Processes and Threads

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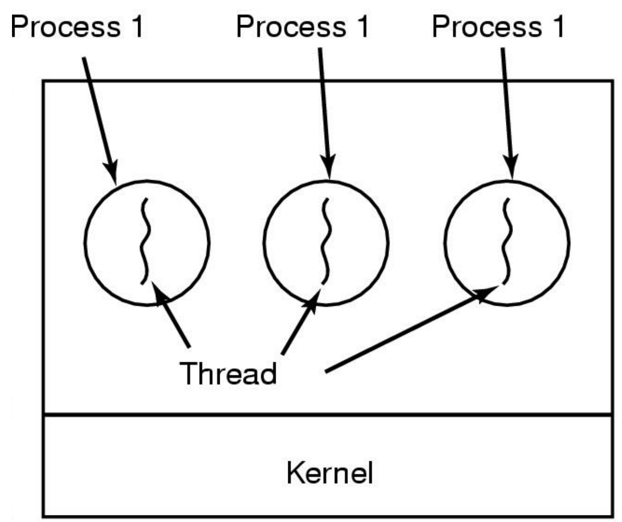
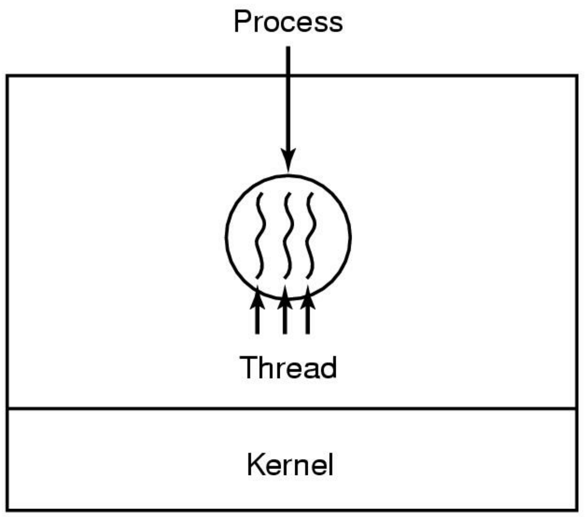
What is a Process?

- A(An) __________ of a program in execution
- Program vs. Process?
- The basic unit of protection
- A process is identified using is process ID (PID)
- A process includes
  - CPU context (registers)
  - OS resources (address space, open files, etc.)
  - Other information (PID, state, owner, etc.)
- Process control block

What is a Thread?

- A thread of control:
  A sequence of instructions being executed in a program
- A thread has its own
  - Thread ID
  - Set of registers including PC & SP
  - Stack
- Threads share an address space
  - Code, Data, and Heap
- Separate the concept of a process from its execution state





Why Threads?

