CSE 306 Operating Systems
Process Management in Linux

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The Process

- A process includes
  - Code in text section
  - Global variables in data section
  - Resources like open files, pending signals
  - Internal kernel data
  - Processor state
  - Memory address space with memory mappings
  - One or more thread of execution

The Processes

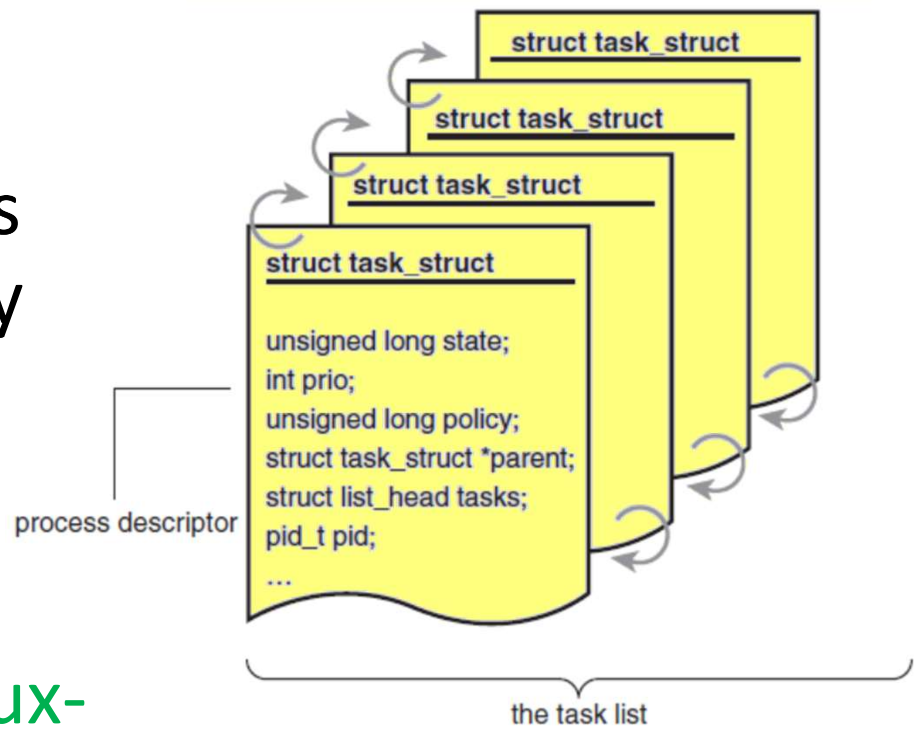
- Processes provide
  - A virtualized processor
    - Gives a process the illusion that it is monopolizing the system
  - A virtual memory
    - Let a process allocate and manage memory as if it alone owned all memory in the system

The Processes

- In Linux
  - fork() creates a process
  - exec() family creates new address space and loads a new program
  - exit() terminates the process and frees its resources
  - wait() inquires the status of a terminated child

