrdm_read_fpwrst(pwrdm);
        if (fpwrst != PWRDM_FUNC_PWRST_OFF)
                pwrdm->fpwrst_counter[fpwrst - PWRDM_FPWRST_OFFSET]++;
        pwrdm->fpwrst = fpwrst;

        return 0;
}
```

Other Devices

- Many devices that depend on a context loss count function pointer do not get that pointer under DT based systems
  - gpio-omap
  - omap_hsmmc
  - omap-serial
- Currently a hack fix with a pointer to omap_pm_get_dev_context_loss_count
- There is a need for a generic framework to inform devices when they have lost power

Other Devices

- Some devices misconfigured in such a way to prevent suspend/resume callbacks during hibernation
- When not using dev_pm_ops, the platform_driver .suspend/.resume callbacks are used for hibernation thaw/freeze/restore/poweroff functionality
- However, when using dev_pm_ops these must be filled in. The helper macro, SET_SYSTEM_SLEEP_PM_OPS should be used to fill in the thaw/freeze/restore/poweroff callbacks (unless special thaw/freeze/restore/poweroff behavior is required).

```
static struct dev_pm_ops omap_hsmmc_dev_pm_ops = {
  .suspend    = omap_hsmmc_suspend,
  .resume       = omap_hsmmc_resume,
  .prepare    = omap_hsmmc_prepare,
  .complete    = omap_hsmmc_complete,
  .runtime_suspend = omap_hsmmc_runtime_suspend,
  .runtime_resume = omap_hsmmc_runtime_resume,
};

static struct platform_driver omap_hsmmc_driver = {
  .probe        = omap_hsmmc_probe,
  .remove       = omap_hsmmc_remove,
  .driver       = {
      .name = DRIVER_NAME,
      .owner = THIS_MODULE,
      .pm = &omap_hsmmc_dev_pm_ops,
      .of_match_table = of_match_ptr(omap_mmc_of_match),
  },
};
```

Other Devices

- Some device *do* need special hibernation callbacks
- The omap watchdog requires special handling because the state of the watchdog under the boot kernel is not known

```
static int omap_wdt_restore(struct device *dev)
{
        struct watchdog_device *wdog = dev_get_drvdata(dev);
        struct omap_wdt_dev *wdev = watchdog_get_drvdata(wdog);

        omap_wdt_resume(dev);

        /*
         * We don't know what the resume kernel last pinged the WDT with. If
         * it pinged it with the same value we ping it with, the ping will be
         * ignored. Double ping to be sure we reset the timer.
         */
        if (wdev->omap_wdt_users)
                omap_wdt_ping(wdog);

        return 0;
}

static const struct dev_pm_ops omap_wdt_pm_ops = {
        .suspend        = omap_wdt_suspend,
        .freeze         = omap_wdt_suspend,
        .poweroff       = omap_wdt_suspend,
        .resume         = omap_wdt_resume,
        .thaw           = omap_wdt_resume,
        .restore        = omap_wdt_restore,
};
```

Saving/Restoring WKUP Domain

- Putting it all together in pm33xx.c

```
static int am33xx_wkup_save_context(void)
{
        int ret;

        ret = pinmux_save_context(pmx_dev, "am33xx_pmx_wkup");
        if (ret < 0)
                return ret;

        omap_intc_save_context();
        am33xx_control_save_context();

        clks_save_context();
        pwrdms_save_context();
        omap_hwmods_save_context();
        clkdm_save_context();
        omap_sram_save_context();