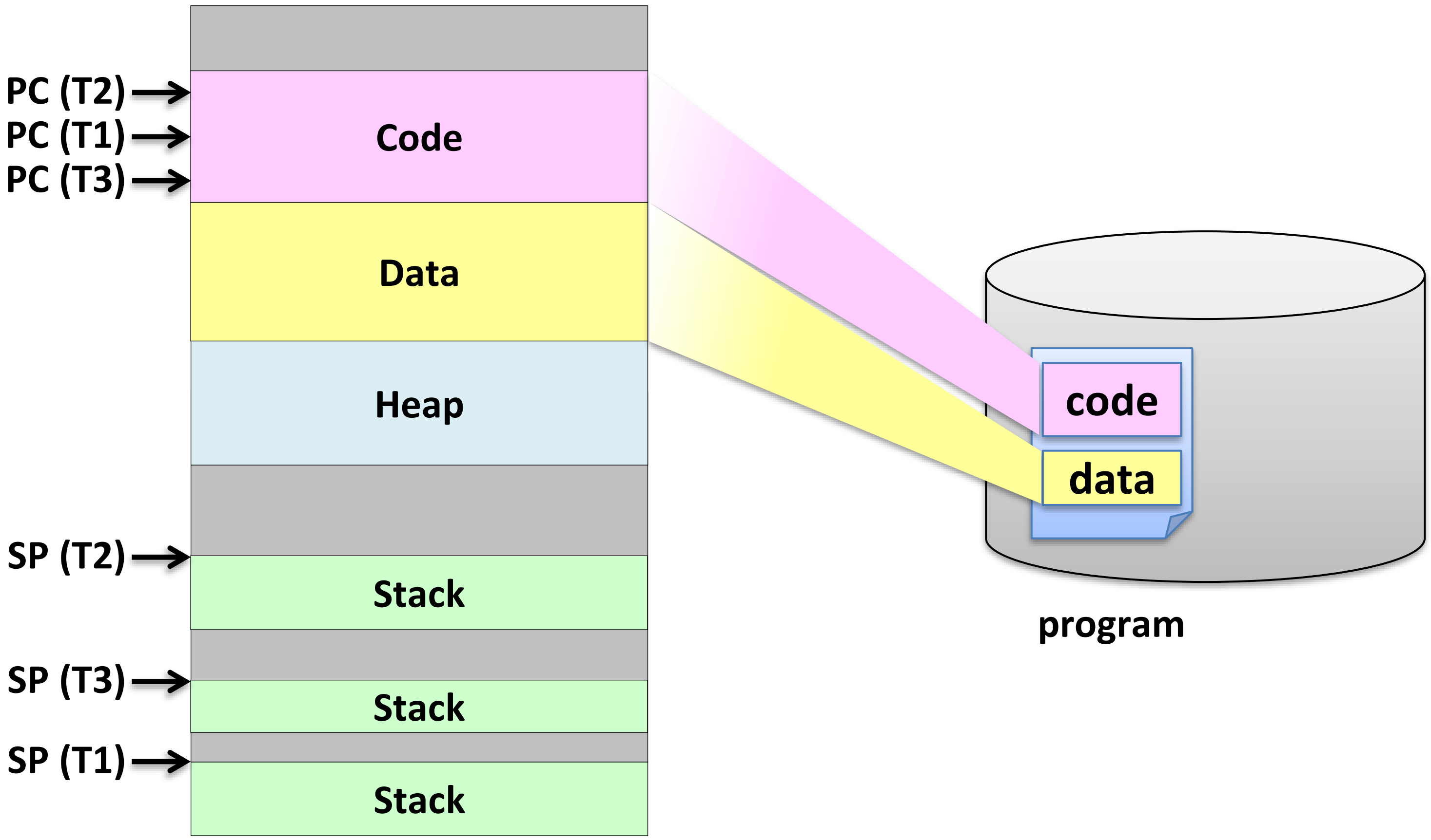
- Concurrency
- Program structure
  - Divide large task across several cooperative threads
- Throughput
  - By overlapping computation with I/O operations
- Responsiveness
  - Can handle concurrent events (e.g., web servers)
- Resource sharing
- Utilization of multi-core architectures
  - Allows building parallel programs

Processes vs. Threads

- A thread is bound to a single process
- A process, however, can have multiple threads
- Sharing data between threads is cheap; all see the same address space
- Threads are the unit of scheduling
- Processes are containers in which threads execute
  - PID, address space, user and group ID, open file descriptors, current working directory, etc.
- Processes are static, while threads are dynamic entities

Image source: https://dribbble.com/shots/1395795-factory-cross-section-progress-4

Address Space with Threads



OS Classification

# threads per addr space: / # of addr spaces:	One	Many
One	**Embedded Systems without OS** MS/DOS Early Macintosh	**Traditional UNIX**
Many	**Many Embedded OSes** (VxWorks, QNX, µClinux, µC/OS-II, …)	**Modern OSes** (Mach, Windows, Linux, Mac OS X, HP-UX, Solaris, AIX, …)

