Protocol Verification Techniques - Belief Logics

Design and Verification of Security Protocols and Security Ceremonies

Programa de Pós-Graduacão em Ciências da Computacão
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Disclaimer

Disclaimer!

This lecture is heavily based on material Professor Ravi Sandhu's from University of Texas San Antonio, and from material from "Paul Syverson and Iliano Cervesato, The Logic of Authentication Protocols, Foundations of Security Analysis and Design, LNCS 2171, SpringerVerlag, 2001."

BAN Logic

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- In an analysis, the protocol is first idealised into messages containing assertions;
- Then assumptions are stated;
- Finally conclusions are inferred based on the assertions in the idealized messages and those assumptions.

The language of BAN

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- As we will see, every formula can be a message, but not every message is a formula.

The language of BAN

- P believes X :

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- P believes X :
- P received X :

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- P believes X :
- P received X :
- P said X :

The language of BAN

- P believes X :
- P received X :
- P said X :
- P controls X :

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- P received X :
- P said X :
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- fresh(X) :

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- $\{X\}_k$:
  - This is the notation for encryption;
  - Principals can recognize their own messages;
  - Encrypted messages are uniquely readable and verifiable as such by holders of the right keys.

BAN Rules: Message Meaning

$$\frac{\begin{array}{c} P \quad \mathit{believes} \quad P \stackrel{k}{\leftrightarrow} Q \\ P \quad \mathit{received} \quad \{X\}_k \end{array}}{P \quad \mathit{believes} \quad Q \quad \mathit{said} \quad X}$$

BAN Rules: Message Meaning

$$\frac{\begin{array}{c} P \quad believes \quad P \overset{k}{\leftrightarrow} Q \\ P \quad received \quad \{X\}_k \end{array}}{P \quad believes \quad Q \quad said \quad X}$$

- “If P receives X encrypted with k and if P believes k is a good key for talking with Q, then P believes Q once said X.”

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$$\frac{\begin{array}{c} P \quad \mathit{believes} \quad PK(Q, k) \\ P \quad \mathit{received} \quad \{X\}_{k^{-1}} \end{array}}{P \quad \mathit{believes} \quad Q \quad \mathit{said} \quad X}$$

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- There is no explicit distinction between signing and encryption;

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- There is no explicit distinction between signing and encryption;
- Both are represented by $\{X\}_k$ or $\{X\}_{k^{-1}}$;
- The distinction is implicit in the notation for the key used: k or k-1.

BAN Rules: Nonce Verification

$$\frac{P \quad believes \quad fresh(X) \qquad P \quad believes \quad Q \quad said \quad X}{P \quad believes \quad Q \quad believes \quad X}$$

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- This rule allows promotion from the past to the present (something said some time in the past to a present belief);

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- This rule allows promotion from the past to the present (something said some time in the past to a present belief);
- In order to be applied, X should not contain any encrypted text.

BAN Rules: Jurisdiction

$$\frac{P \quad believes \quad Q \quad controls \quad X \qquad P \quad believes \quad Q \quad believes \quad X}{P \quad believes \quad X}$$

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$$\frac{P \quad believes \quad Q \quad controls \quad X \qquad P \quad believes \quad Q \quad believes \quad X}{P \quad believes \quad X}$$

- The jurisdiction rule allows inferences that a principal believes a key is good, even though it is a random string that he has never seen before.

BAN Rules: Belief Conjuncatenation

$$\frac{\begin{array}{ccc} P & believes & X \\ P & believes & Y \end{array}}{P \quad believes(X, Y)}$$

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$$\frac{P \quad \textit{believes} \quad X \qquad P \quad \textit{believes} \quad Y}{P \quad \textit{believes}(X, Y)}$$

- The obvious rules apply to beliefs concerning concatenations of messages/conjunctions of formulae;

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$$\frac{\begin{array}{c} P \quad believes \quad X \\ P \quad believes \quad Y \end{array}}{P \quad believes(X, Y)}$$

- The obvious rules apply to beliefs concerning concatenations of messages/conjunctions of formulae;
- Concatenations of messages and conjunctions of formulae are both represented as (X,Y) in the above rules.

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BAN Rules: Freshness Conjuncatenation

$$\frac{P \quad believes \quad fresh(X)}{P \quad believes \quad fresh(X, Y)}$$

BAN Rules: Freshness Conjuncatenation

$$\frac{P \quad \mathit{believes} \quad \mathit{fresh}(X)}{P \quad \mathit{believes} \quad \mathit{fresh}(X, Y)}$$

- This is how nonces lend freshness to other messages in BAN.

BAN Rules: Receiving Rules

$$\frac{P \quad believes \quad P \overset{k}{\leftrightarrow} Q \qquad P \quad received \quad \{X\}_k}{P \quad received \quad X}$$

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- A principal receiving a message also receives sub-messages he can uncover.

