Process management in xv6

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PCB in xv6: struct proc

```
2334 enum procstate { UNUSED, EMBRYO, SLEEPING, RUNNABLE, RUNNING, ZOMBIE };
2335
2336 // Per-process state
2337 struct proc {
2338   uint sz;                     // Size of process memory (bytes)
2339   pde_t* pgdir;                // Page table
2340   char *kstack;                // Bottom of kernel stack for this process
2341   enum procstate state;        // Process state
2342   int pid;                     // Process ID
2343   struct proc *parent;         // Parent process
2344   struct trapframe *tf;        // Trap frame for current syscall
2345   struct context *context;     // swtch() here to run process
2346   void *chan;                  // If non-zero, sleeping on chan
2347   int killed;                  // If non-zero, have been killed
2348   struct file *ofile[NOFILE];  // Open files
2349   struct inode *cwd;           // Current directory
2350   char name[16];               // Process name (debugging)
2351 };
2352
```

struct proc: page table

- Every instruction or data item in the memory image of process (code/data, stack, heap, etc.) has an address
  - Virtual addresses, starting from 0
  - Actual physical addresses in memory can be different (all processes cannot store their first instruction at address 0)
- Page table of a process maintains a mapping between the virtual addresses and physical addresses
- Page table used to translate virtual addresses to physical addresses

struct proc: kernel stack

- Stack to store CPU context when process jumps to kernel mode from user mode, or when process is context switched out
  - Why separate stack? OS does not trust user stack
  - Separate area of memory in the kernel, not accessible by regular user code
  - Linked from struct proc of a process

struct proc: list of open files

- Array of pointers to open files
  - When user opens a file, a new entry is created in this array, and the index of that entry is passed as a file descriptor to user
  - Subsequent read/write calls on a file use this file descriptor to refer to the file
  - First 3 files (array indices 0,1,2) open by default for every process: standard input, output and error
  - Subsequent files opened by a process will occupy later entries in the array

Process table (ptable) in xv6

- Ptable in xv6 is a fixed-size array of all processes
- Real kernels have dynamic-sized data structures

```
2409 struct {
2410   struct spinlock lock;
2411   struct proc proc[NPROC];
2412 } ptable;
```

CPU scheduler in xv6

- The OS loops over all runnable processes in ptable, picks one, and sets it running on the CPU

```
2768    // Loop over process table looking for process to run.
2769    acquire(&ptable.lock);
2770    for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
2771      if(p->state != RUNNABLE)
2772        continue;
2773
2774      // Switch to chosen process.  It is the process's job
2775      // to release ptable.lock and then reacquire it
2776      // before jumping back to us.
2777      c->proc = p;
2778      switchuvm(p);
2779      p->state = RUNNING;
```

xv6 system calls

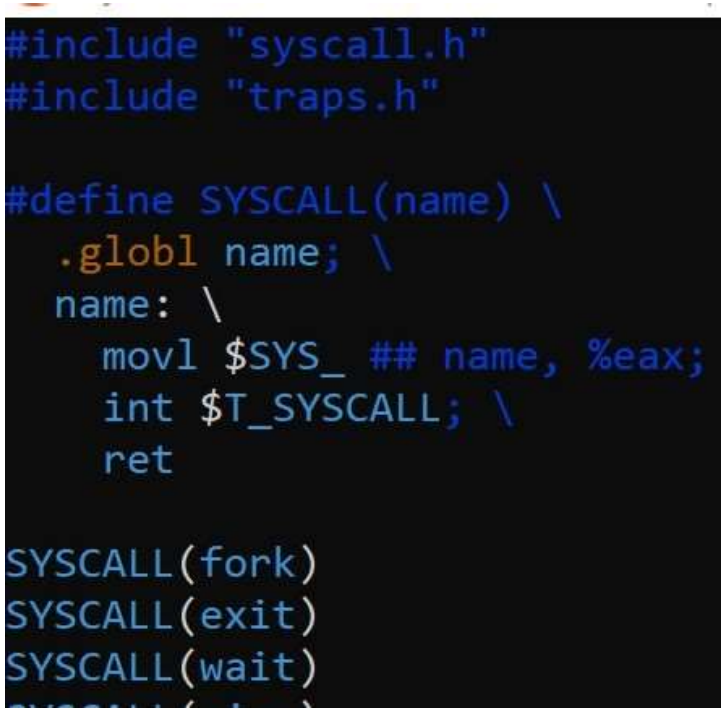
- In xv6, as in other systems, system calls are made by user library functions
  - User code invokes library function only
- System calls available to user programs are defined in user library header “user.h”
  - Equivalent to C library headers (xv6 doesn’t use standard C library)

```
struct stat;
struct rtcdate;

// system calls
int fork(void);
int exit(void) __attribute__((noreturn));
int wait(void);
int pipe(int*);
int write(int, const void*, int);
int read(int, void*, int);
int close(int);
int kill(int);
int exec(char*, char**);
int open(const char*, int);
int mknod(const char*, short, short);
int unlink(const char*);
int fstat(int fd, struct stat*);
int link(const char*, const char*);
int mkdir(const char*);
int chdir(const char*);
int dup(int);
int getpid(void);
char* sbrk(int);
int sleep(int);
int uptime(void);
```

What happens on a system call?

