Principles of Software Construction:
Objects, Design, and Concurrency

Part 1: Introduction

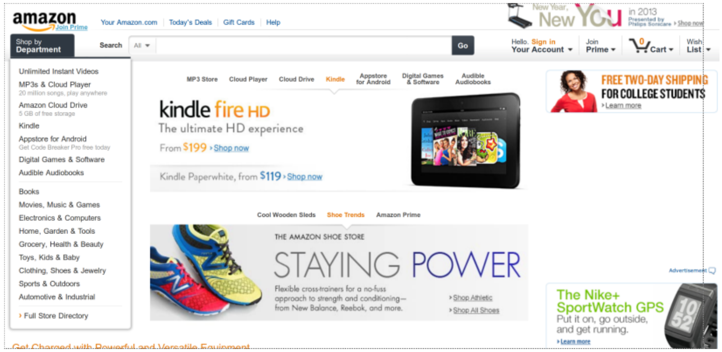
Course overview and introduction to software design

Charlie Garrod Michael Hilton

School of Computer Science

institute for SOFTWARE RESEARCH

Software is everywhere



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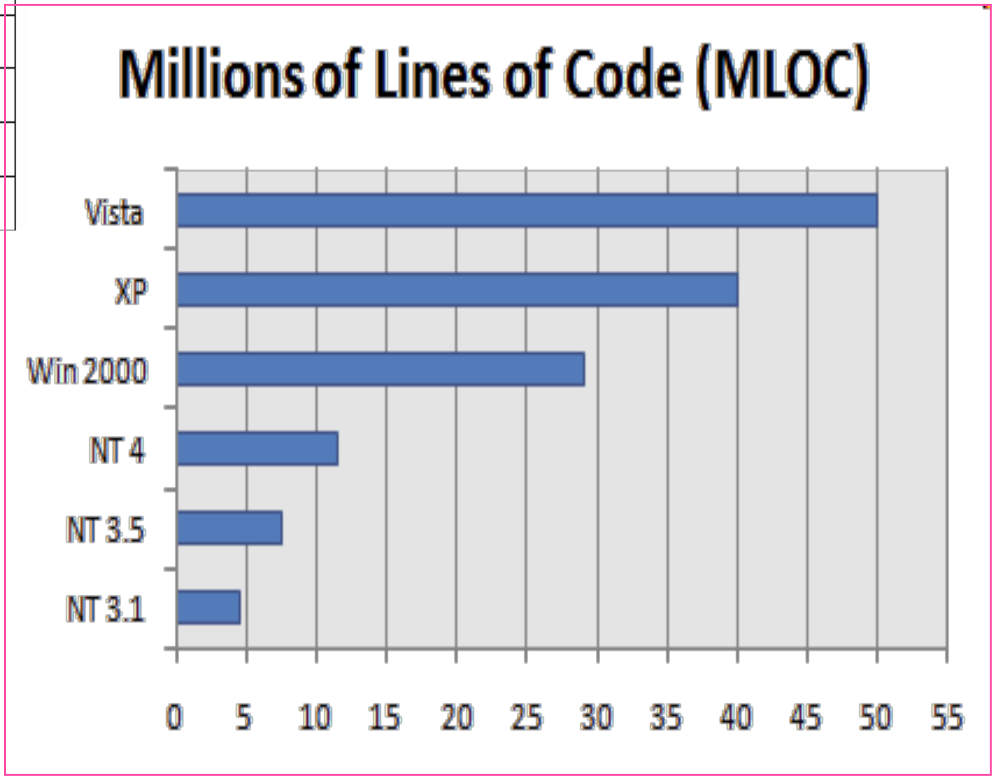
Growth of code and complexity over time

n System	Year	% of Functions Performed in Software
F-4	1960	8
A-7	1964	10
F-111	1970	20
F-15	1975	35
F-16	1982	45
B-2	1990	65
F-22	2000	80



(informal reports)

COMMENTARY

Chris Murphy
Editor, InformationWeek

See more from this author

Why Ford Just Became A Software Company

Ford is upgrading its in-vehicle software on a huge scale, embracing all the customer expectations and headaches that come with the development lifecycle.

