Anonymous Authenticated Communication

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Introduction

Anonymity vs. authenticity: two conflicting goals?

- **Anonymity:** the "identity" of the sender/receiver is *hidden*
- **Authenticity:** the "identity" of the sender is *known*

How can we study this problem **composably**?

We use the **constructive cryptography** (**CC**) framework:

- Resources (functionalities) with an interface for each user
- Identities modeled by the *labels* of the interfaces

Constructive Cryptography (CC)

Two main ingredients:

- **Resources:** $\mathbf{R} \in \Phi$ is a *discrete system* with interfaces $I \in \mathcal{I}$
  - E.g.: $S_1, \ldots, S_n$ for the *senders*, R for the *receiver*, E for the *adversary*
  - **Parallel composition:** for $\mathbf{R}, \mathbf{S} \in \Phi$: $[\mathbf{R}, \mathbf{S}] \in \Phi$ (*sub-interfaces*)
- **Converters:** *discrete system* α s.t. $\alpha^I \mathbf{R} \in \Phi$, for interface $I \in \mathcal{I}$
  - **Protocol:** E.g., $\pi = (\alpha^{S_1}, \ldots, \alpha^{S_n}, \beta^R)$

Construction: $\mathbf{R} \overset{\pi}{\Longrightarrow} \mathbf{S} \iff \exists$ simulator σ: $\pi\mathbf{R} \approx \sigma^E \mathbf{S}$

Composition: $\mathbf{R} \overset{\pi}{\Longrightarrow} \mathbf{S} \ \wedge \ \mathbf{S} \overset{\phi}{\Longrightarrow} \mathbf{T} \implies \mathbf{R} \overset{\phi \circ \pi}{\Longrightarrow} \mathbf{T}$

Anonymous Communication Channels

Four common communication channels (CC resources):

- **Insecure (INS):** adversary can *eavesdrop* and *inject*
- **Authenticated (AUT):** adversary can only *eavesdrop* (**not** *inject*)
- **Confidential (CNF):** adversary can only *inject* (**not** *eavesdrop*)
- **Secure (SEC):** authenticated + confidential

n senders, 1 receiver			1 sender, n receivers		
Symbol	**Leaked**	**Inject**	**Symbol**	**Leaked**	**Inject**
A-INS$_{n\to 1}$	~~$\mathcal{P}_i$~~, m	✓	A-INS$_{1\to n}$	~~P_i~~, m	✓
A-AUT$_{n\to 1}$	~~$\mathcal{P}_i$~~, m	✗	A-AUT$_{1\to n}$	~~P_i~~, m	✗
A-CNF$_{n\to 1}$	~~$\mathcal{P}_i$~~, $\lvert m\rvert$	✓	A-CNF$_{1\to n}$	~~P_i~~, $\lvert m\rvert$	✓
A-SEC$_{n\to 1}$	~~$\mathcal{P}_i$~~, $\lvert m\rvert$	✗	A-SEC$_{1\to n}$	~~P_i~~, $\lvert m\rvert$	✗

$\Longrightarrow$ We are considering **preservation** of *(external)* anonymity

Related Work

- [AHM+15]: $[\underbrace{\text{KEY}_{n\leftrightarrow 1}}_{1\leftrightarrow n}, \underbrace{\textbf{A-INS}_{n\to 1}}_{1\to n}] \overset{\pi_{\text{pMAC}}}{\Longmapsto} \underbrace{\textbf{A-AUT}_{n\to 1}}_{1\to n}$
- [BM20]: $[\underbrace{\text{KEY}_{n\leftrightarrow 1}}_{1\leftrightarrow n}, \overbrace{\underbrace{\textbf{A-AUT}_{n\to 1}}_{1\to n}}^{\textbf{A-INS}_{n\to 1}}] \overset{\overbrace{\pi_{\text{pE}}}^{\pi_{\text{pAE}}}}{\Longmapsto} \underbrace{\textbf{A-SEC}_{n\to 1}}_{1\to n}$
- [KMO+13]: $[\text{1-AUT}_{1\leftarrow n}, \textbf{A-INS}_{1\to n}] \overset{\pi_{\text{PKE}}}{\Longmapsto} \textbf{A-CNF}_{1\to n}$

	Sender anonymity	Receiver anonymity
Symmetric	[AHM+15, BM20]	[AHM+15, BM20]
Asymmetric	**This work**	[KMO+13]

$\Longrightarrow$ Intuitively, *signatures* should be used here!

Anonymous Signatures?

