Foundations of Security

in Distributed Systems

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March 2013
Bertinoro International Spring School

Thanks to the US National Science Foundation, under grant 1116557

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Goals of this Course

- Study the main mechanisms for
  - authentication
  - confidentiality
  - authorization
- Develop methods for
  - finding attacks
  - proof
  - analysis
  - systematic design
- Present a useful tool, CPSA
- Work within a single point of view mainly, the strand space framework

Structure of the Lectures

Monday	Breaking and proving protocols
Tuesday	Shapes and CPSA; the anatomy of TLS
Wednesday	Protocol goals, composition, separability, transformation
Thursday	Authorization, trust management, state change
Friday	Foundations of cryptography, related to strands

Schedule at
`http://cs.wpi.edu/~guttman/biss/schedule.pdf`

How to Break a Protocol

or prove it correct

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What is a Security Protocol?

- For instance, SSL (= TLS), SSH, OAuth, IKE
  - Short sequence of messages
  - Use cryptography for authentication, confidentiality
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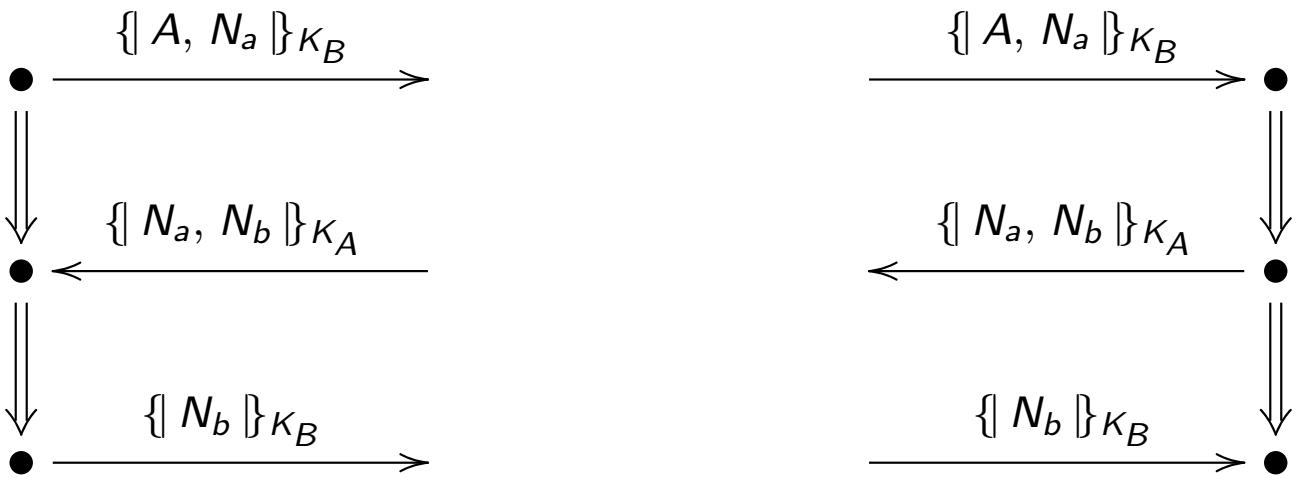
- Protocols establish trust
  - Remote access
  - Secure networking
  - E-commerce
- Security protocols are often wrong
  - Active attackers may subvert goals
  - Even if cryptography is perfect
  - Often fail because assumptions unclear
  - Often misapplied because goals unclear

How to break a protocol

- Try to prove it correct
  - Where you get stuck:
    that's where the flaw is
- Central focus: services provided by protocol
  - Actions the protocol requires
    compliant principals to perform
  - Produce values useful to adversary
- Each protocol poses certain challenges to attacker
  - Services help adversary
    to meet those challenges

Needham-Schroeder Protocol

A Simplest Example

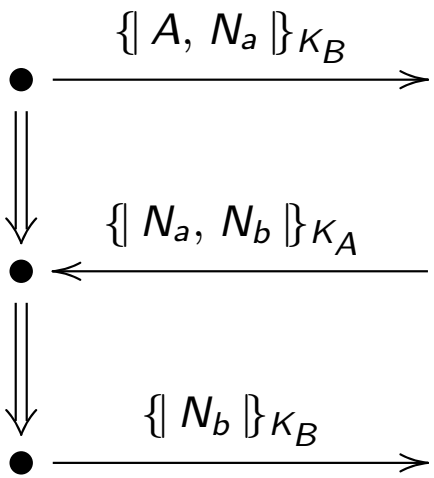


Terminology:

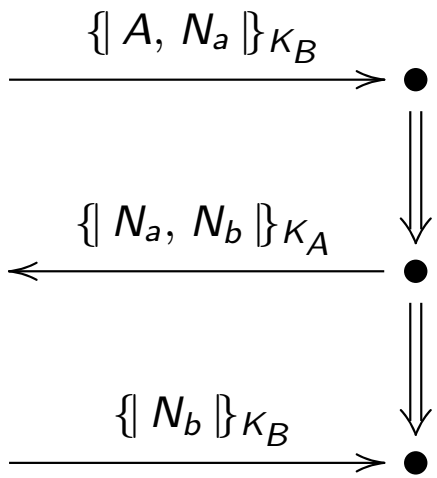
K_A, K_B	Public encryption keys for A and B
N_a, N_b	Randomly chosen bitstrings "nonces"
$\{\mid t \mid\}_K$	t encrypted using K
$N_a,\ N_b$	new shared secret

Roles are templates

Variables instantiated by values



Initiator



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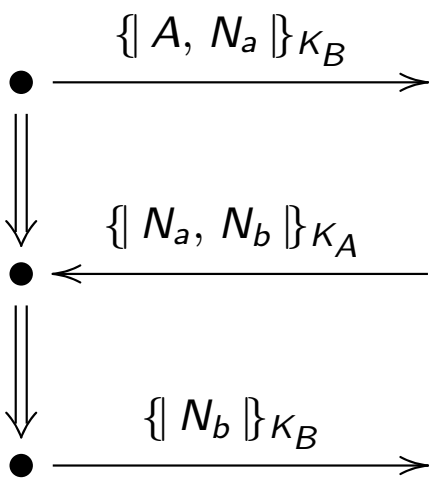

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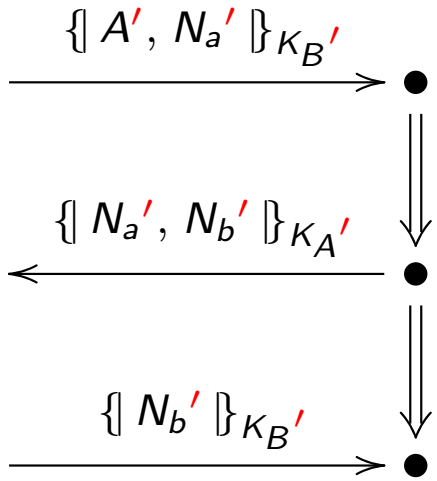

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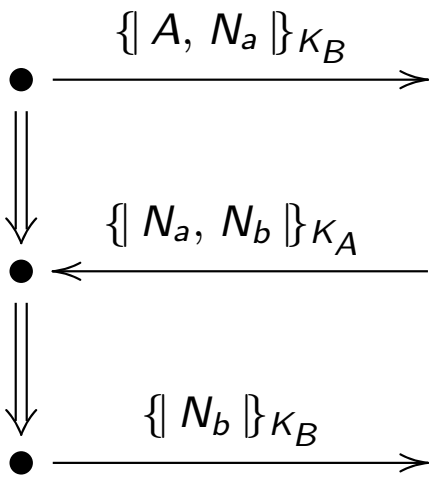

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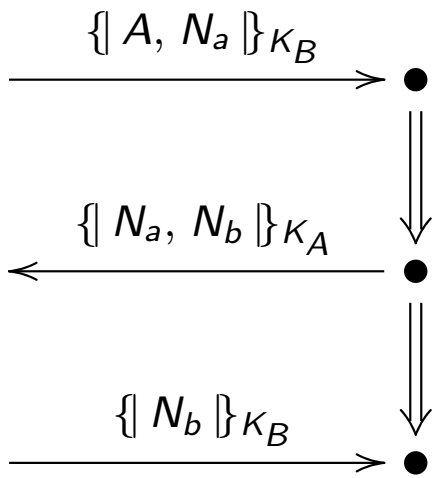

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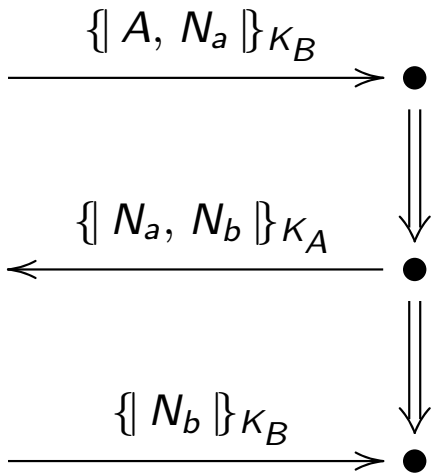
$$\text{In symmetric crypto, } K = K^{-1}$$

- Uncompromised key:

Key used only in accordance with this protocol

Needham-Schroeder: How does it work?