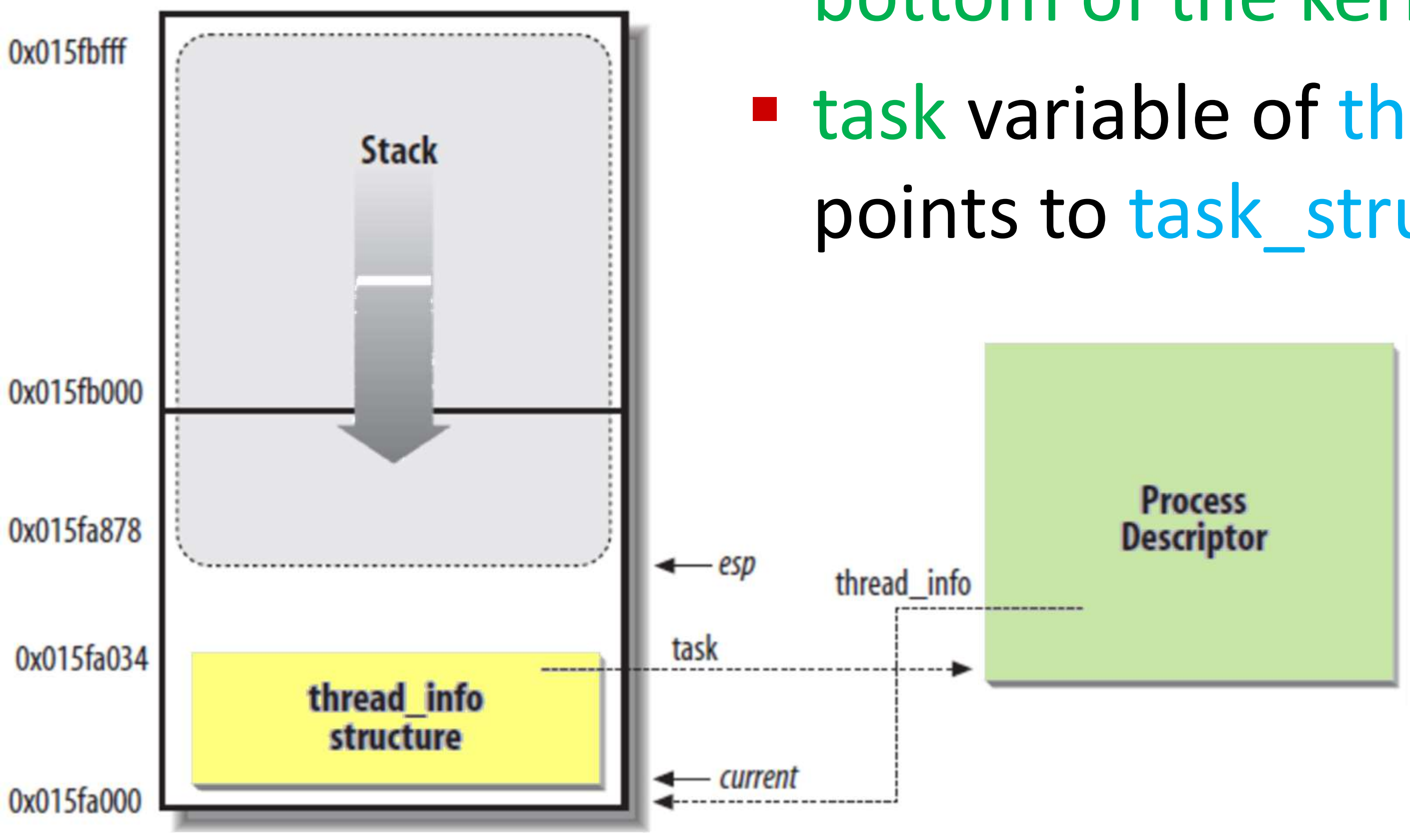
Process Descriptor

- Task list
  - List of process descriptors stored in a circular doubly linked list
- Process descriptor
  - task_struct defined in linux-5.4.49/include/linux/sched.h
  - Contains all the information about a process



Process Descriptor

- Locating process descriptors
  - thread_info structure is at the bottom of the kernel stack
  - task variable of thread_info points to task_struct



Process Descriptor

- current_thread_info()

```
movl $-8192 %eax
andl %esp, %eax
```

```
-8192 in binary
1…1 1110 0000 0000 0000
```

- current macro is equivalent to
  current_thread_info()->task

```
union thread_union {
    struct thread_info thread_info;
    unsigned long stack[THREAD_SIZE / sizeof(long)];
};
```

