Fundamentals of Programming Languages IX

Conclusion

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Report

The deadline is firmly on Jan. 10, 2018!

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Both paper version and electronic version are needed (3203 Software Building & li.g@outlook.com)!

Scoring Policy

- 10% Attendance.
- 20% Homework.
  - Four assignments.
  - Each one is 5pts.
  - Work out individually.
  - Each assignment will be evaluated by A, B, C, D, F (Excellent(5), Good(5), Fair(4), Delay(3), Fail(0))
- 70% Final report.

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Homework is MUCH MORE IMPORTANT than report!

What We Have Learnt

- Theoretical computer sciences
- Program analysis (program analysis = abstraction interpretation + model checking)
- Program semantics
- Functional program language basics

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- Theoretical computer sciences
    - propositional logics (preliminary)
    - set theory (program semantics)
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    - operational semantics
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    - axiomatic semantics
- Functional program language basics
    - lambda calculus
    - simple type of lambda calculus

Theoretical Computer Sciences

Propositional Logic

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Syntax and semantics

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Satisfiability and validity

Propositional Logic

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Normal form

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- Tseitin's Encoding

Propositional Logic

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Proof system

- Natural deduction
- Sequent calculus

Set Theory

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Powerset, Indexed set, Big union, Big intersection

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Product, Disjoint union, Set difference, The axiom of foundation

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Binary relation, Partial function Total function

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Lambda notation, composition of functions, identity function, inverse, $1-1$ correspondence

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Direct image, inverse image, equivalence relation, equivalence class, transitive closure

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Georg Cantor's Diagonal Argument

Abstract Algebra

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Preorder and partial order

- preorder: reflexivity, transitivity
- partial order: reflexivity, transitivity, antisymmetry

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well-quasi order

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Tarski's fixpoint theorem

Automata Theory

Automata Theory

Finite automata: DFA, NFA

Infinite automata: Büchi automata

Pushdown automata and pushdown systems

Computation on automata

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Antichain

Proof Theory

Proof Theory

Mathematical induction

Course-of-values induction

Proof Theory

Mathematical induction

Course-of-values induction

Structural induction

Proof Theory

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Well-founded induction, or Noetherian induction

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Induction on derivations

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Definition by induction

Program Analysis

Slogan

Program Analysis = Abstract Interpretation + Model Checking

Abstraction Interpretation

Specify an analysis in terms of the following data:

1. Preset D (abstract domain).
2. Monotone function F (abstract transfer function).
3. Widening operator ∇ (unless D is finite).
4. Narrowing operator Δ (optional).
5. Galois connection from C (concrete domain) to D.
6. Soundness of F wrt. E (concrete transfer function).

Then, the analysis terminates and is correct (sound).

Abstraction Interpretation

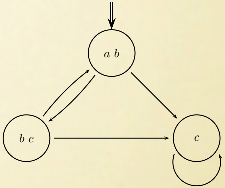
Patrick Cousot awarded John von Neumann Medal

Patrick Cousot is the recipient of the IEEE John von Neumann medal, given "for outstanding achievements in computer-related science and technology". The medal citation states that he is being recognized "for introducing abstract interpretation, a powerful framework for automatically calculating program properties with broad application to verification and optimization." Congratulations!

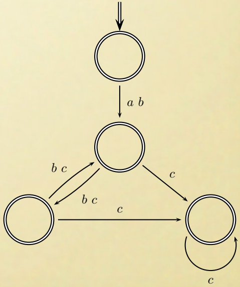
Model Checking: Model

- Kripke structure: $M = (S, S_0, R, L)$
  - S, finite set of state
  - $S_0 \subseteq S$, initial state
  - $R \subseteq S \times S$, transition relations
  - $L : S \rightarrow 2^{AP}$, status label function

    (AP: atomic propositions)

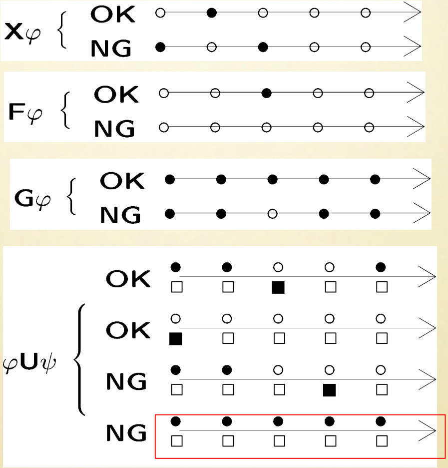


- Finite automata: $\mathcal{A} = (\Sigma, Q, Q_0, F, \delta)$
  - A, finite set of input alphabet
  - Q, finite set of control location
  - $Q_0 \subseteq Q$, initial control locations
  - $F \subseteq Q$, final control locations
  - $\delta \subseteq Q \times \Sigma \times Q$, transitions



Model Checking: Temporal Logic

- Next
- Finally
- Globally
- Until



● : φ, ■ : ψ, ○ : $\neg\varphi$, □ : $\neg\psi$

CTL Vs. LTL

- CTL: temporal operators must be immediately followed by path quantifiers.
  - e.g., $AF\varphi, EG\varphi, AXEG\varphi, EXA(\varphi U \psi)$
- LTL: path quantifiers are allowed only at the outermost position.
  - e.g., $AGF\varphi, EX(\varphi U \psi), A(F\varphi \vee G\psi)$
- Except for fairness, most properties are expressed in CTL $\cap$ LTL.

Decidability of CTL and LTL

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CTL: Polynomial algorithms

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- by tableau
- by Büchi automata: on-the-fly model checking
- by SAT: bounded model checking

What We Did Not and Should Learn?

Symbolic model checking: ordered binary decision diagram (OBDD)

partial reduction: Spin

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Timed automata, well-structured transition systems (WSTS)

Program Semantics

operational semantics

denotational semantics

axiomatic semantics

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Category theory basics

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Recursion theory

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Recursion theory

Gödel incompleteness

Functional Programming Languages

Lambda Calculus and Types

Lambda calculus syntax

β reduction and η reduction

Full β-reduction, normal order strategy, call by name, call by value

Programming in Lambda calculus

Church-Rosser Property

De Bruijn representation of Lambda calculus

Simple types of Lambda calculus

Progress and preservation

What We Did Not and Should Learn?

How to program in functional programming languages, such as SML, Ocaml, Haskell

Algorithms in functional programming languages

Structured types

Type checking and inferences

Normalization, References and Exceptions

Subtyping, recursive types

Higher order systems