Kernel Rookie Guide
Workshop

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SAMSUNG
About me

- A Husband and Lord Father of Two Sons
- Senior Software Engineer
- involved in kernel development since Oct’10
  - ARM/Exynos
  - ~300 commits (JPEG codec - co-maintainer, USB gadget, others)
  - >30k LOC
  - >50k LOP
  - #19 in top 20 contributors for kernel 4.0 (by lines changed 3.19→4.0)
- Kernel Rookie Guide I..V 2012-2017 (internally @ Samsung)
  - Author
  - Instructor
Requirements 1/3

- Some C knowledge
- Ability to use ’make’
- Own laptop with Linux available
- Network connectivity
- Internet browser
Requirements 2/3

- In Linux:
  - qemu-system-arm version at least 2.5.0
  - Cross toolchain
  - Tools for building the kernel
  - tar
  - wget
  - editor
  - wget https://mirrors.edge.kernel.org/pub/linux/kernel/v4.x/linux-4.18.tar.xz
  - workshops.tar.gz (from the instructor)
  - extract linux-4.18.tar.xz and workshops.tar.gz next to each other (expect linux-4.18 and workshops directories next to each other)

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1 arm-linux-gnueabi-gcc expected in $PATH
2 tar xxf <filename>
Requirements 3/3

- On a Ubuntu 18.04 Desktop fresh install
  - `sudo apt-get install qemu-system-arm make gcc bison flex pkg-config libncurses-dev gcc-arm-linux-gnueabi vim-gtk`
- On older Ubuntus you might also need
  - `sudo apt-get install bc libssl-dev`
- Translate these requirements to the distro you intend to use at workshops!

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\(^3\) I tried it in a virtual machine
Workshop plan

Meeting the Linux kernel
OS purpose and Linux Hardware, Kernel & toolchain (Early) userspace

Writing basic modules
In-tree vs out-of-tree Module boilerplate code Linked lists Small allocations

Userspace interface
Syscalls Filesystems Devices

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Concurrency Synchronization primitives

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What now?
Rationale

- Ancient/bare-metal programming vs. modern programming
- More tasks than CPUs at a time (some vs. 1 or more)
- Scarce resources (cannot satisfy everyone at the same time)
- Devices
OS Purpose

- Manage processes (give everyone a chance to execute)
- Manage memory (code and data require memory)
- Manage devices (access peripherals)
OS major design decisions

- Microkernel vs monolithic (Tannenbaum vs Torvalds)
- How to use hardware capabilities
- How to interoperate with users
- Development model & project governance
Linux

- Monolithic, but with loadable modules
- Development discussed on mailing lists, patches
- Source code in git\(^4,5\)
- ~800MB w/o version control
- Indexing, also on-line, e.g.: https://elixir.bootlin.com

\(^4\)git://git.kernel.org/pub/scm/linux/kernel/git/torvalds/linux.git
\(^5\)https://git-scm.com/
Find `container_of` definition in 4.18 and try understanding it

If more than one found choose the one whose location looks most general

https://elixir.bootlin.com, use 4.18

---

6Look for TODO.txt in W0 from the extracted tar.gz
Workshop 0 solution
There is no separate 'kernel process'
User process runs in CPU unprivileged mode
  Until it needs operations which by OS design must happen in privileged mode
  Syscalls (system calls) are gateways between these modes
  A process, once in privileged mode, IS the 'running kernel'
  Privileged code can actually reject servicing the syscall
Multitasking
  schedule()
  Process can voluntarily yield the CPU while in kernel mode
  Timer interrupt
Self contained

---

7 Kernel threads exist, though
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What now?
Hardware flavours

- Originally i386
- Many added, incl. arm and arm64
- Hardware discovery (ACPI, dtb\(^8\), autodetection)
- Workshops
  - Emulated hardware - qemu\(^9\)
  - ARM Versatile Express (qemu: vexpress-a9)

\(^8\)https://www.devicetree.org/
\(^9\)https://www.qemu.org/
Kernel configuration

- Highly configurable
  - Architectures
  - Kernel subsystems (/kernel, /mm, /net, /drivers/*, /arch/* etc.)
  - Peripherals
  - Compile-in/Modularize/Leave out
- Dedicated tools complementing the Makefile

  Kconfig language for specifying kernel composition and dependencies
  defconfig sane set of choices for given architecture
  .config result of defconfig application

```
# sane set of settings
make ARCH=arm vexpress_defconfig

# customization if needed
make ARCH=arm menuconfig
```

Listing 1: Configuring the kernel
Kernel building

- (Cross-)toolchain10 (ARCH=..., CROSS_COMPILE=...)
- Keep your CPU cores busy with -j!

```bash
# either
make -j8 ARCH=arm CROSS_COMPILE=arm-linux-gnueabi-

# or
export CROSS_COMPILE=arm-linux-gnueabi-
make -j8 ARCH=arm
```