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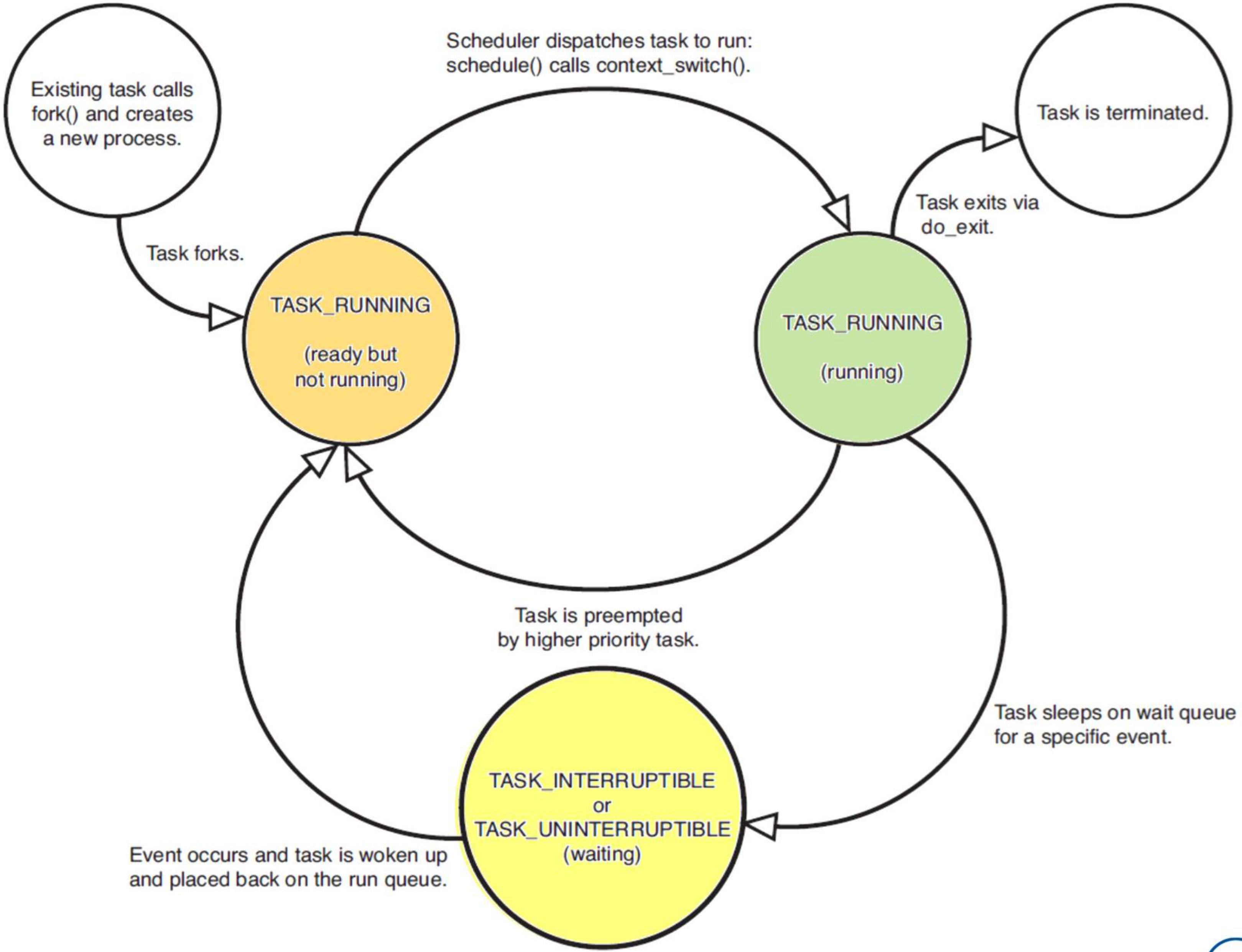
Process State

- The state field of task_struct
  - TASK_RUNNING: currently running or on a run-queue
  - TASK_INTERRUPTABLE: blocked and waiting for some condition to exist
    - On receiving a signal, can wake up prematurely
  - TASK_UNINTERRUPTABLE: blocked and waiting for some condition to exist
    - Does not wake up when it receives a signal
  - __TASK_TRACED: the process is being traced by another process (debugger)
  - __TASK_STOPPED: the process is not running and is not eligible to run

```
set_current_state(state) //changes the state of the current task
```

Process State



Process Context

- Process context
  - Program execution in kernel space on behalf of the process
  - Through a system call or an exception
  - current macro is valid
- Interrupt context
  - Interrupt handler handling an interrupt

Process Family Tree

- init process
  - Kernel starts init in the last step of the boot process
  - init reads initscripts and execute more programs
- Family tree
  - Each process has exactly one parent
  - A process has zero, one, or more children
  - Child processes whose parent are the same are called siblings