6 Comments | Chris Murphy | November 14, 2011 09:31 AM

Sometime early next year, Ford will mail USB sticks to about 250,000 owners of vehicles with its advanced touchscreen control panel. The stick will contain a major upgrade to the software for that screen. With it, Ford is breaking from a history as old as the auto industry, one in which the technology in a car essentially stayed unchanged from assembly line to junk yard.

Ford is significantly changing what a driver or passenger experiences in its cars years after they're built. And with it, Ford becomes a software company--with all the associated high customer expectations and headaches.

Normal night-time image

Blackout of 2003

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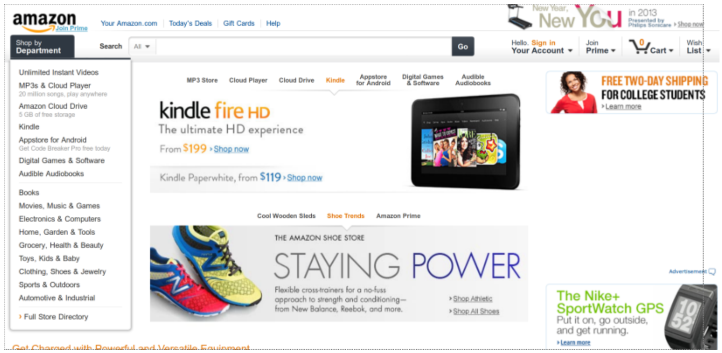
primes

graph search

binary tree

GCD

sorting



From programs to systems

Writing algorithms, data structures from scratch	Reuse of libraries, frameworks
Functions with inputs and outputs	Asynchronous and reactive designs
Sequential and local computation	Parallel and distributed computation
Full functional specifications	Partial, composable, targeted models

Our goal: understanding both the **building blocks** and the **design principles** for construction of software systems

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Objects in the real world

Object-oriented programming

- Programming based on structures that contain both data and methods

```
public class Bicycle {
  private final Wheel frontWheel, rearWheel;
  private final Seat seat;
  private int speed;
  …

  public Bicycle(…) { … }

  public void accelerate() {
    speed++;
  }

  public int speed() { return speed; }
}
```

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Semester overview

- Introduction to Java and O-O
- Introduction to **design**
  - **Design** goals, principles, patterns
- **Designing** classes
  - **Design** for change
  - **Design** for reuse
- **Designing** (sub)systems
  - **Design** for robustness
  - **Design** for change (cont.)
- **Design** case studies
- **Design** for large-scale reuse
- Explicit concurrency

- Crosscutting topics:
  - Modern development tools: IDEs, version control, build automation, continuous integration, static analysis
  - Modeling and specification, formal and informal
  - Functional correctness: Testing, static analysis, verification

Sorting with a configurable order, version A

```
static void sort(int[] list, boolean ascending) {
   …
   boolean mustSwap;
   if (ascending) {
      mustSwap = list[i] < list[j];
   } else {
      mustSwap = list[i] > list[j];
   }
   …
}
```

Sorting with a configurable order, version B

```
interface Comparator {
  boolean compare(int i, int j);
}

class AscendingComparator  implements Comparator {
  public boolean compare(int i, int j) { return i < j; }
}
class DescendingComparator implements Comparator {
  public boolean compare(int i, int j) { return i > j; }
}

static void sort(int[] list, Comparator cmp) {
  …
  boolean mustSwap =
    cmp.compare(list[i], list[j]);
  …
}
```

Sorting with a configurable order, version B'

```
interface Comparator {
  boolean compare(int i, int j);
}

final Comparator ASCENDING  = (i, j) -> i < j;
final Comparator DESCENDING = (i, j) -> i > j;

static void sort(int[] list, Comparator cmp) {
  …
  boolean mustSwap =
    cmp.compare(list[i], list[j]);
  …
}
```

Which version is better?

Version A:

```
static void sort(int[] list, boolean ascending) {
   …
   boolean mustSwap;
   if (ascending) {
      mustSwap = list[i] < list[j];
   } else {
      mustSwap = list[i] > list[j];
   }
   …
}
```

Version B':

```
interface Comparator {
  boolean compare(int i, int j);
}
final Comparator ASCENDING =  (i, j) -> i < j;
final Comparator DESCENDING = (i, j) -> i > j;

static void sort(int[] list, Comparator cmp) {
  …
  boolean mustSwap =
    cmp.compare(list[i], list[j]);
  …
}
```

It depends?