        return 0;
}

static void am33xx_wkup_restore_context(void)
{
        clks_restore_context();
        pwrdms_restore_context();
        clkdm_restore_context();
        omap_hwmods_restore_context();
        am33xx_control_restore_context();
        pinmux_restore_context(pmx_dev, "am33xx_pmx_wkup");
        omap_intc_restore_context();
        wkup_m3_reinitialize();
        omap_sram_restore_context();
}
```

Hibernation support for ARM

- Minimum implementation
  - swsusp_arch_suspend
    - Save current cpu state
    - Call swsusp_save to snapshot memory
    - Return control to swsusp_arch_suspend caller
  - swsusp_arch_resume
    - Perform page copies of pages in the restore_pbelist
    - Restore cpu state from swsusp_arch_suspend
    - Return control to swsusp_arch_suspend caller
  - pfn_is_no_save
    - Return true if this pfn is not to be saved in the hibernation image
  - save_processor_state
    - Save any extra processor state (fp registers, etc)
  - restore_processor_state
    - Restore extra processor state

Hibernation support for ARM

- swsusp_arch_suspend
  - Utilizes cpu_suspend to save current cpu state
  - Second argument of cpu_suspend is called after state is saved
  - Calling cpu_resume causes execution to return to cpu_suspend caller
  - Utilizing soft_restart disables MMU as cpu_resume expects

```
/*
 * Snapshot kernel memory and reset the system.
 * After resume, the hibernation snapshot is written out.
 */
static int notrace __swsusp_arch_save_image(unsigned long unused)
{
        extern int swsusp_save(void);
        int ret;

        ret = swsusp_save();
        if (ret == 0)
                soft_restart(virt_to_phys(cpu_resume));
        return ret;
}

/*
 * Save the current CPU state before suspend / poweroff.
 */
int notrace swsusp_arch_suspend(void)
{
        return cpu_suspend(0, __swsusp_arch_save_image);
}
```

Hibernation support for ARM

- swsusp_arch_resume
  - Uses stack allocated in nosave region to prevent ourselves from overwriting our stack
  - We will overwrite our code, but with the same bytes
  - Uses cpu_resume to restore cpu state and return to cpu_suspend caller

```
/*
 * The framework loads the hibernation image into a linked list anchored
 * at restore_pblist, for swsusp_arch_resume() to copy back to the proper
 * destinations.
 *
 * To make this work if resume is triggered from initramfs, the
 * pagetables need to be switched to allow writes to kernel mem.
 */
static void notrace __swsusp_arch_restore_image(void *unused)
{
        extern struct pbe *restore_pblist;
        struct pbe *pbe;

        cpu_switch_mm(idmap_pgd, &init_mm);
        for (pbe = restore_pblist; pbe; pbe = pbe->next)
                copy_page(pbe->orig_address, pbe->address);

        soft_restart_noirq(virt_to_phys(cpu_resume));
}

static u8 __swsusp_resume_stk[PAGE_SIZE/2] __nosavedata;

/*
 * Resume from the hibernation image.
 * Due to the kernel heap / data restore, stack contents change underneath
 * and that would make function calls impossible; switch to a temporary
 * stack within the nosave region to avoid that problem.
 */
int __naked swsusp_arch_resume(void)
{
        extern void call_with_stack(void (*fn)(void *), void *arg, void *sp);
        cpu_init();     /* get a clean PSR */
        call_with_stack(__swsusp_arch_restore_image, 0,
                __swsusp_resume_stk + sizeof(__swsusp_resume_stk));
        return 0;
}
```

AM33xx Hibernation Support

- With prep work done, adding hibernation support to AM33xx is actually fairly straightforward
- begin/end wrap all hibernation code
- We use disable/enable_hlt to prevent pm_idle from being called

```
static int am33xx_hibernation_begin(void)
{
        disable_hlt();
        return 0;
}

static void am33xx_hibernation_end(void)
{
        enable_hlt();
}
```

- The enter call back just powers down the machine
- These calls make sure that the hardware is in the same state before running the restored image as when it was made

```
static int am33xx_hibernation_enter(void)
{
        machine_power_off();
        return 0;
}
```

```
static int am33xx_hibernation_pre_restore(void)
{
        omap2_gpio_prepare_for_idle(1);
        return 0;
}

static void am33xx_hibernation_restore_cleanup(void)
{
        omap2_gpio_resume_after_idle();
}
```

AM33xx Hibernation Support

- pre_snapshot saves all our state registers and prepares the GPIOs for power loss
- leave is called after restoring an image. We inform the power domains that they have lost power and we restore our wkup context
- finish is called both after restoring an image (after leave) and after snapshotting the system. We continue our context restore and also undo the actions in pre_snapshot

