Towards Bidirectional Ratcheted Key Exchange

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Information Security Group

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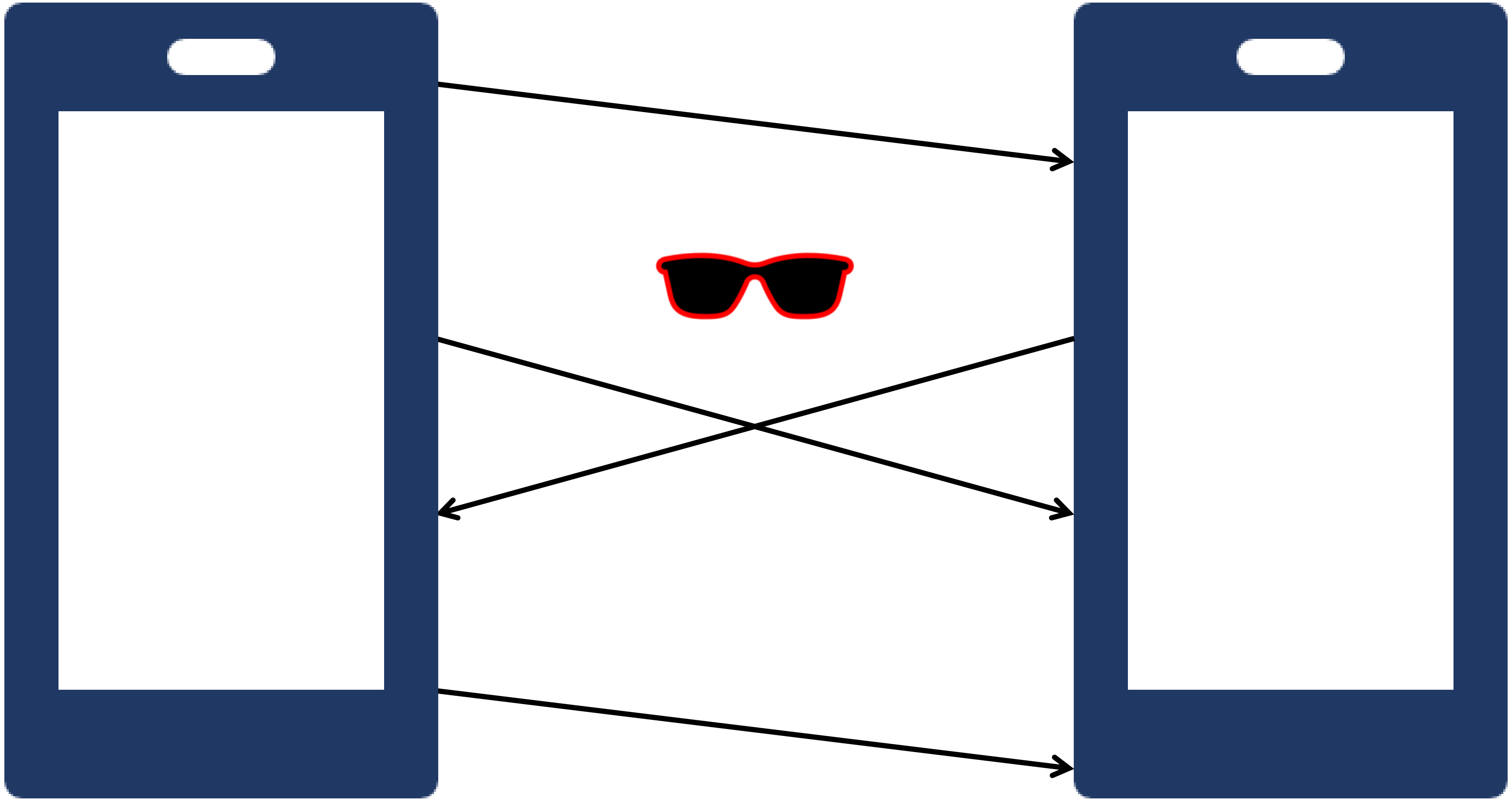
Introduction

- Alice and Bob communicate
- Active adversary



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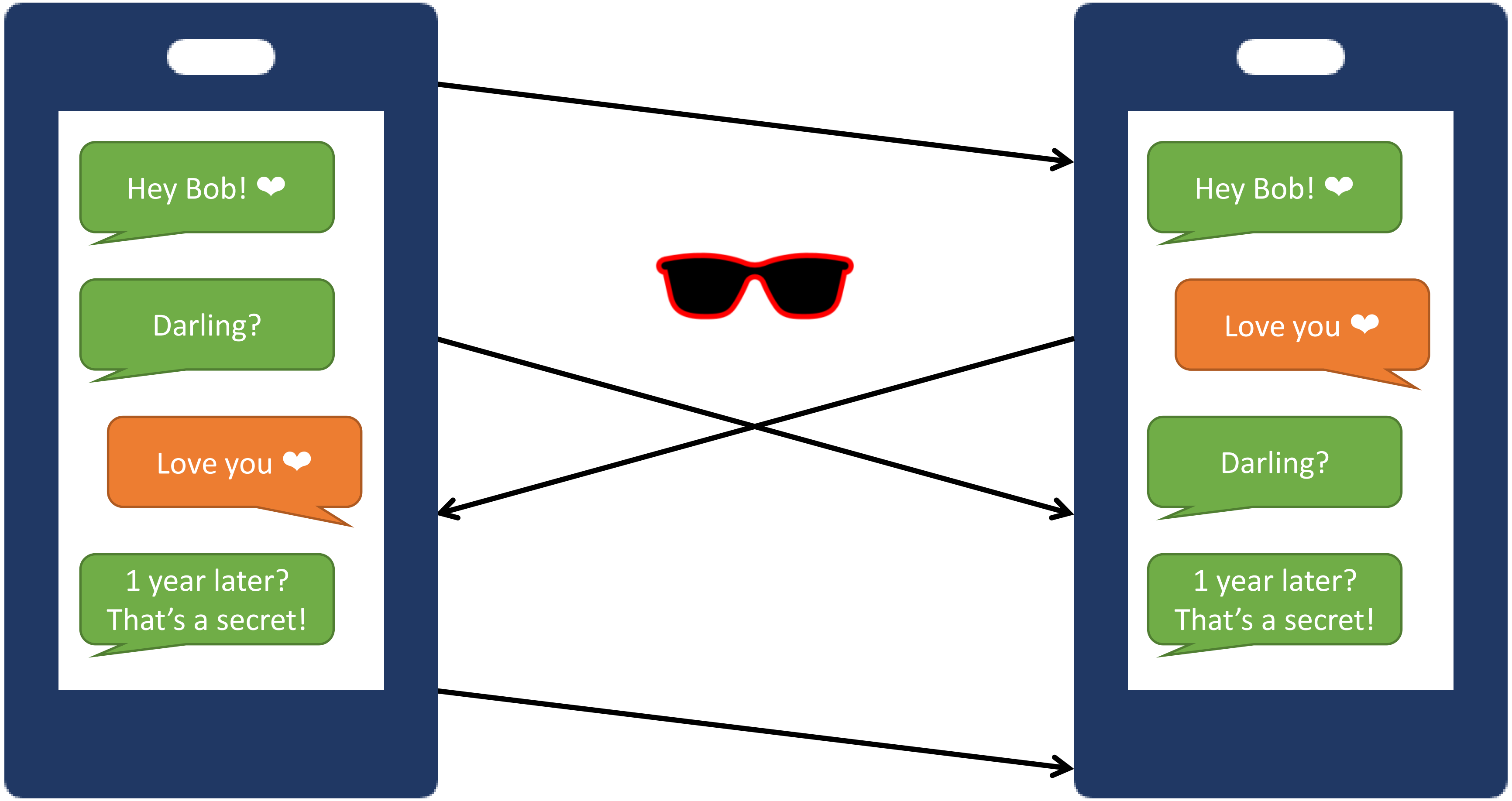
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- Alice and Bob communicate
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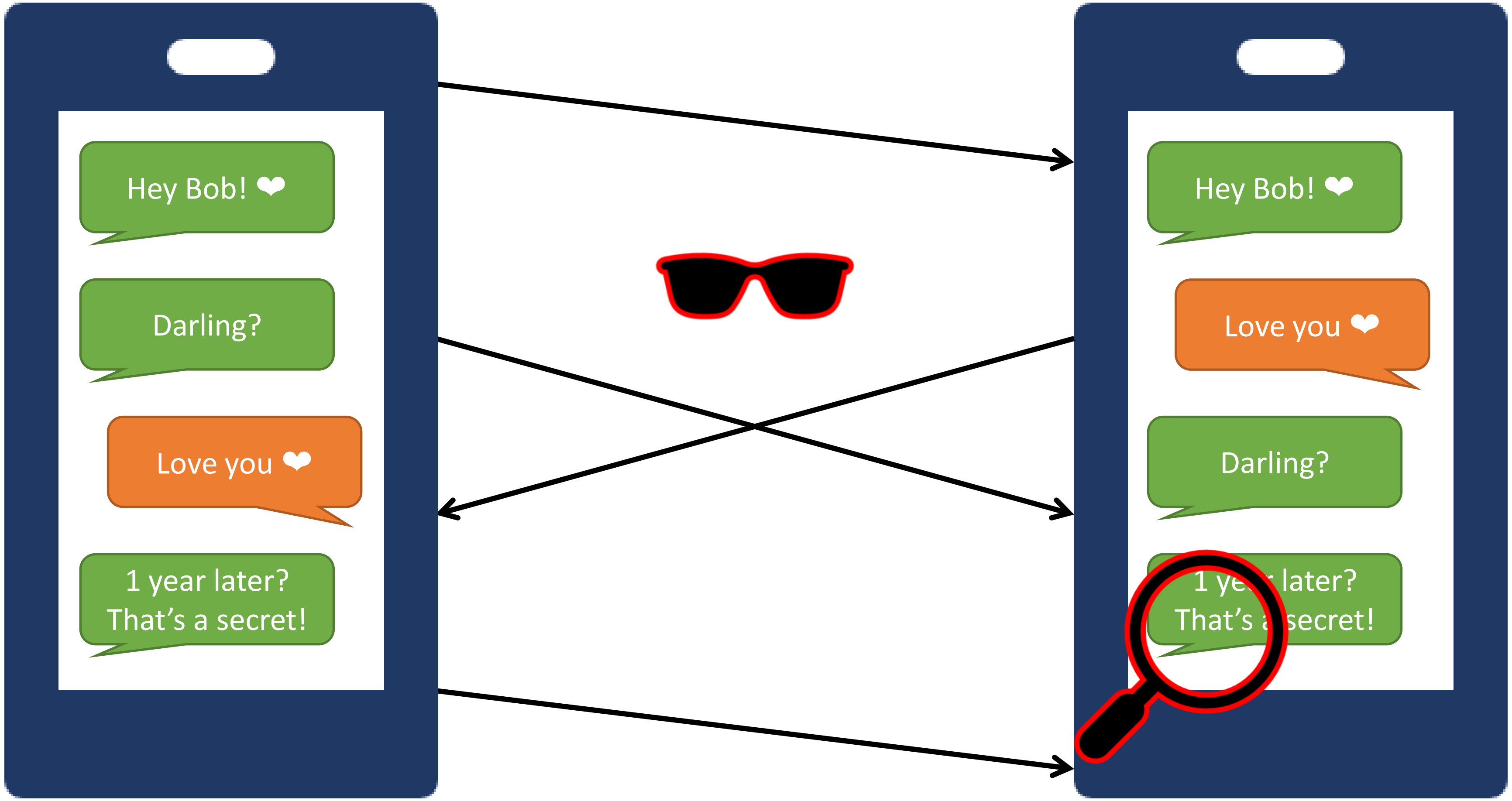
- Long term communication
  - Local (full) state temporarily exposed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- Alice and Bob communicate
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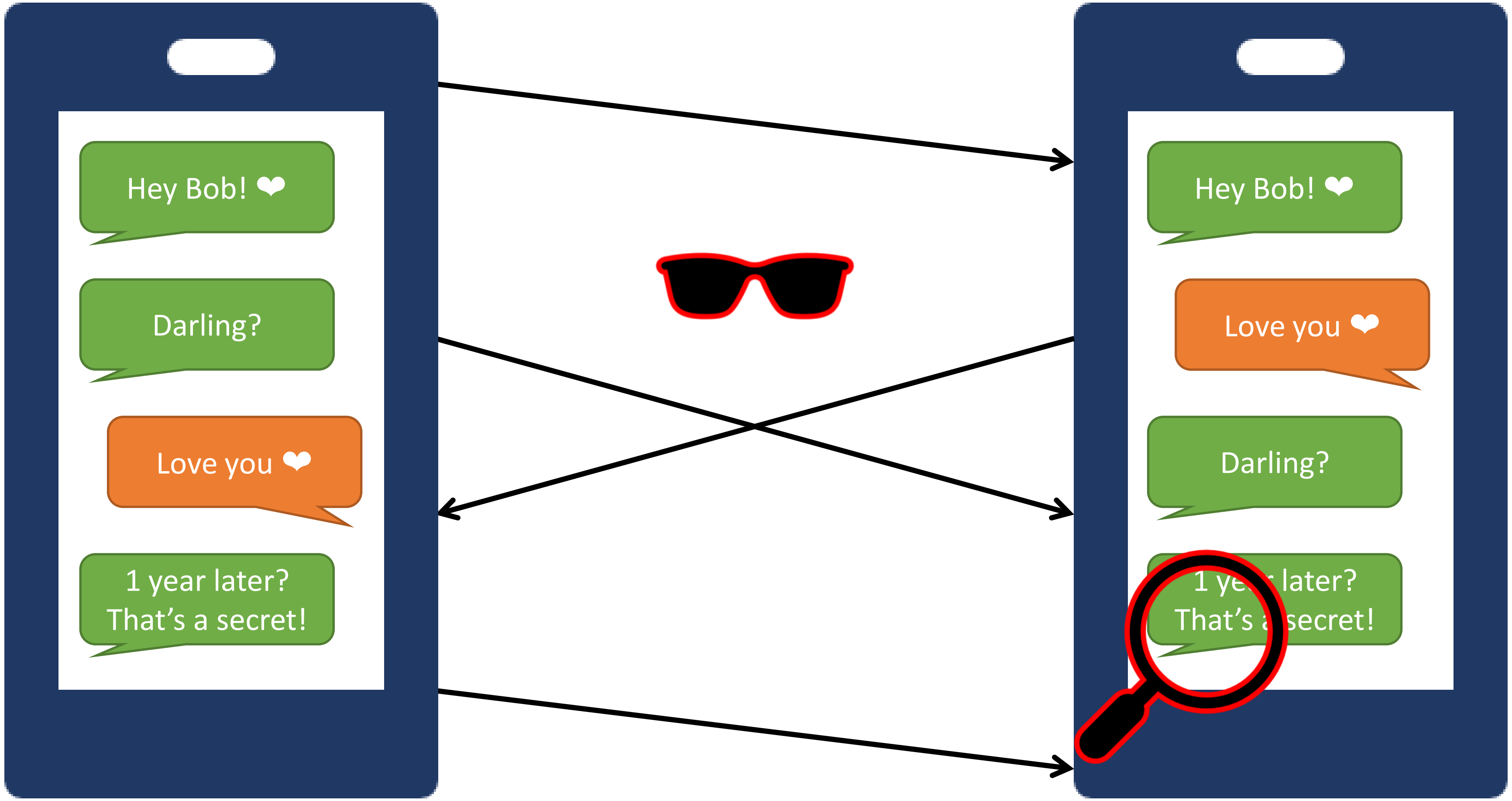
- Long term communication
    - Local (full) state temporarily exposed
- Practical protocols w/o precise security definition
    - E.g., Signal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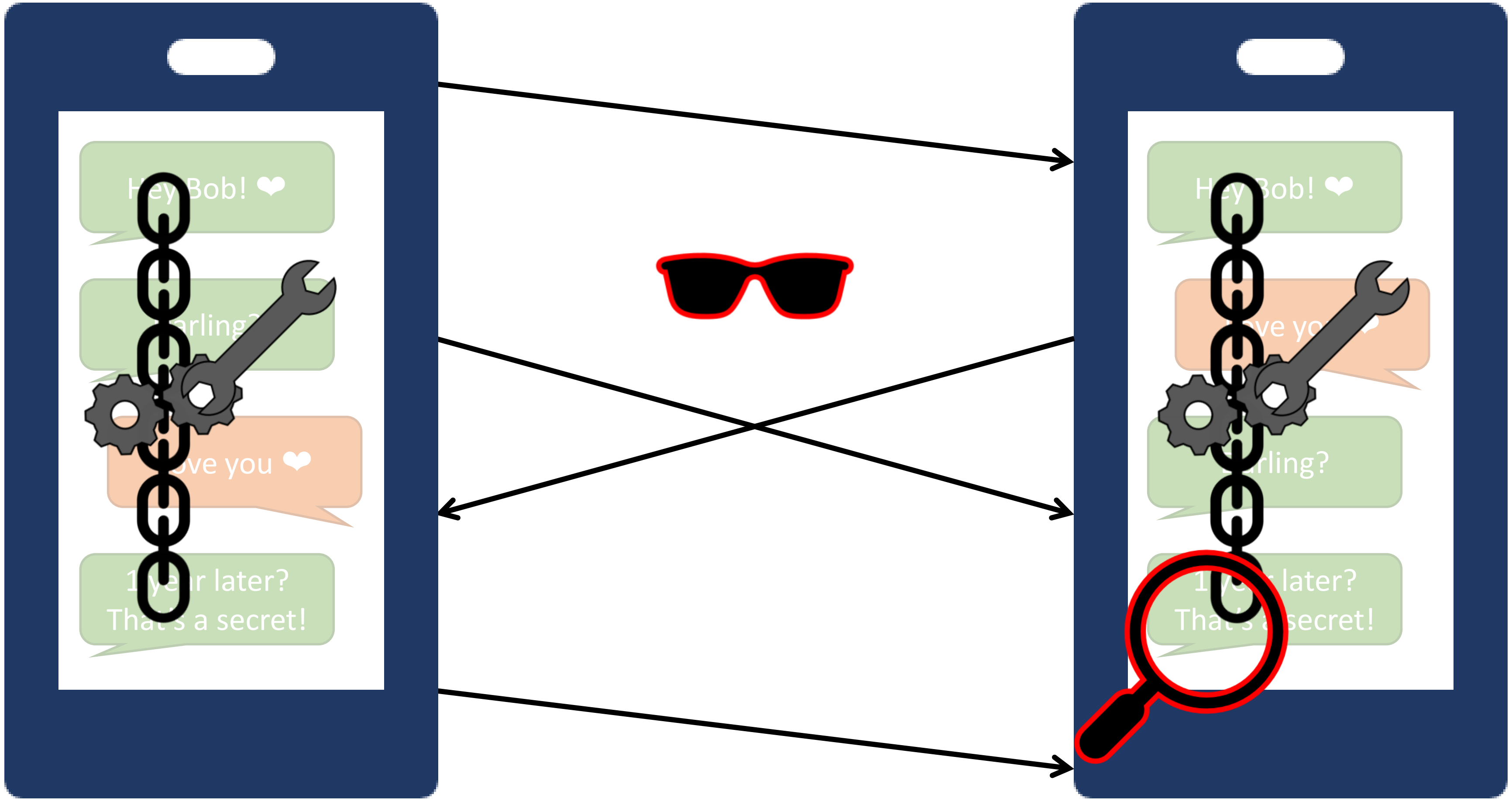
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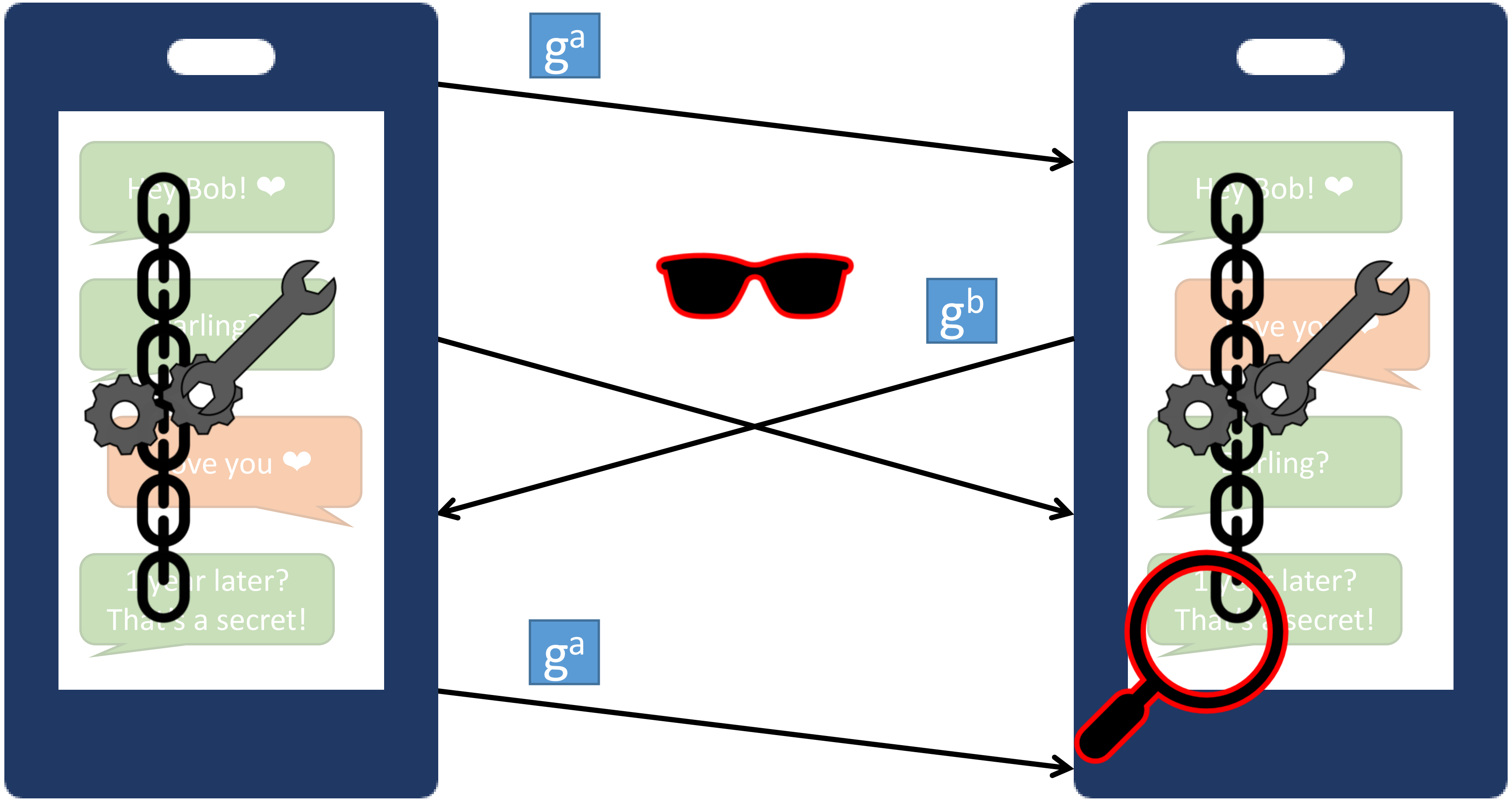

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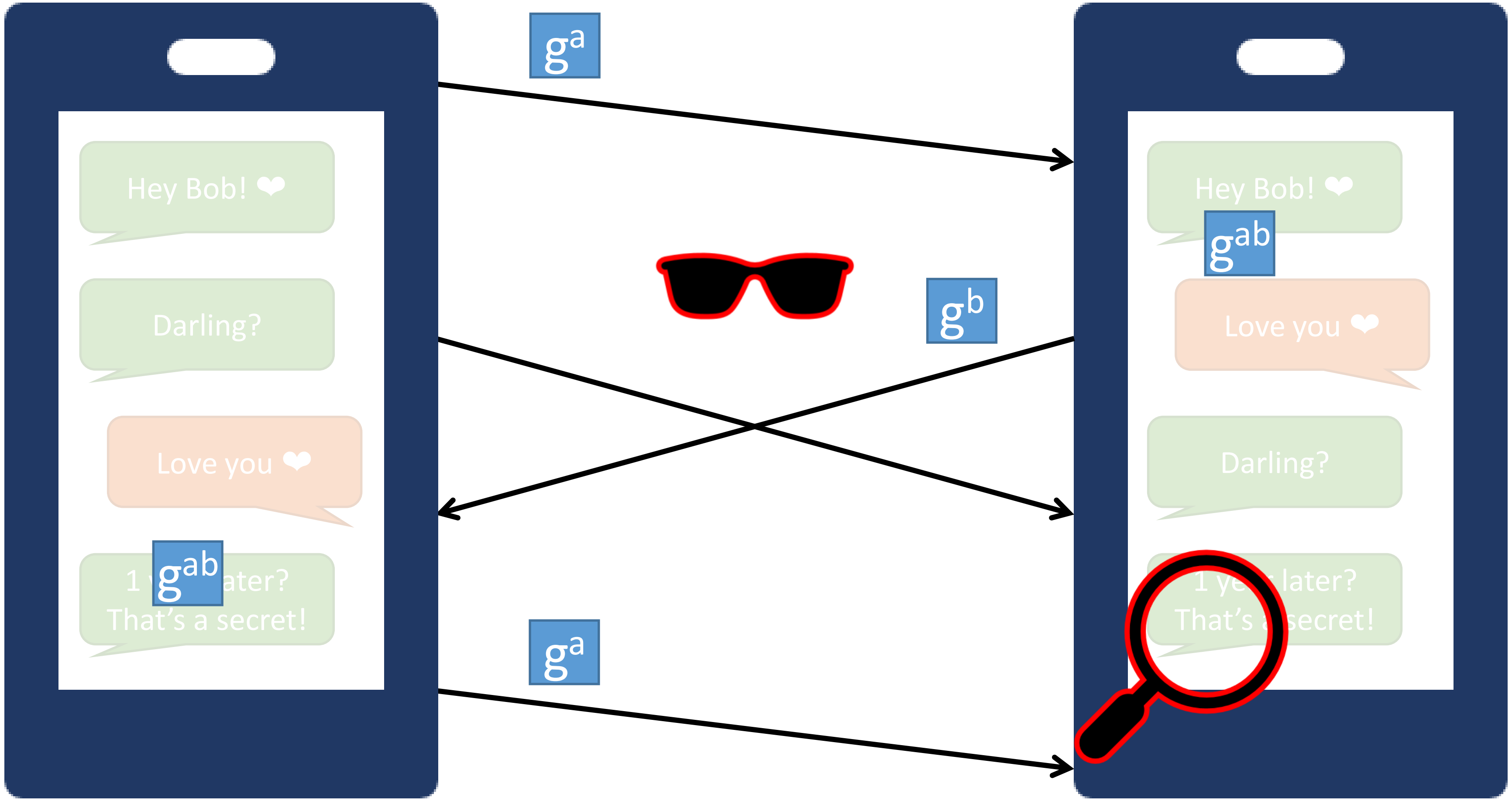

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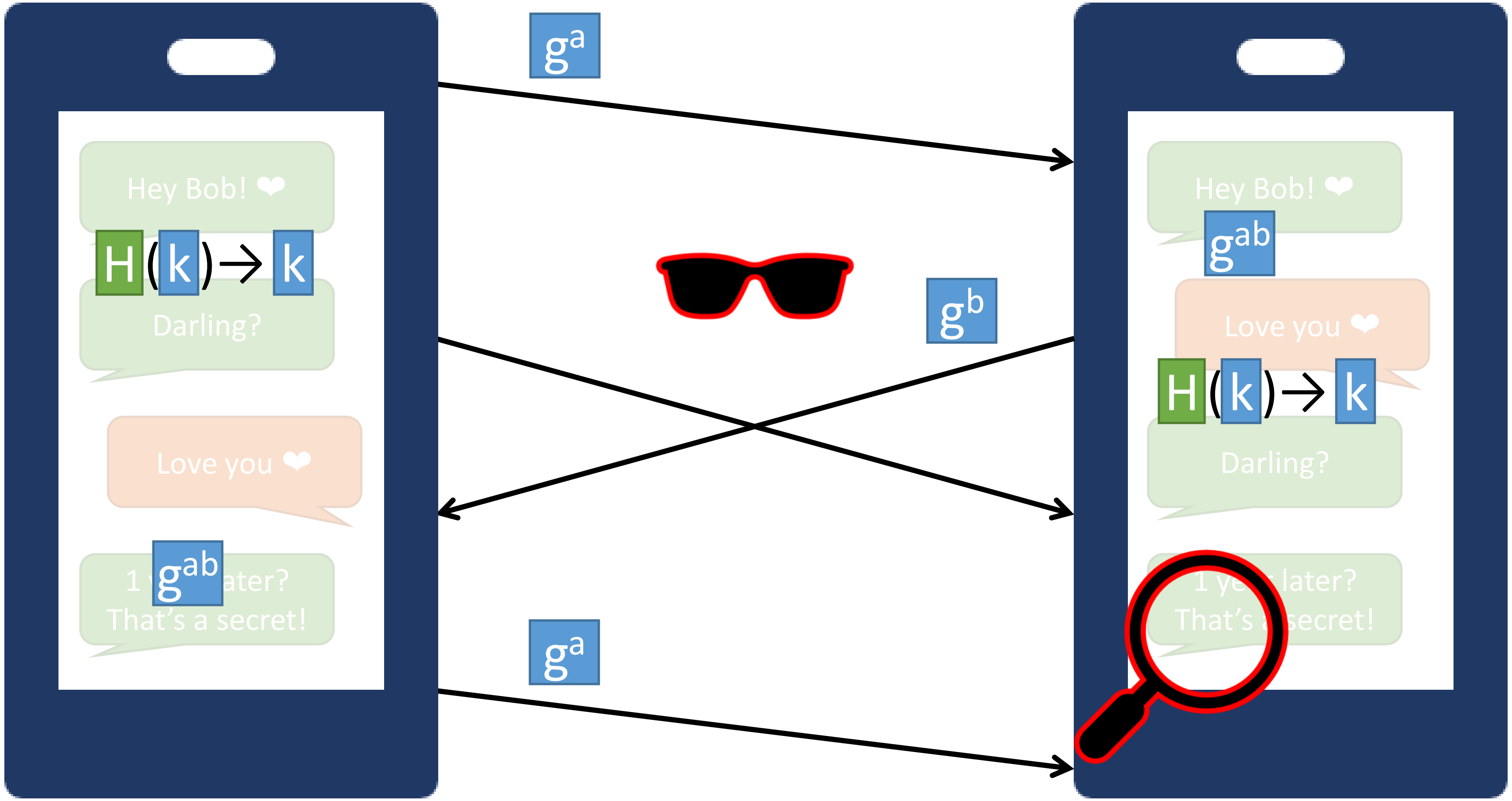

Natural Security Notion for Ratcheting?

