CS477 Formal Software Development Methods

Elsa L Gunter
2112 SC, UIUC
egunter@illinois.edu
http://courses.engr.illinois.edu/cs477

Slides based in part on previous lectures by Mahesh Vishwanathan, and by Gul Agha

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Contact Information

- Office: 2112 SC
- Office Hours:
  - Wednesdays 11:00am - 11:50am
  - Fridays 11:00am - 12:30pm
  - Also by appointment
  - May add more if desirable
- Email: egunter@illinois.edu
- No TA this semester

Course Website

- http://courses.engr.illinois.edu/cs477
- Main page – summary of news items
- Policy – rules governing course
- Lectures – syllabus and slides
- MPs – information about homework
- Exams – exam dates, preparation
- Unit Projects – for 4 credit students
- Resources – tools, subject references
- FAQ

Some Course References

- No required textbook
- Software reliability methods, Doron A. Peled. Springer-Verlag New York, Inc.
- The Spin model checker – primer and reference manual, Gerard J. Holzmann. Addison-Wesley, Pearson Education.
- The Temporal Logic of Reactive and Concurrent Systems:Specification, Zohar Manna and Amir Pnueli. Springer-Verlag.
- Model Checking, Edmund M. Clarke Jr., Orna Grumberg, Doron A. Peled. MIT Press.
- Reference papers found in resources on the course website
  - Will grow over the semester

Course Grading

- Homework 30%
  - Four to five theory homeworks
  - Four to five tool exercises
    - Tool exercises may require access to EWS machines.
  - Handed in using `svn`
  - Late submission penalty: 20% of total assignment value
- Midterm 30%
  - Take-home – March 14
  - **DO NOT MISS EXAM DATE!**
- Final 40% – Take-home – Date TBA
- Fourth Unit Credit – additional 33%

Why Formal Methods?

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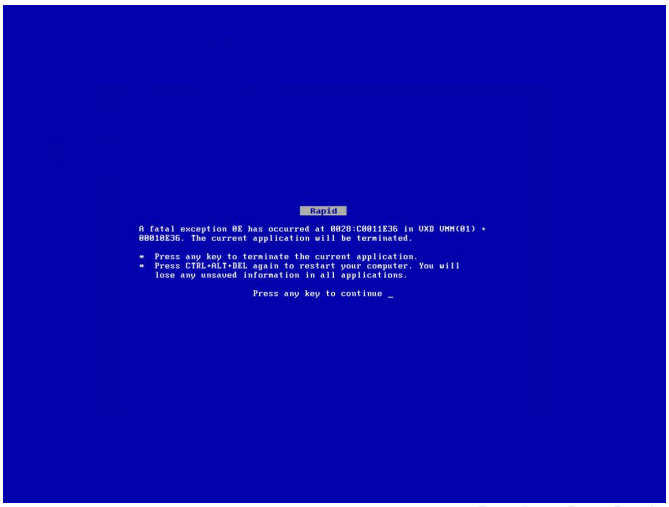
- To find bugs.



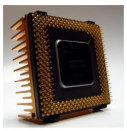
AT&T Network Outage

- 1990: AT&T # 4ESS long distance switch carried all long distance calls in USA, including for Air Traffic Control
- Jan 15, 1990 switch in New York crashes; reboot causes neighboring switches to crash, reboot
- 114 switches caught in oscillating crash - reboot cycle
- Over 60,000 people with no phone service
- No inter-airport ATC communication
  - eventually amateur ham radio help with volunteer network

AT&T Network Outage

- Short-Term Fix: Reload earlier version of 4ESS OS on all switches
- April 1990: AT&T Bell Labs creates new center Computing Sciences Research Center to try to assure never again
  - I was its first employee
- Bug:
  - Many contributing causes
  - One fatal contribution: a misplaced semicolon
  - Could have been caught by a stronger type system

Pentium Chip



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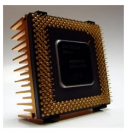

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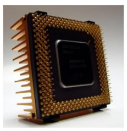

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- 500 million US dollars + loss of image

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  - The plane suddenly zoomed up 3000 feet. The pilot's efforts at gaining manual control succeeded after a physical struggle, and the passengers were safely flown back to Australia.
- Cause: Defective software provided incorrect data about the plane's speed and accelaration.

Malaysian Airlines
Wall Street Journal Analysis

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- "...problems in aviation software stem not from bugs in code of a single program but rather from the interaction between two different parts of a plane's computer system."
- "...Boeing issued a safety alert advising, ..., pilots should immediately disconnect autopilot and might need to exert an unusually strong force on the controls for as long as two minutes to regain normal flight."

Why Formal Methods?

- To catch bugs
- To eliminate whole classes of errors
- Contrast: Testing

Testing	**Formal Methods**
Can find errors in systems	Can find errors in systems
Gen works on actual code maybe simulated env	Gen work on abstract model of code and environment
Can't show errors don't exist	Can show certain types of errors can't exist
Can't show system error-free	Can't show system error-free

Formal Methods Limitations

- Can be expensive
  - Only used fully on safety-critical system components
- Can only prove model of system satisfies given property ("requirements")
  - Model may be wrong
  - requirements may be inadequate or wrong

What Are Formal Methods?

- Method of finding errors in
  - Hardware
  - Software
  - Distributed Systems
  - Computer-Human Operator Systems
  - ...
- Not a way to guarantee nothing will go wrong

What Are Formal Methods?