Listing 2: Compiling the kernel

- Make targets

```bash
make ARCH=arm help
```

Listing 3: Getting help on make targets

---

10 arm-linux-gnueabi-gcc expected in $PATH
Workshop 1

- Patch the kernel with the provided patches
- Configure & cross-compile the kernel for vexpress
- Analyze the vexpress-run.sh script
- Run emulated machine in qemu with the script
  - ^A-X to exit qemu

Look for TODO.txt in W1
Workshop 1 solution
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What now?
System layers

- USERSPACE
- KERNEL
- HARDWARE (SoC)
Ramfs, tmpfs, rootfs, initramfs

ramfs  disk caches mounted as filesystem, no backing storage

tmpfs  ramfs += size limit, swapping

rootfs  special instance of ramfs/tmpfs, always present

initramfs  optional cpio archive\(^{12}\), extracted into rootfs at boot time

- Initramfs handy for experiments with kernel
- We use external initramfs for workshops

\(^{12}\) built into the kernel and/or provided by bootloader
Minimal userspace for workshops

- busybox\textsuperscript{13} + minimal /etc packaged into initramfs
- Single binary containing ’applets’ corresponding to standard tools
- Tool from kernel source tree understands both directories and list files

```plaintext
1 cat initramfs.list
2 file /busybox-armv7r ../initramfs/busybox-armv7r 0755 0 0
3 dir /sbin 0755 0 0
4 dir /proc 0755 0 0
5 dir /sys 0755 0 0
6 dir /bin 0755 0 0
7 dir /usr 0755 0 0
8 dir /usr/sbin 0755 0 0
9 dir /usr/bin 0755 0 0
10 dir /etc 0755 0 0
11 dir /etc/init.d 0755 0 0
12 file /etc/inittab ../initramfs/inittab 0755 0 0
13 file /etc/init.d/rcS ../initramfs/rcS 0755 0 0
```

Listing 4: Initramfs list - host paths relative to kernel source topdir!

\textsuperscript{13}https://busybox.net/
Workshop 2^{14}

- Analyze generate_initramfs.sh
- Add a short text file to initramfs image using generate_initramfs.sh
- Run the virtual machine and verify new file’s presence and contents

^{14}TODO.txt in W2
Workshop 2 solution
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What now?
Source code placement

**in-tree**  inside kernel source directory
**out-of-tree**  outside kernel source directory

- Kernel build system happily handles both!
Out-of-tree Makefile

- LDD3 provides a nice Makefile (meant for compiling modules for currently running kernel)
- The below code creates hello.ko module (from hello.o and implicitly from hello.c)

```bash
# If KERNELRELEASE is defined, we've been invoked from the
# kernel build system and can use its language.
ifeq ($(KERNELRELEASE),)
    obj-m := hello.o
else
    KERNELDIR ?= /lib/modules/$(shell uname -r)/build
    PWD := $(shell pwd)
endif

default:
    $(MAKE) -C $(KERNELDIR) M=$(PWD) modules
```

**Listing 5: Out-of-tree module makefile**

Interaction with modules

- Module dependencies
- Userspace tools
  - `insmod` dependencies must be provided
  - `modprobe` dependencies resolved
  - `rmmod` unload only this module
  - `modprobe -r` unload this module and unused dependencies
  - `lsmod` list loaded modules
  - `depmod` analyze module dependencies

```
# loading
insmod <filename>.ko
# or
modprobe <module name>

# unloading
rmmod <module name>
# or
modprobe -r <module name>

# list loaded
lsmod
```

Listing 6: Loading/unloading kernel modules
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What now?
Module boilerplate code

```c
#include <linux/init.h>
#include <linux/module.h>

static int hello_init(void) {
    return 0;
}
module_init(hello_init);

static void hello_exit(void) {
    module_exit(hello_exit);
}
MODULE_LICENSE("GPL");
```

Listing 7: Linux kernel module boilerplate code
Module parameters

- A value passed to module at insertion\textsuperscript{16,17}
- Several types (int, string, etc)
- A way of associating the said value with a variable in the module

```c
/* use this at file scope! */
module_param(<var_name>, int, <flags>) /* flags for sysfs access mode */
```

Listing 8: Module parameters (selection)

\textsuperscript{16} or in the kernel command line if module compiled-in
\textsuperscript{17} or through sysfs if parameter available there
Kernel diagnostic messages circular buffer

- Always available
- Never runs out of space\(^{18}\)
- Some messages can be simultaneously output to the current system console\(^{19}\)
- `dmesg` to output the diagnostic messages circular buffer contents

