CSE 451: Operating Systems
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Processes

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Process management

- This module begins a series of topics on processes, threads, and synchronization
  - this is the most important part of the class, well, except for file systems and disks…
- Processes and process management
  - what are the OS units of ownership / execution?
  - how are they represented inside the OS?
  - how is the CPU scheduled across processes?
  - what are the possible execution states of a process?
    - and how does the system move between them?
  - How are they created?
  - How can this be made faster

A Digression – Mechanism and Policy

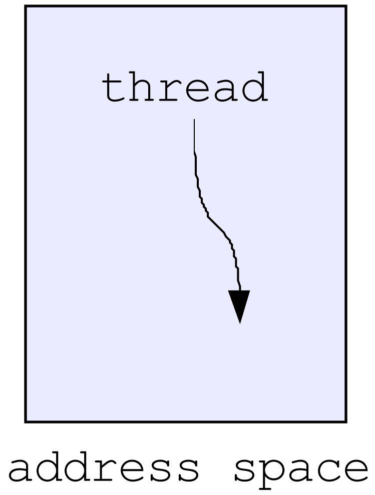
- Mechanism – how to do something (schedule a thread, fix a lightbulb)
- Policy – when to do something, who is authorized to do it (network packet arrived for thread, light is burned out by anyone but me)
- Mechanisms should NOT dictate policy.
    - Allows multiple policies for same mechanism (fix lights in batches)
    - Allows multiple mechanisms for same policy (fix lights by myself [unreliable,cheap], call electrician [reliable,expensive])

The Process

- The process is the OS's abstraction for execution
  - the unit of ownership (root of web/tree of kernel data structures)
  - the unit of execution (sorta)
  - the unit of scheduling (kinda)
  - the dynamic (active) execution context
    - compared with program: static, just a bunch of bytes
- Process is often called a job, task, or sequential process
- The goal of the OS is to present each Process with the view that it is executing in it's own *separate, isolated* computer

What is a “process”?

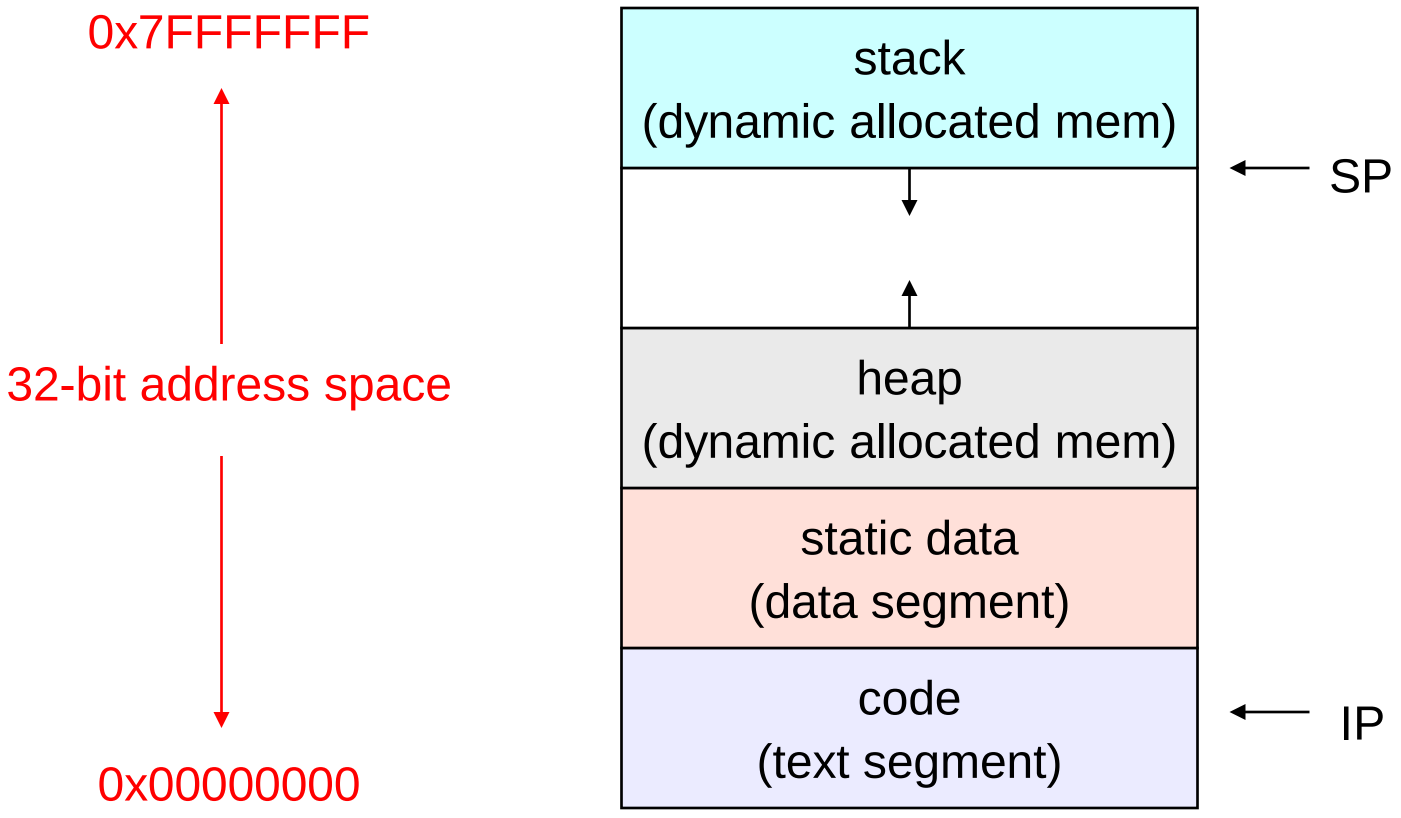
- Simple, classic case (1950’s): a sequential process
  - An address space (abstraction of “memory”)
  - A single bit of execution: a “thread”
- A sequential process is:
  - The unit of execution
  - The unit of scheduling
  - The execution context (registers, OS state,
  - memory, etc.)



