AUTOMATIC TOOLS TO PROVE PRIVACY-TYPE PROPERTIES

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Context

Most communications take place over a public network

It is important to ensure their security

Cryptographic protocols

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- small programs designed to secure communication (e.g. secrecy)
- use cryptographic primitives (e.g. encryption, signature)

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- Reliable cryptography
- Correct protocol specification
- Implementation satisfying the specification

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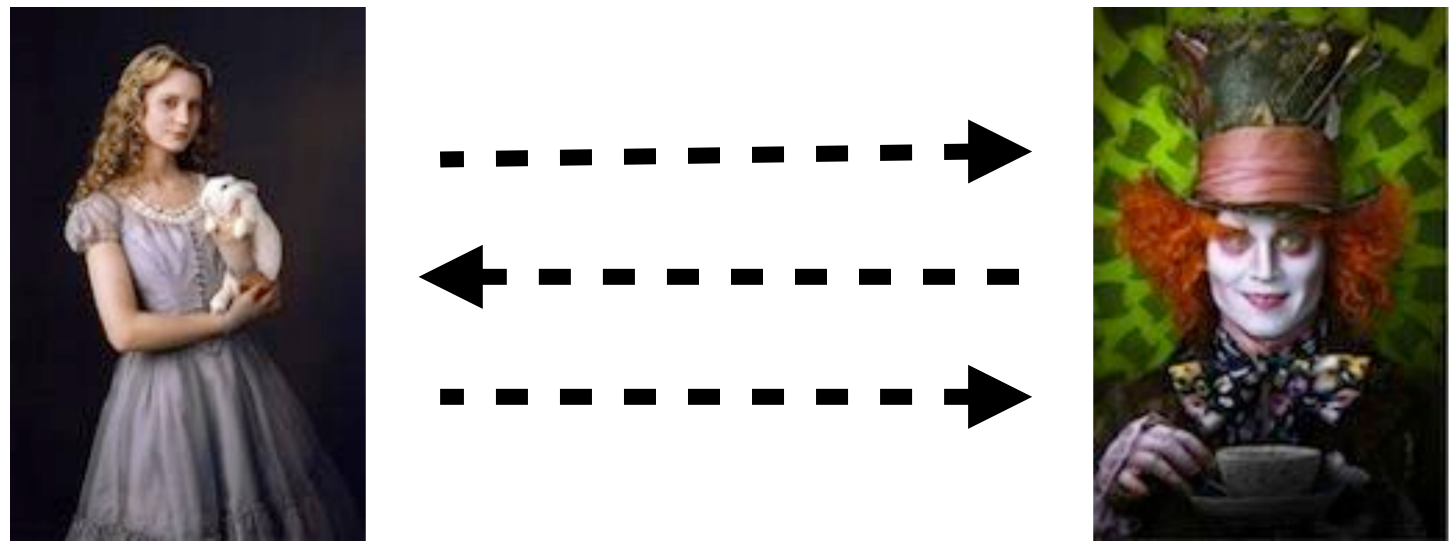
Symbolic model

Alice

Bob

Symbolic model



Alice Bob

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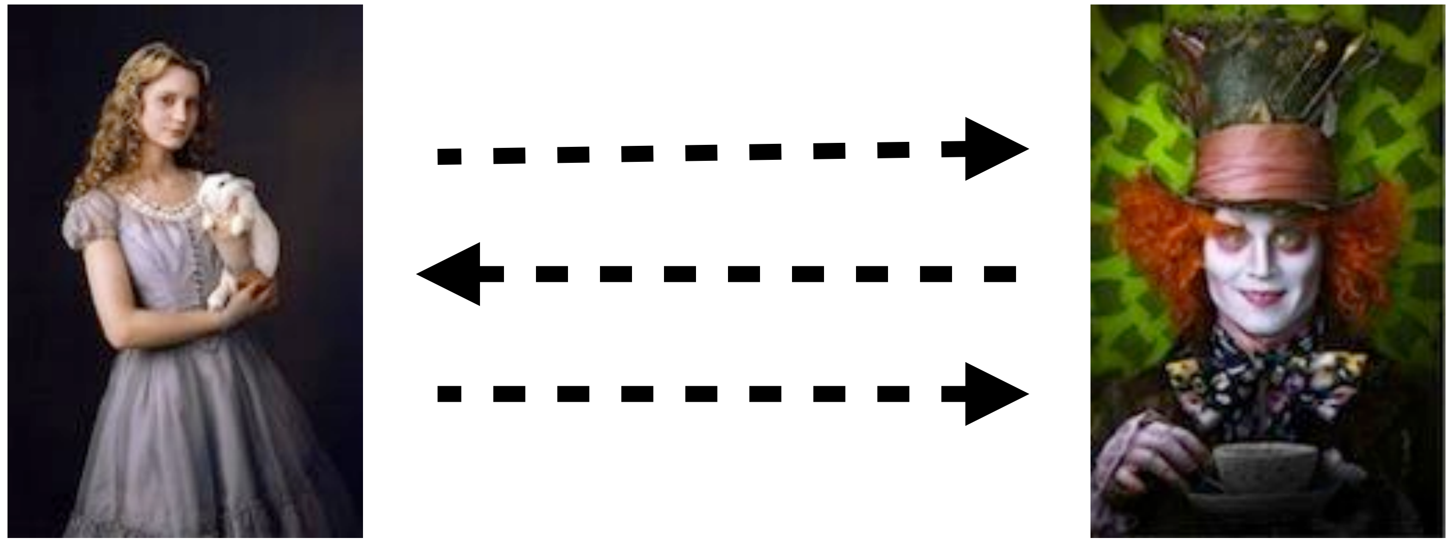

Alice Bob

- We assume perfect cryptographic primitives
- Messages are represented by terms

$$\{N\}_{\mathsf{pk}(k)} \qquad \langle N, M \rangle \qquad \mathsf{adec}(\{N\}_{\mathsf{pk}(k)}, k)$$

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- intercept all messages
- transmit or modify messages
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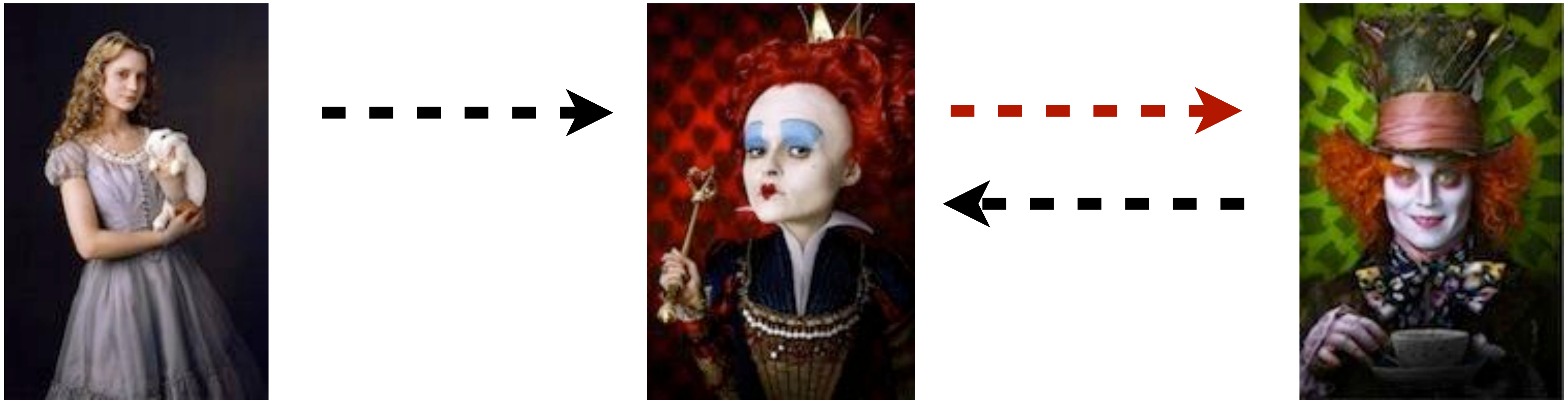

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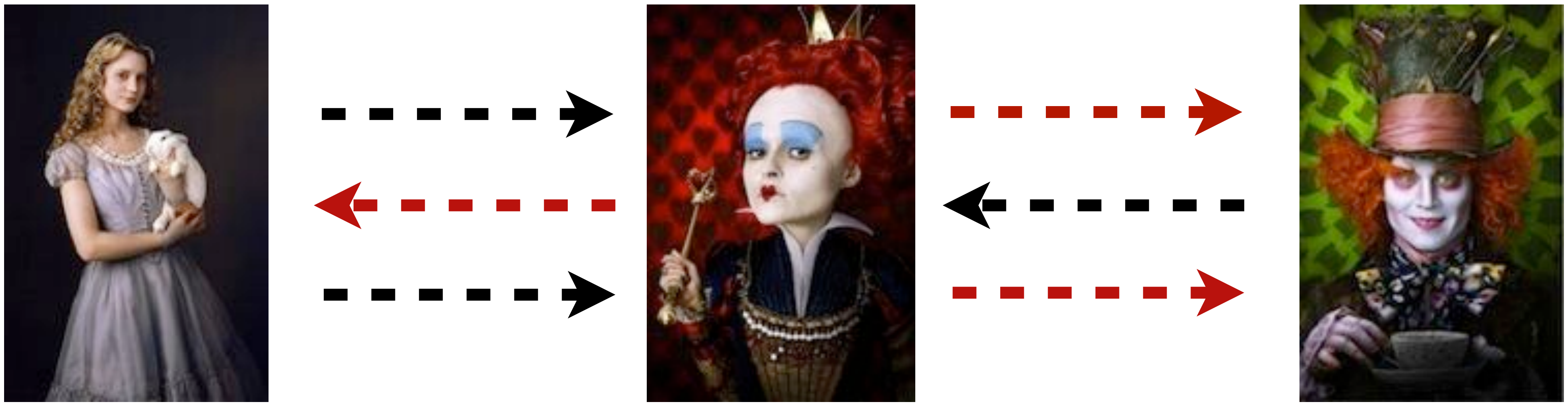

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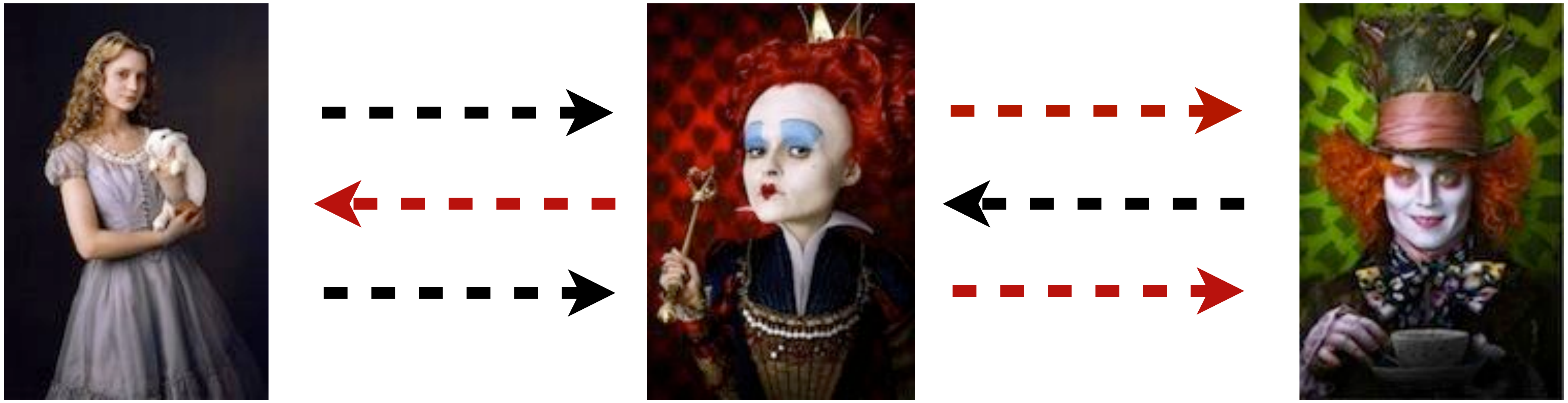


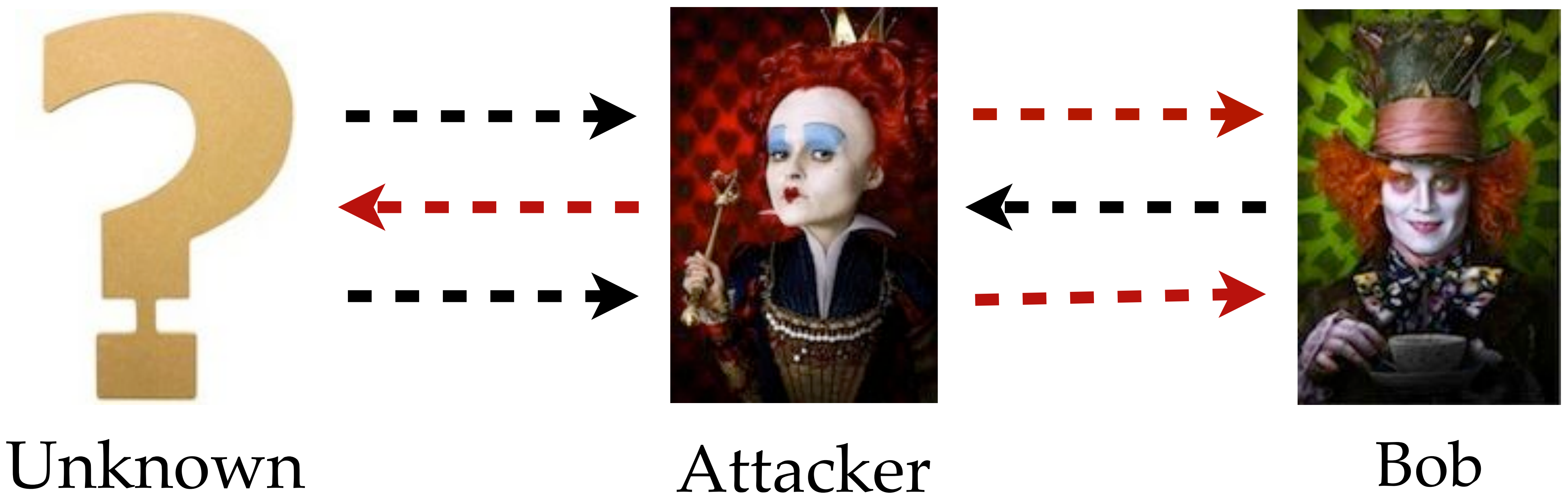
Alice | Attacker | Bob

Security properties:

- Reachability properties
- Equivalence properties

Security properties

Equivalence properties: anonymity



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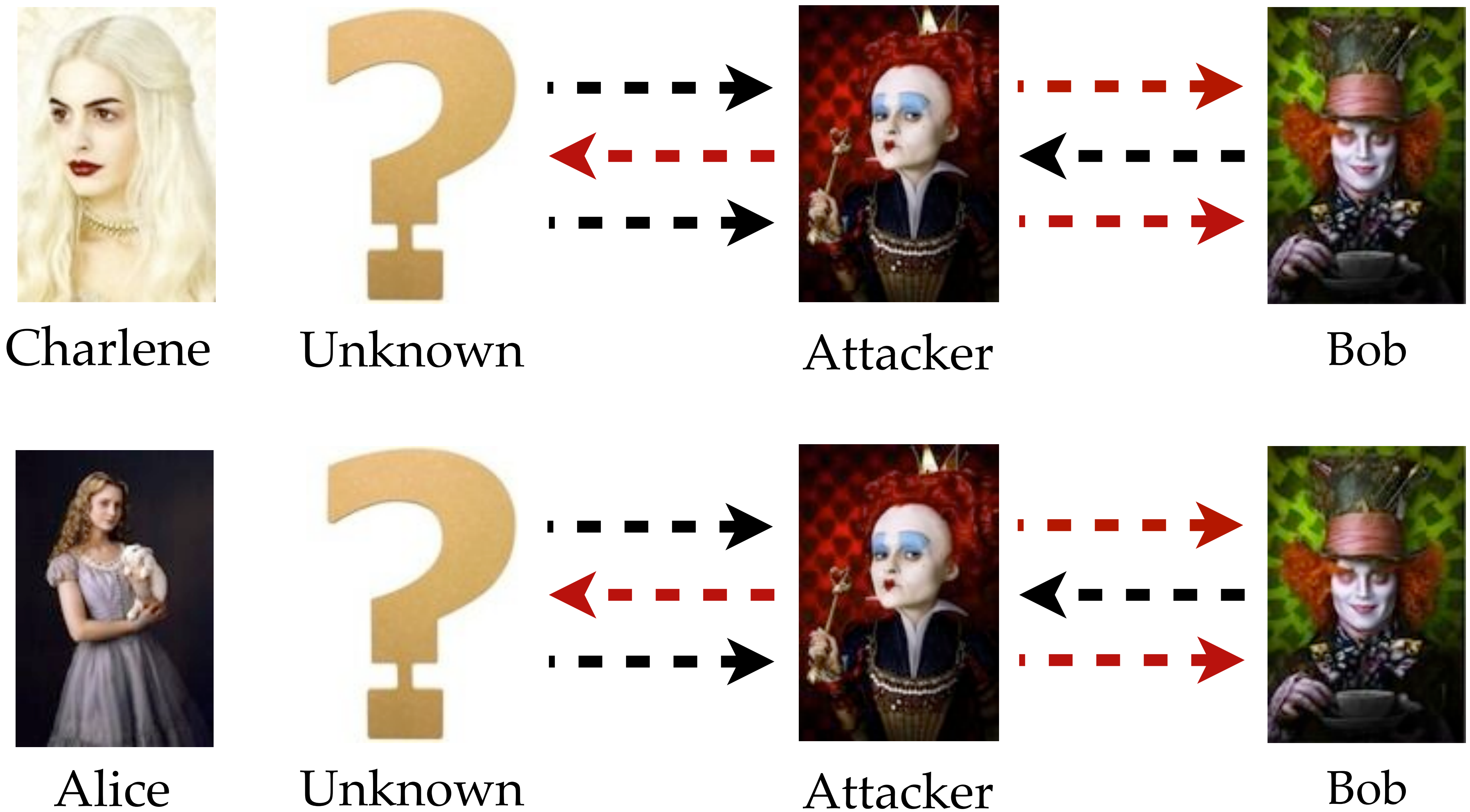

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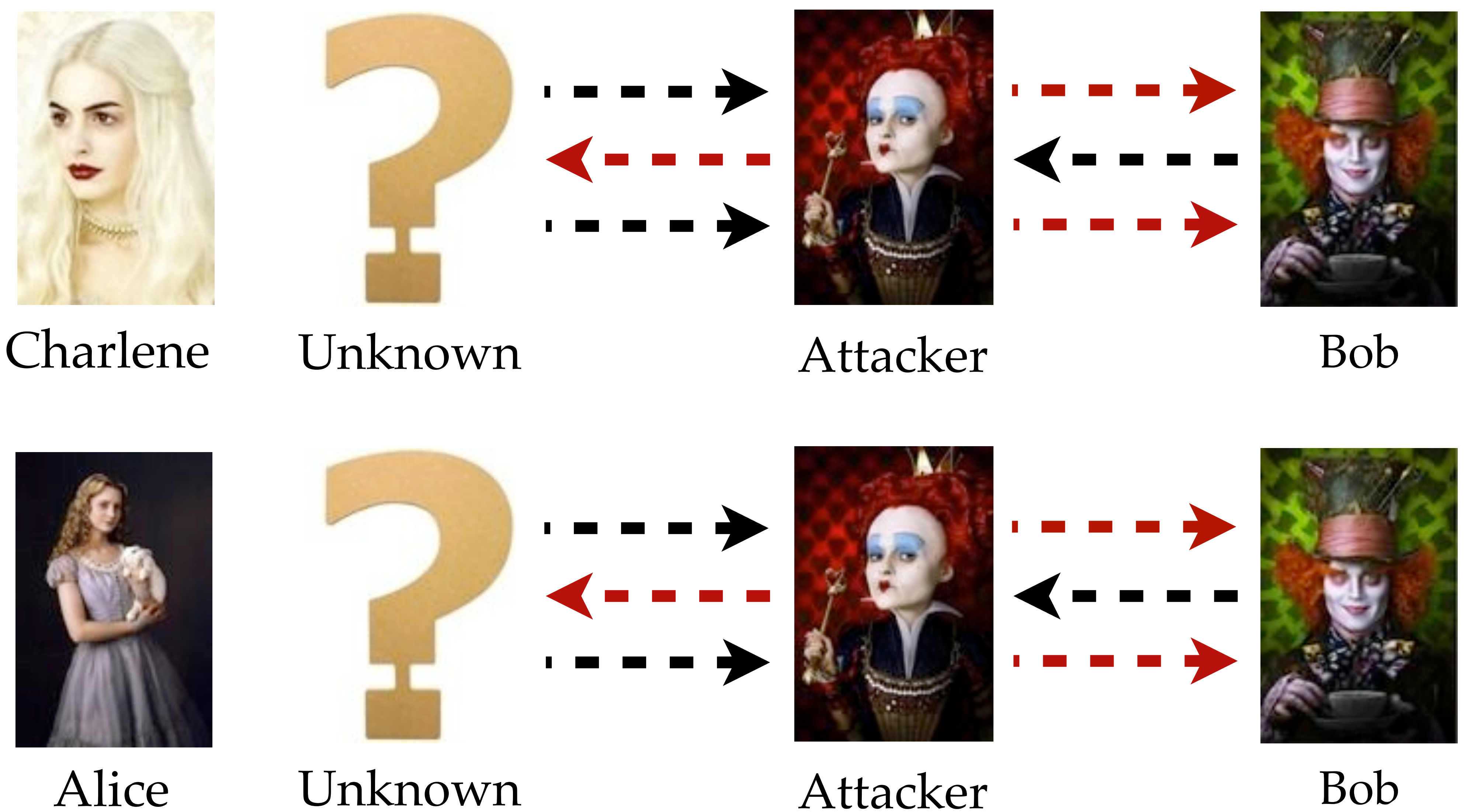

Can the intruder distinguish the two situations ?

Security properties

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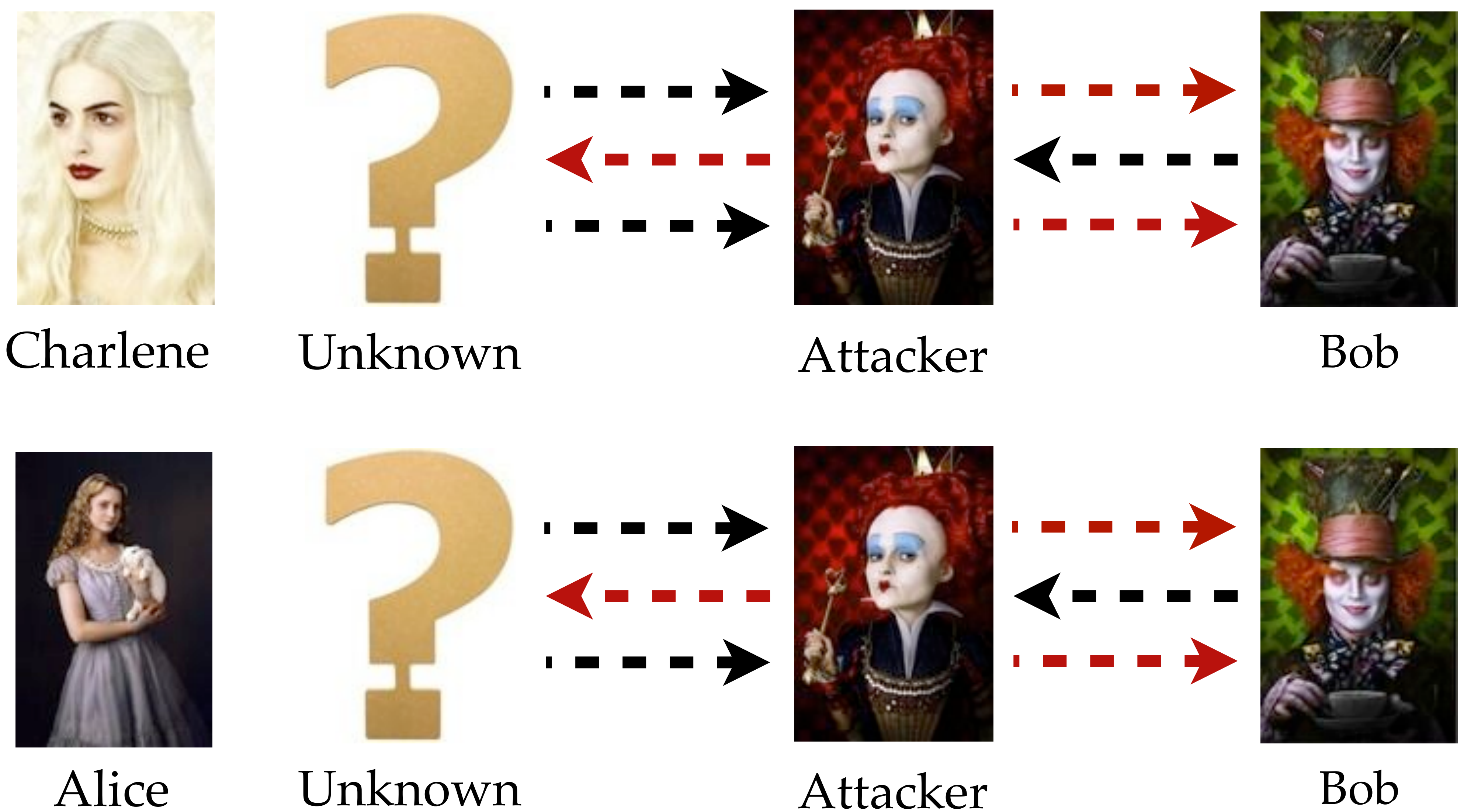

Trace equivalence

Examples

Private authentication protocol

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$\{\langle N_a, \mathsf{pk}(k_A)\rangle\}_{\mathsf{pk}(k_B)}$

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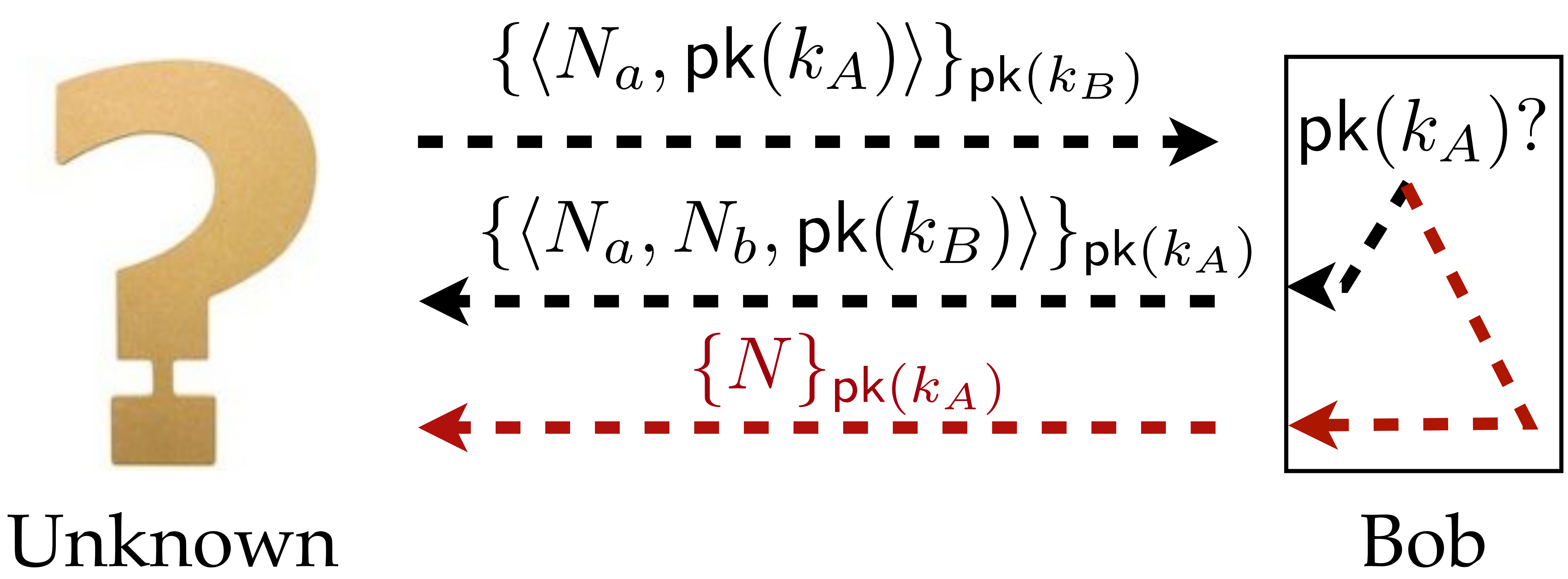

Automatic tools

- For reachability properties

  Avispa, CSP/FDR, ProVerif, Scyther, Maude-NPA, ...