\(^{18}\)But older messages can be overwritten

\(^{19}\)Depends on message levels and current kernel settings
Message levels

- message levels KERN_*
  
  EMERG (0) system is unusable
  ALERT (1) action must be taken immediately
  CRIT (2) critical conditions
  ERR (3) error conditions
  WARNING (4) warning conditions
  NOTICE (5) normal but significant condition
  INFO (6) informational
  DEBUG (7) debug-level messages

```
1 cat /proc/sys/kernel/printk
2 4 4 1 7
```

Listing 9: Printk levels
Writing messages to the console

- Output methods
  
  \begin{verbatim}
  printk printf equivalent
  pr_<level> printf equivalent (level: emerg, alert, crit etc.)\textsuperscript{20}
  \end{verbatim}

- Remember about newlines!

```c
/* default level */
printk("Hello, world!\n");

/* selected level */
printk(KERN_WARNING "Hello, warning!\n");

pr_warning("Hello, warning!\n");
```

Listing 10: Outputting messages from kernel

\textsuperscript{20} for pr_debug see Documentation/admin-guide/dynamic-debug-howto.rst
Workshop 3

- Write, compile and deploy (initramfs!) a module which does (almost) nothing
  - Module’s init shall output a welcome string
  - Module’s exit shall output a goodbye string
- Load/unload the module in the virtual machine

21TODO.txt in W3
Workshop 3 solution
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What now?
Linked lists in kernel

- Doubly-linked
- Circular

```c
struct list_head {
    struct list_head *next, *prev;
};
```

Listing 11: Linked list structure

- Embedded struct list_head
- `container_of`
Linked lists API (selection)

```c
/* declare list handle */
LIST_HEAD(my_list)

/* add/delete */
list_add(struct list_head *new, struct list_head *head)
list_add_tail(struct list_head *new, struct list_head *head)
list_del(struct list_head *entry)

/* query/get elements */
int list_empty(const struct list_head *head)
list_entry(ptr, type, member)
list_first_entry(head, type, member)
list_last_entry(head, type, member)

/* iterate */
list_for_each(pos, head)
list_for_each_safe(pos, next_tmp, head)
list_for_each_entry(pos, head, member)
list_for_each_entry_safe(pos, next_tmp, head, member)

/* see include/linux/list.h for more */
```

Listing 12: Linked lists API (selection)
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What now?
Small allocations

kzalloc allocate (several kB max)
kfree free

- sizeof is your friend
- verify that the return value is != NULL
- For greater amounts use other methods!

```
1  void *kzalloc(size_t size, gfp_t flags) /* flags almost always GFP_KERNEL */
2  kfree(const void *)
```

Listing 13: Small allocations API

---

22 e.g. page allocator, slab caches, vmalloc
Workshop 4

- Analyze krg.c
- Fill the blanks as instructed inline
- Compile and deploy the module
- Test your module
  - Try inserting and removing it several times
  - Try using the 'number' module parameter

23 TODO.txt in W4
Workshop 4 solution
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What now?
Syscalls (1/2)

- Userspace programs don't 'link' against kernel
- Syscalls have numbers (e.g. on ARM exit:1, fork:2, read:3, write:4 etc)
- ABI - defines interaction between binary programs, including convention of passing parameters, receiving results and triggering kernel services
  - CPU registers (e.g. on ARM r0, r1, ...)
  - stack

---

24 Each ABI requires its matching toolchain
Syscalls (2/2)

- ARM Embedded ABI (here: 32-bit)
  - syscall number in r7
  - syscall arguments in r0...r6
  - return value in r0
  - software interrupt #0 triggers syscall execution

Listing 14: Calling a syscall

1 # call syscall 'exit' with parameter 0
2 mov r7, #1
3 mov r0, #0
4 svc #0

- libc is your friend!
- strace is your friend, too!

---

25 man syscall, other ARM ABIs exist, e.g. armhf
Workshop 5

- Analyze, compile and deploy "Hello, world" written in ARM assembly
- Run it in the virtual machine

---

use the provided compile_hello.sh

use the provided compile_hello.sh

TODO.txt in W5
Workshop 5 solution
Adding new syscalls

- Don’t
- Unless you really have to\(^{28}\)
- Or in a training

\(^{28}\)Difficult if you want it upstream
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What now?
Architectural overview

- User
- Syscall interface
- VFS (Virtual Filesystem/Virtual Filesystem Switch)
- 'Real' filesystems (ext2, ext3, ext4....), pseudo filesystems
- Block layer
- Device drivers

29 all available ('real' and pseudo) listed in /proc/filesystems
Pseudo filesystems

