The Wolf Within

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Outline

WORK IN PROGRESS

I. MSR in brief
   - Data Access Specification
   - Dolev-Yao intruder

II. DAS → DY Intruder

III. Protocol Spec. → DAS

Part I

MSR

MSR

- Follows the Dolev-Yao abstraction
- Based on
  - Multiset rewriting, linear logic
  - Type theory
- Used to prove
  - Undecidability of protocol verification
  - Completeness of Dolev-Yao intruder
- Specifications
  - So many protocols … so little time …
- Related to CIL, strands, spi-calculus

What's in MSR 2.0 ?

- Multiset rewriting with existentials
- Dependent types w/ subsorting
- Memory predicates
- Constraints

New

New

New

Roles

Role state pred. var. declarations

- Generic roles

$$\forall A \left(\begin{array}{l} \exists L: \tau'_1(x_1) \times \ldots \times \tau'_n(x_n) \\ \ldots \\ \forall x{:}\tau. \quad lhs \quad \rightarrow \quad \exists y{:}\tau'. \quad rhs \\ \ldots \qquad\qquad \ldots \qquad\qquad \ldots \\ \forall x{:}\tau. \quad lhs \quad \rightarrow \quad \exists y{:}\tau'. \quad rhs \end{array} \right)$$

Role owner

- Anchored roles

$$A \left(\begin{array}{l} \exists L: \tau'_1(x_1) \times \ldots \times \tau'_n(x_n) \\ \ldots \\ \forall x{:}\tau. \quad lhs \quad \rightarrow \quad \exists y{:}\tau'. \quad rhs \\ \ldots \qquad\qquad \ldots \qquad\qquad \ldots \\ \forall x{:}\tau. \quad lhs \quad \rightarrow \quad \exists y{:}\tau'. \quad rhs \end{array} \right)$$

Rules

$\forall x_1 : \tau_1.$

...

$\forall x_n : \tau_n.$

lhs

- N(t) Network
- $\mathcal{L}$(t, …, t) Local state
- M_A(t, …, t) Memory
- χ Constraints

$\rightarrow$

$\exists y_1 : \tau'_1.$

...

$\exists y_{n'} : \tau'_{n'}.$

rhs

- N(t) Network
- $\mathcal{L}$(t, …, t) Local state
- M_A(t, …, t) Memory

NS Initiator

$A \rightarrow B: \{n_A, A\}_{kB}$

$B \rightarrow A: \{n_A, n_B\}_{kA}$

$A \rightarrow B: \{n_B\}_{kB}$

$\forall A$

$\exists L$: princ × princ$^{(B)}$ × pubK B × nonce.

$\forall B$: princ
$\forall k_B$: pubK B

•

$\rightarrow$

$\exists n_A$:nonce.

$L(A,B,k_B,n_A)$
$N(\{n_A,A\}_{kB})$

$\forall$ ...
$\forall k_A$: pubK A
$\forall k'_A$: privK k_A
$\forall n_A, n_B$: nonce

$L(A,B,k_B,n_A)$
$N(\{n_A,n_B\}_{kA})$

$\rightarrow$

$N(\{n_B\}_{kB})$

NS Responder

$A \rightarrow B: \{n_A, A\}_{kB}$

$B \rightarrow A: \{n_A, n_B\}_{kA}$

$A \rightarrow B: \{n_B\}_{kB}$

$\forall B$

$\exists L$: princ$^{(B)}$ x pubK B$^{(kB)}$ x privK k_B x nonce.

