Stateful Protocol Composition or: How we accidentally did Sequential Composition

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This work was supported by the
DFF Sapere Aude project *CompoSec*.

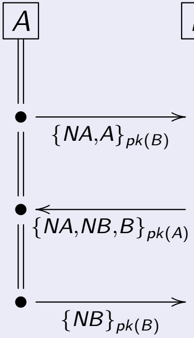
ÖSD 2018

Parallel Composition

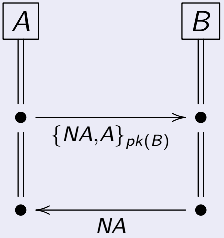
TLS	*IPSec*	*SSH*
Skype	*NemID*	*DNSSec*
DANE	*Quatsch*	*NSL*

Example: Problem with Parallel Composition

NSL

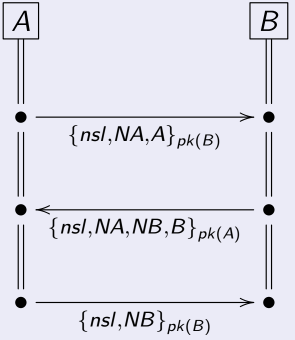


Quatsch



Example: Inserting Tags

NSL



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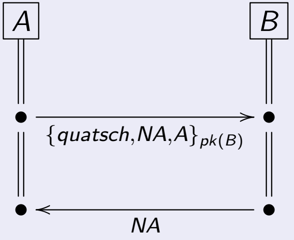
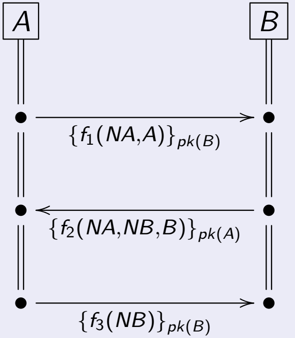
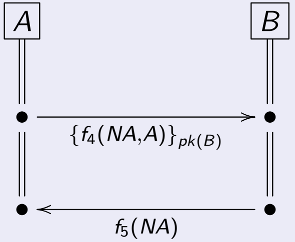


Example: Formats

NSL



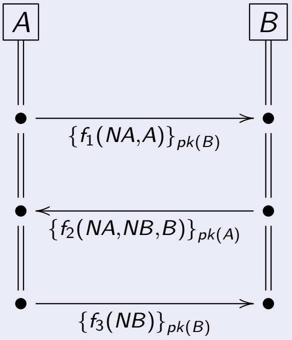
Quatsch



- Transparent functions $f_1, \ldots, f_5$ as abstract syntax
- Concrete syntax must be unambiguous and pairwise disjoint
- Result: Then this it is sound to consider abstract syntax.

Typing Result

NSL



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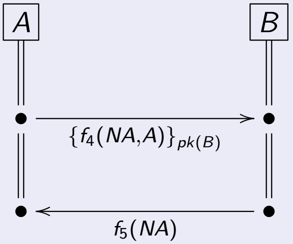
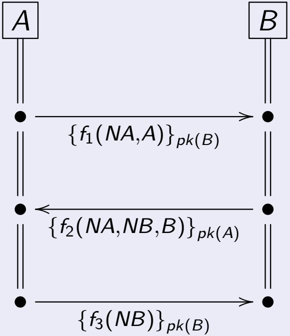


- Assign intended types like $A : Agent$, $NA : Nonce$
- SMP: Patters of the protocol messages (plus subterms, instances)
- Requirement: $s, t \in SMP \setminus \mathcal{V}$ may have a unifier only if they have the same type.
- Result: if there is an attack, then there is well-typed attack

Parallel Composition

NSL



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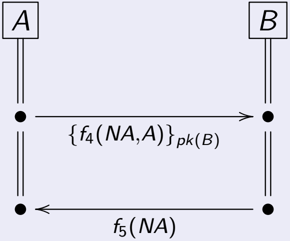
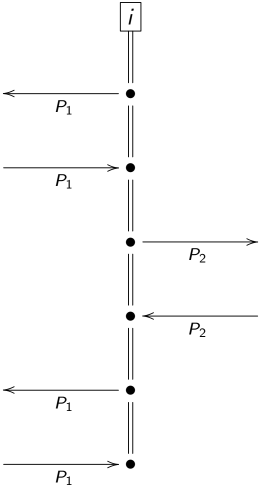


- Requirement: the message patterns (SMP) of the protocols are disjoint
- No protocol leaks long-term secrets to the intruder
- Result: if there is an attack on the composition, then there is one on the individual protocols

The Proof Argument

- Attack trace as a sequence of messages that the intruder sends/receives
- The subtraces for the two protocols work on their own.
- Problem with this argument: often the intruder may use in a P_1 step some messages he learned from a P_2 step.



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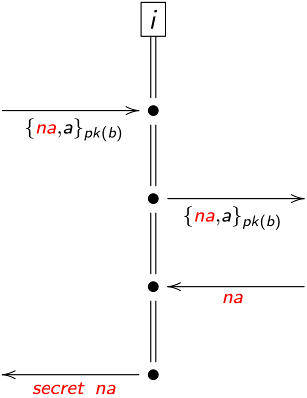
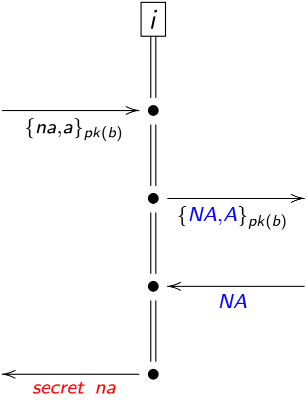


The Proof Argument (Example)

- Constraints – symbolic attack traces
- Describing a set of solutions
- Question: is there one solution where all messages are homogeneous (not mixing the two protocols)?