- Alice and Bob communicate
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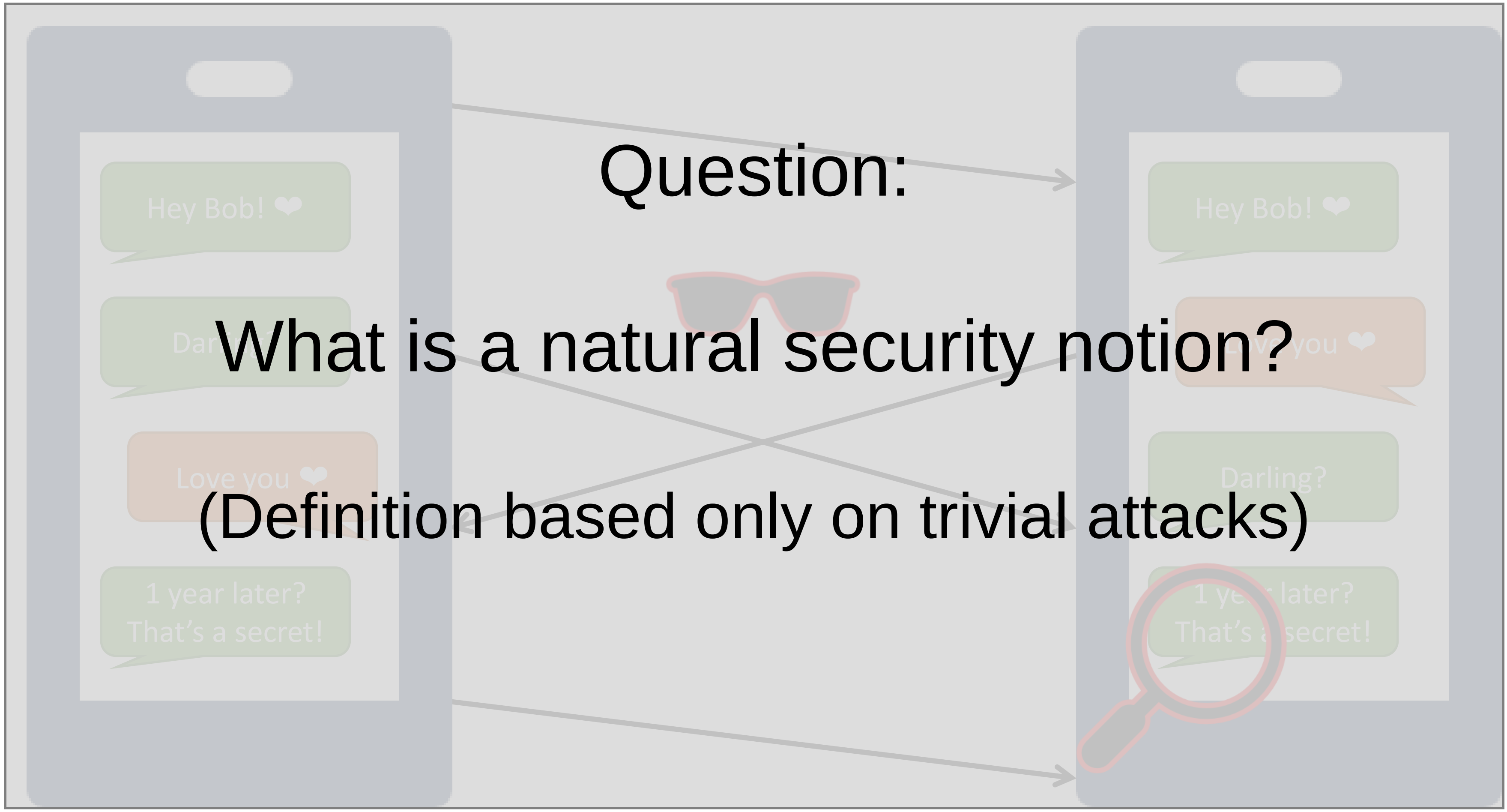
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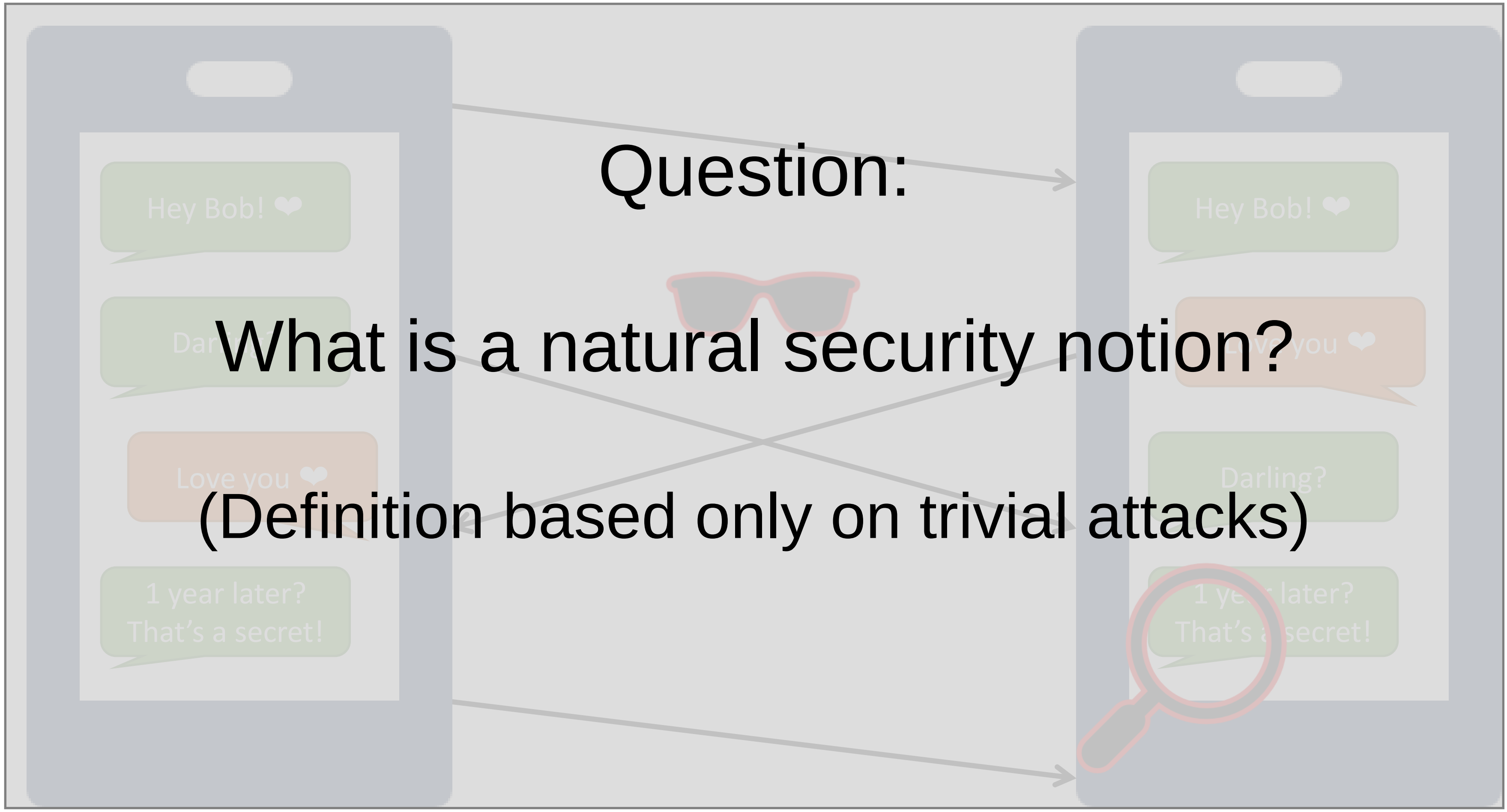
Question:

What is a natural security notion?

(Definition based only on trivial attacks)

Natural Security Notion for Ratcheting?

- Natural security notion
  - Definition based only on trivial attacks
  - Bellare et al. on unidirectional communication C'17
    - Bob cannot be exposed



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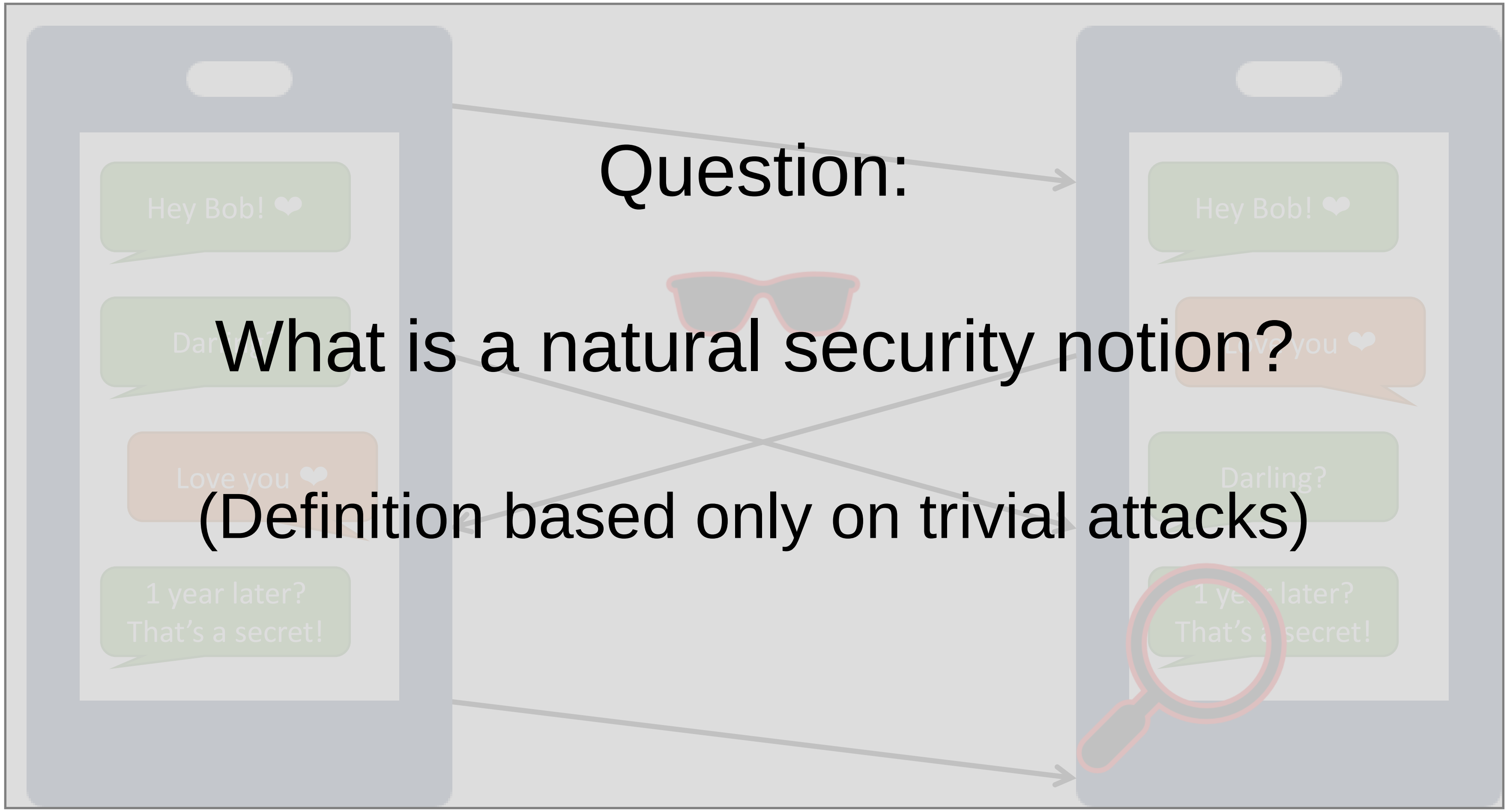


Question:

What is a natural security notion?

(Definition based only on trivial attacks)

Our models require and constructions provide *full* security under:

- Asynchronous communication
- Exposure of both parties

Agenda

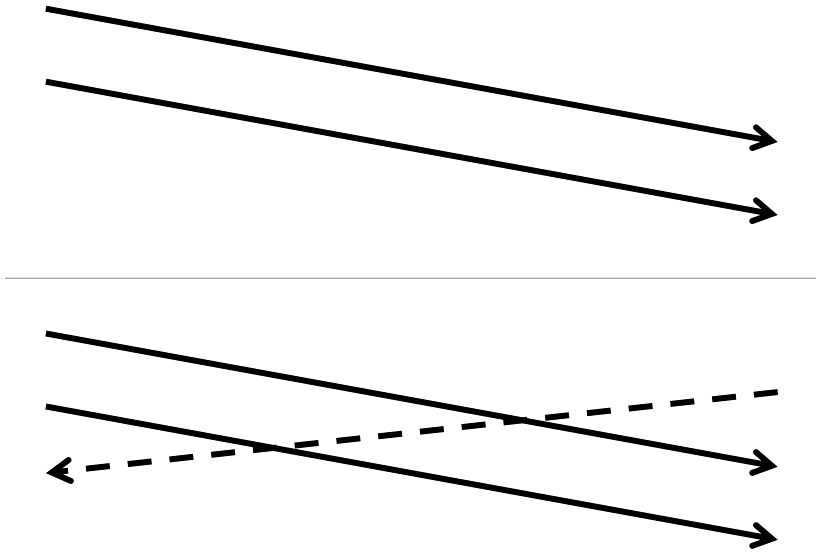
1. **The Primitive Ratcheted Key Exchange**

2. General Adversary Model

3. Unidirectional Ratcheting
   → Model and Construction

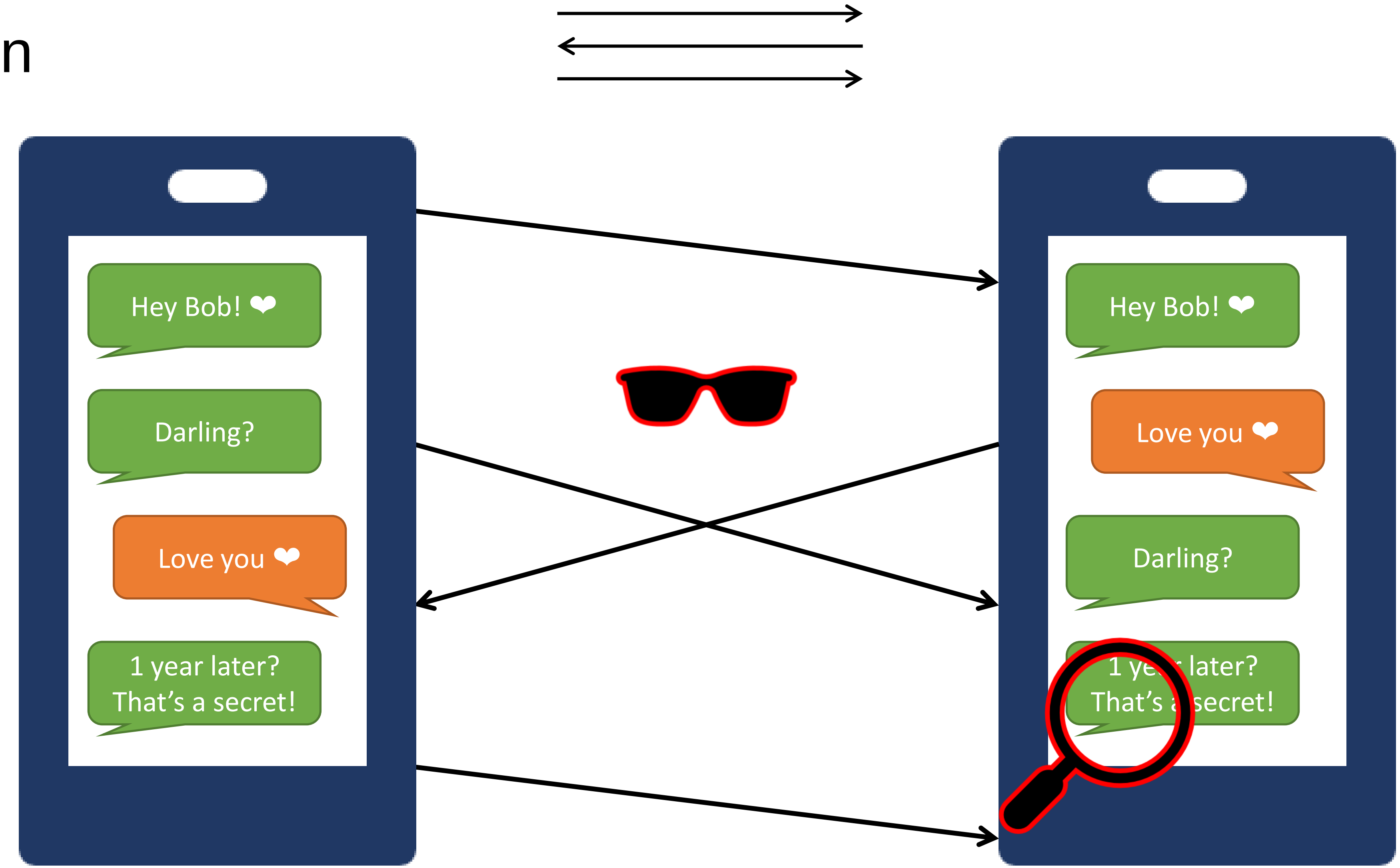
4. Sesquidirectional Ratcheting
   → Model and Construction

5. Results



Natural Security Notion for Ratcheting?

- Natural security notion
  - Definition based only on trivial attacks
- Syntax:
  - Initialization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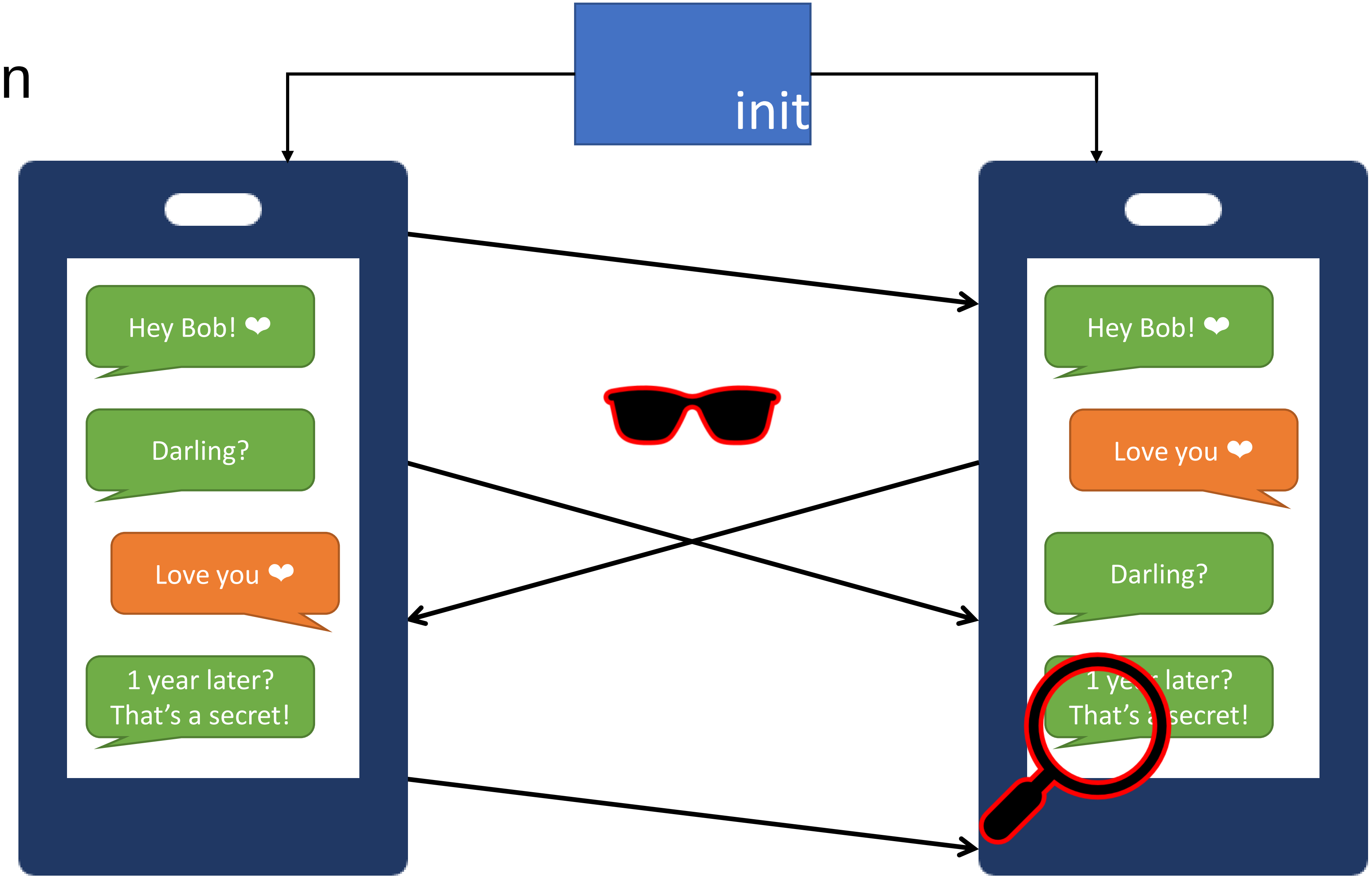
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Natural Security Notion for Ratcheting?

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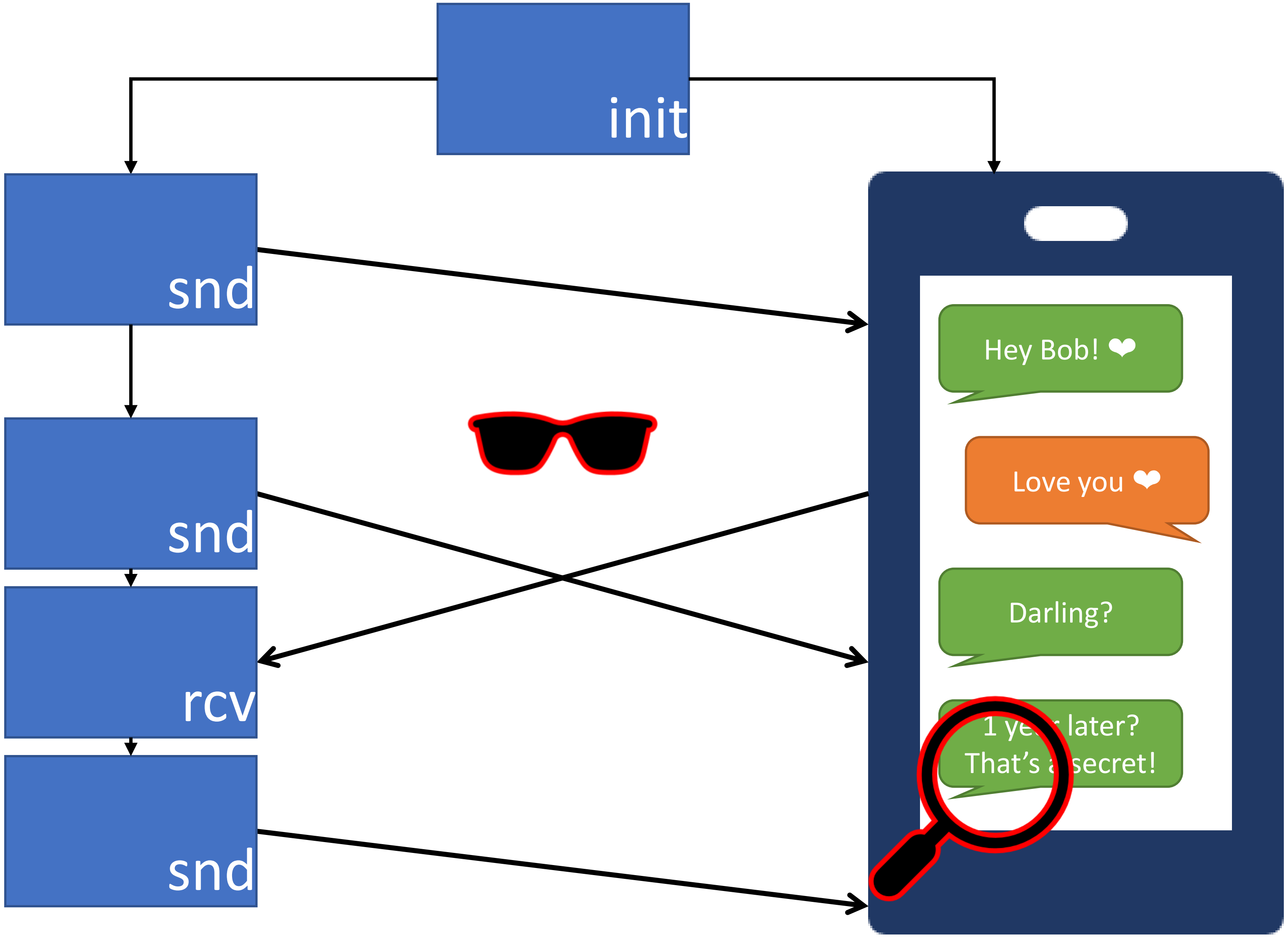
  - Definition based only on trivial attacks
- Syntax:
  - Initialization
  - Sending & receiving



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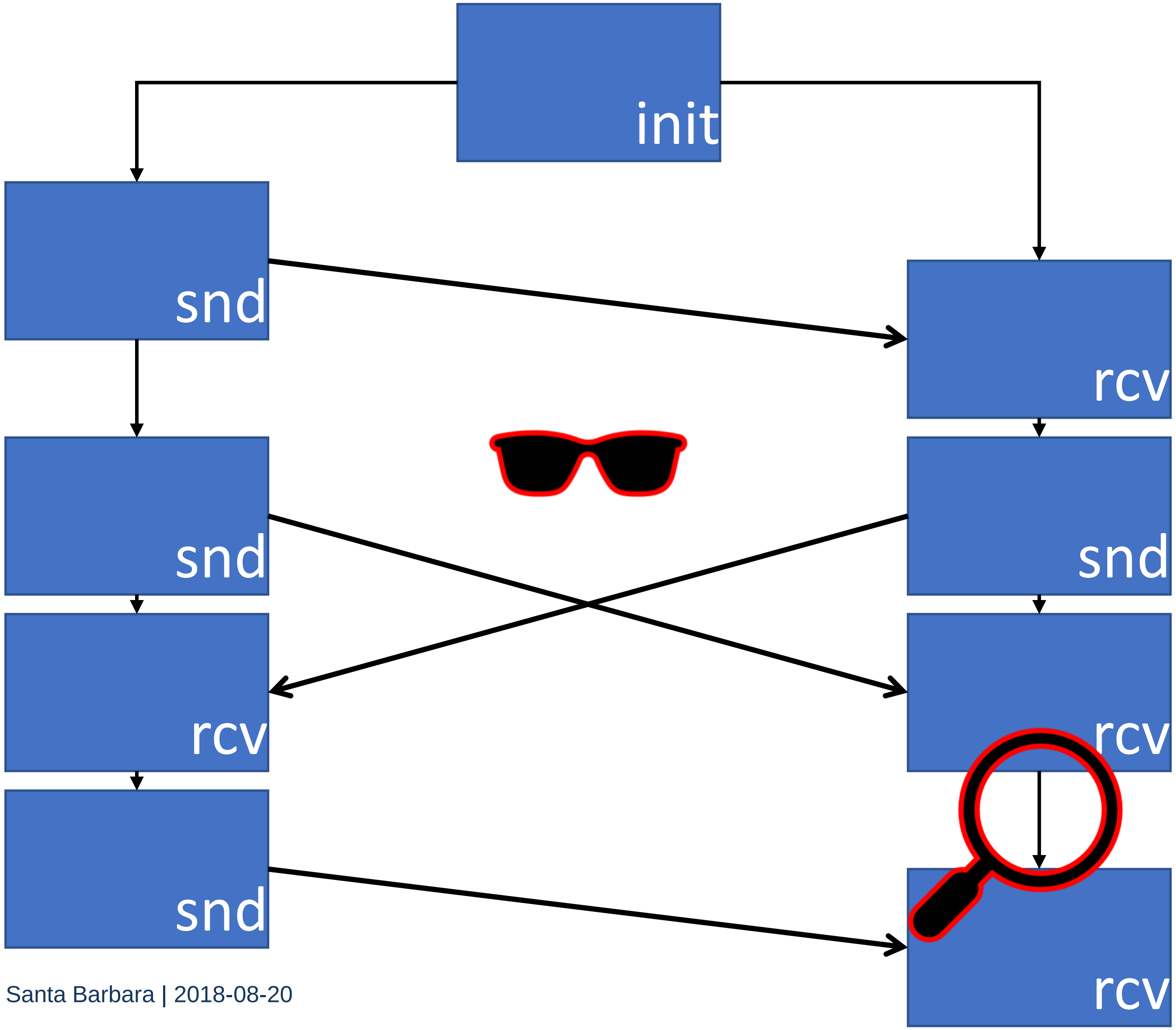
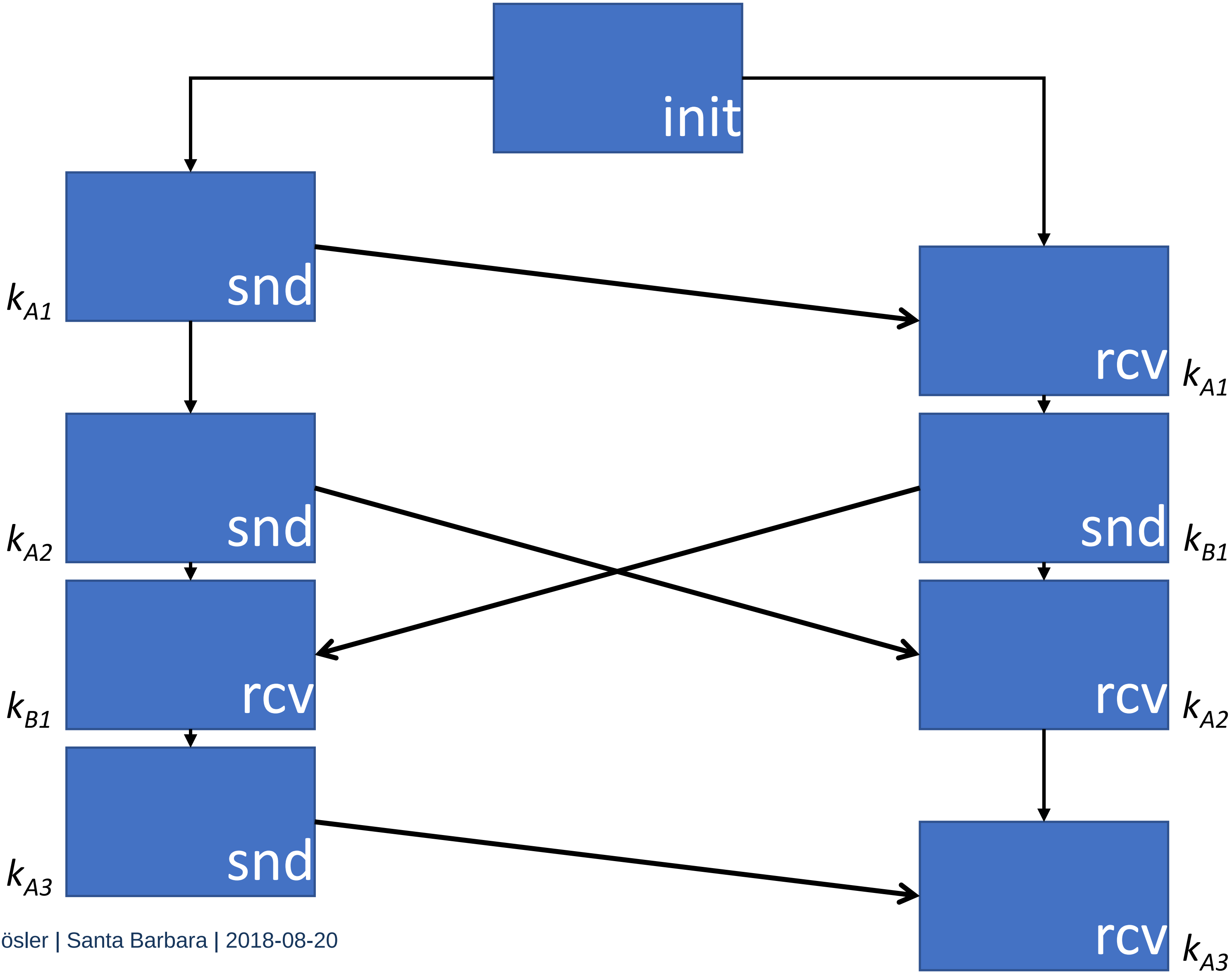


Natural Security Notion for Ratcheting?