- Pseudo filesystems
  - sysfs
  - proc
  - debugfs
  - configfs
  - ...
- No Block layer/Device drivers
- Particular filesystem driver knows what it means to read/write a 'file'
- 'Everything is a file' philosophy
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What now?
Devices and drivers

- One of OS purposes: Manage devices
- Character devices, block devices
- entries in /dev
ioctl

- Swiss army knife of all syscalls\(^\text{30}\)
- Called on device special file file descriptor
- 'Sub-syscall' number encoded in parameter (interpreted by driver)
- Optional pointer to user memory

```
1 int ioctl(int fd, unsigned long request, ...);
```

Listing 15: libc’s ioctl() prototype

\(^\text{30}\) man ioctl
Memory access considerations

- process virtual memory
- kernel virtual memory
- accessing user memory from kernel might be non-trivial!\(^31\)
- `copy_from_user()`, `copy_to_user()`

\(^{31}\)https://youtu.be/EWwfMM2AW9g
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What now?
UP vs SMP?

- SMP: multiple threads of execution at the same time
- UP: single thread of execution at a time

BUT

- Even on UP effectively concurrent!

SO

- Synchronization/locking required in either case
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What now?
Common synchronization primitives 1/3

- Semaphore
  - Can be incremented and decremented at will
  - Any thread of execution can do it
  - If current value 0, next to decrement will be put to sleep
  - Sleeping until someone increments (first come - first served)
  - Potentially long waiting time

```c
/* definition */
/* initial count 1 */
DEFINE_SEMAPHORE(name)
/* any initial count */
struct semaphore my_semaphore = __SEMAPHORE_INITIALIZER(my_semaphore, initial_count)
void sema_init(struct semaphore *sem, int val)
/* increment/decrement */
void up(struct semaphore *sem)
int down_interruptible(struct semaphore *sem)
```

Listing 16: Semaphore API (selection)

---

32 #include <linux/semaphore.h>
Common synchronization primitives 2/3

- **Mutex**
  - Only two states: available and busy (‘a binary semaphore’)
  - Can only be released by the one who acquired
  - If busy, next to acquire will be put to sleep
  - Sleeping until someone releases (first come - first served)
  - Avoid long waiting time

---

```c
/* definition */
#define DEFINE_MUTEX(mutexname)
mutex_init(mutex)

/* acquire/release */
void mutex_lock(struct mutex *lock)
void mutex_unlock(struct mutex *lock)

/* acquire or return, without waiting */
int mutex_trylock(struct mutex *lock)
```

Listing 17: Mutex API (selection)

---

#include <linux/mutex.h>
Common synchronization primitives 3/3

- Spinlock
  - Busy waiting (can be good!)
  - While contended, no guarantee of 'fair' acquiring across all architectures
  - Sometimes turning off interrupts on local CPU required
  - Must be used if sleeping prohibited in a context
  - Supposed to be kept for very short time

```c
/* initialize */
DEFINE_SPINLOCK(lock)

/* acquire/release */
void spin_lock(spinlock_t *lock)
void spin_unlock(spinlock_t *lock)

spin_lock_irqsave(lock, flags)
void spin_unlock_irqrestore(spinlock_t *lock, unsigned long flags)

/* acquire or return, without waiting */
int spin_trylock(spinlock_t *lock)
```

Listing 18: Spinlock API (selection)

```c
#include <linux/spinlock.h>
```
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What now?
Producer and consumer (aka Bounded buffer) problem

```c
1 down(empty_count) /* at init: buffer size */
2 lock(buffer)
3 put_into(buffer)
4 unlock(buffer)
5 up(fill_count)
```

Listing 19: Producer pseudo code

```c
1 down(fill_count) /* at init: 0 */
2 lock(buffer)
3 get_from(buffer)
4 unlock(buffer)
5 up(empty_count)
```

Listing 20: Consumer pseudo code
Workshop 6

- Analyze the userspace program (syscall.c) and discover what it does
- Analyze arch/arm/kernel/sys_arm.c in kernel sources and fill the blanks as instructed inline
- Rebuild the kernel
- Try running ./syscall in the virtual machine
  - ./syscall -p <number> to put element into buffer
  - ./syscall -g to get element from buffer
  - You might need to put either into background with & (e.g. while getting from empty buffer)

35 TODO.txt in W6
Workshop 6 solution
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What now?
Further reading/coding