$\forall k_B$: pubK B
$\forall k'_B$: privK k_B
$\forall A$: princ
$\forall n_A$: nonce
$\forall k_A$: pubK A

$N(\{n_A, A\}_{kB}) \rightarrow \exists n_B$:nonce. $L(B, k_B, k'_B, n_B)$, $N(\{n_A, n_B\}_{kA})$

$\forall$ ...
$\forall n_B$: nonce

$L(B, k_B, k'_B, n_B)$, $N(\{n_B\}_{kB}) \rightarrow$ •

Type Checking

$\Sigma \vdash P$

$\Gamma \vdash t : \tau$

t has type τ in Γ

P is well-typed in Σ

- Catches:
  - Encryption with a nonce
  - Transmission of a long term key
  - Circular key hierarchies, …

Data Access Specification

New

$\Sigma \Vdash P$

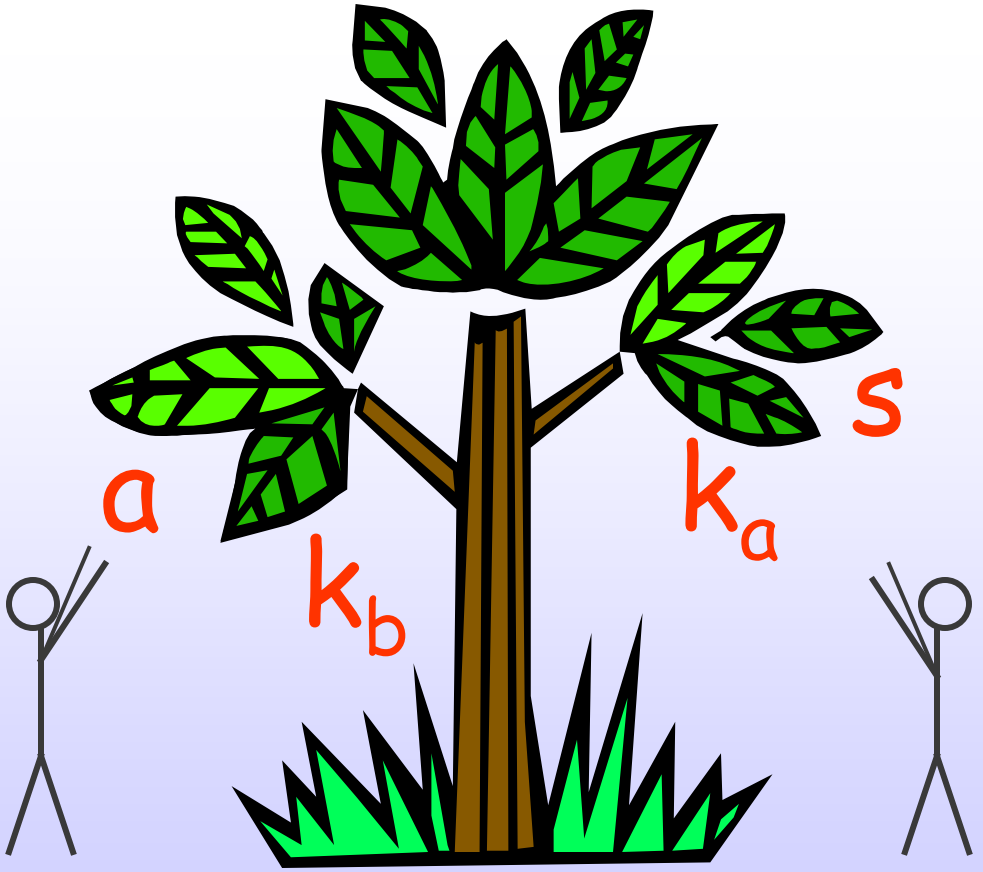
P is DAS-valid in Σ

r is DAS-valid for A in Γ

$\Gamma \Vdash_A r$

- Catches
  - A signing/encrypting with B's key
  - A accessing B's private data, …
- Static
- Decidable
- Gives meaning to Dolev-Yao intruder

... pictorially



An Overview of DAS

- Interpret incoming information
  - Collect received data
  - Access unknown data
- Construct outgoing information
  - Generate data
  - Use known data
  - Access new data

… all along, verify access to data

Verifying a Rule

Knowledge set:

Collects what A knows

Context

$$\frac{\Gamma \Vdash_A lhs \gg \Delta \qquad \Gamma; \Delta \Vdash_A rhs}{\Gamma \Vdash_A lhs \rightarrow rhs}$$

Role owner

Processing Predicates on the LHS

- Network messages

$$\frac{\Gamma ; \Delta \Vdash_A t \gg \Delta'}{\Gamma ; \Delta \Vdash_A N(t) \gg \Delta'}$$

- Memory predicates

$$\frac{\Gamma ; \Delta \Vdash_A t_1,\ldots,t_n \gg \Delta'}{\Gamma ; \Delta \Vdash_A M_A(t_1,\ldots,t_n) \gg \Delta'}$$

Interpreting Data on the LHS

- Pairs

$$\frac{\Gamma;\ \Delta \Vdash_A t_1,\ t_2 \gg \Delta'}{\Gamma;\ \Delta \Vdash_A (t_1,\ t_2) \gg \Delta'}$$

- Encrypted terms

$$\frac{\Gamma;\ \Delta \Vdash_A k \gg \Delta' \qquad \Gamma;\ \Delta' \Vdash_A t \gg \Delta''}{\Gamma;\ \Delta \Vdash_A \{t\}_k \gg \Delta''}$$

- Elementary terms

$$\left\{ \begin{array}{l} \dfrac{}{\Gamma;\ (\Delta,x) \Vdash_A x \gg (\Delta,x)} \\[2ex] \dfrac{}{(\Gamma,x{:}\tau);\ \Delta \Vdash_A x \gg (\Delta,x)} \end{array} \right.$$

Accessing Data on the LHS

- Shared keys

$$\frac{}{\Gamma;\ (\Delta,k) \Vdash_A k \gg (\Delta,k)} \qquad \frac{}{(\Gamma,x{:}\mathit{shK}\ A\ B);\ \Delta \Vdash_A x \gg (\Delta,x)}$$

- Public keys

$$\frac{}{(\Gamma,k{:}\mathit{pubK}\ A,k'{:}\mathit{privK}\ k);\ (\Delta,k') \Vdash_A k \gg (\Delta,k')} \qquad \frac{}{(\Gamma,k{:}\mathit{pubK}\ A,k'{:}\mathit{privK}\ k);\ \Delta \Vdash_A k \gg (\Delta,k')}$$

Generating Data on the RHS

- Nonces

$$\frac{(\Gamma, x{:}\mathsf{nonce});\ (\Delta, x) \Vdash_A \mathsf{rhs}}{\Gamma;\ \Delta \Vdash_A \exists x{:}\mathsf{nonce}.\ \mathsf{rhs}}$$

Constructing Terms on the RHS

- Pairs

$$\frac{\Gamma; \Delta \Vdash_A t_1 \qquad \Gamma; \Delta \Vdash_A t_2}{\Gamma; \Delta \Vdash_A (t_1, t_2)}$$

- Shared-key encryptions

$$\frac{\Gamma; \Delta \Vdash_A t \qquad \Gamma; \Delta \Vdash_A k}{\Gamma; \Delta \Vdash_A \{t\}_k}$$