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  • **ProVerif:** Bruno Blanchet. *An Efficient Cryptographic Protocol Verifier Based on Prolog Rules.*
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Do not handle private authentication protocol and e-passport protocol

Outline

1. Proving more equivalence with ProVerif

2. APTE: Decision procedure for trace equivalence

3. Demo Time !

Proverif

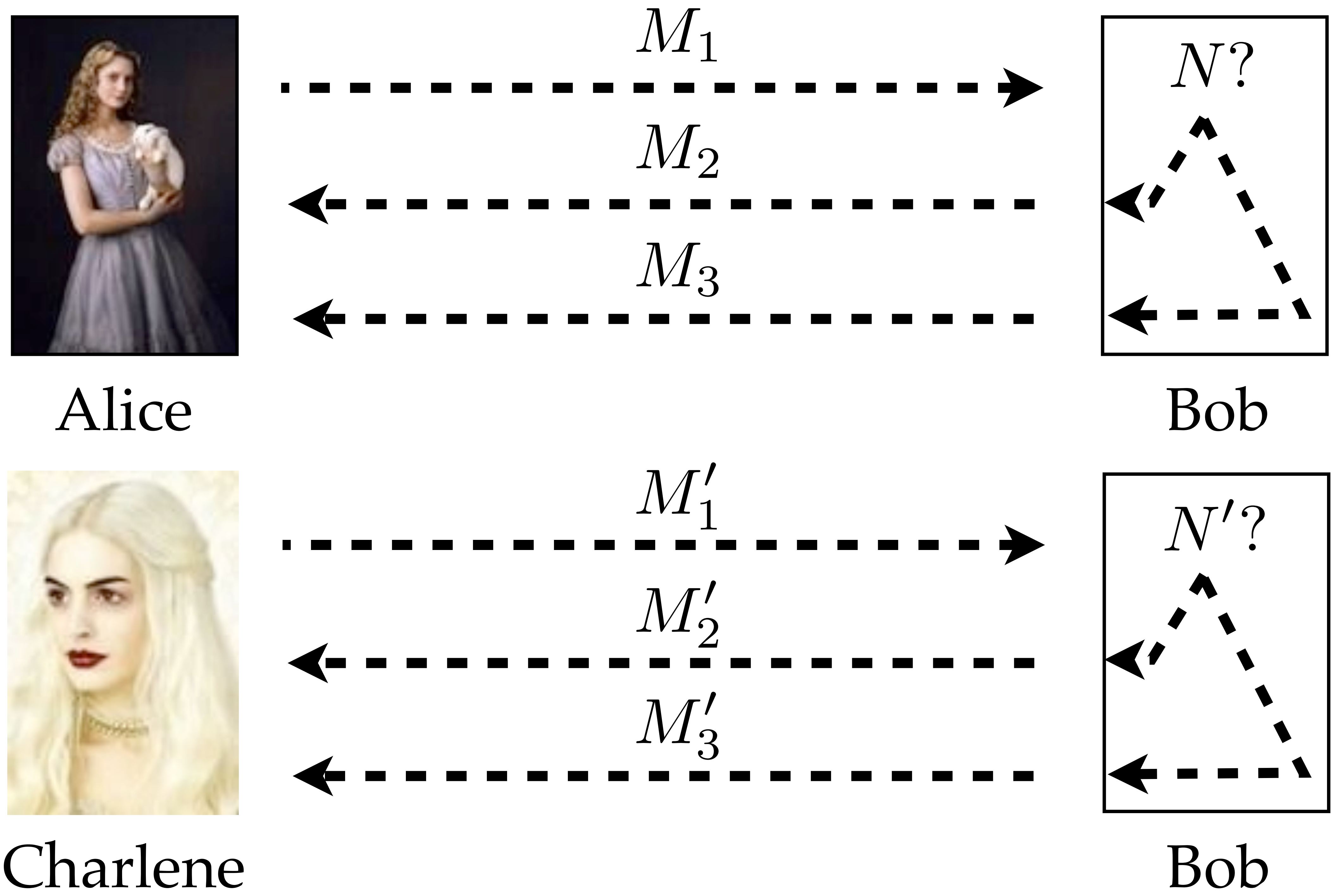
ProVerif was first an analyzer for reachability properties based on Horn clauses.

- Handle reachability and equivalence properties
- Cryptographic primitives described by equational theory and/or rewriting rules
- Handle processes with replication
- Possible false attack
- Does not always terminate

Processes

$$
\begin{aligned}
P, Q := \quad & 0 \\
& \mathsf{in}(c, x); P \\
& \mathsf{out}(c, M); P \\
& P \mid Q \\
& !\, P \\
& \mathsf{new}\ a; P \\
& \mathsf{let}\ x = D\ \mathsf{in}\ P\ \mathsf{else}\ Q
\end{aligned}
$$

Biprocesses



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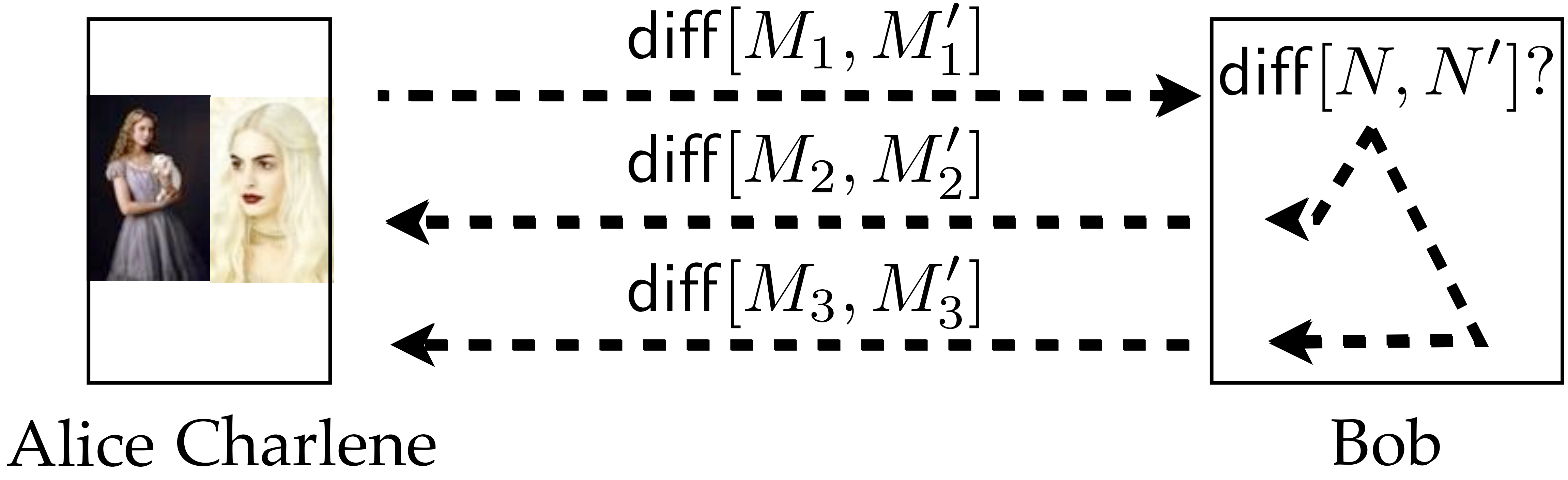

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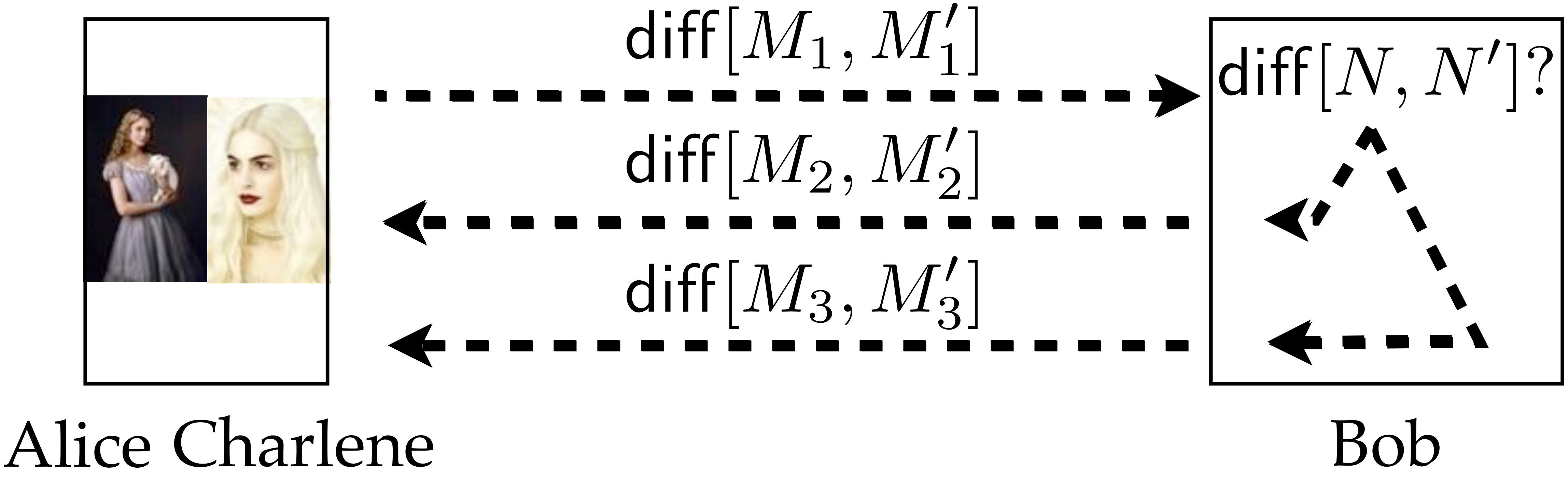

Equivalence too strong: possible false attack

Motivation

The private authentication protocol

Alice

Attacker

Bob

Charlene

Attacker

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Motivation

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$\{\langle x, y\rangle\}_{\mathsf{pk}(k_B)}$

$\mathsf{pk}(k_A) = y$

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← $\{N\}_{\mathsf{pk}(k_A)}$

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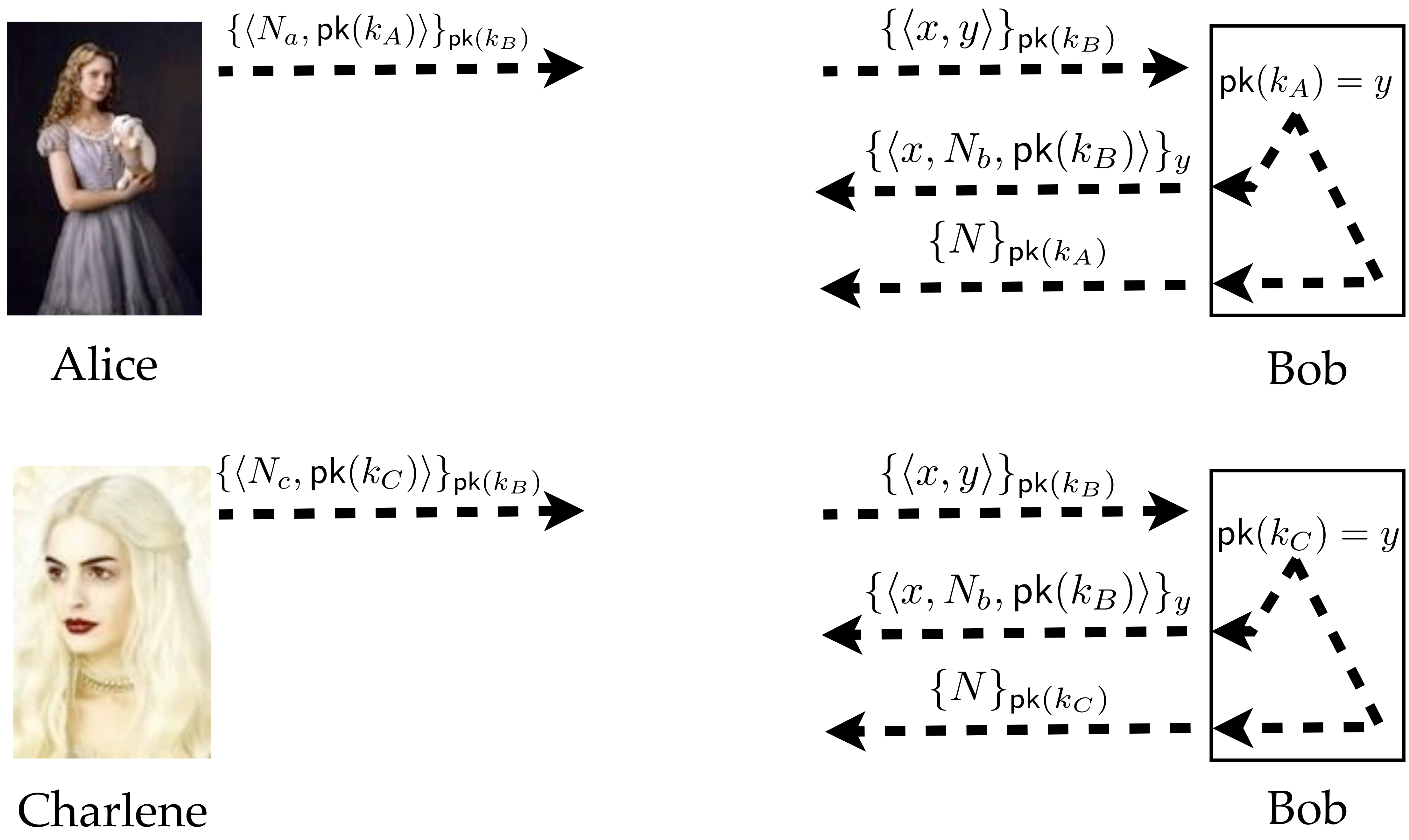