K_A^{-1} uncompromised, N_b fresh



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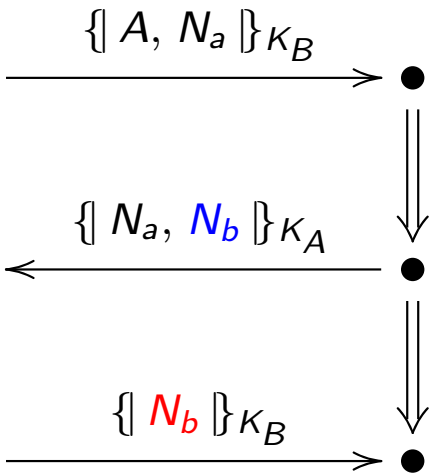

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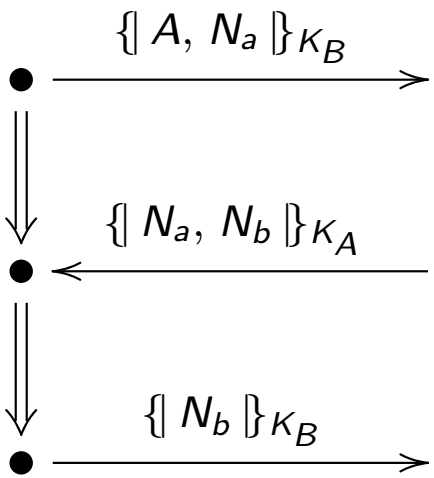

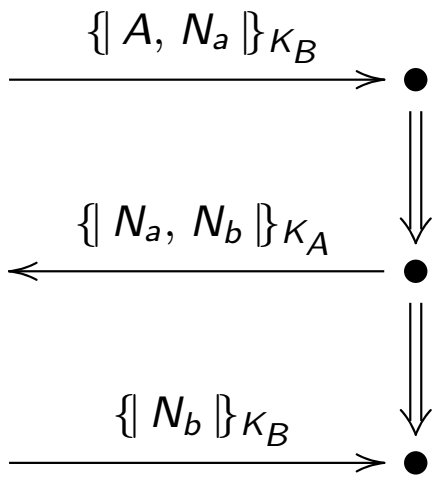

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Responder
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whitespace

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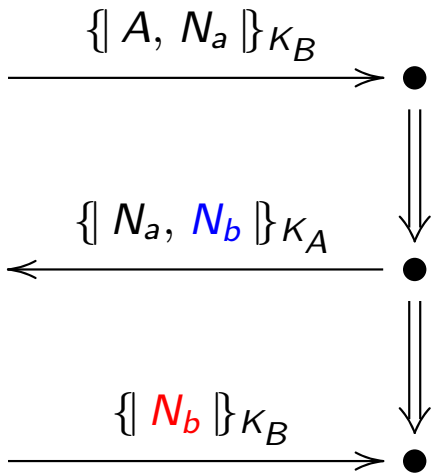

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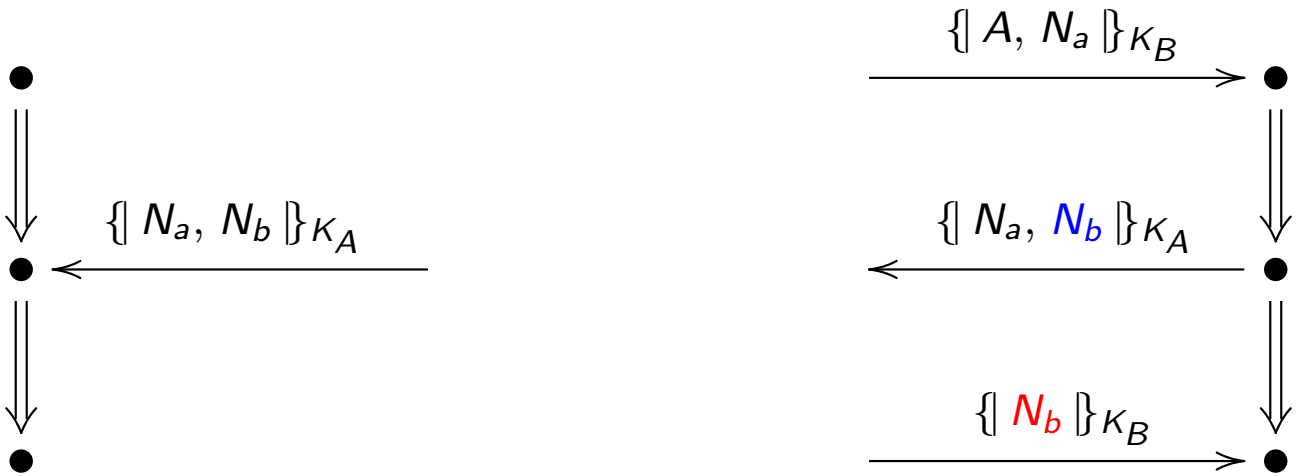

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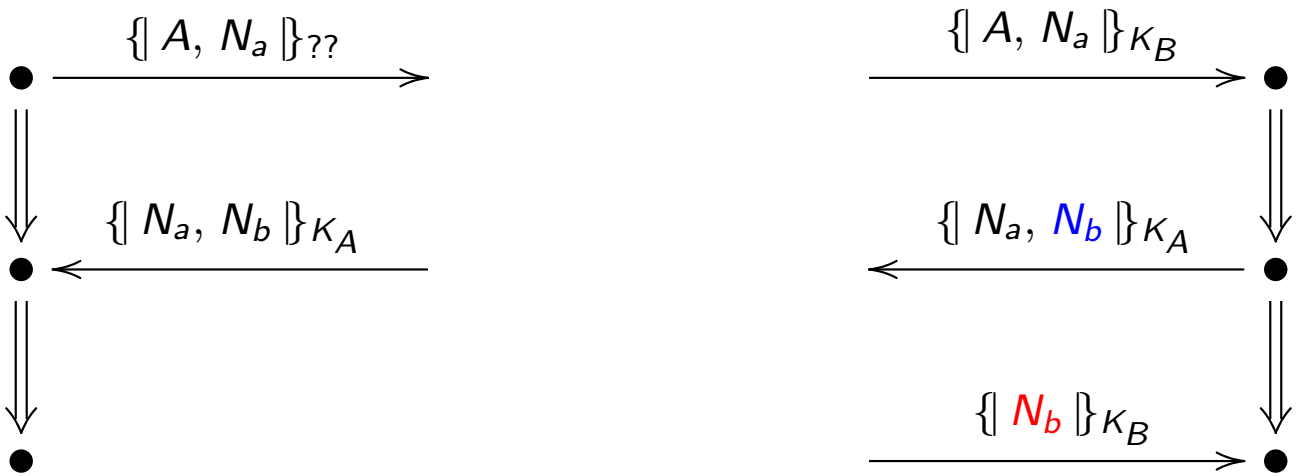