Accessing Data on the RHS

- Principal

$$\frac{}{\Gamma, B{:}princ \Vdash_A B}$$

- Shared key

$$\frac{}{\Gamma, B{:}princ, k{:}shK\ A\ B \Vdash_A k}$$

- Public key

$$\frac{}{\Gamma, B{:}princ, k{:}pubK\ B \Vdash_A k}$$

- Private key

$$\frac{}{\Gamma, k{:}pubK\ A, k'{:}privK\ k \Vdash_A k'}$$

Part II

Data Access Specification

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Dolev-Yao Intruder

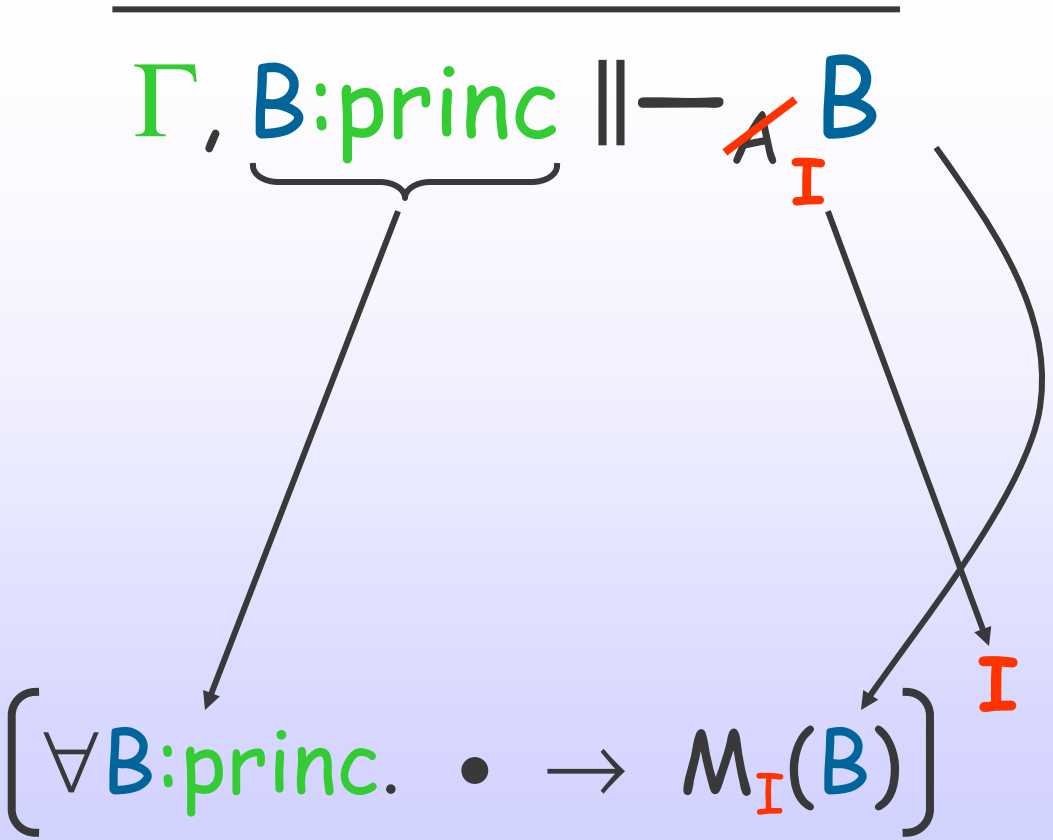
The Dolev-Yao Intruder Model

- Interpret incoming information
  - Collect received data
  - Access unknown data
- Construct outgoing information
  - Generate data
  - Use known data
  - Access new data
- Same operations as DAS!

DAS ⇒ DY

- Interpret messages on LHS
- Access data (keys) on LHS
- Generate data on RHS
- Construct messages on RHS
- Access data on RHS