Consider a *probabilistic* signature scheme $\Sigma \doteq (\texttt{Gen}, \texttt{Sgn}, \texttt{Vrf})$

How could we define anonymity? **Key-indistinguishability (IK)**

Given pk_1 and pk_2, provide m and then distinguish between:

- (σ_1, σ_2), where $\sigma_i \leftarrow \texttt{Sgn}_{sk_i}(m)$
- (σ_1, σ_2), where $\sigma_i \leftarrow \texttt{Sgn}_{sk_I}(m)$, for $I \xleftarrow{\$} [2]$

Does it work? **NO:** we can simply use $\texttt{Vrf}$ with pk_1, pk_2 to distinguish!

In fact, we show: for any protocol π,

$$[\text{1-AUT}_{n\to 1}, \textbf{A-INS}_{n\to 1}] \overset{\pi}{\not\Longrightarrow} \textbf{A-AUT}_{n\to 1}$$

$\Longrightarrow$ We need to modify the syntax of Σ!

Possible Workarounds

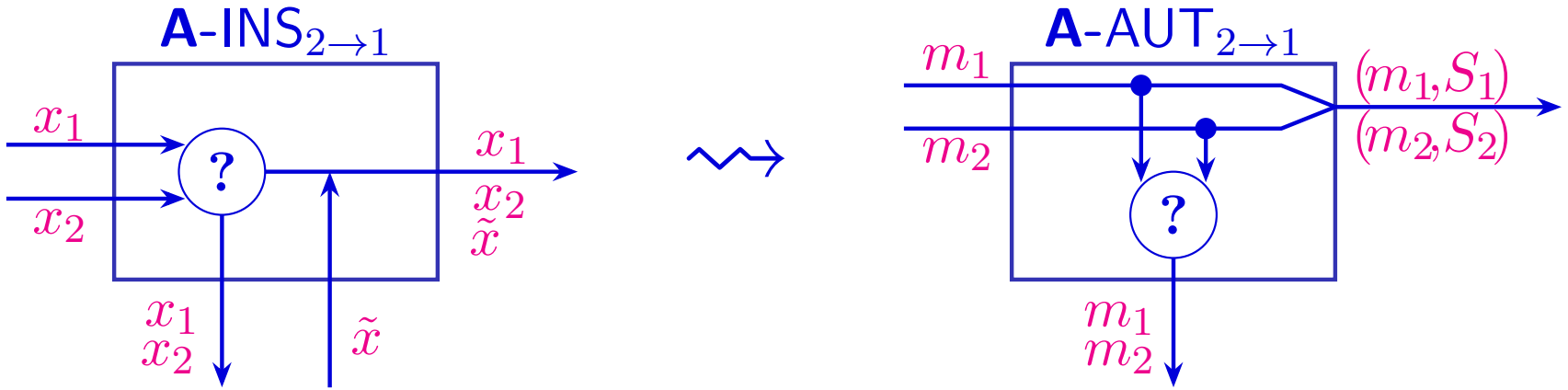
We identify three axis along which we functionally relax the construction

1. Change the *assumed* resource:
   - $[\text{1-AUT}_{n\leftarrow 1}, \text{1-AUT}_{n\rightarrow 1}, \textbf{A}\text{-INS}_{n\rightarrow 1}] \overset{\pi_{\text{BS}}}{\Longmapsto} \textbf{A}\text{-AUT}_{n\rightarrow 1}$
   - **Anonymous authentication:** use *bilateral signatures* (new)
2. Change the *constructed* resource:
   - $[\text{1-AUT}_{n\rightarrow 1}, \textbf{A}\text{-INS}_{n\rightarrow 1}] \overset{\pi_{\text{PS}}}{\Longmapsto} \textbf{D}\text{-AUT}_{n\rightarrow 1}$
   - **De-anonymizable authentication:** use *partial signatures* [BD09]
3. Change *both* resources:
   - $[\text{1-AUT}_{n\circlearrowleft 1}, \textbf{A}\text{-INS}_{n\rightarrow 1}] \overset{\pi_{\text{RS}}}{\Longmapsto} \textbf{RA}\text{-AUT}_{n\rightarrow 1}$
   - **Receiver-side anonymous authentication:** use *ring signatures* [BKM06]

1. Anonymous Authentication

First approach:

- Change the assumed res.: $\mathbf{R} \doteq [1\text{-AUT}_{n\leftarrow 1}, 1\text{-AUT}_{n\rightarrow 1}, \mathbf{A}\text{-INS}_{n\rightarrow 1}]$
- Keep the constructed resource: $\mathbf{S} \doteq \mathbf{A}\text{-AUT}_{n\rightarrow 1}$



$\Longrightarrow$ We preserve anonymity towards an *eavesdropper*

Bilateral Signatures

Idea: make verification require a *secret from the receiver*!

