Project 2: Android Memory and Scheduler

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Objectives

1. Compile the Android kernel
2. Familiarize Android memory
3. Tracing memory for tasks
4. Implement a Race-Averse Scheduler

Recompile the Kernel

Compile the Linux Kernel

- Make sure that your environment variables are correct.

```
export JAVA_HOME=/usr/lib/jdk1.8.0_73
export JRE_HOME=/usr/lib/jdk1.8.0_73/jre
export CLASSPATH=.:$CLASSPATH:$JAVA_HOME/lib:$JRE_HOME/lib
export PATH=$PATH:$JAVA_HOME/bin:$JRE_HOME/bin
export PATH=~/Kit/android-sdk-linux/platform-tools:$PATH
export PATH=~/Kit/android-sdk-linux/tools:$PATH
export PATH=~/Kit/android-ndk-linux:$PATH
export PATH=~/Kit/android-ndk-linux/toolchains/arm-linux-androideabi-4.9/prebuilt/linux-x86_64/bin:$PATH
```

Compile the Linux Kernel (cont.)

- Modify Makefile in the kernel
  - Change
    - ARCH ?= $(SUBARCH)
    - CROSS_COMPILE ?=
  - To

```
export KBUILD_BUILDHOST := $(SUBARCH)
ARCH            ?= arm
CROSS_COMPILE   ?= arm-linux-androideabi-

# Architecture as present in compile.h
```

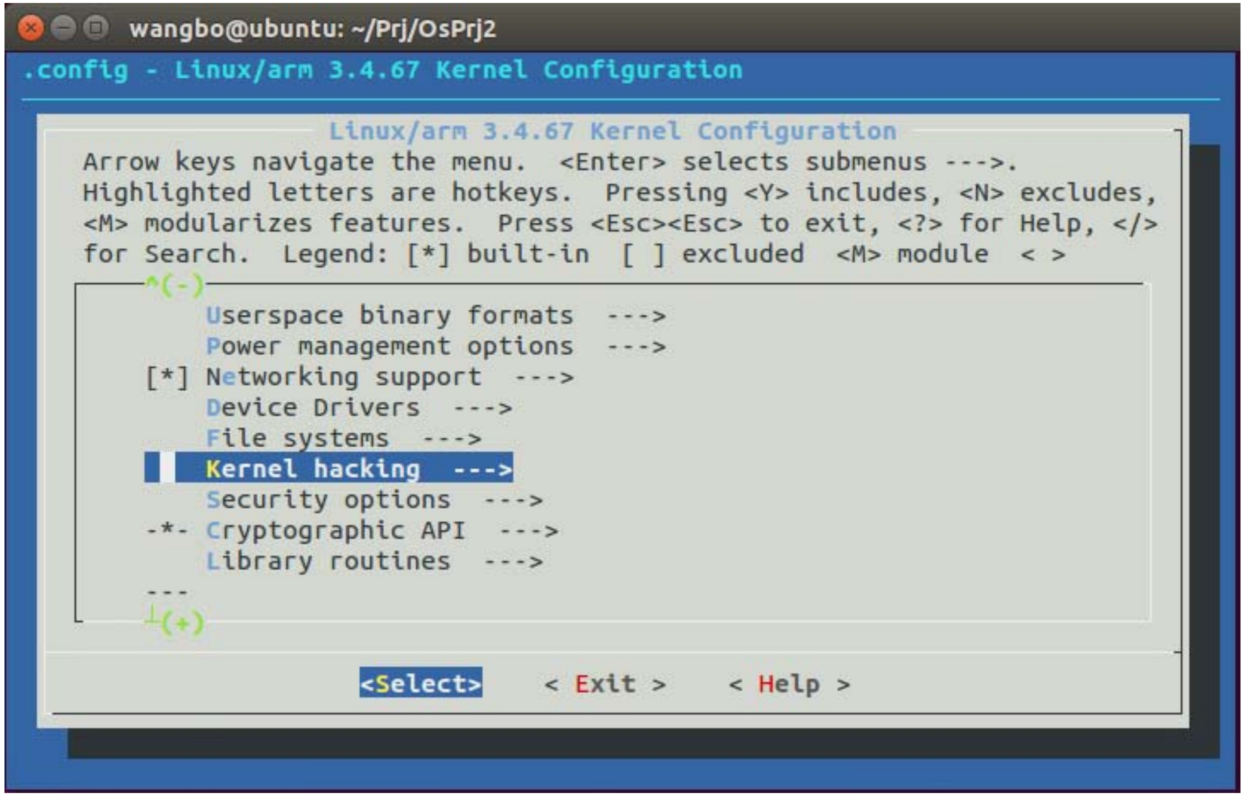
Compile the Linux Kernel (cont.)

