NachOS Tutorial

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Introduction

In teaching operating system at undergraduate level, it is very important to provide a project that is realistic enough to show how real operating systems work, yet simple enough that the student can understand and modify it in significant ways.

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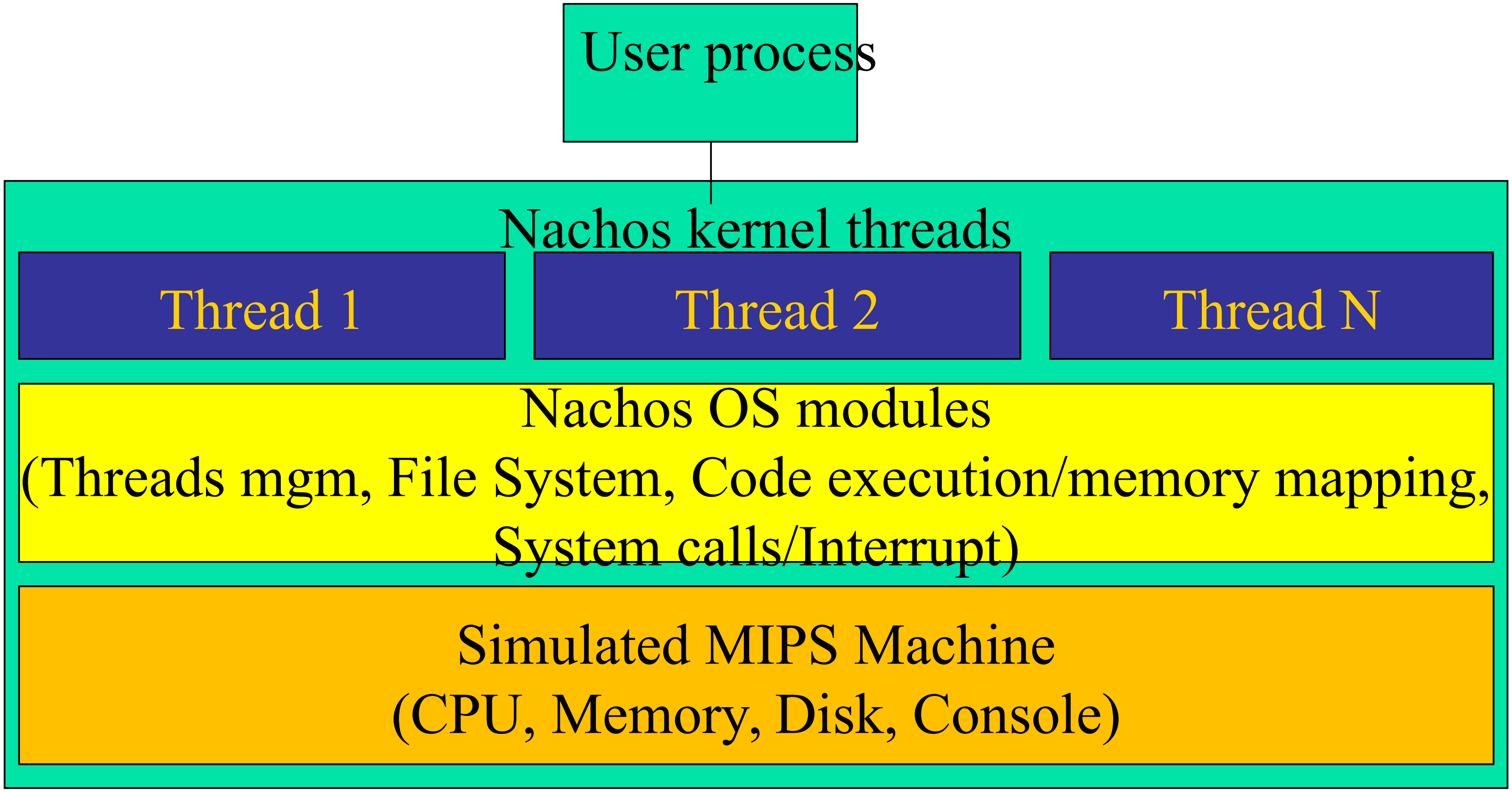
NachOS: a chinese proverb

- I hear and I forget
- I see and I remember
- I do and I understand

What is NachOS?

- Nachos is an instructional operating system
  - Designed for use in operating system classes
  - Allow students to modify an almost real OS
  - Has the same components of a real OS
    - Threads
    - Memory Management
    - File System
    - Network
- Kept small to be easy to modify
  - Small and easy compared to real OSes

What is NachOS?