```
static int am33xx_hibernation_pre_snapshot(void)
{
        am33xx_per_save_context();
        omap2_gpio_prepare_for_idle(1);
        am33xx_wkup_save_context();

        return 0;
}

static void am33xx_hibernation_leave(void)
{
        pwrdms_lost_power();
        am33xx_wkup_restore_context();
}

static void am33xx_hibernation_finish(void)
{
        omap2_gpio_resume_after_idle();
        am33xx_per_restore_context();
}
```

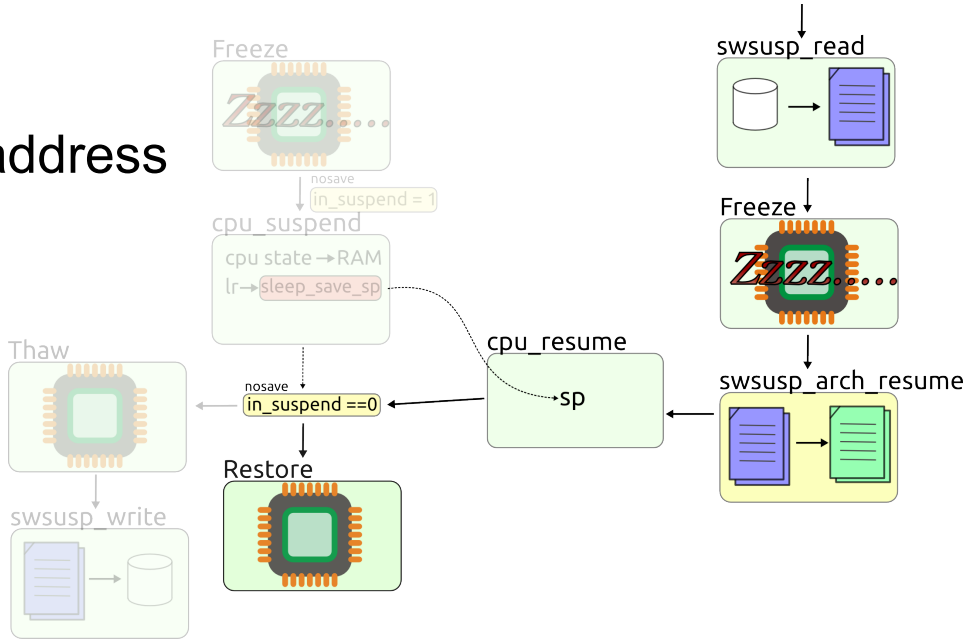
Debugging Methods

- Debugging can be difficult as the hardware is usually in some unknown state.
- Debugging using GPIOs
  - GPIOs are usually pretty easy to configure clocks for and enable with just a few register writes, even from assembly
  - Binary search of where the code is failing can be performed by moving the GPIO enable around
- printk
  - The kernel logging facility is useful so long as you are getting to a point where serial output is enabled
- Register map comparisons
  - Utilizing devmem2 to snapshot register values before and after a hibernation file is useful to track down missed registers or buggy restore code

Restore from U-Boot

swsusp and U-Boot

- Restoring from hibernation just involves copying pages from disk into memory and jumping to an address
  - Thats what U-Boot does!
- Restoring from U-Boot can be faster than booting a kernel just to copy pages
- Issues
  - U-Boot has no idea what address to jump to
  - U-Boot doesn't know the contents or even location of the nosave pages



Kernel Modifications

- U-Boot doesn't know about nosave pages or their address
- We instead save and restore them from the kernel
- Backup nosave pages are saved at boot
- Special version of cpu_resume is provided that restores nosave pages before calling the real cpu_resume