- symbol exporting (EXPORT_SYMBOL*)
- more allocators and memory management, including DMA
- more locking (atomics, rw locks, RCU, memory barriers...)
- character devices
- driver model
- frameworks, subsystems
- Device Tree
- git & patches preparation
- mailing lists
Thank you for attention!
andrzej.p@samsung.com
Appendix
Listing 21: generate_initramfs.sh

```bash
#!/bin/bash
LINUX_SOURCE=../linux-4.18
INITRAMFS_PATH=${PWD}/initramfs
MODULES_PATH=${PWD}/..
INITRAMFS_LIST_PATH=${PWD}/initramfs

cd ${LINUX_SOURCE}
scripts/gen_initramfs_list.sh -o ${INITRAMFS_PATH}/initramfs.cpio \${INITRAMFS_LIST_PATH}/initramfs.list
```

Listing 22: vexpress_run.sh

```bash
#!/bin/bash
LINUX_SOURCE=../linux-4.18
INITRAMFS_PATH=initramfs
QEMU_PREFIX=

${QEMU_PREFIX}qemu-system-arm \-nographic \-M vexpress-a9 \-kernel ${LINUX_SOURCE}/arch/arm/boot/zImage \-append "root=/dev/ram rdinit=/busybox-armv7r init=/init,console=ttyAMA0,115200n8 earlyprintk" \-dtb ${LINUX_SOURCE}/arch/arm/boot/dts/vexpress-v2p-ca9.dtb \-initrd ${INITRAMFS_LIST_PATH}/initramfs.cpio
```
Listing 23: initramfs.list

1 ::sysinit:/etc/init.d/rcS
2 ::askfirst:-/bin/sh
3 ::ctrlaltdel:/sbin/reboot
4 ::shutdown:/sbin/swapoff -a
5 ::shutdown:/sbin/umount -a -r
6 ::restart:/sbin/init

Listing 24: inittab
#!/busybox-armv7r sh
/busybox-armv7r --install
mount -t proc none /proc
mount -t sysfs none /sys
mdev -s
echo /sbin/mdev > /proc/sys/kernel/hotplug

Listing 25: rcS
From 3aae8f646785afab58f219511d6280029af7ac0 Mon Sep 17 00:00:00 2001
From: Andrzej Pietrasiewicz <andrzej.p@samsung.com>
Date: Fri, 17 Aug 2018 13:58:36 +0200
Subject: [PATCH] kbuild: make sorting initramfs contents independent of locale

Some LANG values (e.g. pl_PL.UTF-8) cause the sort command to output
files before their parent directories, which makes them inaccessible for
the kernel. In other words, when the kernel populates the rootfs, it is
unable to create files whose parent directories have not yet created.

This patch makes sorting use the default (LANG=C) locale, which results in
correctly laid out initramfs images (parent directories before files).

Signed-off-by: Andrzej Pietrasiewicz <andrzej.p@samsung.com>

---
scripts/gen_initramfs_list.sh | 2 +- 
1 file changed, 1 insertion(+), 1 deletion(-)
diff --git a/scripts/gen_initramfs_list.sh b/scripts/gen_initramfs_list.sh
index 10e528b..0aad760 100755
--- a/scripts/gen_initramfs_list.sh
+++ b/scripts/gen_initramfs_list.sh
@@ -174,7 +174,7 @@ dir_filelist() {
    ${dep_list}header "$1"
    srcdir=$(echo "$1" | sed -e 's://*:/:g')
    - dirlist=$(find "$srcdir" -printf "%p:%m:%U:%G\n" | sort)
+  dirlist=$(find "$srcdir" -printf "%p:%m:%U:%G\n" | LANG=C sort)
    # If $dirlist is only one line, then the directory is empty
    if [ "$(echo "$dirlist" | wc -l)" -gt 1 ]; then
        --
2.7.4

Listing 26: kbuild patch
From 21cf89b5a128b6a3390ef6d6c160f67edfde20fa9 Mon Sep 17 00:00:00 2001
From: Bartlomiej Zolnierkiewicz <b.zolnierkie@samsung.com>
Date: Fri, 31 Aug 2018 11:53:36 +0200
Subject: [PATCH] Revert "irqdomain: Don't set type when mapping an IRQ"

This reverts commit 1e2a7d78499ec8859d2b469051b7b80bad3b08aa.

This makes ARM QEMU vexpress platform work again.

Signed-off-by: Bartlomiej Zolnierkiewicz <b.zolnierkie@samsung.com>

---
include/linux/irqdomain.h | 3 ---
kernel/irq/irqdomain.c | 23 +++++------------------
2 files changed, 5 insertions(+), 21 deletions(-)

diff --git a/include/linux/irqdomain.h b/include/linux/irqdomain.h
index dccfa65..e93742d 100644
--- a/include/linux/irqdomain.h
+++ b/include/linux/irqdomain.h
@@ -526,9 +526,6 @@ static inline int irq_domain_alloc_irqs(struct irq_domain *domain,
 return -1;
 }
static inline void irq_domain_free_irqs(unsigned int virq,
-    unsigned int nr_irqs) { }
- static inline bool irq_domain_is_hierarchy(struct irq_domain *domain)
{ }
static inline int irq_domain_alloc_irqs(struct irq_domain *domain,}
    return -1;