- Execute the following command:

```
wangbo@ubuntu:~/Prj/OsPrj2$ make goldfish_armv7_defconfig
#
# configuration written to .config
#
wangbo@ubuntu:~/Prj/OsPrj2$ sudo apt-get install ncurses-dev
wangbo@ubuntu:~/Prj/OsPrj2$ make menuconfig
```

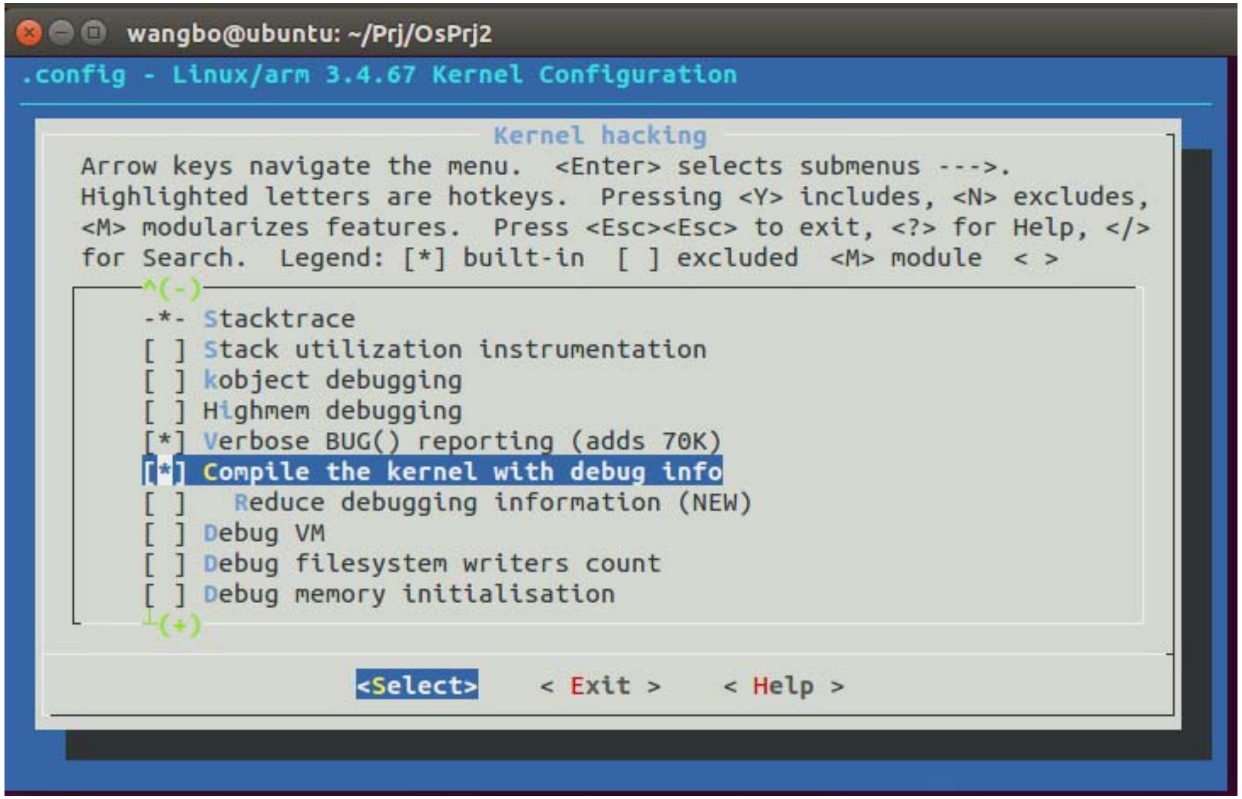
Compile the Linux Kernel (cont.)

