NachOS Introduction & MP1

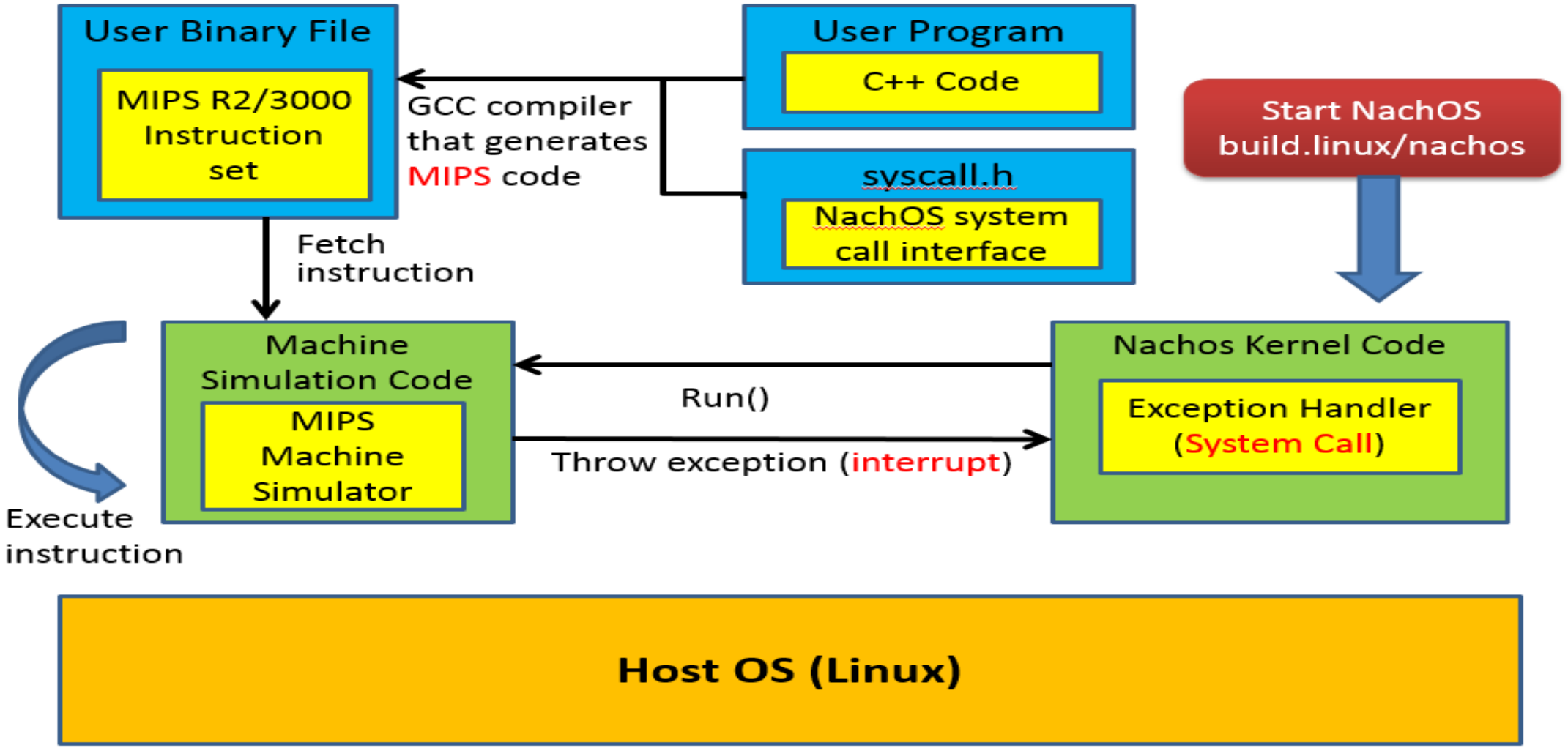
LECTURE: JERRY CHOU

2019/9/25

NachOS
Not Another Completely Heuristic Operating System

- What is NachOS?
  - Nachos is instructional software for **teaching undergraduate**, and potentially graduate, level operating systems courses.
  - Illustrate and explore all areas of modern operating systems, including threads and concurrency, multiprogramming, system calls, virtual memory, software-loaded TLB's, file systems, network protocols, remote procedure call, and distributed systems.
- How NachOS works?
  - written in C++ for MIPS
  - Nachos runs as a user-process on a host operating system
  - A MIPS simulator executes the code for any user programs running on top of the Nachos operating system.
- Website: https://homes.cs.washington.edu/~tom/nachos/

NachOS Architecture



NachOS Directory Structure

lib/

- Utilities used by the rest of the Nachos code

machine/

- The **machine simulation**.
- **All files here CANNOT be modified for any homework assignments**

threads/

- **Nachos is a multi-threaded program**. Thread support is found here. This directory also contains the **main() routine of the nachos program in main.cc**.