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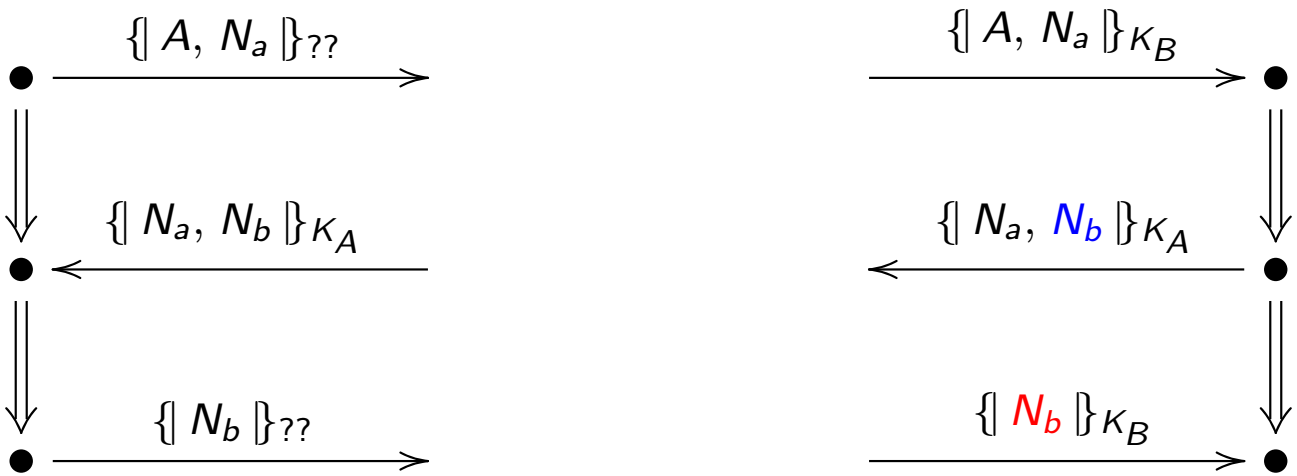

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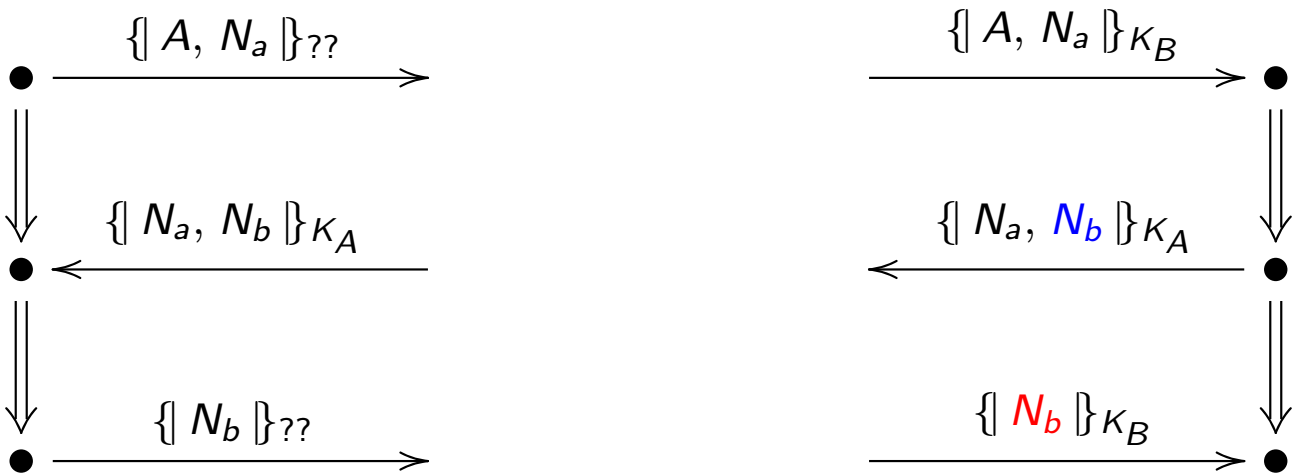
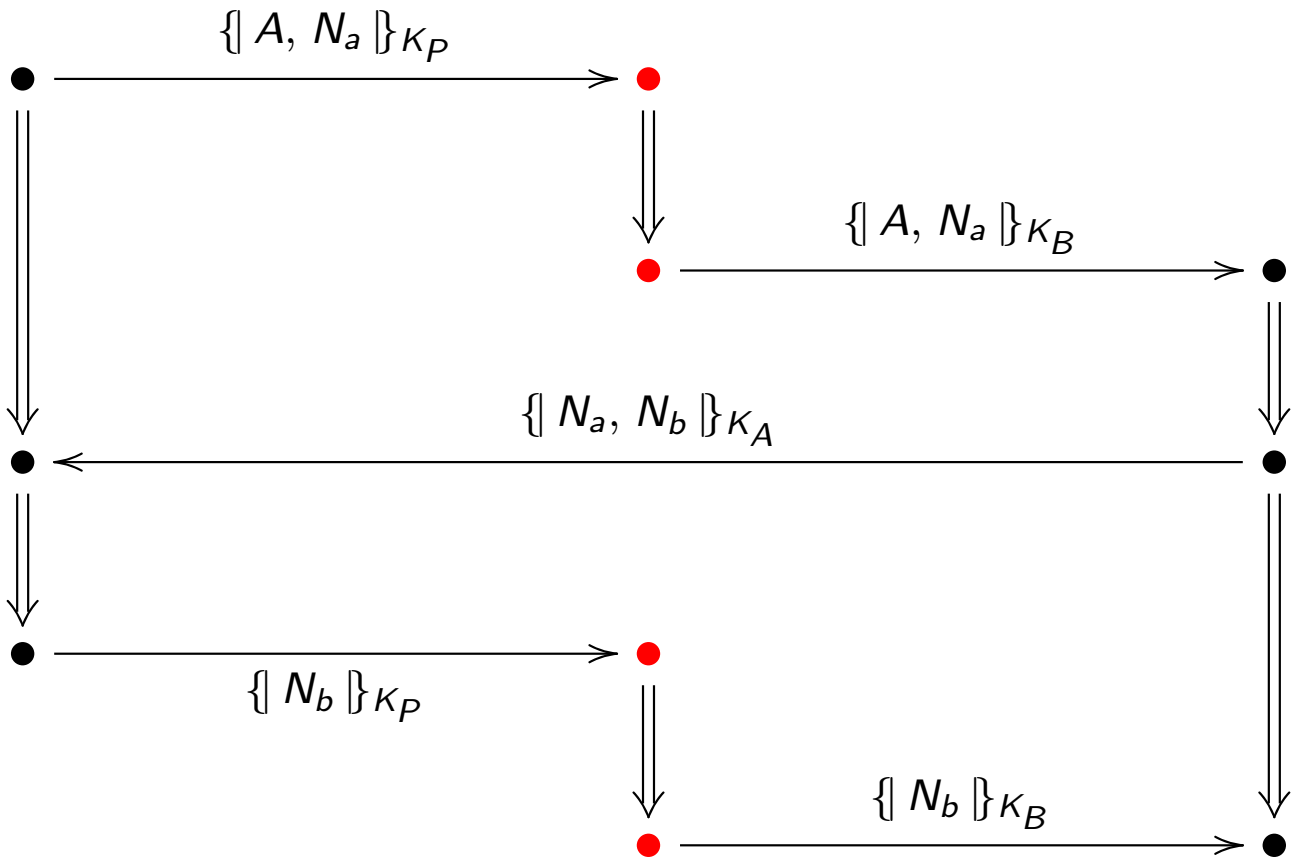


Whoops

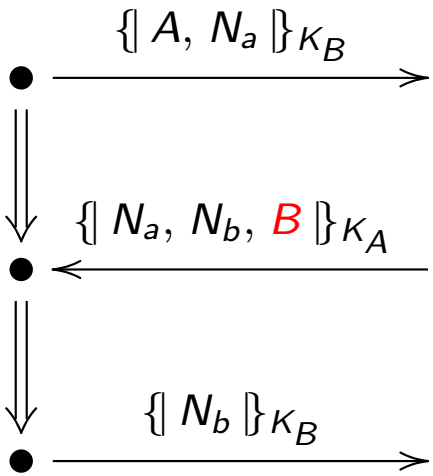
Needham-Schroeder Failure

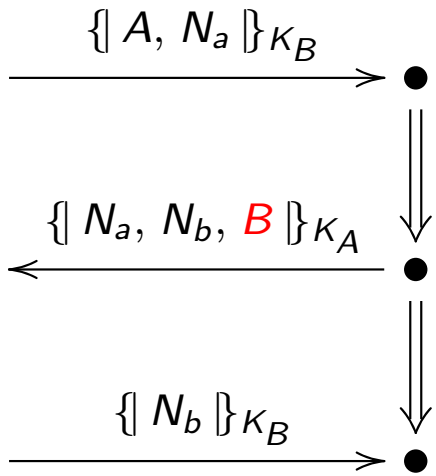
If $?? = K_P$, where K_P^{-1} is compromised:



due to Gavin Lowe

Needham-Schroeder-Lowe





Needham-Schroeder-Lowe Analysis

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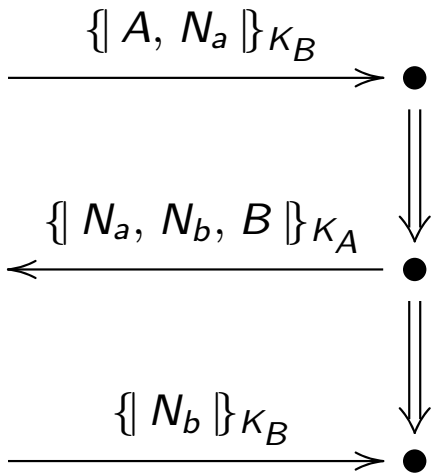

