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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**

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**

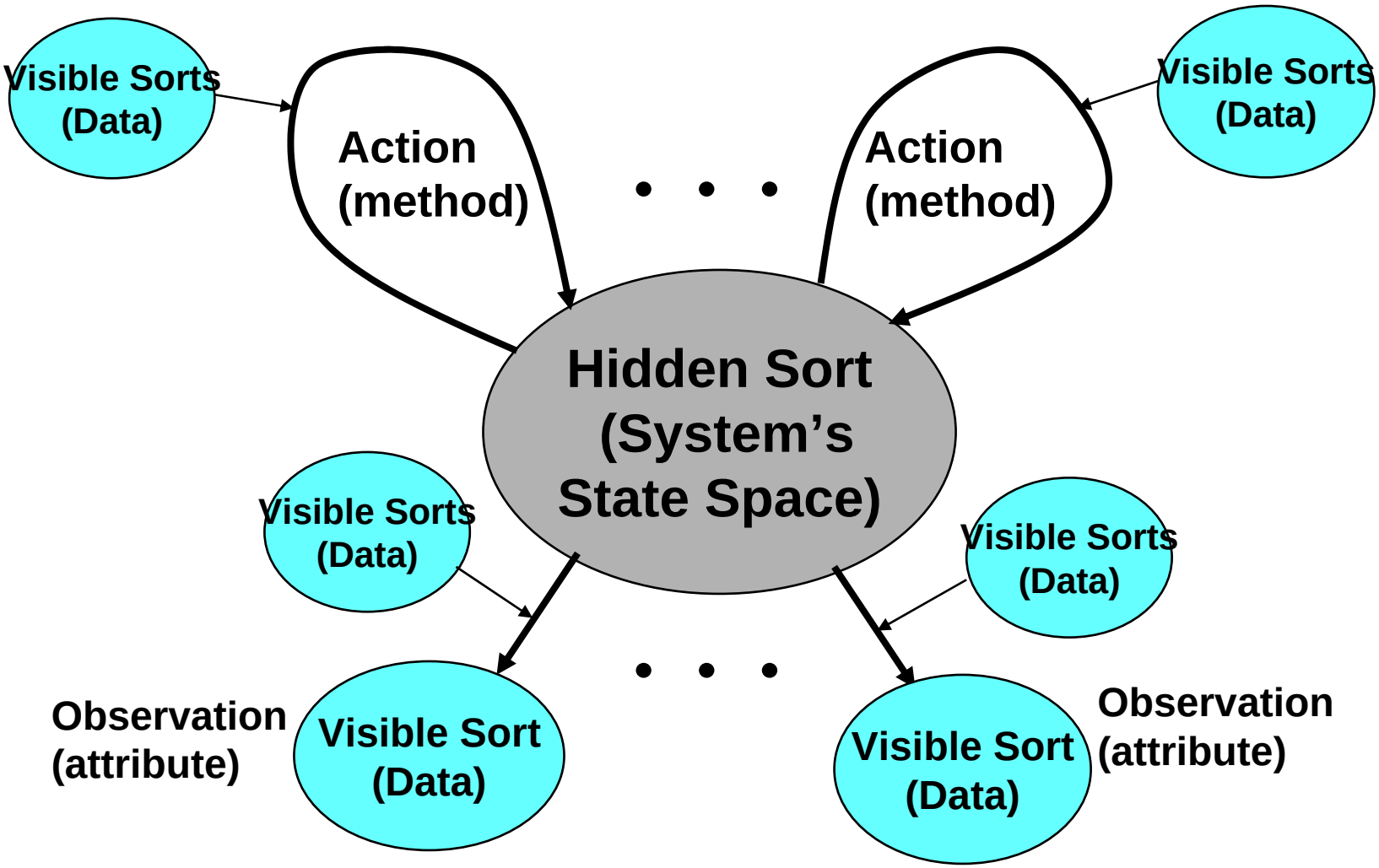
- **CASL language of European researchers is an attempt of developing a common algebraic specification language**
  - **Two volumes of LNCS are already published**

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**

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/