Rewriting Systems

http://d3s.mff.cuni.cz

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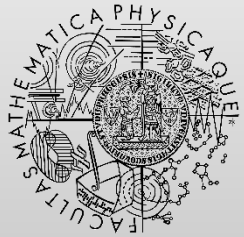

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Motivation: executable specifications

- Systematic rewriting based on equations
- Example: list length
- Rewrite systems
  - Theory (background)
  - Practice (Maude)

Substitution

- Signature: the set V of variable names
- Substitution $\sigma : V \rightarrow X$
  - Unifier of t_1 and t_2 if $\sigma(t_1) = \sigma(t_2)$
- Inductively defined sub-expressions
- Reducible sub-expression $t_1[\beta]$ // redex
  - If $\sigma(\beta) = \sigma(t_2)$

Rewriting rules & systems

- Rule $r : l \rightarrow p$
- Application of a rule
  - $\sigma(t)[\beta \leftarrow \sigma(p)]$
- Rewriting system: set R of rules
- Derivation $t \rightarrow_R u$
  - Reflexive transitive closure $\rightarrow_{R^*}$
- Irreducible expressions
  - Normal form (canonical)

Properties of rewriting systems

- Confluence
  - $\forall\ t, t_1, t_2 \bullet ((t \rightarrow_{R^*} t_1 \wedge t \rightarrow_{R^*} t_2) \Rightarrow \exists\ u \bullet t_1 \rightarrow_{R^*} u \wedge t_2 \rightarrow_{R^*} u)$
- Terminating
  - Normal form always exists
- Canonical
  - Single normal form

Canonical values

- Classes of equivalent terms (expressions)
  - Generated by equations (sentences) in the set E
- Canonical representatives of classes
- Canonical values (forms) of expressions

Knuth-Bendix procedure

- Input: $Q = (S, \sum, E), \leq \subseteq X \times X$

- Algorithm
  1) $R := \emptyset$
  2) if $E == \emptyset$ then return R // canonical rewriting system
  3) take any $t_1 = t_2 \in E$ such that either $t_1 \leq t_2$ or $t_2 \leq t_1$
     - 3a) if $\exists\ t_1 = t_2$ then $E := E - \{t_1 = t_2\}$
     - 3b) if t_1 and t_2 not comparable then fail // R cannot be created
  4) if $t_2 \leq t_1$ then $R := R \cup \{R(t_1) \rightarrow R(t_2)\}$
  5) if $t_1 \leq t_2$ then $R := R \cup \{R(t_2) \rightarrow R(t_1)\}$
  6) if $R(t_1) \neq R(t_2)$ then $E := E \cup \{R(t_1) = R(t_2)\}$
  7) continue with step 2

Connection to algebraic specifications

- Equations
  - Simple rewriting semantics (simplification)
  - Left-hand side replaced by right-hand side

Maude

- Web: https://maude.cs.illinois.edu/
  - source code, documentation, examples
- Version: 3.5 or newer

- Main features
  - Functional modules and theories
    - Algebraic specifications
  - Objects with state (configurations)
  - Numeric and string data types
  - Computation (rewriting, equations)
    - based on the membership equational logic
    - rewrite rules over terms and configurations
  - much more (check the web site)

Maude: installation & running

- Linux / MacOS
  - https://maude.cs.illinois.edu/wiki/Maude_download_and_installation
- Windows
  - Option 1: use the WSL (Windows Subsystem for Linux)
  - Option 2: download Windows binaries
    - http://maude.cs.illinois.edu/w/index.php/Installation_guidelines
    - http://maude.ucm.es/strategies/maude+strat-windows.zip
- Running
  - <directory with Maude>/maude
  - From the command-line in a working directory that contains your input files

Maude: basic commands

- 1) Prepare specification in a text file
- 2) run the Maude tool
- 3) load your input file: `load <file>`
- 4) apply rewriting on some expression

  `reduce [in <module> :] <expr>`
- 5) Exit the Maude prompt: `quit`

Maude programs: syntax and semantics

- Functional modules
  - sorts, variables, operations, equations
- Notation for operations: prefix, mixfix
- Comments
- Built-in sorts and modules
  - Bool, NAT, INT, FLOAT, RAT, QID, STRING

Maude programs: syntax and semantics

- Examples
  - Natural numbers (Peano arithmetic)
  - Stack of natural numbers
- Theories
- Conditional equations
- Membership axioms
- Attributes of operations

Maude programs: advanced concepts

- Parameterized modules (generic)
  - Example: generic stack
- Importing modules
  - protecting
  - extending
  - including

Maude programs: there is even more

- Data structures (MAP, ARRAY, others)
- Rewriting rules (“basic”, conditional)
- Useful built-in modules (CONFIGURATION)

Maude: configurations and rules

- Rewrite module
  - Functional module + rewrite rules
- Configurations: special terms (“runtime objects”)
- Rules: possible transitions between configurations
- Conditional rules (with guards)
- Syntax and examples
  - https://maude.lcc.uma.es/maude-manual/maude-manualch5.html
  - https://maude.lcc.uma.es/maude-manual/maude-manualch6.html

Literature

- Documentation
  - https://maude.cs.illinois.edu/wiki/Maude_Manual_and_Examples
  - Primer (for version 2.0.1, still applicable)
    - https://maude.cs.illinois.edu/w/images/6/63/Maude-primer.pdf

- Maude and Rewriting Logic
  - M. Clavel, F. Duran, S. Eker, P. Lincoln, N. Marti-Oliet, J. Meseguer, and J.F. Quesada. Maude: Specification and Programming in Rewriting Logic. Theoretical Computer Science, 285 (2), 2002
  - http://maude.cs.illinois.edu/w/index.php/Some_Papers_on_Maude_and_on_Rewriting_Logic
  - http://maude.cs.illinois.edu/papers/