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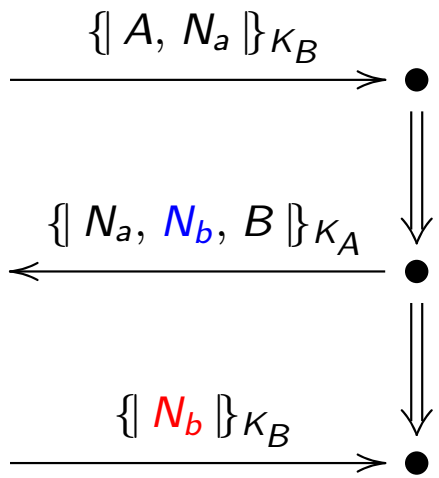

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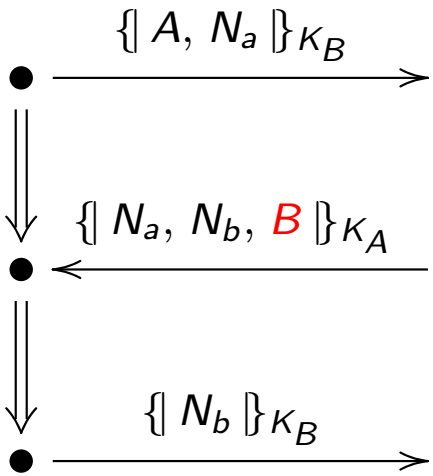

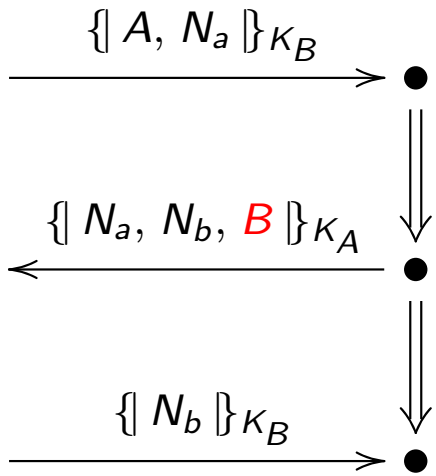

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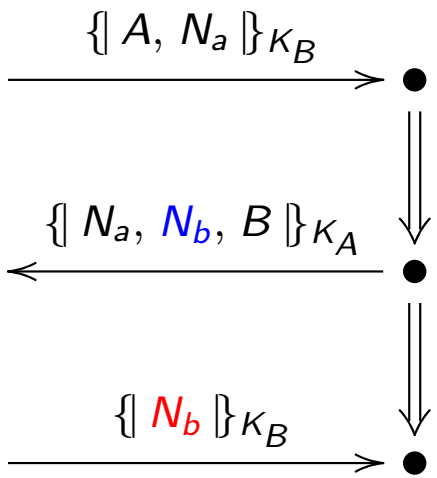

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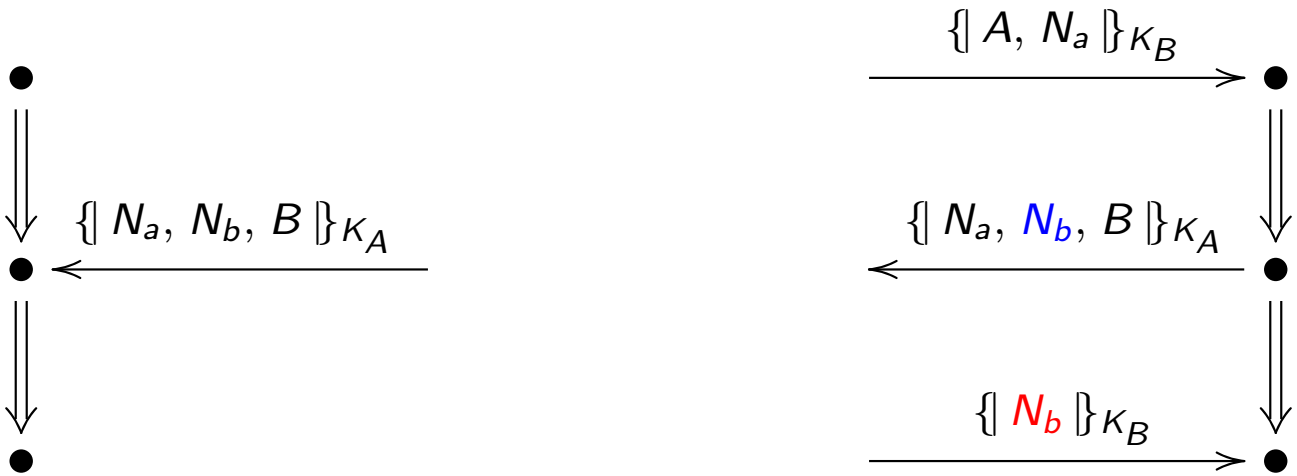

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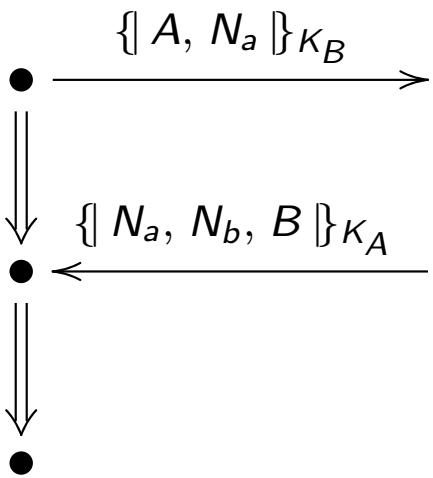

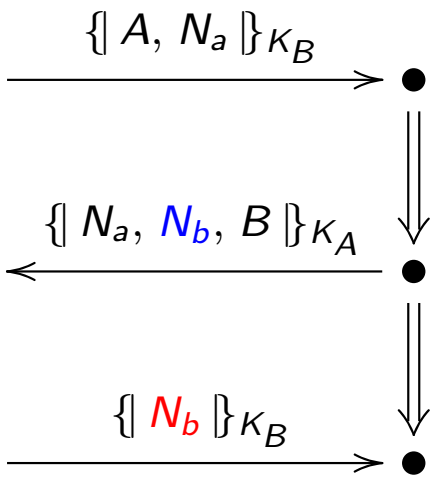

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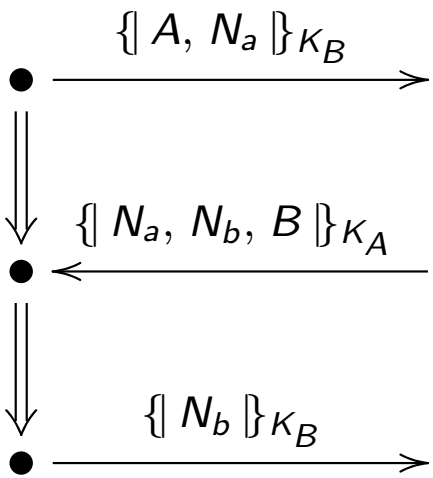