NachOS Directory Structure

test/

- **User test programs** to run on the simulated machine. This directory contains **its own Makefile**.
- **This is where you can write your own test programs**

userprog/

- **Nachos operating system code** to support the creation of address spaces, loading of user (test) programs, and execution of test programs on the simulated machine.
- You might need to modify the kernel code here

NachOS Directory Structure

network/

- Nachos operating system support for networking. Several independent simulated Nachos machines can talk to each other through a simulated network.
- We don’t need to touch the code in this course.

filesys/

- Two different file system implementations are here. The "**real**" file system uses the simulated workstation's simulated disk to hold files. A "**stub**" file system translates Nachos file system calls into UNIX file system calls.
- Some files need to be modified in MP1 and MP4
- MP1 uses the **stub** file system; MP4 uses the **real** file system

Setup NachOS Environment

- IP address: 140.114.78.227 port:22 (ssh)
  - Account username & password have been emailed to you by TA
  - ***You MUST setup your own password after first login***
  - If you have problems, email to os@lsalab.cs.nthu.edu.tw

- Installation (under your home directory)

```
$ cp -r /home/os2019/share/NachOS-4.0_MP1 .
$ cd NachOS-4.0_MP1/code/build.linux
$ make clean
$make
```

Build NachOS kernel

- You must rebuild NachOS every time after you modify anything in NachOS (files under any folder, except test/), otherwise you won't change the execution results.

```
$ cd NachOS-4.0_MP1/code/build.linux
$ make clean
$ make
```

If you don't do this, changes to "*.h" files won't be detected during compilation

Build & Run Test Programs

- You can build any test program under test/ folder to test your NachOS kernel implementation
- Example to build the **halt** test program:

```
$ cd NachOS-4.0_MP1/code/test
$ make clean
$ make halt
```

- Example to build the **halt** test program:

```
$ ../build.linux/nachos -e halt
```

"-e" means to execute a binary code in NachOS

Makefile

- Make is Unix utility that is designed **to start execution of a makefile**.
- A Makefile is a special file, **containing shell commands**
- Most often, the *makefile* directs ***make*** on how to compile and link a program.
- How Makefile (test/Makefile) make test programs ?

```
CC = $(GCCDIR)gcc
AS = $(GCCDIR)as
LD = $(GCCDIR)ld

INCDIR =-I../userprog -I../lib
CFLAGS = -G 0 -c $(INCDIR) -B/usr/bin/local/nachos/lib/gcc-lib/decstation-ultrix/2.95.2/ -B/usr/bin/local/nachos/decstation-ultrix/bin/
```

```
PROGRAMS = add halt createFile fileIO_test1 fileIO_test2
```

```
all: $(PROGRAMS)

start.o: start.S ../userprog/syscall.h
        $(CC) $(CFLAGS) $(ASFLAGS) -c start.S

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

```
clean:
        $(RM) -f *.o *.ii
        $(RM) -f *.coff
```

You may follow the rules for your own new test program

NachOS Debug Message

- NachOS provides different types of debug message that only be printed on screen by the debug message flag in your execution command
  - Type definitions can be seen from "lib/debug.h".

```
const char dbgAll = '+';
const char dbgSys = 'u';
const char dbgTraCode = 'c';
```

    "dbgSys" and "dbgTraCode" can be helpful to you.
  - Messages type is specified in the code

```
DEBUG(dbgTraCode, "In ExceptionHandler(), Received Exception "
<< which << " type: " << type << ", " << kernel->stats->totalTicks);
DEBUG(dbgSys, "Shutdown, initiated by user program.\n");
```

  - To show the debug message