- Natural security notion
  - Definition based only on trivial attacks
- Syntax:
  - Initialization
  - Sending & receiving
  - Key exchange
    - Consecutive establishment of keys in session

  ≠ *Authenticated key exchange*!



Natural Security Notion for Ratcheting?

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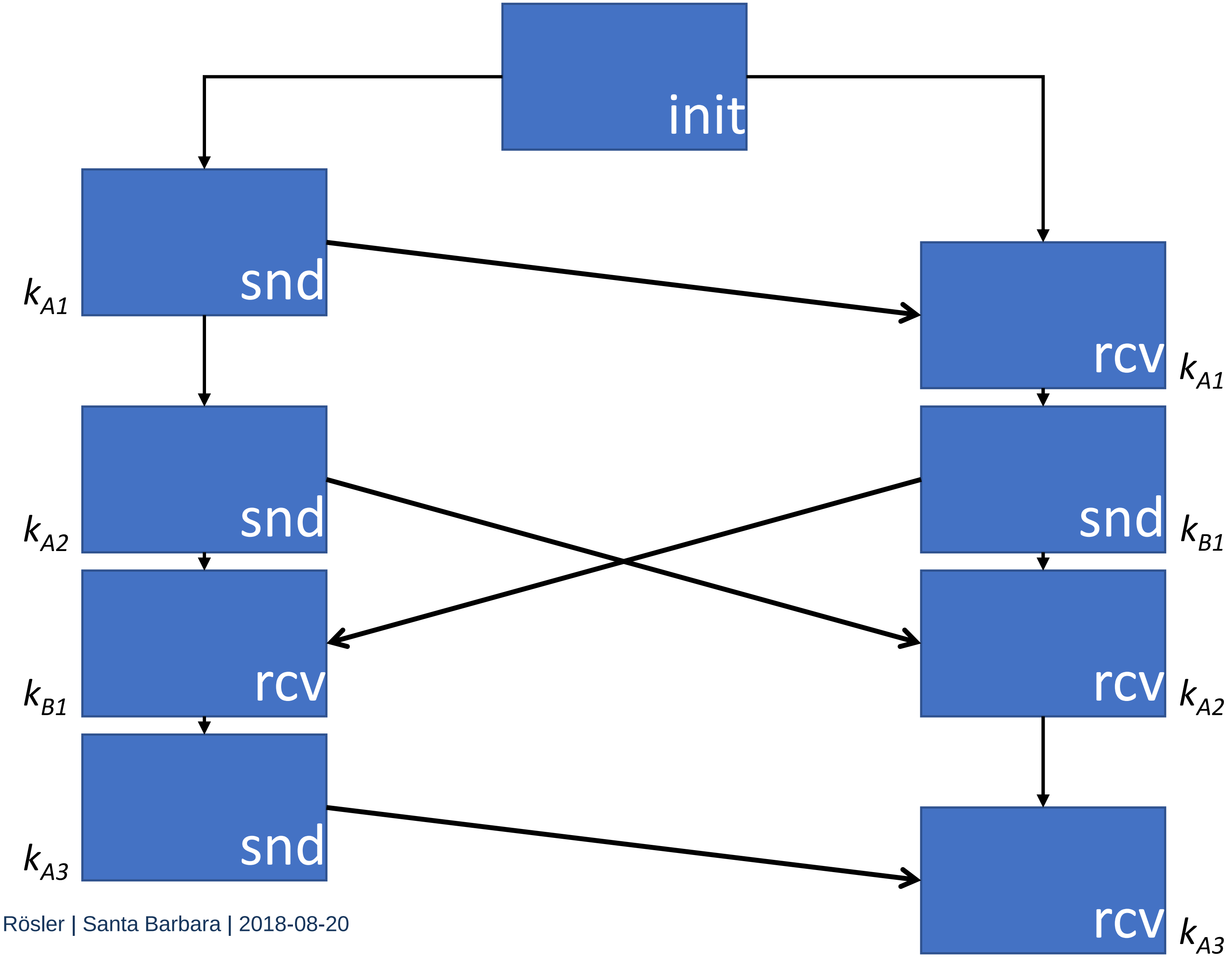
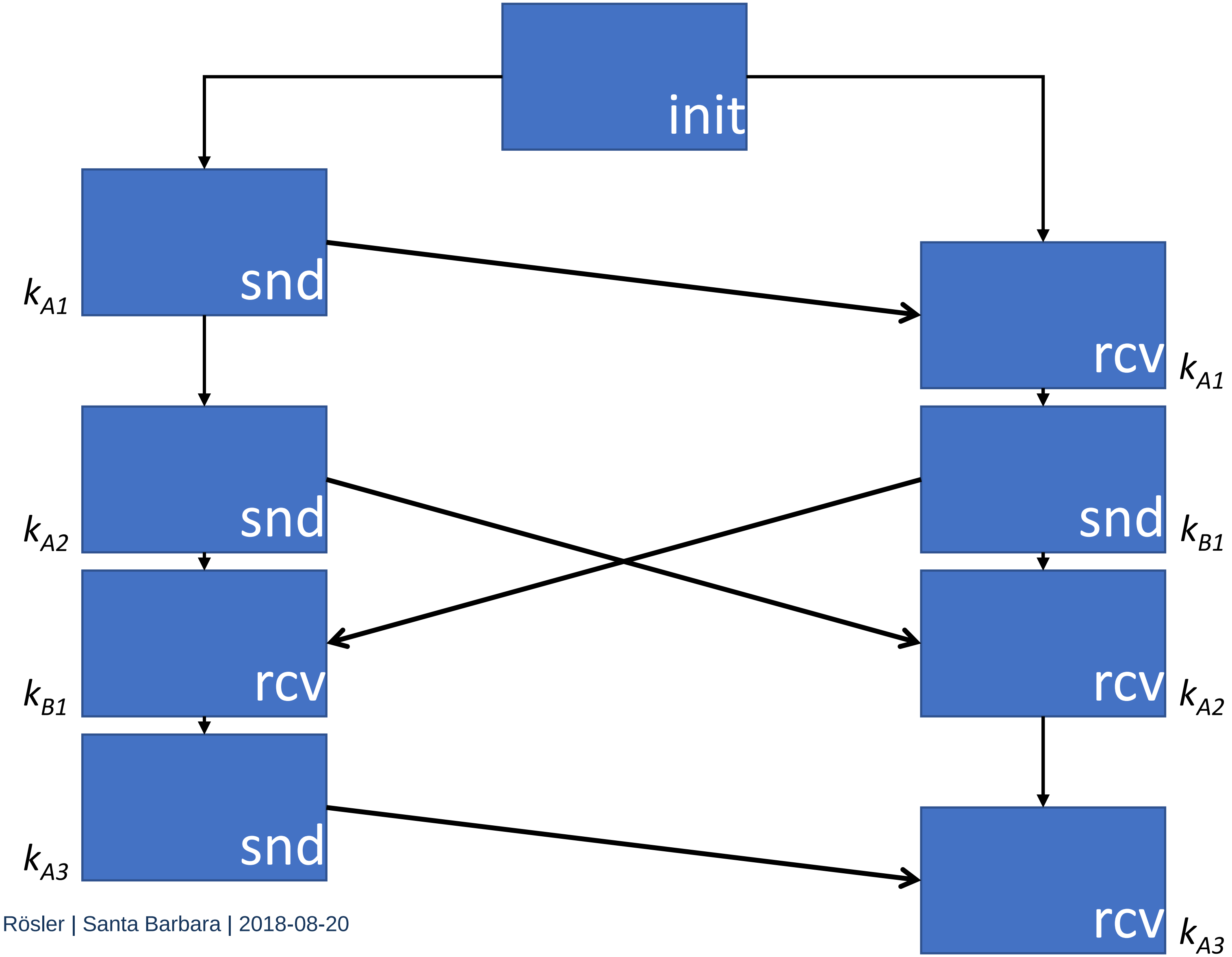
- Syntax:
  - Initialization
  - Sending & receiving
  - Key exchange
    - Composition in Bellare et al. C’17



Three Variants of Ratcheting

- Bidirectional ratcheting is complicated

→ Understand its components



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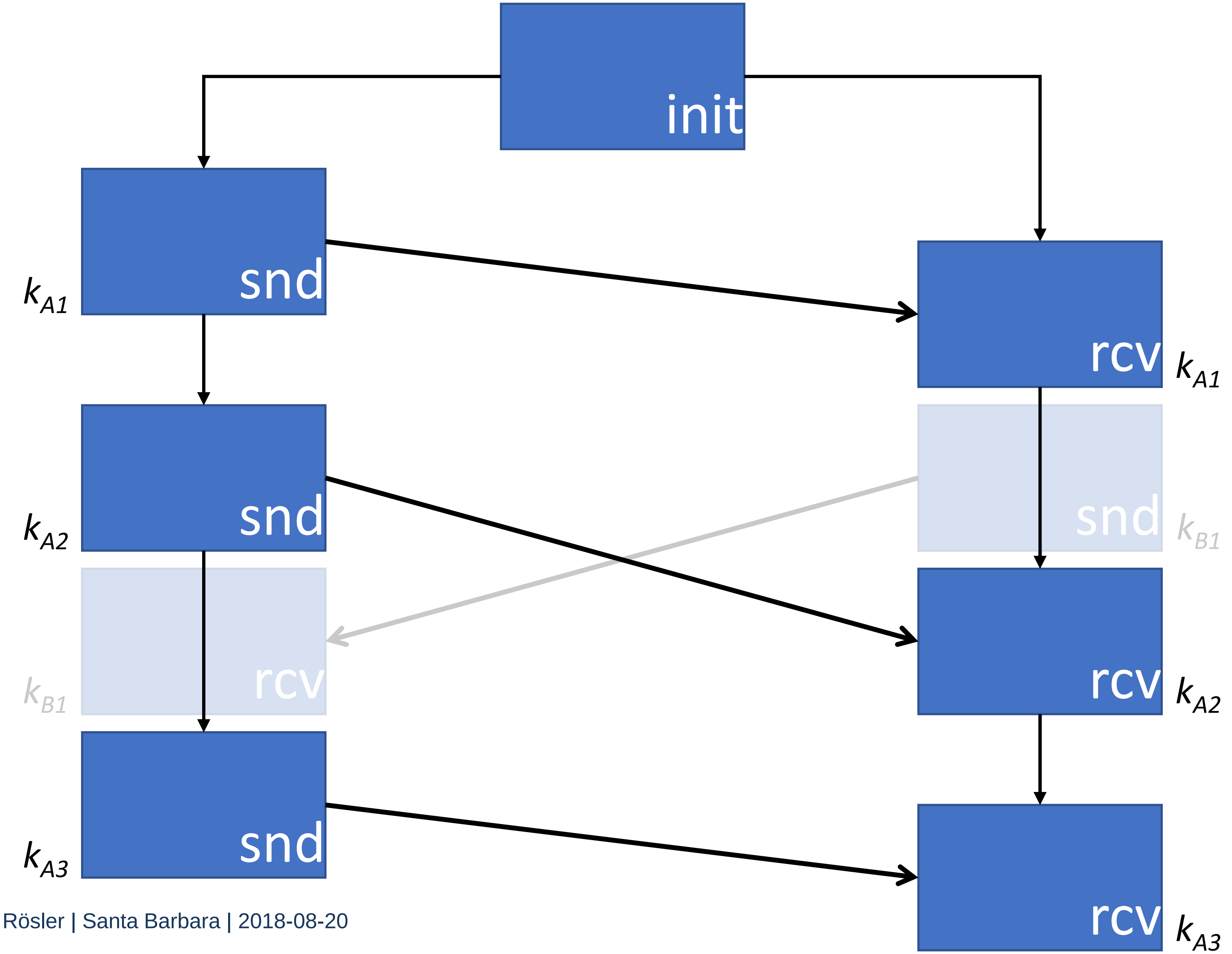
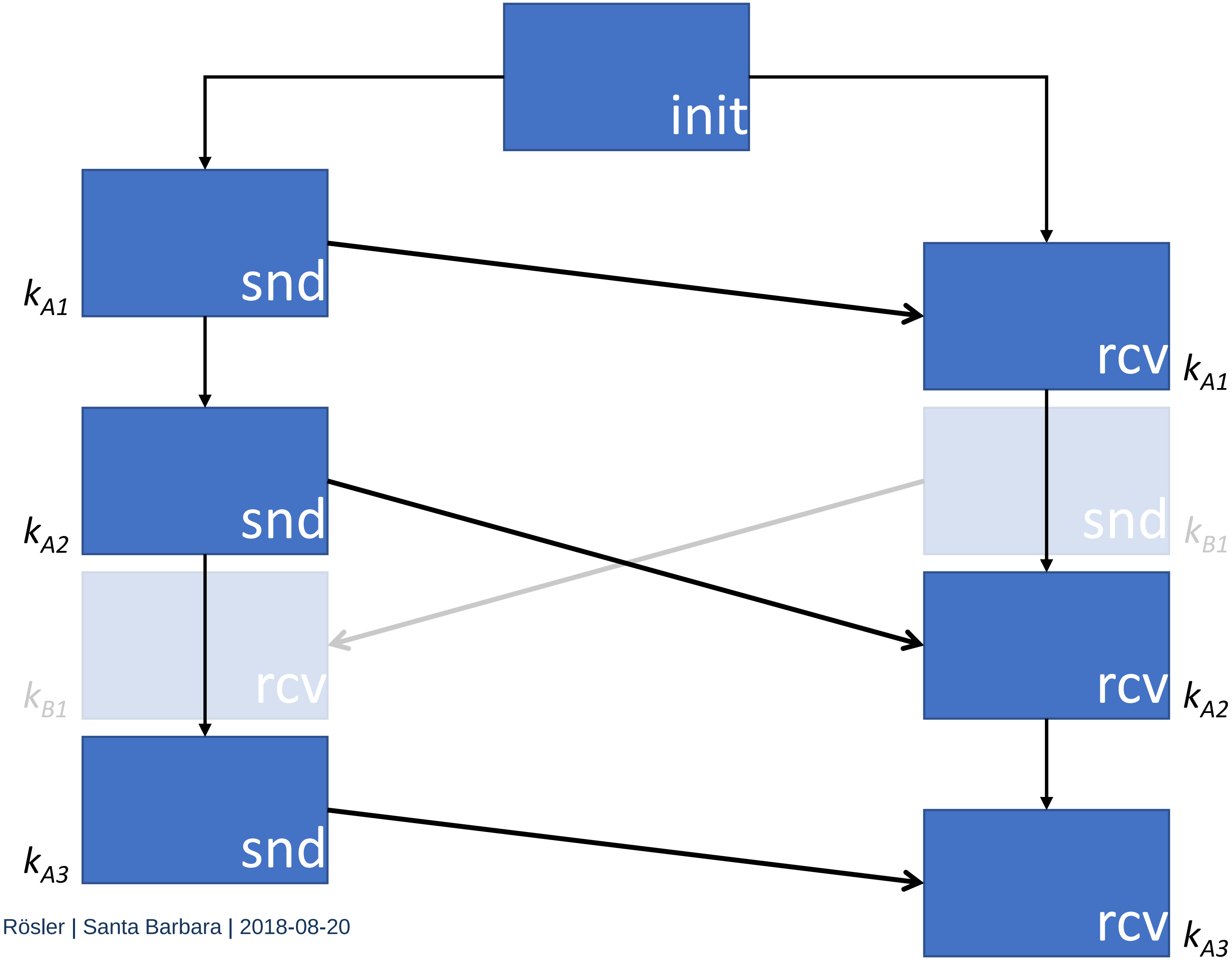


Three Variants of Ratcheting

- Bidirectional ratcheting is complicated

→ Understand its components:

  - Unidirectional key establishment
  - Alice initiates computation of new key
  - Bob does not respond



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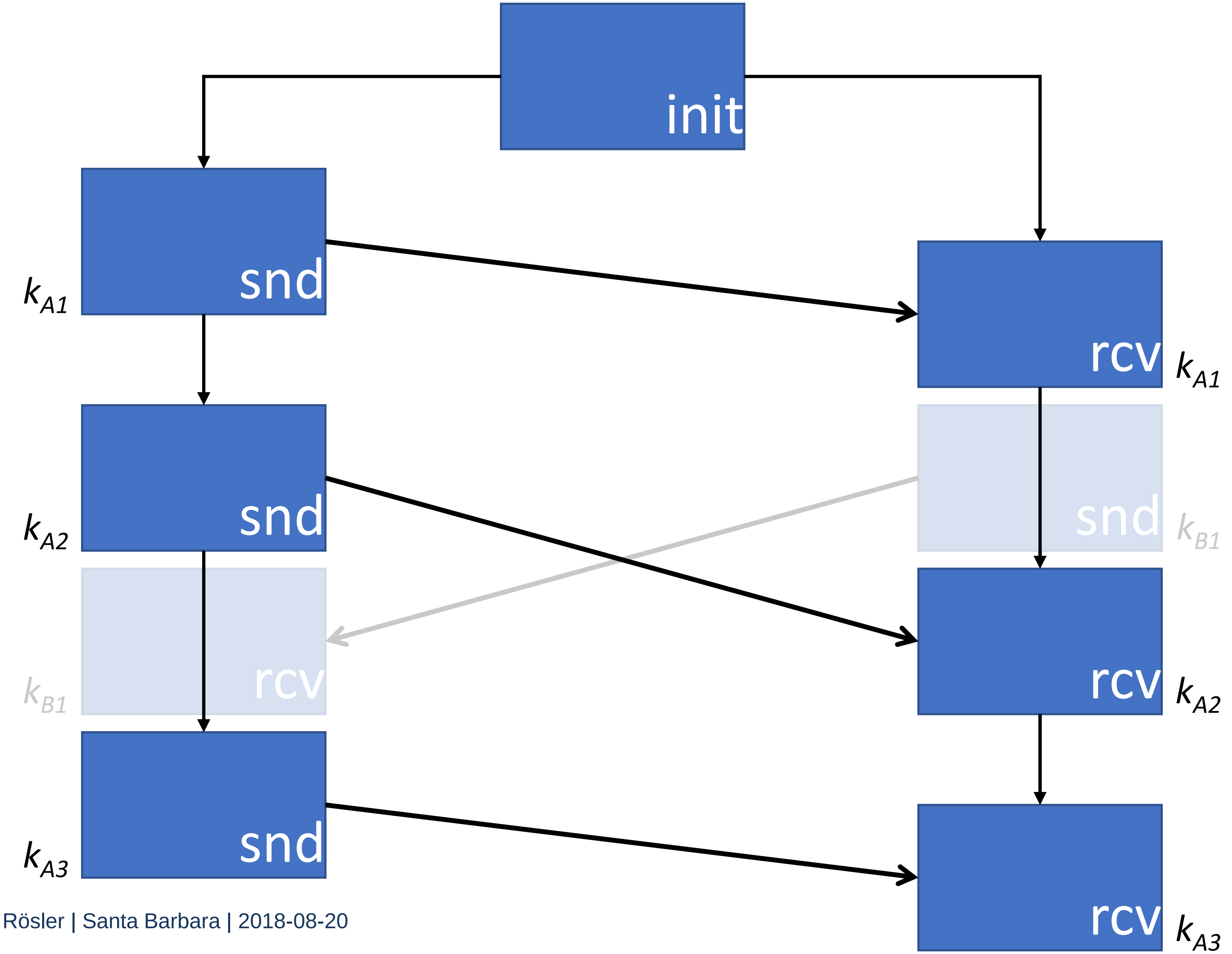
Three Variants of Ratcheting

- Bidirectional ratcheting is complicated

→ Understand its components:

  - Unidirectional ratcheted key exchange (RKE)



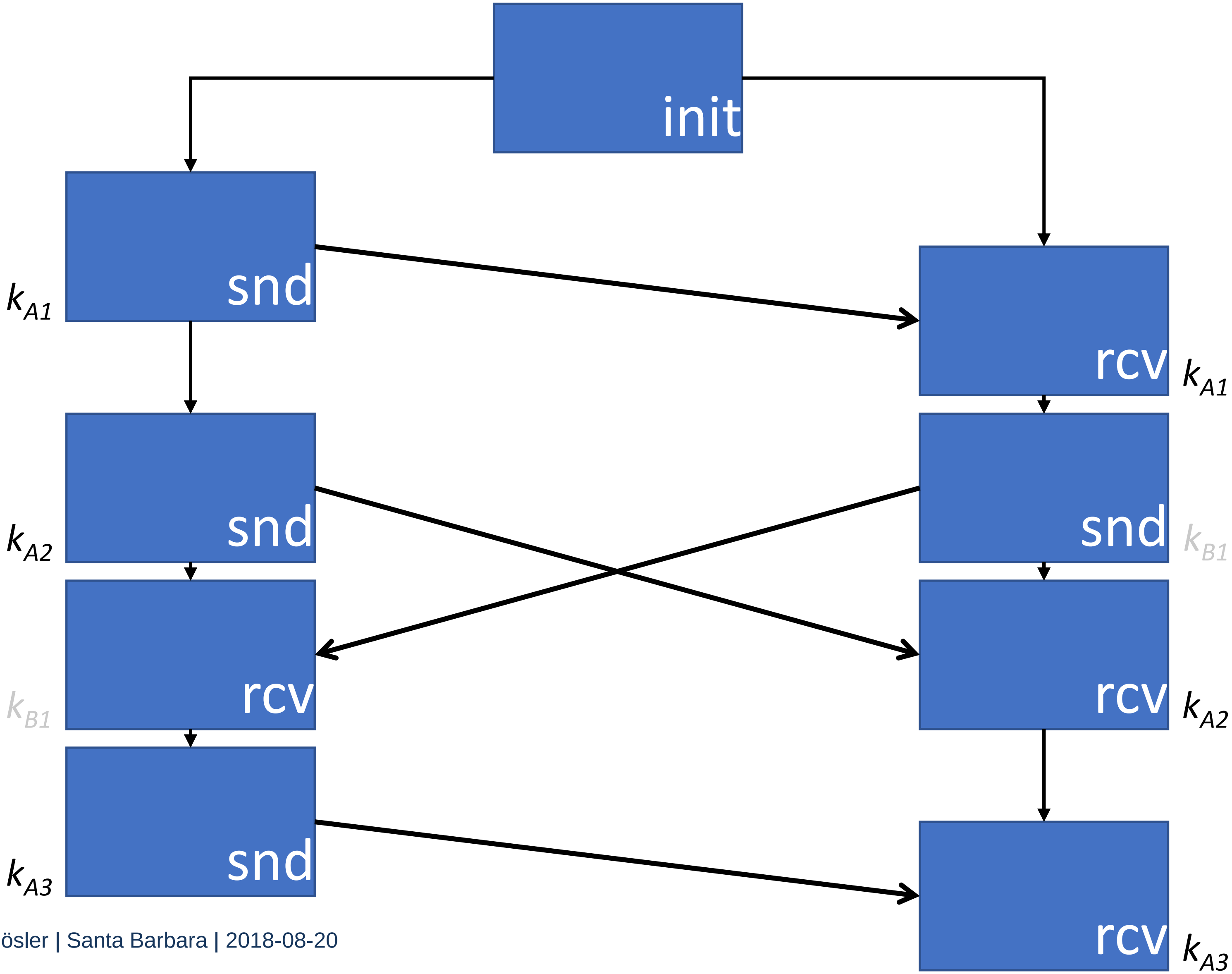
Three Variants of Ratcheting

- Bidirectional ratcheting is complicated

→ Understand its components:

  - Unidirectional RKE
  - Sesquidirectional RKE
  - Bob contributes (but cannot establish keys)
  - Adds security

(sesqui = 1.5)



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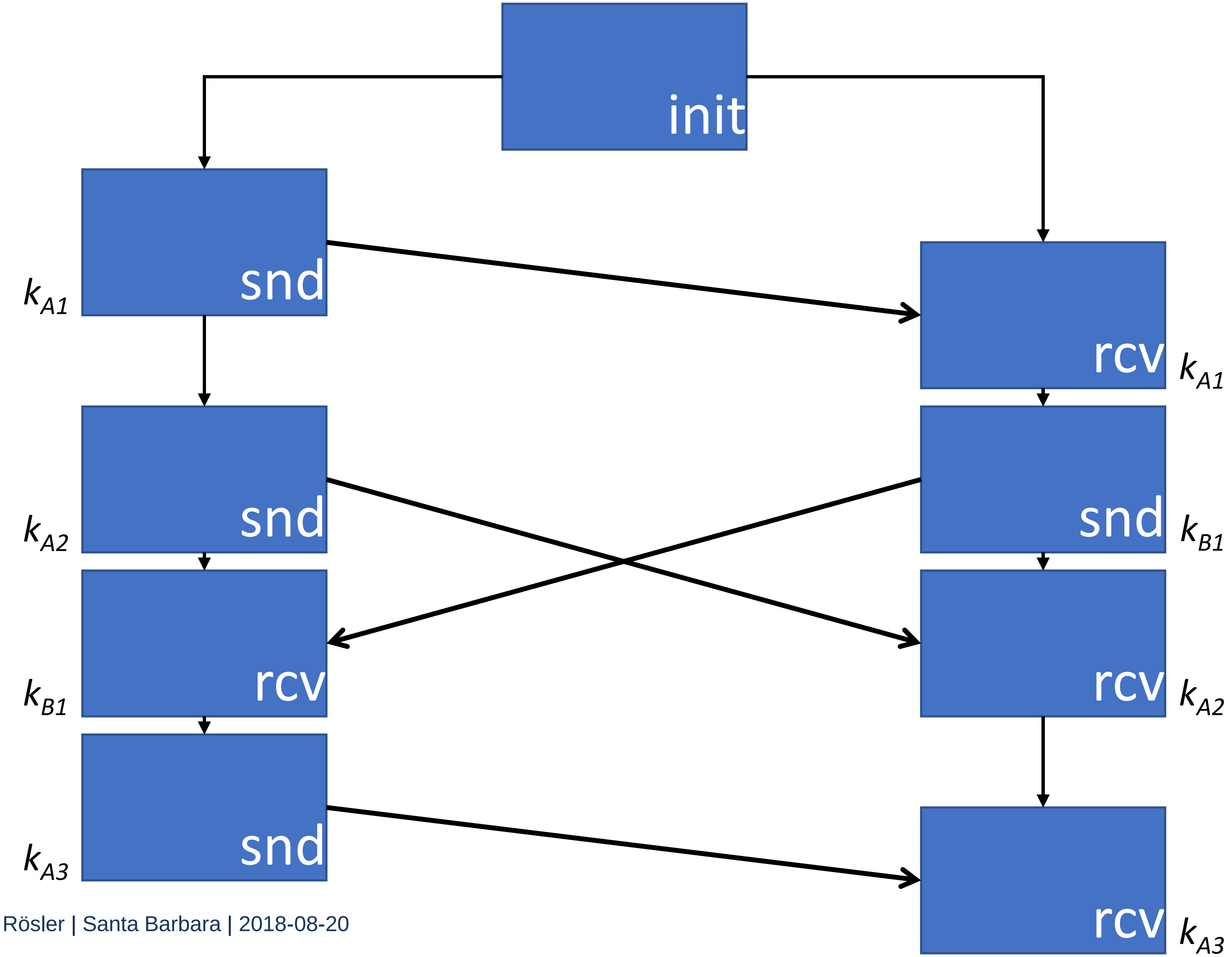
→ Understand its components:

  - Unidirectional RKE
  - Sesquidirectional RKE
  - Symmetric roles



Three Variants of Ratcheting

- Bidirectional ratcheting is complicated

→ Understand its components:

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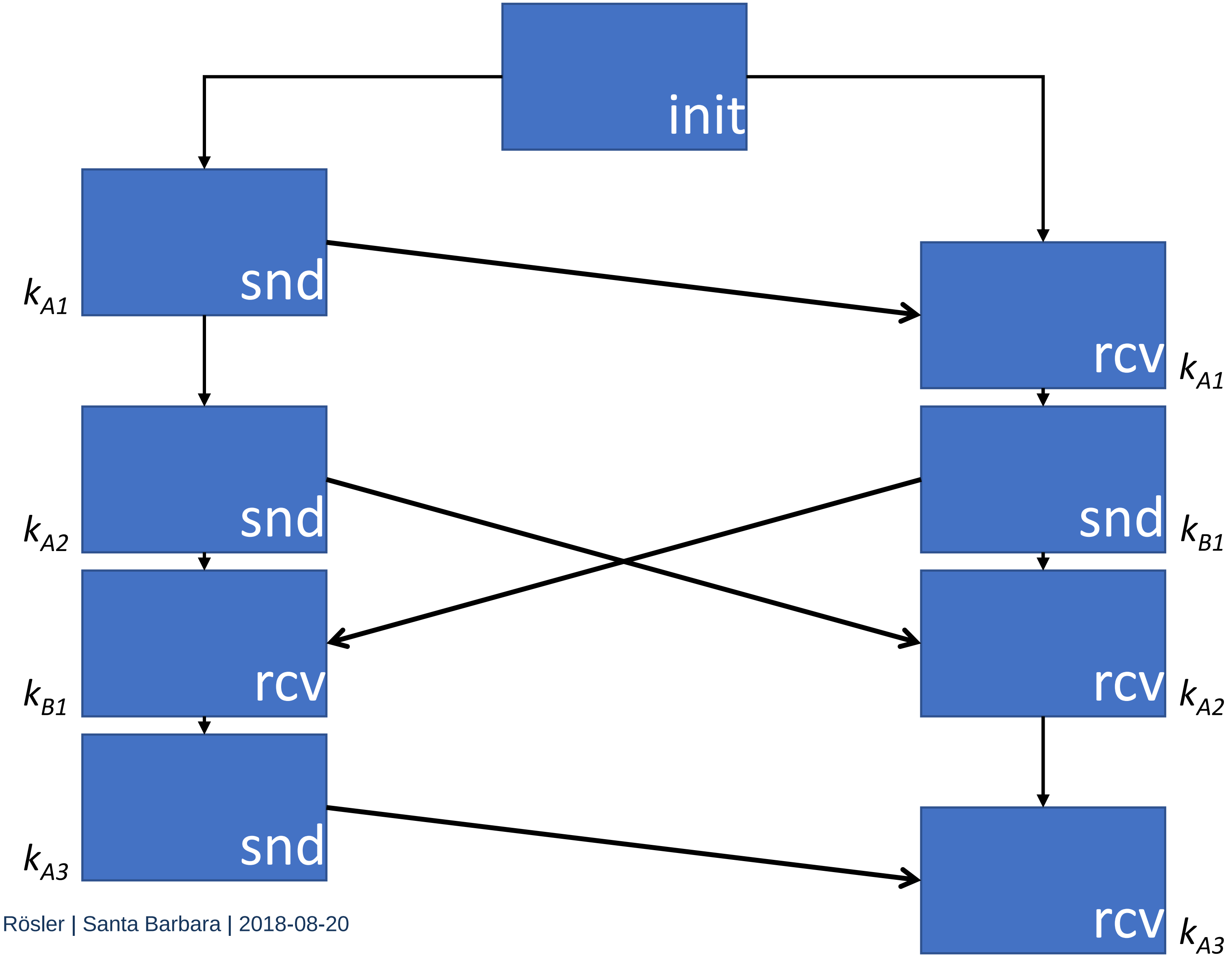
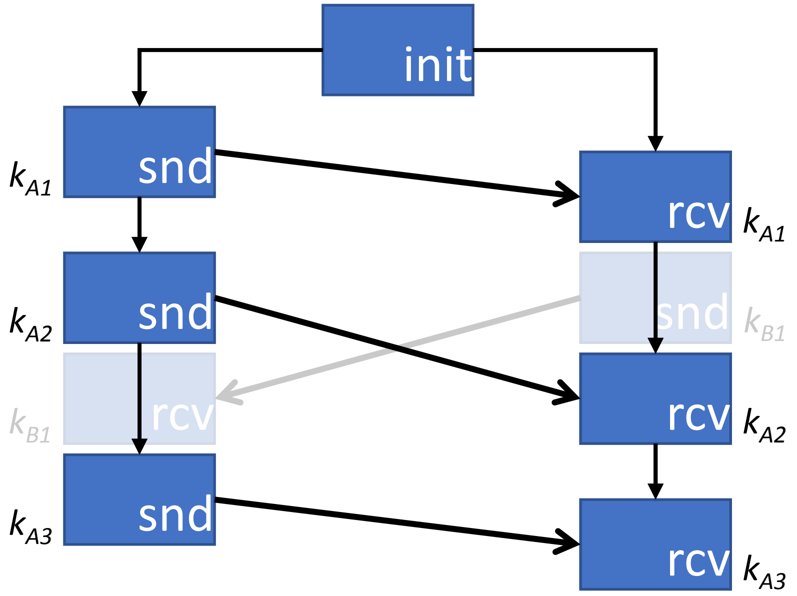
  - Symmetric roles
  - Bidirectional RKE = 2x Sesquid. RKE (extended version)