What is a process?

- Process == fundamental abstraction for program execution
  - an address space which contains:
    - the code for the running program
    - the data for the running program
  - at least one thread with state
    - Registers, IP
    - Floating point state
    - Stack and stack pointer
  - a set of OS resources
    - open files, network connections, security caches, sound channels, …
- In other words, it’s all the stuff you need to run the program

A process's address space (overly simplified)



The OS’s process namespace

- (Like most things, the particulars depend on the specific OS, but the principles are general)
- The name for a process is called a process ID (PID)
  - An integer (how many bits?), possibly a string(!)
- The PID namespace is global to the system
  - Only one process at a time has a particular PID: uniqueness
- Operations that create processes return a PID
  - E.g., NtCreateProcess, ShellExecute
- Operations on processes take PIDs as an argument
  - E.g., NtOpenProcess

The Process Object

- There's a data structure called the process object (_KPROCESS in base\ntos\inc\ke.h) that holds all this stuff
  - Processes are identified from user space by a process ID, returned by NtCreateProcess.
- OS keeps all of a process's hardware execution state in the _KTHREAD (same file) when the process isn't running
  - IP, SP, registers, etc.
  - when a process is unscheduled (i.e., processor is taken away from the process) , the state is transferred out of the hardware into the _KTHREAD
- Note: It is natural to think that there must be some esoteric techniques being used
  - fancy data structures that you'd never think of yourself

Wrong! It's pretty much just what you'd think of!

Except for some clever assembly code in one place…

_KTHREADs and hardware state

- When a process is running, its hardware state is inside the CPU
  - IP, SP, registers
  - CPU contains current values
- When a process is transitioned to the waiting state, the OS saves its CPU state in the _KTHREAD (actually, _PRCB, but that's not important ☺)
  - when the OS returns the process to the running state, it loads the hardware registers with values from that process's _KTHREAD
- The act of switching the CPU from one process to another is called a context switch
  - systems may do 100s or 1000s of switches/sec.
  - takes a few microseconds on today's hardware
- Choosing which process to run next is called scheduling, more when we talk about threads

Process creation

- New processes are created by existing processes
  - creator is called the parent
  - created process is called the child
  - what creates the first process, and when?
- In some systems, parent defines or donates resources and privileges for its children
  - LINUX/UNIX: child inherits parent's security context, environment, open file list, etc.
  - NT: all the above are *optional (remember, mechanism vs policy)*, the Windows subsystem provides policy.
- When child is created, parent may either wait for it to finish, or may continue in parallel, or both!

Process Creation 2

- In LINUX, fork/exec pairs.
  - fork() *clones* the current process, duplicates all memory, “inherit” open files
  - exec() throws away all memory and loads new program into memory. Keeps all open files!
  - Very useful, but… wasteful. >99% of all fork() calls followed by exec(). Copy-on-write memory helps but still a big overhead (have to “duplicate” all data structures)
- Windows has parent process doing the work
  - Create process
  - Fill in memory
  - Pass handles
  - Create thread with stack and IP
  - Many system calls (compared with LINUX) but all policy is in user code. More flexible.

Process Destruction

- Privileged operation!
  - Process can always kill itself
  - Killing another process requires permission
- Terminates all threads
- Releases owned resources to known state
  - Files
  - Events
  - Memory
- Notification sent to interested parties
- KPROCESS is freed

So you want to run a process..

- How was it created?
  - Someone wrote some C/C#/C++/etc
  - Compile/fix-errors/compile again
  - Get *object files*
- What’s in the .o or .obj files?
  - Code and data and *fixups*
  - Code and data are easy
  - Fixups describe relationships
    - Targets of jumps/calls
    - Data references
  - What do you do about references to other (extern) code/data?
    - Fixups too!

More of what’s in .o / .obj files

- Old style format (reflecting stream view of files)
  - Stream of records <tag><data> where <tag> was
    - DATA: <data> was constant data
    - BSS: <data> was just the size of the BSS reserved
    - CODE: just like DATA
    - FIXUP: applies to previous CODE/DATA record, may list a name (external) or an offset into some other prior record and describe a width (8, 16, 32, 64) and an operation (ADD, IMM, SELF-REL)
- Modern format (take advantage of memory mapping)
  - Header on file describes *sections* suitable for mmap()

What’s a section?