```
$ ../build.linux/nachos -e halt -d u
$ ../build.linux/nachos -e halt -d c
```

MP1: System Call

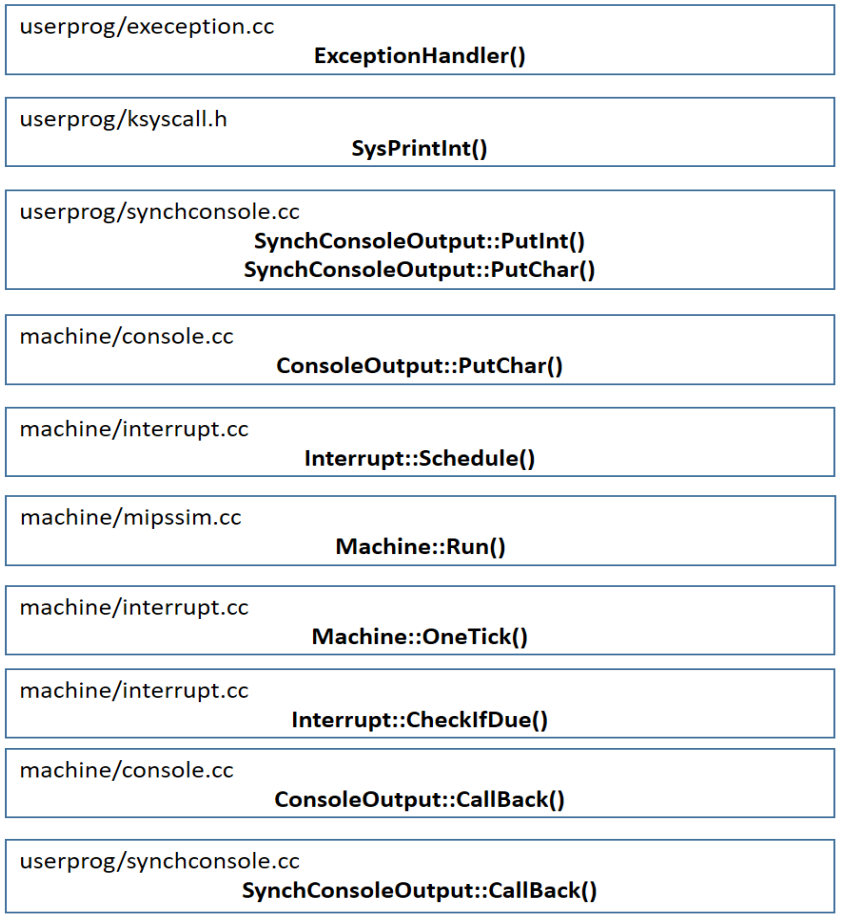
- Spec
  - https://drive.google.com/file/d/1RZ3hywH_WLMG-uCrXAap3XICS09UdiuG/view?usp=sharing
- Goal:
  - Understand how to work under **Linux** platform.
  - Understand how **system calls** are implemented by OS.
  - Understand the difference between **user mode** and **kernel mode**.
- TA: 楊季蓁 cc.yang@lsalab.cs.nthu.edu.tw
- Deadline: 2019/10/20 23:59

Part1: Trace code

- **Working items**

1. **SC_Halt (halt.c)**
2. **SC_Create (**createFile.c**)**
3. **SC_PrintInt (**add.c**)**

- **Requirements**
  - Explain the purposes and details of each function call listed in the code path above in **report**.
  - Explain how the arguments of a system call is passed from user program to kernel in **report**.



Part2: Implementations

- Working items
1. OpenFileId Open(char *name)
2. int Write(char *buffer, int size, OpenFileId id);
3. int Read(char *buffer, int size, OpenFileId id);
4. int Close(OpenFileId id);

Hint: Files to be modified
- test/start.S
- userprog/syscall.h, exception.cc, ksyscall.h
- filesys/filesys.h

- **Requirements**
  - Must use the table entry number of fileDescriptorTable as the FileId.
  - Must handle invalid file open requests, including the non-existent file, exceeding opened file limit (i.e., 20), etc.
  - All valid file open requests must be accepted if the opened file limit (i.e., 20) is not reached.
  - More detailed in the google document spec

Part3: Report

- Working items:

1. Cover page, including team members, Team member contribution
2. Explain how system calls work in NachOS
3. Explain your implementation

Grading

1. Implementation correctness – 50%
   - Pass all the test cases.
   - You DO NOT need to upload NachOS code to iLMS.
   - Your working folder will be locked after deadline.
2. Report – 30%
   - Upload it to iLMS with the Filename: MP1_report_[GroupNumber].pdf.
3. Demo– 20%
   - Answer questions during demo.
   - Demo will take place on our server, so you are responsible to make sure your code works on our server.

*Refer to syllabus for late submission penalty.

Code Trace: userprog/syscall.h

```
/* syscalls.h
 *      Nachos system call interface.  These are Nachos kernel operations
 *      that can be invoked from user programs, by trapping to the kernel
 *      via the "syscall" instruction.