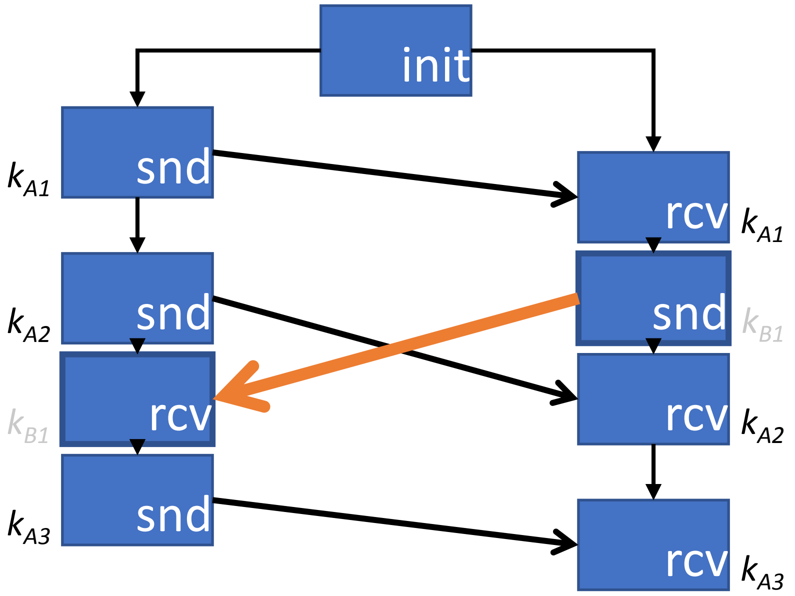
Three Variants of Ratcheting

Unidirectional RKE
(+ Exposure of Bob)



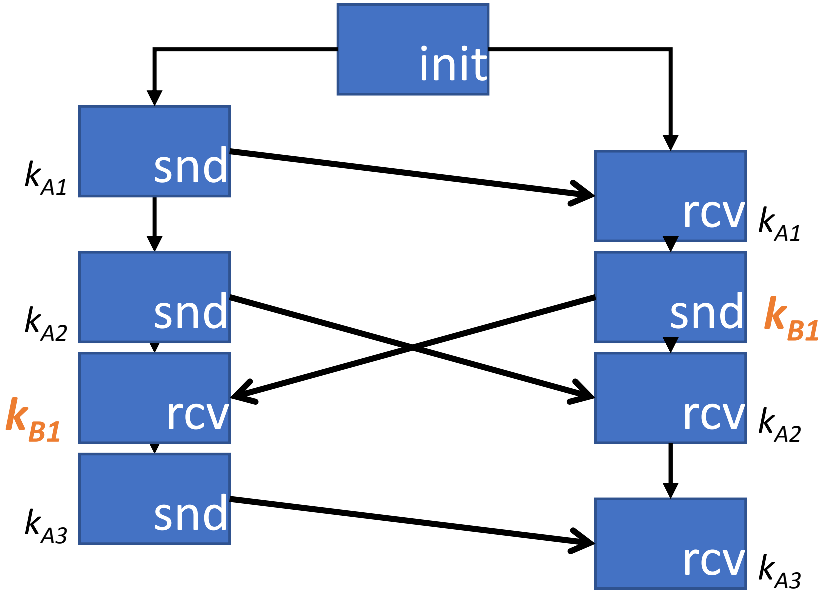
No responses from Bob

Sesquidirectional RKE



Bob’s responses only help to recover

Bidirectional RKE



Symmetric roles

(extended version)

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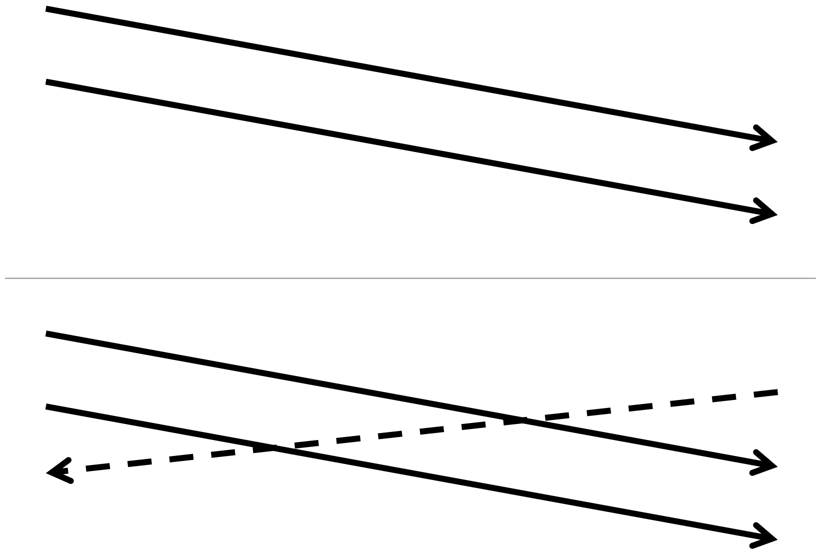
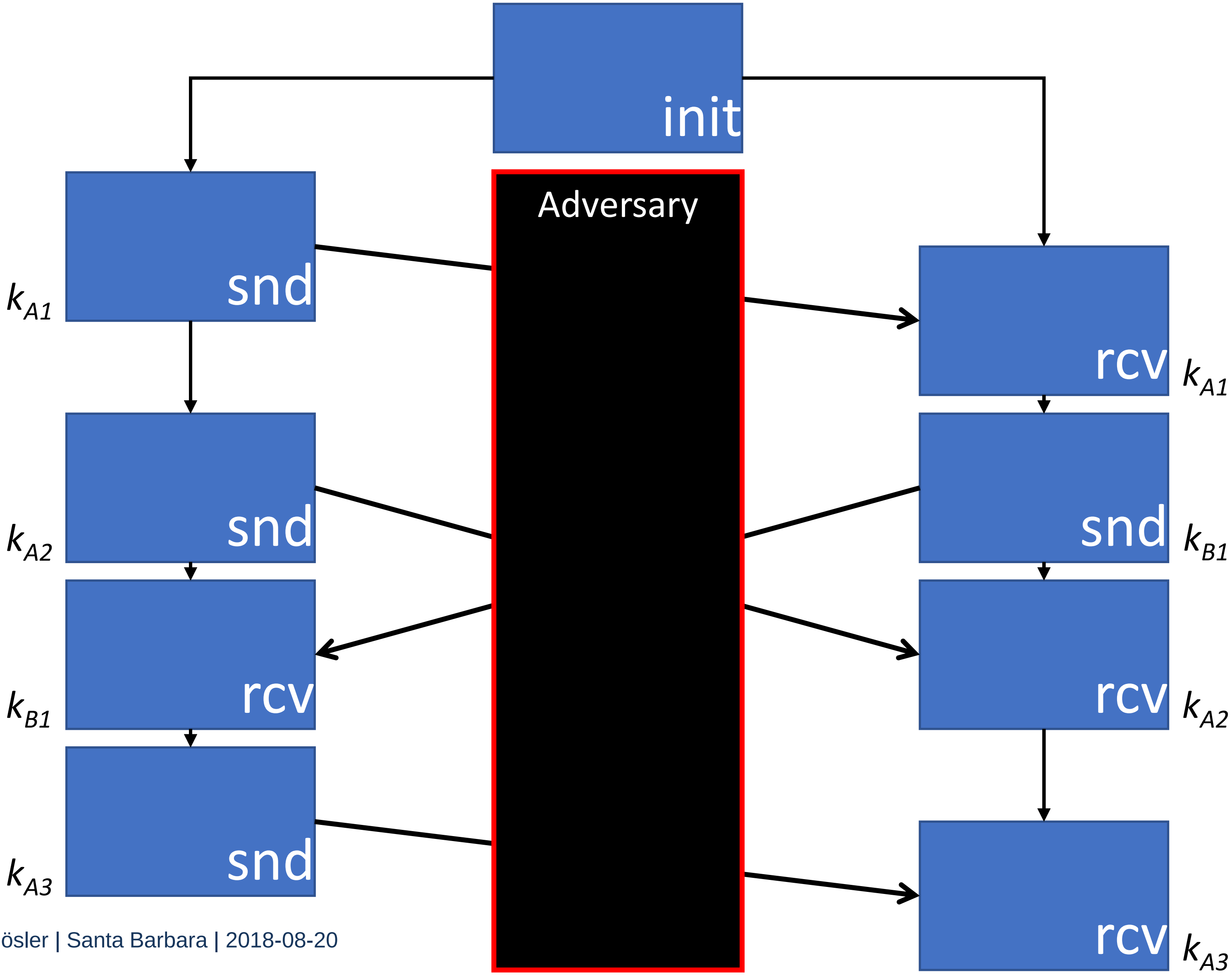


Modeling Ratcheted Key Exchange

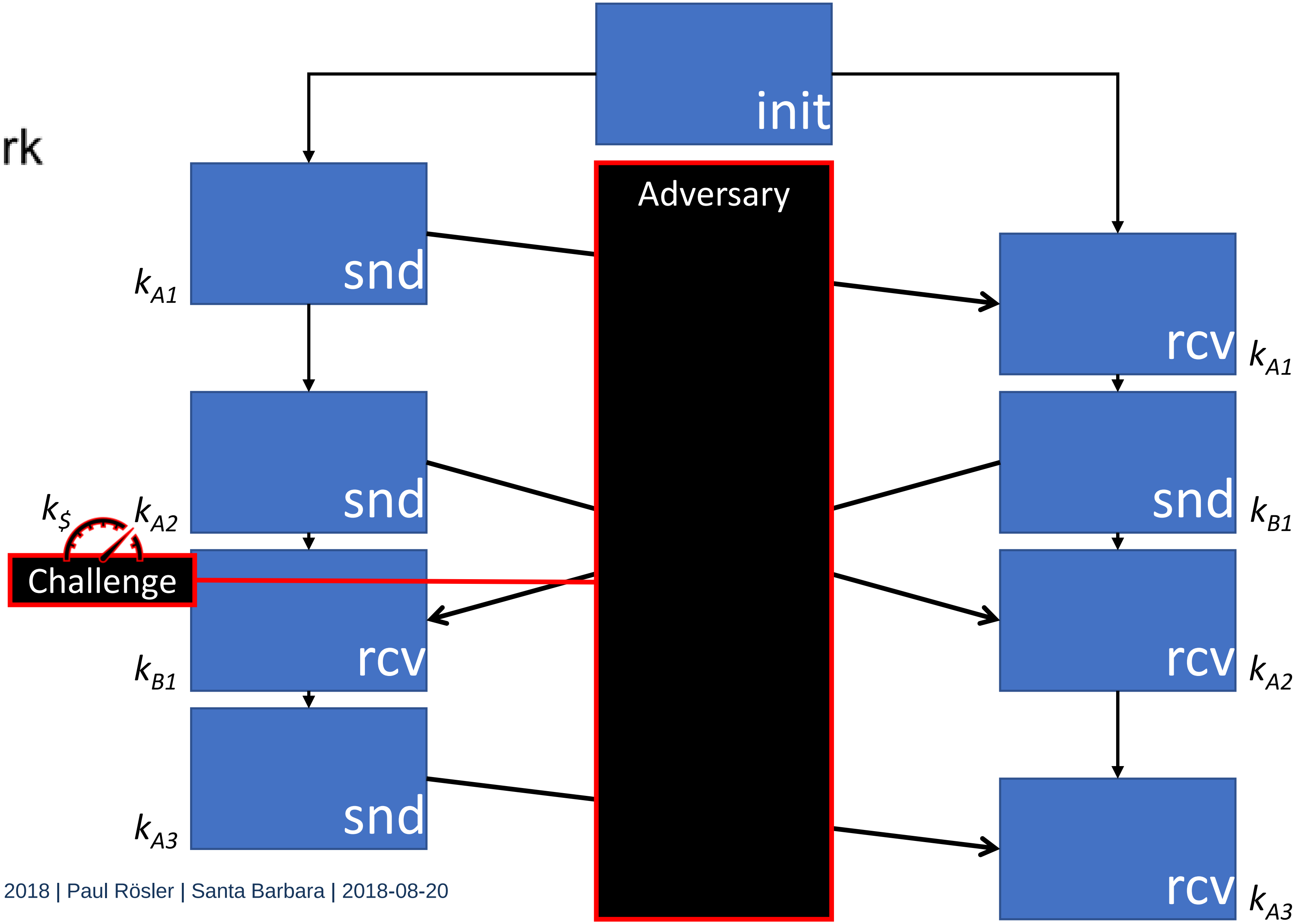
- Active adversary
  - Control whole network traffic



Modeling Ratcheted Key Exchange

- Active adversary
  - Control whole network traffic
- Analyze key indistinguishability
  - Multi-challenge real or random key

  → Guess bit $b \in \{0,1\}$



Modeling Ratcheted Key Exchange

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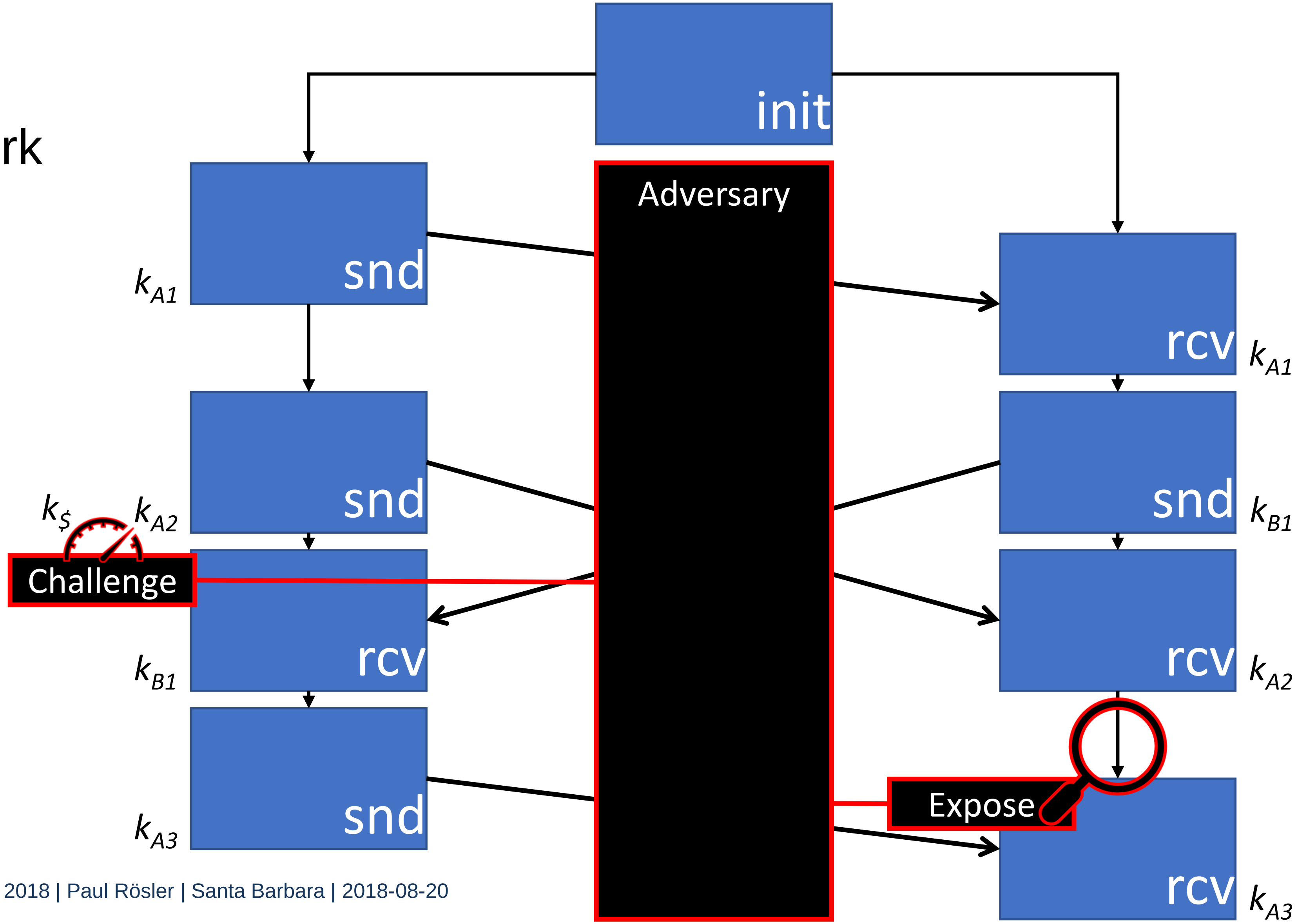

Modeling Ratcheted Key Exchange

- Active adversary
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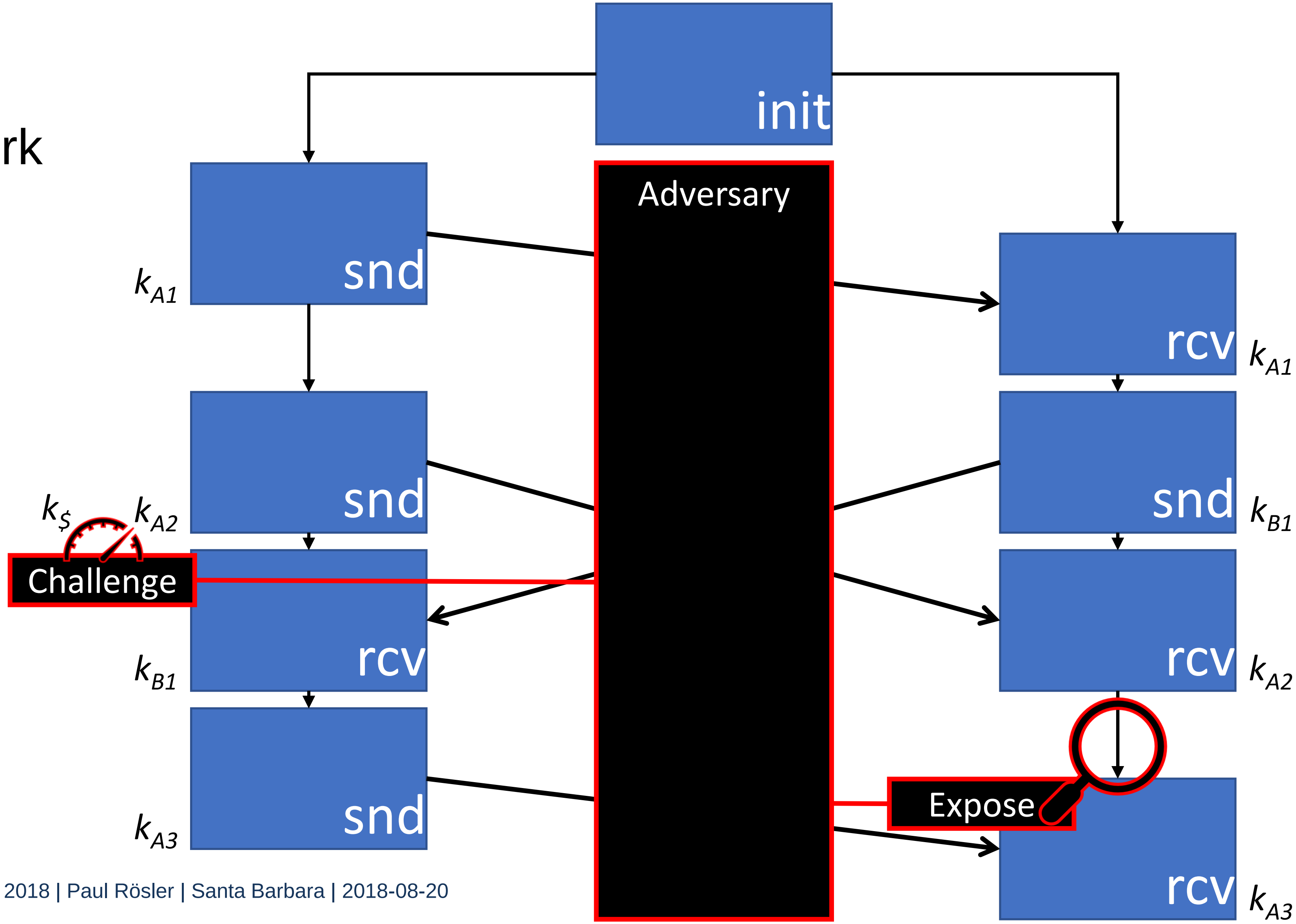
  - Multi-challenge real or random key
- Model exposures of local state
- Single session
- Init abstracted



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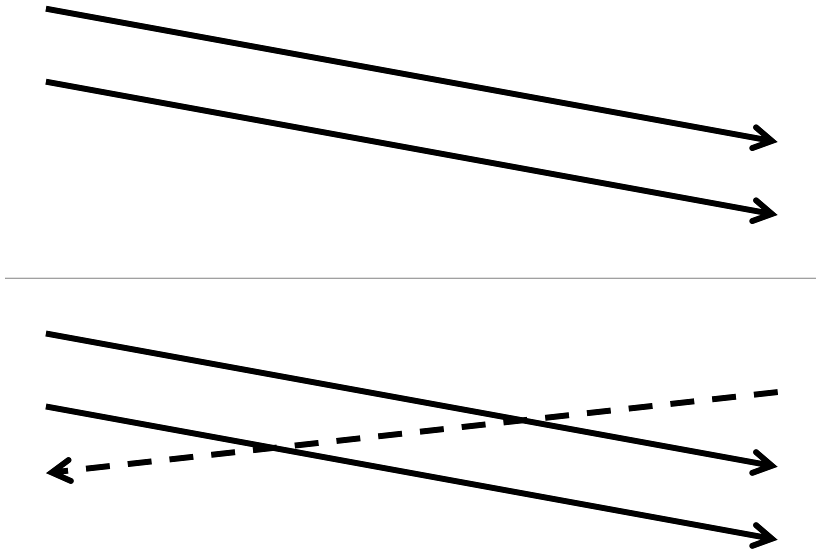
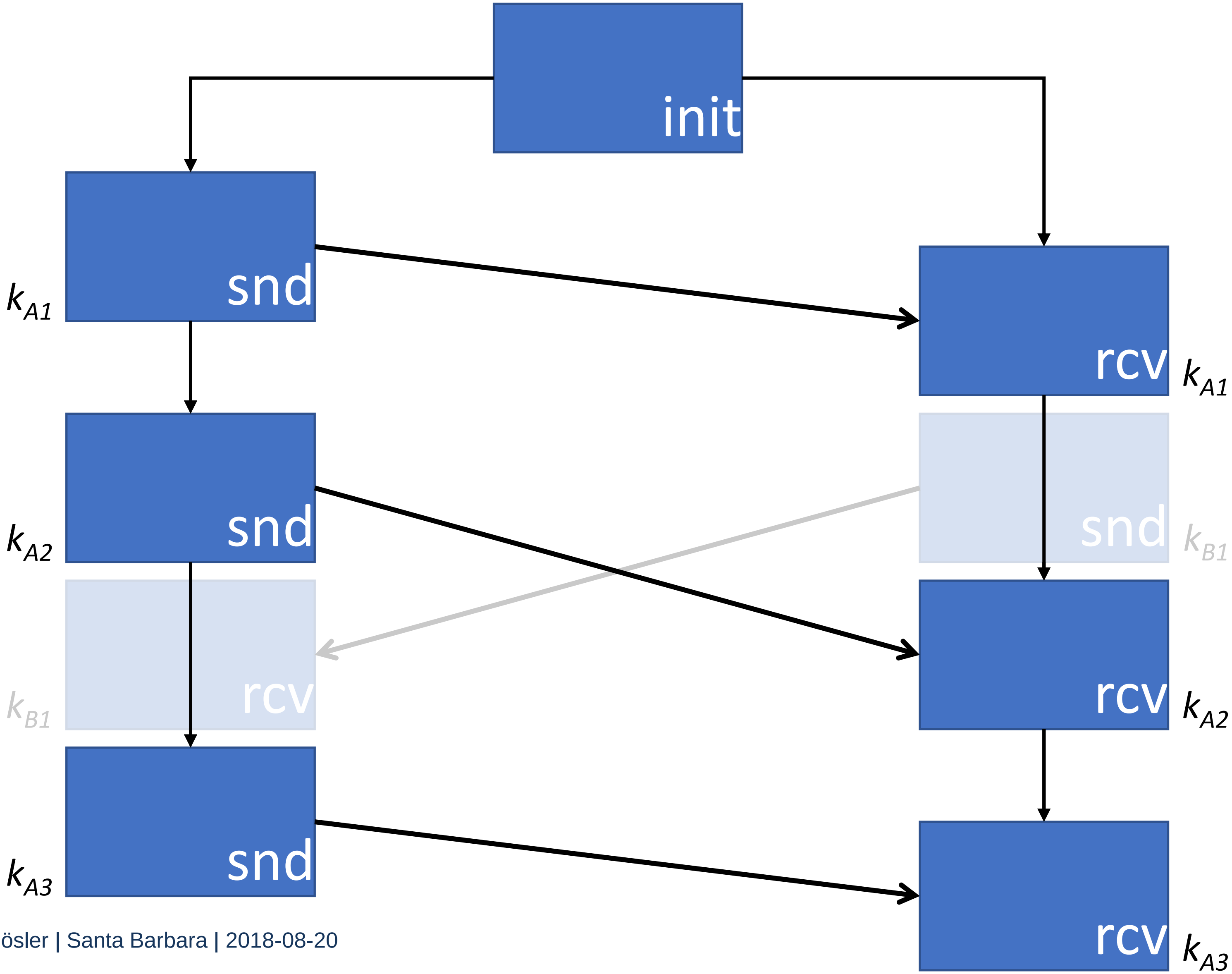


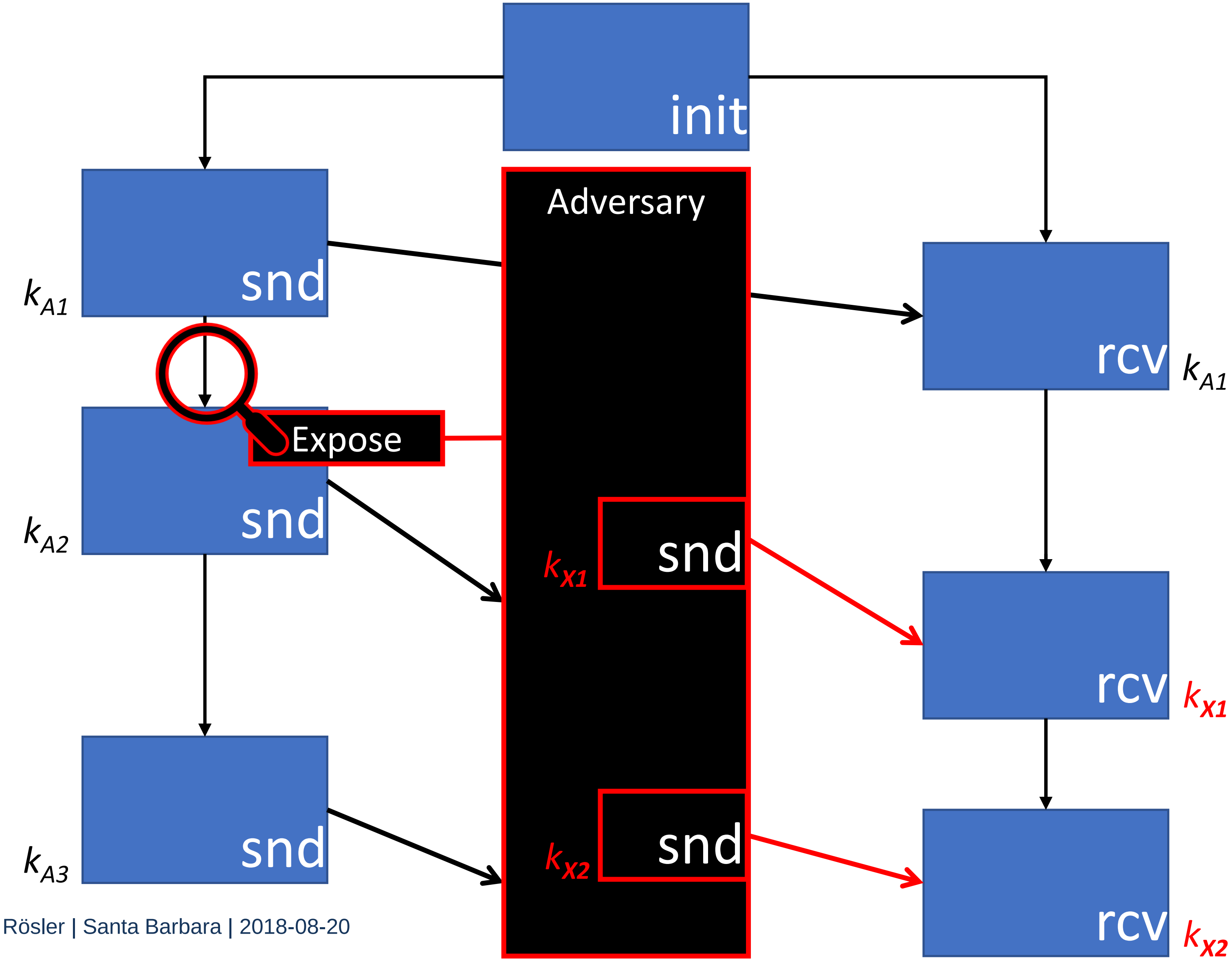
What is Ratcheting?
- Modeling RKE
Construction Intuition
Results

