ProveIt

How to make proving cryptographic protocols less tedious

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28.01.2012

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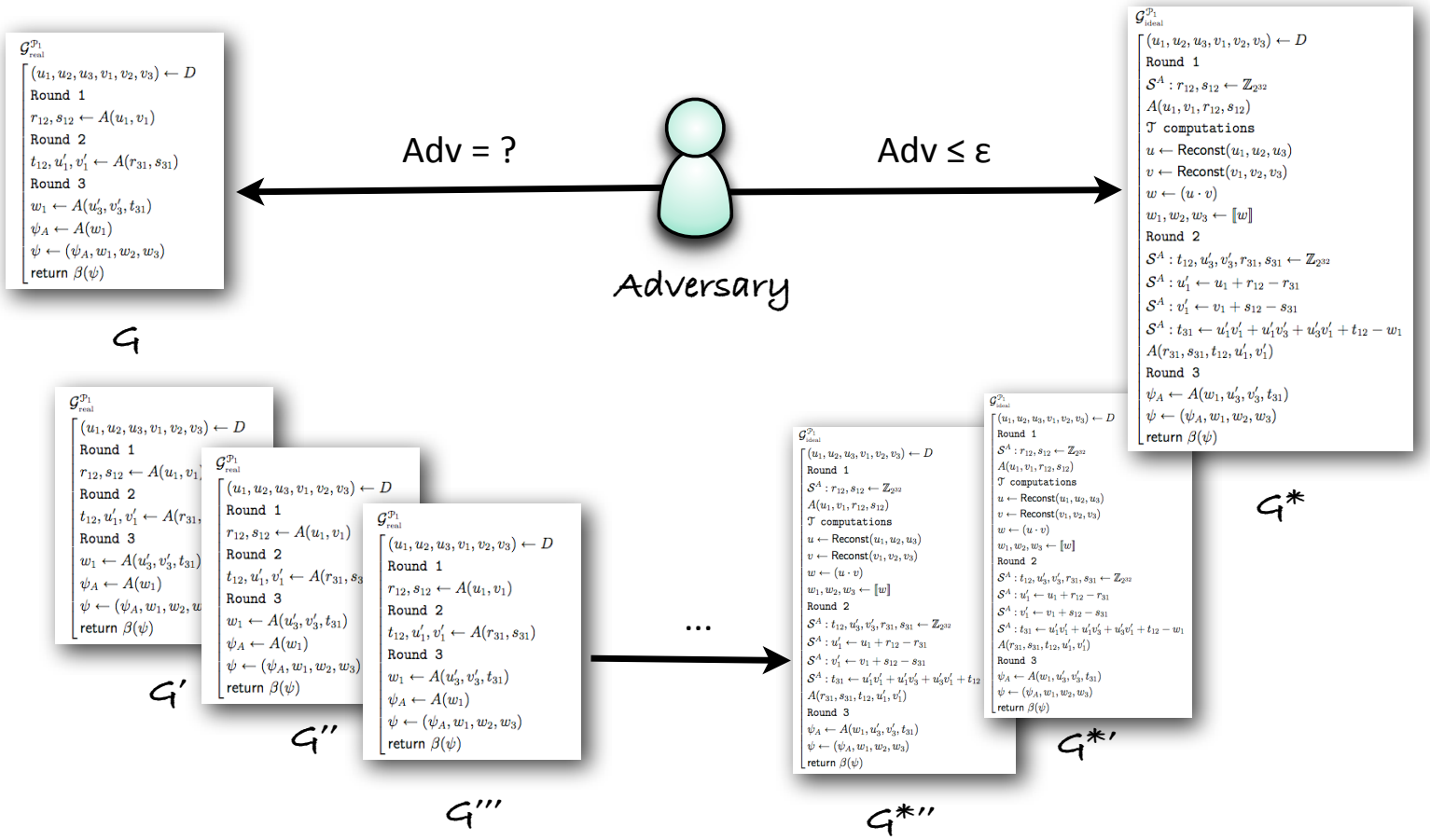
Overview

- Motivation
- Game-based protocol proofs
- ProveIt
- Who is it for?

