VERIFYING PRIVACY-TYPE PROPERTIES IN A MODULAR WAY

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CONTEXT

To verify security properties on protocols,
we model protocols in isolation

Protocols are never alone

Possible problems:

- Protocols may share same keys
- Protocols may share same cryptographic primitives
- Tools may not be able to prove the security property

CONTEXT

Our goal

Verifying **S** on **P** and Verifying **S** on **Q**

↓

Verifying **S** on **P** and **Q** running in parallel

where

- **P** and **Q** may share secrets and cryptographic primitives
- **S** is a security property

CONTEXT

Security properties

CONTEXT

Security properties

Reachability properties

- Secrecy, Authentication, ...

CONTEXT

Security properties

Reachability properties

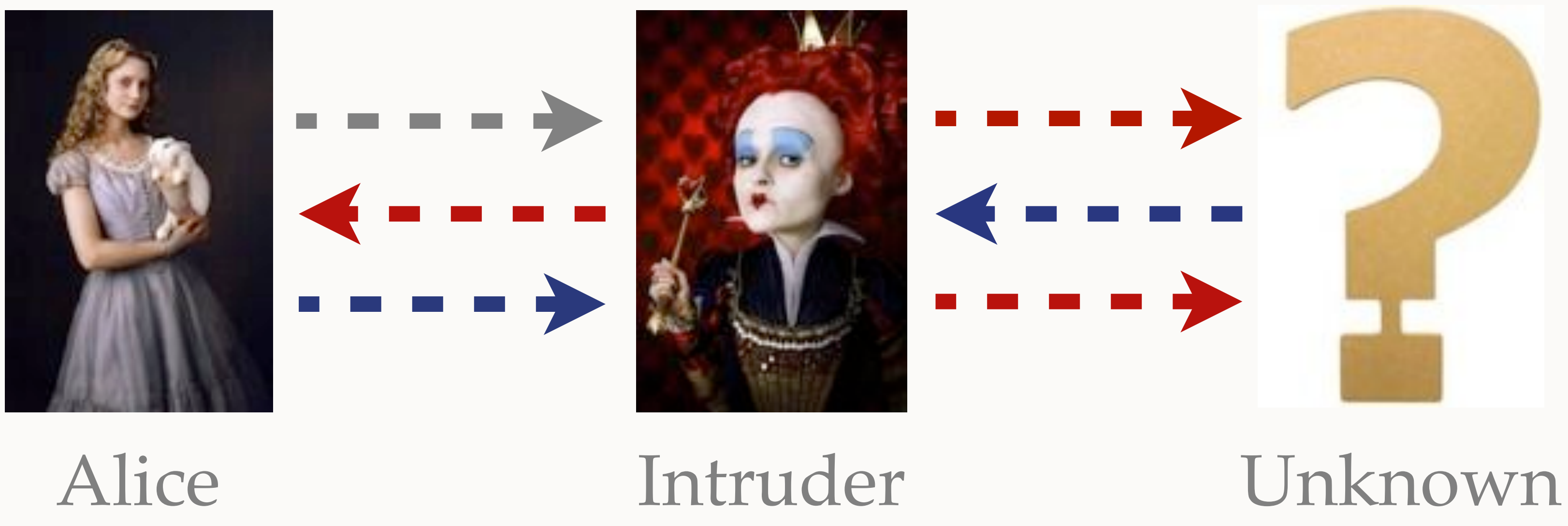
- Secrecy, Authentication, ...

Equivalence properties

- Anonymity, Privacy, Receipt-Freeness, ...

