Lecture 1

Course Overview & Introduction

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Course Overview

- Instructor: Zvonimir Rakamarić
- Teaching assistant: Shaobo He
- Course page is on Canvas
- Main goals
  - Gain solid understanding of basic theory and practice behind proving correctness of systems (mainly programs)
  - Cover advanced topics (interpolants, dealing with concurrency) in second part of the course
- Textbook: The Calculus of Computation by Aaron R. Bradley and Zohar Manna
  - Electronic version is free through SpringerLink

Topics

- Propositional logic and SAT
- First-order logic and SMT
- Verification conditions
  - Weakest precondition
- Proving program correctness
  - Pre- and post-conditions
  - Loop invariants
- Symbolic and concolic execution
- Advanced topics
  - Analyzing concurrent programs

Course Organization

- Lectures
  - Discuss basic and advanced software verification topics
  - Emphasize on lasting foundations and theory
- Homework assignments
  - Hands-on exercises accompanying presented material
  - Some coding required in your programming language of choice
- Projects
  - Focused, practical exploration of a topic related to software verification (and ideally your research too!)

Course Communication

- Leverage Canvas
  - Post questions
  - Discuss concerns
  - Ask for help and clarifications

- Email: zvonimir@cs.utah.edu
  - Private questions (e.g., questions related to your grade)

Grading

- 40% homework assignments
  - 4-5 practical homework assignments
  - Each assignment is worth the same
- 60% course project
  - Project proposal (10 points)
  - Final presentation (30 points)
  - Final report (50 points)
  - Peer review (10 points)

- 5110 students will be graded differently

Course Projects

- Mini research projects
  - Publishing a (workshop) paper is the ultimate goal
- Deadlines still not defined
  - I will update the webpage by the end of this week
- I will also come up with a list of potential topics

- Team work
  - Allowed (up to 2 students)
  - You have to do twice as much work
  - If it is not clearly specified who did how much work, both students will get the same grade

Collaboration vs Cheating

- **Discussing homework and project solutions at high-level is fine and encouraged**
- **Basing your code/write-up on any other code/write-up is cheating**
  - **do not copy solutions from another student**
  - **do not copy solutions from the internet**
  - **do not even look at solutions from another student**
  - **do not ask for solutions on online forums**
  - **……**
- **Acknowledge appropriately any outside materials you used or rely on**

Collaboration vs Cheating cont.

- **I will officially report instances of cheating**
  - **I will request that you fail this class**
  - **If confirmed, cheating will be on your record with this department**

- **Ignorance is not a valid excuse**
  - **Read our policies on cheating**
  - **Talk to professors if you are still not sure**

Late Policy

- Late homework assignments and project deliverables will not be accepted unless you contact me before the deadline and have a good excuse

Discussion

- Where can software be found nowadays?
- Any bad software bugs you heard about?

Introduction to Software Verification

- Software is everywhere
  - Personal computers, mobile phones, in cars, ATMs, banks, planes, space shuttles, hospitals…
- Software has errors
  - Software systems are generally large, complex, and prone to errors…
  - And getting larger and more complex…
    - Multi-cores and many-cores
  - …and more error prone!

Worst Software Bugs (Wired, 2005)

[http://www.wired.com/software/coolapps/news/2005/11/69355]

- 1962: Mariner I space probe
- 1982: Soviet gas pipeline
- 1985-87: Therac-25 medical accelerator
- 1988: Berkeley Unix finger daemon
- 1988-96: Kerberos Random Number Generator
- 1990: AT&T Network Outage
- 1993: Intel Pentium floating point divide
- 1995-96: The Ping of Death
- 1996: Ariane 5 Rocket
- 2000: Cancer institute's therapy planning software

Therac-25 Medical Accelerator

- Radiation therapy machine produced by Atomic Energy of Canada Limited (AECL)
- Bug: Race condition (concurrency error) between concurrent tasks in the Therac-25 software
  - Massive overdoses of radiation
- Between 1985-87 at least five patients die; others are seriously injured