Processes and Threads in Linux

Linux Tasks

- Tasks
  - In Linux, tasks represent both processes and threads
  - Each task is described using a task structure
- `struct task_struct`
  - @ `include/linux/sched.h`
  - Everything the kernel has to know about a task
  - About 6.5KB in size (Kernel 6.1.14 on x86_64)
  - Allocated by the slab allocator (cf. `/proc/slabinfo`)
  - Task list (`t->tasks`): the list of task structures in a circular linked list

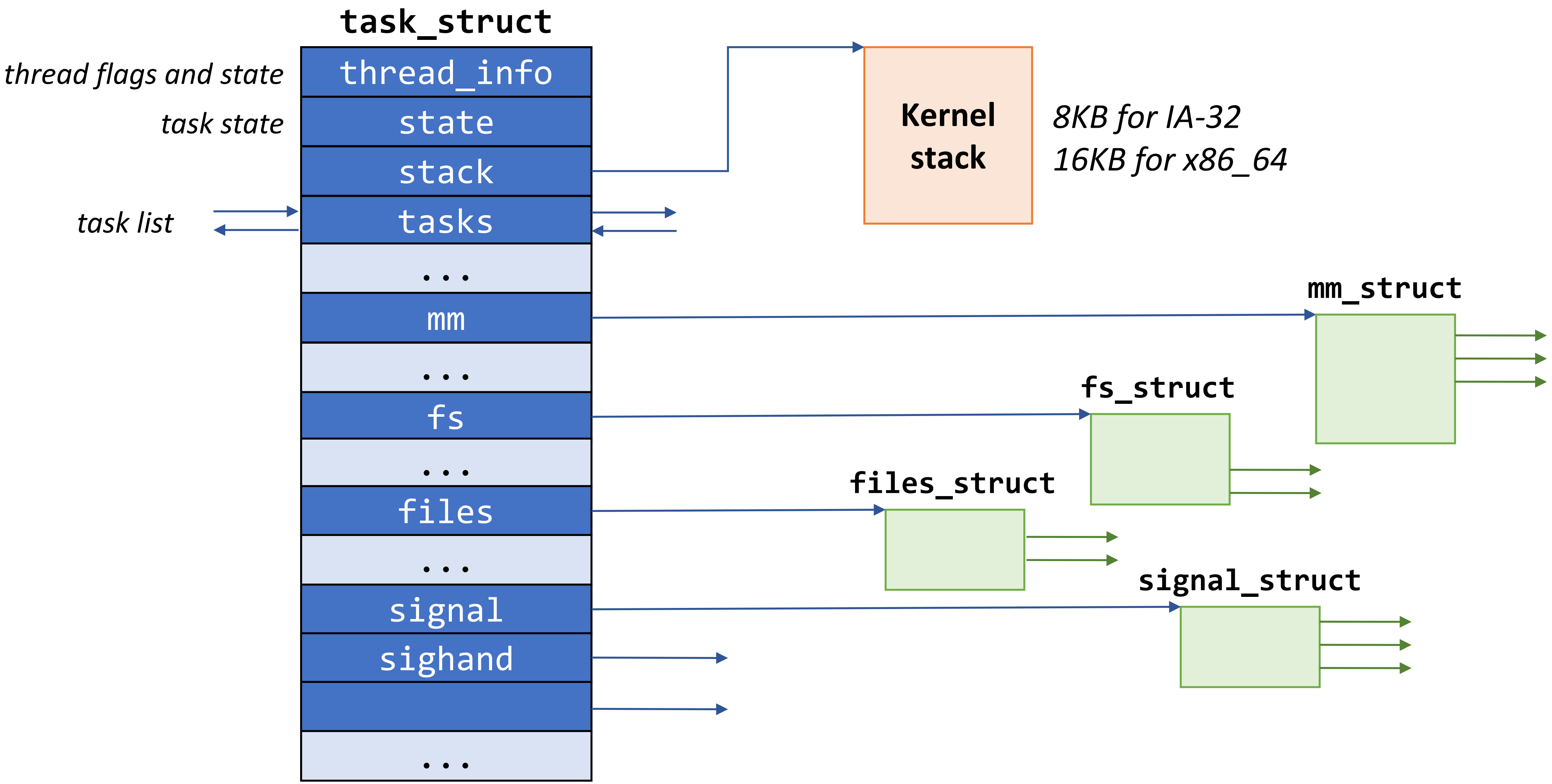
```
struct task_struct {
#ifdef CONFIG_THREAD_INFO_IN_TASK
  /*
   * For reasons of header soup (see current_thread_info()), this
   * must be the first element of task_struct.
   */
  struct thread_info     thread_info;
#endif
  /* -1 unrunnable, 0 runnable, >0 stopped: */
  volatile long      state;

  /*
   * This begins the randomizable portion of task_struct. Only
   * scheduling-critical items should be added above here.
   */
  randomized_struct_fields_start

  void          *stack;
  refcount_t      usage;
  /* Per task flags (PF_*), defined further below: */
  unsigned int       flags;
  unsigned int       ptrace;

#ifdef CONFIG_SMP
  struct llist_node   wake_entry;
  int          on_cpu;
#ifdef CONFIG_THREAD_INFO_IN_TASK
  /* Current CPU: */
  unsigned int       cpu;
#endif
```