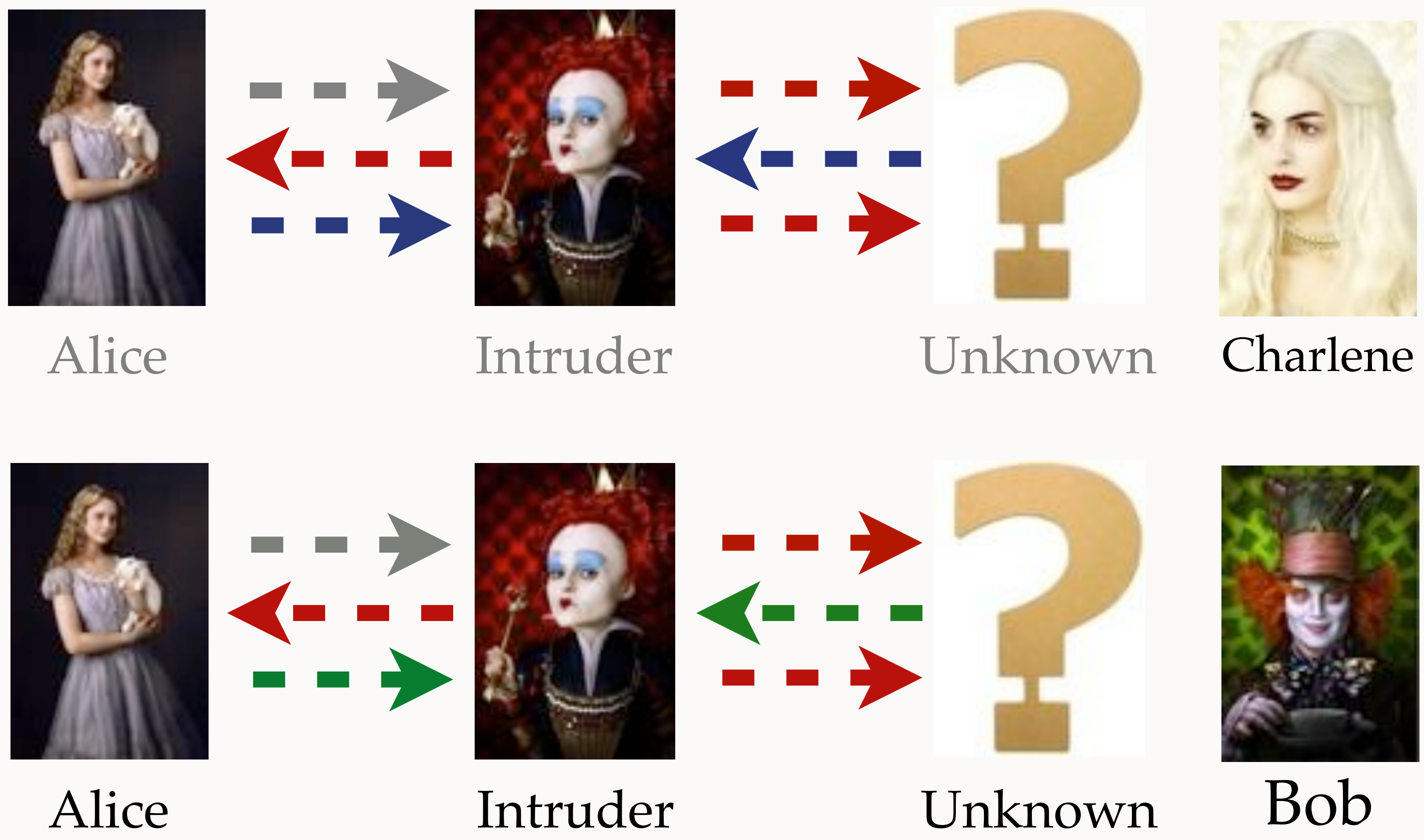
CONTEXT

Example of equivalence property : anonymity



CONTEXT

Example of equivalence property : anonymity



Can the intruder distinguish the two situations ?

