Maude Implementation of MSR

Demo

Cast

Analyst

Programmer

Customer

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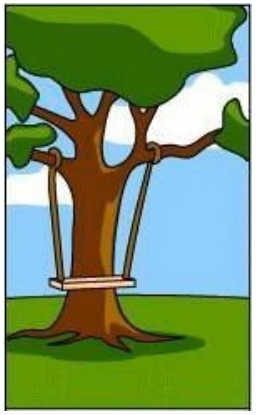
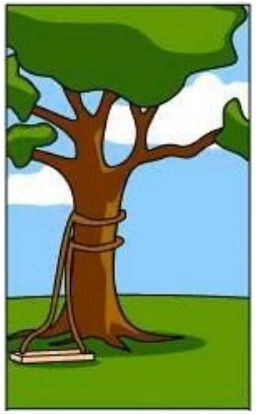
http://theory.stanford.edu/~iliano/

What the customer explained



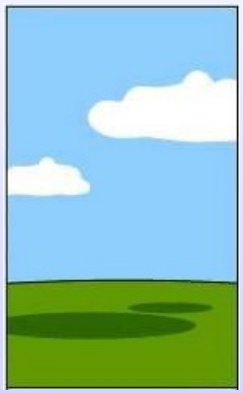
What the project manager understood

What the analyst designed

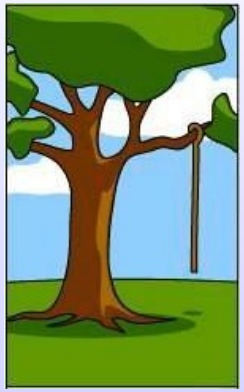


What the programmer delivered

What the consultant defined

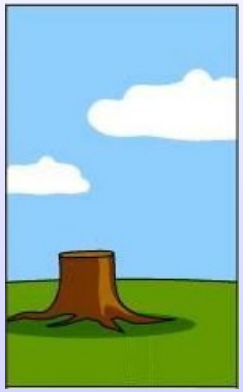


What was documented



What was installed

What the client was charged

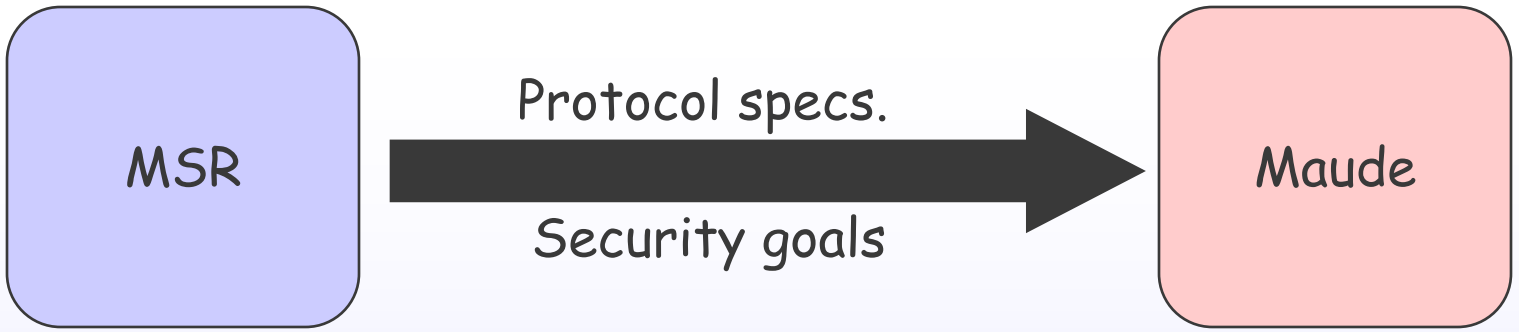