    /* system call codes
    #define SC_Create       4
    #define SC_Remove       5
    #define SC_Open         6
    #define SC_Read         7
    #define SC_Write        8
    #define SC_PrintInt     16
```

```
/* The system call interface.
  * an assembly language stub stuffs the system call
  * code into a register, and traps to the kernel.

/* Print Integer */
void PrintInt(int number);

/* Return 1 on success, negative error code on failure */
int Create(char *name);

/* Open the Nachos file "name", and return an
  * "OpenFileId" that can be used to R/W the file. */
OpenFileId Open(char *name);

/* A unique identifier for an open Nachos file. */
typedef int OpenFileId;
```

Code Trace: test/start.S

```
/* System call stubs:
*      Assembly language assist to make system calls to the Nachos kernel.
*      There is one stub per system call, that places the code for the
*      system call into register r2, and leaves the arguments to the
*      system call alone (in other words, arg1 is in r4, arg2 is in r5)
*
*      The return value is in r2. This follows the standard C calling
*      convention on the MIPS.
```

```
        .globl  PrintInt
        .ent    PrintInt
PrintInt:
        addiu $2,$0,SC_PrintInt
        syscall
        j       $31
        .end  PrintInt
```

register r2

system call instruction

return address defined in machine.h
#define RetAddrReg 31

ADDIU -- *Add immediate unsigned (no overflow)*

Description:	Adds a register and a sign-extended immediate value and stores the result in a register
Operation:	$t = $s + imm; advance_pc (4);
Syntax:	addiu $t, $s, imm

Code Trace: machine/mipssim.cc

```
//      Simulate the execution of a user-level program on Nachos.
//      Called by the kernel

void Machine::Run()
{
    Instruction *instr = new Instruction;  // storage for decoded instruction

    if (debug->IsEnabled('m')) {
        cout << "Starting program in thread: " << kernel->currentThread->getName();
                cout << ", at time: " << kernel->stats->totalTicks << "\n";
    }
    kernel->interrupt->setStatus(UserMode);
    for (;;) {
        OneInstruction(instr);
        kernel->interrupt->OneTick();
        if (singleStep && (runUntilTime <= kernel->stats->totalTicks))
            Debugger();
    }
}
```

Leave **kernel level program**

Execute **one instruction from user level**

Code Trace: File System Stub

- A "stub" file system translates Nachos file system calls into UNIX file system calls.
- It is enabled by the compiler directive flag “-DFILESYS_STUB”
  - The flag is pre-configured (enabled) in NachOS’s makefile (build.linux/Makefile)

```
DEFINES =  -DFILESYS_STUB -DRDATA -DSIM_FIX
```

- The flag determines what part of the code will be compiled

```
#ifdef FILESYS_STUB
    //code that will be compiled when FILESYS_STUB is defined
#elseif
    //code that will be compiled when FILESYS_STUB is NOT defined
#endif
```

Code Trace: File System Stub

```
#ifdef FILESYS_STUB                     // Temporarily implement file system calls as
                                        // calls to UNIX, until the real file system
                                        // implementation is available
typedef int OpenFileId;

class FileSystem {
  public:
    FileSystem() {
        for (int i = 0; i < 20; i++) fileDescriptorTable[i] = NULL;
    }

    bool Create(char *name) {
        int fileDescriptor = OpenForWrite(name);

        if (fileDescriptor == -1) return FALSE;
        Close(fileDescriptor);
        return TRUE;
    }
};

#else // FILESYS
class FileSystem {
  public:
    FileSystem(bool format);            // Initialize the file system.
};

#endif // FILESYS
```

Code Trace: Call Back Function

```
/* machine/interrupt.cc */
void Interrupt::Schedule(CallBackObj *toCall, int fromNow, IntType type)
{
    int when = kernel->stats->totalTicks + fromNow;
    PendingInterrupt *toOccur = new PendingInterrupt(toCall, when, type);
    pending->Insert(toOccur);
}

bool Interrupt::CheckIfDue(bool advanceClock) {
    ……..
    do {
        next = pending->RemoveFront();
        next->callOnInterrupt->CallBack();
        delete next;
    } while (!pending->IsEmpty() && (pending->Front()->when <= stats->totalTicks));
}
```

Register interrupt callback function in pending queue

Pull interrupt from pending queue

Call interrupt service routine (callback function)

References

- Text editor: vim
  - https://www.radford.edu/~mhtay/CPSC120/VIM_Editor_Commands.htm
- Shell script tutorial
  - https://www.shellscript.sh/
- Linux command
  - Summary of common Unix Commands
  - Common Unix Commands
  - SystemV Commands Pocket Guide