Software engineering is the branch of computer science that creates **practical, cost-effective solutions** to computing and information processing problems, preferably by applying scientific knowledge, developing software systems in the service of mankind.

Software Engineering for the 21st Century: A basis for rethinking the curriculum
Manifesto, CMU-ISRI-05-108

Software engineering is the branch of computer science that creates **practical, cost-effective solutions** to computing and information processing problems, preferably by applying scientific knowledge, developing software systems in the service of mankind.

Software engineering entails making **decisions under constraints** of limited time, knowledge, and resources…

Engineering quality resides in engineering **judgment**…

Quality of the software product depends on the engineer's **faithfulness to the engineered artifact**…

Engineering requires reconciling **conflicting constraints**…

Engineering skills improve as a result of careful systematic **reflection** on experience…

Costs and time constraints matter, **not just capability**…

Software Engineering for the 21st Century: A basis for rethinking the curriculum
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Goal of software design

- For each desired program behavior there are infinitely many programs
  - What are the differences between the variants?
  - Which variant should we choose?
  - How can we synthesize a variant with desired properties?

A typical Intro CS design process

1. Discuss software that needs to be written
2. Write some code
3. Test the code to identify the defects
4. Debug to find causes of defects
5. Fix the defects
6. If not done, return to step 1

Metrics of software quality

Source: Braude, Bernstein, Software Engineering. Wiley 2011

- Sufficiency / functional correctness
  - Fails to implement the specifications … Satisfies all of the specifications
- Robustness
  - Will crash on any anomalous event … Recovers from all anomalous events
- Flexibility
  - Must be replaced entirely if spec changes … Easily adaptable to changes
- Reusability
  - Cannot be used in another application … Usable without modification
- Efficiency
  - Fails to satisfy speed or storage requirement … satisfies requirements
- Scalability
  - Cannot be used as the basis of a larger version … is basis for much larger version…
- Security
  - Security not accounted for at all … No manner of breaching security is known

Design challenges/goals

Better software design

- Think before coding
- Consider non-functional quality attributes
  - Maintainability, extensibility, performance, …
- Propose, consider design alternatives
  - Make explicit design decisions

Using a design process

- A design process organizes your work
- A design process structures your understanding
- A design process facilitates communication

Preview: Design goals, principles, and patterns

- ***Design goals*** enable evaluation of designs
  - e.g. maintainability, reusability, scalability
- ***Design principles*** are heuristics that describe best practices
  - e.g. high correspondence to real-world concepts
- ***Design patterns*** codify repeated experiences, common solutions
  - e.g. template method pattern

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Concurrency

- Simply: doing more than one thing at a time

Summary: Course themes

- Object-oriented programming
- Code-level design
- Analysis and modeling
- Concurrency

Software Engineering (SE) at CMU

- 15-214: Code-level design
  - Extensibility, reuse, concurrency, functional correctness
- 15-313: Human aspects of software development
  - Requirements, teamwork, scalability, security, scheduling, costs, risks, business models
- 15-413 Practicum, 17-413 Seminar, Internship
- Various Master's level courses on requirements, architecture, software analysis, etc.
- SE Minor: http://isri.cmu.edu/education/undergrad

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COURSE ORGANIZATION

Preconditions

- 15-122 or equivalent
  - Two semesters of programming
  - Knowledge of C-like languages
- 21-127 or equivalent
  - Familiarity with basic discrete math concepts
- Specifically:
  - Basic programming skills
  - Basic (formal) reasoning about programs
    - Pre/post conditions, invariants, formal verification
  - Basic algorithms and data structures
    - Lists, graphs, sorting, binary search, etc.