How it was maintained

What the client needed

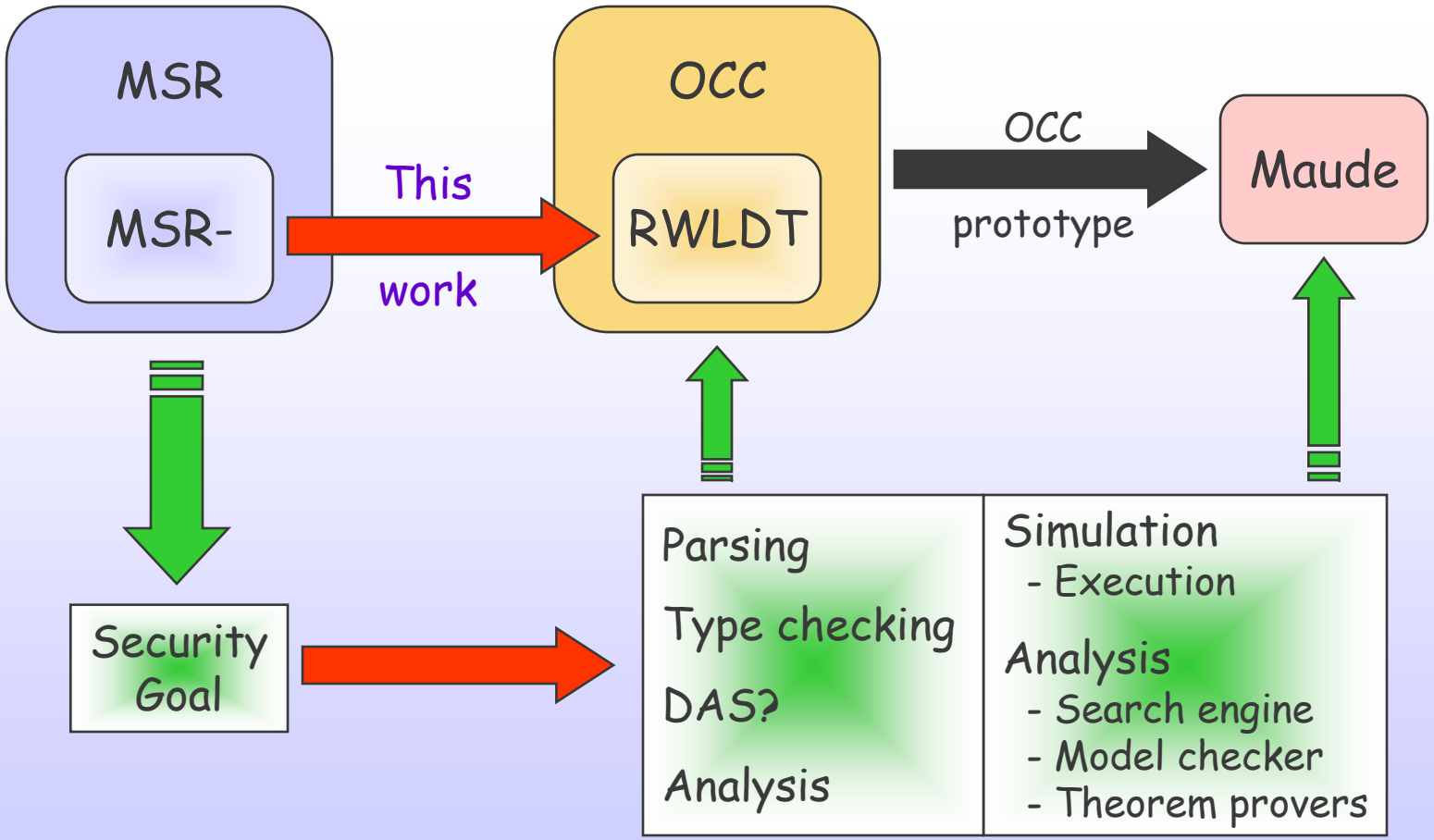
From http://muetze.net/links/fun/kundenprojekte-e.html

Big Picture



- **MSR**
  - Protocol specification language
  - Multiset rewriting
  - Dependent types
  - Existentials
- **Maude**
  - Flexible specification framework
  - Rewriting logic
  - Equational reasoning
  - Reflection

Implemented Architecture



Bestiary

- MSR-
  - MSR (2) with some restrictions
- RWLDT
  - Rewriting Logic with Dependent Types
  - Typed version of Maude
- OCC
  - Open Calculus of Constructions
  - Mark-Oliver's thesis (589 pages)
  - Prototype implemented in Maude