Therapy Planning Software

- November 2000, National Cancer Institute, Panama City
  - Therapy planning software miscalculates the proper dosage of radiation for patients undergoing radiation therapy
- At least 8 patients die, another 20 receive overdoses likely to cause significant health problems

Ariane 5 Rocket

- June 4, 1996: Ariane 5 Flight 501 crash
- Working code for the Ariane 4 rocket is reused in the Ariane 5
  - Ariane 5's faster engines trigger an overflow condition in an arithmetic routine inside the rocket's flight computer
- Flight computer crashes
  - The rocket explodes 40 seconds after launch

Automotive Industry

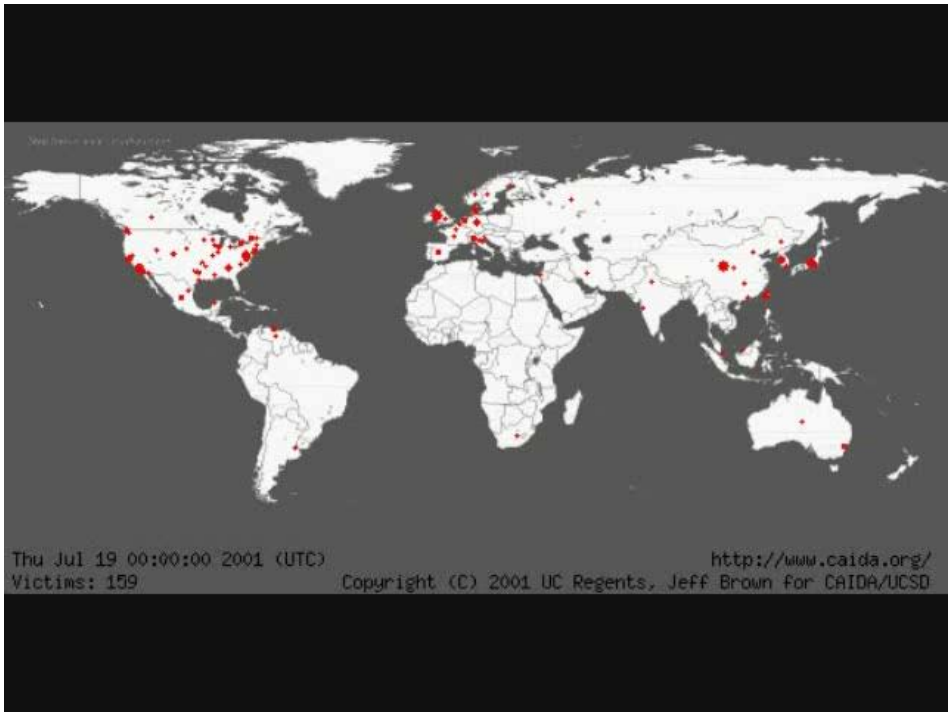
[http://www.embedded.com/columns/embeddedpulse/179100752]

- 2001: 52,000 Jeeps recalled due to a software error that can shut down the instrument cluster.
- 2002: BMW recalls the 745i since the fuel pump would shut off if the tank was less than 1/3 full.
- 2003: A BMW trapped a Thai politician when the computer crashed. The door locks, windows, A/C and more were inoperable. Responders smashed the windshield to get him out.

Automotive Industry cont.

- 2004: Pontiac recalls the Grand Prix since the software didn't understand leap years. 2004 was a leap year.
- 2005: Toyota recalls 75,000 Prius hybrids due to a software defect
  - Cars stall or shut down while driving at highway speeds
  - Owners advised to bring their cars into dealers for an hour-long software upgrade
- 2010: Toyota recalls 300,000 Prius cars
  - Software bug?