- Section is a piece of contiguous memory
  - Named
  - Protected: read only, read/write, execute, read/execute, etc.
  - Location in file
  - Location in memory
- Some names are important
  - DATA
  - CODE
  - BSS
  - DEBUG
  - FIXUP

Putting .o/.obj files together

- The “linker”
  - take a collection of object files and produce an executable image
  - Gathers and appends like named/protected sections
  - Evaluates fixups and establishes addressing (linkages) between sections
  - Emits special sections
    - DEBUG
    - IMPORT
    - EXPORT
  - All into a file *with the same general format as .o/.obj files*
    - A few new sections
    - But it’s header says it’s executable
    - Called the *image file*

Executing the image file

- What does exec() or CreateProcess() do?
  - Easy stuff:
    - Allocate KPROCESS
    - Create address space
  - Harder stuff
    - Create first thread
    - Copy handle environment from parent
  - The meat:
    - Opens image file
    - Memory maps header (section table of contents)
    - For each section:
      - Memory map the appropriate portion of the file
      - Into the correct address space location
      - With correct memory protection

Is that all?

- Once upon a time, yes
  - All code was in one file
  - Included all special stuff for calling the OS
- Not nearly useful enough
  - What if system call #’s changed?
  - What about sharing common code between apps?
  - What about 3rd party code?
  - What about extensibility?

Dynamic (aka Shared) Libraries

- Goal: break down single images into multiple pieces
  - Independently distributable
  - Breakdown based on functionality / extensibility
- Implications on image format
  - Need a way to reference between image files
  - Add IMPORT and EXPORT sections
  - IMPORT lists all functions required by the image file (executable or library)
  - EXPORT lists all functions offered by the image file
- Big implications on process creation

Process Creation with libraries

- Easy/Harder stuff still the same
- Hardest stuff:
  - No longer loading just a single file, loading multiple modules
  - Walking each IMPORT table, finding references to modules not yet loaded and loading them
  - Big graph traversal (remember “transitive closure”?)
  - How are linkages established between modules?

Module Linkage

- Naïve approach is to use something similar to fixups
  - Modify the sections to establish linkage
  - Modifies the memory mapped pages
    - Don’t want to modify the original file
    - Copy-on-write
    - Bigger page file
    - More dirty pages in memory
- Work with compiler
  - Observe that inter-module references are always direct (never self-relative). Call or pointer reference
  - Keywords in language (or header files) that change direct calls into indirect calls and direct addressing into indirect addressing.

Efficient Linkage

- Foo(args) turns into (*import_Foo)(args)
- Gather all import_X addresses into a single section
  - Called IAT (import address table)
  - Usually only a single page in size, not inefficient to dirty
  - Still have to do some big work
- Can we do better?

Binding

- Floating modules
  - No known address
  - IAT required to handle differing locations based on other modules’ locations
- Bind modules to specific locations
  - Section table describes location, mapping is trivial
  - IAT can be pre-built with locations already in mind
  - Zero program-startup fixups
- What’s the issue?

Binding

- What address do you assign?
  - 32 bit address space *seems* large enough
  - XP has >1200 modules.
- What if there’s a *collision*?
  - New release of module grows in size (bug fixes, functionality)
  - Modules produced by two independent companies
  - Loader needs to be robust in the face of this
  - Choose another location
  - Fix up IAT (small number of pages)

A few cheats

- Compiler needs to generate self-relative instructions
  - Otherwise relocation of module would require fixups
  - Works well on x86…
  - Most of XP’s DLL’s can be broken into disjoint groups and addresses assigned to each

Vista cool feature

- “dynamic rebasing”
  - At install time, all modules are rebased to random addresses
  - Just edit the IATs, still have speedy program start
  - What problem would this solve?
- Buffer overflow attacks
  - Operate by overflowing a stack buffer and overwriting a return address
  - Knowing where special code might be would allow attacker to hijack return to code in a module not directly referenced
  - Not if the module moves…

Windows CreateProcess

- Different from fork/exec.
  - Fork/exec are in kernel mode and embody the entire process creation experience
  - Windows Kernel has
    - NtCreateProcess – creates a new process address space. BUT NO THREAD
    - NtCreateThread – creates a new thread in a given process
    - NtSetThreadInformation – sets execution context for thread (notably stack and PC)

Windows CreateProcess

- CreateProcess is user code in kernel32 module
  - Creates process (NtCreateProcess)
  - Maps in kernel call DLL (ntdll)
  - Maps in image (but no libraries)
  - Creates initial thread
  - Sets thread to initialization routine in ntdll (LdrpInitializeProcess)
  - Go!
- LdrpInitializeProcess does all the memory mapping work
  - Executing in the new image’s context
  - Walking module lists is just memory access
  - Makes NtCreateSection calls

Why not do what Unix did?

- Extensibility
  - Differing loader policies (OS/2, DOS)
  - New loader implementations
  - Smaller kernel
- Simpler kernel loader code