What is NachOS

- NachOS runs as a Normal Unix Process
  - Single binary image
  - Make changes then just recompile
  - Simulate underlying hardware

- Not Another Completely Heuristic Operating System

Why use NachOS?

- To really see what OS is all about...

- NachOS allows students to learn in a hand on environment
    - Take lessons from class and implement them
    - Look under the hood of a realistic OS
- By implementing concepts you learn how things really work
    - Important addition to the theoretical knowledge from class

Why use NachOS?

- Implement useful things without writing million of lines of code...
- NachOS and project designed to minimize the amount of busy work
  - Maximize the learning/time spent ration
- Highly modularized design
  - Keeps changes for a project relatively localized
- Code you write early on will be used in later projects

Why use NachOS?

- Because it is simple!
- Real Oses are huge
  - Generally not designed for readability
  - Never designed for simplicity
- In NachOS, you can understand the code!
- NachOS allows you to make the design decision between performance and simplicity
  - But remember, correctness always comes first

Why use NachOS?

- Did I say it is simple?

- NachOS gretly simplifies the development process
  - Make changes, then recompiles (no reboots)
  - Can run under the debugger (GDB)
  - Deteministic/repeatable behavior

Why use NachOS?

- Answer to basic questions like
  - How does the OS start a thread? A process?
  - What happens on a system call?
  - How does address translation work?
  - What data needs to be written to disk on file creation?
  - How deos the OS interface with I/O devices?
  - What FS structures are stored on disk? In Memory?
  - What happens on a thread context switch?
  - How do all the pieces of an OS fit together?

Projects

- Project 1: Getting started
- Project 2: Systems calls and I/O functions
- Project 3: Multithreading
- Project 4: Virtual memory and multiprograming
- Project 5: File System
- Project 6: Networking

Project 1: Getting Started

- This is what you are supposed to do during the first week
- Install, compile and test the installation
- Understand: read the code, get into the code structure and understand NachOS organization

- This is a difficult project because it is all so new
- Without this first effort, the next projects will be rather complex

Project 2: System calls and I/O

- In NachOS, you can execute user programs
- The problem is that the initial version of NachOS does not allow user IO
  - The following proram does not run

```
#include "syscall.h"
    void print (char c, int n)
     {
        int i;
        for (i=0; i<n;i++)
             PutChar (c+i);
        PutChar ('\n') ;
     }

     int main ()
     {
        print ('a',4) ;
        Halt () ;
     }
```

Project 2: Goals

- Understand the system calls
- Implement system call for user I/O

- This is a working lab and you are supposed to get it finished at the end of second week

Project 3: Multithreading

- You know what a multithreaded program is
  - Several threads execute in the same process, sharing data and code, executing in parallel
  - Well, this is not possible with the initial version of NachOS

Project 3: Multithreading

- Here is one thread...

```
#include “syscall.h”
    void print (char c, int n)
     {
      int i;
      for (i=0; i<n;i++)
        PutChar (c+i);
      PutChar ('\n') ;
     }

     int main ()
     {
       print ('a',4) ;
       Halt () ;
    }
```

Project 3: Multithreading

- Two threads
  - main thread
  - another thread

```
#include “syscall.h”
    void print (char c, int n)
     {
      int i;
      for (i=0; i<n;i++)
         PutChar (c+i;
      PutChar ('\n');
     }

     int main ()
     {
       param=createParam(b,10);
       CreateThread(print,param);
       print ('a',4) ;
       Halt () ;
      }
```

Project 3: Goal

- Implement multithreading
  - Understand how the address space of a process is organized and managed
  - Implement sharing of the address space for multiple threads
  - Be able to execute programs with 2,3… threads

Project 4: Virtual memory

- The initial version of NachOS may launch only one process
- The memory management is very simple
  - Direct use of physical memory and hence of physical addresses
  - There are the bases for paging