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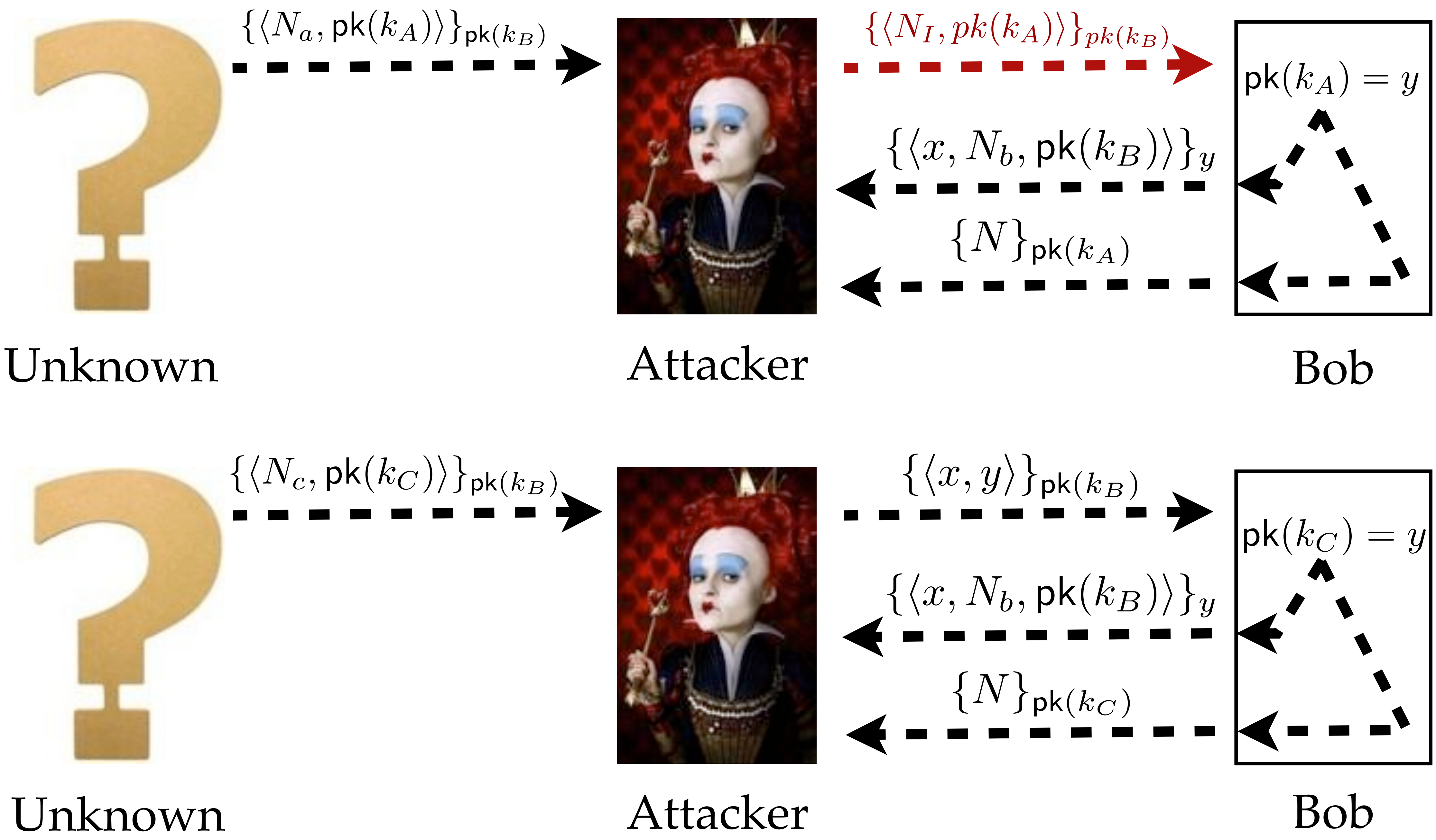

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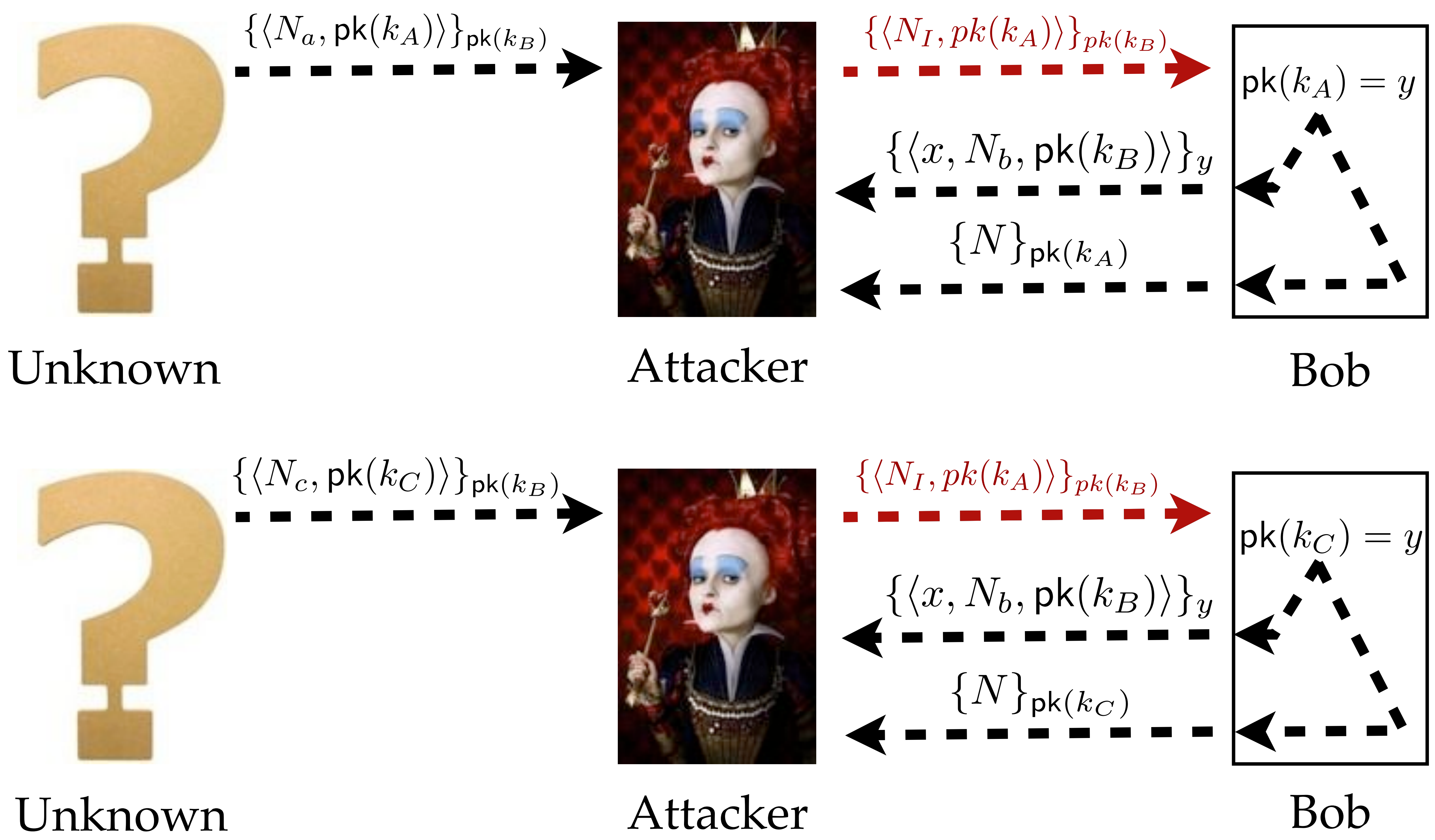

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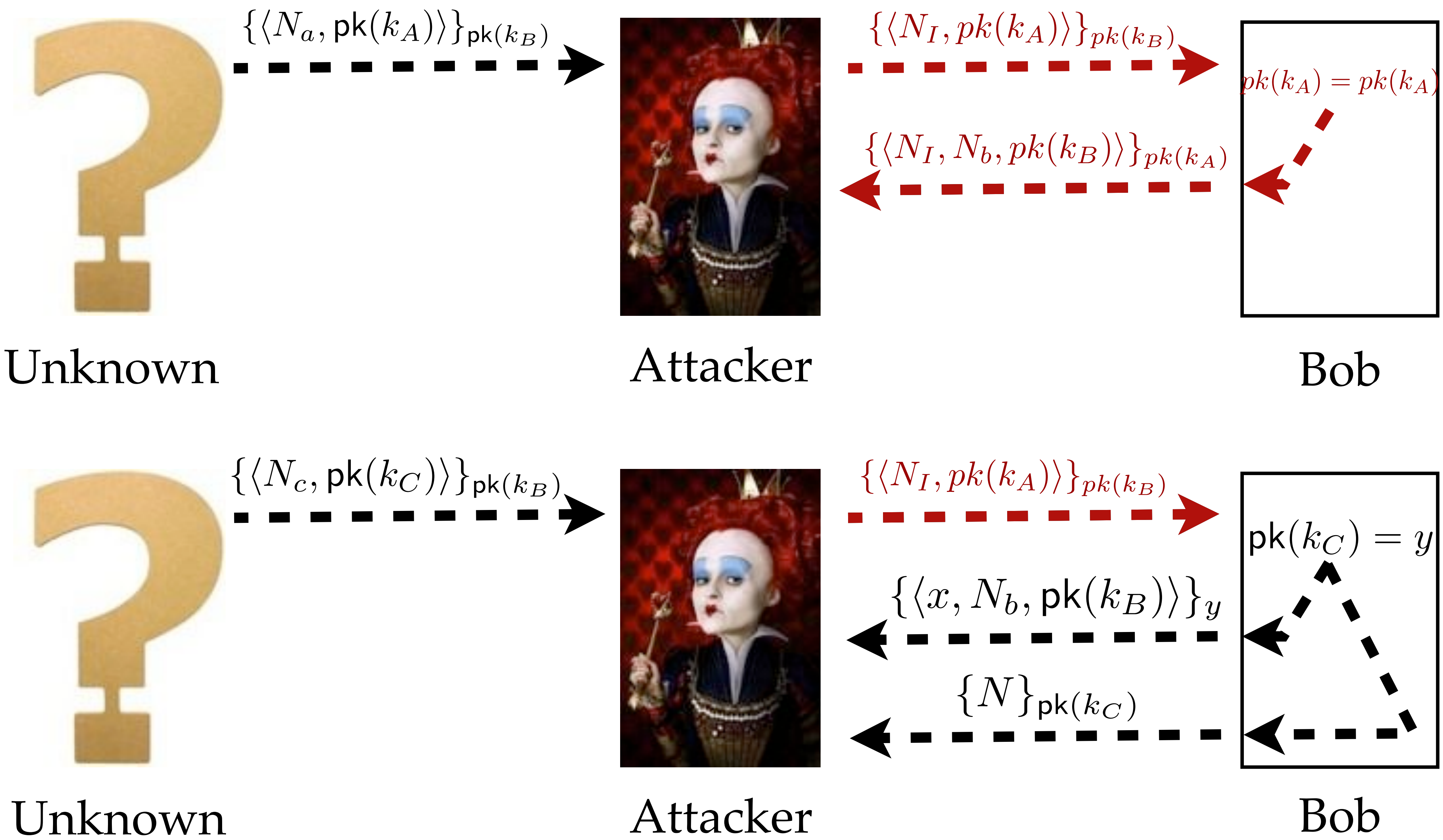

