Basic OS Progamming Abstractions

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Recap

- We’ve introduced the idea of a process as a container for a running program
- And we’ve discussed the hardware-level mechanisms to transition between the OS and applications (interrupts)
- This lecture: Introduce key OS APIs
  - Some may be familiar from lab 1
  - Others will help with lab 2

Outline

- Files and File Handles
- Inheritance
- Pipes
- Sockets
- Signals
- Synthesis Example: The Shell

2 Ways to Refer to a File

- Path, or hierarchical name, of the file
  - Absolute: “/home/porter/foo.txt”
    - Starts at system root
  - Relative: “foo.txt”
    - Assumes file is in the program’s current working directory
- Handle to an open file
  - Handle includes a cursor (offset into the file)

Path-based calls

- Functions that operate on the directory tree
  - Rename, unlink (delete), chmod (change permissions), etc.
- Open – creates a handle to a file
  - int open (char *path, int flags, mode_t mode);
    - Flags include O_RDONLY, O_RDWR, O_WRONLY
    - Permissions are generally checked only at open
  - Opendir – variant for a directory

Handle-based calls

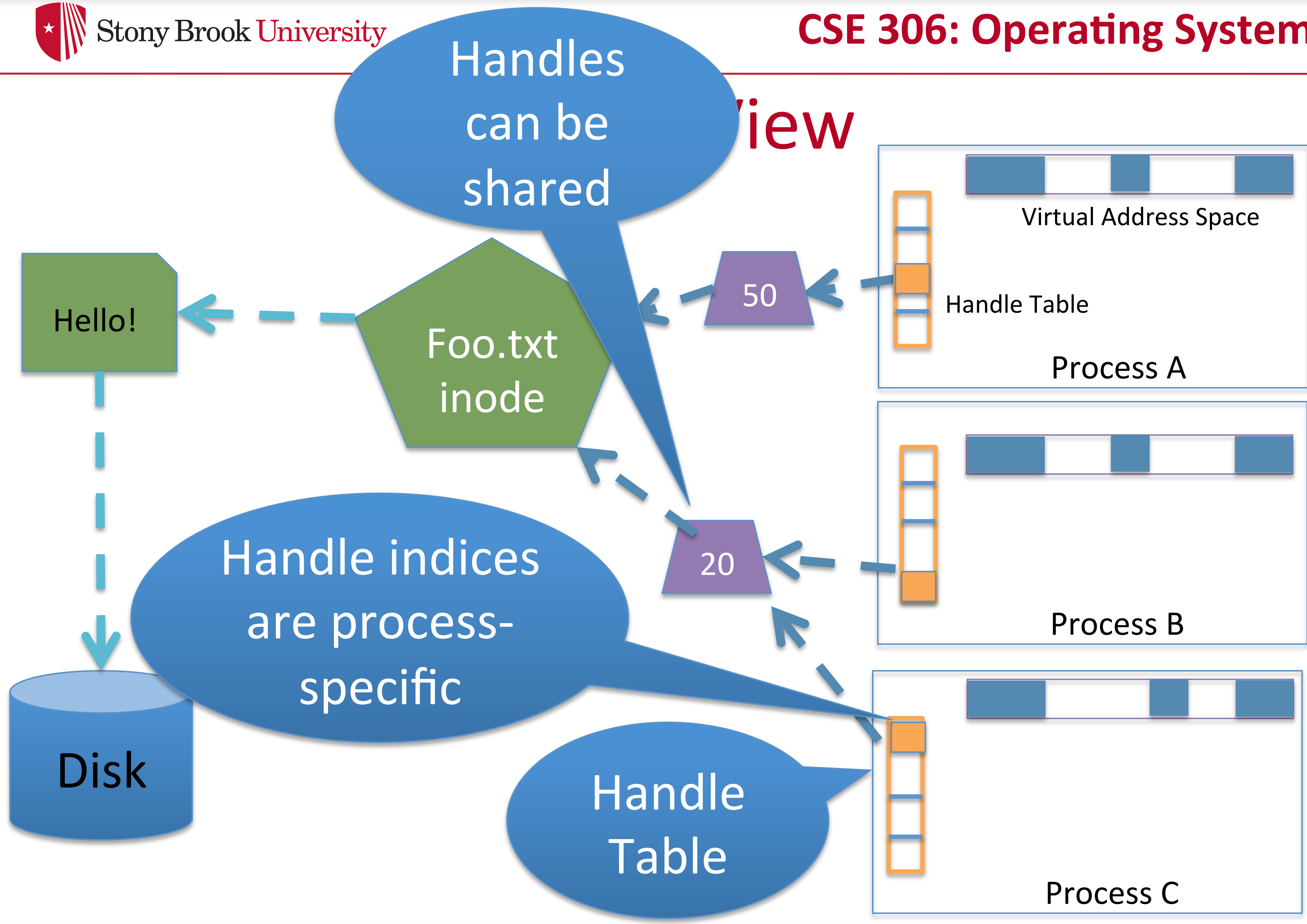
- ssize_t read (int fd, void *buf, size_t count)
  - Fd is the handle
  - Buf is a user-provided buffer to receive count bytes of the file
  - Returns how many bytes read
- ssize_t write(int fd, void *buf, size_t count)
  - Same idea, other direction
- int close (int fd)
  - Close an open file

Example

```
char buf[9];  // stack allocate a char buffer
int fd = open ("foo.txt", O_RDWR);
ssize_t bytes = read(fd, buf, 8);
if (bytes != 8) // handle the error
memset (buf, "Awesome", 7);
buf[7] = '\0';
bytes = write(fd, buf, 8);
if (bytes != 8) // error
close(fd);
```

But what is a handle?