BAN Protocol Analysis

1. Choose a protocol;

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1. Choose a protocol;
2. Write assumptions about the initial state;
3. Annotate the protocol:
    - For each message transmission $P \rightarrow Q : M$ in the protocol, assert Q received M;
4. Use the logic to derive the beliefs held by protocol principals.

Chosen Protocol: Needham-Schroeder Shared Key Protocols

1. A $\rightarrow$ S: A, B, N_A

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4. B $\rightarrow$ A: $\{N_B\}_{K_{AB}}$

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3. A $\rightarrow$ B: $\{K_{AB}, A\}_{K_{BS}}$
4. B $\rightarrow$ A: $\{N_B\}_{K_{AB}}$
5. A $\rightarrow$ B: $\{N_B - 1\}_{K_{AB}}$

Idealized Needham-Schroeder Shared Key Protocol

2. S $\rightarrow$ A: $\{N_A, A \xleftrightarrow{K_{AB}} B, fresh(K_{AB}), \{A \xleftrightarrow{K_{AB}} B\}_{K_{BS}}, from \quad S$

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- With a shared key, if a recipient can decrypt a message, she can tell who it is from;
- What is inside the encrypted messages is also altered;
- Specifically, the key k_{AB} is replaced by assertions about it;
- Also in the last message $N_B - 1$ is changed to just N_B.

Needham-Schroeder Shared Key Protocol Assumptions

P1 A *believes* $A \overset{K_{AS}}{\longleftrightarrow} S$

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P4 B *believes* S *controls* $A \overset{K_{AB}}{\longleftrightarrow} B$

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P1 A *believes* $A \xleftrightarrow{K_{AS}} S$

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P3 A *believes* S *controls* $A \xleftrightarrow{K_{AB}} B$

P4 B *believes* S *controls* $A \xleftrightarrow{K_{AB}} B$

P5 A *believes* S *controls* $fresh(A \xleftrightarrow{K_{AB}} B)$

Needham-Schroeder Shared Key Protocol Assumptions

P1	A	*believes*	$A \overset{K_{AS}}{\longleftrightarrow} S$		
P2	B	*believes*	$B \overset{K_{BS}}{\longleftrightarrow} S$		
P3	A	*believes*	S	*controls*	$A \overset{K_{AB}}{\longleftrightarrow} B$
P4	B	*believes*	S	*controls*	$A \overset{K_{AB}}{\longleftrightarrow} B$
P5	A	*believes*	S	*controls*	$fresh(A \overset{K_{AB}}{\longleftrightarrow} B)$
P6	A	*believes*	$fresh(N_A)$		

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P4	B	*believes*	S	*controls*	$A \overset{K_{AB}}{\longleftrightarrow} B$
P5	A	*believes*	S	*controls*	$fresh(A \overset{K_{AB}}{\longleftrightarrow} B)$
P6	A	*believes*	$fresh(N_A)$		
P7	B	*believes*	$fresh(N_B)$		

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- P1, P2 are beliefs in quality of long term keys;
- S has similar beliefs but are not relevant;
- P3, P4, P5 are jurisdiction beliefs;
- P6, P7 are beliefs in freshness of each principal's nonces.

Needham-Schroeder Shared Key Protocol Annotations

P8 $\quad A \quad recieved \quad \{N_A, A \xleftrightarrow{K_{AB}} B, fresh(K_{AB}),$
$\{A \xleftrightarrow{K_{AB}} B\}_{K_{BS}}, from \quad S$

Needham-Schroeder Shared Key Protocol Annotations

$$\begin{array}{lll} \text{P8} & A \quad \textit{recieved} & \{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, \textit{fresh}(K_{AB}), \\ & \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}, \textit{from} \quad S & \\ \text{P9} & B \quad \textit{recieved} & \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}, \textit{from} \quad S \end{array}$$

Needham-Schroeder Shared Key Protocol Annotations

$$
\begin{array}{llll}
\text{P8} & A & \textit{recieved} & \{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, \textit{fresh}(K_{AB}), \\
& \multicolumn{3}{l}{\{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}, \textit{from} \quad S} \\
\text{P9} & B & \textit{recieved} & \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}, \textit{from} \quad S \\
\text{P10} & A & \textit{recieved} & \{N_B, A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{AB}}, \textit{from} \quad B
\end{array}
$$

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\text{P10} & A & \textit{recieved} & \{N_B, A \stackrel{K_{AB}}{\longleftrightarrow} B\}_{K_{AB}}, \textit{from} \quad B \\
\text{P11} & B & \textit{recieved} & \{N_B, A \stackrel{K_{AB}}{\longleftrightarrow} B\}_{K_{AB}}, \textit{from} \quad A
\end{array}
$$