Process Family Tree

- Related links in task_truct

```
struct task_struct {
...
    struct task_struct __rcu *real_parent; //real parent process
    struct task_struct __rcu *parent;//recipient of SIGCHLD, wait4() reports

    struct list_head children;  //list of my children
    struct list_head sibling;   //linkage in my parent's children list
...
};
```

- To iterate over child process descriptors

```
struct task_struct *task;
struct list_head *list;
list_for_each(list, &current->children) {
    task = list_entry(list, struct task_struct, sibling);
    /*task now points to one of current's children */
}
```

Process Creation

- copy_process() within fork() (kernel/fork.c)
  - dup_task_struct()
    - Create kernel stack, thread_info, task_struct
  - Variables of task_struct are cleared or initialized
  - Child's state is set to TASK_UNINTERRUPTABLE
  - Update flags member
    - PF_SUPERPRIV is cleared, PF_FORKNOEXEC is set
  - Assign a new PID to the child
  - Duplicate or share
    - Open files, filesystem information, signal handlers, process address space, and namespace

Process Creation

- Copy-on-Write (COW)
  - A technique to delay or prevent copying of data
  - Rather than duplicate the process address space, parent and child share a single copy
  - When data is actually written, each process receives a unique copy
- Overhead of fork()
  - Duplication of page table, creation of a process descriptor (task_struct)

Process Termination

- do_exit() in kernel/exit.c
  - Sets PF_EXITING in the flags of task_struct
  - Calls del_timer_sync() to remove any kernel timers
  - Calls acct_update_integrals() to write out accounting info
  - Calls exit_mm(), exit_files(), and exit_fs() to release the objects
  - Sets the exit_code member of task_struct
  - Calls exit_notify() to send signals to the task's parent
  - Calls schedule() to switch to new process

Process Termination

- After do_exit
  - The process descriptor for the terminated process still exists
  - The process is a zombie and is unable to run
  - wait() family of functions get the exit code and destroy the process descriptor

Kernel Threads

- Kernel threads
  - For the kernel to perform operations in the background
  - Kernel threads are a process
    - Schedulable and preemptable
  - Kernel threads don't have a user address space
    - mm pointer of task_struct is NULL
    - Operates only in kernel-space

Kernel Threads

- Some interfaces in include/linux/kthread.h

```
struct task_struct *kthread_create_on_node(int(*threadfn)(void *data),
    void *data,
    int node,
    const char namefmt[], ...);

#define kthread_run(threadfn, data, namefmt, ...)                     \
({                                                                   \
    struct task_struct *__k                                          \
        = kthread_create(threadfn, data, namefmt, ## __VA_ARGS__); \
    if (!IS_ERR(__k))                                                \
        wake_up_process(__k); /*start the task*/                     \
    __k;                                                             \
})

int kthread_stop(struct task_struct *k);
```

Example: exploring task_structs

```
#include <linux/syscalls.h>
#include <linux/kernel.h>
#include <linux/sched.h>
#include <linux/init_task.h>
#include <linux/list.h>
#include <linux/fs.h>
#include <linux/fs_struct.h>
#include <linux/kthread.h>
#include <linux/semaphore.h>

static void print_task(struct task_struct *task, int depth)
{
    char buf[100];

    printk("%*c%5d:%s\n",
        depth*4, '+',
        task->pid,
        d_path(&task->fs->pwd, buf, sizeof(buf)));
}
```

```c
static void print_family(struct task_struct *task, int depth)
{
    struct list_head *pos;
    print_task(task, depth);        //self

    list_for_each(pos, &task->children) {
        struct task_struct *t;
        //t = list_entry(pos, struct task_struct, sibling);
        t = container_of(pos, struct task_struct, sibling);
        print_task(t, depth + 1); //child
    }
}
```

```c
static int threadfn(void *data) {
    int pid = (long)data;
    struct list_head *head = &init_task.tasks;
    struct list_head *pos;
    for (pos = head; pos->next != head; pos = pos->next) {
        struct task_struct *task = container_of(
                                      pos->next, struct task_struct, tasks);
        if (task->pid == pid) {
            print_family(task, 0);
            return 0;
        }
    }
    printk("pid %d not found\n", pid);
    return -1;
}

SYSCALL_DEFINE1(print_family, int, pid) {
    kthread_run(threadfn, (void*)(long)pid, "printfamily_%d", 0);
    return 0;
}
```