Motivation

- Proving a security protocol using game rewriting is often
  - Error-prone
  - Time consuming

Game-Based Proofs



[Bellare, Rogaway 04], [Shoup 04]

Transformations

- Consider two games $\mathcal{G}$ and $\mathcal{H}$ with adversaries *A* and *B* and let $p_{\mathcal{G}}$ and $p_{\mathcal{H}}$ be the respective probabilities, that *A* wins $\mathcal{G}$ and *B* wins $\mathcal{H}$
- Transformation is **safe** if $p_{\mathcal{G}} \leq p_{\mathcal{H}}$
- Transformation is **conservative** if $p_{\mathcal{G}} = p_{\mathcal{H}}$
- Transformation is **lossy** if

$$p_{\mathcal{G}} \leq p_{\mathcal{H}} + \varepsilon \quad \text{or} \quad p_{\mathcal{G}} \leq c \cdot p_{\mathcal{H}}$$

for some particular $\varepsilon > 0$ or $c > 1$

Features of ProveIt

- Protocol entered in pseudocode
- Protocol parsed from text to abstract syntax tree
- Transformations:
  - FreeStep, User Defined Step
  - PRP/PRF Switching, Function Rename
  - Dead Code Elimination, Statement Switching

FreeStep, User Defined Step

- Preconditions: none
- Application rules: can be applied to any statement
- Difference between the games: user specified

PRP/PRF Switching

- Preconditions: the secret key used in the pseudorandom permutation *f* must not appear on the right side of other statements
- Application rules: can be applied to the function call of *f*
- Difference between the games?

PRP/PRF Switching Lemma

- Let $n \geq 1$ be an integer. Let A be an adversary that asks at most q oracle queries. Then

$$|\Pr[A^{\pi} \Rightarrow 1] - \Pr[A^{\rho} \Rightarrow 1]| \leq \frac{q(q-1)}{2^{n+1}}$$

- π - randomly sampled from the set of all permutations on $\{0,1\}^n$
- ρ - randomly sampled from the set of all functions from $\{0,1\}^n$ to $\{0,1\}^n$

PRP/PRF Switching

- Preconditions: the secret key used in the pseudorandom permutation *f* must not appear on the right side of other statements
- Application rules: can be applied to the function call of *f*
- Difference between the games:

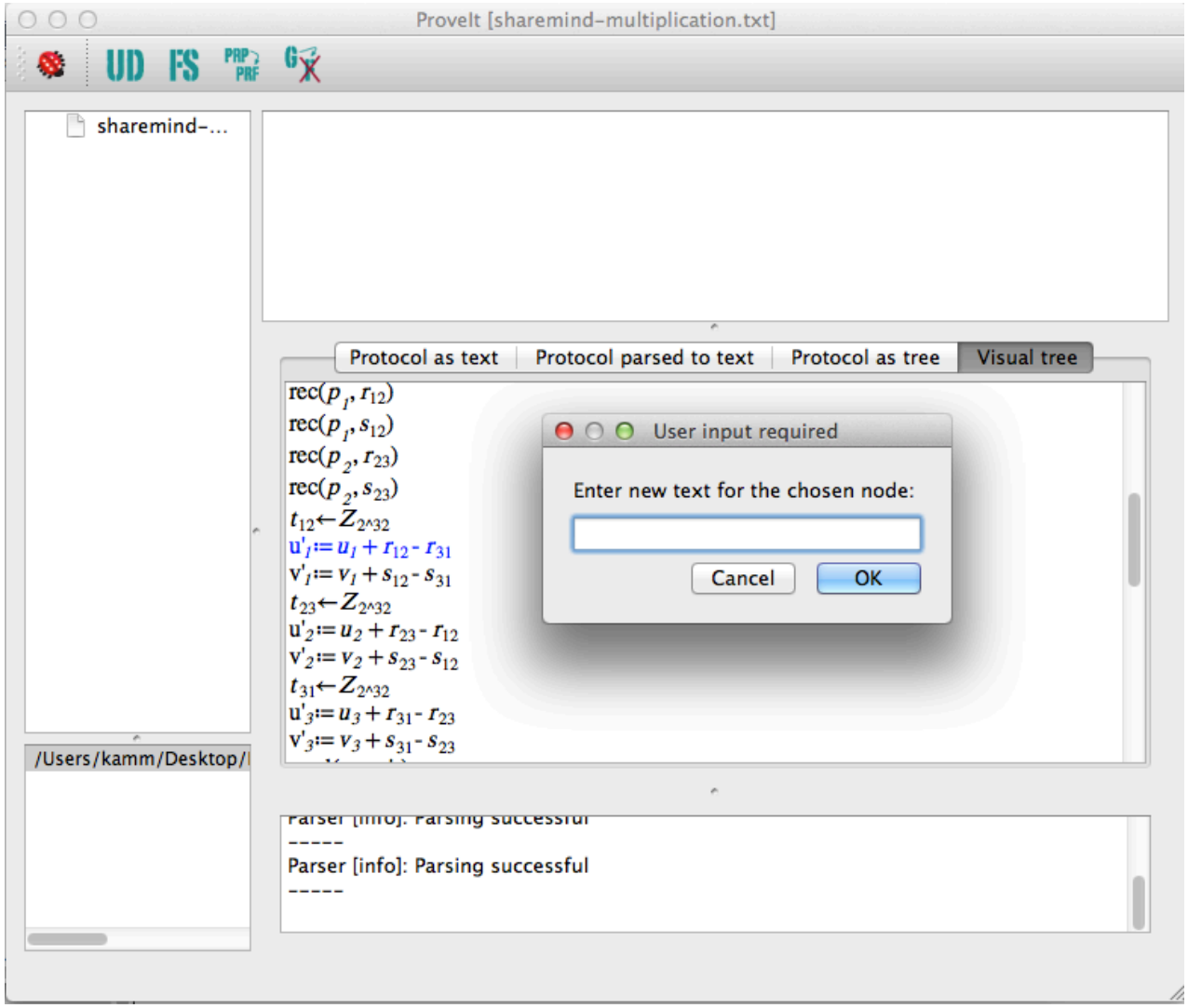
$$\mathsf{sd}(\mathcal{G}_0^A, \mathcal{G}_1^A) \leq \frac{q(q-1)}{2^{n+1}}$$