PREVIOUS WORKS

- On reachability properties
  - J.D. Guttman and F.J. Thayer. *Protocol independence through disjoint encryption.*
  - S. Ciobâca and V. Cortier. *Protocol composition for arbitrary primitives.*
  - S. Andova, C. Cremers, K. Gosteen, S. Mauw. S. M. Isnes and S. Radomirovic. *A framework for compositional verification of security protocols.*

- On equivalence properties : Tagged protocol
  - S. Delaune, S. Kremer and M.D. Ryan. *Composition of password-based protocols.*
  - C. Chevalier, S. Delaune and S. Kremer. *Transforming password protocols to compose.*

MOTIVATION

Privacy-type properties: Anonymity and unlinkability

Concrete example: e-passport protocols

- Basic Access Control (BAC) : establishes sessions keys between reader and a passport
- Passive Authentication (PA)
- Active Authentication (AA)

Passive Authentication and Active Authentication are executed in parallel

FORMALISM

Composition context for anonymity

$$P: \quad A \to S : \{id_A\}^r_{\mathsf{pk}(k_S)}$$

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Composition context for anonymity

$$P: \quad A \rightarrow S : \{id_A\}^r_{\mathsf{pk}(k_S)}$$

Definition from : M. Arapinis, T. Chothia and M. Ryan. *Analysing unlinkability and anonymity using the applied pi calculus.*

FORMALISM

Composition context for anonymity

$$P: \quad A \rightarrow S : \{id_A\}^r_{\mathsf{pk}(k_S)}$$

$$C'[\_] \stackrel{\mathsf{def}}{=} \texttt{new}\ k_S.\ !\texttt{new}\ id_A.\ !\_$$

$$C[\_1, \_2] \stackrel{\mathsf{def}}{=} \texttt{new}\ k_S.((!\texttt{new}\ id_A.\ !\_1)\ |!\_2)$$

$$C[P, P\{^{id_O}/_{id_A}\}] \approx C'[P]$$

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$$C[P, P\{^{id_O}/_{id_A}\}] \approx C'[P]$$

$$C[Q, Q\{^{id_O}/_{id_A}\}] \approx C'[Q]$$

$$C[Q \mid P, (Q \mid P)\{^{id_O}/_{id_A}\}] \approx C'[Q \mid P]$$

Definition from : M. Arapinis, T. Chothia and M. Ryan. *Analysing unlinkability and anonymity using the applied pi calculus.*

CONDITIONS

No shared key revealed

$$P: \quad A \rightarrow S : \{id_A\}^r_{\mathsf{pk}(k_S)}$$
$$Q: \quad S \rightarrow A : k_S$$

P preserves the anonymity of A
Q preserves the anonymity of A

$P \mid Q$ does not preserve the anonymity of A

CONDITIONS

Tag shared cryptographic primitives

$$P: \quad A \to S : \{id_A\}^r_{\mathsf{pk}(k_S)}$$

$$Q: \quad A \to S : \{N_a\}^r_{\mathsf{pk}(k_S)}$$
$$S \to A : N_a$$

P preserves the anonymity of A
Q preserves the anonymity of A

$P \mid Q$ does not preserve the anonymity of A

CONDITIONS

Public key revealed at the beginning

$$P_i : \quad A \rightarrow S : \{\mathsf{tag}_a(id_i)\}_{\mathsf{pk}(k_S)}$$

$$Q : \quad S \rightarrow A : \mathsf{pk}(k_S)$$

$$C[\_] \overset{\mathsf{def}}{=} \mathtt{new}\ k_S.\ \_$$

CONDITIONS

Public key revealed at the beginning

$$P_i : \quad A \rightarrow S : \{\mathsf{tag}_a(id_i)\}_{\mathsf{pk}(k_S)}$$

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$$C[\_] \stackrel{\mathsf{def}}{=} \mathtt{new}\ k_S.\ \_$$

$$C[P_1] \approx C[P_2] \quad \text{and} \quad C[Q] \approx C[Q]$$

But $C[P_1 \mid Q] \not\approx C[P_2 \mid Q]$

MAIN THEOREM

$$\frac{C[P_A] \approx C'[P'_A] \qquad C[P_B] \approx C'[P'_B]}{C[P_A \mid P_B] \approx C'[P'_A \mid P'_B]}$$

If :