π_{BS} uses scheme $\Sigma_{\mathsf{BS}} \doteq (\mathtt{Gen}_S, \mathtt{Gen}_R, \mathtt{Sgn}, \mathtt{Vrf})$ as follows:

- Setup:
  - Sender S_i gets $(ssk_i, spk_i) \leftarrow \mathtt{Gen}_S$ and sends spk_i over $\text{1-AUT}_{n\to 1}$
  - Receiver R gets $(rsk, rpk) \leftarrow \mathtt{Gen}_R$ and sends rpk over $\text{1-AUT}_{n\leftarrow 1}$
- Communication:
  - S_i sends (m, σ) over $\textbf{A-INS}_{n\to 1}$, where $\sigma \leftarrow \mathtt{Sgn}_{ssk_i, rpk}(m)$
  - R gets $v_i = \mathtt{Vrf}_{rsk, spk_i}(m, \sigma)$ for all i and outputs (m, S_i) iff $v_i = 1$

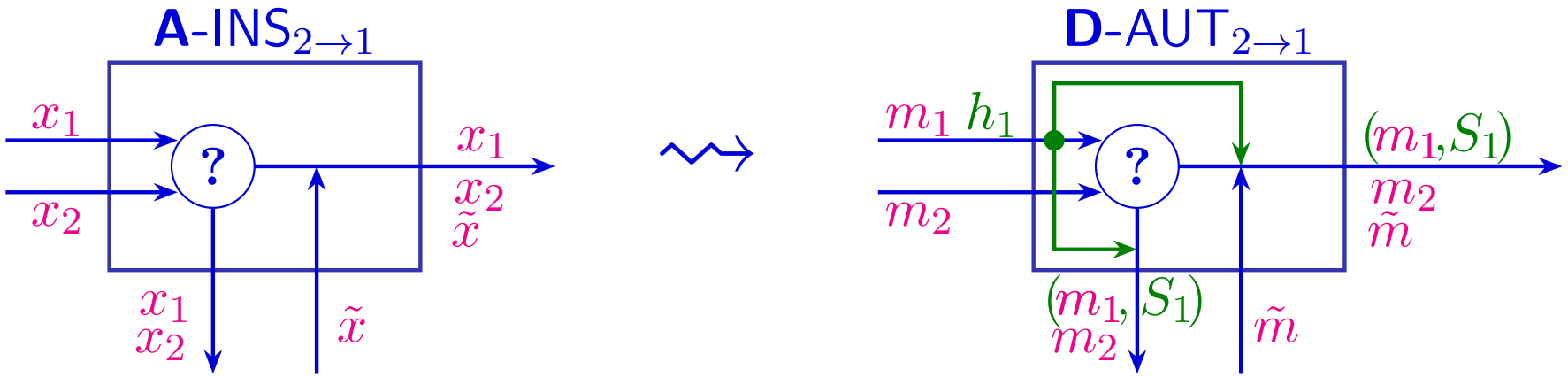
We show: if Σ_{BS} is UF (auth.) and IK (anon.) secure, then

$$[\text{1-AUT}_{n\leftarrow 1}, \text{1-AUT}_{n\to 1}, \textbf{A-INS}_{n\to 1}] \overset{\pi_{\mathsf{BS}}}{\Longmapsto} \textbf{A-AUT}_{n\to 1}$$

2. De-Anonymizalbe Authentication

Second approach:

- Change the constructed resource: $\mathbf{S} \doteq \textbf{D-AUT}_{n\to 1}$
- Keep the assumed resource: $\mathbf{R} \doteq [\text{1-AUT}_{n\to 1}, \textbf{A-INS}_{n\to 1}]$



$\Longrightarrow$ *Selective* anonymity towards *eavesdropper and receiver*

Partial Signatures

Idea: split signatures into *anonymous* **stub** σ and *authenticating* **tag** τ!

$\implies$ σ anon. but *not authentic*, (σ, τ) auth. but *not anonymous*

π_{PS} uses scheme $\Sigma_{\mathsf{PS}} \doteq (\mathtt{Gen}, \mathtt{Sgn}, \mathtt{Vrf})$ as follows:

- Setup: sender S_i gets $(sk_i, pk_i) \leftarrow \mathtt{Gen}$ and sends pk_i over $\text{1-AUT}_{n\to 1}$
- Communication:
  1. Committing to m:
     - S_i sends (m, σ) over $\textbf{A-INS}_{n\to 1}$, where $(\sigma, \tau) \leftarrow \mathtt{Sgn}_{sk_i}(m)$
     - R outputs m, but could be from any S_i or adversary (can't use $\mathtt{Vrf}$)
  2. De-anonymizing m:
     - S_i sends (m, σ, τ) over $\textbf{A-INS}_{n\to 1}$
     - R gets $v_i = \mathtt{Vrf}_{pk_i}(m, \sigma, \tau)$ for all i and outputs (m, S_i) iff $v_i = 1$