Accessing Principal Names

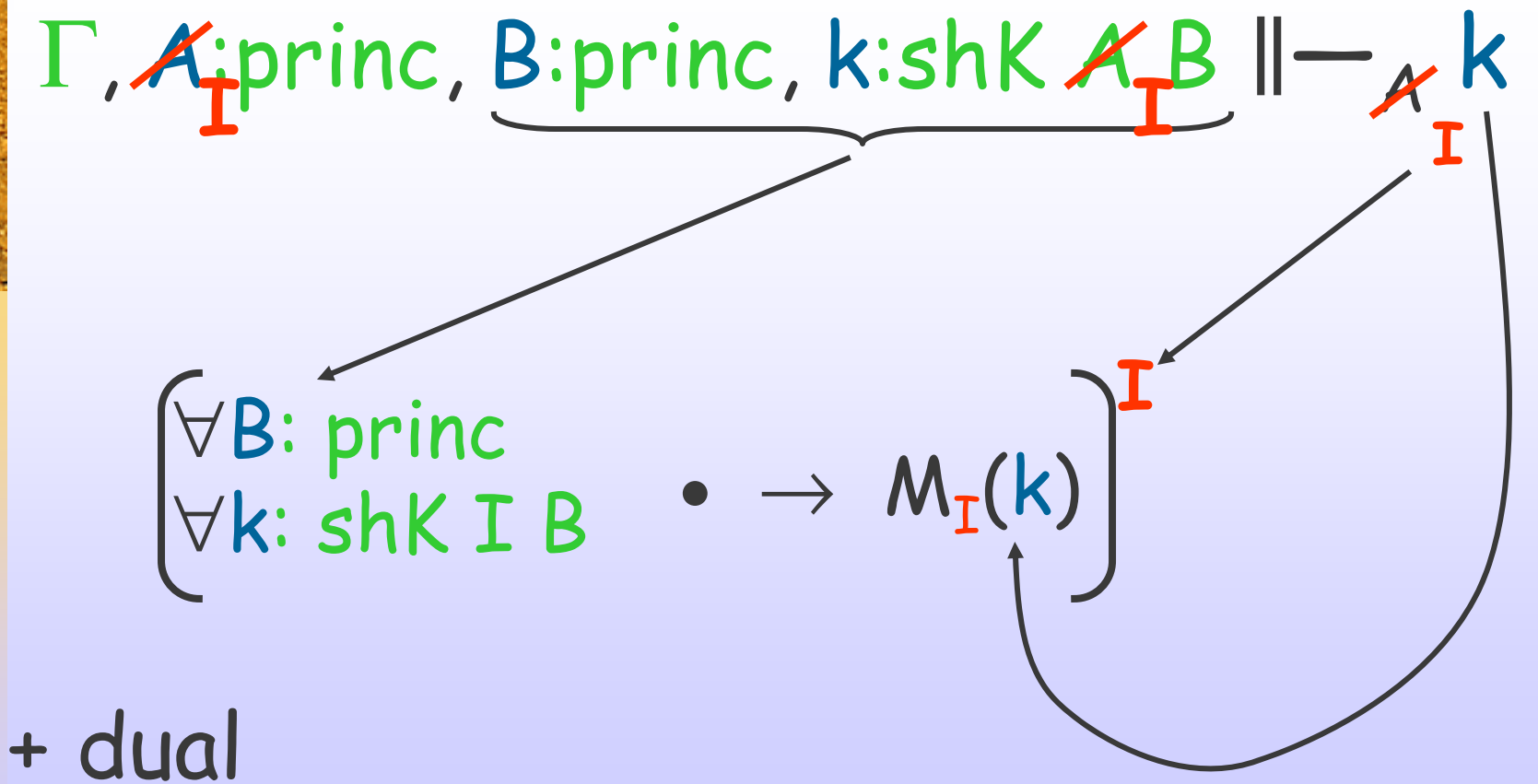


What did we do?

RHS data access:

- Instantiate acting principal to **I**
- Accessed data → Intruder knowledge
- Meta-variables → Rule variables
- Context provides types

Checking it out: Shared Keys



+ dual

Getting Confident: Pub./Priv. Keys

$$\frac{\Gamma, B{:}\mathrm{princ}, k{:}\mathrm{pubK}\ B \Vdash_{\cancel{A}\,I} k \qquad \left[\begin{array}{l}\forall B{:}\ \mathrm{princ} \\ \forall k{:}\ \mathrm{pubK}\ B\end{array} \bullet \rightarrow M_I(k)\right]^I}{}$$

$$\frac{\Gamma, \underset{I}{\cancel{A}}{:}\mathrm{princ}, k{:}\mathrm{pubK}\ \underset{I}{\cancel{A}}, k'{:}\mathrm{privK}\ k \Vdash_{\cancel{A}\,I} k' \qquad \left[\begin{array}{l}\forall k{:}\ \mathrm{pubK}\ I \\ \forall k'{:}\ \mathrm{privK}\ k\end{array} \bullet \rightarrow M_I(k')\right]^I}{}$$