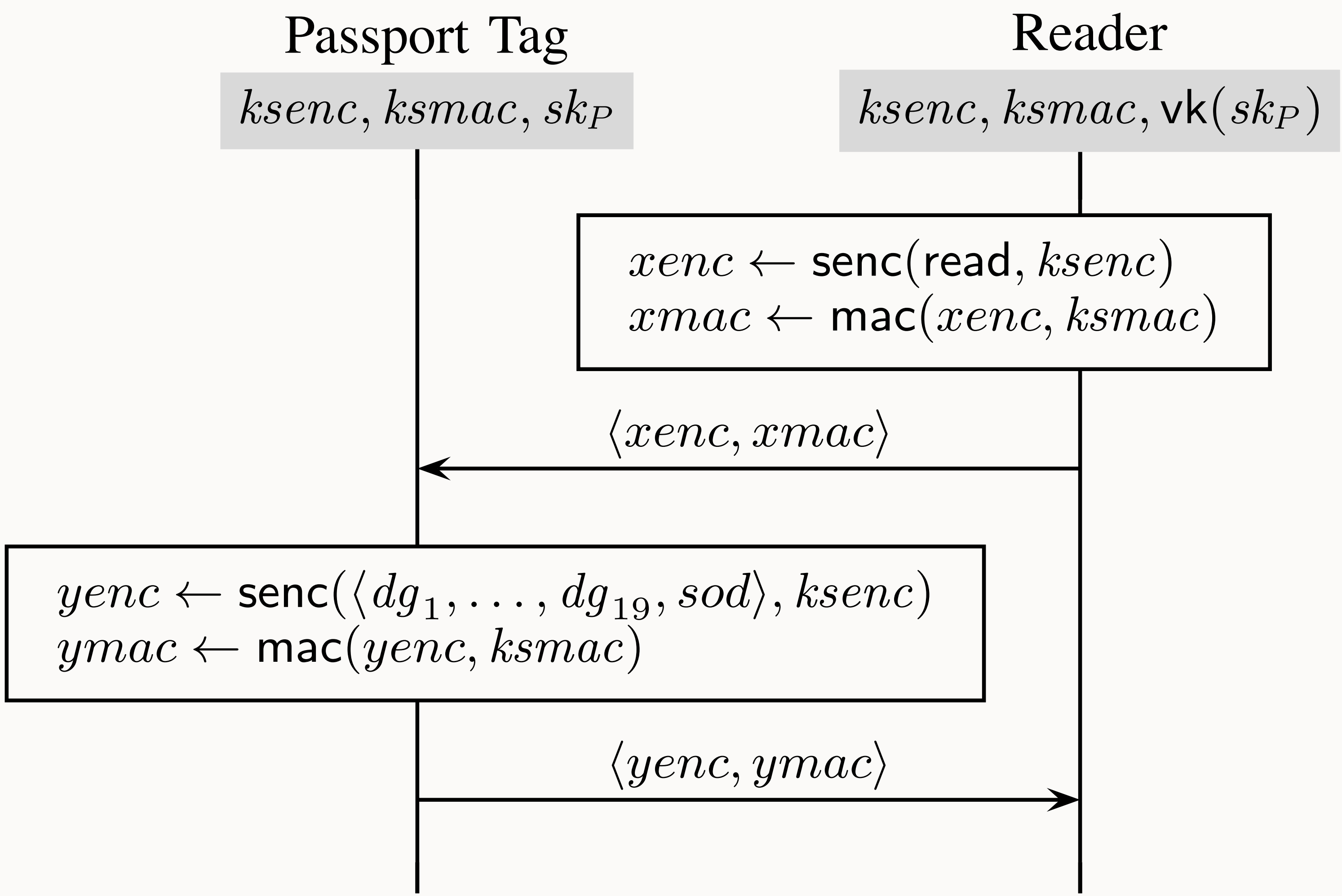
-The shared keys of C and C′ are not revealed