```
static int __init swsusp_arch_init(void)
{
        char *backup;
        size_t len;

        len = &__nosave_end - &__nosave_begin;
        backup = kmalloc(len, GFP_KERNEL);
        if (backup) {
                pr_info("%s: Backed up %d byte nosave region\n", __func__, len);
                memcpy(backup, &__nosave_begin, len);
        }

        __nosave_backup_phys = virt_to_phys(backup);
        __nosave_begin_phys = virt_to_phys(&__nosave_begin);
        __nosave_end_phys = virt_to_phys(&__nosave_end);

        return 0;
}
late_initcall(swsusp_arch_init);
```

```
ENTRY(cpu_resume_restore_nosave)
        ldr     r0, =__nosave_backup_phys
        ldr     r0, [r0]
        ldr     r1, =__nosave_begin_phys
        ldr     r1, [r1]
        ldr     r2, =__nosave_end_phys
        ldr     r2, [r2]
1:      ldmia   r0!, {r3-r10}
        stmia   r1!, {r3-r10}
        cmp     r1, r2
        bne     1b
        b       cpu_resume
```

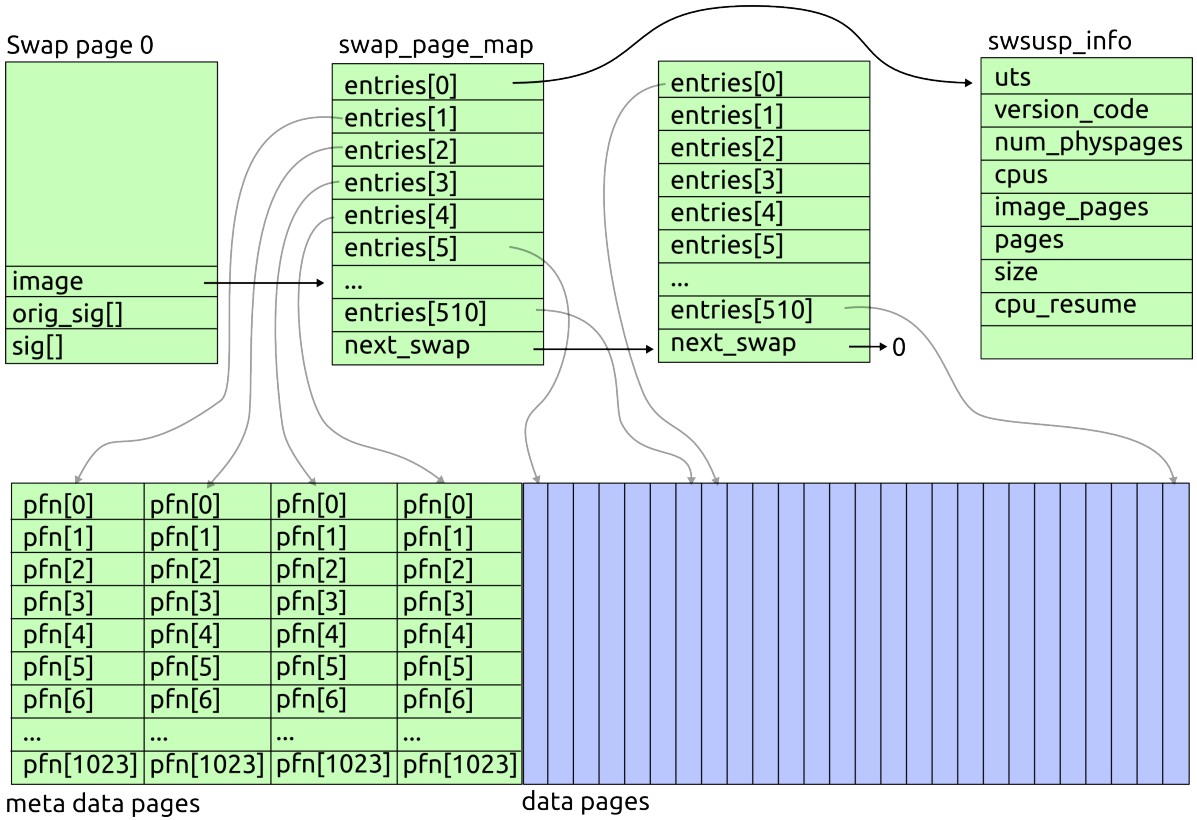
Kernel Modifications

- Need to pass address of cpu_resume function to U-Boot
  - Store in swsusp_info page
  - Add arch callback for storing that data in the swsusp_page
- Just stores the physical address of the new version of cpu_resume that first copies the nosave pages