DAS ⇒ DY

- Interpret messages on LHS
- Access data (keys) on LHS
- Generate data on RHS
- Construct messages on RHS
- Access data on RHS

Constructing Messages: Pairs

$$\frac{\Gamma; \Delta \Vdash_I t_1 \qquad \Gamma; \Delta \Vdash_I t_2}{\Gamma; \Delta \Vdash_I (t_1, t_2)}$$

$$\left[\forall t_1, t_2 : msg.\ M_I(t_1), M_I(t_2) \rightarrow M_I((t_1, t_2))\right]^I$$

$$\frac{\Gamma \vdash t_1 : msg \qquad \Gamma \vdash t_2 : msg}{\Gamma \vdash (t_1, t_2) : msg}$$

Now, what did we do?

RHS message construction:

- Instantiate acting principal to **I**
- Meta-variables → Rule variables
- Premises → antecedent
- Conclusion → consequent
- Types from auxiliary typing derivation

Carrying on: Shared-Key Encrypt.

$$\frac{\Gamma; \Delta \Vdash_I t \qquad \Gamma; \Delta \Vdash_I k}{\Gamma; \Delta \Vdash_I \{t\}_k}$$

$$\left[\begin{array}{l} \forall A,B: \text{princ} \\ \forall k: \text{shK } A\ B \quad M_I(t), M_I(k) \rightarrow M_I(\{t\}_k) \\ \forall t: \text{msg} \end{array}\right]^I$$

Similar for public-key encryption

DAS ⇒ DY

- Interpret messages on LHS
- Access data (keys) on LHS
- Generate data on RHS
- Construct messages on RHS
- Access data on RHS

Generating Nonces

$$\frac{(\Gamma, x{:}\mathsf{nonce});\ (\Delta, x) \Vdash_I \mathsf{rhs}}{\Gamma;\ \Delta \Vdash_I \exists x{:}\mathsf{nonce}.\ \mathsf{rhs}}$$

$$\left[\ \bullet \rightarrow \exists x{:}\mathsf{nonce}.\ M_I(x)\ \right]^I$$

Similarly for other generated data

Now, what did we do?

Data generation on the RHS:

- Instantiate acting principal to **I**
- Auxiliary typing derivation gives types
- Remember generated object
- Follow knowledge acquisition flow

DAS ⇒ DY

- Interpret messages on LHS
- Access data (keys) on LHS
- Generate data on RHS
- Construct messages on RHS
- Access data on RHS

Accessing Shared Keys on the LHS

$$\frac{}{(\Gamma,\ k{:}shK\ I\ B);\ \Delta \Vdash_I k \gg (\Delta, k)}$$

$$\left(\begin{array}{l}\forall B{:}\ princ \\ \forall k{:}\ shK\ I\ B\end{array}\ \bullet \rightarrow M_I(k)\right)^I$$

Similarly for other keys

Now, what did we do?

LHS data access:

- Instantiate acting principal to **I**
- Meta-variables → Rule variables
- Types from auxiliary typing derivation
- Follow knowledge acquisition flow
- Remember generated object

Same target rules as for RHS data access

DAS ⇒ DY

- Interpret messages on LHS
- Access data (keys) on LHS
- Generate data on RHS
- Construct messages on RHS
- Access data on RHS

Interpreting Shared-Key Encrypt.

$$\frac{\Gamma;\ \Delta \Vdash_I k \gg\!> \Delta' \qquad \Gamma;\ \Delta' \Vdash_I t \gg\!> \Delta''}{\Gamma;\ \Delta \Vdash_I \{t\}_k \gg\!> \Delta''}$$

$$\left[\begin{array}{l}\forall A,B\text{: princ}\\ \forall k\text{: shK } A\ B\\ \forall t\text{: msg}\end{array}\quad M_I(\{t\}_k),\ M_I(k) \rightarrow M_I(t)\right]^I$$

Similar for public-key encryption and pairing

Now, what did we do?