-The public keys are revealed at the beginning

-The protocols A and B are tagged

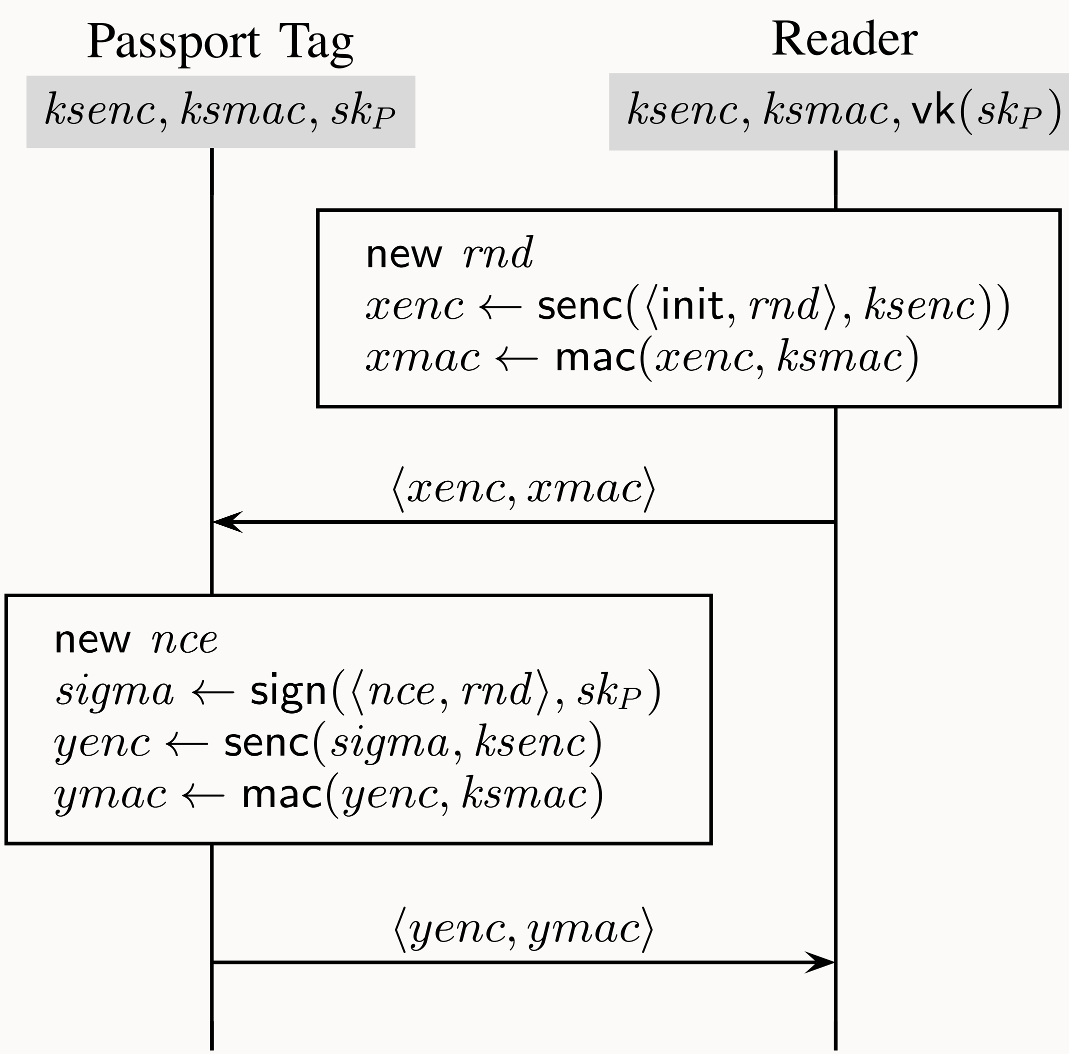
E-PASSPORT

Passive Authentication (PA)



E-PASSPORT

Active Authentication (AA)



E-PASSPORT

Result

With ProVerif,

- we prove anonymity for AA
- we can not prove anonymity for PA
- we can not prove anonymity for $PA \mid AA$

E-PASSPORT

Result

With ProVerif,

- we prove anonymity for *AA*
- we can not prove anonymity for *PA*
- we can not prove anonymity for *PA* | *AA*