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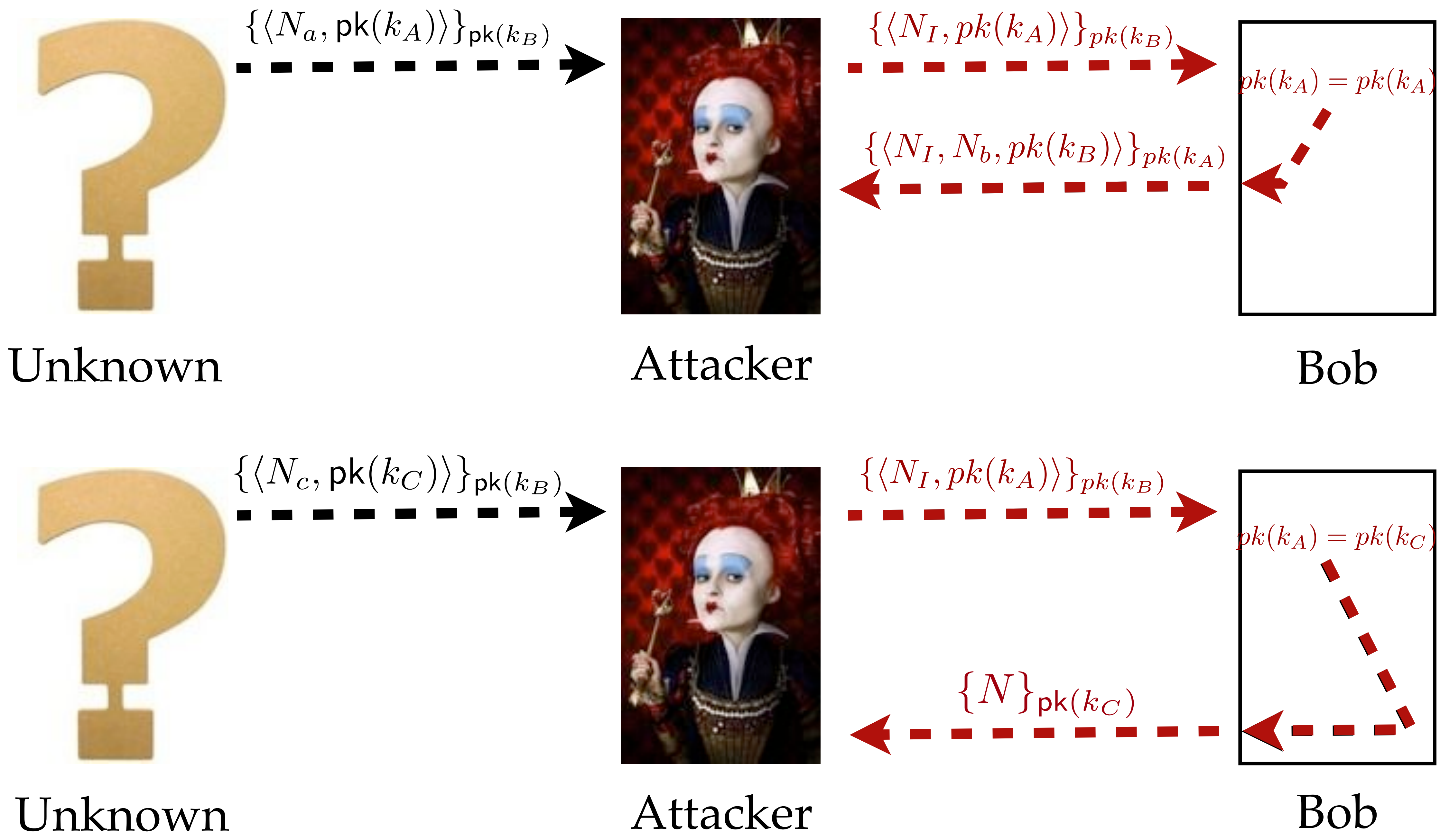

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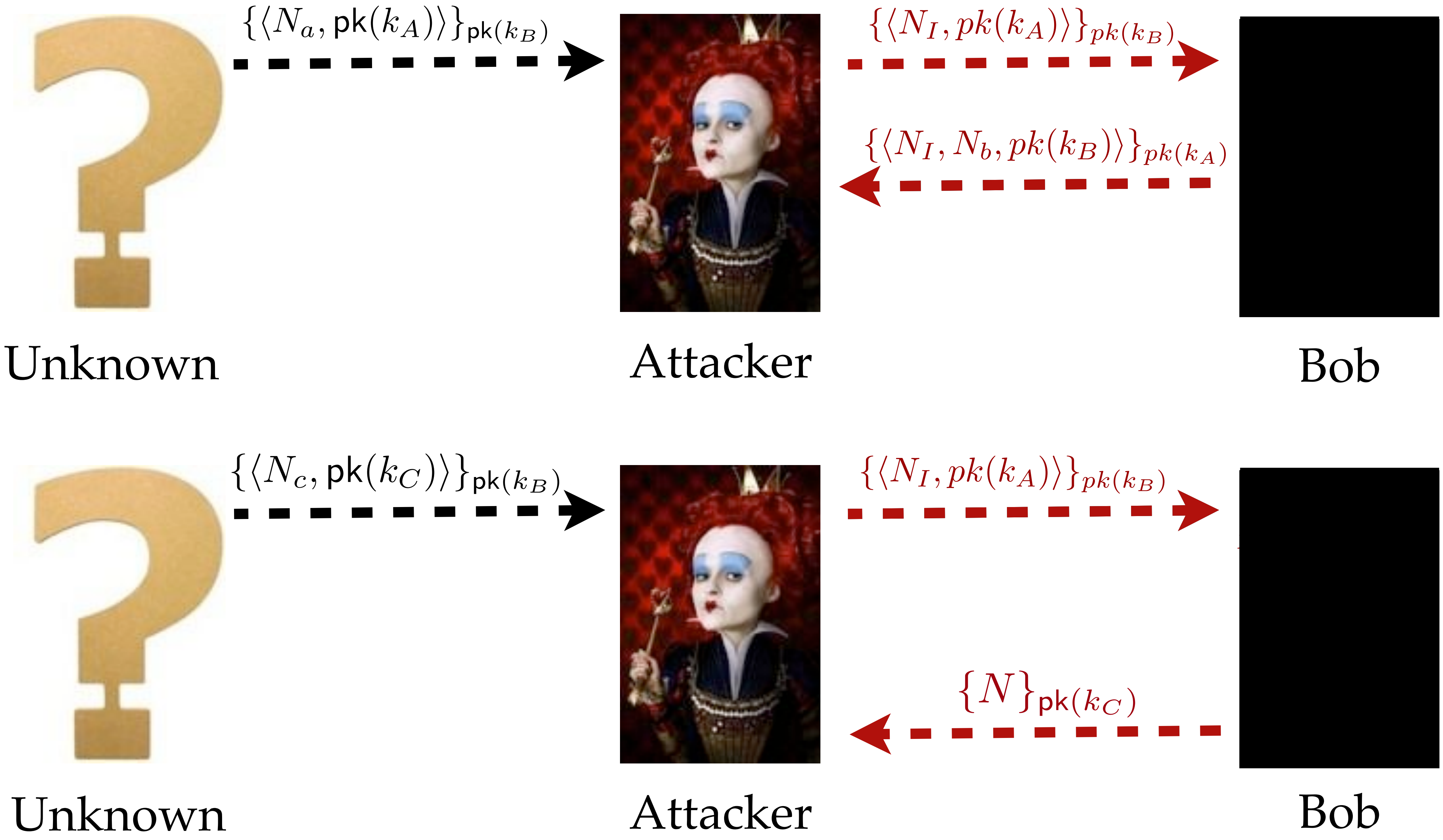

Contribution

Introduction of destructors with tests between terms

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The *If-then-else* destructor:

$$\mathsf{ifthenelse}(x, x, z, t) \rightarrow z$$

$$\mathsf{ifthenelse}(x, y, z, t) \rightarrow t \quad \text{with} \quad x \neq y$$

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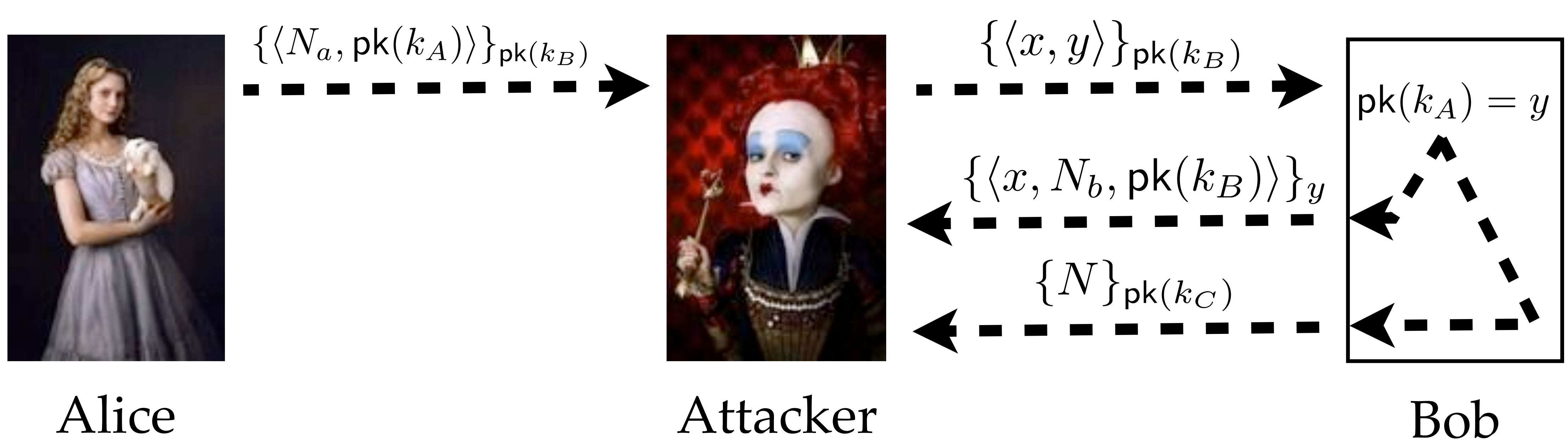

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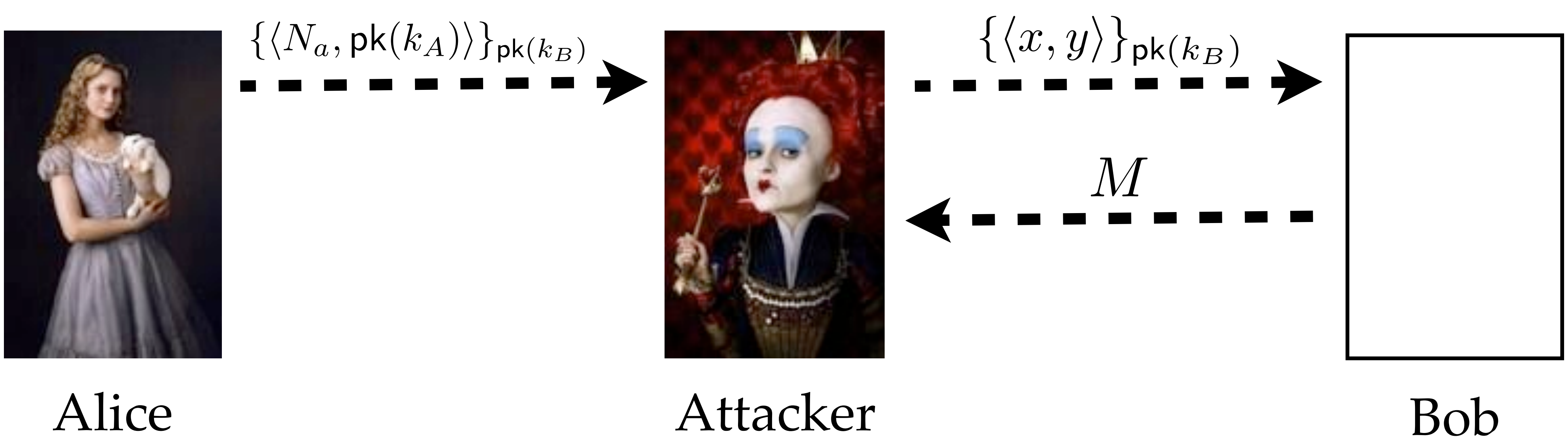

$$M = \mathsf{ifthenelse}(y, \mathsf{pk}(k_A), \{x, N_b, \mathsf{pk}(k_B)\}_y, \{N\}_{\mathsf{pk}(k_A)})$$

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Automatic transformation: *simpl*

For all processes P, $simpl(P) \approx P$

Implementation

Beta release:

ProVerif version 1.87beta

http://prosecco.gforge.inria.fr/personal/bblanche/proverif/

Content:

- Rewrite rules with tests
- Automatic transformation of biprocesses
- Equivalence between processes with different control structures

Results:

- Prove anonymity for private authentication protocol (unbounded number of sessions)

Outline

1. Proving more equivalence with ProVerif
2. APTE: Decision procedure for trace equivalence
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Constraint systems

One constraint system = several traces

Alice

Attacker

Bob

$\mathsf{pk}(k_A), \mathsf{pk}(k_B), \mathsf{pk}(k_C), N_I$

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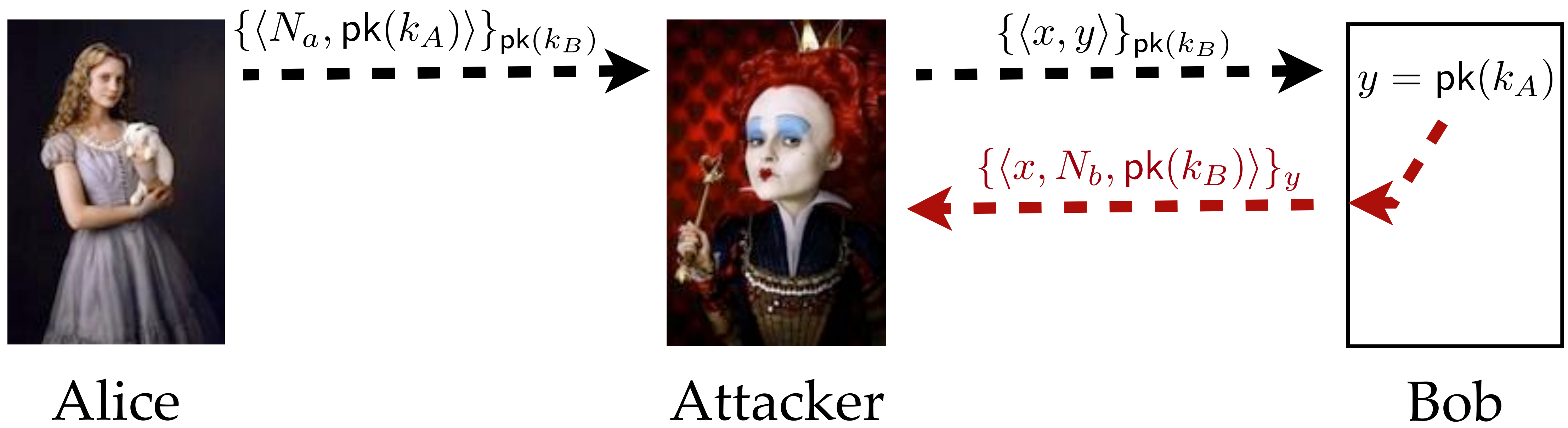