Learning goals

- Ability to **design** medium-scale programs
- Understanding **OO programming** concepts & design decisions
- Proficiency with basic **quality assurance** techniques for functional correctness
- Fundamentals of **concurrency**
- Practical skills

Course staff

- Michael Hilton
  mhilton@cmu.edu
  Wean 5122

- Charlie Garrod
  charlie@cs.cmu.edu
  Wean 5101

- Teaching assistants: Alex, Alvin, Dustin, Nick, Shuli, Zilei

Course meetings

Smoking
Section

- Lectures: Tuesday and Thursday 12:00 – 1:20pm Wean 7500
  - Electronic devices discouraged
- Recitations: Wednesdays 9:30 - … - 2:20pm
  - Supplementary material, hands-on practice, feedback
  - Bring your laptop
- Office hours: see course web page
  - https://www.cs.cmu.edu/~charlie/courses/15-214/

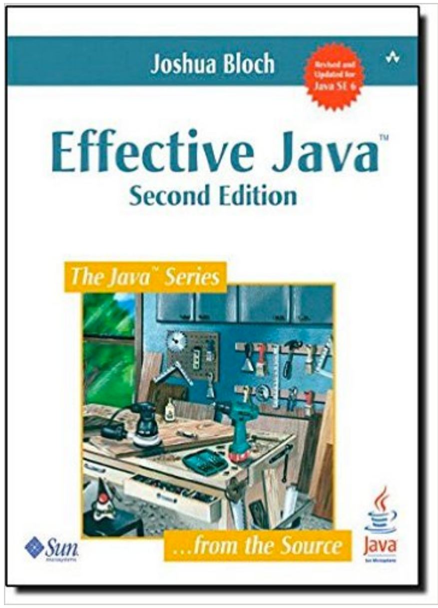
Recitation attendance is required

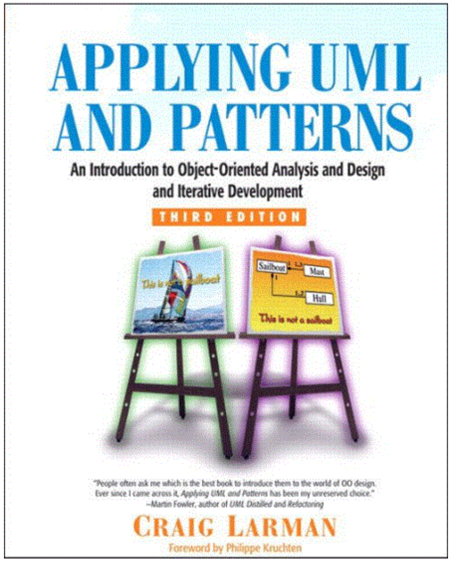
Infrastructure

- Course website: http://www.cs.cmu.edu/~charlie/courses/15-214
  - Schedule, office hours calendar, lecture slides, policy documents
- Tools
  - Git, Github: Assignment distribution, hand-in, and grades
  - Piazza: Discussion board
  - Eclipse or IntelliJ: Recommended for code development (other IDEs are fine)
  - Gradle, Travis-CI, Checkstyle, Findbugs: Practical development tools
- Assignments
  - Homework 1 available tomorrow
- First recitation is tomorrow
  - Introduction to Java and the tools in the course
  - Install Git, Java, some IDE, Gradle beforehand

Textbooks

- Required course textbooks (electronically available through CMU library):
  - Joshua Bloch. Effective Java, Second Edition. Addison-Wesley, ISBN 978-0321356680.
  - Craig Larman. Applying UML and Patterns. 3rd Edition. Prentice Hall, ISBN 978-0321356680.
- Additional readings on design, Java, and concurrency on the course web page





Approximate grading policy

- 50% assignments
- 20% midterms (2 x 10% each)
- 20% final exam
- 10% quizzes and participation

This course does not have a fixed letter grade policy; i.e., the final letter grades will not be A=90-100%, B=80-90%, etc.

Collaboration policy (also see the course syllabus)

- *We expect your work to be your own*
  - You must clearly cite external resources so that we can evaluate your own personal contributions.
- Do not release your solutions (not even after end of semester)
- Ask if you have any questions
- If you are feeling desperate, please mail/call/talk to us
  - Always turn in any work you've completed *before* the deadline
- We use cheating detection tools

Late day policy

- You may turn in each* homework up to 2 days late
  - 5 free late days per semester
  - 10% penalty per day after free late days are used
    - …but we don't accept work 3 days late
- See the syllabus for additional details
- Got extreme circumstances? Talk to us

10% quizzes and participation

- Recitation participation counts toward your participation grade
- Lecture has in-class quizzes

Summary

- Software engineering requires decisions, judgment
- Good design follows a process
- You will get lots of practice in 15-214!