User-Space Program

```c
//wrapper.c
…
#define __NR_print_family 453
…
long print_family(int pid)
{
    return syscall(__NR_print_family, pid);
}

//print_family.c
…
int main()
{
    long res = print_family(1);
    printf("%ld\n", res);
}
```

```
ykwon4@youngbox2:~/ home$dmesg
...
[  162.737252] +    1:/
[  162.737257]    +  982:/
[  162.737259]    + 1000:/
[  162.737262]    + 1602:/
...
[  162.737270]    + 1837:/
[  162.737273]    + 1843:/var/spool/cron
[  162.737275]    + 1848:/
...
[  162.737291]    + 1979:/
[  162.737293]    + 2102:/etc/avahi
[  162.737295]    + 2122:/
[  162.737297]    + 2180:/
[  162.737299]    + 2199:/var/lib/lightdm
[  162.737301]    + 2203:/
[  162.737303]    + 2213:/var/lib/lightdm
[  162.737304]    + 2222:/
[  162.737306]    + 2230:/var/lib/lightdm
[  162.737308]    + 2232:/var/lib/lightdm
[  162.737310]    + 2234:/var/lib/lightdm
[  162.737313]    + 2289:/proc
[  162.737315]    + 2288:/
[  162.737317]    + 2312:/
[  162.737319]    + 2319:/
```

Processes and Threads

- Two characteristics of a process
  - Resource ownership
    - Virtual address space (program, data, stack, PCB…)
    - Main memory, I/O devices, files
  - Scheduling/execution
    - Execution of a process follows an execution path
    - Execution may be interleaved with that of other processes

Processes and Threads

- Resource ownership and Scheduling/execution can be treated independently by the OS
  - Thread (lightweight process): the unit of dispatching
  - Process (task): the unit of resource ownership

Why Threads

- Parallel execution
  - Without relying on interrupts, timers, context switches
  - Parallel entities sharing an address space and data
- Easier and faster to create and destroy than processes
  - 10 ~ 100 times faster
- Performance gain
  - Not much for CPU bounded applications
  - Substantial for I/O bounded applications
- Real parallelism with multiple CPUs

Multithreading

- Threads within a process have
  - Thread execution state (Running, Ready, …)
  - Saved thread context (PC, registers, …)
  - Execution stack
  - Per-thread static storage for local variables
  - Access to resources shared with other threads in the process

Multithreading

- All threads of a process share the states and resources of the process
  - If a thread alters data, other threads will see the change
  - If a thread opens a file with a read privilege, others can also read the file

Per-process items	Per-thread items
Address space	Program counter
Global variables	Registers
Open files	Stack
Child processes	State
Pending alarms	
Signals and signal handlers	
Accounting information	

POSIX Threads (Pthreads)

- A standard interface for manipulating threads from C programs
- Defines about 60 functions that allow programs
  - to create, kill, and reap threads
  - to share data safely with peer threads
  - to notify peers about changes in the system state

Thread call	Description
Pthread_create	Create a new thread
Pthread_exit	Terminate the calling thread
Pthread_join	Wait for a specific thread to exit
Pthread_yield	Release the CPU to let another thread run

Threads in Linux

- Threads of a process
  - Share memory address space
  - Share open files and other resources
- Thread in Linux
  - Threads are a process that share certain resources with other processes
  - Each thread has a unique task_struct and appears to the kernel as a normal process

Thread in Linux

- Creating a thread

```
clone(CLONE_VM | CLONE_FS | CLONE_FILES | CLONE_SIGHAND, 0);
```

```
#define CLONE_VM       0x00000100 //set if VM shared between processes
#define CLONE_FS       0x00000200 //set if fs info shared between processes
#define CLONE_FILES    0x00000400 //set if open files shared between processes
#define CLONE_SIGHAND  0x00000800 //set if signal handlers and blocked signals shared
...
```

Assignment 2

- In this assignment, we will practice
  - Using and navigating task_struct
  - Making a kernel thread
  - Thread synchronization using semaphore
- Submit the files you changed or added
  - Implement the system call in print_tree.c
  - Mark your change with //CSE306 tag
  - Due date: 4/4/2024