```
void swsusp_arch_add_info(char *archdata, size_t size)
{
        *(u32 *) archdata = virt_to_phys(cpu_resume_restore_nosave);
}
```

swsusp Image Layout

- Each metadata entry is associated with the same numbered data page
- Each data page is to be loaded into memory at the pfn indicated by its metadata pfn entry



U-Boot modifications

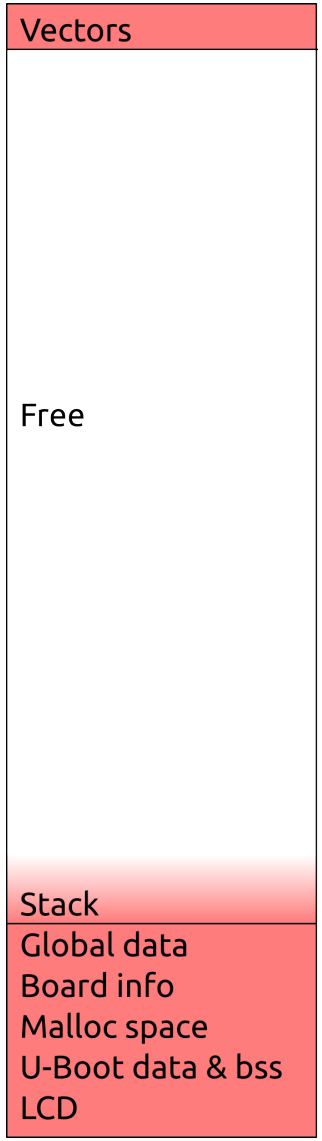
```
U-Boot# help swsusp
swsusp - Restore SWSUSP hibernation image

Usage:
swsusp <interface> [<dev[:part]>] [<offset>]
```

- Provide cmd_swsusp
  - No-op if S1SUSPEND sig does not exist
  - Rewrites sig with orig_sig to prevent boot loop on bad image
    - Snapshot booting can populate orig_sig with S1SUSPEND
  - Reads in metadata pages with pfn mappings
    - Also populates bitmap of used pages for easy access to free pages
  - Copy each data page to memory
    - Original location if it is free
    - Other wise copy to first available free page and update remap list
  - Copy finish function and cpu_resume address to free data page
  - Run finish function from free data page (use stack contained in free page)
    - Copies remapped pages to their correct location
    - Jumps to cpu_resume function

U-Boot Memory Mapping

- The U-Boot memory mapping makes it very easy to see if we can load a page directly into its original location
- If not, we load it into a location not used by U-Boot or the final location of any of the swsusp pages



Loading pfn and Free Page Mapping

- We utilize malloc'd pages to store the pfn index
- Mark used pages as we go

```
memset(pfn_pages, 0, nr_pfn_pages * sizeof(u32 *));
for (i = 0; i < nr_pfn_pages; i++) {
        u32 idx;
        pfn_pages[i] = malloc(PAGE_SIZE);
        if (!pfn_pages[i])
                goto mem_err;
        if (image_page_get_next(pfn_pages[i]) <= 0)
                goto read_err;
        for (idx = 0; idx < PAGE_SIZE / sizeof(u32); idx++) {
                u32 page = pfn_pages[i][idx];
                if (page == ~0UL)
                        break;
                free_page_mark_used(page);
        }
}
```

Loading swsusp Pages Into Memory

- Utilize free pages to store remapping lists, malloc'd data will be overwritten
- min_page is first free page in U-Boot memory map
- max_page is last free page in U-Boot memory map (well before stack pointer)
- If a page is to be copied into U-Boot's memory space, it is instead copied into an unused free page