Protocols

Protocol as text | Protocol parsed to text | Protocol as tree | Visual tree

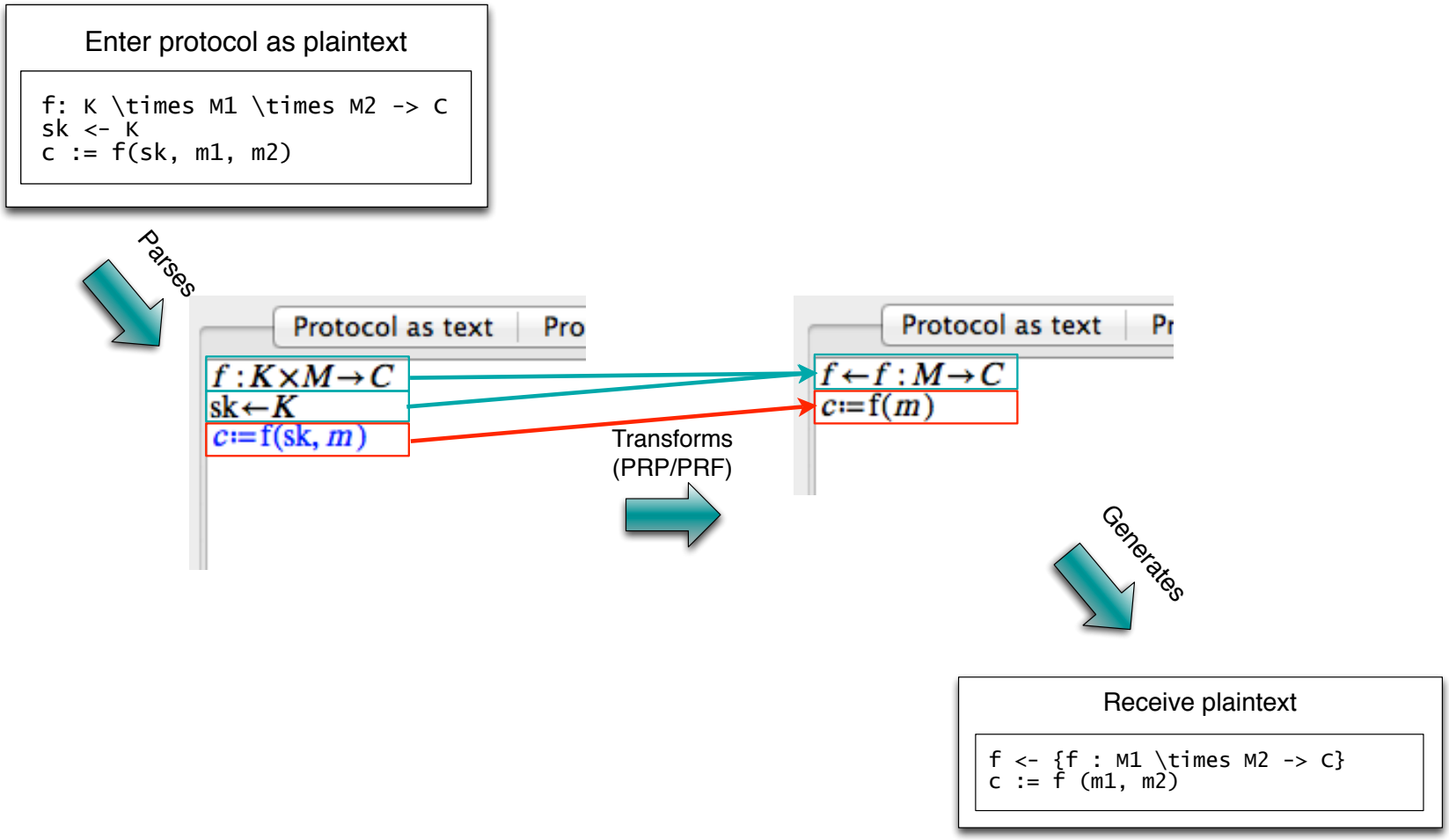
```
r_23 <- Z_2^32
s_23 <- Z_2^32
r_31 <- Z_2^32
s_31 <- Z_2^32
send(p_2, r_12)
send(p_2, s_12)
send(p_3, r_23)
send(p_3, s_23)
send(p_1, r_31)
send(p_1, s_31)

rec(p_3, r_31)
rec(p_3, s_31)
rec(p_1, r_12)
rec(p_1, s_12)
rec(p_2, r_23)
rec(p_2, s_23)
t_12<- Z_2^32
u'_1 := u_1 + r_12 - r_31
v'_1 := v_1 + s_12 - s_31
t_23 <- Z_2^32
u'_2 := u_2 + r_23 - r_12
v'_2 := v_2 + s_23 - s_12
t_31 <- Z_2^32
u'_3 := u_3 + r_31 - r_23
v'_3 := v_3 + s_31 - s_23
send(p_2, u'_1 )
send(p_2, v'_1)
send(p_2, t_12)
send(p_3, u'_2 )
send(p_3, v'_2)
```