Advantages over MSR → Maude

- Separation of concerns
  - MSR -> RWLDT
    - Preserves terms and types
    - Maps operations
  - RWLDT: takes care of type checking
  - Maude: untyped execution
- Abstraction
  - MSR and RWLDT have similar types and terms
  - Emulate MSR execution in RWLDT
  - Shallow encoding
- Reasoning
  - Express verification tasks in OCC [future work]

MSR ➔ MSR-

Small changes to simplify encoding

- Work-arounds
  - Subtyping
    - Coercions

  } Emulated via pre-processing

- Omissions
  - Data Access Specification

  } Future work

- Additions
  - Equations

  } Beta version

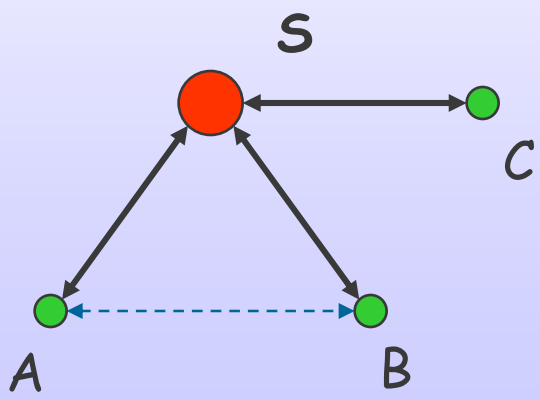
Supported Operations

- Parsing for MSR-
  - Minor limitations (currently worked on)
- Type reconstruction
  - Rule-level missing (currently worked on)
- Type checking
- Simulation
    - Indirect via *OCC* (currently worked on)
  - `search [n] (goal)`
  - `rew [n] (goal)`
  - `choose n`

Example: Otway-Rees Protocol

1. A -> B: $n\ A\ B\ \{n_A\ n\ A\ B\}_{KAS}$
2. B -> S: $n\ A\ B\ \{n_A\ n\ A\ B\}_{KAS}\ \{n_B\ n\ A\ B\}_{KBS}$
3. S -> B: $n\ \{n_A\ k_{AB}\}_{KAS}\ \{n_B\ k_{AB}\}_{KBS}$
4. B -> A: $n\ \{n_A\ k_{AB}\}_{KAS}$

- A, B, C, ... have keys to **S**
- A and B want to talk
- Use **S** to get common key
  - Key distribution
  - Authentication



MSR Spec.

1. A -> B: n A B $\{n_A\ n\ A\ B\}_{KAS}$
2. B -> S: n A B $\{n_A\ n\ A\ B\}_{KAS}$ $\{n_B\ n\ A\ B\}_{KBS}$
3. S -> B: n $\{n_A\ k_{AB}\}_{KAS}$ $\{n_B\ k_{AB}\}_{KBS}$
4. B -> A: n $\{n_A\ k_{AB}\}_{KAS}$

- Types
  - Subsorting

```
msg, princ, nonce: type.
shK, stK, ltK: princ -> princ -> type.
        princ, nonce, stK A B <: msg.
        stK A B, ltK A B <: shK A B.
```

- Constructors

```
_ _: msg -> msg -> msg.
{_}_ : msg -> shK A B -> msg.
S : princ.
```

- Predicates

```
N: msg -> state.
```

- Roles for
  - S
  - A, B

Next slide

- Principals and keys

```
...
```

B's Role

1. A -> B: n A B X
2. B -> S: n A B X $\{n_B\ n\ A\ B\}_{KBS}$
3. S -> B: n Y $\{n_B\ k_{AB}\}_{KBS}$
4. B -> A: n Y

$\forall$B:princ.

$\exists$L:ΠB:princ. nonce * nonce * ltK B **S** -> state.