Modeling Unidirectional RKE



Modeling Unidirectional RKE

- Impersonation
  ⇒ No future Challenge on Bob



Modeling Unidirectional RKE

- Impersonation
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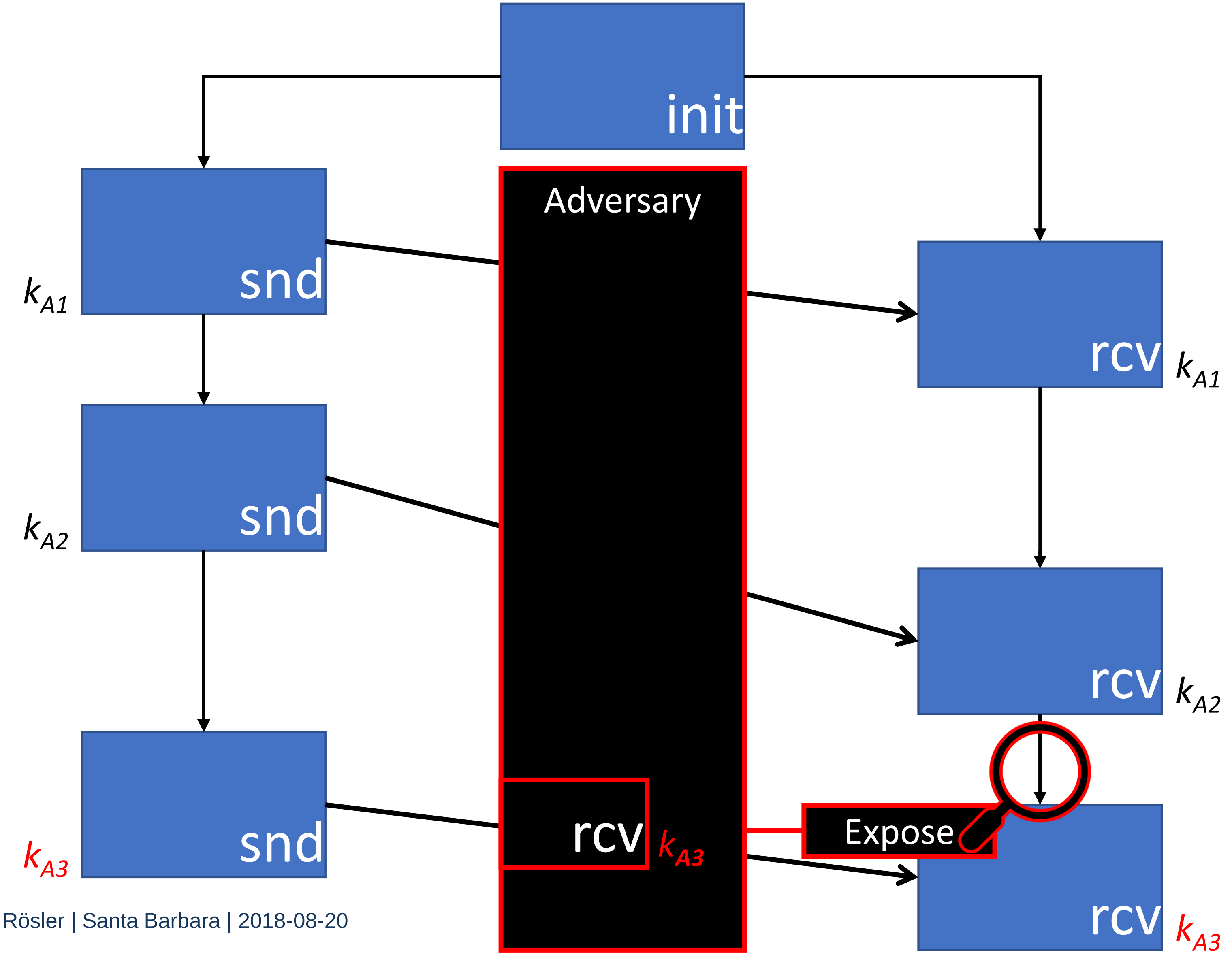
- Expose Bob
  → Allowed in our model



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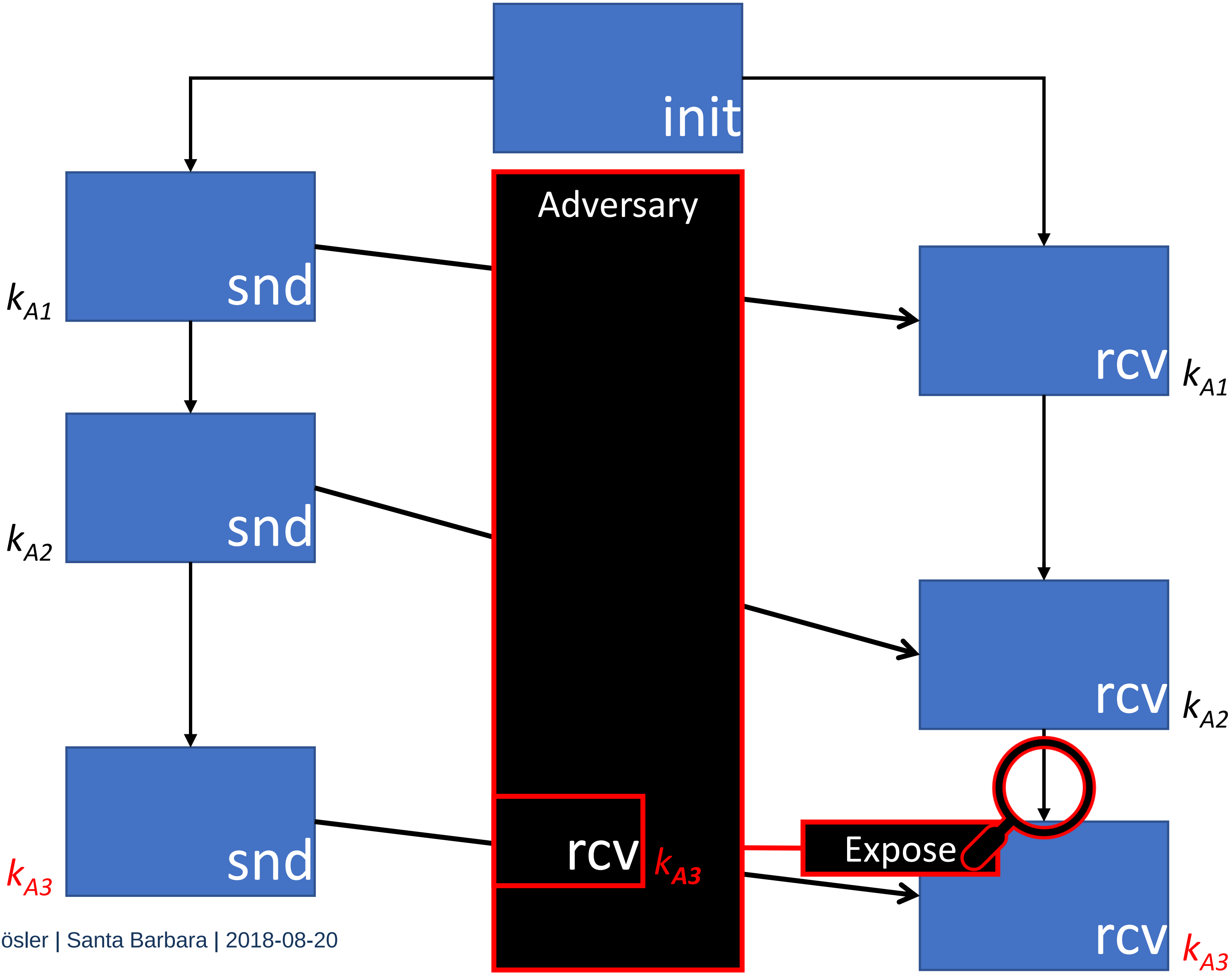

Modeling Unidirectional RKE

- Impersonation
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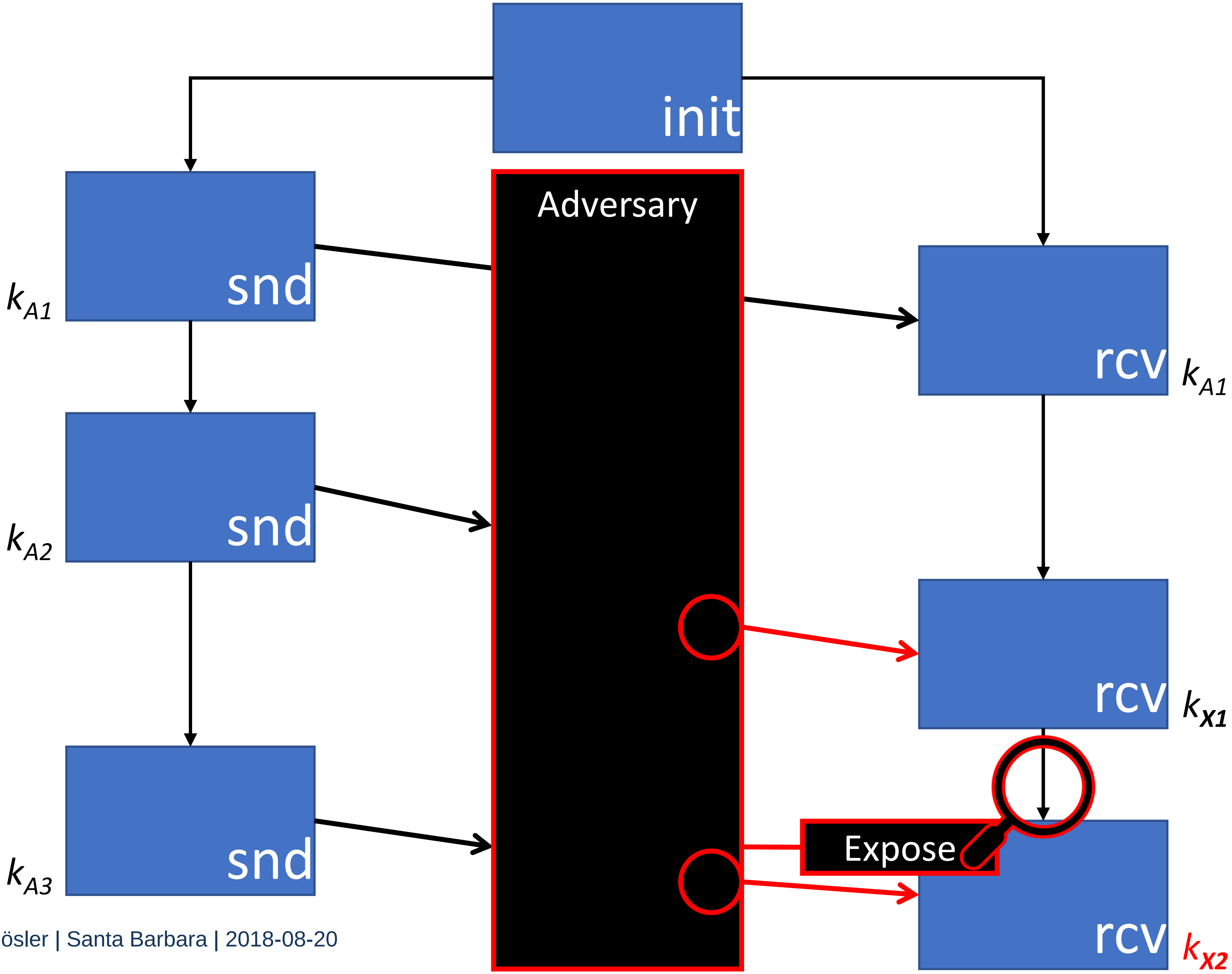
- Expose Bob
  ⇒ No future Challenge **if synchronous** (= if no previous active attack)



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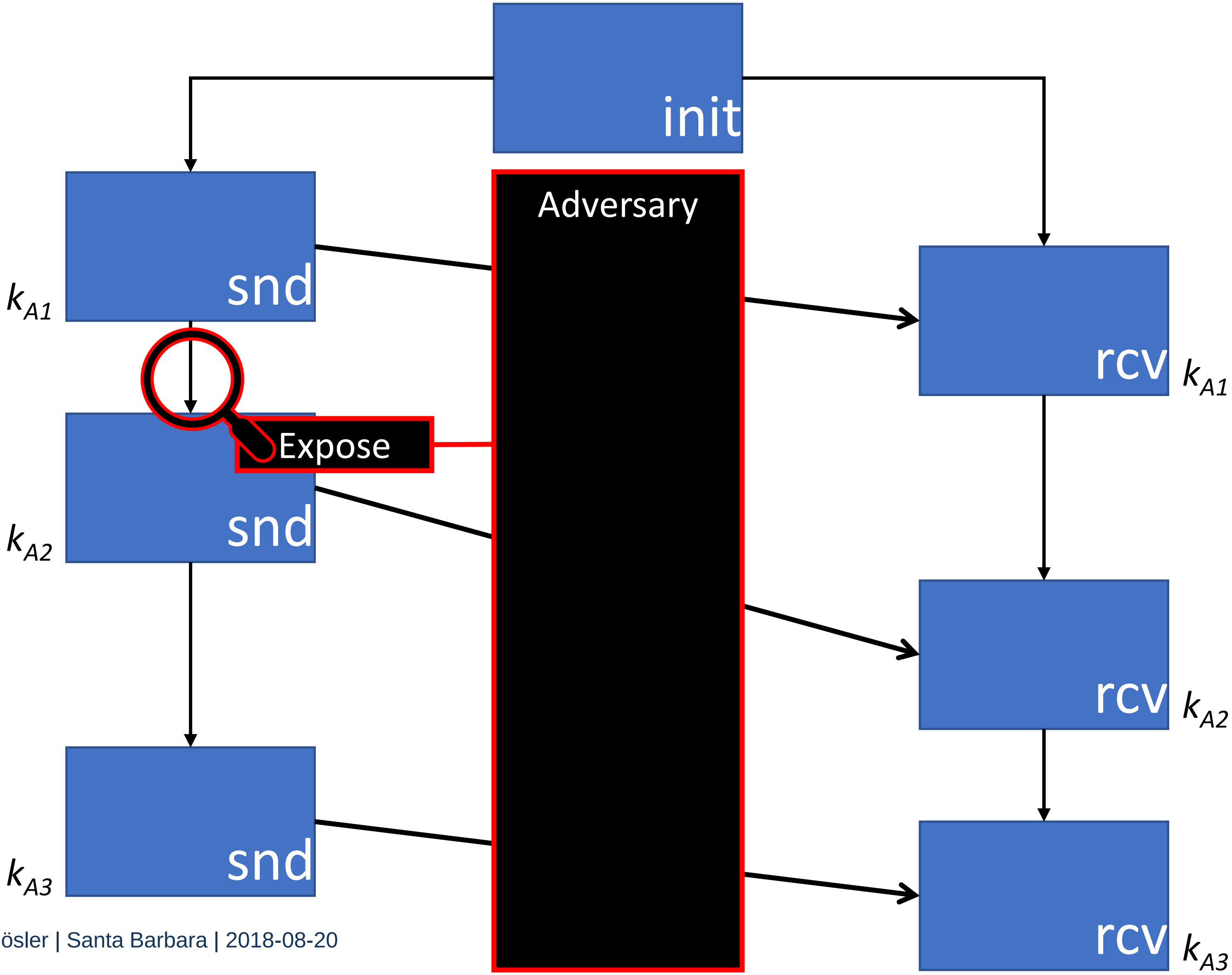
⇒ Exposure of Alice (solely) “okay”



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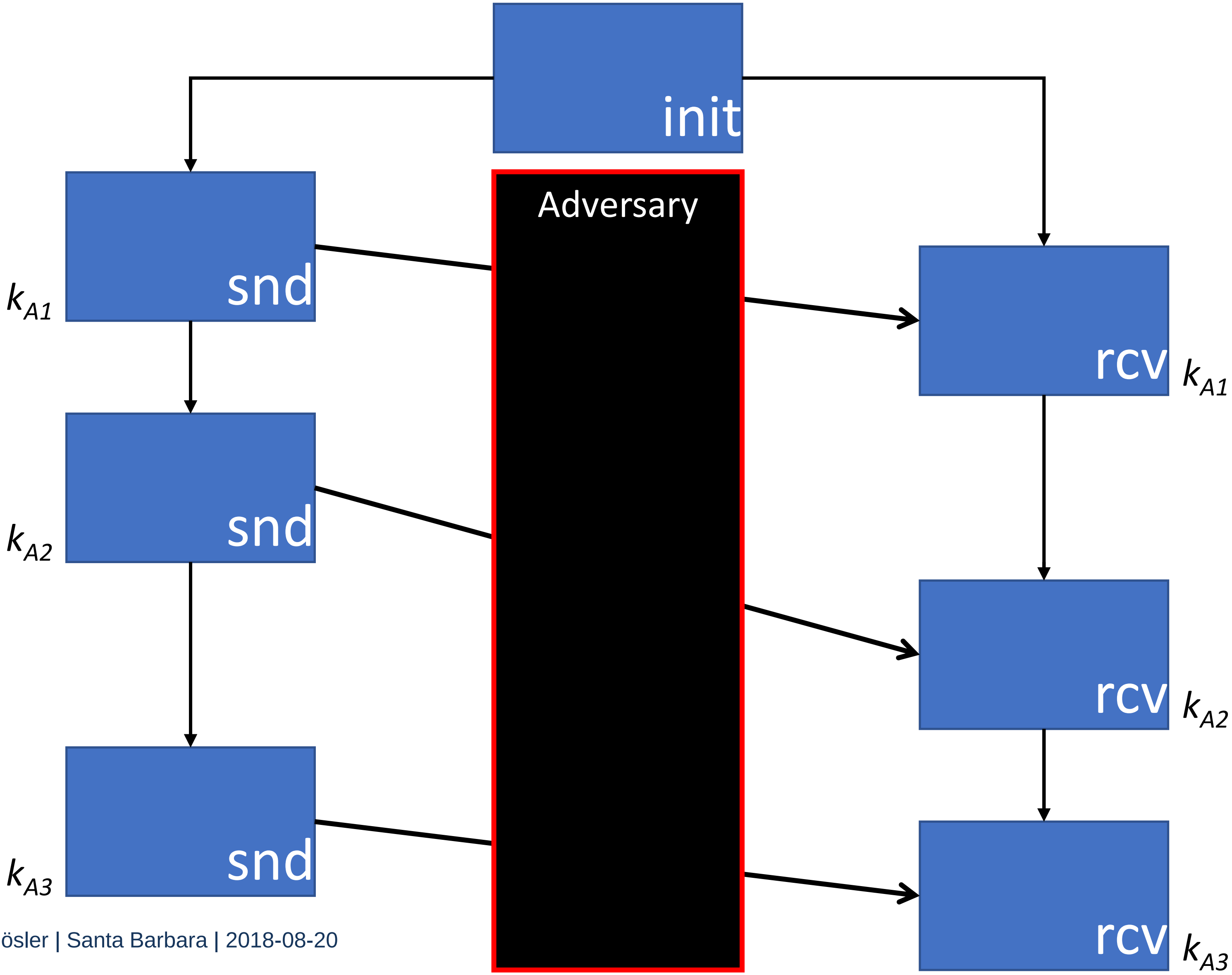

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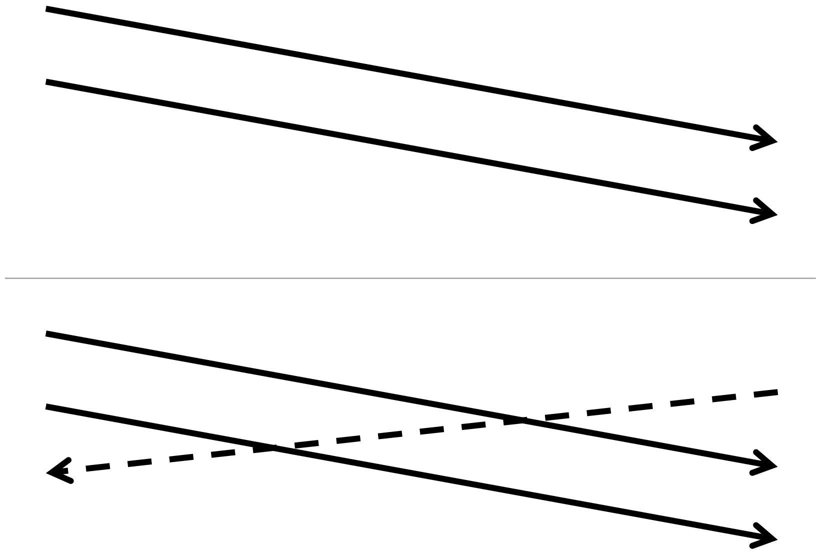
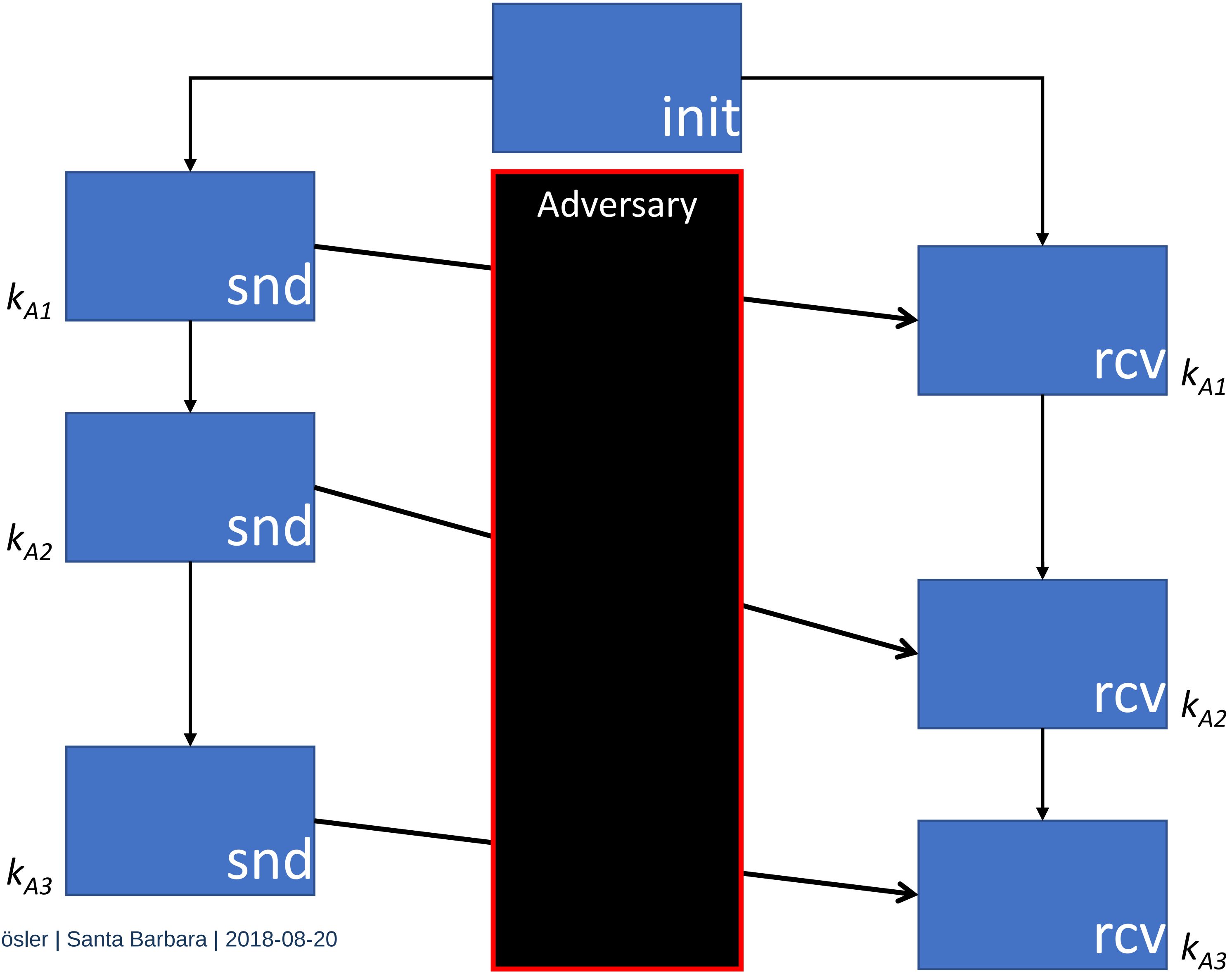


Constructing Unidirectional RKE

- **Expose Alice okay**

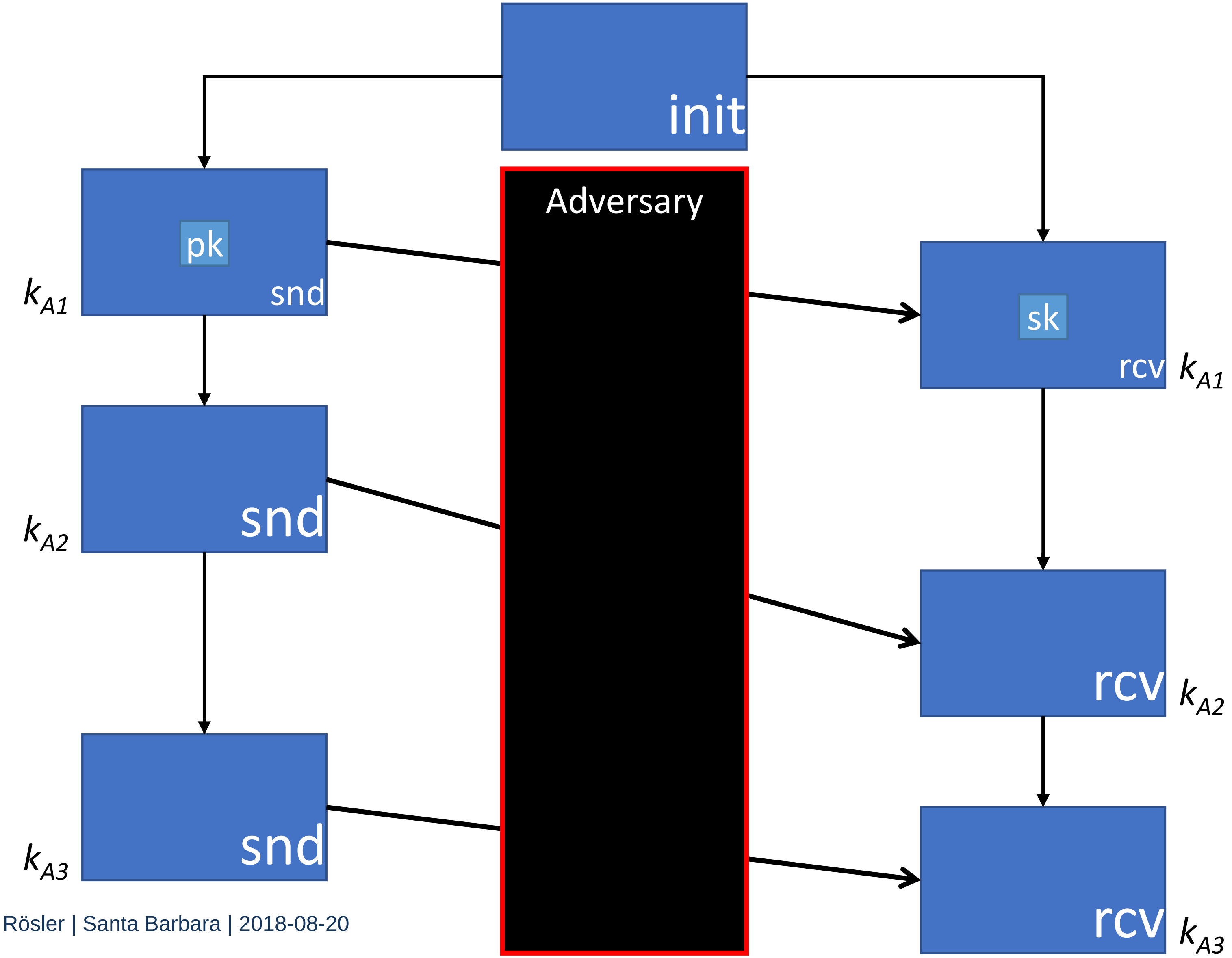
- **Expose Bob**
  ⇒ No future Challenge if synchronous



Constructing Unidirectional RKE

- **Expose Alice okay**
  → Public key crypto

- **Expose Bob**
  ⇒ No future Challenge if synchronous



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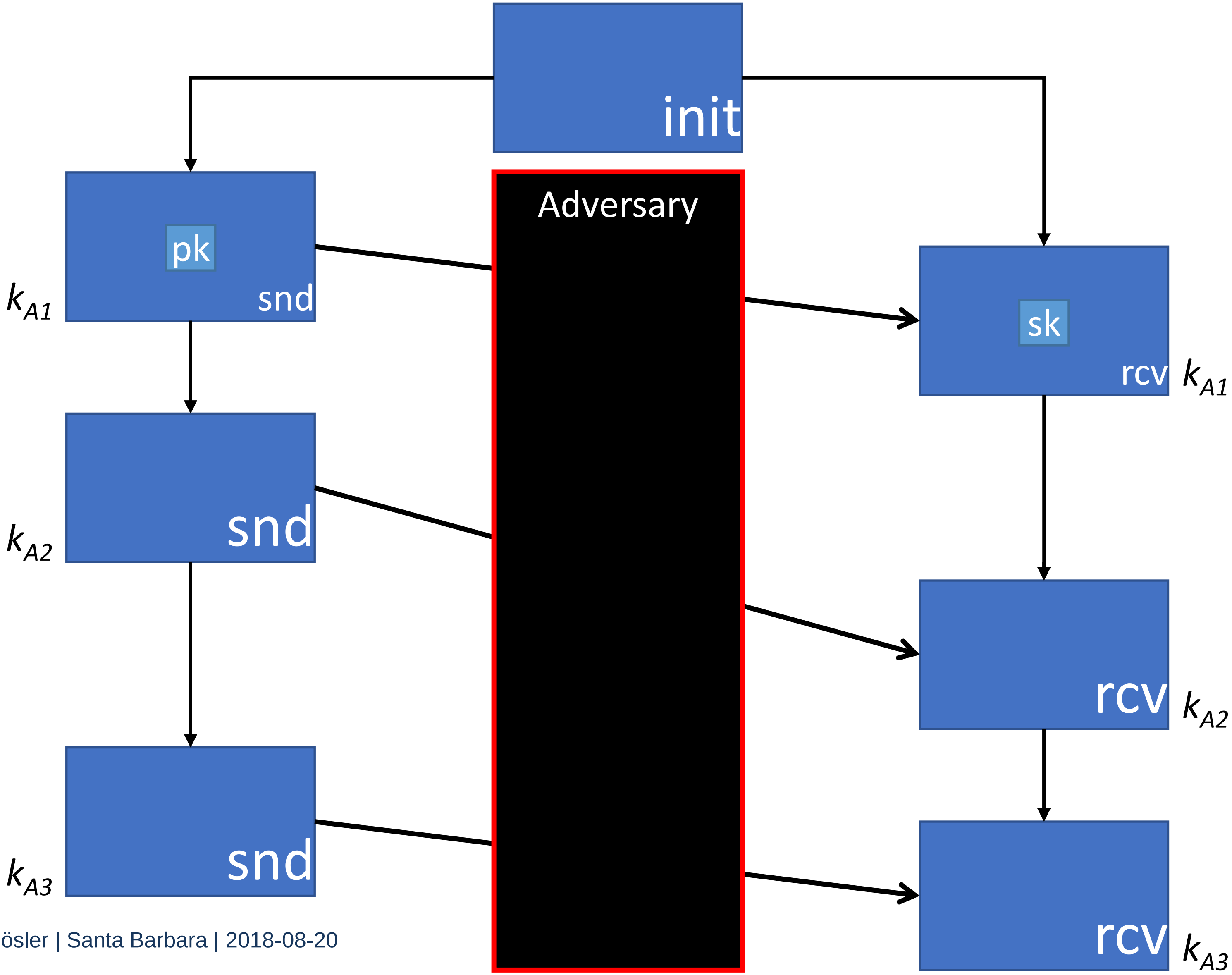
Constructing Unidirectional RKE