- A reference to an open file or other OS object
  - For files, this includes a cursor into the file
- In the application, a handle is just an integer
  - This is an offset into an OS-managed table


Handles can be shared
iew
Virtual Address Space
Handle Table
50
Hello!
Foo.txt inode
Process A
Process B
20
Handle indices are process-specific
Disk
Handle Table
Process C

Handle Recap

- Every process has a table of pointers to kernel handle objects
  - E.g., a file handle includes the offset into the file and a pointer to the kernel-internal file representation (inode)
- Application's can't directly read these pointers
  - Kernel memory is protected
  - Instead, make system calls with the indices into this table
  - Index is commonly called a handle

Rearranging the table

- The OS picks which index to use for a new handle
- An application explicitly copy an entry to a specific index with dup2(old, new)
  - Be careful if new is already in use…

Other useful handle APIs

- We've seen mmap already; can map part or all of a file into memory
- seek() – adjust the cursor position of a file
  - Like rewinding a cassette tape

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Inheritance

- By default, a child process gets a copy of every handle the parent has open
  - Very convenient
  - Also a security issue: may accidentally pass something the program shouldn't
- Between fork() and exec(), the parent has a chance to clean up handles it doesn't want to pass on
  - See also CLOSE_ON_EXEC flag

Standard in, out, error

- Handles 0, 1, and 2 are special by convention
  - 0: standard input
  - 1: standard output
  - 2: standard error (output)
- Command-line programs use this convention
  - Parent program (shell) is responsible to use open/close/dup2 to set these handles appropriately between fork() and exec()

Example

```
int pid = fork();
if (pid == 0) {
     int input = open ("in.txt",
O_RDONLY);
     dup2(input, 0);
     exec("grep", "quack");
}
//…
```

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Pipes

- FIFO stream of bytes between two processes
- Read and write like a file handle
  - But not anywhere in the hierarchical file system
  - And not persistent
  - And no cursor or seek()-ing
  - Actually, 2 handles: a read handle and a write handle
- Primarily used for parent/child communication
  - Parent creates a pipe, child inherits it

Example

```
int pipe_fd[2];
int rv = pipe(pipe_fd);
int pid = fork();
if (pid == 0) {
     close(pipe_fd[1]); //Close unused 
write end
     dup2(pipe_fd[0], 0); // Make the 
read end stdin
     exec("grep", "quack");
} else {
     close (pipe_fd[0]);  // Close unused 
read end …
```

Sockets

- Similar to pipes, except for network connections
- Setup and connection management is a bit trickier
  - A topic for another day (or class)

Select

- What if I want to block until one of several handles has data ready to read?
- Read will block on one handle, but perhaps miss data on a second…
- Select will block a process until a handle has data available
  - Useful for applications that use pipes, sockets, etc.

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Signals

- Similar concept to an application-level interrupt
  - Unix-specific (more on Windows later)
- Each signal has a number assigned by convention
  - Just like interrupts
- Application specifies a handler for each signal
  - OS provides default
- If a signal is received, control jumps to the handler
  - If process survives, control returns back to application

Signals, cont.

- Can occur for:
  - Exceptions: divide by zero, null pointer, etc.
  - IPC: Application-defined signals (USR1, USR2)
  - Control process execution (KILL, STOP, CONT)
- Send a signal using kill(pid, signo)
  - Killing an errant program is common, but you can also send a non-lethal signal using kill()
- Use signal() or sigaction() to set the handler for a signal

How signals work

- Although signals appear to be delivered immediately…
  - They are actually delivered lazily…
  - Whenever the OS happens to be returning to the process from an interrupt, system call, etc.
- So if I signal another process, the other process may not receive it until it is scheduled again
- Does this matter?

More details

- When a process receives a signal, it is added to a pending mask of pending signals
  - Stored in PCB
- Just before scheduling a process, the kernel checks if there are any pending signals
  - If so, return to the appropriate handler
  - Save the original register state for later
  - When handler is done, call sigreturn() system call
    - Then resume execution

Meta-lesson

- Laziness rules!
  - Not on homework
  - But in system design
- Procrastinating on work in the system often reduces overall effort
  - Signals: Why context switch immediately when it will happen soon enough?

Language Exceptions

- Signals are the underlying mechanism for Exceptions and catch blocks
- JVM or other runtime system sets signal handlers
  - Signal handler causes execution to jump to the catch block

Windows comparison

- Exceptions have specific upcalls from the kernel to ntdll
- IPC is done using Events
  - Shared between processes
  - Handle in table
  - No data, only 2 states: set and clear
  - Several variants: e.g., auto-clear after checking the state

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Shell Recap

- Almost all ‘commands’ are really binaries
  - /bin/ls
- Key abstraction: Redirection over pipes
  - ‘>’, ‘<‘, and ‘|’implemented by the shell itself

Shell Example

- Ex: **`ls | grep foo`**
- Implementation sketch:
  - Shell parses the entire string
  - Sets up chain of pipes
  - Forks and exec's 'ls' and 'grep' separately
  - Wait on output from 'grep', print to console

What about Ctrl-Z?

- Shell really uses select() to listen for new keystrokes
  - (while also listening for output from subprocess)
- Special keystrokes are intercepted, generate signals
  - Shell needs to keep its own “scheduler” for background processes
  - Assigned simple numbers like 1, 2, 3
- ‘fg 3’ causes shell to send a SIGCONT to suspended child

Other hints

- Splice(), tee(), and similar calls are useful for connecting pipes together
  - Avoids copying data into and out-of application

Summary

- Understand how handle tables work
  - Survey basic APIs
- Understand signaling abstraction
  - Intuition of how signals are delivered
- Be prepared to start writing your shell in lab 2!