$\forall$A:princ. $\forall$n:nonce. $\forall k_{BS}$:ltK B **S**. $\forall$X:msg.
N(n A B X) ➔ $\exists n_B$:nonce.
N(n A B X $\{n_b\ n\ A\ B\}k_{BS}$),
L(A, B, n, n_B, k_{BS})

$\forall$A:princ. $\forall$n, n_B:nonce. $\forall k_{BS}$:ltK B **S**.
$\forall$Y:msg. $\forall k_{AB}$:stK A B.
N (n Y $\{n_B\ k_{AB}\}_{kBS}$),
L(A, B, n, n_B, k_{BS}) ➔ N (n Y)

Main Features of MSR

- Open signatures
- Multiset rewriting
  - Msets of F.O. formulas
  - Rules
    - $\forall(\text{LHS} \rightarrow \exists \mathbf{n}{:}\tau.\ \text{RHS})$
    - Existentials
  - Roles
    - $\forall A.\ \exists \mathbf{L}{:}\tau.\ r$
- Types
  - Possibly dependent
  - Subsorting
  - Type reconstruction
- More
  - Constraints
  - Modules
  - Equations
- Static checks
  - Type checking
  - Data access spec.
- Execution

Black = implemented
Brown = work-around
Red = future work

Rewriting Logic with Dep. Types

- Combination of methodologies
  - Conditional rewriting modulo equations
    - $\forall x{:}S.\ A = B$ if C (generalizes equational logic)
    - $\forall x{:}S.\ A \Rightarrow B$ if C (generalizes rewriting logic)
  - Dependent type theory
    - $\lambda x{:}S.\ M : \Pi x{:}S\ T$ (generalizes simple types)

  Fragment of Open Calculus of Constructions
- Features
  - Open computation system
  - Proposition-as-types interpretation
    - $\forall x{:}S.\ P(x)$ interpreted as $\Pi x{:}S.\ P(x)$
      - Expressive higher-order logic
  - Model-theoretic semantics

Example: Commutative Monoid

```
state: Type.

empty: state.
union: state -> state -> state.

state_comm: || {s1,s2 : state}
   (union s1 s2) = (union s2 s1).
state_assoc: || {s1,s2,s3 : state}
   (union s1 (union s2 s3)) = (union s1 (union s2 s3)).
state_id: || {s : state}
   (union s empty) = s.
```

Structural equality

Π s:state. …

- This implements MSR's state

Encoding Strategy

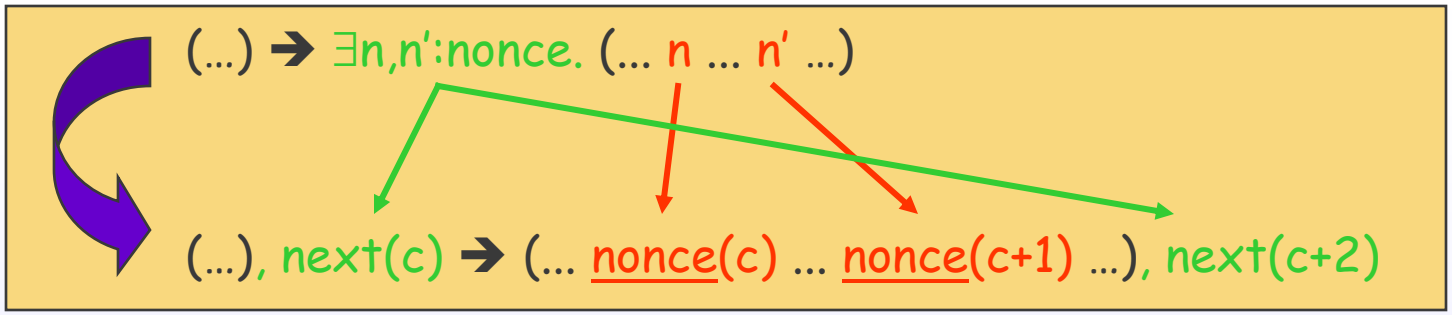
- Types and terms
  - Homomorphic mapping
    - Subsorting via coercions
- States
  - RWLDT terms
- Roles
  - Add 1 RWLDT rewrite axiom for role instantiation
  - Simulate ∃ using counters
- Rules
  - Mapped to RWLDT rewrite axioms
    - Simulate ∃ using counters

Optimizations [not implemented]