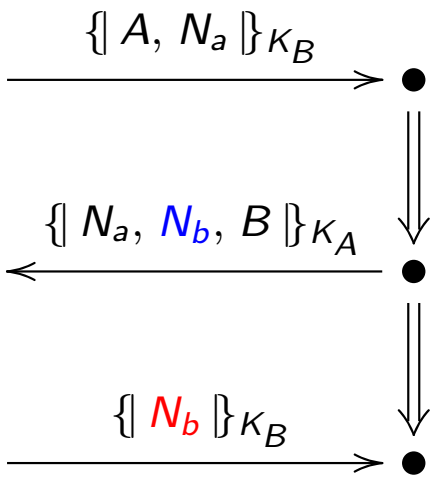

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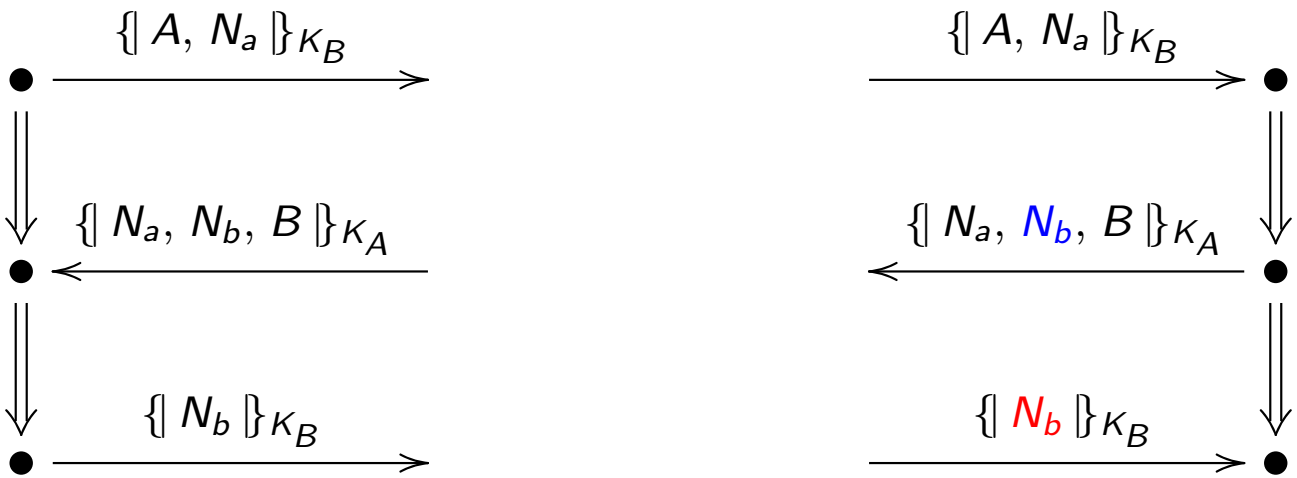

This proves "everything that's true" in this situation

How to break a protocol: Unintended services

Needham-Schroeder Failure

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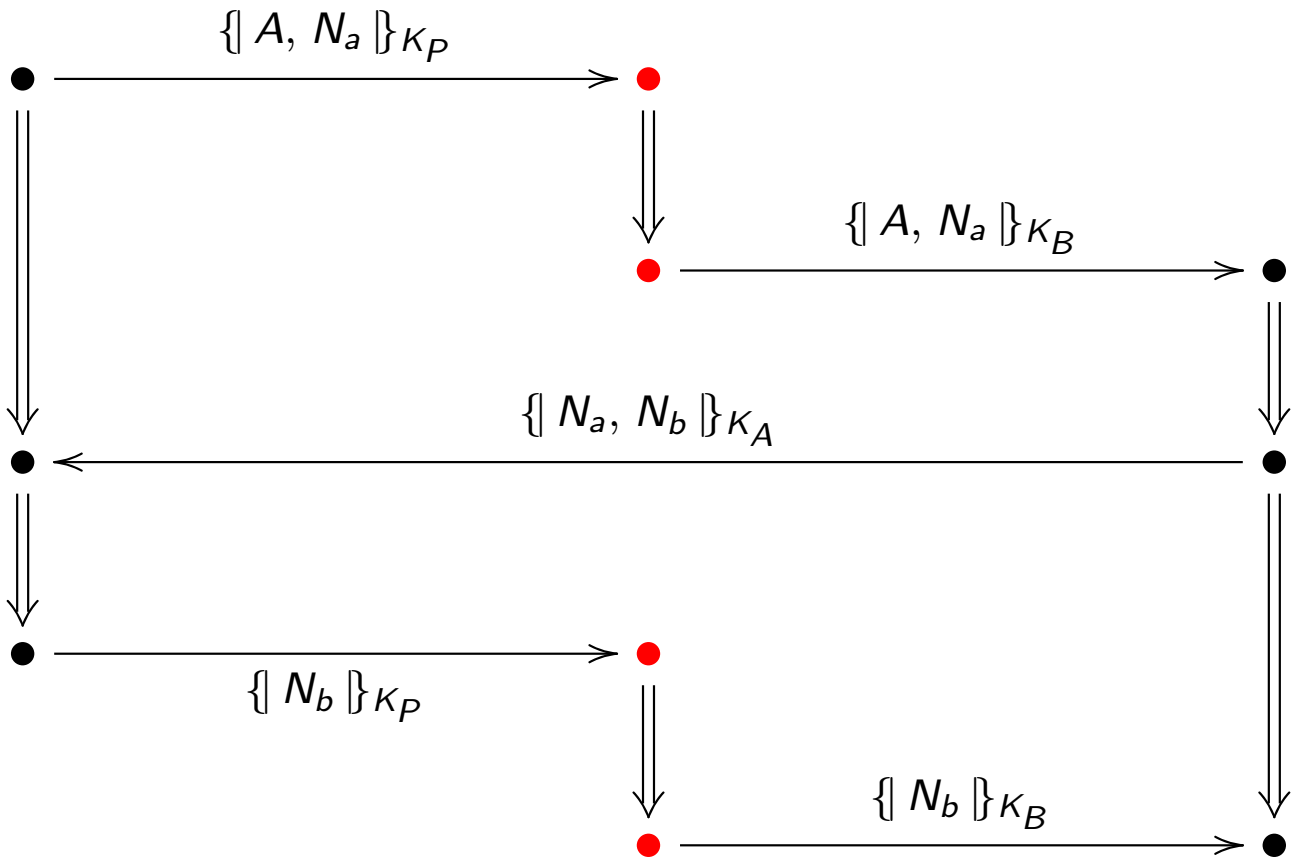

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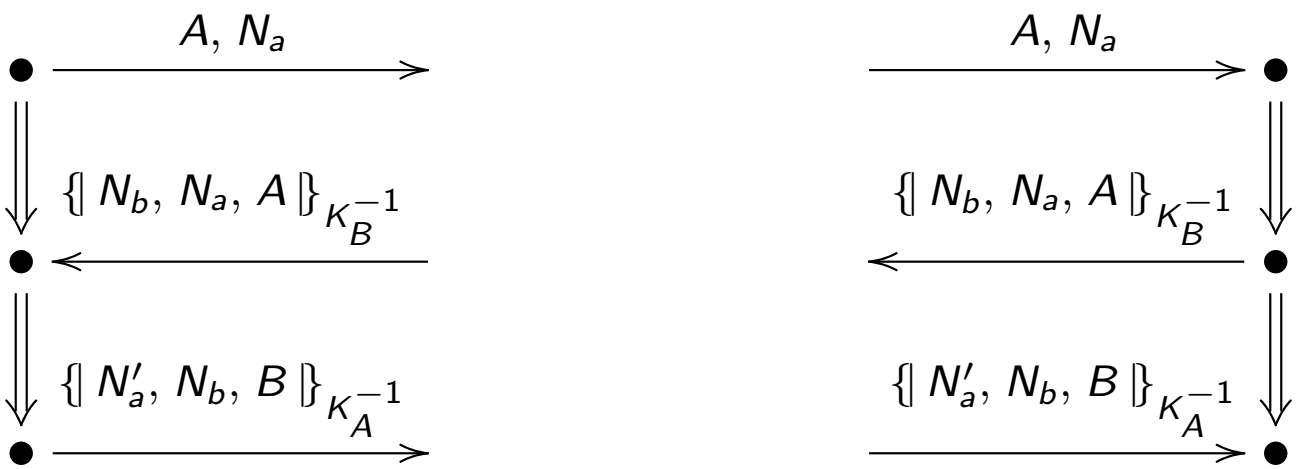
  - "Unintended service"
- Attacker needs to get some value i.e. N_b
  Regular participant unwittingly provides it