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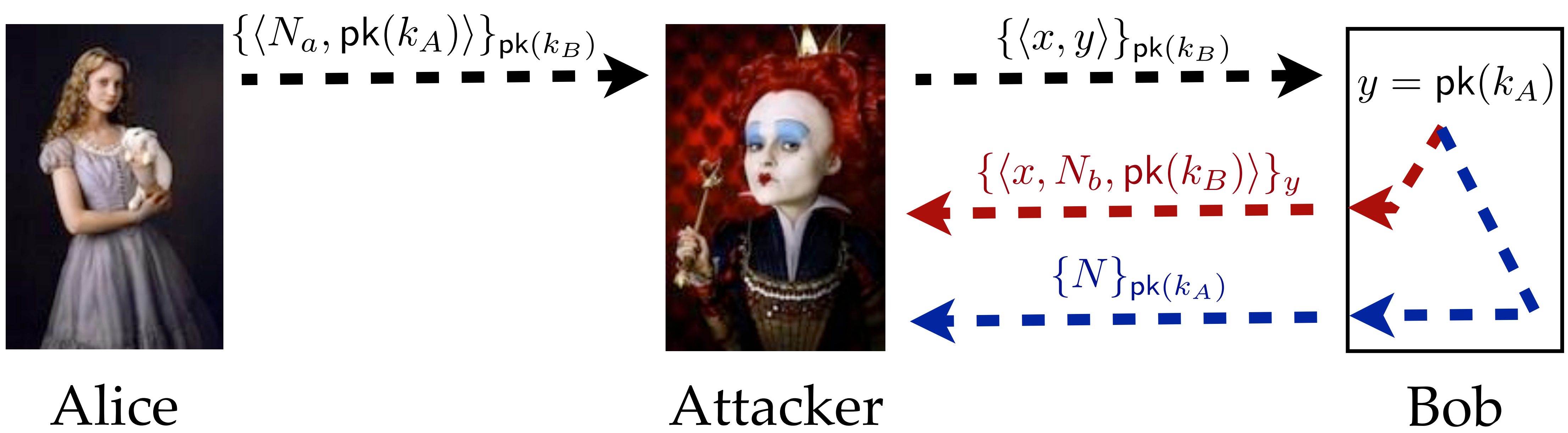

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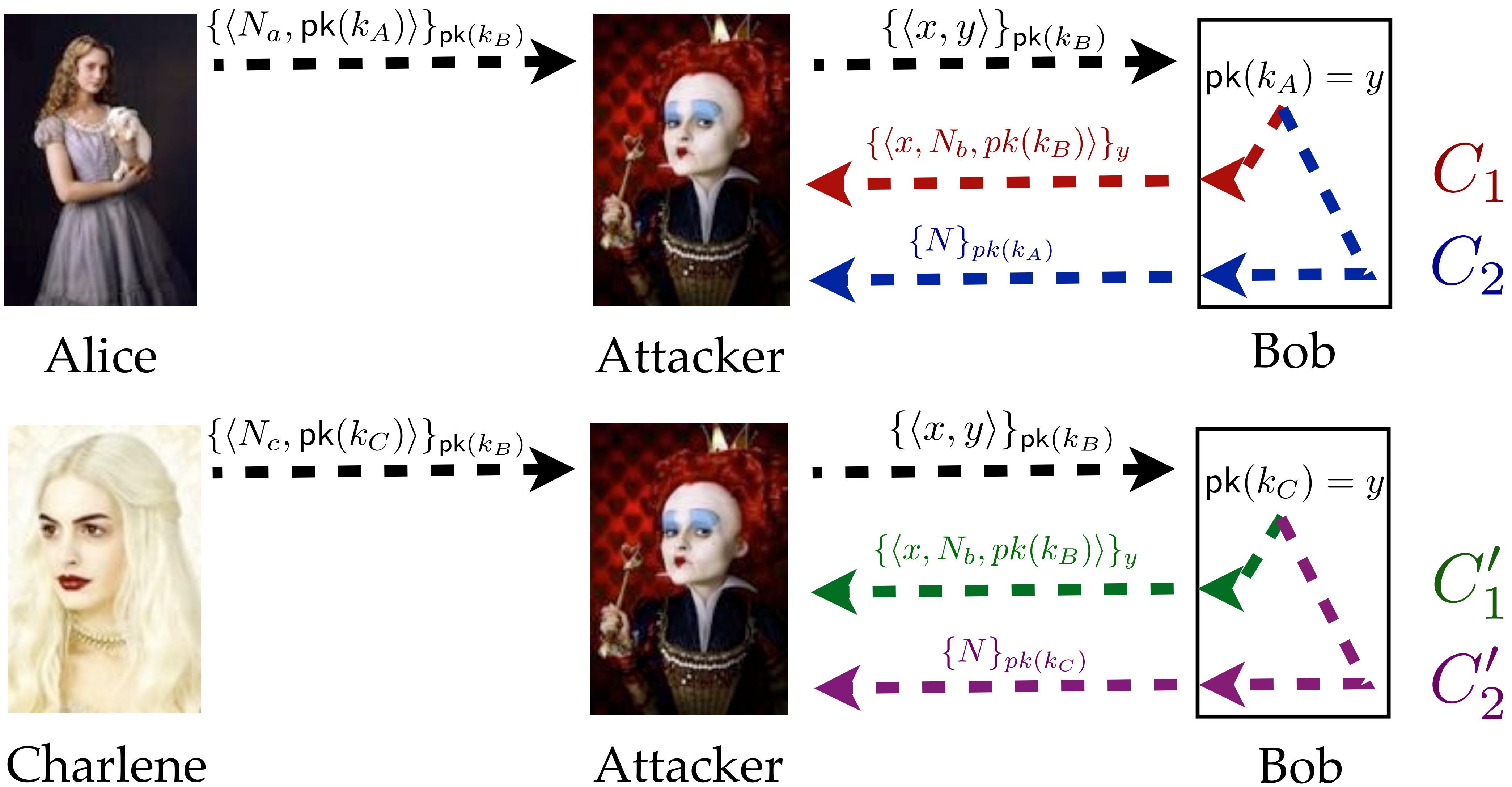
$$y \neq \mathsf{pk}(k_A)$$

Sets of constraint systems



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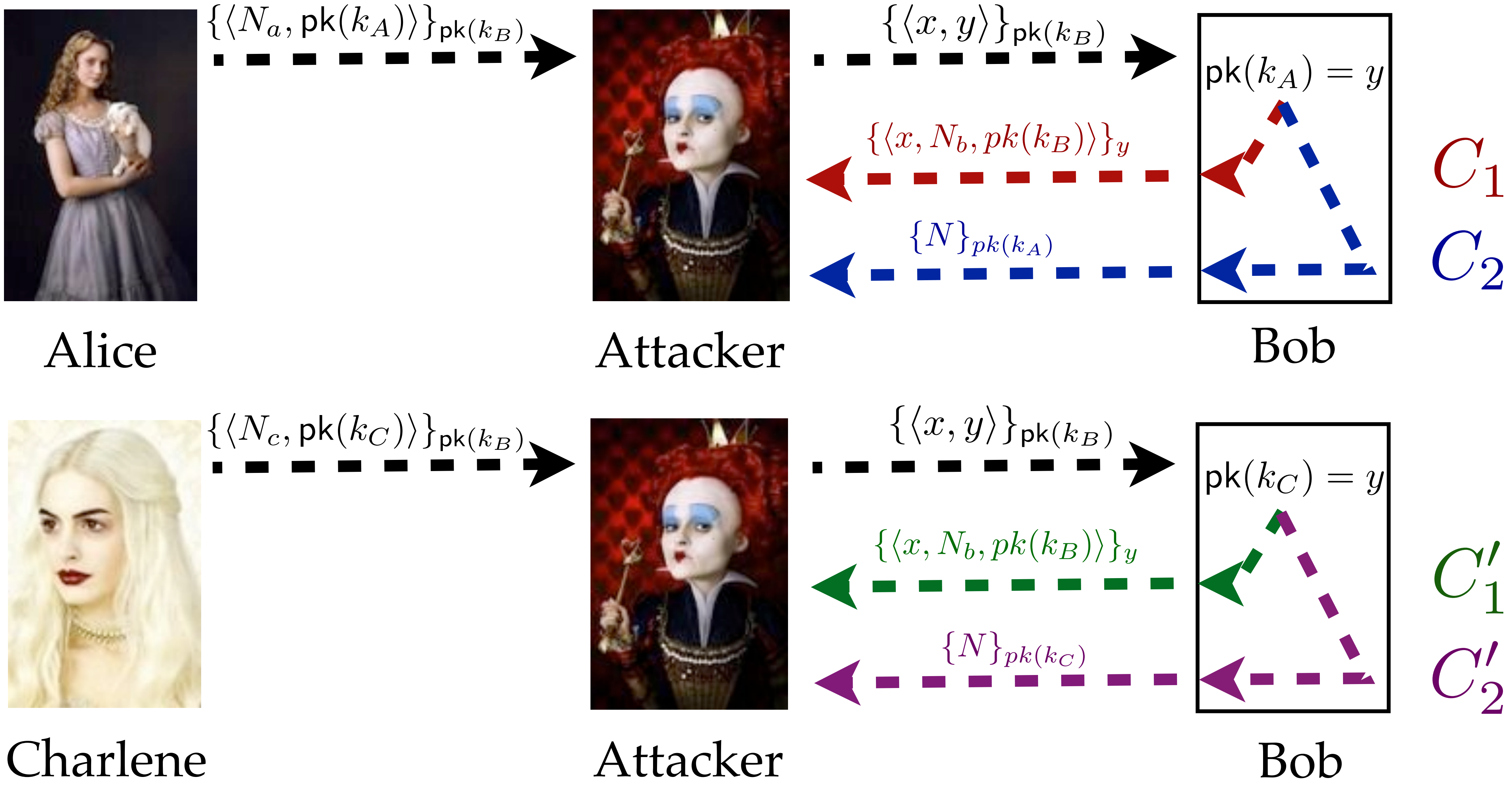

$$\{C_1;\ C_2\} \approx \{C'_1;\ C'_2\}$$

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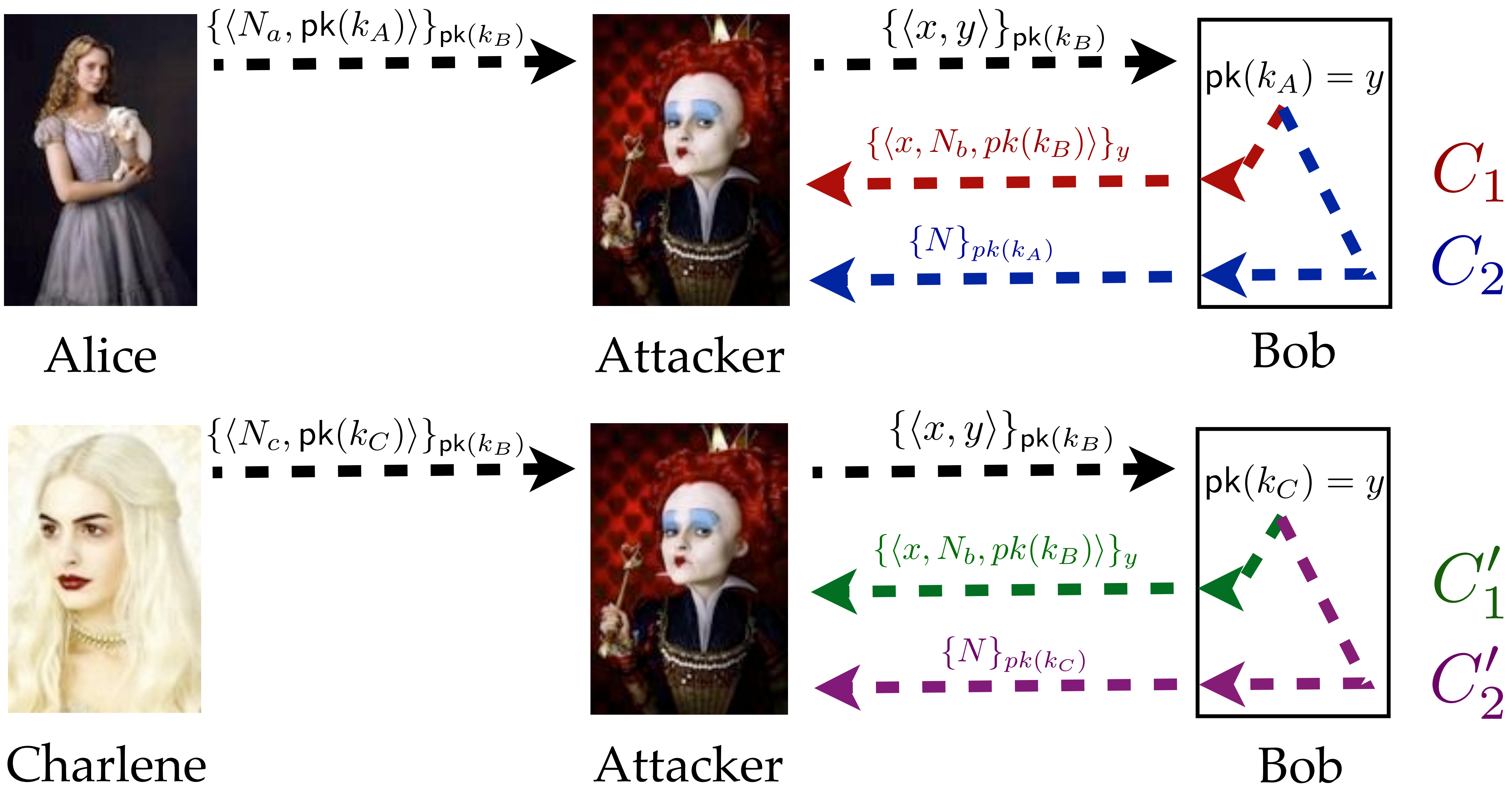