- Then you can see a GUI configuration dialog:



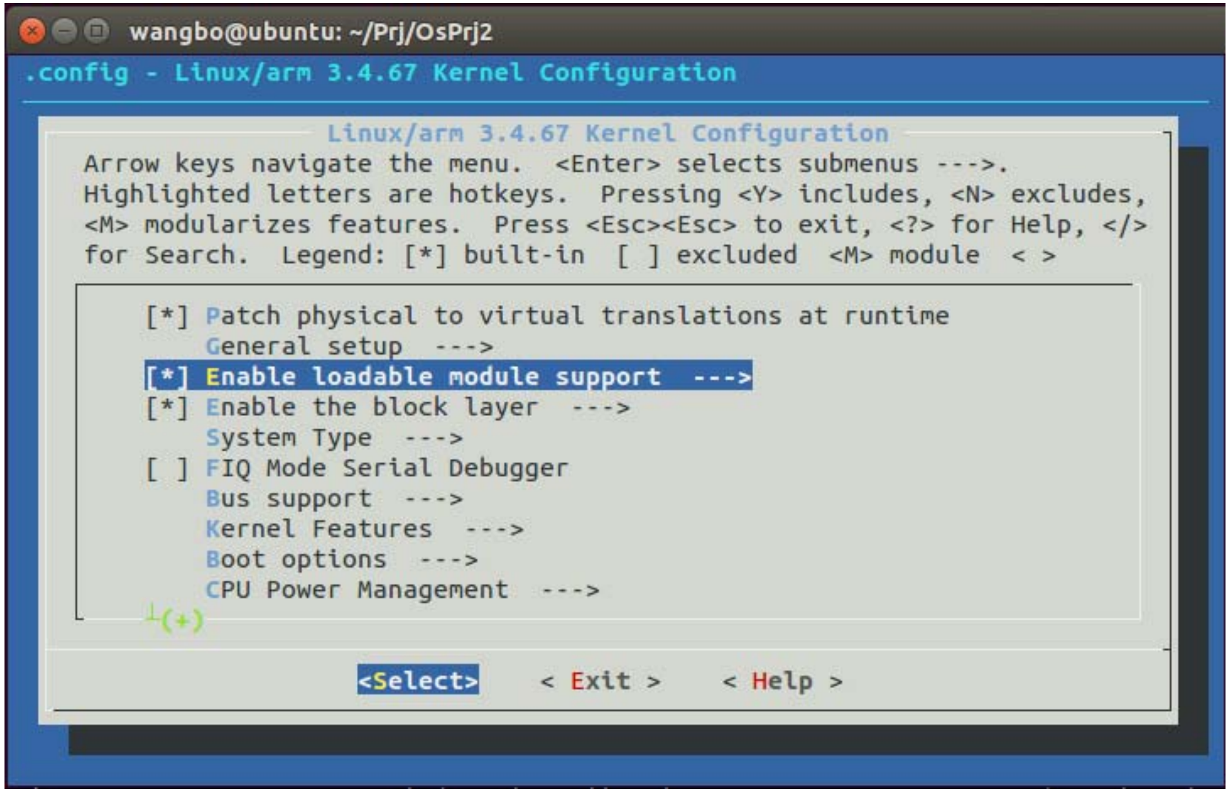
Compile the Linux Kernel (cont.)

- Open the *Compile the kernel with debug info* in *Kernel hacking*:



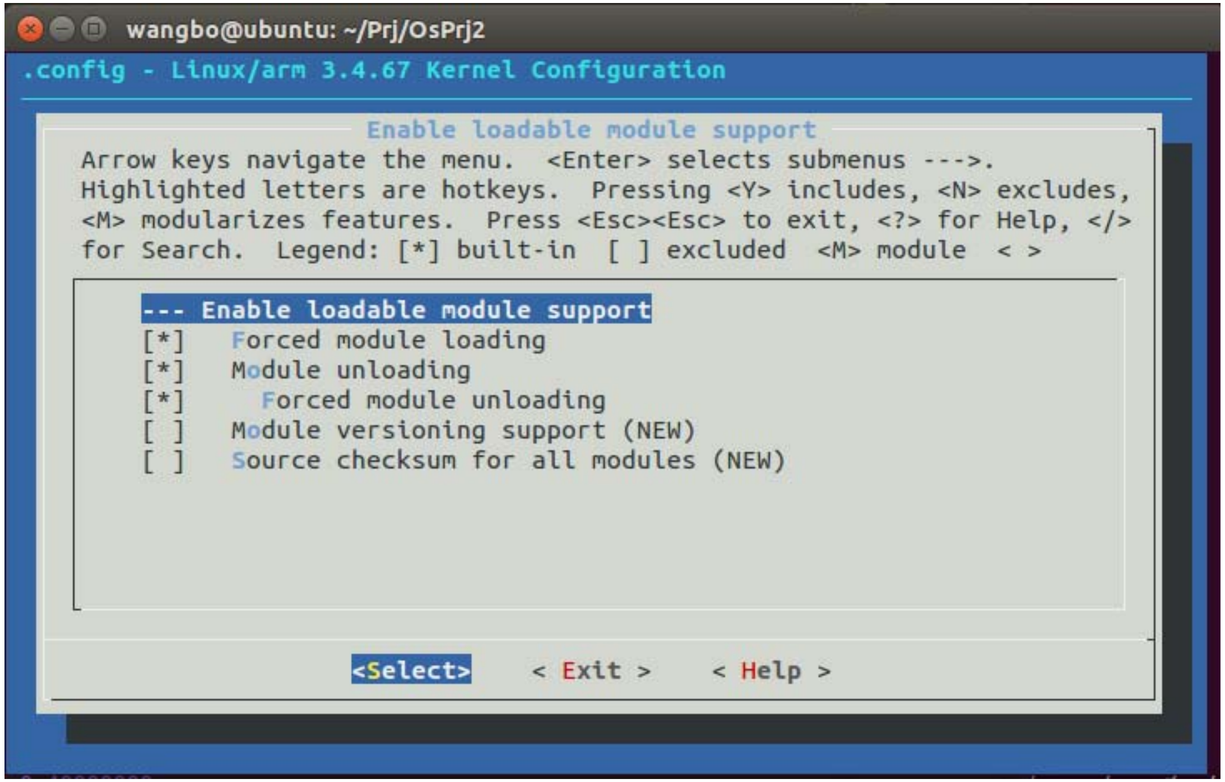
Compile the Linux Kernel (cont.)

- *Enable loadable module support* with Forced module loading, Module unloading and Forced module unloading in it:



Compile the Linux Kernel (cont.)

- *Enable loadable module support* with Forced module loading, Module unloading and Forced module unloading in it:



Compile the Linux Kernel (cont.)

- Compile it
  - The number of -j* depends on the number of cores of your system.

```
wangbo@ubuntu:~/Prj/OsPrj2$ make -j4
  SYSMAP  System.map
  SYSMAP  .tmp_System.map
  OBJCOPY arch/arm/boot/Image
  Kernel: arch/arm/boot/Image is ready
  GZIP    arch/arm/boot/compressed/piggy.gzip
  AS      arch/arm/boot/compressed/piggy.gzip.o
  LD      arch/arm/boot/compressed/vmlinux
  OBJCOPY arch/arm/boot/zImage
  Kernel: arch/arm/boot/zImage is ready
wangbo@ubuntu:~/Prj/OsPrj2$
```

Page Access Tracing

√ 20分.

Problem

- Tracing memory access for tasks (or say processes) is useful in Android systems.
- In Linux, although the hardware uses a R bit and a M bit to track if a page has been referenced or modified, it does not maintain access frequency for each task.
- In this problem, you are required to implement **three system calls** to support **per-task page access tracing**, which can trace the number of times a page is **written** by a particular task.

Problem

- **System call 361** should tell the kernel to start tracing page writes for the process pid.
- void* sys_start_trace(pid_t pid);

- **System call 362** should tell the kernel to stop tracing page writes of process pid.
- void* sys_stop_trace(pid_t pid);

- **System call 363** should return the page writes frequency wcounts of the process pid and print it.
- void* sys_get_trace(pid_t pid, int *wcounts);

Hints

- Hints on implementation:
  - To trace the write operation of a task, the recommended way is to set the page tables as if memory writes fails, such that you can increase the task's write counter in the page fault handler.
  - You may find more information in the system call mprotect in /mm/mprotect.c and page fault function in /arch/arm/mm/fault.c

Hints

- Hints on implementation:
  - The page fault handler will send a fault signal to the process. If the process want to write into the protected page, you can temporally deactivate the fault signal for the process.
  - You need to implement segv_handler function and use the struct sigaction to handle the page fault signal.
  - In segv_handler function, you can cancel the protection for pages. And after finishing the access, you need to set protection again.

```c
void segv_handler(int signal_number)
{
    ... // cancel mprotect
}

int main()
{
    ...
    struct sigaction sa;
    memset(&sa, 0, sizeof(sa));
    sa.sa_handler = &segv_handler;
    sigaction(SIGSEGV, &sa, NULL);
    ...

    //mprotect before each memory access
}
```

Implementation Details

- Files MAY NEED Modification
  - /include/linux/sched.h
  - /arch/arm/mm/fault.c
- To implement three new system calls, you need to write three *.c files and make them.
  - start_trace.c
  - stop_trace.c
  - get_trace.c
- You need to create test files (your processes) according to the framework described in the previous slide.