Another Example: ISO reject



Digital signatures provide authentication

No new secrets

Diagnosis: ISO reject

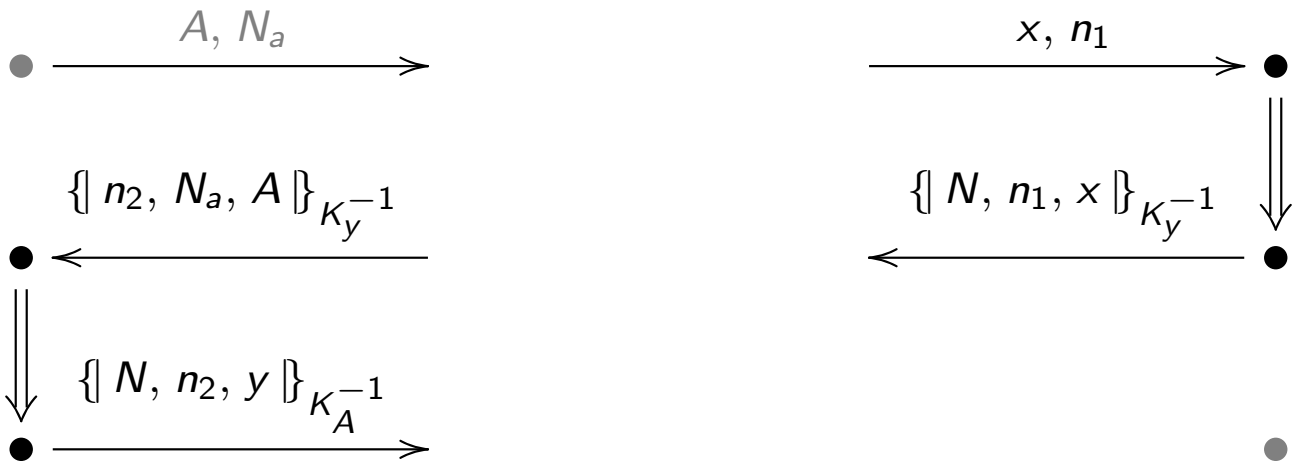
- Responder only gets two messages
  - First message $A,\ N_a$ has no authenticating force
  - Anybody can create a message like that
  - "Junk term"
- Attacker only needs to create

$$\{\!|\ N'_a,\ N_b,\ B\ |\!\}_{K_A^{-1}}$$

  for some N'_a
- What services are useful?

Services in ISO reject

lower case letters are variables chosen by adversary



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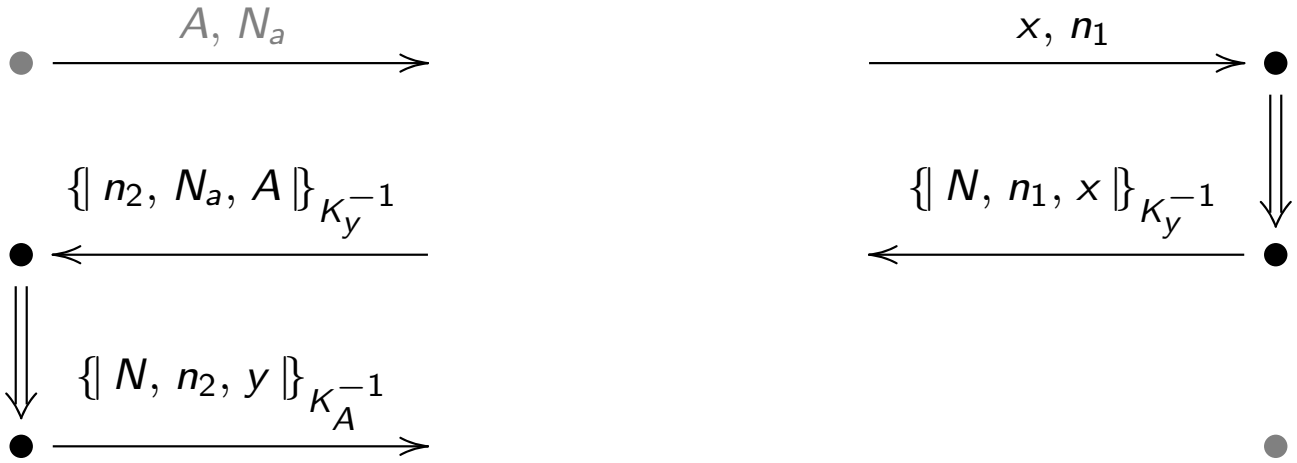

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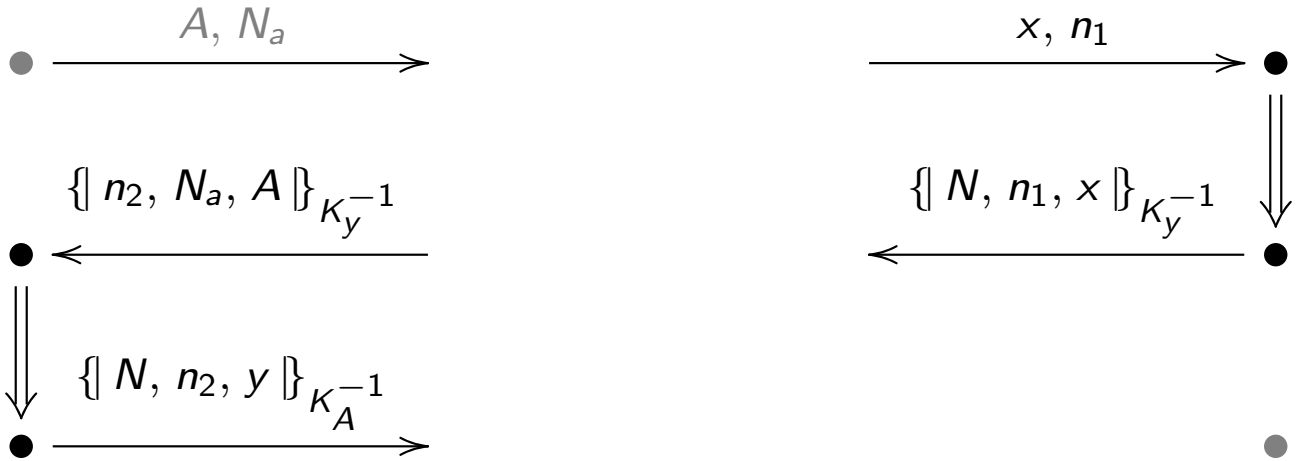