Code Red Worm



- 2001: Code Red worm attacks the Index Server ISAPI Extension in Microsoft Internet Information Services
- Exploit used: Buffer overflow bug
- Worm released on July 13
- The number of infected hosts reached 359,000 on July 19
- Estimated damages are $2.6 billion

Motivation

- Software errors are costly
  - US National Institute of Standards & Technology:
    Software errors cost the US economy alone an estimated $60 billion each year
- Improving software quality and reliability is a major software engineering concern

Testing

- Quality assurance relies heavily on testing
- Pros
  - Scalable, precise (no false bugs)
  - Easy to adopt and understand
  - Testing (even random) does find lots of bugs
- Cons
  - Time consuming and costly
    - Writing (good) test cases
    - Tester:Developer ratio at Microsoft around 1:1
  - Coverage
    - Important bugs still escape

Simple Testing Example

```
void foo(int x) {
   …
   …
   …
}
```

```
foo(???);

foo(INT_MAX);
foo(INT_MIN);
foo(0);
foo(random());
foo(random());
foo(random());

……
```

Example Where Testing Works

```
void foo(int x) {
   if (x == 0) {
      BUG!
   }
}
```

Example Where Testing Fails

```
void foo(int x) {
   if (x == 914) {
      BUG!
   }
}
```

Formal Software Verification

- Definition from Wikipedia:

  “Statically proving or disproving the correctness of a program with respect to a certain formal specification or property using formal methods of mathematics.”