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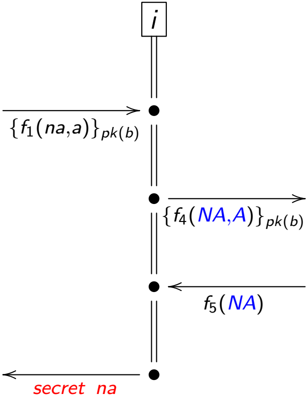
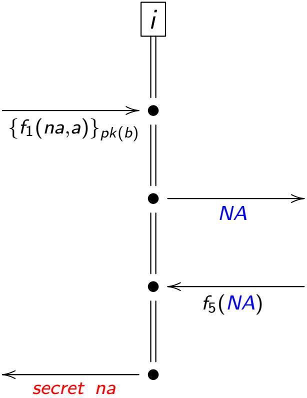


The Proof Argument (Example)

- Constraint reduction: a complete way to find all solutions of a constraint
- If the protocols have disjoint SMPs, the procedure will never unify messages from the two protocols
- The remaining variables represent choices of the intruder and there is always a homogeneous one.



zeb's Keyserver

$Registration(U : User, S : Server, PK : Value)$

$$
\begin{array}{rl}
U/S: & \mathrm{create}(PK) \\
 & \mathrm{insert}(PK, ring(U)) \\
 & \mathrm{insert}(PK, db(S, U, valid)) \\
U/S \rightarrow \_ & PK
\end{array}
$$

$Update(U : User, S : Server, PK : Value, NPK : Value)$

$$
\begin{array}{rl}
U: & \mathrm{select}(PK, ring(U)) \\
 & \mathrm{delete}(PK, ring(U)) \\
 & \mathrm{create}(NPK) \\
 & \mathrm{insert}(NPK, ring(U)) \\
U \rightarrow S: & sign(inv(PK), NPK) \\
S: & \mathrm{in}(PK, db(S, U, valid)) \\
 & \mathrm{notin}(NPK, db(S, \_, \_)) \\
 & \mathrm{delete}(PK, db(S, U, valid)) \\
 & \mathrm{insert}(PK, db(S, U, revoked)) \\
 & \mathrm{insert}(NPK, db(S, U, valid)) \\
S \rightarrow \_: & inv(PK)
\end{array}
$$

Extension to Stateful Protocols

- Idea: set operations (insert, delete, positive/negative checks) can be encoded in constraints with inequalities
- Typing result still works for a large class of problems
- Compositionality also relatively easily as long as
  - ★ The composed protocols do not share the database
  - ★ All secrets are persistent (e.g. not revealing private key after revocation)
  - ★ Can we do without these restrictions?

Another Protocol that uses the database

$PasswordBasedRegistration(U : User, S : Server, PK : Value)$

$S \to U :$	N
$U :$	create(PK)
$U \to S :$	$\{pw(U,S), N, PK\}_{pk(B)}$
$S :$	$insert(PK, db(S, U, valid))$
$S \to \_ :$	PK

- This protocol inserts into the same database.
- Both protocols do ensure authentication and freshness of the key and do not leak it while a key is in the valid set.
- Should be ok to compose like this!

Idea: Protocol Abstraction

- Problem: due to shared use of databases we cannot split the constraints into individual protocols anymore.
- Idea: abstract each protocol into the modifications it can make to the shared database.

zeb's keyserver abstraction

- ★ For honest agents A: generate fresh key and insert into valid database of A.
- ★ For intruder: insert any intruder-known key into valid database for i.
- ★ Revocation: delete a key from valid and give private key to the intruder.

- Verify each protocol individually but together with the abstraction of the other protocol.
  - ★ $P_1 \parallel P_2^\star$
  - ★ $P_1^\star \parallel P_2$
  - ★ i.e., taking into account the changes the other protocol can make.

Stateful Parallel Composition

- Protocols can share the database
- Abstract the modifications each protocol can make and take into account in the other.
    - ★ Assume–guarantee reasoning: e.g. inserted keys are authenticated.
- Declassification of secrets possible: just coordinate via a shared set (e.g. valid)

How we accidentally did Sequential Composition

Scenario

- P_1 generates and exchanges a shared key (e.g. TLS handshake)
- P_2 uses the shared key to start with (e.g. Application protocol with TLS transport)
- Under which conditions is the composition secure?

- Basically, a special case of Stateful Parallel Composition where
  - ★ P_1 inserts the generated key into a shared set $keys(A, B)$
  - ★ P_2 consumes keys from there.

Instead of a Conclusion

- Core result formalized in Isabelle:
  - ★ Typing result (CSF 2017)
  - ★ Typing result for stateful protocols (CSF 2018)
  - ★ Stateful composition result on the constraint level (submitted)
- Revealed several mistakes in existing composition proofs
- The clean formalization has lead to simplifications and generalizations
- Applicable as a theorem in Isabelle:
  - ★ Prove the security of the protocols individually in the typed model
  - ★ Apply our result to get the proof for the untyped model and their composition