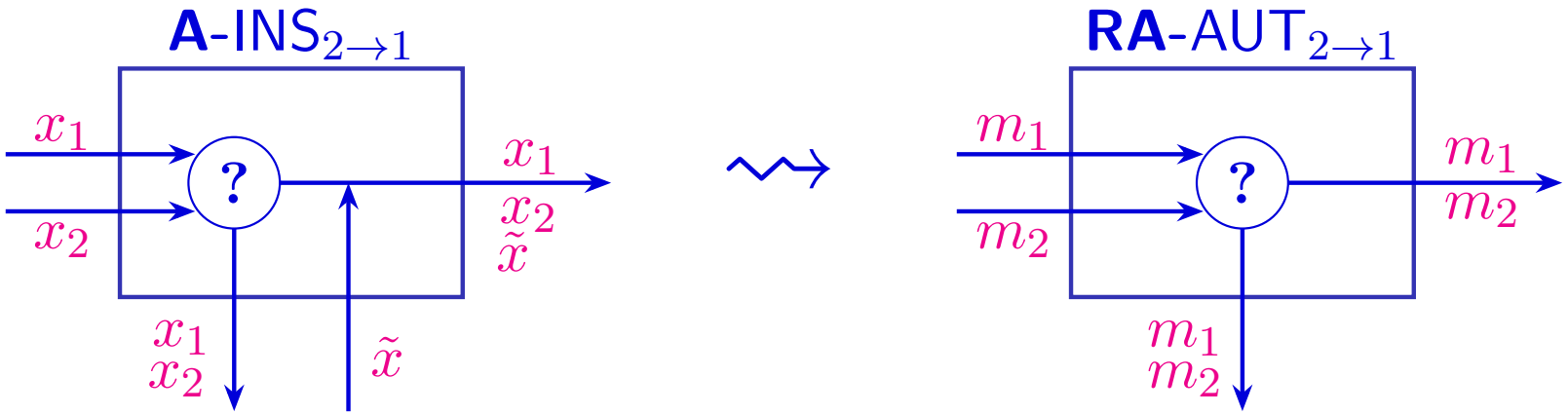
We show: if Σ_{PS} is UF (auth.), IK (anon.), UA (unamb.) secure, then

$$[\text{1-AUT}_{n\to 1}, \textbf{A-INS}_{n\to 1}] \overset{\pi_{\mathsf{PS}}}{\Longrightarrow} \textbf{D-AUT}_{n\to 1}$$

3. Receiver-Side Anonymous Authentication

Third approach:

- Change the assumed resource: $\mathbf{R} \doteq [\text{1-AUT}_{n\circlearrowleft 1}, \textbf{A-INS}_{n\to 1}]$
- Change the constructed resource: $\mathbf{S} \doteq \textbf{RA-AUT}_{n\to 1}$



$\Longrightarrow$ Anonymity towards both *eavesdropper and receiver*

Ring Signatures

Idea: make signatures depend on a *group of senders*!

π_{RS} uses scheme $\Sigma_{\mathsf{RS}} \doteq (\mathtt{Gen}, \mathtt{Sgn}, \mathtt{Vrf})$ as follows:

- Setup:
  - Sender S_i gets $(sk_i, pk_i) \leftarrow \mathtt{Gen}$ and sends pk_i over $\text{1-AUT}_{n\circlearrowleft 1}$
  - Each S_i and R set $\boldsymbol{pk} \doteq (pk_1, \ldots, pk_n)$
- Communication:
  - S_i sends (m, σ) over $\textbf{A-INS}_{n\to 1}$, where $\sigma \leftarrow \mathtt{Sgn}_{i,sk_i,\boldsymbol{pk}}(m)$
  - R gets $v = \mathtt{Vrf}_{\boldsymbol{pk}}(m, \sigma)$ and outputs m iff $v = 1$

We show: if Σ_{RS} is UF (auth.) and IK (anon.) secure, then

$$[\text{1-AUT}_{n\circlearrowleft 1}, \text{1-AUT}_{n\to 1}, \textbf{A-INS}_{n\to 1}] \overset{\pi_{\mathsf{RS}}}{\Longrightarrow} \textbf{RA-AUT}_{n\to 1}$$

Conclusions

- We filled a gap in the composable treatment of anonymity
  - Not as "straightforward" as in previous works
    - Multiple possible solutions (are there more?)
    - In one we incurred the simulator commitment "problem"

      $\Longrightarrow$ Solved using the recent technique of "interval-wise relaxations" [JM20]
- Future work:
  - Adaptive security?
  - Anonymity *creation* (rather than preservation)?
    - E.g, **A**-SEC$_{n\to 1}$ from from INS$_{n\to 1}$ using mix-nets/onion routing

Thank you for your attention!

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