Symbolic equivalence between sets of constraint systems

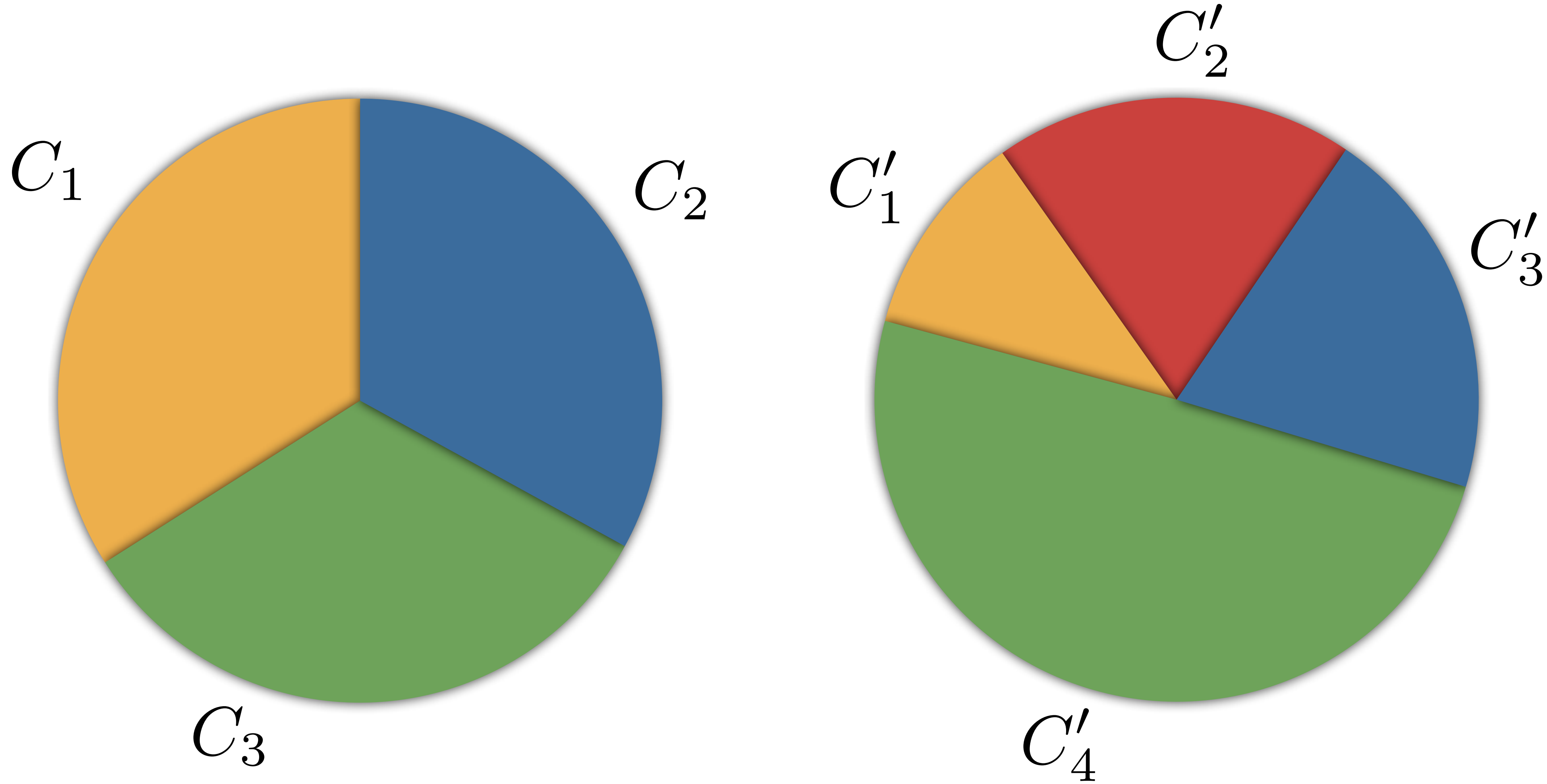
Previous works

1. M. Baudet. *Sécurité des protocoles cryptographiques : aspects logiques et calculatoires*. Phd thesis (2007)
2. Y. Chevalier and M. Rusinowitch. *Decidability of equivalence of symbolic derivations*. JAR (2012)
3. A. Tiu and J. E. Dawson. *Automating open bisimulation checking for the spi calculus*. CSF (2010)

- Do not handle set of constraint systems
- Do not handle inequations
- Do not handle non-deterministic processes

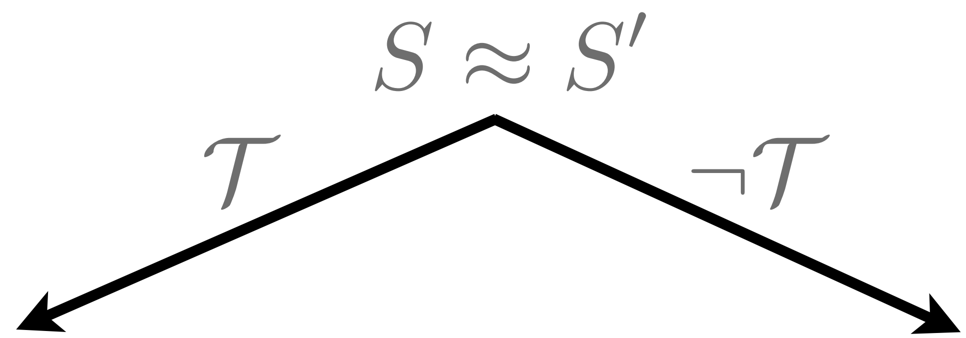
Sets of constraint systems

Why are they necessary ?



$S = \{C_1; C_2; C_3\}$ $S' = \{C'_1; C'_2; C'_3; C'_4\}$

The Algorithm



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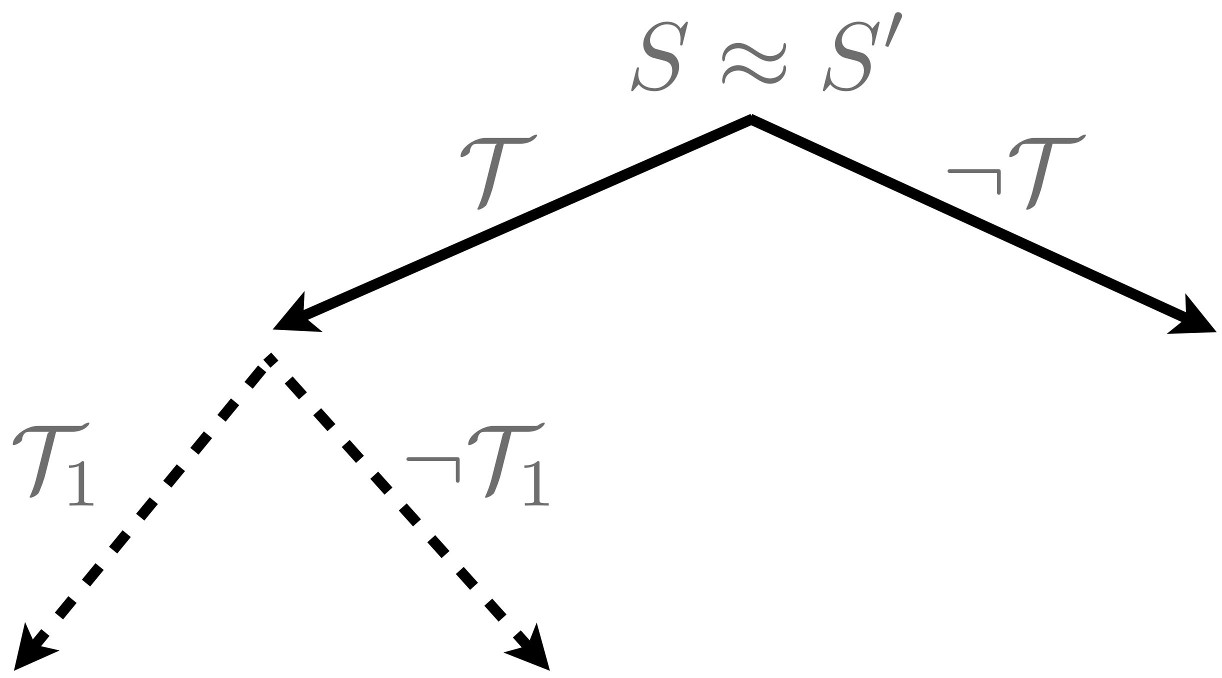

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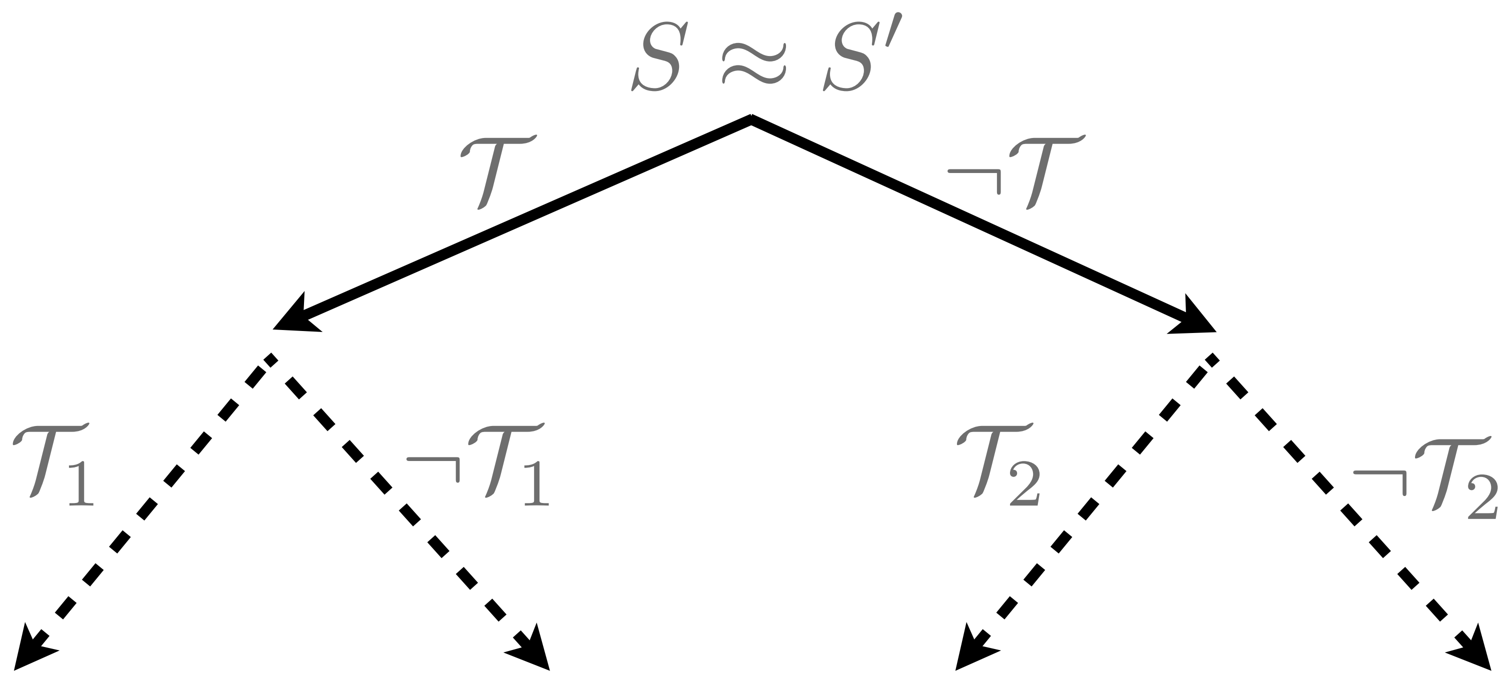