Implementation Details

/include/linux/sched.h

- In this file, you need to:
  - You should modify task_struct : add a integer variable wcounts to record the write times and a boolean variable trace_flag to determine when to start tracin.

```
struct task_struct {
    volatile long state;    /* -1 unrunnable, 0 runnable, >0 stopped */
    void *stack;
    atomic_t usage;
    unsigned int flags; /* per process flags, defined below */
    unsigned int ptrace;

    //my race_proc
```

Implementation Details

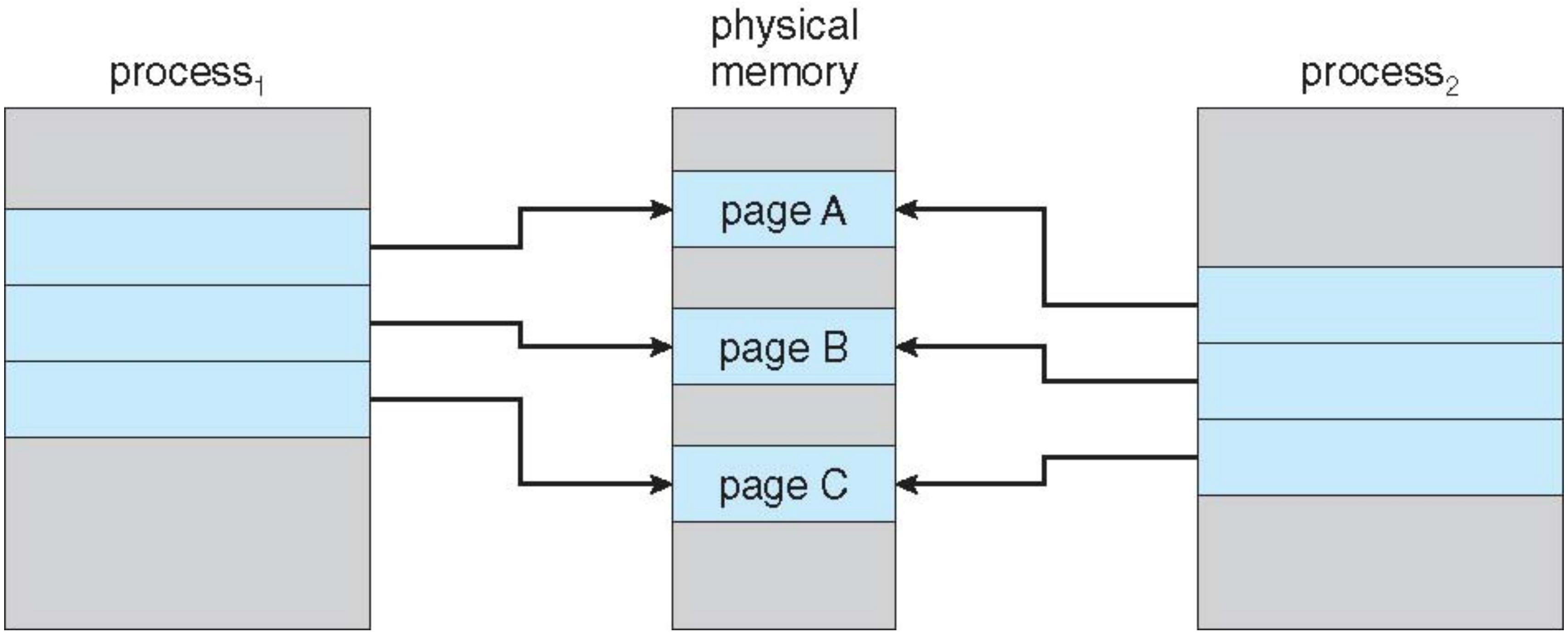
/arch/arm/mm/fault.c

- In this file, you need to:
  - You should modify do_page_fault and access_error : increase wcount when the kernel catches a page write fault.

```c
do_page_fault(unsigned long addr, unsigned int fsr, struct pt_regs *regs)
{
    struct task_struct *tsk;
    struct mm_struct *mm;
    int fault, sig, code;
    int write = fsr & FSR_WRITE;
    unsigned int flags = FAULT_FLAG_ALLOW_RETRY | FAULT_FLAG_KILLABLE |
                (write ? FAULT_FLAG_WRITE : 0);
```

Race-Averse Scheduler

Page Racing between Processes



Problem

- When the Linux kernel scheduler chooses a task, it considers a variety of factors.
- The likelihood that a task may race with one of the currently running tasks is not considered.
- In this problem, you are required to implement a **Race-Averse Scheduling** (RAS) algorithm to the Linux.
- The scheduling should be a **weighted round robin** style scheduling according to **race probabilities** of each tasks.