Logical page	frame
0	0
1	1
2	2
3	3

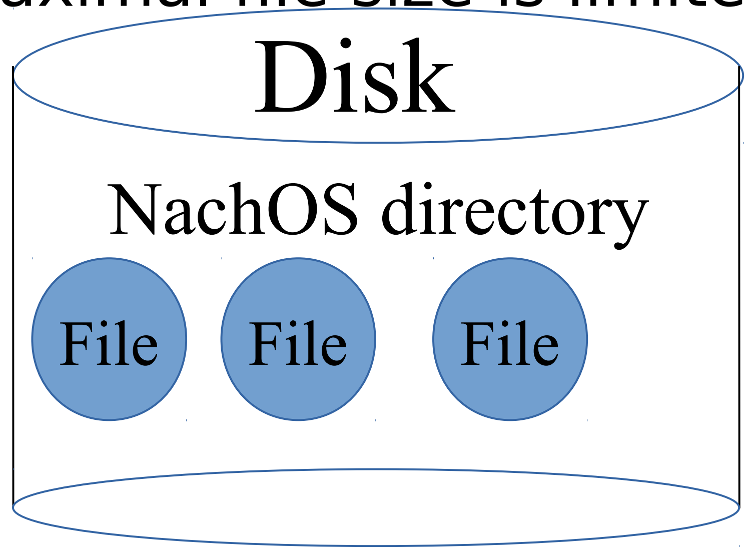
Projects 4: Goals

- Implement paging
  - To be able to load each program anywhere in physical memory
  - Non contigous storage of processor memory space in physical memory
  - Implement malloc/free in NachOS

- Implement multi-programming
  - Launch multiple processes
    - Manage their respective address spaces
    - Implement the fork system call
    - Implement a shell

Project 5: File System

- NachOS comes with a very simple file system
  - 1 directory
  - 10 files
  - Maximal file size is limited



Project 5: Goals

- Understand File Management
  - File Headers
  - Directory Management Structure
  - Disk Space Management
- Implement Tree Directories
  - Implement . And ..
  - Implement File Paths
    - Current Directory
  - Increase Max File Size (with I-node)

Project 6: Networking

- Is it possible to launch several machines and make them communicate?
  - The protocol is not reliable (some messages are lost)

Project 6: Goals

- Implement a reliable communication protocol
  - TCP/IP like
- Implement a file transfer protocol (ftp)
- Implement process migration

Outline

- Directory & File Structure
- Threads & Synchronization
- Unix vs. Kernel vs. User Programs
- MIPS Simulator & Nachos
- Address Spaces & Executables
- Common Problems

Directory & File Structure

- code/
  - filesys/
  - lib/
  - machine/
  - network/
  - test/
  - threads/
  - userprog/

Directory & File Structure

- code/filesys/
  - Holds implementation of both stub and real file system

Directory & File Structure

- code/lib/
  - Holds the class library and debug routines.
  - Learn and make good use of the Nachos class library (list, hash table, etc.) and debug facilities.
  - Avoid the STL (Standard Template Library) as it incurs too much disk space.

Directory & File Structure

- code/machine/
  - Holds the MIPS simulator that Nachos uses to execute user programs
  - Do NOT change anything in this directory
  - Allowed to change a few constants such as the NumPhysPages (in machine.h)
  - Familiarizing yourself with the simulator and the flow of control will help in debugging and design

Directory & File Structure

- code/network/
  - Holds the networking code for Nachos
  - Doesn’t interfere with the working of Nachos
  - The networking code does create one thread call “postal worker” that is always dormant

Directory & File Structure

- code/test/
  - Holds all the test cases and the environment to build new test cases.
  - Follow the format in Makefile to make new tests

```
PROGRAMS = . . .  <test>

<test>.o: <test>.c
        $(CC) $(CFLAGS) -c <test>.c
<test>: <test>.o start.o
        $(LD) $(LDFLAGS) start.o <test>.o
<test>.coff:
        $(COFF2NOFF) <test>.coff <test>
```

Directory & File Structure

- code/threads/
  - Holds the threading and related routines for Nachos.
  - No changes needed in here unless you really want to change the threading internals, or are modifying the scheduler
  - Good idea to familiarize yourself with the threading and synchronization in Nachos

Directory & File Structure

- code/userprog/
  - Holds the beginnings of user program support and system calls handling
  - This is the only non functional portion of the Nachos directory structure.

Threads & Synchronization

- Nachos contains a complete threading library
- Nachos contains a complete synchronization library.
- The scheduler is already in place and uses simple FCFS scheduling.
- Use of provided synchronization primitives will implicitly control threads and scheduling.
- No need to explicitly control thread execution and scheduling

Threads & Synchronization

- Try to solve problems using the thread abilities before writing a new solution
- Use the synchronization classes as much as possible.
- Example (Join):

```
Process A (in Join()):
    Semaphore* s = new Semaphore("AJoinsB");
    S->P(); // A blocks on
Process B (in Exit()):
    Semaphore* s = GetSemaphore("AJoinsB");
    S->V(); // wake up A
```