```
remap_orig = pg2addr(free_page_get_next());
remap_temp = pg2addr(free_page_get_next());
remap_idx = 0;

for (i = 0; i < swsusp_info->image_pages; i++) {
        u32 page = pfn_pages[i >> 10][i & 0x3ff];
        if (page < min_page || page > max_page) {
                if (nr_remap == remap_idx + 1)
                        goto err;
                remap_orig[remap_idx] = pg2addr(page);
                page = free_page_get_next();
                remap_temp[remap_idx] = pg2addr(page);
                remap_idx++;
        }
        if (image_page_get_next(pg2addr(page)) <= 0)
                goto read_err;

}
```

Prepare to Copy Remapped Pages

- Final copy must happen from memory unused by swsusp or U-Boot
  - remap_orig/remap_temp already exist in free page
  - Utilize free page for final copy of remapped pages
    - Copy swsusp_finish into page
    - Copy context information into page
    - Setup stack pointer at end of page

```
/* put end markers on the remap list */
remap_orig[remap_idx] = (void *) ~0UL;
remap_temp[remap_idx] = (void *) ~0UL;

/* Make a copy of swsusp_finish in a free data page */
data_page = pg2addr(free_page_get_next());
memcpy(data_page, swsusp_finish, PAGE_SIZE);
swsusp_finish_copy = (void *) data_page;

/* Setup context for swsusp_finish */
context = (struct swsusp_finish_context *) (data_page + PAGE_SIZE);
context--;
context->remap_orig = remap_orig;
context->remap_temp = remap_temp;
context->cpu_resume = swsusp_info->cpu_resume;

/* Get a stack pointer for swsusp_finish */
stack_addr = ((char *) context) + PAGE_SIZE - sizeof(u32);

cleanup_before_linux();

/* Copy the final data from a safe place */
call_with_stack(swsusp_finish_copy, context, stack_addr);
```

Copy Remaining Pages

- Moved remapped pages into their originally intended location
- Call cpu_resume (actually cpu_resume_copy_nosave)

```
static void swsusp_finish (void *userdata)
{
        struct swsusp_finish_context *context = userdata;

        while (*context->remap_orig != (void *) ~0UL) {
                u32 *orig, *temp;
                int count;

                count = PAGE_SIZE / 4;
                orig = *context->remap_orig;
                temp = *context->remap_temp;
                while (count--)
                        *orig++ = *temp++;

                context->remap_orig++;
                context->remap_temp++;
        }
        context->cpu_resume();
}
```

Questions?

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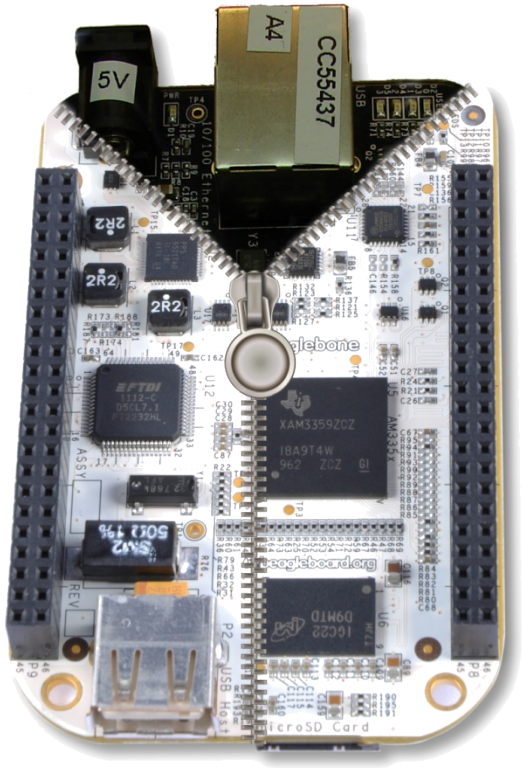

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