ECE 2400 / ENGRD 2140
Computer Systems Programming
Course Overview

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http://www.csl.cornell.edu/courses/ece2400
ECE 2400 / ENGRD 2140
Computer Systems Programming

What is Computer Systems Programming?

Activity 1: Comparing Algorithms

Trends in Computer Systems Programming

Activity 2: Compiling C to Machine Instructions

Course Logistics
The Computer Systems Stack

Application

Gap too large to bridge in one step (but there are exceptions, e.g., a magnetic compass)

Technology
The Computer Systems Stack

- Application
- Algorithm
- Programming Language
- Operating System
- Compiler
- Instruction Set Architecture
- Microarchitecture
- Register-Transfer Level
- Gate Level
- Circuits
- Devices
- Technology

Sort an array of numbers
2,6,3,8,4,5 -> 2,3,4,5,6,8

Out-of-place selection sort algorithm
1. Find minimum number in array
2. Move minimum number into output array
3. Repeat steps 1 and 2 until finished

C implementation of selection sort
void sort( int b[], int a[], int n ) {
  for( int idx, k = 0; k < n; k++ ) {
    int min = 100;
    for( int i = 0; i < n; i++ ) {
      if( a[i] < min ) {
        min = a[i];
        idx = i;
      }
    }
    b[k]   = min;
    a[idx] = 100;
  }
}
The Computer Systems Stack

Mac OS X, Windows, Linux
Handles low-level hardware management

C Compiler
Transform programs into assembly

MIPS32 Instruction Set
Instructions that machine executes

```
int a = b + c;
A[i] = a;
addu $t0, $t1, $t2
sw $t0, 0($t3)
blez $a2, done
move $a7, $zero
li $t4, 99
move $a4, $a1
li $a3, 99
lw $a5, 0($a4)
```
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How data flows through system

Boolean logic gates and functions

Combining devices to do useful work

Transistors and wires

Silicon process technology

Register-Transfer Level

Circuits

Devices

Technology
In its broadest definition, computer engineering is the development of the abstraction/implementation layers that allow us to execute information processing applications efficiently using available manufacturing technologies.
Python for Application-Level Programming

- High-level, user-facing software
- Enable productively developing applications that provide new functionality to users
- Enable productively collecting, analyzing, visualizing data
- Sometimes called a productivity-level language

Computer Engineering
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Application-Level Software
What is Computer Systems Programming?

C/C++ for System-Level Programming

- Connects application software to the low-level computer hardware
- Enables carefully managing performance and resource constraints
- Sometimes called an efficiency-level language
What is Computer Systems Programming?

**Activity 1** Trends in Computer Systems Programming  
**Activity 2** Course Logistics

Dynamically Interpreted vs. Statically Compiled

```python
def min(a, b):
    if a < b:
        c = a
    else:
        c = b
    return c
```

The standard Python interpreter is called CPython and it is written in C!
Computer Systems Programming is Diverse

- Application
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- Python, MATLAB
- Ruby, Javascript
- SQL, LINQ
- NumPy
- GUI frameworks

- Interpreters
- Compilers
- Databases
- Numerical libraries
- Operating systems
- Embedded control
Aside: C/C++ for Application-Level Software
### A Tale of Two Programming Languages

<table>
<thead>
<tr>
<th>Python Programming Language</th>
<th>C/C++ Programming Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduced: 1991</td>
<td>Introduced: 1972(C), 1979(C++)</td>
</tr>
<tr>
<td>Most of the machine details are hidden from programmer</td>
<td>Most of the machine details are exposed to the programmer</td>
</tr>
<tr>
<td>Programmer gives up some control for improved productivity</td>
<td>Programmer is in complete control for improved efficiency</td>
</tr>
<tr>
<td>Easily supports multiple programming paradigms</td>
<td>C++ easily supports multiple programming paradigms</td>
</tr>
<tr>
<td>Extensive standard library is included</td>
<td>More limited standard library is included</td>
</tr>
<tr>
<td>Slow and memory inefficient</td>
<td>Fast and memory efficient</td>
</tr>
</tbody>
</table>
Comparing the Performance of Python vs. C/C++
Program = Data Structure + Algorithm

While this course covers C/C++ and system-level programming, this course also builds off of your prior programming experience to further develop your understanding of data-structures and algorithms.