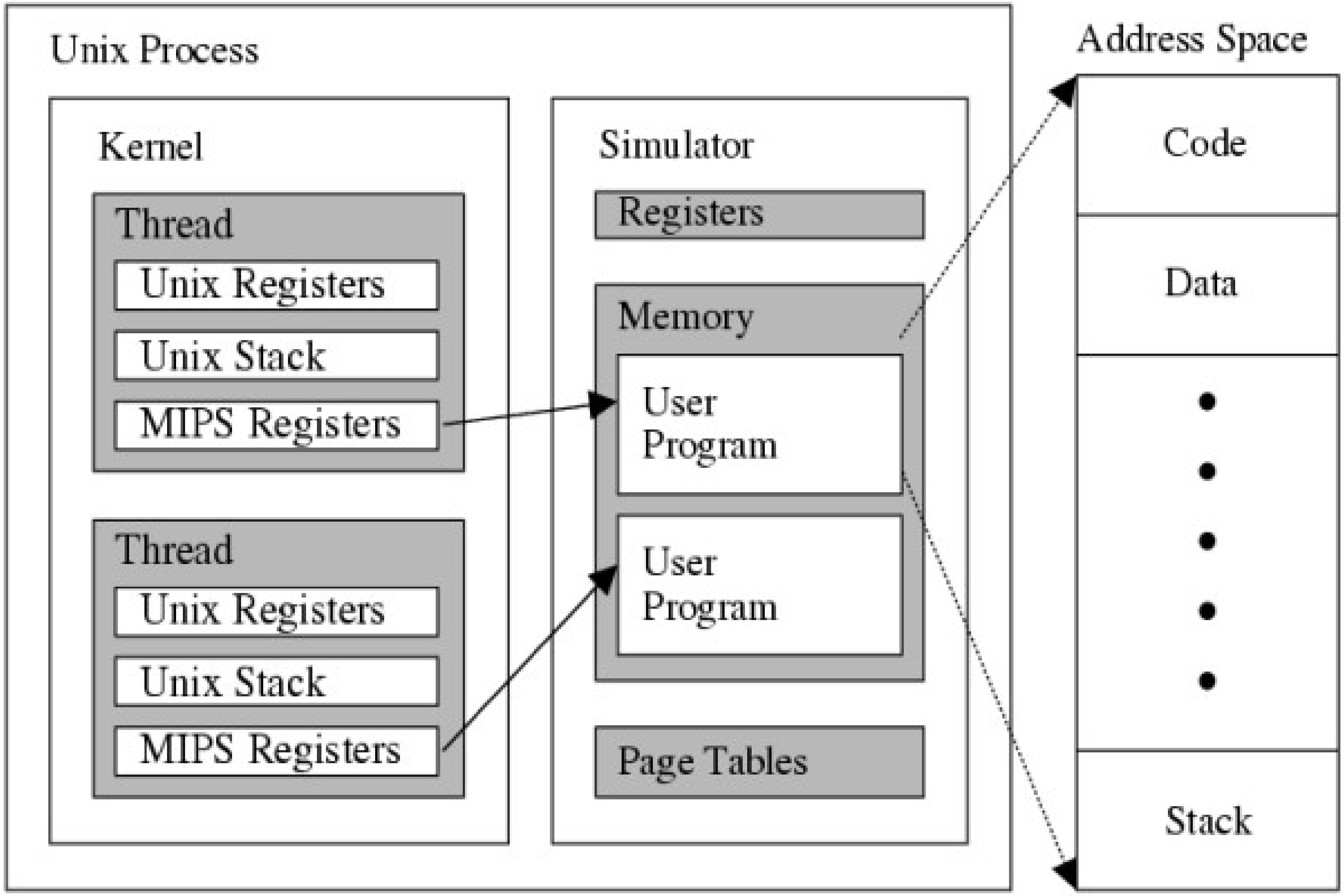
Threads & Synchronization

- Thread Miscellany
  - Threads do not interrupt at any point in time (not preemptive).
  - Thread switching happens at various places as a result of calling certain functions
  - A `while(1);` will stop Nachos
  - Stack space for threads is limited so don't define local variables like `char bigString[20000];`
  - Concurrency & Synchronization issues are a BIG deal.