Problem

- Weighted Round Robin (WRR)
  - Round-robin scheduling treats all tasks equally, but there are times when it is desirable to give some tasks preference over the others.
  - WRR assigned more milliseconds as a time slice for tasks with lower race probabilities. (In our problem, it is inversely proportional to the race probabilities from 10ms to 100ms)
  - The blog relevant to linux kernel scheduler could be helpful:
    - https://helix979.github.io/jkoo/post/os-scheduler/

Problem

- Race Probabilities
  - The race probability of a task is represented as an integer in the rage of [0, 10). The higher the integer is, the more likely that the tasks may race with others.
  - To simplify the assignment, it is assumed a large enough number of tasks are in scheduling, and they may compete at a given range of virtual addresses.
  - Thus, the race probability of a certain task is proportional to its frequency of accessing the given range of virtual addresses.

Implementation Details

- Files MAY NEED Modification
  - /arch/arm/configs/goldfish_armv7_defconfig
  - /include/linux/sched.h
  - /kernel/sched/core.c
  - /kernel/sched/sched.h

- To implement RAS scheduler, you need to create a new class in the directory /kernel/sched/, that is
  - /kernel/sched/ras.c

IMPORTANT: If you feel confused on what to do in ras.c, read /kernel/sched/rt.c carefully. In rt.c, RR and FIFO are well implemented.

Implementation Details

/arch/arm/configs/goldfish_armv7_defconfig

- In this file, you need to add a new line as follows:

```
CONFIG_RT_GROUP_SCHED=y
CONFIG_RAS_GROUP_SCHED=y
CONFIG_BLK_DEV_INITRD=y
```

Implementation Details

/include/linux/sched.h

In this file, you need to:

- Define SCHED_RAS (Refer to SCHED_RR, about Line 40). The value of SCHED_RAS should be 6.
- Define sched_ras_entity (Refer to sched_rt_entity, about Line 1250)
- Define RAS_TIMESLICE. (Refer to RR_TIMESLICE, about Line 1270)
- Add a sched_was_entity varaible to task_struct (About Line 1310).
- Declare a ras_rq struct. (Refer to struct cfs_rq, about Line 150)
- Maybe a little more to be revised. It depends on your implementation.

Implementation Details

/kernel/sched/sched.h （path is different from last page）

In this file, you need to:

- Declare a ras_rq struct. (Refer to struct rt_rq, about Line 80)

```
81  struct rt_rq;
82  struct ras_rq;
```

- Define a new struct ras_rq (Refer to rt_rq, about Line 290).
- Add a ras_rq variable to struct rq (About line 400) and similarly add a list_head variable as the figure shows.

```
428 #ifdef CONFIG_RT_GROUP_SCHED
429     struct list_head leaf_rt_rq_list;
430 #endif
431
432 #ifdef CONFIG_RAS_GROUP_SCHED
433     struct list_head leaf_ras_rq_list;
434 #endif
```

- Declare some extern variables and functions（*）. (You can refer to extern var/func of rt in the same file, About Line 190-210, Line 880, Line 900, Line 1170-1180). E.g.

```
898 extern const struct sched_class rt_sched_class;
899 extern const struct sched_class ras_sched_class;
900 extern const struct sched_class fair_sched_class;
901 extern const struct sched_class idle_sched_class;
```

- Maybe a little more to be revised. It depends on your implementation.

Implementation Details

/kernel/sched/core.c

In this file, you need to:

- Revise function: static void __sched_fork(struct task_struct *p)
- Revise function: static void __setscheduler(struct rq *rq, struct task_struct *p, int policy, int prio)
- Revise function: static void __sched_setscheduler(struct task_struct *p, int policy, const struct sched_param *param, bool user)
- Add init_ras_rq(&rq->ras). (Refer to init_rt_rq(), about Line 7230)
- Revise function: static void free_sched_group(struct task_group *tg) and struct task__group *sched_create_group(struct task_group *parent) (about Line 7500-7600)
- Maybe a little more to be revised. It depends on your implementation.