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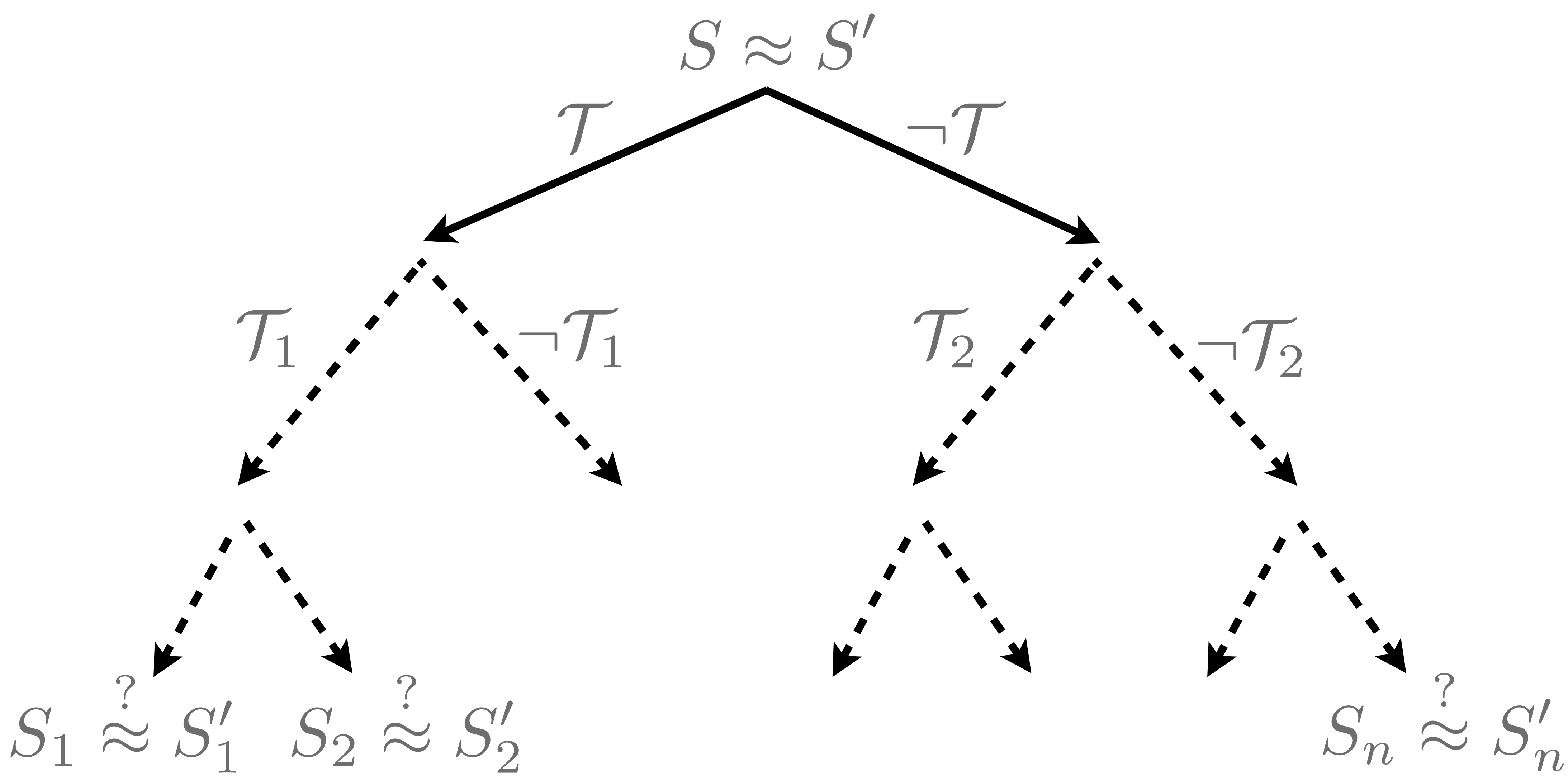

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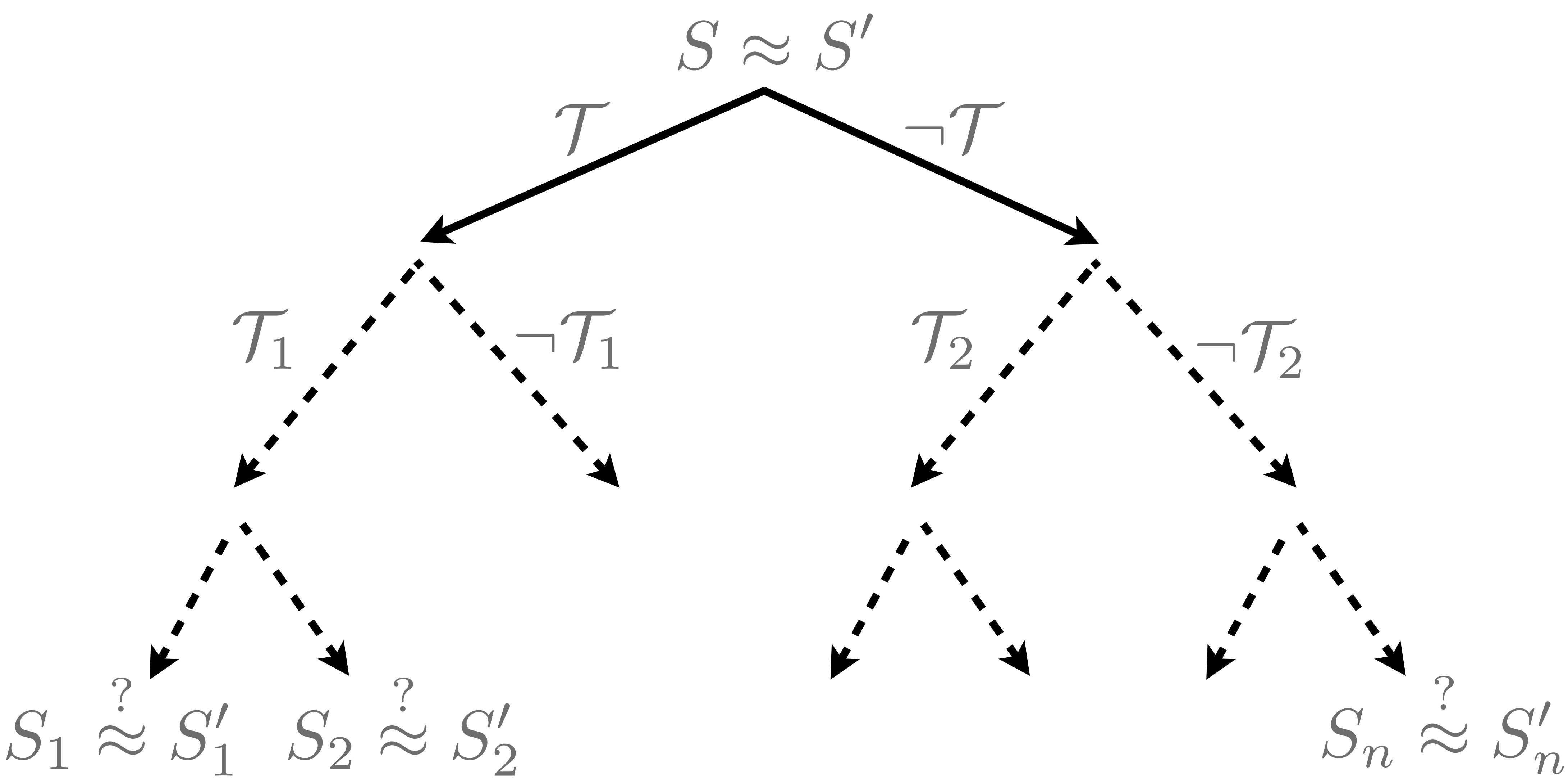

The symbolic equivalence is syntactically decided on each leaf

Results

Decision procedure for proving trace equivalence for bounded number of sessions.

Class of accepted processes:

- Non-deterministic (e.g. private channel) with else-branches
- Classic cryptographic primitives (symmetric and asymmetric encryption, signature, pairing, hash)

Include:

- E-passport protocols
- Private authentication protocols

Length of messages

Example

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Attacker

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Charlene

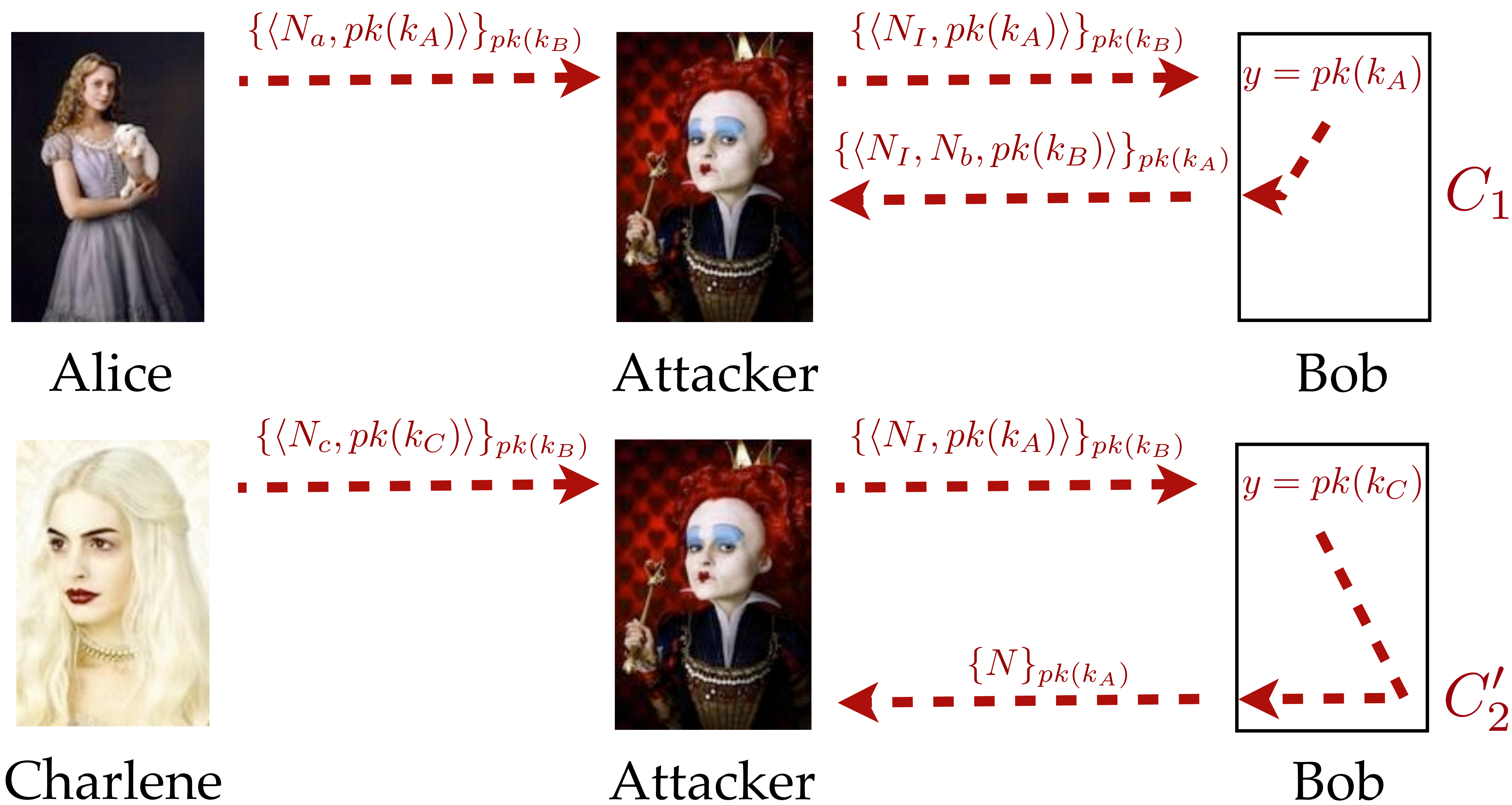
Attacker

$y = pk(k_C)$

Bob

Length of messages

Example



Length of messages

Linear length functions

$$\mathsf{enc}(x, y) \qquad \ell_{\mathsf{enc}}(x, y) = \alpha + \beta_1 x + \beta_2 y$$

$$\langle x, y \rangle \qquad \ell_{\langle\ \rangle}(x, y) = \alpha' + \beta_1' x + \beta_2' y$$

Length of messages

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$$\langle x, y \rangle \qquad \ell_{\langle\ \rangle}(x, y) = \alpha' + \beta'_1 x + \beta'_2 y$$

$$\ell(\mathsf{enc}(\langle n, n \rangle, k)) = \ell_{\mathsf{enc}}(\ell(\langle n, n \rangle), \ell(k))$$

Length of messages

Linear length functions

$$\mathsf{enc}(x, y) \qquad \ell_{\mathsf{enc}}(x, y) = \alpha + \beta_1 x + \beta_2 y$$

$$\langle x, y \rangle \qquad \ell_{\langle\ \rangle}(x, y) = \alpha' + \beta'_1 x + \beta'_2 y$$

$$\begin{aligned}\ell(\mathsf{enc}(\langle n, n \rangle, k)) &= \ell_{\mathsf{enc}}(\ell(\langle n, n \rangle), \ell(k)) \\ &= \alpha + \beta_1 \ell(\langle n, n \rangle) + \beta_2 \ell(k))\end{aligned}$$

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$$\begin{aligned}
\ell(\mathsf{enc}(\langle n, n \rangle, k)) &= \ell_{\mathsf{enc}}(\ell(\langle n, n \rangle), \ell(k)) \\
&= \alpha + \beta_1 \ell(\langle n, n \rangle) + \beta_2 \ell(k)) \\
&= \alpha + \beta_1 \ell_{\langle\rangle}(n, n) + \beta_2 \ell(k))
\end{aligned}$$

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$$\begin{aligned}
\ell(\mathsf{enc}(\langle n, n \rangle, k)) &= \ell_{\mathsf{enc}}(\ell(\langle n, n \rangle), \ell(k)) \\
&= \alpha + \beta_1 \ell(\langle n, n \rangle) + \beta_2 \ell(k)) \\
&= \alpha + \beta_1 \ell_{\langle\rangle}(n, n) + \beta_2 \ell(k)) \\
&= \alpha + \beta_1 (\alpha' + \beta'_1 \ell(n) + \beta'_1 \ell(n)) \\
&\quad + \beta_2 \ell(k)
\end{aligned}$$

Implementation

Alpha version:

APTE v0.2alpha
http://www.cs.bham.ac.uk/~chevavfp/tools/apte/

Content:

- Front-end similar to ProVerif
- Handle equivalence between processes without replication
- Display witness of non-equivalence
- Handle equivalences between sequences of messages
- Handle reachability properties for processes without replication
- Handle equivalence with respect to length of messages

Outline

1. Proving more equivalence with ProVerif

2. APTE: Decision procedure for trace equivalence

3. Demo Time !