Unix vs. Kernel vs. User Programs

- The kernel runs inside of a Unix process
- The simulator runs alongside the kernel inside the Unix process
- The user program run inside the simulator
- The are many things called the same thing that are different depending on where they are (i.e. stacks, registers, threads, processes)
- It is easy to get mixed up about these things

Unix vs. Kernel vs. User Programs



MIPS Simulator & Nachos

- The simulator is in control of Nachos from the beginning (from Machine::Run)
- Kernel code only gets executed as a result of a few specific events
- Interrupts cause the simulator to call the appropriate interrupt handler
- Exceptions cause the simulator to call the exception handler
- System Calls cause the simulator to call the exception handler

MIPS Simulator & Nachos

- Interrupts
  - Interrupts are generated by the simulated hardware in response to particular external events
  - These include the disk I/O, console I/O and timers
  - The interrupt mechanism is completely automatic and you have no control over it
  - For instance when a timer interrupt happens the kernel will yield the current thread and then the scheduler will automatically schedule the next thread to run (see timer.cc and alarm.cc)

MIPS Simulator & Nachos

- Exceptions and System Calls
  - Exceptions are things like divide by zero and page faults which need to be handled
  - System Calls are requests from user programs for the kernel to perform a desired action
  - The entry point is ExceptionHandler() in exception.cc
  - Once ExceptionHandler returns the simulator is in control again

MIPS Simulator & Nachos

- Running the Simulator
  - The simulator is started by calling Machine::Run
  - This should be done ***only once per process***
  - The simulator is self contained and only uses the registers, memory and page tables (or TLB)
  - During a context switch the register swapping is handled by the thread
  - During a context switch the page table (or TLB) information needs to be updated (the beginnings are in addrspace.cc)

Address Spaces & Executables

- Address Spaces
  - The current address space implementation is very basic
  - Need to extend this to support nonlinear frame mapping and allocating memory
  - Need to add support for translating and reading to/from an address space
  - Take care when modifying the address space to include all the sections of the NOFF file and the stack

Address Spaces & Executables

- Executables
  - Nachos uses an executable format called NOFF
  - NOFF files consist of a few sections:
    - .code
      - The program instructions that the simulator will execute
    - .initdata
      - The initialized data that holds predefined variable values
    - .uninitdata
      - The uninitialized data. The is the only section where the values are not read from the file. Initialize to zero.
    - .rdata
      - The read-only data in the executable. This is comprised mainly of literal strings (i.e. `char* temp = "Kevin";`)S

Address Spaces & Executables

- Creating Address Spaces
  - When creating address spaces, deal with every section of the NOFF file explicitly
  - Don’t forget the required stack space
  - Make sure to mark the pages that are to be read-only as such
  - Deal with pages that contain more than one section (i.e. pages with half code and half data)
  - Create the page table for the process and efficiently allocate the required memory for that process

Common Problems

- New & Delete
  - New & Delete can cause crashes because of invalid memory accesses that occurred at other locations
  - Hard to track down source
  - Example (fictitious):

```
// in one function
char* temp = new char[10];
temp[11] = ‘a’; // incorrect, but works

. . .

// in another function further down
char* temp2 = new char[10]; // causes segfault
```

Common Problems

- Creating a new thread
  - Once a thread is created it is automatically scheduled
  - The new thread can start running at any time
  - Cannot pass a member function to the Thread::Fork routine.
  - Incorrect Solution:

```
Thread* t = new Thread;
Process* p = new Process;
t->Fork(Process::Start, p); // compiler error
```

Common Problems

- Creating a new thread (cont.)
  - Correct solution:

```
void ProcessStart(void* arg)
 {
 Process* p = (Process*) arg;
 p->Start();
 }
. . .
Thread* t = new Thread;
Process* p = new Process;
t->Fork(ProcessStart, (void*)p);
```

Common Problems

- Segmentation Faults (and Bus Errors)

```
fred@mud: ~ > ./test
Segmentation Fault (core dumped)
fred@mud: ~ > gdb test
(gdb) run
Program received signal SIGSEGV, Segmentation fault.
0xef6a4734 in strlen () from /usr/lib/libc.so.1
(gdb) bt
#0  0xef6a4734 in strlen () from /usr/lib/libc.so.1
#1  0xef6da65c in _doprnt () from /usr/lib/libc.so.1
#2  0xef6e37b8 in printf () from /usr/lib/libc.so.1
#3  0x1095c in func1 () at test.c:6
#4  0x10970 in func2 () at test.c:11
#5  0x10984 in main () at test.c:16
(gdb)
```

Common Problems

- Translation
  - The translation routines in the machine class are a good start but not general purpose.
  - These routine are designed for single byte/integer
  - In designing translation routines consider larger translations for reading and writing
  - In particular consider cross page conditions and dealing with null terminated strings
  - Also watch out for the endianness change between MIPS & Kernel

Conclusion

This was only a brief introduction to Nachos

Understanding Nachos internals will help a great deal in debugging and designing

http://imag-moodle.e.ujf-grenoble.fr/course/view.php?id=126

Get started on *Etape 1* ASAP

A good work on *Etape 1* will reduce the workload needed for future *Etapes*