- **Expose Alice okay**
  → KEM:

enc (pk) →$_\$$ c k   dec (sk c) →$_\$$ k

- **Expose Bob**
  ⇒ No future Challenge if synchronous



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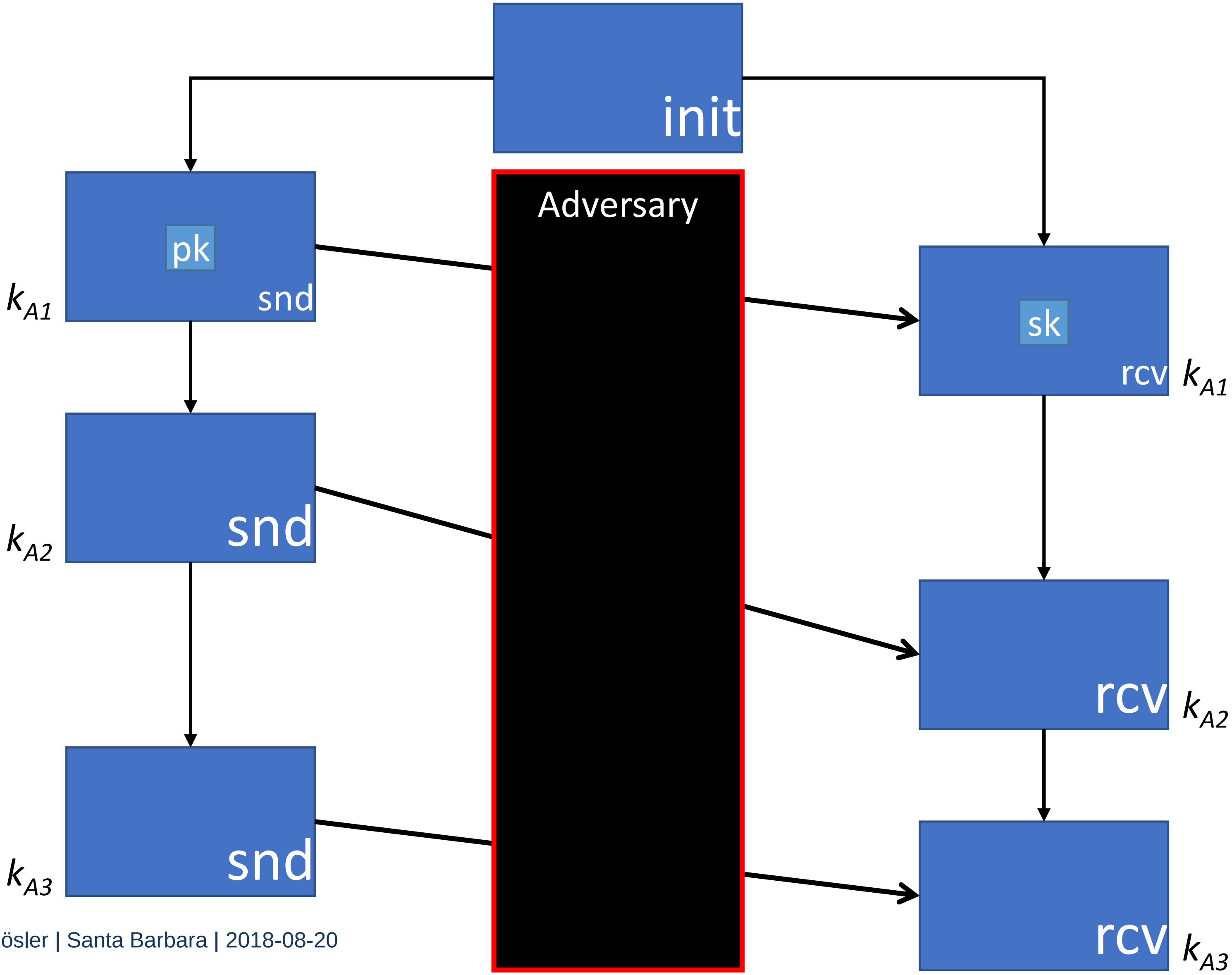

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- **Expose Alice okay**
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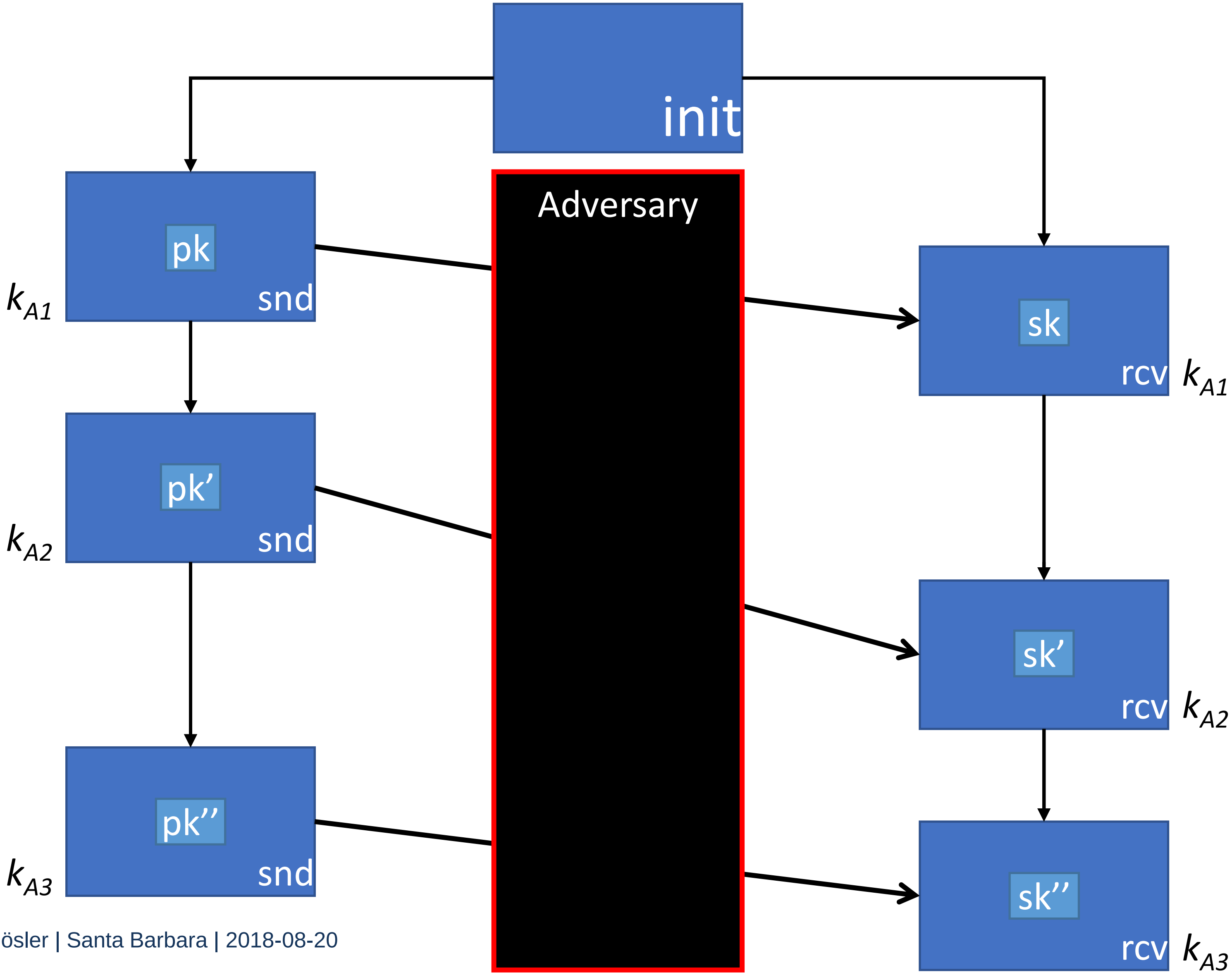
  ⇒ No future Challenge if synchronous
  → Forward secrecy of Bob’s state



Constructing Unidirectional RKE

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  → KEM:
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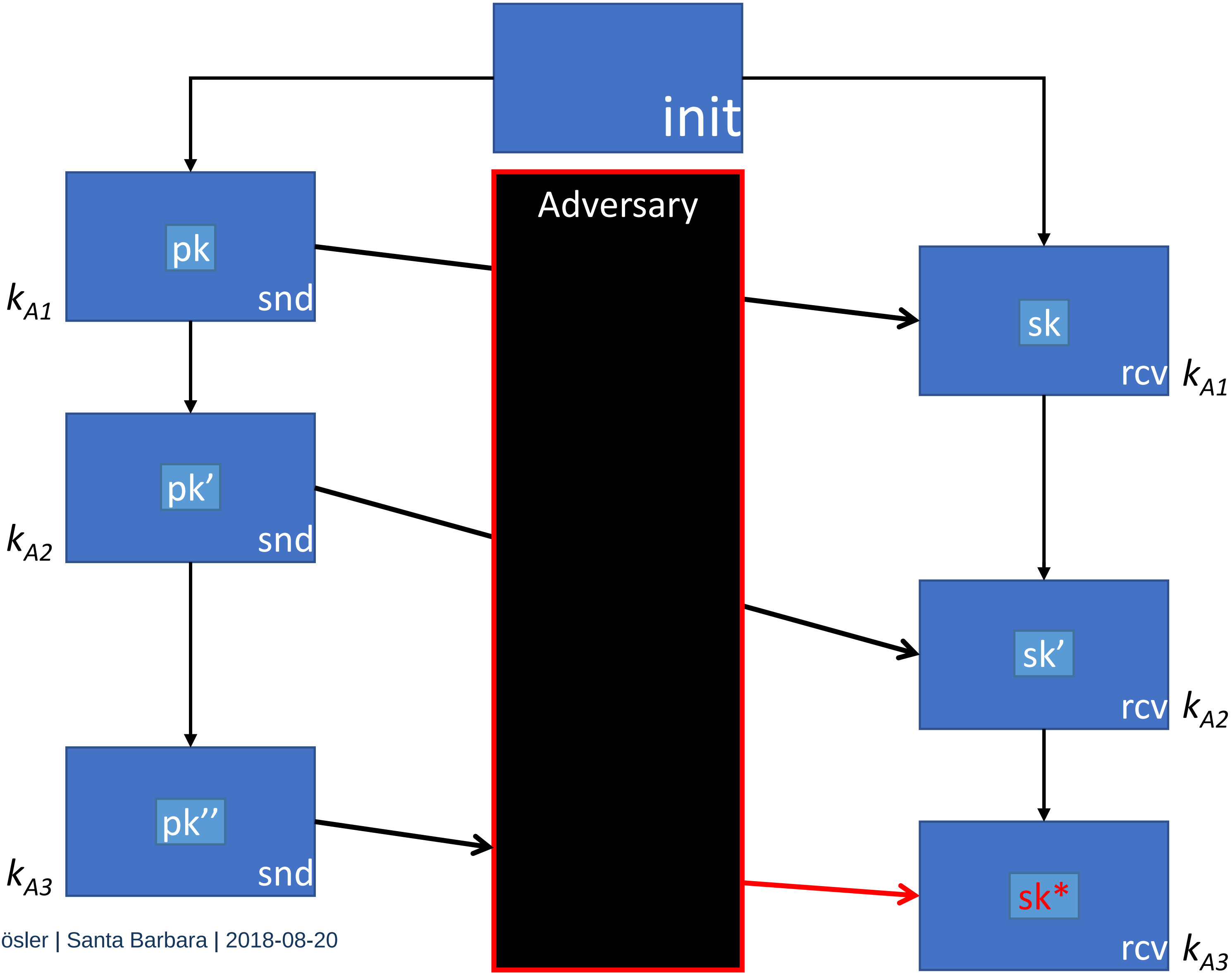
- **Expose Bob**
  ⇒ No future Challenge if synchronous
  → Forward secrecy of Bob's state
  → Divergence of states



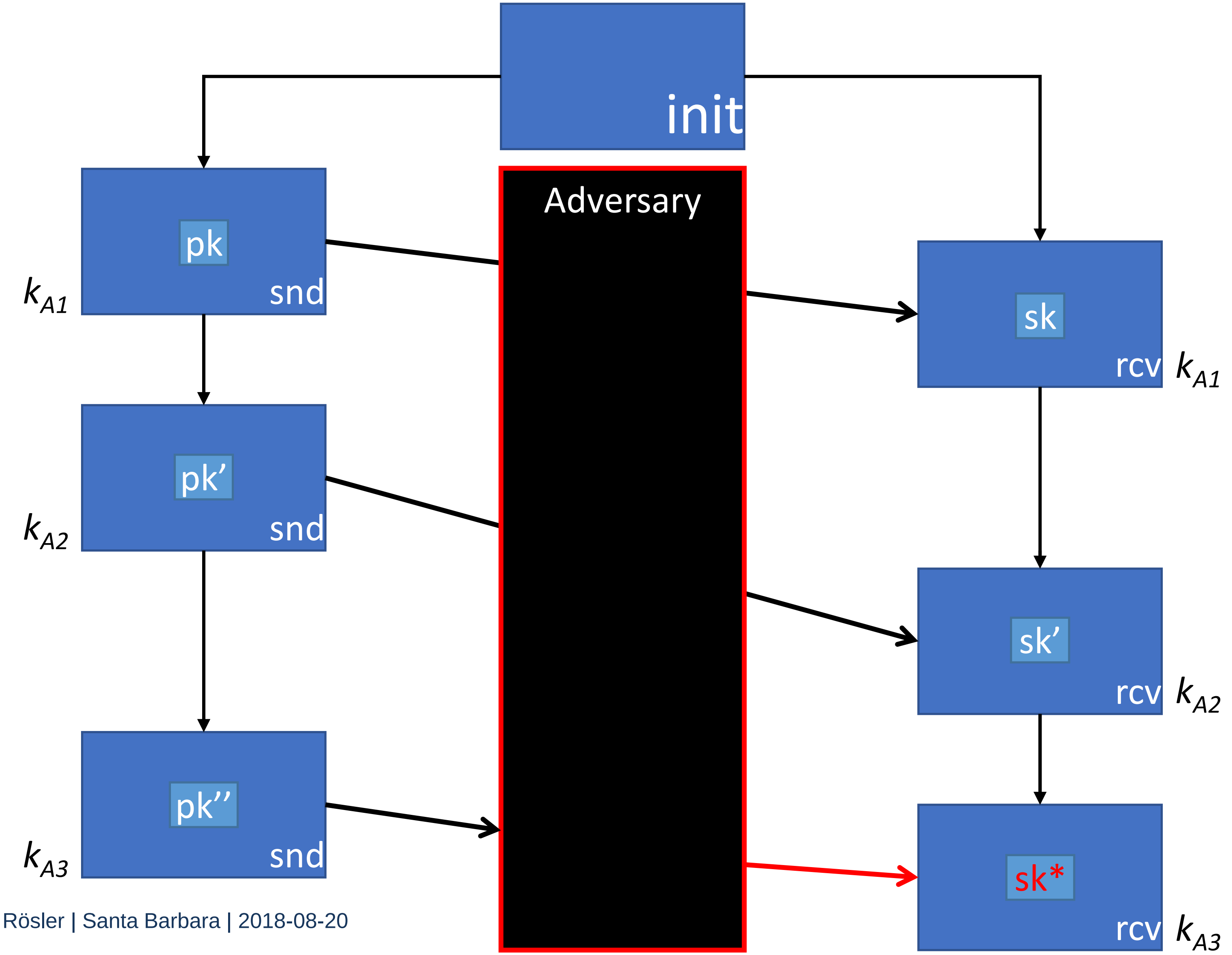
Constructing Unidirectional RKE

- Expose Alice okay
  → KEM:

  $\mathrm{enc}(pk) \rightarrow_{\$} c\ k$ $\quad$ $\mathrm{dec}(sk\ c) \rightarrow_{\$} k$

- **Expose Bob**
  ⇒ No future Challenge if synchronous
  → Forward secrecy of Bob's state
  → Divergence of states
  → Random oracle:

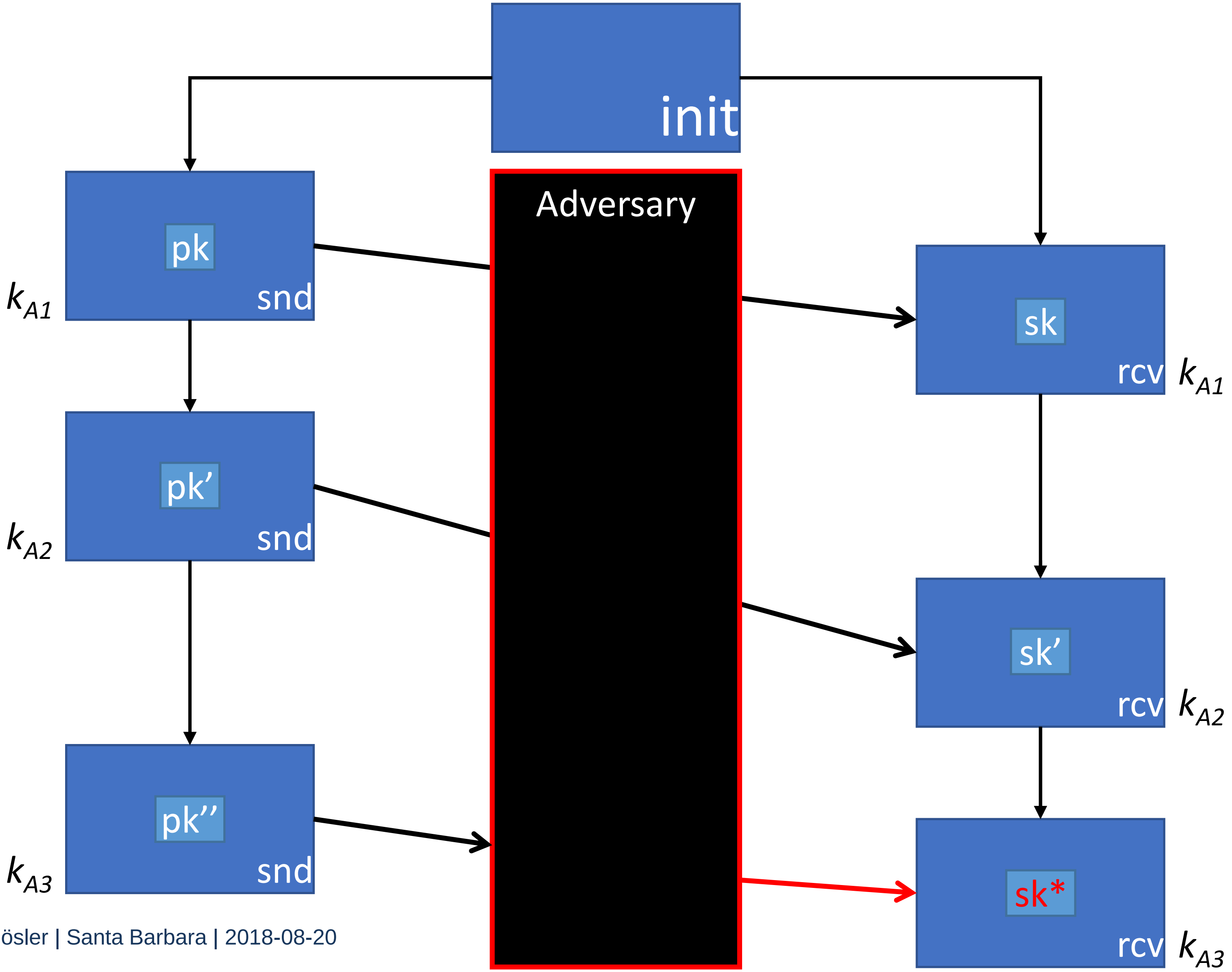
  $H(c\ k) \rightarrow k_{Xn}\ sk$



Constructing Unidirectional RKE

- **Expose Alice okay**
  → KEM:
  enc(pk)→$_\$$ c k dec(sk c)→$_\$$ k

- **Expose Bob**
  ⇒ No future Challenge if synchronous
  → Forward secrecy of Bob's state
  → Divergence of states
  → Random oracle:
  H(c k)→ k_{Xn} sk
  gen(sk)→pk



Constructing Unidirectional RKE

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  → KEM:
  enc(pk)$\rightarrow_{\$}$ c k dec(sk c)$\rightarrow_{\$}$ k

- **Expose Bob**
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  → Divergence of states
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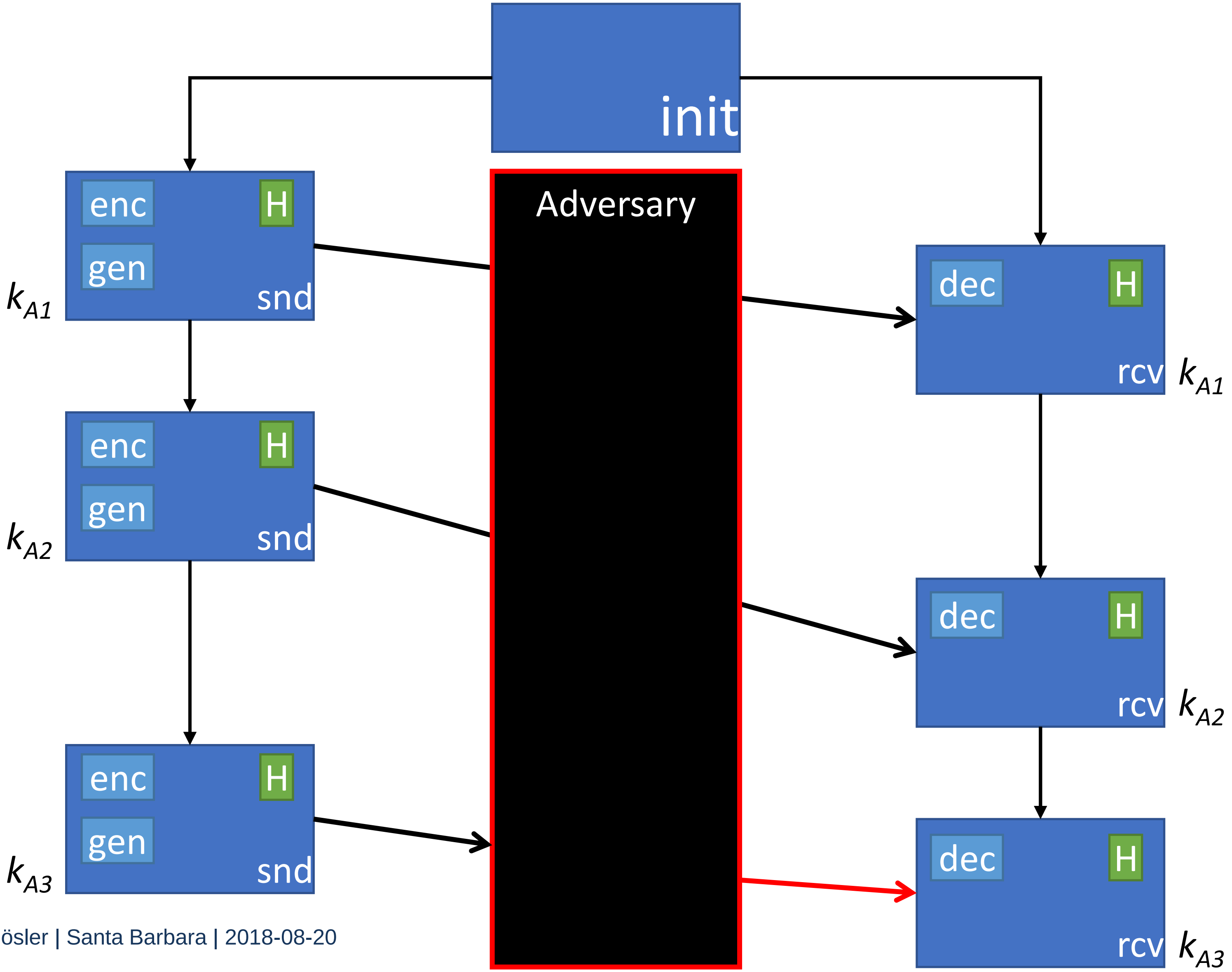
  gen(sk)→pk



Agenda

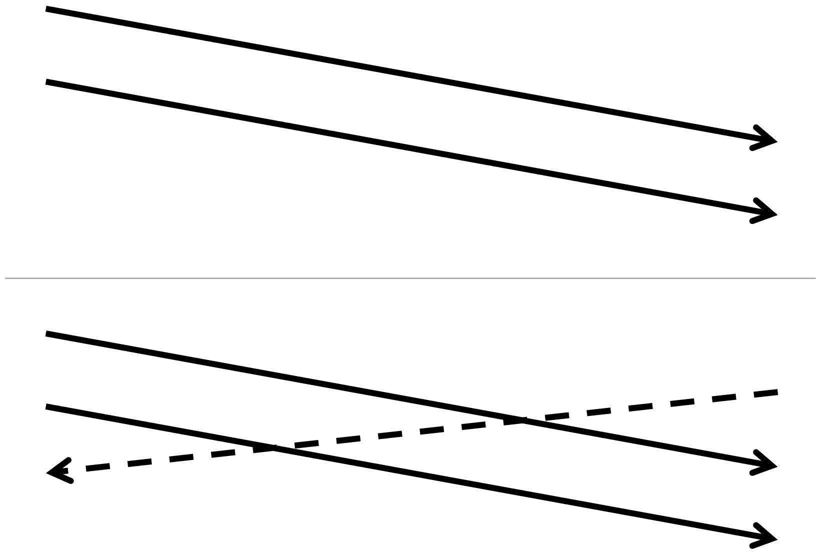
1. The Primitive Ratcheted Key Exchange

2. General Adversary Model

3. Unidirectional Ratcheting
   → Model and Construction

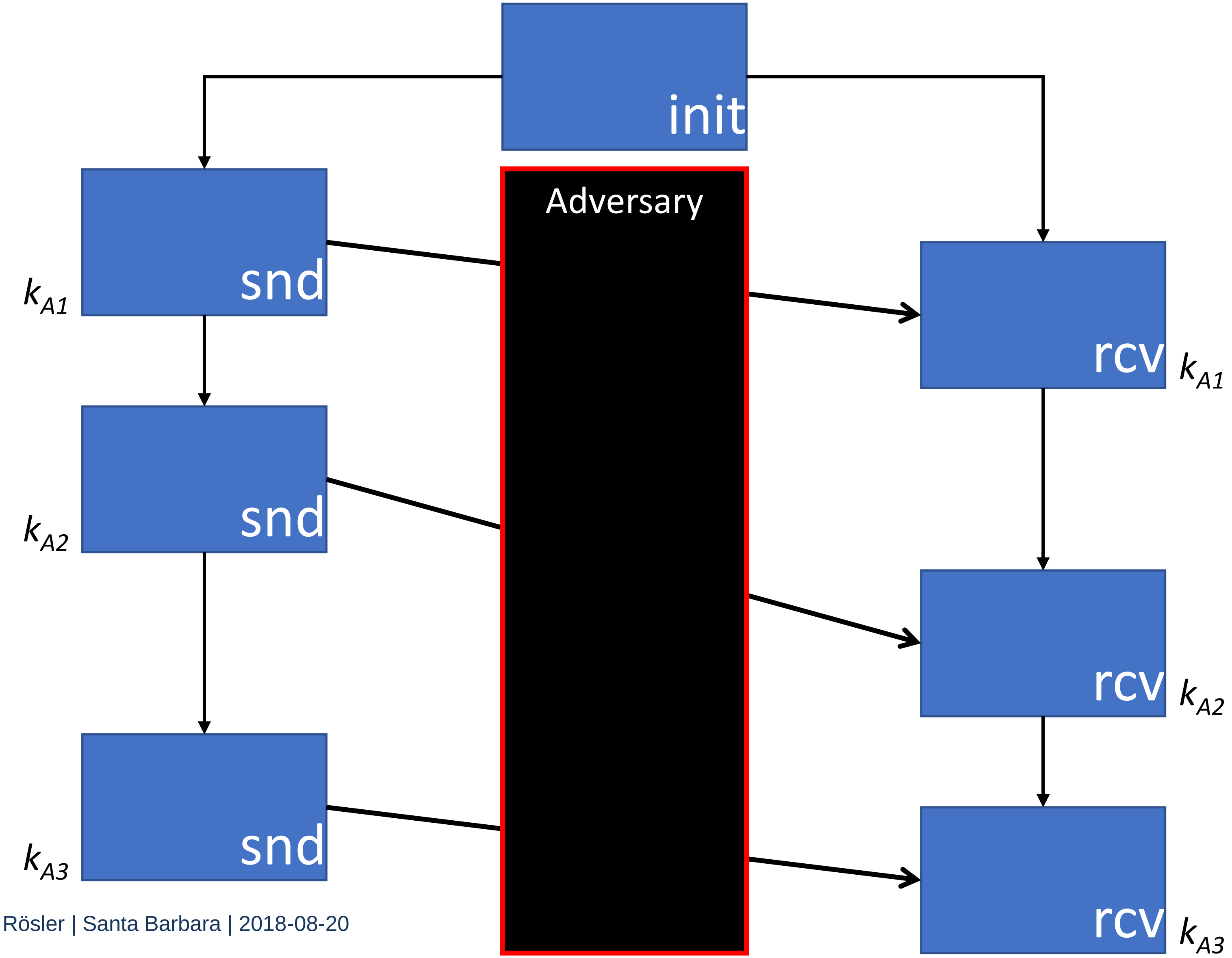
4. **Sesquidirectional Ratcheting**
   → **Model** and Construction

5. Results



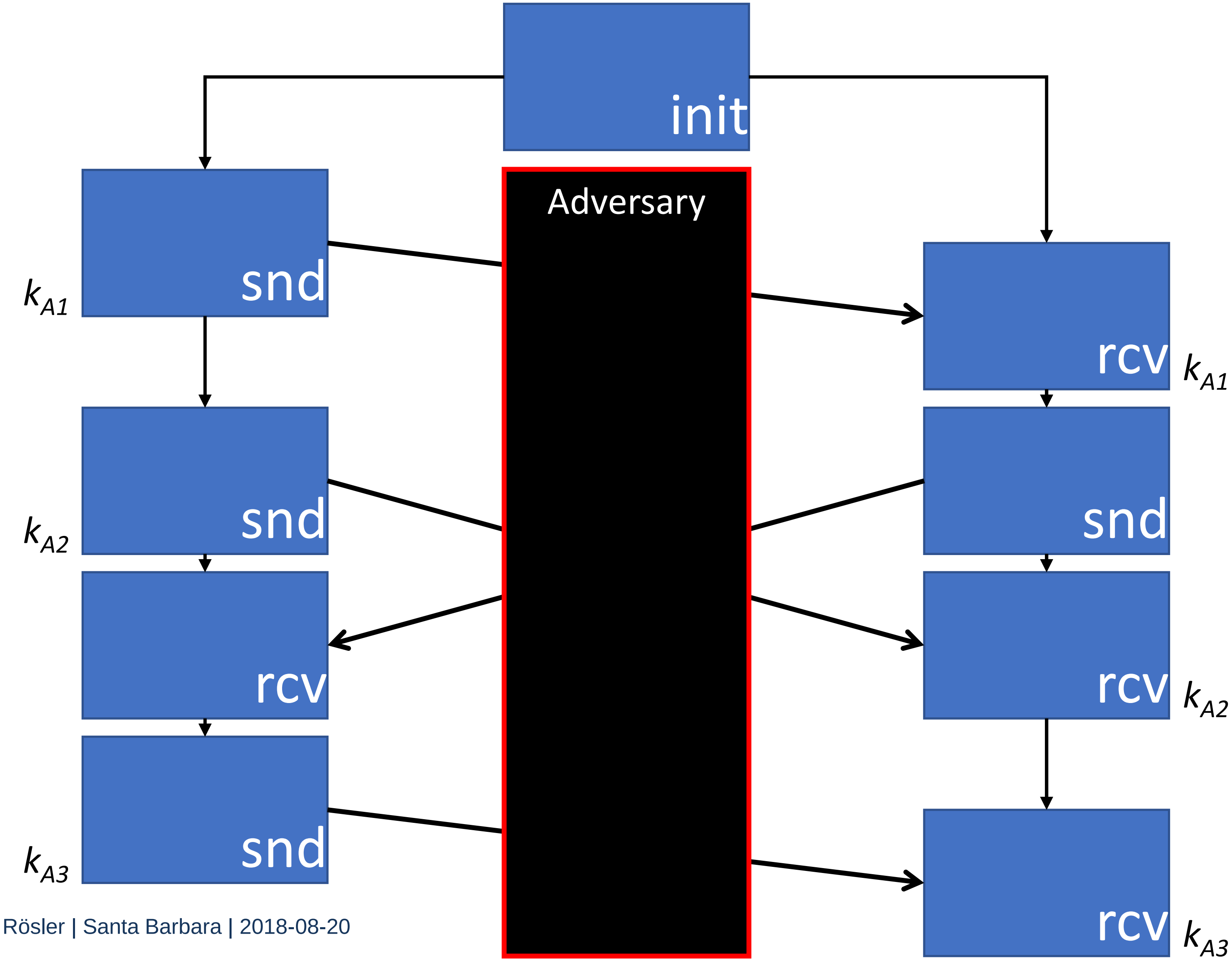
Modeling Unidirectional RKE

- Impersonation A → B
  ⇒ No future Challenge on Bob
- Expose Bob
  ⇒ No future Challenge if synchronous