Needham-Schroeder Shared Key Protocol Derivations

1. A believes S said $((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}));$

Needham-Schroeder Shared Key Protocol Derivations

1. A believes S said $((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}))$;
    - By Message Meaning using P1, P8;

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   - By Message Meaning using P1, P8;
2. A believes fresh$((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, \mathit{fresh}(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}))$;

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   - By Message Meaning using P1, P8;
2. A believes fresh$((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}))$;
   - By Freshness Conjuncatenation using 1, P6;

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   - By Message Meaning using P1, P8;
2. A believes fresh$((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}))$;
   - By Freshness Conjuncatenation using 1, P6;
3. 3. A believes S believes $((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}))$;

Needham-Schroeder Shared Key Protocol Derivations

1. A believes S said $((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}));$
   - By Message Meaning using P1, P8;
2. A believes fresh$((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}));$
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3. 3. A believes S believes $((\{N_A, A \overset{K_{AB}}{\longleftrightarrow} B, fresh(K_{AB}), \{A \overset{K_{AB}}{\longleftrightarrow} B\}_{K_{BS}}))$;
   - By Nonce Verification using 2, 1;

Needham-Schroeder Shared Key Protocol Derivations

4. A believes S believes ($A \xleftrightarrow{K_{AB}} B$);

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   - By Belief Conjuncatenation using 3;

Needham-Schroeder Shared Key Protocol Derivations

4. A believes S believes $(A \overset{K_{AB}}{\longleftrightarrow} B)$;
   - By Belief Conjuncatenation using 3;
5. A believes S believes fresh$(A \overset{K_{AB}}{\longleftrightarrow} B)$;

Needham-Schroeder Shared Key Protocol Derivations

4. A believes S believes ($A \xleftrightarrow{K_{AB}} B$);
   - By Belief Conjuncatenation using 3;
5. A believes S believes fresh($A \xleftrightarrow{K_{AB}} B$);
   - By Belief Conjuncatenation using 3;

Needham-Schroeder Shared Key Protocol Derivations

4 A believes S believes ($A \overset{K_{AB}}{\longleftrightarrow} B$);
   - By Belief Conjuncatenation using 3;

5 A believes S believes fresh($A \overset{K_{AB}}{\longleftrightarrow} B$);
   - By Belief Conjuncatenation using 3;

6 A believes ($A \overset{K_{AB}}{\longleftrightarrow} B$);

Needham-Schroeder Shared Key Protocol Derivations

4. A believes S believes $(A \overset{K_{AB}}{\longleftrightarrow} B)$;
   - By Belief Conjuncatenation using 3;
5. A believes S believes fresh$(A \overset{K_{AB}}{\longleftrightarrow} B)$;
   - By Belief Conjuncatenation using 3;
6. A believes $(A \overset{K_{AB}}{\longleftrightarrow} B)$;
   - By Jurisdiction using 4, P3;

Needham-Schroeder Shared Key Protocol Derivations

7 A believes fresh($A \overset{K_{AB}}{\longleftrightarrow} B$);

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- By Jurisdiction using 4, P5;

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Here we finished proving Alice's Beliefs. She believes K_{AB} is secure and fresh.

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- By Message Meaning using P2, P9;

Needham-Schroeder Shared Key Protocol Derivations

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Here we finished proving Alice's Beliefs. She believes K_{AB} is secure and fresh.

8 B believes S said ($A \overset{K_{AB}}{\longleftrightarrow} B$);

- By Message Meaning using P2, P9;

Bob believes K_{AB} is secure, but has nothing regarding freshness.

Needham-Schroeder Shared Key Protocol Derivations

We need to introduce a new Assumption:

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$$\text{P12} \quad B \quad \textit{believes} \quad \textit{fresh}(A \xleftrightarrow{K_{AB}} B)$$

Needham-Schroeder Shared Key Protocol Derivations

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Attention!

This is sketchy, since Bob believes that a random value generated by someone else is fresh.

Needham-Schroeder Shared Key Protocol Derivations

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Needham-Schroeder Shared Key Protocol Derivations

9. B believes S believes ($A \overset{K_{AB}}{\longleftrightarrow} B$);
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    - By Jurisdiction using P4, 9.

Needham-Schroeder Shared Key Protocol Derivations

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  - By Nonce Verification using 12, 11;

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  - By Belief Conjuncatenation using 13.

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- In particular, BAN logic assumes that agents always recognize and ignore messages that they have sent themselves;
- BAN logic assumes that all protocol participants are honest. No compromised agents are considered. Attackers do not have valid keys.

Needham's Quotation

Roger Needham

"The main contribution of BAN logic was to make the study of 3-line protocols intellectually respectable."

Questions????

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