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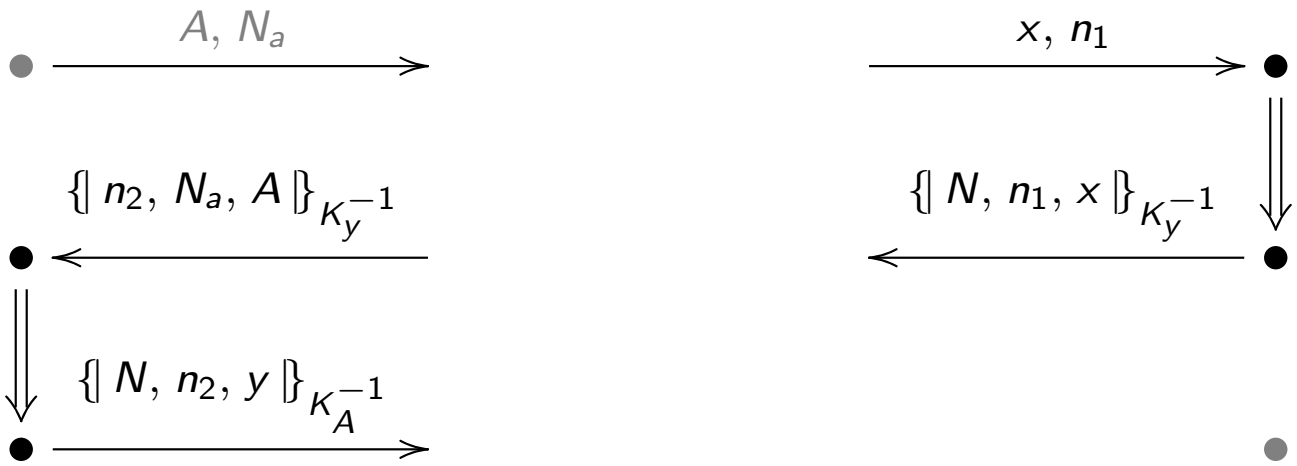
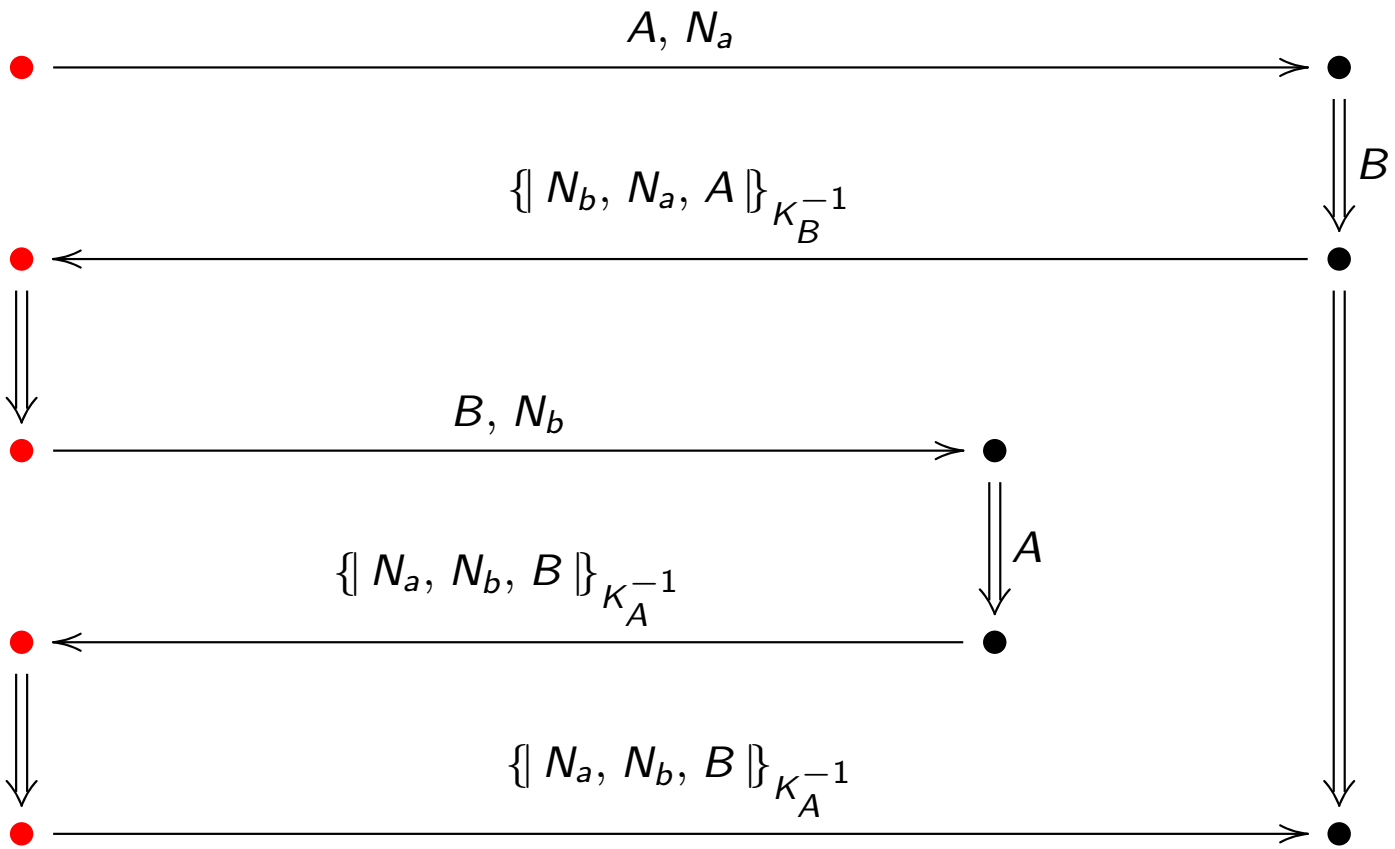


- Adversary freely instantiates lower-case variables
- Want to produce $\{\!|\ N,\ N_b,\ B\ |\!\}_{K_A^{-1}}$ for some N
- Can use A as respondent, $B,\ N_b$ as selected msg i.e. substitution $[B/x, A/y, N_b/n_1]$

The resulting attack

The Canadian Attack



What goal is refuted?

- A executed a signature
- So "entity authentication" may hold for A

Whatever that means

- But A never initiated any session with B

Dolev-Yao Attacks: A Recipe

- Identify and discard "junk" messages
  - They don't contribute to authentication
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- Combine unintended services

What unintended services occur?

Signature:	N_a	$\mapsto$	$\{ N_a \}_{K^{-1}}$
Encryption:	N_a	$\mapsto$	$\{ N_a \}_K$
Decryption:	$\{ N_a \}_K$	$\mapsto$	N_a
Translation:	$\{ N_a \}_K$	$\mapsto$	$\{ N_a \}_{K'}$

Examples:

Signature service: *ISO reject protocol*
Encryption service: *Woo-Lam*
Decryption service: *None* *(too obvious?)*
Key-translation service: *NS PK*

The Dolev-Yao Problem

- Given a protocol, and assuming all cryptography perfect, find
  - What secrecy properties
  - What authentication properties

  the protocol achieves
- Find counterexamples to other properties
  - Unintended services useful
- What does perfect cryptography mean?
  - No collisions
  - Need key to make encrypted value
  - Need key to decrypt and recover plaintext

How to break a protocol

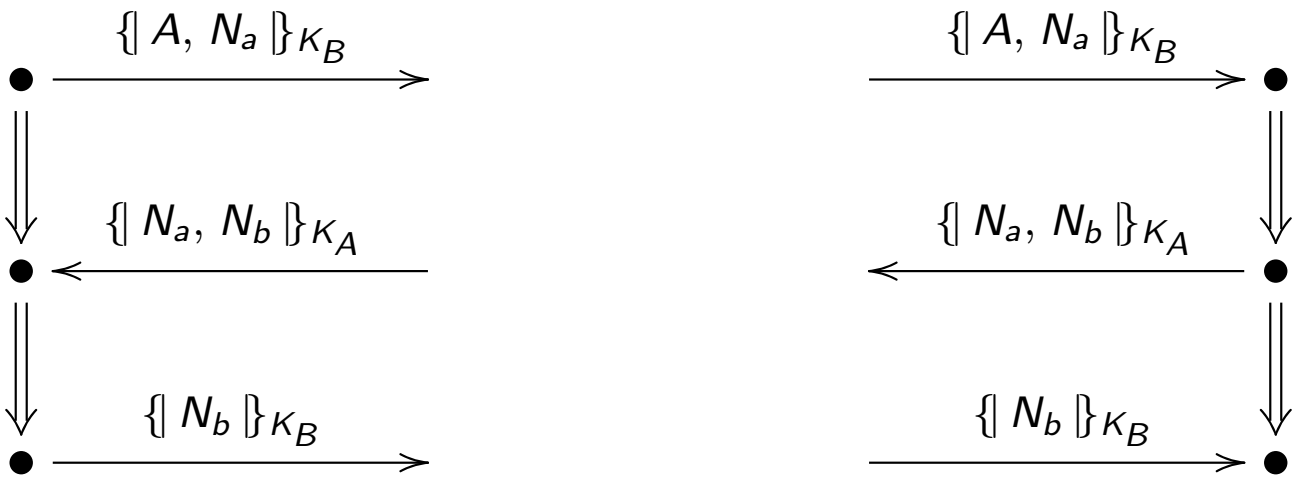
- Try to prove it correct
  - Where you get stuck:
    that's where the flaw is
- Central focus: services provided by protocol
  - Actions the protocol requires
    compliant principals to perform
  - Produce values useful to adversary
- Each protocol poses certain challenges to attacker
  - Services help adversary
    to meet those challenges

How to break a protocol

- Try to prove it correct
  - Where you get stuck:
    that's where the flaw is
- Central focus: services provided by protocol
  - Actions the protocol requires
    compliant principals to perform
  - Produce values useful to adversary
- Each protocol poses certain challenges to attacker
  - Services help adversary
    to meet those challenges
- How to prove a protocol:
  - Try to break it
  - If you get stuck — run out of services — it's correct