Protocols


ProveIt [sharemind-multiplication.txt]
UD
FS
PRP
PRF
sharemind-...
Protocol as text
Protocol parsed to text
Protocol as tree
Visual tree
rec(p1, r12)
rec(p1, s12)
rec(p2, r23)
rec(p2, s23)
t12←Z2^32
u'1:= u1 + r12 - r31
v'1:= v1 + s12 - s31
t23←Z2^32
u'2:= u2 + r23 - r12
v'2:= v2 + s23 - s12
t31←Z2^32
u'3:= u3 + r31 - r23
v'3:= v3 + s31 - s23
User input required
Enter new text for the chosen node:
Cancel
OK
/Users/kamm/Desktop/
Parser [info]: Parsing successful

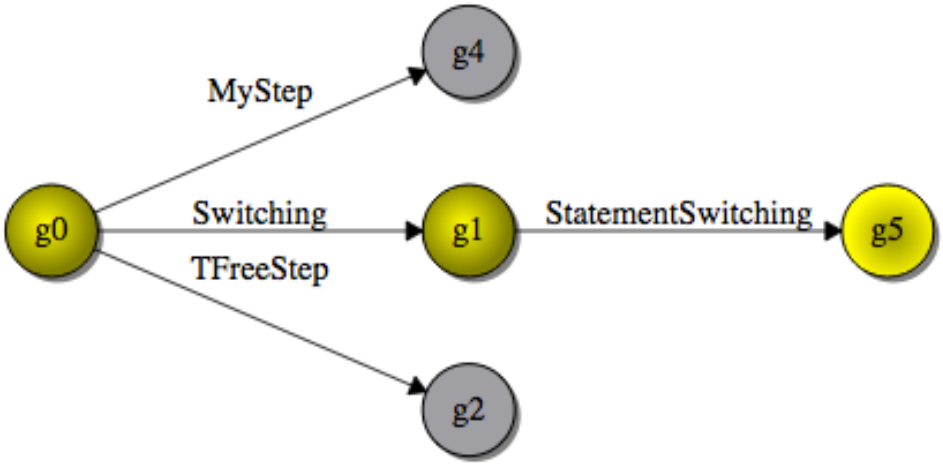
Parser [info]: Parsing successful

Workflow


Enter protocol as plaintext
f: K \times M1 \times M2 -> C
sk <- K
c := f(sk, m1, m2)
Parses
Protocol as text
Pro
$f : K \times M \to C$
$\mathrm{sk} \leftarrow K$
$c := \mathrm{f}(\mathrm{sk}, m)$
Transforms
(PRP/PRF)
Protocol as text
Pr
$f \leftarrow f : M \to C$
$c := \mathrm{f}(m)$
Generates
Receive plaintext
f <- {f : M1 \times M2 -> C}
c := f (m1, m2)

Game Trees


g0
Switching
g1
RFSimulation
g2
DeadDefinition
g3
StatementSwitching
g4


g4
MyStep
g0
Switching
g1
StatementSwitching
g5
TFreeStep
g2

Advantages

- Automatic game-rewriting
  - Reduces the number of rewriting errors
  - Makes the proving process faster
- Checks for rule usage
  - Is it possible to use a certain proof step for the selected statement?
  - What steps can I use for a selected statement?
- Helps researchers, students, teaching assistants

Ongoing Work

- Control flow analysis
- Type inference
- Protocol presentation
- More transformations
- Translation to EasyCrypt and CertiCrypt
- User feedback
  - Students
  - Researchers

Demo?