Listing 27: irqdomain patch 1/3
diff --git a/kernel/irq/irqdomain.c b/kernel/irq/irqdomain.c
index 5d9fc01b..75f175b 100644
--- a/kernel/irq/irqdomain.c
+++ b/kernel/irq/irqdomain.c
@@ -744,7 +744,6 @@ static void of_phandle_args_to_fwspec(struct of_phandle_args *irq_data,
 unsigned int irq_create_fwspec_mapping(struct irq_fwspec *fwspec)
 {
  struct irq_domain *domain;
- struct irq_data *irq_data;
  irq_hw_number_t hwirq;
  unsigned int type = IRQ_TYPE_NONE;
  int virq;
-@@ -792,11 +791,7 @@ unsigned int irq_create_fwspec_mapping(struct irq_fwspec *fwspec)
   if (irq_get_trigger_type(virq) == IRQ_TYPE_NONE) {
-    irq_data = irq_get_irq_data(virq);
-    if (!irq_data)
-      return 0;
-    irqd_set_trigger_type(irq_data, type);
+   irq_set_irq_type(virq, type);
    return virq;
   }
   */
   if (irq_get_trigger_type(virq) == IRQ_TYPE_NONE) {
@@ -816,18 +811,10 @@ unsigned int irq_create_fwspec_mapping(struct irq_fwspec *fwspec)
       irq_data = irq_get_irq_data(virq);
      if (!irq_data)
        return 0;
-      irqd_set_trigger_type(irq_data, type);
+     irq_set_irq_type(virq, type);
        return virq;
   }
@@ -816,18 +811,10 @@ unsigned int irq_create_fwspec_mapping(struct irq_fwspec *fwspec)
       return virq;
   }
- irq_data = irq_get_irq_data(virq);
- if (!irq_data) {
- if (irq_domain_is_hierarchy(domain))
- irq_domain_free_irqs(virq, 1);

Listing 28: irqdomain patch 2/3
else
    irq_disable_mapping(virq);
    return 0;
}

/* Store trigger type */
irq_set_trigger_type(irq_data, type);

/* Set type if specified and different than the current one */
if (type != IRQ_TYPE_NONE &&
    type != irq_get_trigger_type(virq))
    irq_set_irq_type(virq, type);
return virq;
}
EXPORT_SYMBOL_GPL(irq_create_fwspec_mapping);
Signed-off-by: Andrzej Pietrasiewicz <andrzej.p@samsung.com>

---

```
arch/arm/kernel/sys_arm.c | 116 ++++++++++++++++++++++++++++++++++++++++++++++
arch/arm/tools/syscall.tbl |    2 +
2 files changed, 118 insertions(+)
```

```
diff --git a/arch/arm/kernel/sys_arm.c b/arch/arm/kernel/sys_arm.c
index bdf7514..072cc11 100644
--- a/arch/arm/kernel/sys_arm.c
+++ b/arch/arm/kernel/sys_arm.c
@@ -27,6 +27,9 @@
 #include <linux/ipc.h>
 #include <linux/uaccess.h>
 #include <linux/slab.h>
+#include <linux/semaphore.h>
+#include <linux/mutex.h>
+#include <linux/list.h>

 /*
  * Since loff_t is a 64 bit type we avoid a lot of ABI hassle
  @@ -37,3 +40,116 @@ asmlinkage long sys_arm_fadvise64_64(int fd, int advice,
  {
      return ksys_fadvise64_64(fd, offset, len, advice);
  }

Listing 30: krg workshop patch 1/5
+struct krg_job {
+    struct list_head entry;
+    int id;
+};
+
+static struct semaphore krg_empty_count = __SEMAPHORE_INITIALIZER(krg_empty_count, KRG_BUF_SIZE);
+static struct semaphore krg_fill_count = __SEMAPHORE_INITIALIZER(krg_fill_count, 0);
+
+static LIST_HEAD(krg_jobs);
+static DEFINE_MUTEX(krg_mutex);
+
+SYSCALL_DEFINE1(krg_put, int, id)
+{
+    struct krg_job *job;
+    job = NULL;
+    /
+    * TODO: allocate struct krg_job
+    * use kzalloc()
+    */
+    if (!job)
+        return PTR_ERR(job);
+    /
+    * TODO: set job id */
+    +
+    */
+    * TODO: decrement empty count, use
+    */
+    +
+    if (down_interruptible()) {
+        * TODO: avoid memory leak
+        * use kfree()
+    }*
+    +
+    // upper layers can handle retrying

Listing 31: krg workshop patch 2/5
```c
+ * return -ERESTARTSYS;
+ * }
+ */
+ */
+ */
+ */
+ printk("> put:%d\n", job->id);
+ */
+ */
+ */
+ */
+ */
+ */
+ return 0;
+ }
+ } krg_get
SYSCALL_DEFINE0(krg_get)
+ {
+ struct krg_job *job;
+ int ret;
```

Listing 32: krg workshop patch 3/5
Listing 33: krg workshop patch 4/5

