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: Comparing Algorithms

Trends in Computer Systems Programming

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
In its broadest definition, computer engineering is the development of the abstraction/implemention 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
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

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

- Application-Level Software
- System-Level Software
The standard Python interpreter is called CPython and it is written in C!
Computer Systems Programming is Diverse

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

Pytho, MATLAB
Ruby, Javascript
SQL, LINQ
NumPy
GUI frameworks

Interpreters
Compilers
Databases
Numerical libraries
Operating systems
Embedded control
Aside: C/C++ for Application-Level Software

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Application-Level & System-Level Software
A Tale of Two Programming Languages

Python Programming Language

- Introduced: 1991
- Most of the machine details are hidden from programmer
- Programmer gives up some control for improved productivity
- Easily supports multiple programming paradigms
- Extensive standard library is included
- Slow and memory inefficient

C/C++ Programming Language

- Introduced: 1972(C), 1979(C++)
- Most of the machine details are exposed to the programmer
- Programmer is in complete control for improved efficiency
- Easily supports multiple programming paradigms
- More limited standard library is included
- Fast and memory efficient
## Comparing the Popularity of Python vs. C/C++

<table>
<thead>
<tr>
<th>Language Rank</th>
<th>Types</th>
<th>Spectrum Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Python</td>
<td>🌐📱💻</td>
<td>100.0</td>
</tr>
<tr>
<td>2. C++</td>
<td>📱💻📱</td>
<td>99.7</td>
</tr>
<tr>
<td>3. Java</td>
<td>🌐📱💻</td>
<td>97.5</td>
</tr>
<tr>
<td>4. C</td>
<td>📱💻📱</td>
<td>96.7</td>
</tr>
<tr>
<td>5. C#</td>
<td>🌐📱💻</td>
<td>89.4</td>
</tr>
<tr>
<td>6. PHP</td>
<td>🌐📱</td>
<td>84.9</td>
</tr>
<tr>
<td>7. R</td>
<td>📱💻</td>
<td>82.9</td>
</tr>
<tr>
<td>8. JavaScript</td>
<td>🌐📱</td>
<td>82.6</td>
</tr>
<tr>
<td>9. Go</td>
<td>🌐💻</td>
<td>76.4</td>
</tr>
<tr>
<td>10. Assembly</td>
<td>🌐📱</td>
<td>74.1</td>
</tr>
<tr>
<td>11. Matlab</td>
<td>📱💻</td>
<td>72.8</td>
</tr>
</tbody>
</table>

The 2018 Top Programming Languages, IEEE Spectrum
Comparing the Performance of Python vs. C/C++

The Computer Language Benchmarks Game
Program = Algorithm + Data Structure

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 algorithms and data structures.

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

Algorithm B

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

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 column 2
    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.


Y. Lee et al. "Modular 1mm3 Die-Stacked Sensing Platform ..." JSSC, Jan 2013.
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
Machine Learning (ML): Training vs. Inference

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

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
ECE 2400 Within the Engineering Curriculum

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 Objectives

- **describe** a variety of algorithms and data structures and how to analyze these algorithms and data structures in terms of time and space complexity
- **apply** the C/C++ programming languages to implement algorithms and data structures using different programming paradigms
- **evaluate** algorithm and data structure alternatives and make a compelling theoretical and/or practical argument for one approach
- **create** non-trivial C/C++ programs (roughly 1,000 lines of code) and the associated testing strategy from an English language specification
- **write** concise yet comprehensive technical reports that describe a program implemented in C/C++, explain the testing strategy used to verify functionality, and evaluate the program to characterize its performance and memory usage
Course Structure

- **Part 1: Procedural Programming**
  - introduction to C, variables, expressions, functions, conditional & iteration statements, recursion, static types, pointers, arrays, dynamic allocation

- **Part 2: Basic Algorithms and Data Structures**
  - lists, vectors, complexity analysis, insertion sort, selection sort, merge sort, quick sort, hybrid sorts, stacks, queues, sets, maps

- **Part 3: Multi-Paradigm Programming**
  - transition to C++, namespaces, flexible function prototypes, references, exceptions, new/delete, *object oriented programming* (C++ classes and inheritance for dynamic polymorphism), *generic programming* (C++ templates for static polymorphism), *functional programming* (C++ functors and lambdas), *concurrent programming* (C++ threads and atomics)

- **Part 4: More Algorithms and Data Structures**
  - trees (binary trees, binary search trees), tables (lookup tables, hash tables), graphs
Programming Assignments

▶ **PA1–3: Fundamentals**
  ▶ PA1: Math functions
  ▶ PA2: List and Vector Data Structures
  ▶ PA3: Sorting Algorithms

▶ **PA4–5: Handwriting Recognition System**
  ▶ PA5: Linear vs. Binary Searching
  ▶ PA5: Trees vs. Tables

▶ **Every programming assignment involves**
  ▶ C/C++ “agile” programming
  ▶ State-of-the-art tools for build systems, version control, continuous integration, code coverage
  ▶ Performance measurement
  ▶ Short technical report
Application-Level Software

System-Level Software
Course Staff

- Prof. Batten  Instructor
- Yanghui Oh   ECE PhD
- Justin Joco  ECE MEng
- Mariangel Rivera  CS senior
- Grace Zheng  CS senior
- Sarah North  ECE junior
- Rikako Onuma  CS junior

Course Staff C/C++ Experience
- Many upper-level courses which use C/C++
- Internship on YouTube image processing application (C)
- Internship on chip design file format parser (C)
- Internship on low-latency stock market trade validator (C)
- Internship on drone detection using optical flow (C++)
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?
   ▶ Kind of but you should probably take CS 2110

▶ ECE/CS Dual Majors – Can I use ECE 2400 in place of CS 2110?
   ▶ Absolutely! (NEW)

▶ CS Minors – Can I use ECE 2400 in place of CS 2110?
   ▶ Absolutely! (NEW)
Frequently Asked Questions

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

- **ECE MEngs** – How does ECE 2400 satisfy degree requirements?
  - ECE 2400 can count as a technical elective, but you remember you can only use one ECE undergraduate course as a technical elective

- Should I take both ECE 2400 and CS 2110?
  - Sure! (recall popularity and performance data)
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.