Verifying Specifications with Proof Scores

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(this talk is based on our research results
with many persons’ contributions)

I am going to talk about…

- Our perception of current situation of formal methods
- Introducing Proof Score Approaches and its realization in CafeOBJ
  - how to write formal specifications and verify properties of them with proof scores in CafeOBJ (hopefully with simple demonstration)
- What kinds of formal models are used for writing formal specifications/proof-scores in CafeOBJ
- Current achievements of the proof score approach

Application areas of formal methods (FM)

1. Analysis and verification of developed program codes (post-coding)
   -- model checking has brought many successes in code verification but ･･･
2. Analysis and verification of requirements, specifications, designs before coding (pre-coding) or without coding/programming

Successful application of formal methods to the area of requirements, specifications, designs (pre-coding) can bring drastic effects for system developments, but it is not well exploited and/or practiced yet

Difficulties in req., spec, design area

- High level req., spec., design are inherently partial and evolutional
- Usually there is no established formal (mathematical) model for the problem
- It is not easy to be convinced that some important property holds for req., spec., design

Interactive developments with analyses/verifications are inevitable!

Our perception of the current situation of FM

- Verification with formal specifications still have a potential to improve the practices in upstream (pre-coding) of software production processes
- Model checking has brought a big success but still has limitations
  - It is basically “model checking” for program codes
    - initially for post-coding; applied at designs/specs later
  - Infinite state to finite state transformation can be unnatural and difficult
- Established (interactive) theorem provers are not necessary well accepted to software engineers
  - especially in requirement/spec/design (pre-coding) phase

Our approach

- Reasonable blend of user and machine capabilities, intuition and rigor, high-level planning and tedious formal calculation
  - fully automated proofs are not necessary good for human beings to perceive logical structures of real systems

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Proof Score Approach

Proof Score Approach

- Requirement/specification engineers are expected to construct proof scores together with formal specifications

- proof scores are instructions such that when executed (or "played") and everything evaluates as expected, then the desired property is convinced to be hold (or proved)

Specifications and Proof Scores in CafeOBJ

- Specifications are only algebraic equational specifications
- Proof score is a sequence of reduction (simplification) commands for reducing expressions (usually boolean) to its normal form in some situations
  - situations: a set of equations (axioms) with some bindings (a set of name->object relationships)
  - proof score also contains CafeOBJ codes which build an appropriate situation in which expressions are reduced

A simple example of proof score in CafeOBJ

The definitions of two factorial functions and the proof scores for verifying that the two can compute the same function using induction

[Demonstration]

Introducing CafeOBJ

- CafeOBJ is an algebraic formal specification language
- CafeOBJ is a formal language for writing formal models and reasoning about them with rewritings/reductions (ACIZ-rewritings)
- CafeOBJ is a successor of OBJ and developed by an international team headed by KF for last 10-15 years

Related ongoing Language Development Projects

- Maude Language of SRI/UIUC is another project for following up the OBJ language

- CASL language of European researchers is an attempt of developing a common algebraic specification language
  - Two volumes of LNCS are already published

Two kinds of formal models in CafeOBJ

- **Abstract data types with tight semantics**
  - **Initial algebra semantics**
  - **Induction based reasoning**
- **Abstract machines (abstract process types) with loose semantics**
  - **Coherent hidden algebra semantics**
  - **Co-induction based reasoning**

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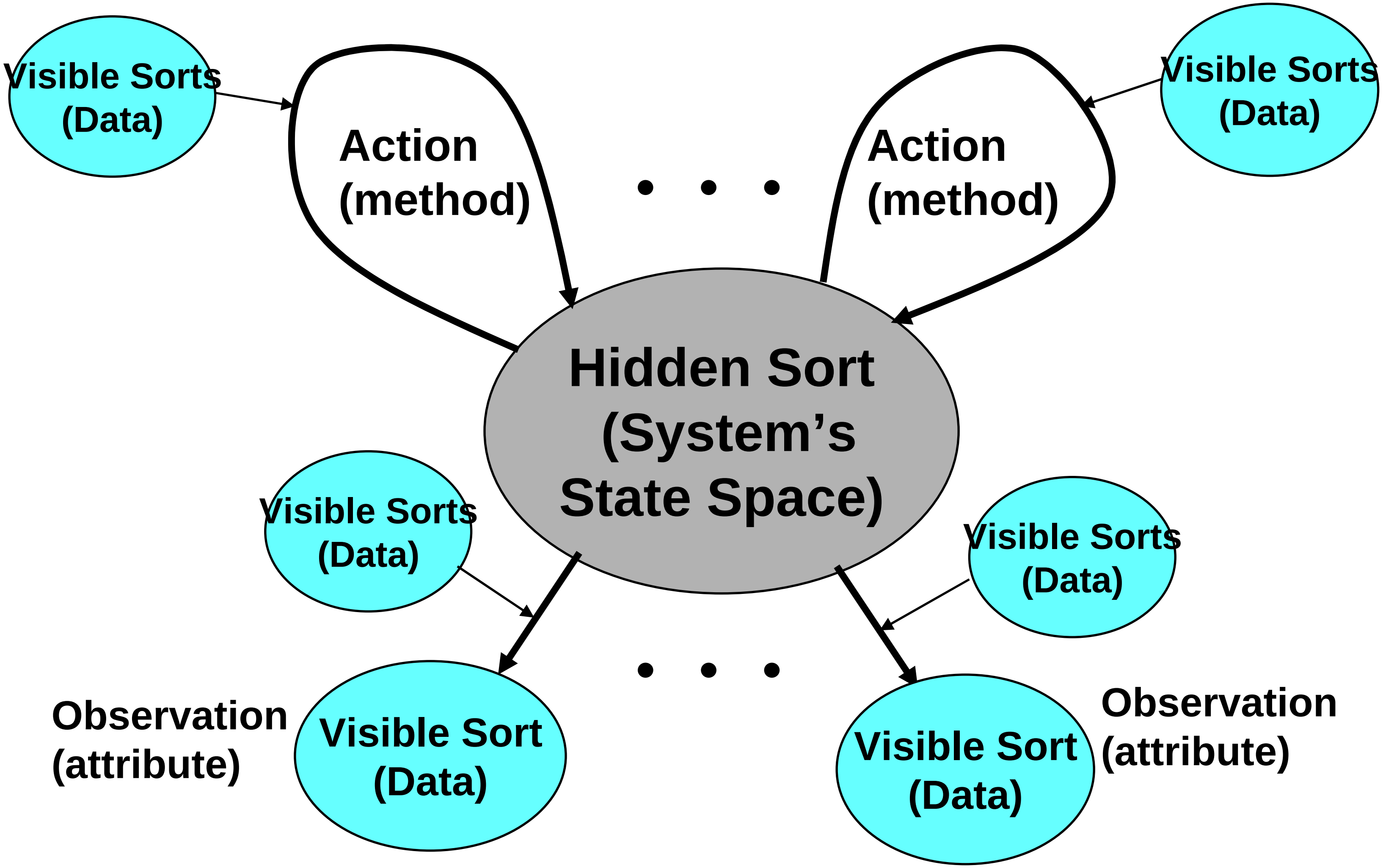
Can provide unified specification style both for static and dynamic systems