Needham-Schroeder Protocol

A Simplest Example

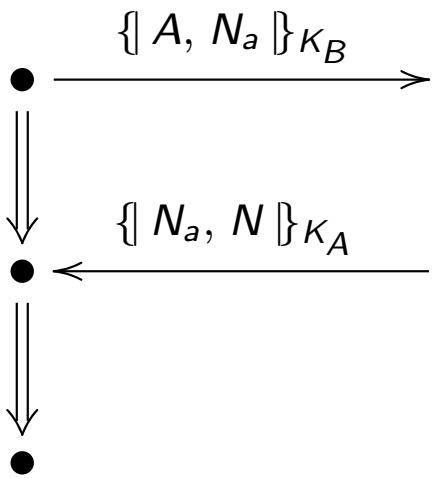


Terminology:

K_A, K_B	Public encryption keys for A and B
N_a, N_b	Randomly chosen bitstrings "nonces"
$\{\mid t \mid\}_K$	t encrypted using K
$N_a,\ N_b$	new shared secret

NS Analysis: Initiator's point of view

Assume K_A^{-1}, K_B^{-1} uncompromised, N_a fresh



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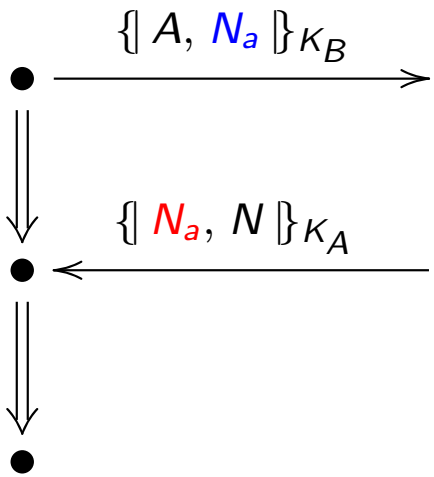

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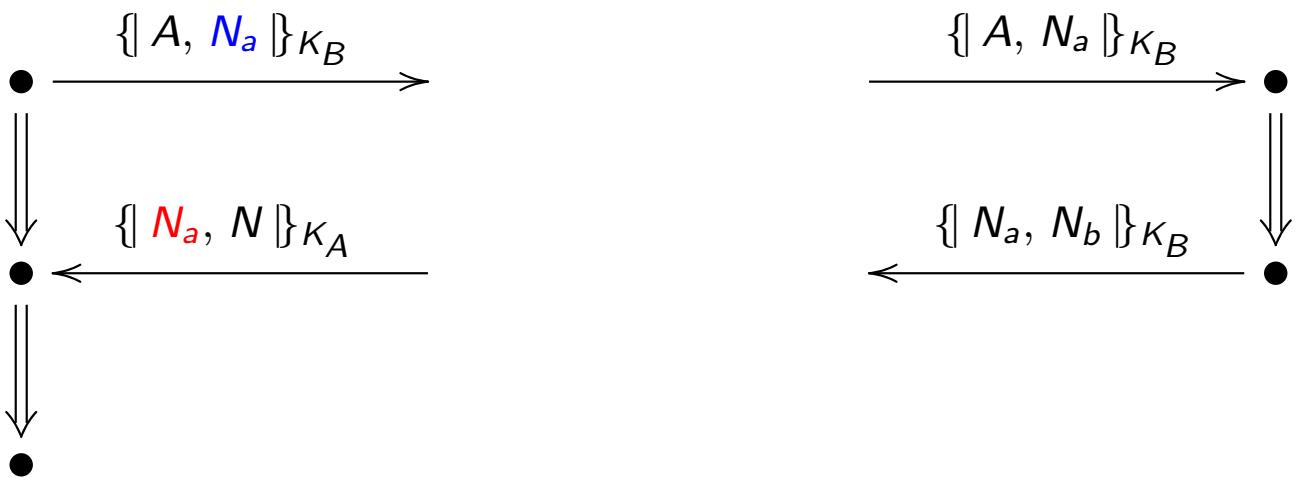

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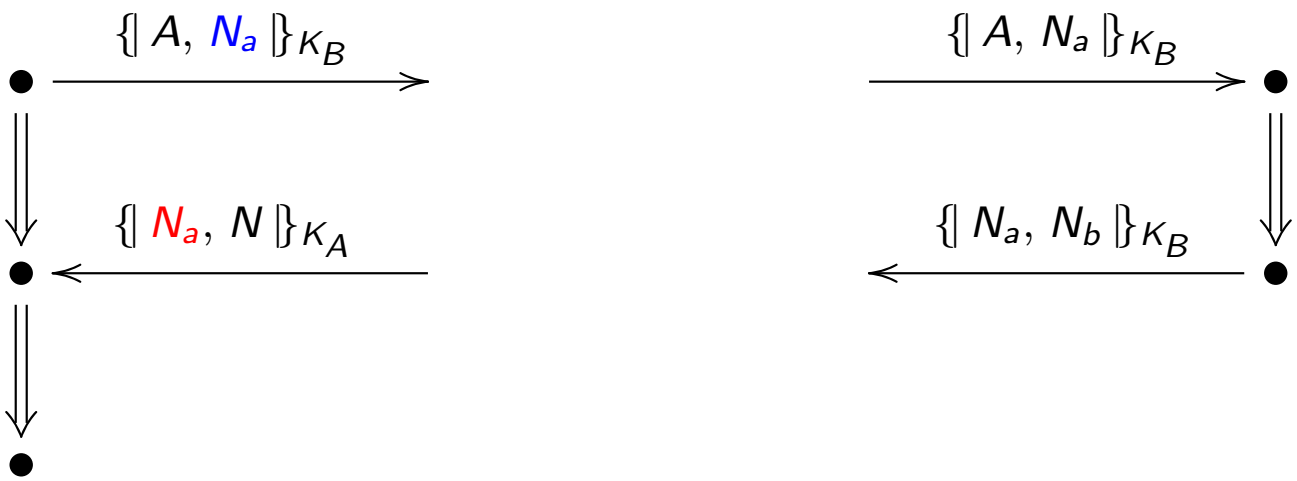

Does $N = N_b$?

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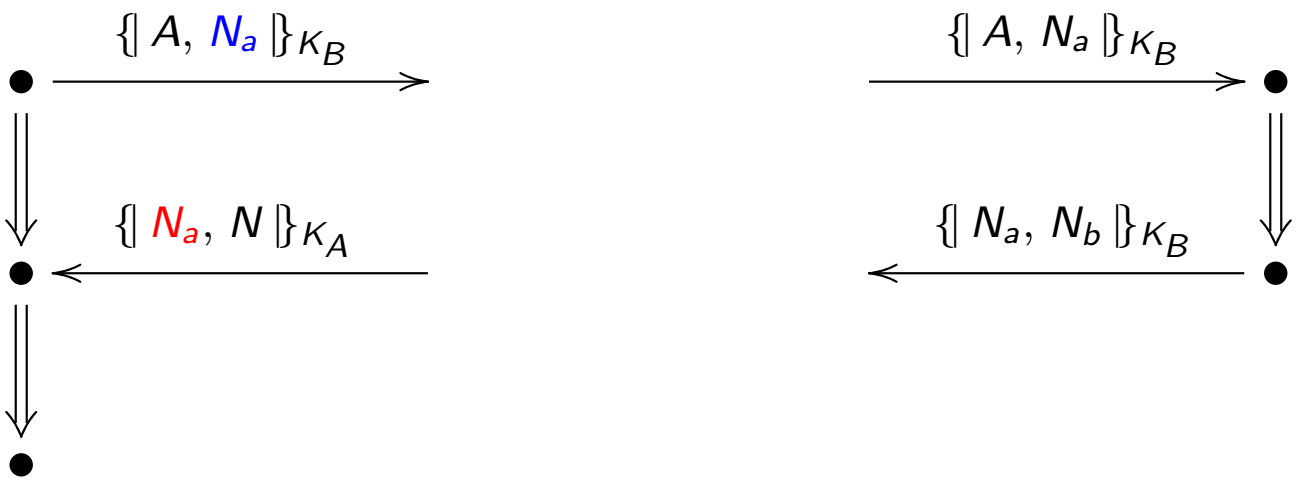

Does $N = N_b$?

Yes, there are no available services!

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Thanks to collaborators:

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