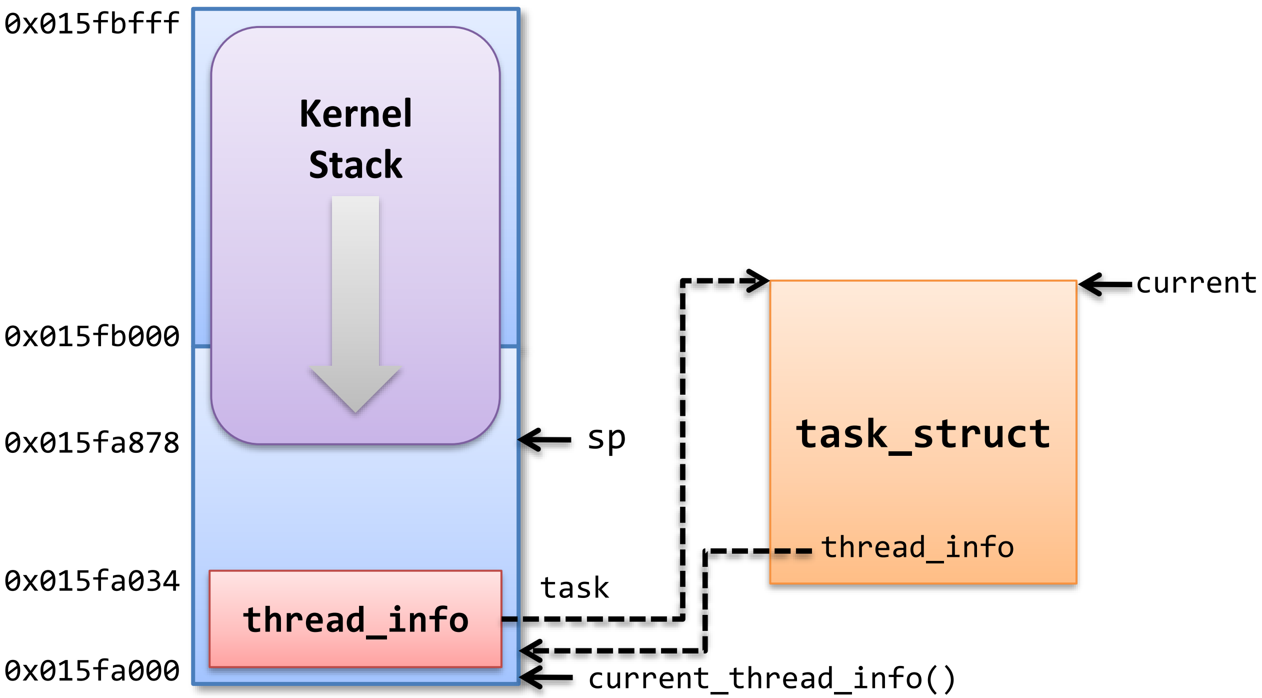
Task Structure



Finding the Current Task

- `get_current()`
  - Per-cpu variable called `current_task` is maintained

- The old way
  - When `CONFIG_THREAD_INFO_IN_TASK=n`
  - Put the `thread_info` at the top of the kernel stack
  - Get current `thread_info` from the stack pointer
  - `thread_info` has a pointer to the `task_struct`