OTS/CafeOBJ Behavioral/Observational Model



OTS in CafeOBJ

OTS is naturally used to model distributed concurrent systems in CafeOBJ

- Typed data for specifying a system are represented as visible sorts
- The state space of a system is represented by a hidden sort

* Behavioral/Observational equivalence need not (or can not) appear in OTS by definition

An simple example of OTS

A Bank Account Example
-- a most simplest example of OTS

[Demonstration]

Prerequisites for proof score writing in CafeOBJ (1)

- **Algebraic modeling:**

  development of algebraic specifications

  - **defining signature for a real problem**
  - **expressing the problem in equations**
    - **more exactly, if you want to prove some property of the spec, expressing the problem in reduction rules**

Prerequisites for proof score writing in CafeOBJ (2)

- Equational logic, rewriting, and propositional calculus with complete rewriting calculus
  - equationl reasoning
    - equivalence relation, equational calculus, …
  - reduction/rewriting
    - termination, confluence, sufficiently completeness
  - propositional calculus with “xor” normal forms which has the complete rewriting calculus

Prerequisites for proof score writing in CafeOBJ (3)

- **Proof by induction with case analyses and lemma discoveries**
  - ♦ **case splitting using key predicates in specifications**
  - ♦ **discovery of lemmas**
  - ♦ **decomposition of a goal predicate into an appropriate conjunctive form**

These are the most difficult parts of proof score writing

Equational proof by reduction/rewriting

Why do we care about

equational reasoning by reduction ?

- It is simple and powerful and a good light weighted formal reasoning method
  - easy to understand and can be more acceptable for software engineers
- It supports transparent relation between specs and reasoning by reduction (good traceability)

Traceability in proof score approach with CafeOBJ

- **All reductions are done exactly using equations in specifications**
    - **this make it easy to detect necessary changes in specs for letting something happen (or not happen)**
- **Usually reductions are sufficiently fast, and encourage prompt interactions between user and system**

This is a quit unique feature of the proof score approach with CafeOBJ comparing to other verification method which often involves several formalisms/logics and translations between them

Current Achievements of OTS/CafeOBJ proof score approach

OTS/CafeOBJ approach has been applied to the following problems and found usable:

- Some classical mutual exclusion algorithms
- Some real time algorithms
  e.g. Fischer’s mutual exclusion protocol
- Authentication protocol
  e.g. NSL, Otway-Rees, STS protocols
- Practical sized e-commerce protocol of SET
  (some of proof score exceeds 60,000 lines;
  specification is about 2,000 lines,
  20-30 minutes for reduction of the proof score)
- UML semantics (class diagram + OCL-assertions)
- Formal Fault Tree Analyses
- Secure workflow models

Future Plan

- Develop proof score writing environment
  - Standard platforms for programming environment can be naturally used (e.g. Eclipse Env.)

    Write specs and proof-socres as writing programs!
- Automate case analysis and lemma discovery
  - Automation of inductive proof (Crème)
    - NSLPK and STS protocol verification is already done automatically
  - Incorporation of model checking technologies into proof score approach
    - Especially for finding counter examples
- Apply to the new areas
  - business and/or social system specs and analyses/verifications
    - Secure workflows/processes
    - E-commerce domain models
  - System Biology

CafeOBJ Home Page

- **CafeOBJ official home page:**
  http://www.ldl.jaist.ac.jp/cafeobj/