> proving anonymity for *PA*
>
> implies
>
> proving anonymity for *PA* | *AA*

SKETCH OF PROOF

$C[P_A] \approx C'[P'_A]$ and $C[P_B] \approx C'[P'_B]$

SKETCH OF PROOF

$$C[P_A] \approx C'[P'_A] \quad \text{and} \quad C[P_B] \approx C'[P'_B]$$

$$\Downarrow$$

$$C[P_A] \mid C[P_B] \approx C'[P'_A] \mid C'[P'_B]$$

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SKETCH OF PROOF

$$C[P_A] \mid C[P_B] \approx C[P_A \mid P_B]$$

$$\texttt{new}\ k.[P_A \mid P_B]$$

$$\texttt{new}\ k.P_A \mid \texttt{new}\ k.P_B$$

SKETCH OF PROOF

$$C[P_A] \mid C[P_B] \approx C[P_A \mid P_B]$$

$$\mathtt{new}\ k.[P_A \mid P_B] \longrightarrow P_1 \dashrightarrow P_n$$

$$\mathtt{new}\ k.P_A \mid \mathtt{new}\ k.P_B$$

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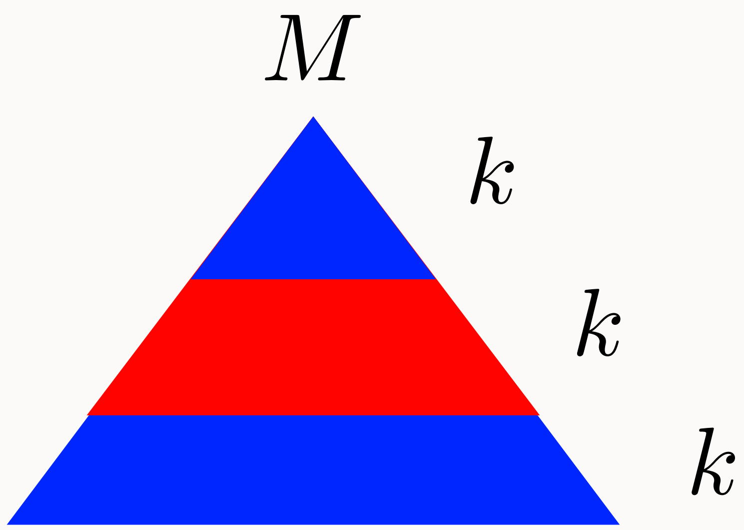

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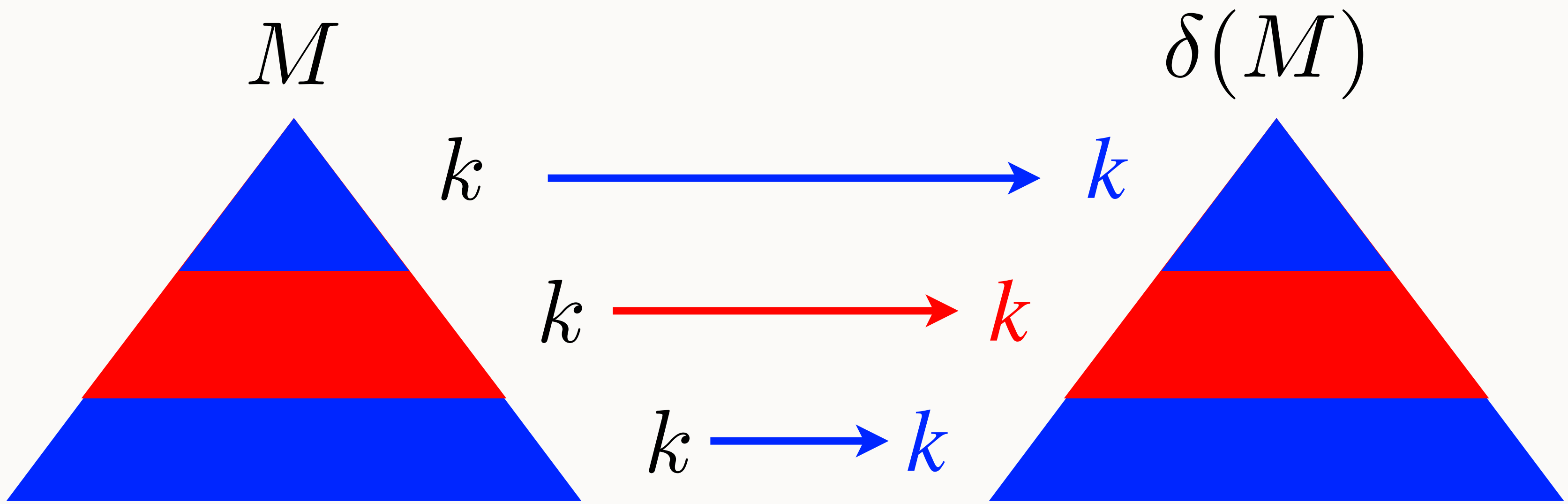