- **Data Structure**: Way of efficiently organizing and storing data along with methods for accessing and manipulating this data.
- **Algorithm**: Clear set of steps to solve any problem instance in a particular class of problems.
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Course Logistics
Activity 1: Comparing Algorithms

► **Application:** Sort 16 numbers

► **Activity Steps**
  ▶ 1. Half the class will use Algorithm A, half uses Algorithm B
  ▶ 2. When instructor starts timer, flip over worksheet
  ▶ 3. Sort 16 numbers using assigned algorithm
  ▶ 4. Lookup when completed and write time on worksheet
  ▶ 5. Raise hand
  ▶ 6. When everyone is finished, then analyze data

► **Algorithm A**

  repeat 16 times
    find smallest number not crossed off in input list
    copy smallest number to next open entry in output list
    cross smallest number off input list
Activity 1: Comparing Algorithms

▶ Algorithm B

repeat 8 times, once for each pair in column 1
  copy smallest into next open entry in next column
  copy largest into next open entry in next column

repeat 4 times, once for group of 4 in column 2
  repeat 4 times
    compare top two numbers not crossed off in both groups
    copy smallest number to next open entry in next column
  cross smallest number off input list

... and so on ...
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Course Logistics
Trend towards IoT and Cloud w/ Novel Hardware

Roughly every decade a new, smaller, lower priced computer class forms based on a new programming platform resulting in entire new industries.

Cloud Computing
- Often requires low-latency, high-throughput to meet overall application requirements
- Increasingly w/ specialized HW

Internet-of-Things
- Very limited resource constraints (e.g., energy, memory)
- Requires carefully managing these resources to meet overall application requirements
- Increasingly w/ specialized HW
Example Application: Image Recognition

Starfish

Dog
Machine Learning (ML): Training vs. Inference

Training
- Many images
- Model
  - Forward: "starfish"
  - Backward: error

Inference
- Few images
- Model
  - Forward: "dog"
Computer Systems Programming in ML

**Google TPU**
- Training is done using the TensorFlow C++ framework
- Training can take weeks
- Google TPU is custom chip
- High-level ML frameworks use C++ under the hood

**Movidius Myriad 2**
- Custom chip for ML on embedded IoT devices
- Carefully crafted C/C++ ML libraries for inference
- Embedded control also in C/C++
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Course Logistics
Try entering this example from the textbook and examine the corresponding machine instructions.

```c
int myFunction( int x, int y )
{
    int z = x - 2*y;
    return z * x;
}
```

ECE 2300 uses a MIPS-like architecture. Try choosing MIPS gcc 5.4 (el) from the drop-down menu.

Now try this example from earlier in today’s lecture.

```c
int min( int a, int b )
{
    int c;
    if ( a < b )
        c = a;
    else
        c = b;
    return c;
}
```

Try entering `-O3` into the compiler options text box.
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Course Logistics
ECE 2400 is also an ENGRD and thus satisfies the engineering distribution requirement. ECE 2400 can be an excellent way to generally incorporate programming into your non-ECE engineering curriculum.
Course Structure

▶ Part 1: C Programming and Basic Data Structures & Algorithms
  ▶ recursion, types, pointers, arrays, dynamic allocation, computational cost, abstract data types, lists, stacks, queues, sets, maps, sequence sorting, sequence alignment

▶ Part 2: C++ Programming and Advanced Data Structures & Algorithms
  ▶ transition from C to C++, object-oriented programming, template meta-programming, binary search trees, priority queues, hash tables, graphs

▶ Part 3: Systems Programming in the UNIX Environment
  ▶ standard I/O, processes, threads

▶ Format
  ▶ lectures, optional discussion section, short in-class quizzes, readings, programming assignments, two prelim exams, final exam
Programming Assignments

► PA1–4: Basics
  ▶ PA1: Complex math functions
  ▶ PA2: Cracking passwords
  ▶ PA3: Searching and sorting
  ▶ PA4: RPN calculator

► PA5–6: System Software
  ▶ PA5: In-memory cache for distributed systems
  ▶ PA6: Financial trading system

► Every programming assignment involves
  ▶ C/C++ programming
  ▶ Performance measurement
  ▶ Short report
Frequently Asked Questions

➤ I have not taken CS 1110 nor CS 1112, can I take this class?
   ▶ We assume some basic programming experience, discuss with instructor

➤ ECE Majors – How does ECE 2400 satisfy degree requirements?
   ▶ ECE 2400 can count as your second ENGRD course
   ▶ ECE 2400 can count as an outside-ECE technical elective
   ▶ ECE 2400 satisfies the ECE advanced programming requirement

➤ CS Majors – Can I use ECE 2400 in place of CS 2110?
   ▶ No

➤ Other Majors – How does ECE 2400 satisfy degree requirements?
   ▶ ECE 2400 can count as one of your two required ENGRD courses

➤ Should I take both ECE 2400 and CS 2110?
   ▶ Maybe? Maybe not?
Take-Away Points

- Computer systems programming involves developing software to connect the low-level computer hardware to high-level, user-facing application software and usually requires careful consideration of performance and resource constraints.

- We are entering an exciting era where computer systems programming will play a critical role in enabling both cloud computing and the internet-of-things.