- Could be a very effective way to deal with the software reliability problem

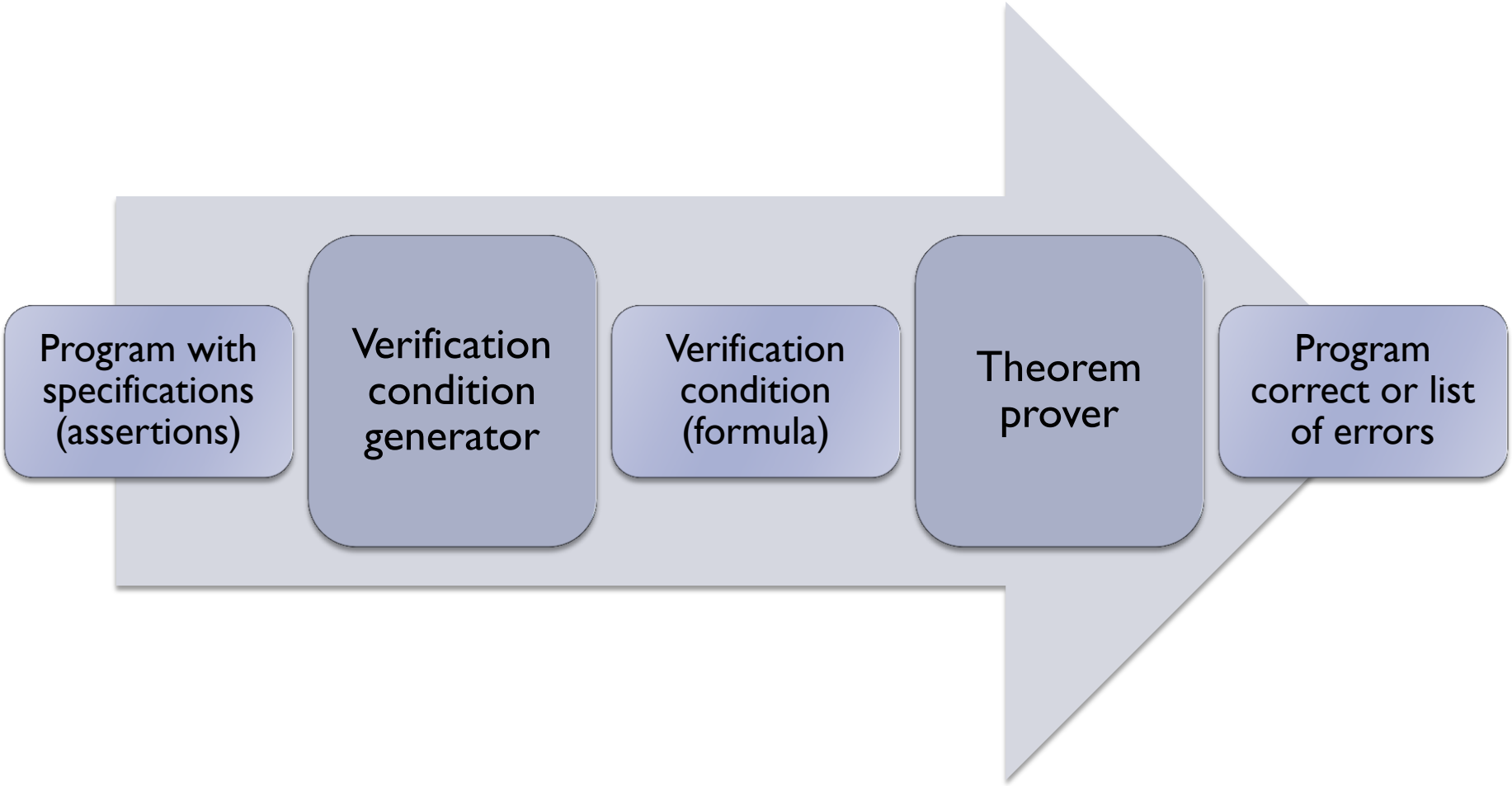
Brief History

- Turing, “Checking a Large Routine”, 1949.
  - We need proofs of programs
  - Mentions modularity
  - Early attempt at a general proof method
- Floyd, “Assigning Meaning to Programs”, 1967.
  - Workable proof method
- Hoare, “An Axiomatic Basis for Computer Programming”, 1969.
  - Further formalized
- Dijkstra, “A Discipline of Programming”, 1976.
  - Further formalized

Why Formal Verification?

- Static (or source code) analysis
  - Doesn’t execute code, no test cases
  - High coverage
    - Explores all possible paths through code
  - Finds more hard bugs
- Lower costs and turn-around time
- No silver bullet
  - Undecidable in general
    - Either misses bugs or returns false errors
  - Scalability and precision

Basic Verifier Architecture



Some Industry Success Stories

- Microsoft
  - SLAM – device drivers
  - Pex – automatic unit testing of .NET
  - Code Contracts – contracts for .NET
  - SAGE – whitebox fuzzing for security
- Startups
  - Coverity, Polyspace, Fortify…
- Astree project in France
  - Used by Airbus
- Verified software efforts
  - NICTA's secure microkernel
  - Microsoft Hypervisor

SAGE

- Finding security bugs using whitebox fuzzing
- Security bugs are expensive (MSR report)
  - Cost of each serious security bug: $Millions
  - Cost due to worms: $Billions
- Running on 100s machines 24/7
- Fuzzing 100s of applications
  - Media players, image processors, file decoders, document parsers…
- Finding 100s of security bugs
  - Saves tons of money/time/energy

SAGE cont.

“Every second Tuesday of every month, also known as "Patch Tuesday," Microsoft releases a list of security bulletins and associated security patches to be deployed on hundreds of millions of machines worldwide. Each security bulletin costs Microsoft and its users millions of dollars. If a monthly security update costs you $0.001 (one tenth of one cent) in just electricity or loss of productivity, then this number multiplied by a billion people is $1 million. Of course, if malware were spreading on your machine, possibly leaking some of your private data, then that might cost you much more than $0.001. This is why we strongly encourage you to apply those pesky security updates.”

Summary

- Software has bugs
- Bugs can be very expensive
- Catch easy bugs with testing, etc.
- Use software verification techniques to catch hard bugs

Next Lecture

- Propositional logic
- SAT solvers