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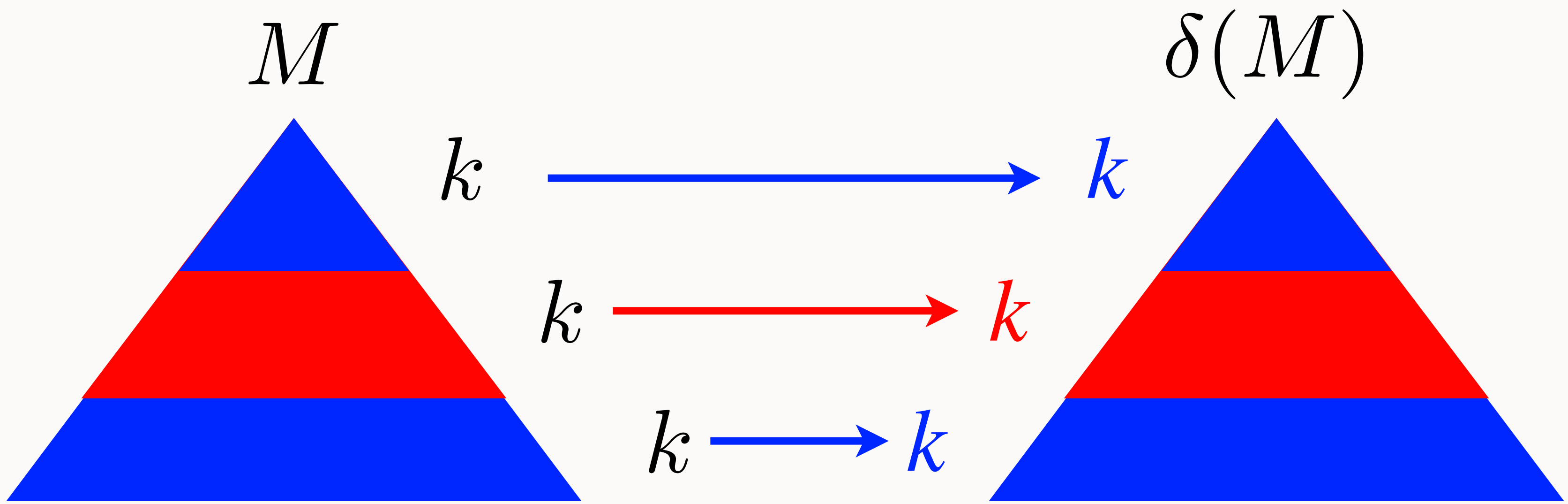

$\texttt{new}\ k.P_A \mid \texttt{new}\ k.P_B \longrightarrow \delta(P_1) \dashrightarrow \delta(P_n)$

CONCLUSION & FUTURE WORK

- Parallel composition theorem for equivalence properties

Conditions:

- The shared keys are not revealed
- The public keys are revealed at the beginning
- The protocols are tagged

- Future work : Sequential composition

E-passport protocols

- Basic Access Control (BAC) : establishes sessions keys between reader and a passport
- Passive Authentication (PA)
- Active Authentication (AA)

- Future work : Removing the tags

- Tags imply heavy transformation of the protocol
- Almost no current protocol tags all their message
- Protocols may behave as if they were tagged (ex: nonce exchange)