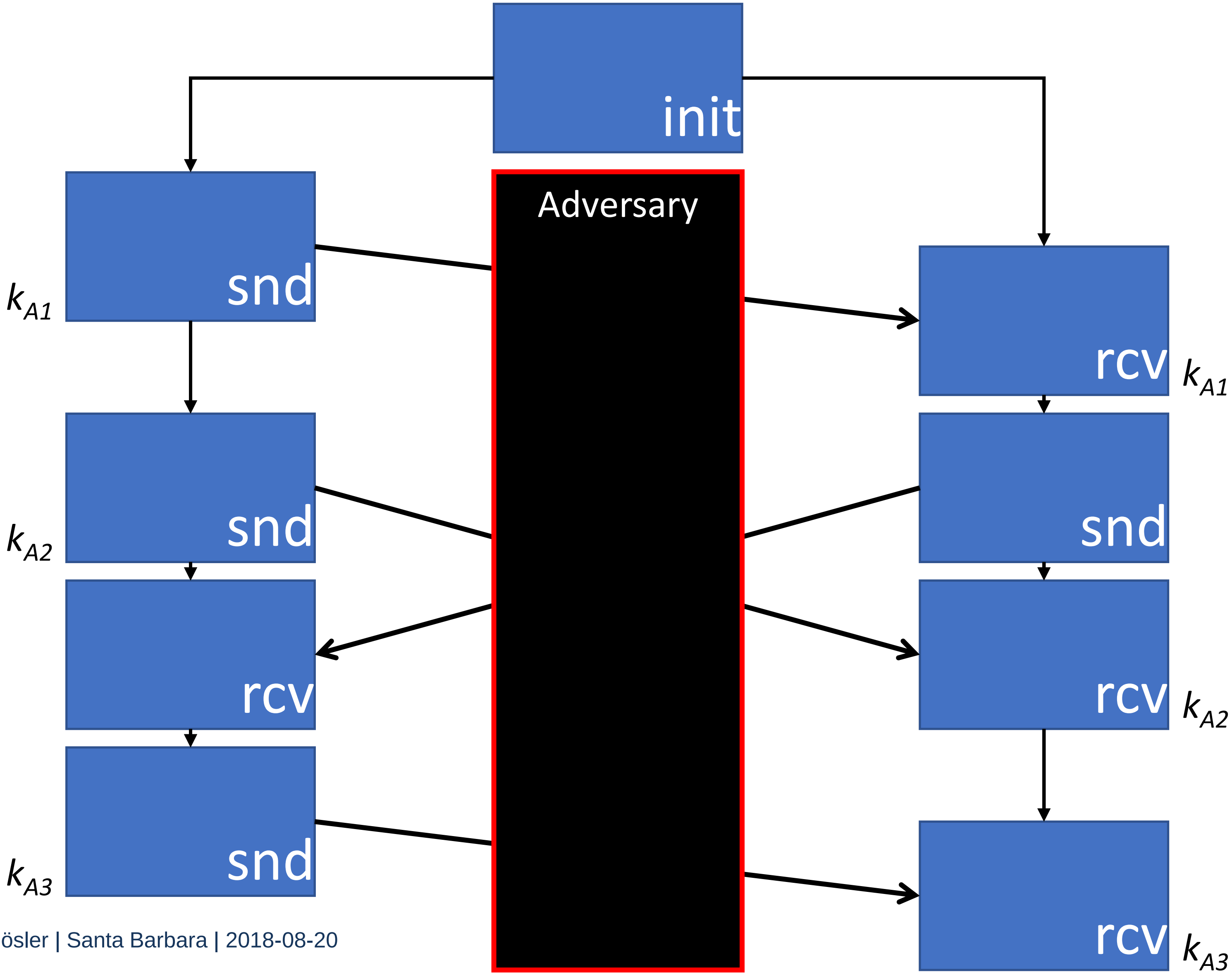
Modeling Sesquidirectional RKE

- Impersonation A → B
  ⇒ No future Challenge on Bob
- Expose Bob
  ⇒ No future Challenge if synchronous



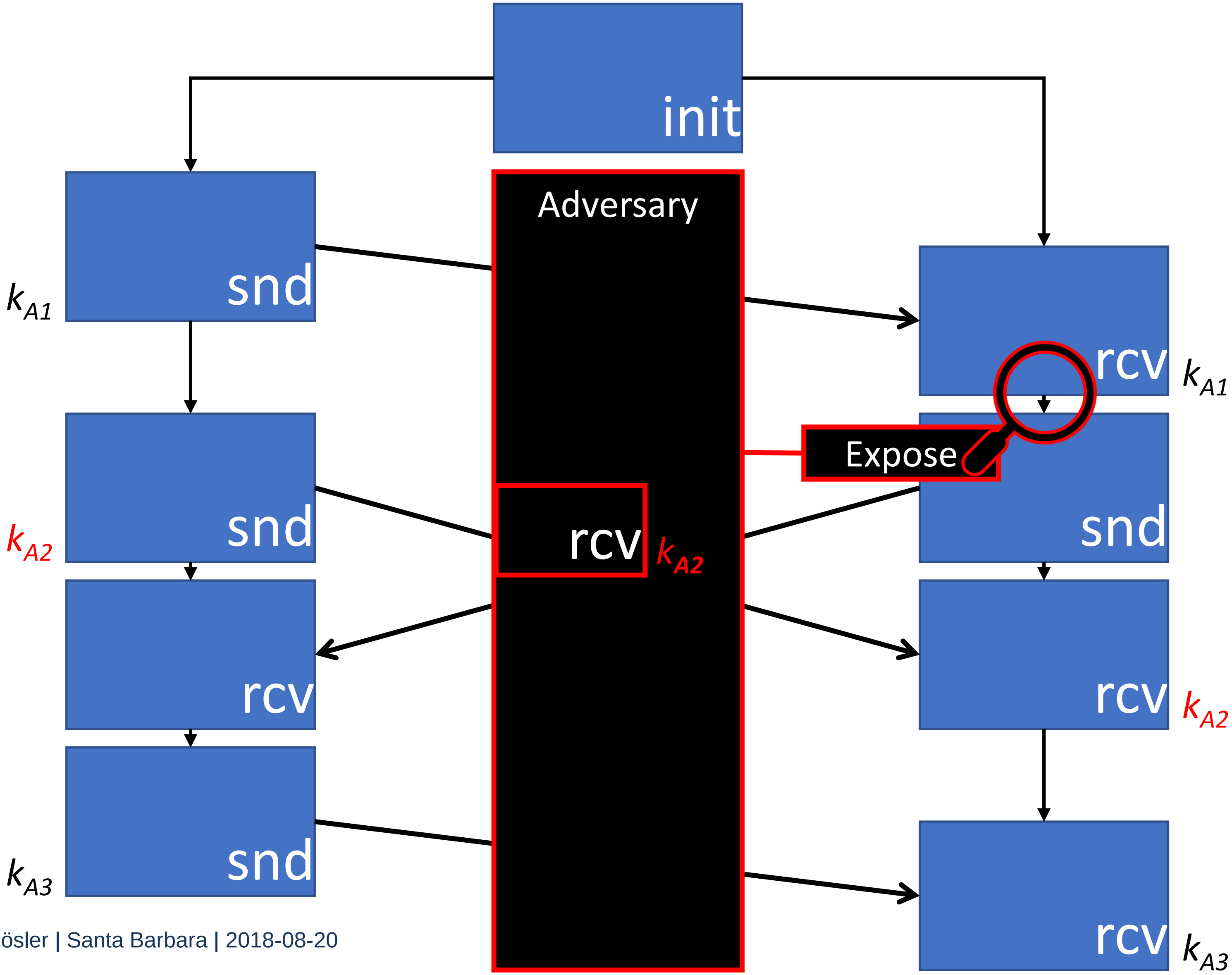
Modeling Sesquidirectional RKE

- Impersonation A → B
  ⇒ No future Challenge on Bob
- Impersonation B → A
  ⇒ No future Challenge on Alice
- Expose Bob
  ⇒ No future Challenge if synchronous



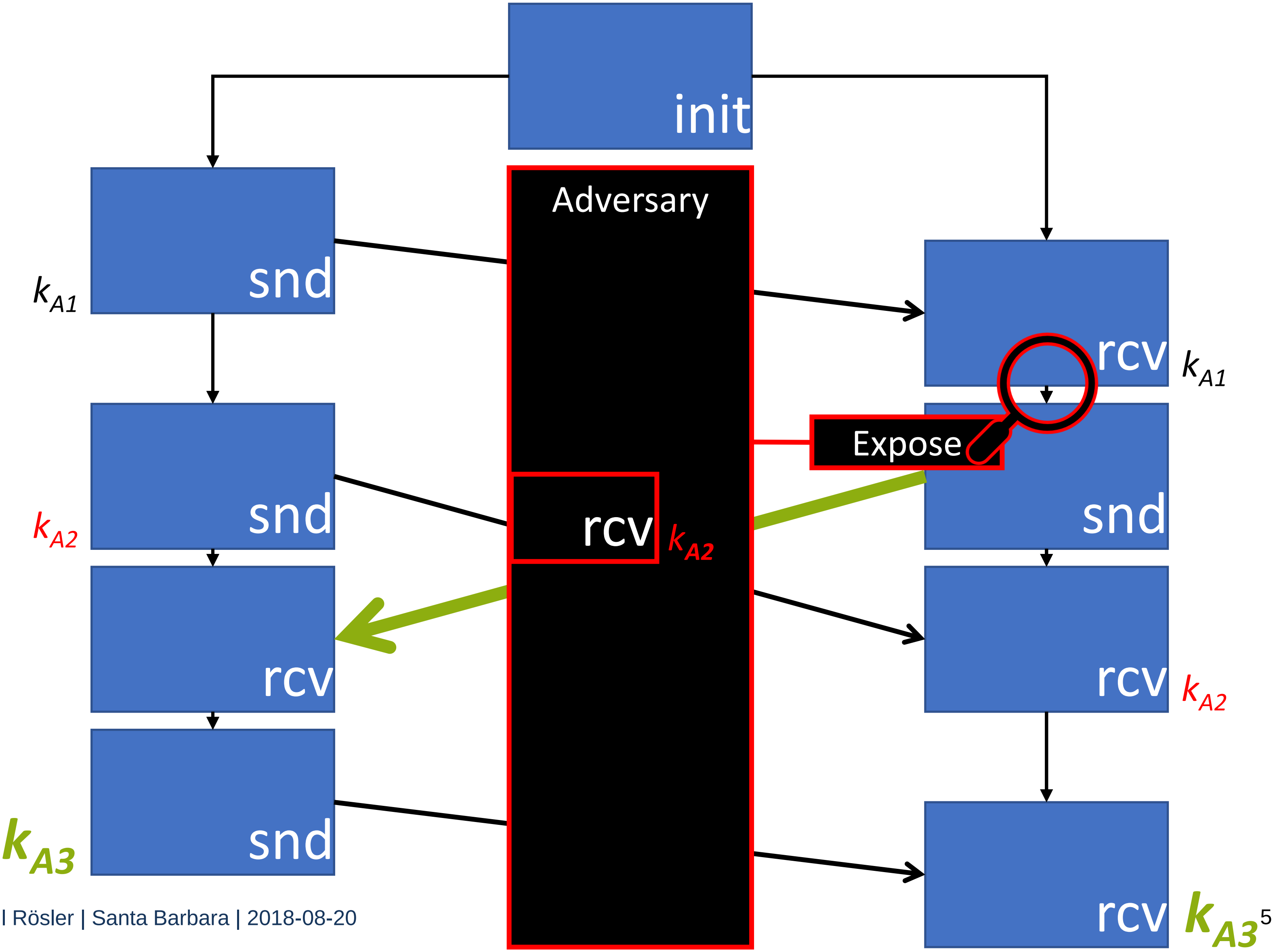
Modeling Sesquidirectional RKE

- Impersonation A → B
  ⇒ No future Challenge on Bob
- Impersonation B → A
  ⇒ No future Challenge on Alice
- Expose Bob
  ⇒ No future Challenge if synchronous **until Bob recovered**



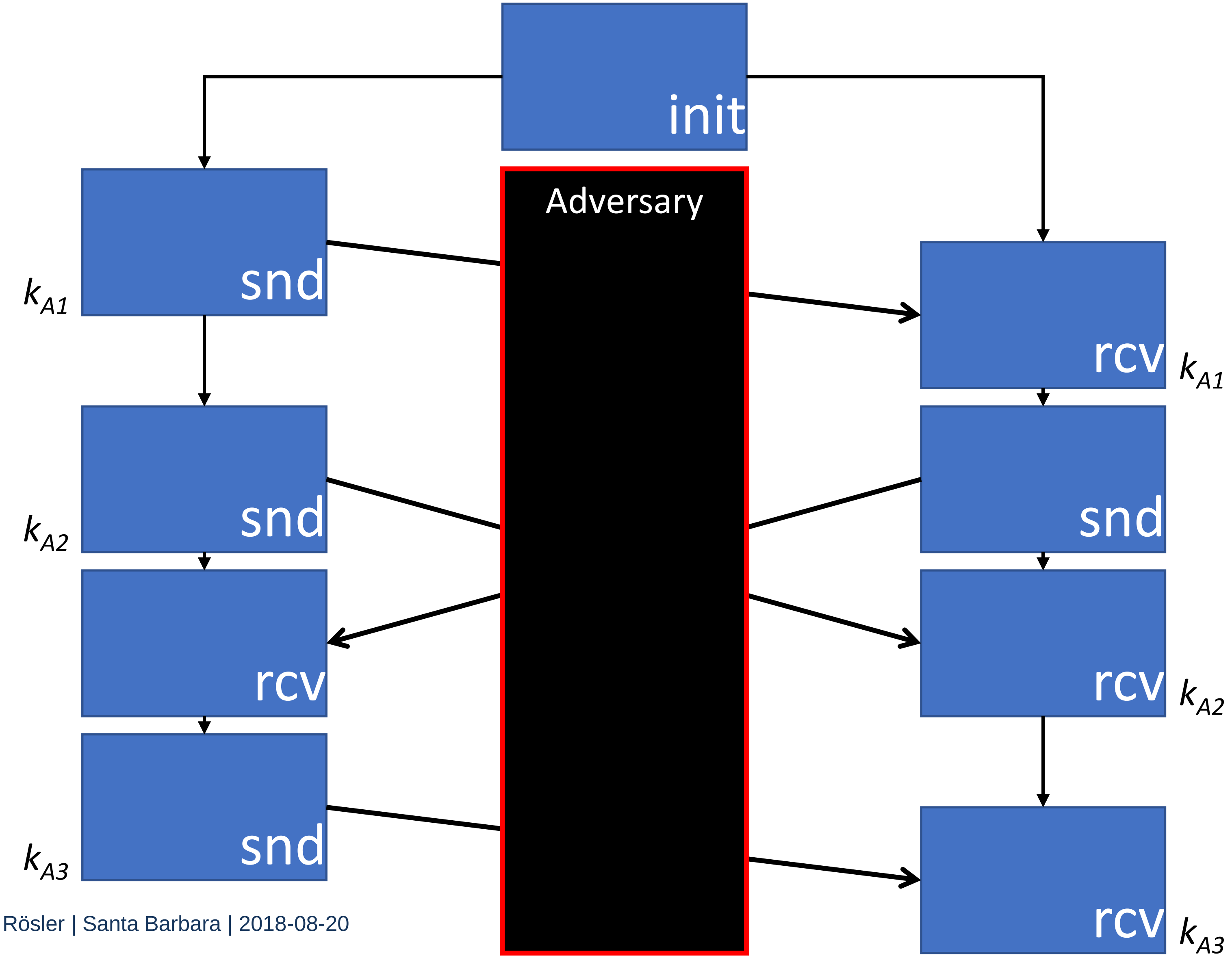
Modeling Sesquidirectional RKE

- Impersonation A → B
  ⇒ No future Challenge on Bob
- Impersonation B → A
  ⇒ No future Challenge on Alice
- Expose Bob
  ⇒ No future Challenge if synchronous **until Bob recovered**



Modeling Sesquidirectional RKE

- Impersonation A → B
  ⇒ No future Challenge on Bob
- Impersonation B → A
  ⇒ No future Challenge on Alice
- **Expose Bob**
  ⇒ No future Challenge if synchronous until Bob recovered



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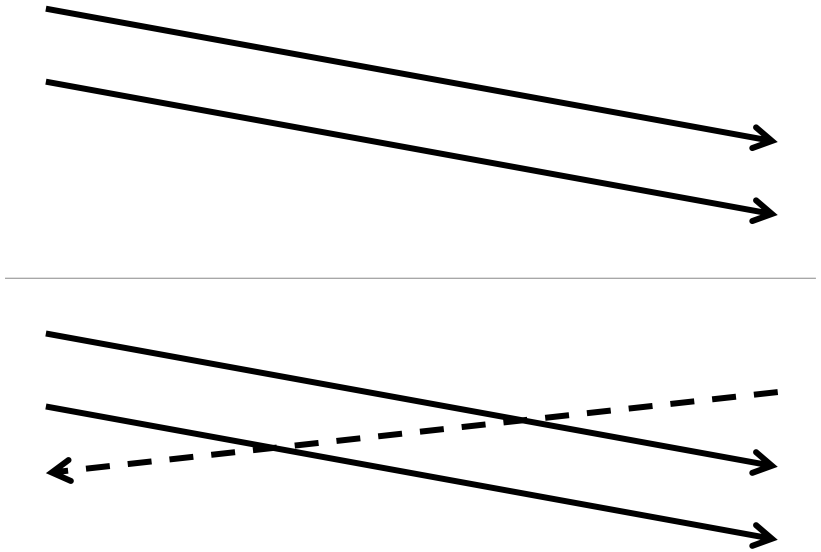
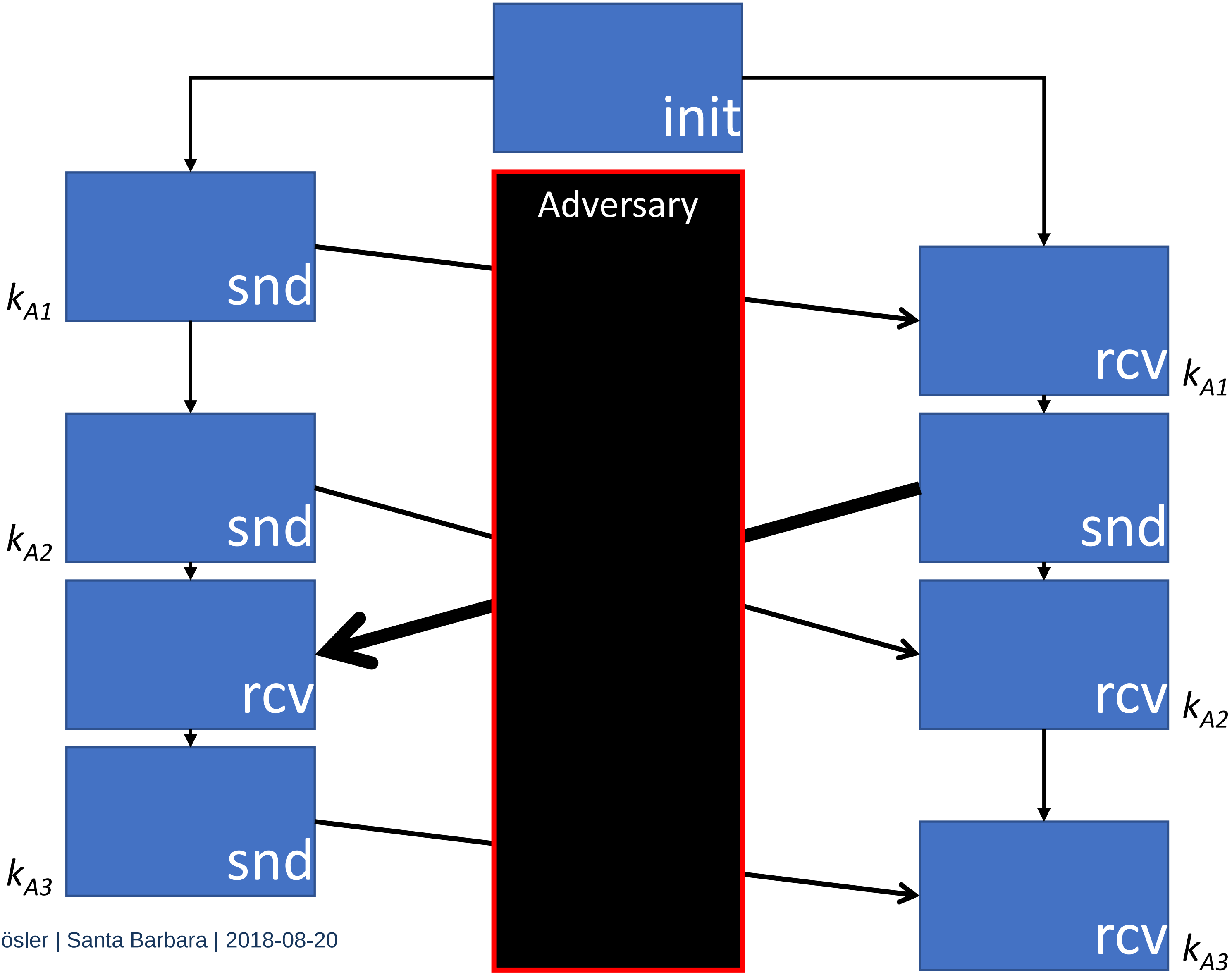


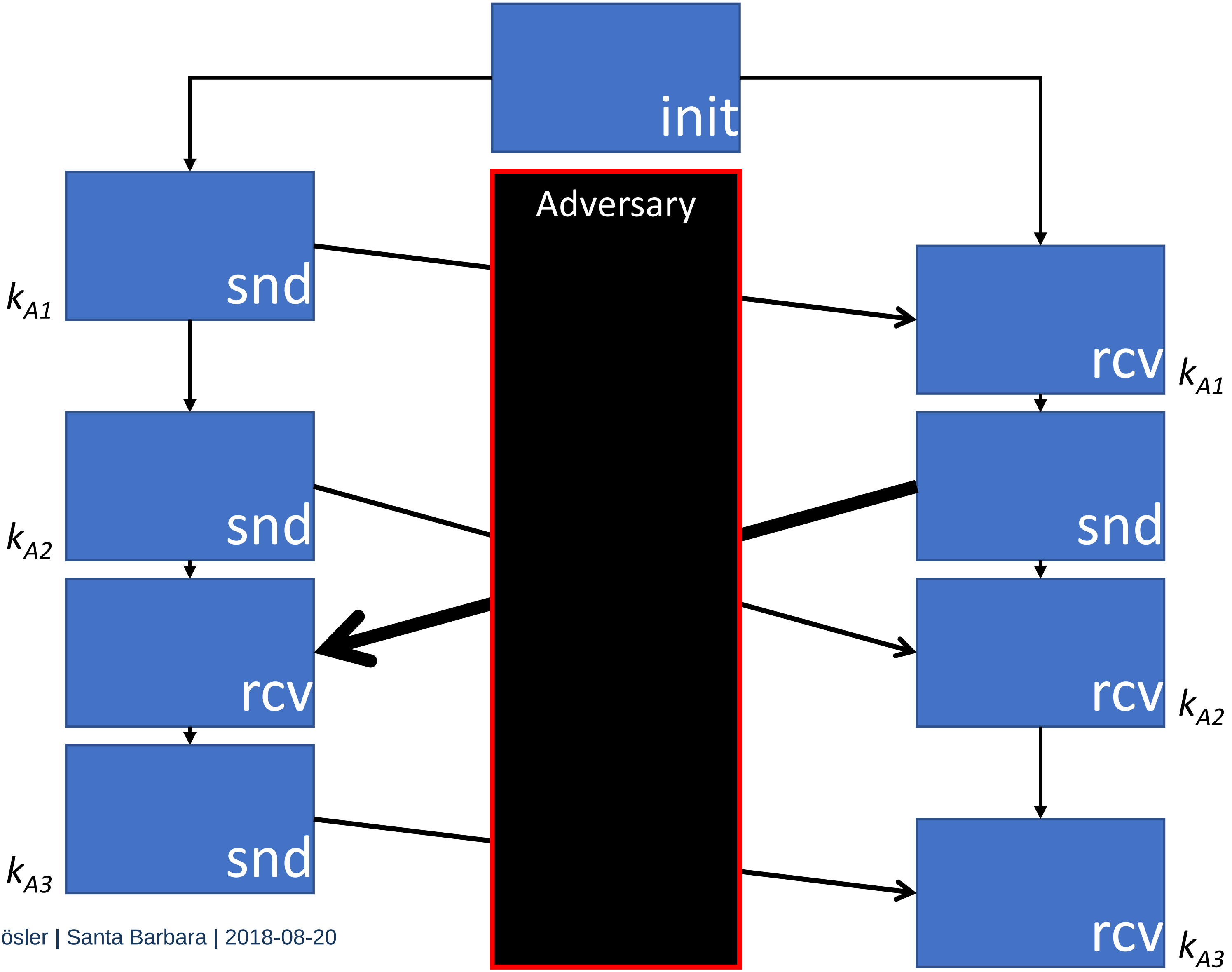
Constructing Sesquidirectional RKE

- **Expose Bob**
  ⇒ No future Challenge
  if synchronous
  until Bob recovered



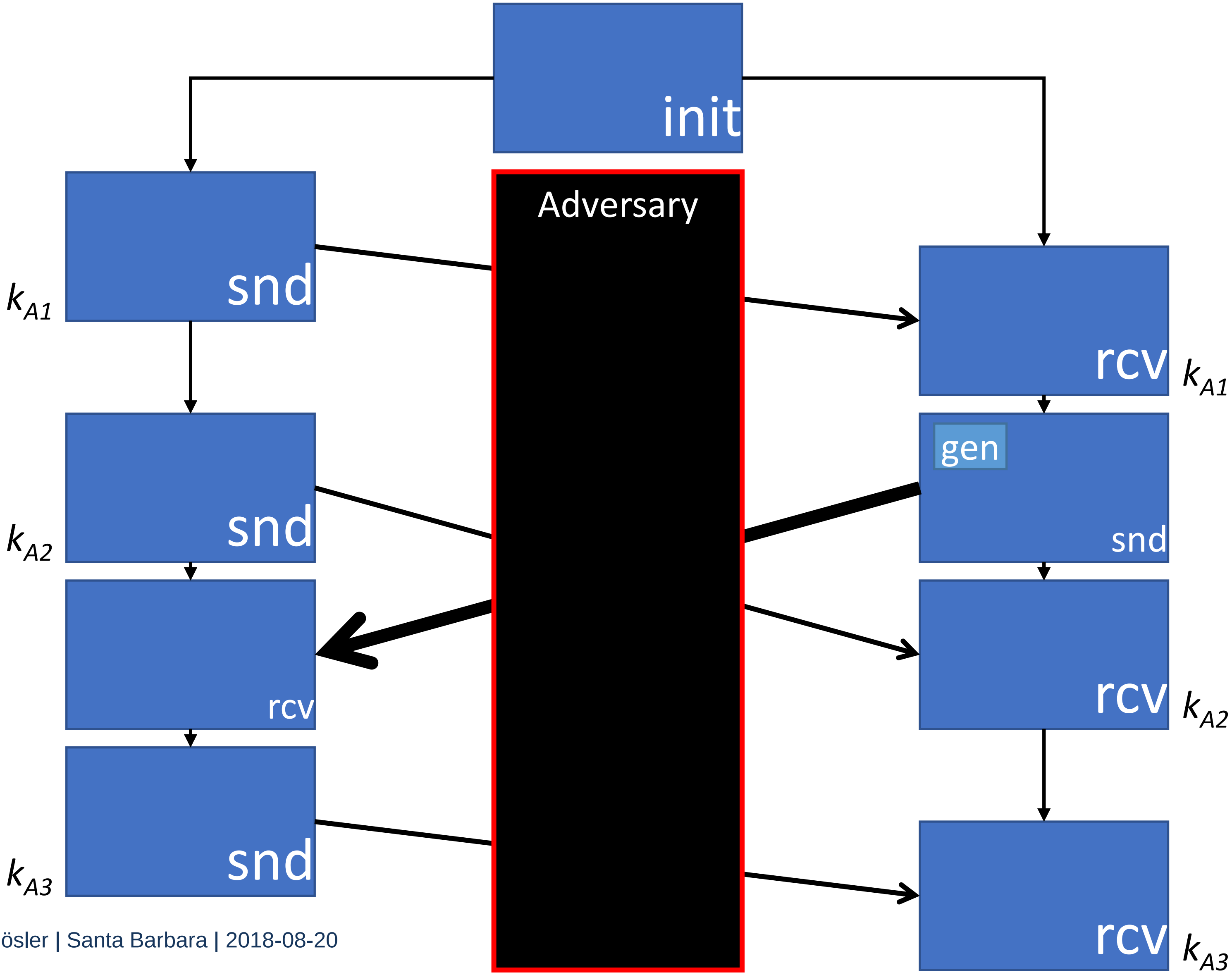
Constructing Sesquidirectional RKE

- **Expose Bob**
  ⇒ No future Challenge if synchronous until Bob recovered
  → Forward secrecy and recovery of Bob's state