Assignment 2

- Write a system call that returns the whole family tree from the init process

```
SYSCALL_DEFINE2(print_tree, char*, buf, int, buflen);
```

  - System call number for print_tree is 454
  - The output is returned in buf as a string
  - Prepare an internal buffer of buflen using kmalloc

Assignment 2

- For each process, the corresponding line in the output string should include
  - PID (task->pid)
  - tty name (task->signal->tty->name)
  - total elapsed time in sec.msec format

    ```
    task_cputime(task, &utime, &stime);
    msec = (utime+stime) / 1000000;
    ```

  - process name (task->comm)
  - Each line should be indented by the depth of the node in the tree
  - Use sprintf

Assignment 2

- A pointer to the init task descriptor is &init_task
- Visit the child tasks in the depth-first traversal order
  - Recursion is not recommended due to the limited kernel stack size

```
static void print_tree(struct task_struct *task, int depth)
{
    struct list_head *pos;
    printk("%*d\n", depth*4, task->pid)

    list_for_each(pos, &task->children) {
        struct task_struct *child;
        child = list_entry(pos, struct task_struct, sibling);

        print_tree(child, depth + 1);
    }
}
```

Assignment 2

- To remove recursion, implement a stack explicitly

```
struct task_frame {
    struct task_struct *task;
    int depth;
};
static struct task_frame frame_stack[10000];
static int frame_sp = 0;
static void push_frame(struct task_struct *task, int depth);
static void pop_frame(struct task_struct **task, int *depth);
```

Assignment 2

- Make print_tree a thread function
  - Use list_for_each_prev to visit child processes in the reverse order
  - When done, increase the semaphore to unblock the system call function

```
struct ptree_param {
    struct task_struct *task;
    struct semaphore *sem;
    int buflen;
    char *buf;
};
static int print_tree(void *data) {  //thread function
    struct ptree_param *p = (struct ptree_param*) data;
…
```

Assignment 2

- In sys_print_tree (system call handler),
  - Run print_tree in a kernel thread
  - Wait for the thread to finish by decreasing the semaphore

```
struct semaphore …;

void sema_init(struct semaphore *sem, int val);

void down(struct semaphore *sem);

void up(struct semaphore *sem);
```

Assignment 2

- Header files to include

```
#include <linux/syscalls.h>
#include <linux/kernel.h>
#include <linux/sched.h>
#include <linux/init_task.h>
#include <linux/list.h>
#include <linux/fs.h>
#include <linux/kthread.h>
#include <linux/semaphore.h>
#include <linux/mm.h>
#include <linux/dcache.h>
#include <linux/sched/cputime.h>
#include <linux/slab.h>
#include <linux/tty.h>
#include <linux/uaccess.h>
```

Assignment 2 (user-space program)

```
//wrapper.c
#define __NR_print_tree 454

long print_tree (char *buf, int buflen) {
    return syscall(__NR_print_tree, buf, buflen);
}

//print_tree.c
int main() {
    char buf[4096];
    long res = print_tree(buf, sizeof(buf));
    if (res)
        printf("%ld\n", res);
    else
        printf("%ld\n%s\n", res, buf);
}
```

Assignment 2 (sample output)

```
ykwon4@youngbox2:~/home$ ./a.out
0
+    0:.:0.104:swapper/0
   +    1:.:1.244:systemd
       +  987:.:0.110:systemd-journal
       + 1829:.:0.23:avahi-daemon
           + 1842:.:0.0:avahi-daemon
       + 1832:.:0.6:acpid
       + 1961:.:0.21:lightdm
           + 1967:tty7:0.514:Xorg
           + 2053:.:0.10:lightdm
               + 2108:.:0.1:lightdm-greeter
                   + 2142:.:0.335:unity-greeter
           + 2194:.:0.3:lightdm
       + 1966:.:0.6:systemd-hostnam
       + 1970:tty1:0.3:agetty
       + 1976:ttyS0:0.23:login
           + 2349:ttyS0:0.67:bash
               + 2366:ttyS0:0.1:a.out
       + 2063:.:0.17:systemd
           + 2077:.:0.0:(sd-pam)
```