- Reduce non-determinism

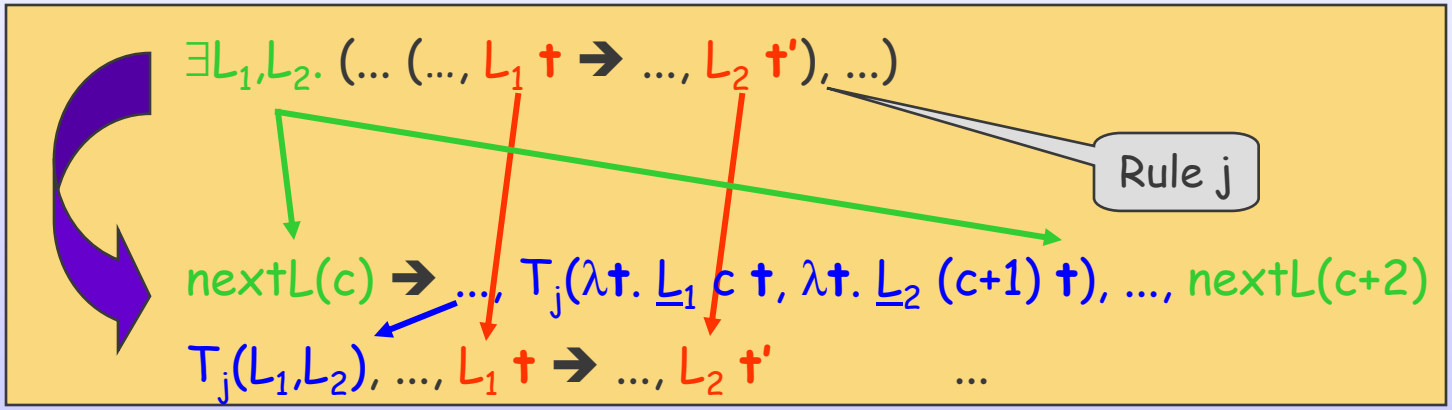
Representing Fresh Objects

- In rules



  - nonce : nat -> nonce is an injection

- In roles



  - Li : nat -> τi -> state are injections

(done using conditional rewriting)

Representing Roles

$\forall A{:}princ.\ \exists Ls.\ (lhs_1 \rightarrow rhs_1, \ldots, lhs_n \rightarrow rhs_n)$

$princ(A), nextL(c) \rightarrow T_1(A,Ls), \ldots, T_n(A,Ls), princ(A), nextL(c')$

$T_1(A,Ls), lhs_1 \rightarrow rhs_1$

...

$T_n(A,Ls), lhs_n \rightarrow rhs_n$

Enhancement

- Force rule application upon activation
  - $princ(A), nextL(c), lhs_i \rightarrow T_1(A,Ls), \ldots, rhs_i \ldots, T_n(A,Ls), princ(A), nextL(c')$
  - $T_i(A,Ls), lhs_i \rightarrow rhs_i$

Representing Rules

$\forall x{:}\tau.$ lhs ➔ rhs

$\underline{\tau}(x), \ldots, \ldots,$ lhs ➔ $\underline{\tau}(x), \ldots,$ rhs

- Handles x's occurring only in rhs
  - Allows encoding to untyped rewrite systems
  - Types τ must be finite and enumerated in state
- Enhancement
  - Limit to x's occurring only on rhs

Optimizations [not implemented]

- Use single counter
  - ∀A. ∃L. (lhs ➔ ∃n. rhs)
- Minimal control-flow analysis
  - Trace uses of L's
  - Do not generate unreachable rules
    - T's often duplicates L's

Substantial code reduction

- Could be further improved

Trivia

- Versions
  - Alpha (this)
    - Partial reconstruction
    - Non-integrated search (exit MSR; call OCC)
    - No equations
    - Not-so-pretty-printing
  - Beta (mid-October – already working, mostly)
- Space and Time
  - 3,700 lines of Maude (1,300 for testing)
  - 6 months designing, 3 months coding
- Examples
  - Otway-Rees
  - Needham-Schroeder PK
  - Kerberos (abstract, full, cross-realm – soon)
  - … more soon …

Wanna Play?

`http://formal.cs.uiuc.edu/stehr/msr.html`

`http://theory.stanford.edu/~iliano/MSR/`

- Download
  - Currently alpha-release
  - Soon beta-release
- Papers
- News

Future Work

- Short-term
  - Complete beta-released
  - Get degree (Stefan)
- Medium term – language
  - Library of protocols
  - Data Access Specification
  - MSR 3
    - Embedded rules and more
- Medium/long-term – Verification
  - Implement various methodologies
  - MSR as verification middleware

Demo Time!!!