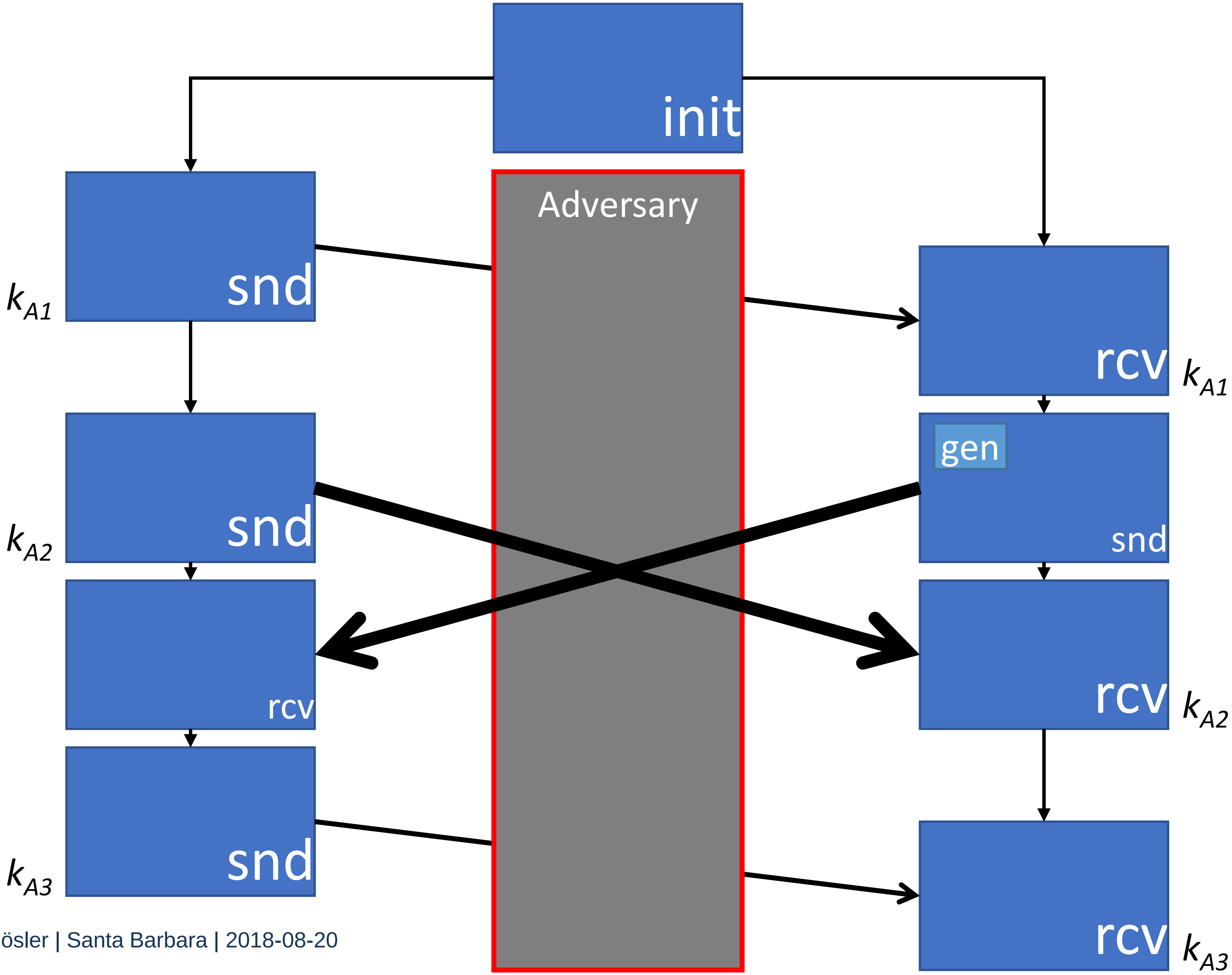
Constructing Sesquidirectional RKE

- **Expose Bob**
  ⇒ No future Challenge if synchronous until Bob recovered
  → Forward secrecy and recovery of Bob’s state
  → Send new pk



Constructing Sesquidirectional RKE

- **Expose Bob**
  ⇒ No future Challenge if synchronous until Bob recovered
  → Forward secrecy and recovery of Bob’s state
  → Send new pk
  → Divergence of states



Constructing Sesquidirectional RKE

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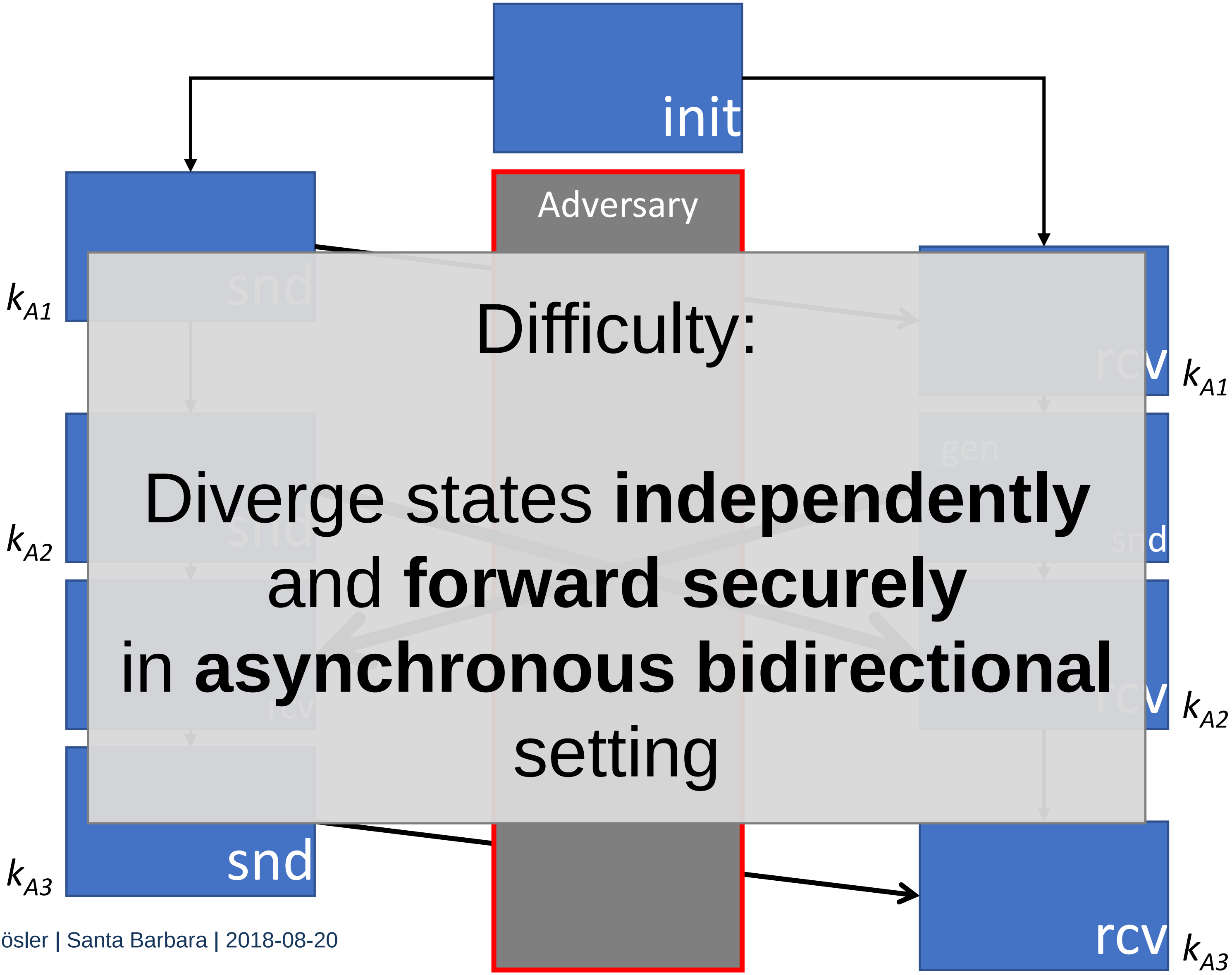
  → Send new pk
  → Divergence of states

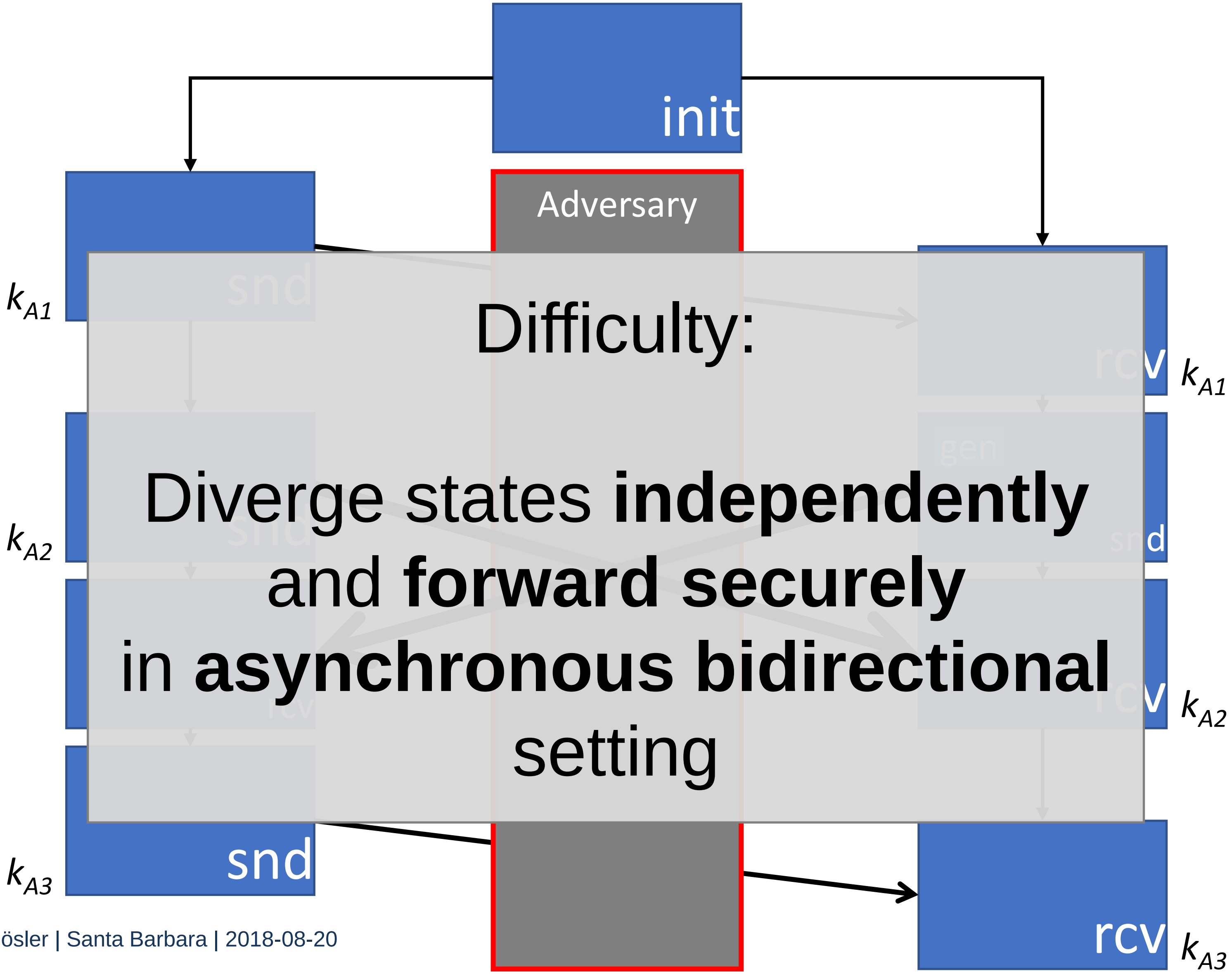


Difficulty:

Diverge states **independently** and **forward securely** in **asynchronous bidirectional** setting

Constructing Sesquidirectional RKE

- **Expose Bob**
  ⇒ No future Challenge if synchronous until Bob recovered
  → Forward secrecy and recovery of Bob’s state
    → Send new pk
  → Divergence of states
    → Update key pair



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Constructing Sesquidirectional RKE

- **Expose Bob**
  ⇒ No future Challenge if synchronous until Bob recovered
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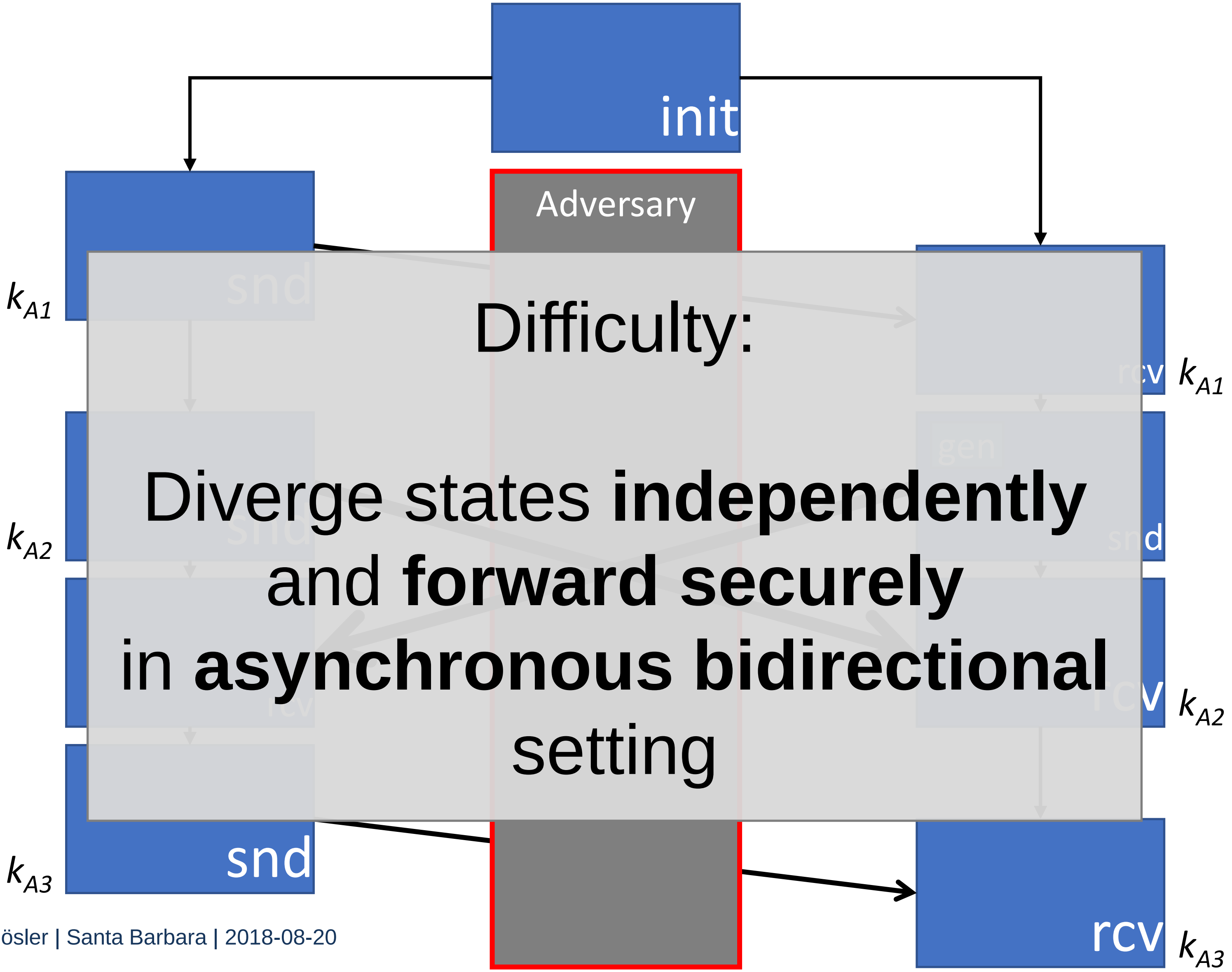
  → Send new pk
  → Divergence of states
  → Update key pair

up (sk, *T*)→sk

up (pk, *T*)→pk



Difficulty:

Diverge states **independently** and **forward securely** in **asynchronous bidirectional** setting

Constructing Sesquidirectional RKE

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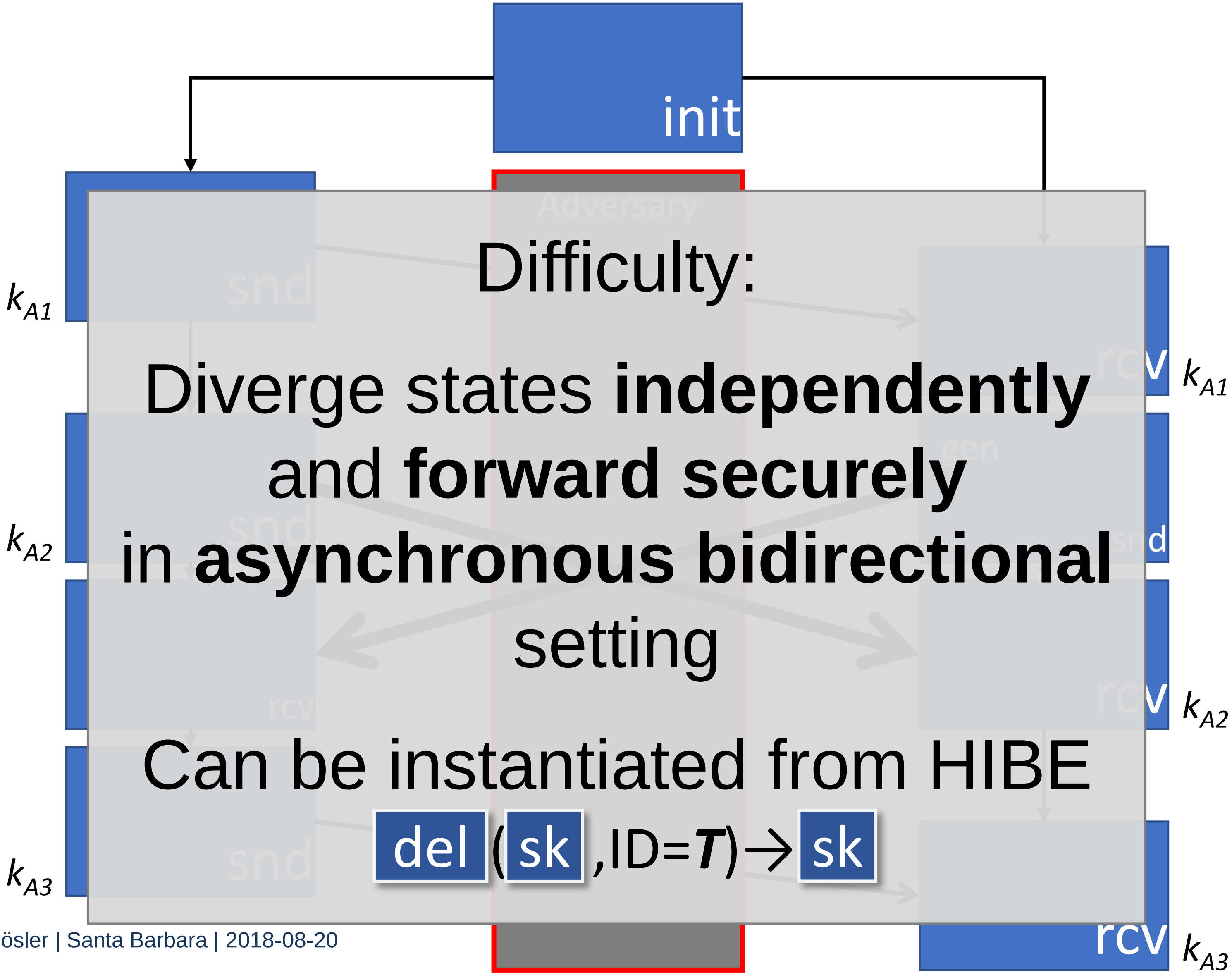

Difficulty:

Diverge states **independently** and **forward securely** in **asynchronous bidirectional** setting

Can be instantiated from HIBE

del(sk,ID=T)→sk

Constructing Sesquidirectional RKE

- **Expose Bob**
  ⇒ No future Challenge if synchronous until Bob recovered
  → Forward secrecy and recovery of Bob's state
  → Send new pk
  → Divergence of states
  → Update key pair

up(sk, T)→sk

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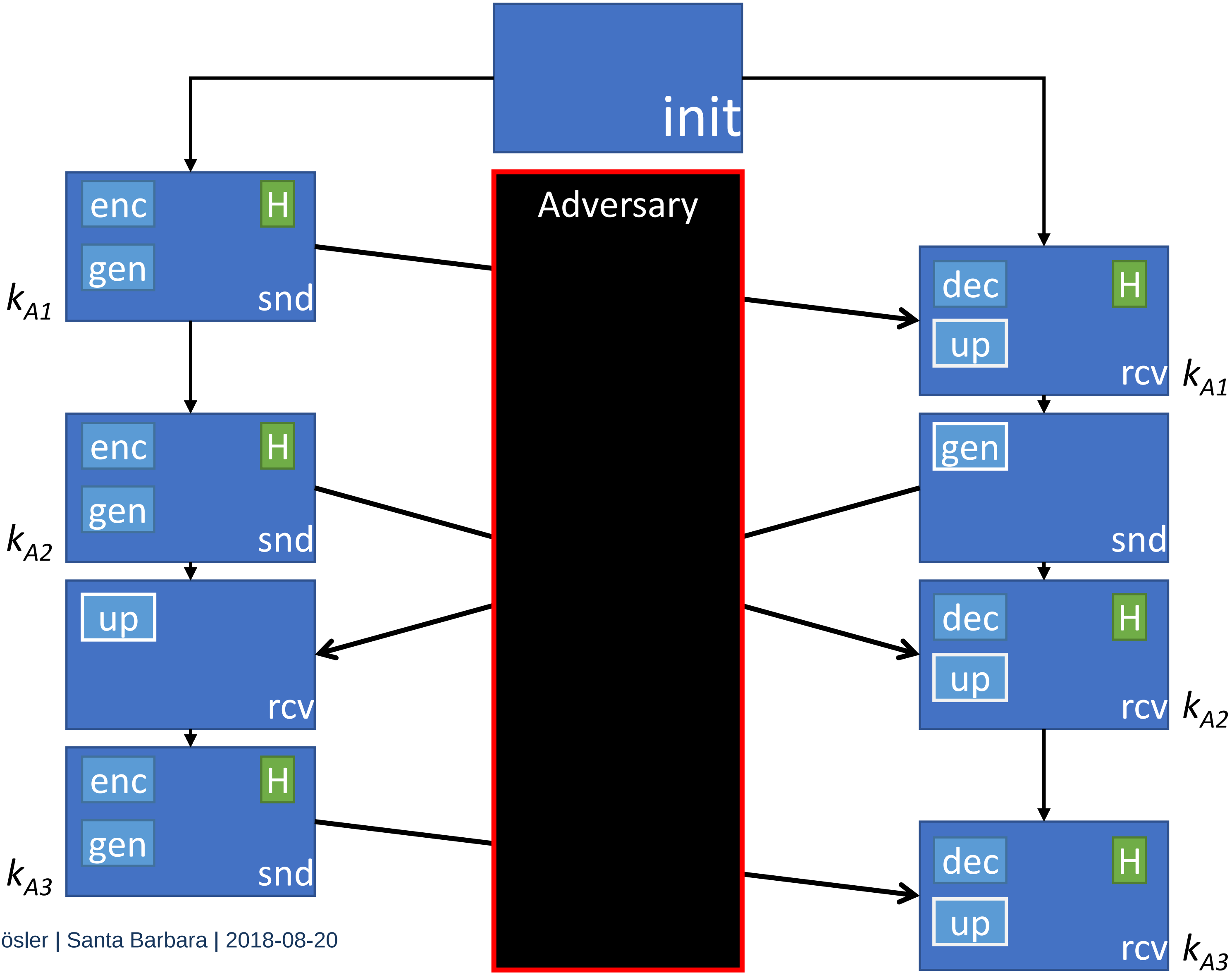

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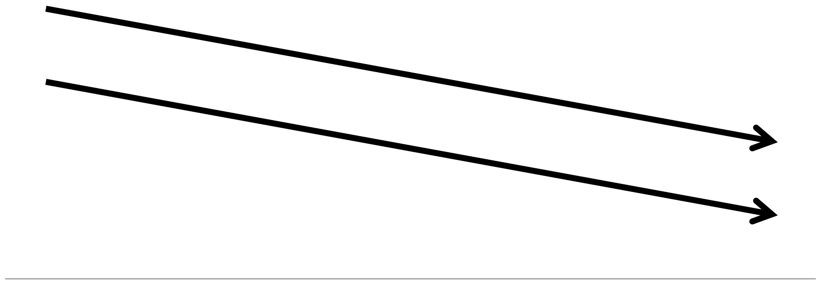
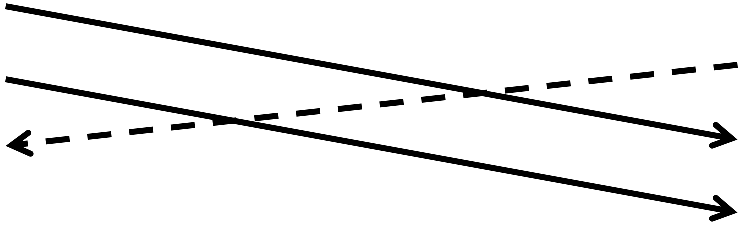


4. Sesquidirectional Ratcheting
   → Model and Construction



5. **Results**

Results

- Unidirectional RKE
    - KEM + ROM (+ MAC)

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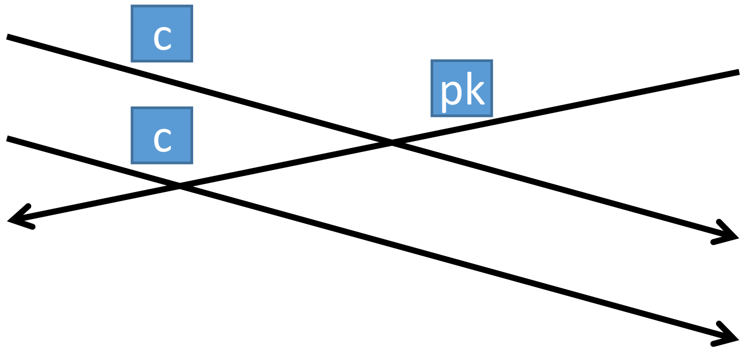
Results

- Unidirectional RKE
  - KEM + ROM (+ MAC)
- Sesquidirectional RKE
  - Key updatable KEM (+ signatures)
  - # up (sk *T*) = #*crossing* ciphertexts

    → Depth of HIBE practically bounded



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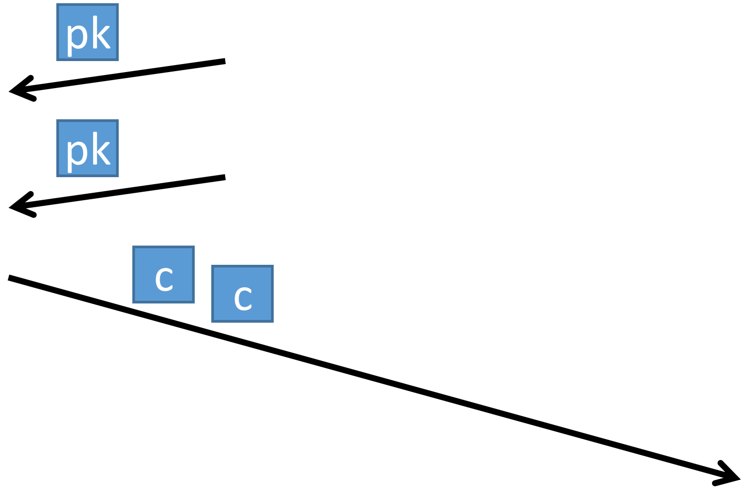
Results

- Unidirectional RKE
  - KEM + ROM (+ MAC)
- Sesquidirectional RKE
  - Key updatable KEM (+ signatures)
  - # up (sk ***T***) = #*crossing* ciphertexts

    → Depth of HIBE practically bounded
  - Multi encapsulation

    → Bounded in ping-pong pattern

    → Alternative: key updatable signatures



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Results

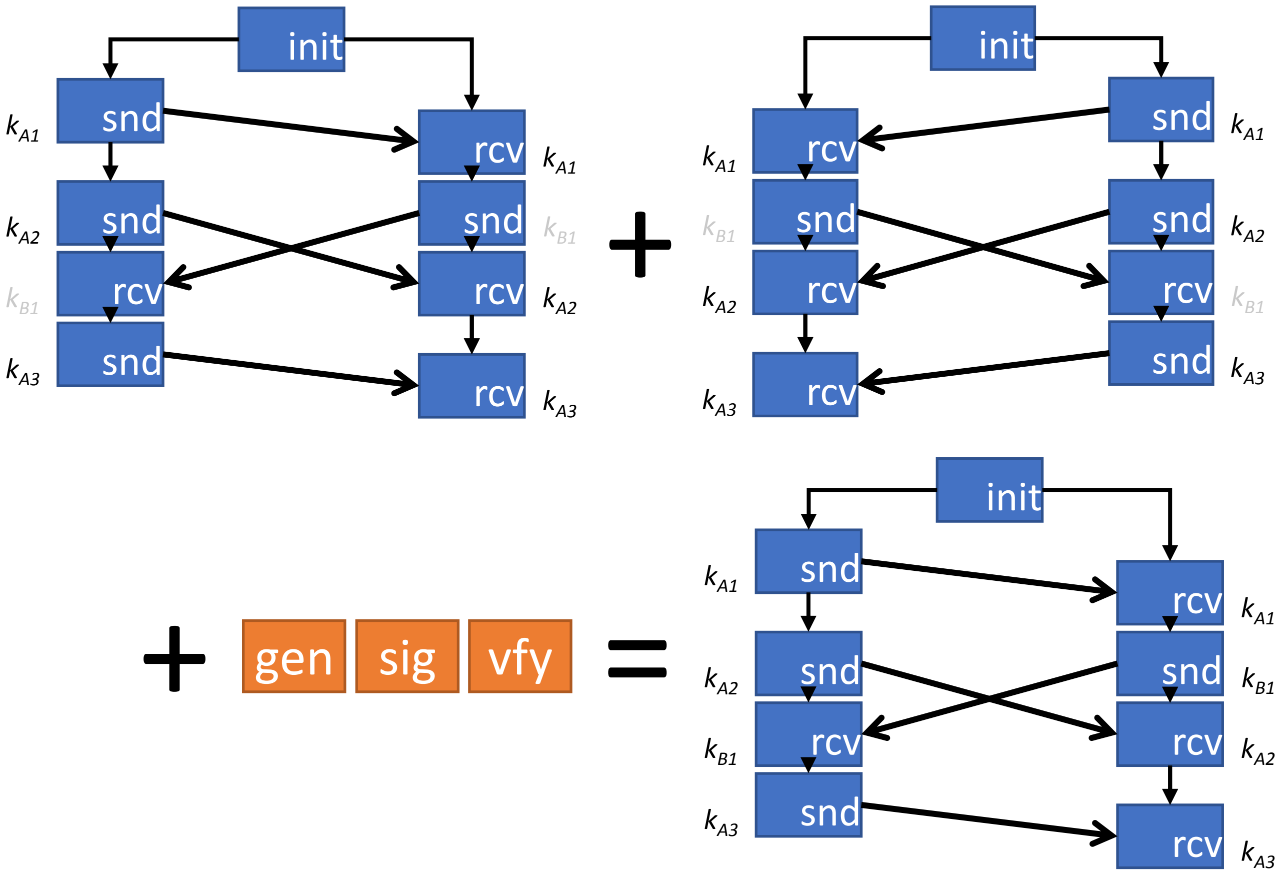
- Unidirectional RKE
  - KEM + ROM (+ MAC)
- Sesquidirectional RKE
  - Key updatable KEM (+ signatures)
  - # up (sk T) = #crossing ciphertexts

    → Depth of HIBE practically bounded
  - Multi encapsulation

    → Bounded in ping-pong pattern

    → Alternative: key updatable signatures
- BRKE = 2x SRKE + OT signatures

  → Build SRKE, BRKE too complex!



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