```c
+ /*
+  * TODO: decrement fill count, use
+  * if (down_interruptible())
+  * return -ERESTARTSYS;
+  */
+
+ /*
+  * TODO: ensure only one process accesses the buffer
+  * use mutex_lock()
+  */
+
+ /*
+  * TODO: let 'job' point to the first element of the buffer
+  * use job = list_first_entry()
+  */
+
+ printk("<@get:%d\n", job->id);
+
+ ret = job->id;
+
+ /*
+  * TODO: remove the element from the buffer
+  * use list_del()
+  */
+
+ /*
+  * TODO: avoid memory leak
+  * use kfree()
+  */
+
+ /*
+  * TODO: let other processes access the buffer
```
diff --git a/arch/arm/tools/syscall.tbl b/arch/arm/tools/syscall.tbl
index fbc74b5..febf960 100644
--- a/arch/arm/tools/syscall.tbl
+++ b/arch/arm/arm/tools/syscall.tbl
@@ -413,3 +413,5 @@
 396 common pkey_free  sys_pkey_free
 397 common statx  sys_statx
 398 common rseq  sys_rseq
+399 eabi krg_put  sys_krg_put
+400 eabi krg_get  sys_krg_get
--
 2.7.4

Listing 34: krg workshop patch 5/5
1. Find container of definition in 4.18 and try understanding it

2. If more than one found choose the one whose location looks most general

3. [elkix.bootlin.com](https://elixir.bootlin.com), use 4.18

Listing 35: W0/TODO.txt

1. Patch the kernel with the provided patches

   In kernel source directory:

   ```
   patch -p1 < PATH_TO_WORKSHOPS/kernel-patches/0001-kbuild....
   patch -p1 < PATH_TO_WORKSHOPS/kernel-patches/0001-Revert....
   patch -p1 < PATH_TO_WORKSHOPS/kernel-patches/0001-krg....
   ```

2. Configure & cross-compile the kernel for vexpress

   In kernel source directory:

   ```
   make ARCH=arm vexpress_defconfig
   make -j8 ARCH=arm CROSS_COMPILE=arm-linux-gnueabi-
   ```

3. Analyze the vexpress-run.sh script

4. Run emulated machine in qemu with the script

   `^A-X` to exit qemu

Listing 36: W1/TODO.txt
1. Add a short text file to initramfs image

Use initramfs.list - pay special attention to host paths which are relative to kernel source toplevel directory!

2. Use generate initramfs.sh to build initramfs

3. Run the virtual machine and verify new file’s presence and contents

Listing 37: W2/TODD.txt

1. Write, compile and deploy (initramfs!) a module which does (almost) nothing

Module’s init shall output a welcome string
Module’s exit shall output a goodbye string

Use the W3 directory and a Makefile there.

Remember about ARCH=arm and CROSS_COMPILE=arm-linux-gnueabi-

2. Load/unload the module in the virtual machine

Listing 38: W3/TODD.txt
```bash
ifneq (${KERNELRELEASE},)

obj-m := hello.o

else

# modify appropriately
LINUX_SOURCE := ../../linux-4.18

PWD := $(shell pwd)

default:

${MAKE} -C ${LINUX_SOURCE} SUBDIRS=${PWD} modules

clean:

${MAKE} -C ${LINUX_SOURCE} SUBDIRS=${PWD} clean

endif
```

Listing 39: W3/Makefile

1. Analyze krg.c
2. Fill the blanks as instructed inline
3. Compile and deploy the module
   Remember about ARCH=arm and CROSS_COMPILE=arm-linux-gnueabi-
4. Test your module
   Try inserting and removing it several times
   Try using the ‘number’ module parameter

Listing 40: W4/TODO.txt
ifneq (${KERNELRELEASE},)

obj-m := krg.o

else

# modify appropriately
LINUX_SOURCE := ../..\linux-4.18

PWD := $(shell pwd)

default:
    ${MAKE} -C ${LINUX_SOURCE} SUBDIRS=${PWD} modules

clean:
    ${MAKE} -C ${LINUX_SOURCE} SUBDIRS=${PWD} clean

endif

Listing 41: W4/Makefile
#include <linux/module.h>
#include <linux/list.h>
#include <linux/slab.h>

struct data {
    int id;
    struct list_head entry;
};

static LIST_HEAD(collection);

/* The module allocates ‘number’ instances (default: 3) of struct data
 * and adds them to ‘collection’.
 */
static int number = 3;
module_param(number, int, 0);

int krg_init(void)
{
    struct data *data;
    int i;

    /* we want our list to have some length, no more than 1000 */

    for (i = 0; i < number; i++)
    {
        data = &collection.entry;
        data->id = i;
        data->entry.next = NULL;
        data->entry.prev = NULL;
        add_to_list(data, &collection);
    }

    return 0;
}
if (number <= 0 || number > 1000)
    return -EINVAL;

/* TODO: ensure appropriate ‘number‘ of iterations */
for (i = 0; i < 0; ++i) {
    /*
     * TODO: allocate a struct data
     * use kzalloc()
     */
    data = NULL;
    if (!data)
        goto no_memory;

    /* TODO: set the id member of struct data to i */

    /*
     * TODO: add struct data after the last element of collection
     * use list_add_tail()
     */
    printk("%s added:%d@%px\n", __func__, data->id, data);
}

return 0;

no_memory:
while (i--) {
    /*
     * TODO: let ‘data‘ point to last element of collection
     * use list_last_entry()
     */
}

Listing 43: W4/krg.c 2/4
* TODO: remove the element from the collection
* use list_del()
*/

/*
 * TODO: free the memory occupied by the removed element
 * use kfree()
 */

return -ENOMEM;
}

module_init(krg_init);

void krg_exit(void)
{
  struct data *data;

  while (number--)
  {
    /*
     * TODO: let 'data' point to last element of collection
     * use list_last_entry()
     */

    /*
     * TODO: remove the element from the collection
     * use list_del()
     */

    printk("%s removed:%d@%px\n", __func__, data->id, data);

    /*
     * TODO: free the memory occupied by the removed element
     * use kfree()
     */
Listing 45: W4/krg.c 4/4

1. Analyze, compile and deploy 'Hello, world' written in ARM assembly

See hello.S
use the provided compile_hello.sh

symbolic numbers of write and exit syscalls

necessary ARM assembly:

```asm
mov rX, <immediate>  - store <immediate> value in register rX
ldr rX, <address>    - store <address> value in register rX
svc <immediate>      - trigger software interrupt number <immediate>
```

2. Run it in the virtual machine

Listing 46: W5/TODO.txt
#!/bin/bash

LINUX_SOURCE=../../linux-4.18
#
# IMPORTANT!
#
# run these commands once before running this script:
#
# cd $LINUX_SOURCE
# make ARCH=arm headers_install
#
arm-linux-gnueabi-gcc hello.S -c -static -I$LINUX_SOURCE/usr/include
arm-linux-gnueabi-ld hello.o -o hello

Listing 47: W5/compile_hello.sh

#include "linux/unistd.h"
.data
hello_string:
.ascii "Hello\nWorld\n"
.text
.globl _start
_start:
    mov r7, __NR_write
    mov r0, #1
    ldr r1,=hello_string
    mov r2, #12
    svc #0
    mov r7, __NR_exit
    mov r0, #0
    svc #0

Listing 48: W5/hello.S
1. Analyze the userspace program (syscall.c) and discover what it does

2. Analyze arch/arm/kernel/sys_arm.c in kernel sources and fill the blanks as instructed inline

3. Rebuild the kernel

Remember about ARCH=arm CROSS_COMPILE=arm-linux-gnueabi-

4. Try running ./syscall in the virtual machine

./syscall -p <number> to put element into buffer
./syscall -g to get element from buffer
You might need to put either into background with &
(e.g. while getting from empty buffer)

When trying to get from empty buffer the process will sleep waiting on the semaphore. If you don’t put the process into background you have no other shell available to put the element into buffer.
Converse situation happens when trying to put into full buffer.

Listing 49: W6/TODO.txt
```c
#include <ctype.h>
#include <errno.h>
#include <getopt.h>
#include <stdbool.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include "linux/unistd.h"

int main(int argc, char *argv[]) {
    int value;

    while ((value = getopt(argc, argv, "p:g")) != -1)
        switch (value) {
            case 'p':
                if (!isdigit(optarg[0])) {
                    fprintf(stderr, "Cannot parse put argument!\n");
                    exit(EXIT_FAILURE);
                }
                value = atoi(optarg);
                return (syscall(__NR_krg_put, value) < 0) ? errno : 0;
            case 'g':
                value = syscall(__NR_krg_get);
                return (value < 0) ? errno : 0;
            default:
                exit(EXIT_FAILURE);
        }
    return 0;
}
```

Listing 50: W6/syscall.c