Execution Contexts

- Process context
  - Process enters kernel space by a system call or an exception
  - The kernel is executing on behalf of the process
  - The `current` variable is valid

- Interrupt context
  - The system is executing an interrupt handler
  - There is no task tied to interrupt handlers
  - The `current` variable should not be used (except for the scheduler)

Creating a New Process

- `sys_fork()` → `_do_fork()` (@ `kernel/fork.c`)
- `copy_process()`
  - Check parameters
  - Invoke `dup_task_struct()` to create a new kernel stack and `task_struct` for the new process
  - Make sure the child will not exceed the resource limit
  - Invoke `sched_fork()` to initialize the scheduler-related data structure
  - Invoke `copy_files()`, `copy_fs()`, `copy_sighand()`, `copy_signal()`, `copy_mm()`, etc. to copy those data structures
  - Invoke `copy_thread_tls()` to initialize user registers of the child
  - Allocate a new PID by calling `alloc_pid()`

Creating a New Process (cont'd)

- `copy_process()` (cont'd)
  - Initialize the fields for parenthood relationship and thread group
  - Invoke `attach_pid()` to insert the child PID to the PID hash table
- `wake_up_new_task()`
  - Invoke `activate_task()` to insert the child into the runqueue
- Returns the PID of the child

Linux Threads

- **Linux implements all threads using standard tasks**
  - There is no concept of a thread
  - A thread is merely a task that shares certain resources with other tasks
- **One-to-one model**
  - Linux creates a task for each application thread using `clone()` system call
- **Sharing resources**
  - Resources to be shared can be specified in the `flags` argument in `clone()`
  - CLONE_VM: parent and child share address space
  - CLONE_FILES: parent and child share open files
  - CLONE_FS: parent and child share filesystem information
  - CLONE_SIGHAND, … (cf.) `$ man 2 clone`

POSIX Compatibility

- Basic difference in multithreading model
  - POSIX: a single process that contains one or more threads
  - Linux: separate tasks that may share one or more resources

- Resources
  - POSIX: the following resources are specific to a thread, all other resources are global to a process
    - CPU registers, user stack, blocked signal mask
  - Linux: the following resources may be shared between tasks via `clone()`, while all other resources are local to each task
    - Address space, signal handlers, open files, working directory, …

- `getpid()`, `fork()`, `exec()`, `exit()`, signals, suspend/resume, …?

Thread Group

- A set of threads that act as a whole with regards to some system calls
- The first thread (task) in a process becomes the thread group leader
  - A new thread created with CLONE_THREAD is placed in the same thread group as the calling thread
- Handling process-based system calls:
  - `getpid()` returns the PID of the thread group leader (`t->tgid`)
  - On `exec()`, all threads other than the thread group leader are terminated, and the new program is executed in the thread group leader
  - After all of the threads in a thread group terminate, a SIGCHLD signal is sent to the parent process
  - Signals may be sent to a thread group as a whole

Kernel Threads

- Standard tasks that exist solely in the kernel space
  - Kernel threads share the kernel's address space
  - They operate only in the kernel space and do not context switch into the user space
  - Kernel threads are, however, schedulable and preemptable as normal tasks
  - Used to perform certain tasks in background (e.g., kswapd)

- Creating a kernel thread
  - `pid_t kernel_thread(int (*fn)(void *), void *arg, unsigned long flags)`
  - kthread API @ `include/linux/kthread.h` (e.g., `kthread_create()`, ...)