LHS message interpretation

- Instantiate acting principal to **I**
- Meta-variables → Rule variables
- Types from auxiliary typing derivation
- Follow knowledge acquisition flow

- Conclusion → antecedant
- "Last" premises → consequent

Network Rules

$$\frac{\Gamma\ ;\ \Delta \Vdash_A t \gg \Delta'}{\Gamma;\ \Delta \Vdash_A N(t) \gg \Delta'}$$

LHS

$$\left[\forall t{:}msg.\ N(t) \rightarrow\ M_I(t)\right]^I$$

RHS

$$\frac{\Gamma\ ;\ \Delta \Vdash_A t}{\Gamma;\ \Delta \Vdash_A N(t)}$$

$$\left[\forall t{:}msg.\ M_I(t) \rightarrow\ N(t)\right]^I$$

... Other Rules?

Either

- redundant, or

$$\left[\forall t{:}msg.\ N(t) \rightarrow\ N(t)\right]^{I}$$

- or, innocuous (but sensible)

$$\left[\forall t_1,\ldots,t_n :msg.\ M'_I(t_1,\ldots,t_n) \rightarrow\ M_I(t_1),\ldots,M_I(t_n)\right]^{I}$$

Part III

Protocol Spec.

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Data Access Spec. Rules

Automating DAS Rule Design?

- One size does not fit all
- Look at protocol
  - Typed MSR spec.
  - Usage of constructs
- Involve construct declarations
  - Not sufficient
  - Use annotations

Generating DAS rules from use

Constructors atoms

- Interpret message components on LHS
- Access data (keys) on LHS
- Generate data on RHS
- Construct messages on RHS
- Access data on RHS

Accessing data

- Annotate the type of freely accessible data

anybody can access

```
princ: +type
```

- Make it conditional for dep. types

```
pubK: *princ -> +type
```

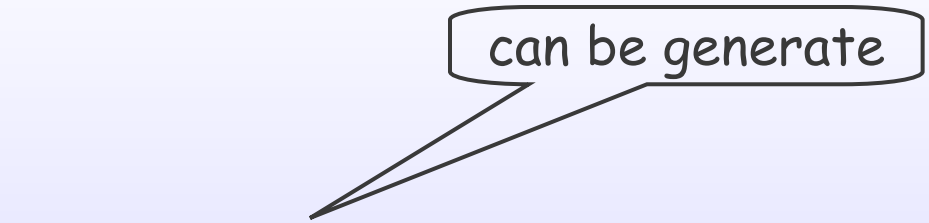
doesn't matter

```
privK: ΠA:+princ. +pubK A -> +type
```

owner

Generating data

- Again, annotate types




```
nonce: !type

shK: +princ -> +princ -> !type

shK: +princ -> +princ -> !type
```

Pattern-matching constructors

- Mark *arguments* as input or output

output

input

```
_,_: -msg -> -msg -> msg

{_}_: -msg -> ΠA:+princ. ΠB:+princ.+shK A B -> msg

{{_}}_: -msg -> ΠA:+princ. Πk:+pubK A.+privK k -> msg

hash: +msg -> msg

[_]_: +msg -> ΠA:*princ. Πk:*sigK A.*verK k -> msg
```

+ or -

Annotating Declarations

- Integrates semantics of types and constructors
- "Trimmed down" version of DAS
- Allows constructing DAS rules
  - … and Dolev-Yao intruder

... alternatively

Compute DAS rules from protocol

- There are finitely many annotations
- Check protocol against each of them
- Keep the most restrictive ones that validate the protocol

Exponential!

More efficient algorithms?

Further Questions ...

- Relationship to "intruder-less" languages
  - E.g. Spi-calculus