- The user library makes the actual system call to invoke OS code
- NOT a regular function call to OS code as it involves CPU privilege level change
- User library invokes special “trap” instruction called “int” in x86 (see usys.S) to make system call
- The trap (int) instruction causes a jump to kernel code that handles the system call
  - More on trap instruction later



```
#include "syscall.h"
#include "traps.h"

#define SYSCALL(name) \
  .globl name; \
  name: \
    movl $SYS_ ## name, %eax; \
    int $T_SYSCALL; \
    ret

SYSCALL(fork)
SYSCALL(exit)
SYSCALL(wait)
```

proc->tf->eax holds the syscall number upon entry and the return value upon exit.

xv6: fork system call implementation

```
2579 int
2580 fork(void)
2581 {
2582   int i, pid;
2583   struct proc *np;
2584   struct proc *curproc = myproc();
2585
2586   // Allocate process.
2587   if((np = allocproc()) == 0){
2588     return -1;
2589   }
2590
2591   // Copy process state from proc.
2592   if((np->pgdir = copyuvm(curproc->pgdir, curproc->sz)) == 0){
2593     kfree(np->kstack);
2594     np->kstack = 0;
2595     np->state = UNUSED;
2596     return -1;
2597   }
2598   np->sz = curproc->sz;
2599   np->parent = curproc;
2600   *np->tf = *curproc->tf;
2601
2602   // Clear %eax so that fork returns 0 in the child.
2603   np->tf->eax = 0;
2604
2605   for(i = 0; i < NOFILE; i++)
2606     if(curproc->ofile[i])
2607       np->ofile[i] = filedup(curproc->ofile[i]);
2608   np->cwd = idup(curproc->cwd);
2609
2610   safestrcpy(np->name, curproc->name, sizeof(curproc->name));
2611
2612   pid = np->pid;
2613
2614   acquire(&ptable.lock);
2615
2616   np->state = RUNNABLE;
2617
2618   release(&ptable.lock);
2619
2620   return pid;
2621 }
```

To change the state, we're locking and unlocking it.

xv6: fork system call explanation

- Parent process invokes fork to create new child
  - Allocates new process in ptable, get new PID for child
  - Variable “np” is pointer to newly allocated struct proc of child
  - Variable “currproc” is pointer to struct proc of parent
  - Copies information (memory, files, size, …) from currproc to np
- Child process set to runnable, scheduler runs it at a later time
- Return value in parent is PID of child
- Return value in child is set to 0 (by changing child’s EAX register)

xv6: exit system call implementation

```
2626 void
2627 exit(void)
2628 {
2629   struct proc *curproc = myproc();
2630   struct proc *p;
2631   int fd;
2632
2633   if(curproc == initproc)
2634     panic("init exiting");
2635
2636   // Close all open files.
2637   for(fd = 0; fd < NOFILE; fd++){
2638     if(curproc->ofile[fd]){
2639       fileclose(curproc->ofile[fd]);
2640       curproc->ofile[fd] = 0;
2641     }
2642   }
2643
2644   begin_op();
2645   iput(curproc->cwd);
2646   end_op();
2647   curproc->cwd = 0;
2648
2649   acquire(&ptable.lock);
2650   // Parent might be sleeping in wait().
2651   wakeup1(curproc->parent);
2652
2653   // Pass abandoned children to init.
2654   for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
2655     if(p->parent == curproc){
2656       p->parent = initproc;
2657       if(p->state == ZOMBIE)
2658         wakeup1(initproc);
2659     }
2660   }
2661
2662   // Jump into the scheduler, never to return.
2663   curproc->state = ZOMBIE;
2664   sched();
2665   panic("zombie exit");
2666 }
```

syscall

close all the open files.

Ensure the safe environment.

The process acquires a lock on the process table (ptable.lock) for thread-safe operation.

if any parent is sleeping(waiting) child process to be reaped.

change the parent pointers to the init processes.

set to zombie state but don't reap it yet.

schedule or run the next process which is ready.

This will execute if scheduler() fails. Very rare.

If the process trying to exit is the init process (the root of all processes in xv6), the kernel halts execution by invoking panic. This prevents the loss of the critical parent process.

iput is used to decrement the reference count of the inode associated with the current working directory.

xv6: exit system call explanation

- Exiting process cleans up some state (e.g., close files)
- Wakes up parent process that may be waiting to reap
- Passes abandoned children (orphans) to init
- Marks itself as zombie and invokes scheduler, never gets scheduled again

xv6: wait system call implementation

```
2670 int
2671 wait(void)
2672 {
2673   struct proc *p;
2674   int havekids, pid;
2675   struct proc *curproc = myproc();
2676
2677   acquire(&ptable.lock);
2678   for(;;){
2679     // Scan through table looking for exited children.
2680     havekids = 0;
2681     for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
2682       if(p->parent != curproc)
2683         continue;
2684       havekids = 1;
2685       if(p->state == ZOMBIE){
2686         // Found one.
2687         pid = p->pid;
2688         kfree(p->kstack);
2689         p->kstack = 0;
2690         freevm(p->pgdir);
2691         p->pid = 0;
2692         p->parent = 0;
2693         p->name[0] = 0;
2694         p->killed = 0;
2695         p->state = UNUSED;
2696         release(&ptable.lock);
2697         return pid;
2698       }
2699     }
```

free the virtual memory.

```
2700     // No point waiting if we don't have any children.
2701     if(!havekids || curproc->killed){
2702       release(&ptable.lock);
2703       return -1;
2704     }
2705
2706     // Wait for children to exit.  (See wakeup1 call in proc_exit.)
2707     sleep(curproc, &ptable.lock);
2708   }
2709 }
```

why isn't there any return value after sleep?

If there's a child and hasn't been reaped yet or is running currently then wait for it to finished executing and then reap it and return;

xv6: wait system call explanation

- Search for dead children in process table
- If dead child found, clean up memory of zombie, return its PID
- If no children, return -1, no need to wait waitpid() will have different implementation.
- If children exist but haven't terminated yet, wait until one dies

xv6: exec system implementation overview

- Copy new executable into memory from disk
- Create new stack, heap
- Copy command line arguments to new stack
- Switch process page table to use new memory image
- Process begins to run new code after system call ends
- Revert back to old memory image in case of any error