Implementation Details

/kernel/sched/core.c

- To know what to revise, you have to read the code carefully and know what are they implemented for.

- For example, when revising *__sched_setscheduler*, we meet the following code segment:

```
	if (policy != SCHED_FIFO && policy != SCHED_RR &&
			policy != SCHED_NORMAL && policy != SCHED_BATCH &&
			policy != SCHED_IDLE)
		return -EINVAL;
	}
```

Since we have one more policy RAS now, we should change it to:

```
	if (policy != SCHED_FIFO && policy != SCHED_RR &&
			policy != SCHED_NORMAL && policy != SCHED_BATCH &&
			policy != SCHED_IDLE && policy != SCHED_RAS)
		return -EINVAL;
	}
```

Implementation Details

/kernel/sched/ras.c

- This is the *major file* in which you write codes. You can refer to rt.c in the same directory to learn how to write ras.c
- Here, we give a framework of ras_sched_class

```c
const struct sched_class ras_sched_class = {
	.next			= &idle_sched_class,		/*Required*/
	.enqueue_task		= enqueue_task_ras,		/*Required*/
	.dequeue_task		= dequeue_task_ras,		/*Required*/
	.yield_task		= yield_task_ras,		/*Required*/

	.check_preempt_curr = check_preempt_curr_ras,	/*Required*/

	.pick_next_task		= pick_next_task_ras,		/*Required*/
	.put_prev_task		= put_prev_task_ras,		/*Required*/

#ifdef CONFIG_SMP
	.select_task_rq		= select_task_rq_ras,		/*Never need impl*/

	.set_cpus_allowed		= set_cpus_allowed_ras,	/*Never need impl*/
	.rq_online			= rq_online_ras,		/*Never need impl*/
	.rq_offline			= rq_offline_ras,		/*Never need impl*/
	.pre_schedule		= pre_schedule_ras,		/*Never need impl*/
	.post_schedule		= post_schedule_ras,		/*Never need impl*/
	.task_woken		= task_woken_ras,		/*Never need impl*/
	.switched_from		= switched_from_ras,		/*Never need impl*/
#endif

	.set_curr_task			= set_curr_task_ras,	/*Required*/
	.task_tick		= task_tick_ras,		/*Required*/

	.get_rr_interval	= get_rr_interval_ras,		/*Required*/

	.prio_changed		= prio_changed_ras,		/*Never need impl*/
	.switched_to		= switched_to_ras,		/*Required*/
};
```

Implementation Details

/kernel/sched/ras.c

For functions labeled “Required”, you need to implement it in ras.c

```
static void switched_to_ras(struct rq *rq, struct task_struct *p)⋯
```

For functions labeled “Never need impl”, you can just put them dummy

```
static void prio_changed_ras(struct rq *rq, struct task_struct *p, int oldprio)
{
}
```

Implementation Details

/kernel/sched/ras.c

- Remember that in ras.c, when you want to allocate time slice to a task with RAS as its policy, you should judge whether it is a foreground task or background task, and allocate corresponding time slice to it.
- The blog relevant to *linux kernel scheduler* could be helpful to you：
  - https://helix979.github.io/jkoo/post/os-scheduler/

Implementation Details

To put your */kernel/sched/ras.c* into effect:

- You need to revise the Makefile in */kernel/sched* like this:

```
ifdef CONFIG_FUNCTION_TRACER
CFLAGS_REMOVE_clock.o = -pg
endif

ifneq ($(CONFIG_SCHED_OMIT_FRAME_POINTER),y)
# According to Alan Modra <alan@linuxcare.com.au>, the -fno-omit-frame-pointer is
# needed for x86 only.  Why this used to be enabled for all architectures is beyond
# me.  I suspect most platforms don't need this, but until we know that for sure
# I turn this off for IA-64 only.  Andreas Schwab says it's also needed on m68k
# to get a correct value for the wait-channel (WCHAN in ps). --davidm
CFLAGS_core.o := $(PROFILING) -fno-omit-frame-pointer
endif

obj-y += core.o clock.o idle_task.o fair.o rt.o stop_task.o ras.o
obj-$(CONFIG_SMP) += cpupri.o
obj-$(CONFIG_SCHED_AUTOGROUP) += auto_group.o
obj-$(CONFIG_SCHEDSTATS) += stats.o
obj-$(CONFIG_SCHED_DEBUG) += debug.o
```

What’s next

What to show

Basic

- Add some printk(“”) in fault.c, mprotect.c, system call files or some other places to proves page access tracing works normally.
- Write a test file, which can test three system calls you implemented.
  - Trace page access of a task and give out the result.
  - You should repeat the test for different virtual address range and different time intervals.