- Formal Methods are the application of rigorous mathematics to the
  - specification
  - modeling
  - implemetation, and
  - verifcation

  of systems with programmable components
  - Software
  - Hardware
  - Control Systems
  - Combined Computer - Human Operator Systems, ...
- via computer programs implementing the math

What Types of Maths?

- Sets, Graphs, Trees
- Automata
- Logic and Proof Theory, Temporal Logics
- Process Algebras
- Induction, especially structural induction and well-founded induction, inductive relations
- Category Theory
- Probability
- ...
- Differential Equations, PDEs
- ...

What Types of Tools?

- Type Checkers, Type Inference
  - Java, ML (Ocaml, Standard ML), Haskell, ...
- Model Checkers, SAT solvers
  - SPIN, NuSMV, Mocha, SAL, ...
- Interactive Theorem Provers
  - Isabelle, Coq, HOL4, PVS, ...
- Runtime Monitoring
  - JavaMOP

Course Overview

- Review of basic math underlying most formal methods
- Intro to interactive theorem proving
  - Intro to Isabelle/HOL
- Floyd-Hoare Logic (aka Axiomatic Semantics)
  - Verification Conditions
  - Verification Condition Generators (VCGs)
- Rewrite Logic
  - Intro to Maude
- Operation Semantics
  - Structured Oper. Sem., Transition Sem., Contexts Reduction Sem.
- Models of Concurrency
  - Finite State Automata, Buchi Automata, Concurrent Game Structures, Petri Nets

Course Overview

- Temporal Logics
  - LTL
  - CTL
- Model Checkers
  - Spin
  - NuSMV
  - SAL
- Process Algebras, Pi Calculus, CSP, Actors
  - Intro to FDR
  - Intro to Rebeca
- Type Systems
  - Type Soundness
  - Dependent Types, Liquid Types, DML
  - Communication Types (aka Session Types)
  - Runtime Type Checking, Runtime Verification

Course Objectives

- How to do proofs in Hoare Logic, and what role a loop invaraint plays
- How to use finite automata to model computer systems
- How to express properties of concurrent systems in a temporal logic
- How to use a model checker to verify / falsify a temporal safety property of a concurrent system
- The connection between types and propgram properties
- What type soundness does and does not guarantee about a well-typed program

Propositional Logic

The Language of Propositional Logic

- Begins with constants $\{\mathbf{T}, \mathbf{F}\}$
- Assumes countable set AP of propositional variables, a.k.a. propositional atoms, a.k.a. atomic propositions
- Assumes logical connectives: $\wedge$ (and); $\vee$ (or); $\neg$ (not); $\Rightarrow$ (implies); $\Leftrightarrow$ = (if and only if)
- The set of propositional formulae $PROP$ is the inductive closure of these as follows:
  - $\{\mathbf{T}, \mathbf{F}\} \subseteq PROP$
  - $AP \subseteq PROP$
  - if $A \in PROP$ then $(A) \in PROP$ and $\neg A \in A$
  - if $A \in PROP$ and $B \in PROP$ then $(A \wedge B) \in PROP$, $(A \vee B) \in PROP$, $(A \Rightarrow B) \in PROP$, $(A \Leftrightarrow B) \in PROP$.
  - Nothing else is in $PROP$
- Informal definition; formal definition requires math foundations, set theory, fixed point theorem ...

Semantics of Propositional Logic: Model Theory

Model for Propositional Logic has three parts

- Mathematical set of values used as meaning of propositions
- Interpretation function giving meaning to props built from logical connectives, via structural recursion

Standard Model of Propositional Logic

- $\mathcal{B} = \{\text{true}, \text{false}\}$ boolean values
- $v : AP \to \mathcal{B}$ a valuation
- Interpretation function ...

Semantics of Propositional Logic: Model Theory

Standard Model of Propositional Logic (cont)

- Standard interpretation $\mathcal{I}_v$ defined by structural induction on formulae:
  - $\mathcal{I}_v(\mathbf{T}) = \text{true}$ and $\mathcal{I}_v(\mathbf{F}) = \text{false}$
  - If $a \in AP$ then $\mathcal{I}_v(a) = v(a)$
  - For $p \in PROP$, if $\mathcal{I}_v(p) = \text{true}$ then $\mathcal{I}_v(\neg p) = \text{false}$, and if $\mathcal{I}_v(p) = \text{false}$ then $\mathcal{I}_v(\neg p) = \text{true}$
  - For p, $q \in PROP$
    - If $\mathcal{I}_v(p) = \text{true}$ and $\mathcal{I}_v(q) = \text{true}$, then $\mathcal{I}_v(p \wedge q) = \text{true}$, else $\mathcal{I}_v(p \wedge q) = \text{false}$
    - If $\mathcal{I}_v(p) = \text{true}$ or $\mathcal{I}_v(q) = \text{true}$, then $\mathcal{I}_v(p \vee q) = \text{true}$, else $\mathcal{I}_v(p \vee q) = \text{false}$
    - If $\mathcal{I}_v(q) = \text{true}$ or $\mathcal{I}_v(p) = \text{false}$, then $\mathcal{I}_v(p \Rightarrow q) = \text{true}$, else $\mathcal{I}_v(p \Rightarrow q) = \text{false}$
    - If $\mathcal{I}_v(p) = \mathcal{I}_v(q)$ then $\mathcal{I}_v(p \Leftrightarrow q) = \text{true}$, else $\mathcal{I}_v(p \Leftrightarrow q) = \text{false}$

Truth Tables

Interpretation function often described by truth table

p	q	$\neg p$	$p \wedge q$	$p \vee q$	$p \Rightarrow q$	$p \Leftrightarrow q$
true	true					
true	false					
false	true					
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