What to show

Basic

- Add some printk(“”) in ras.c or some other places which proves there is a task using RAS as a policy.
- Write a test file, which can change the scheduler in user space.
  - It is recommend that you should create multiple tasks, and each task requests different sizes of memory to form a race relationship.
  - Change the apk’s scheduler to RAS, and give out some information (pid, name, timeslice, and some others you like).
- To check the pid of *test_file* in Android shell, you may use PS -P

What to show

Basic

Print information when switching scheduler:

```
Please input the Choice of Scheduling algorithms (0-NORMAL, 1-FIFO, 2-RR, 6-RAS) : 6
Current scheduling algorithm is SCHED_RAS
Please input the id (PID) of the testprocess : 248
Wcount for this task : 2
Set process's priority (1-99): 0
current scheduler's priority is : 0
pre scheduler : SCHED_NORMAL
cur scheduler : SCHED_RAS
Switch finish.
```

OR:

```
Please input the Choice of Scheduling algorithms (0-NORMAL, 1-FIFO, 2-RR, 6-RAS) : 6
Current scheduling algorithm is SCHED_RAS
Please input the id (PID) of the testprocess : 131
Start trace for task 131
Set process's priority (1-99): 0
current scheduler's priority is : 0
pre scheduler : SCHED_NORMAL
cur scheduler : SCHED_RAS
Switch finish.
```

What to show

Bonus (10 points in Final Score):

- Any extended ideas can be considered into the bonus!
- Here are some of the ideas we provide, I hope you won't be limited to these:
  - Can you come up with a method to compare the performance of RR, FIFO, and RAS?
  - Can you use different ways to compute race probabilities? For example, identifying the accesses to actually shared pages by checking the tasks' page tables.
  - Can you build RAS in a multi-cpu architecture and implement load balance?

Hints

- To change the scheduler, study several functions with SYSCALL in their names. For example, SYSCALL_DEFINE3 (sched_setscheduler…….). Try to use these system calls in user space.

- You can firstly change scheduler to RR or FIFO to see if your testing file is logically correct.

- You can take full use of printk and the functions defined in /kernel/sched/debug.c for debugging.

- Helpful files:
  - /kernel/sched/core.c and /kernel/sched/sched.h tells you how the Linux scheduler works.
  - /kernel/sched/rt.c tells you how to create a scheduler.
  - /include/linux/sched.h concerns run-state processes.

Be patient enough to read them carefully!

Report

- Explain how you trace page write of a task.
- Explain how you compute race probabilities.
- Explain how your RAS works.
- Show your results of test runs.
- Any further analysis is welcome.

Something to Specify

- To give you an **overview** of this project:
  - You need to write 500 lines (more or less) of codes in:
    - /kernel/sched/ras.c
  - You need to revise the following files to put *ras.c* into effect:
    - /arch/arm/configs/goldfish_armv7_defconfig
    - /include/linux/sched.h
    - /kernel/sched/sched.h
    - /kernel/sched/core.c
    - /arch/arm/mm/fault.c
    - */kernel/sched/Makefile*
  - You need to create test scripts to test page access tracing and RAS scheduling, respectively, to make sure you get at least part of the scores.

Distribution of Credits

- Problem 1: 5 points
- Problem 2: 10 points
- Problem 3: 15 points
- Technical Report: 5 points
- Extra Bonus: up to 10 points
- Optional Presentation: up to 10 points

Deadline

Mid-night, May 27, 2022

Demo & Presentation

- Demo:
  - **May 28-29, 2022**. Demo slots will be posted in the WeChat group. Please sign your name in one of the available slots.
- Presentation:
  - You are encouraged to present your design of the project optionally. The presentation will be in the **afternoon of May 29, 2022**.

For Help?

- Teaching Assistant
  - Da Huo
    - Email: sjtuhuoda@sjtu.edu.cn
  - Hang Zeng
    - Email: nidhogg@sjtu.edu.cn

- Some useful website
  - http://www.csdn.net/
  - http://stackoverflow.com/
  - http://developer.android.com/