On Tightly Secure Non-Interactive Key Exchange

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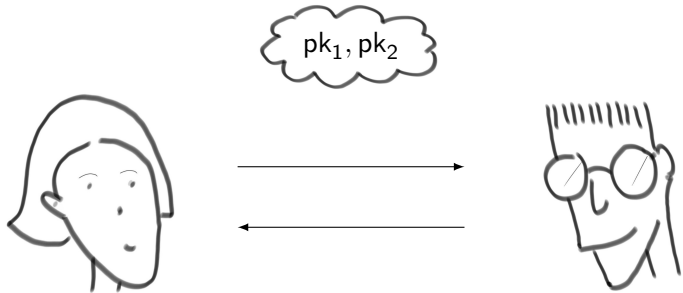
Non-Interactive Key Exchange (NIKE)



$(\mathsf{pk}_1, \mathsf{sk}_1) \leftarrow \texttt{KeyGen}$ $(\mathsf{pk}_2, \mathsf{sk}_2) \leftarrow \texttt{KeyGen}$

$K_{21} = \texttt{SharedKey}(\mathsf{pk}_2, \mathsf{sk}_1) \quad = \quad K_{12} = \texttt{SharedKey}(\mathsf{pk}_1, \mathsf{sk}_2)$

Tight security

Scheme $\mathcal{S}$ secure if problem $\mathcal{P}$ hard:

$\mathcal{A}$ attacks $\mathcal{S}$ $\implies$ $\mathcal{B}$ attacks $\mathcal{P}$ s.t.

$$\text{Advantage}^{\mathcal{S}}_{\mathcal{A}} \leq \underbrace{L}_{\text{security loss}} \cdot \text{Advantage}^{\mathcal{P}}_{\mathcal{B}} \ (+ \text{ similar runtime})$$

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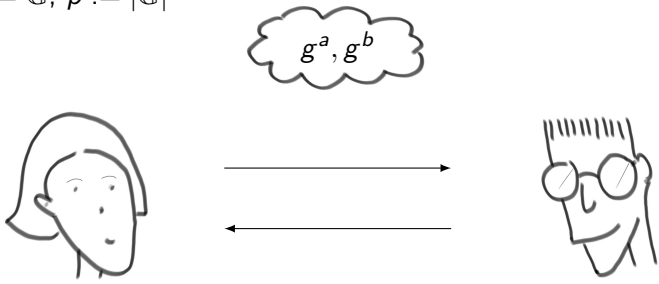
Why do we care?

- **Theory:** closer relation between $\mathcal{P}$ and $\mathcal{S}$
- **Practice:** smaller keys $\Rightarrow$ more efficient instantiations

Recap: Diffie-Hellman Key Exchange

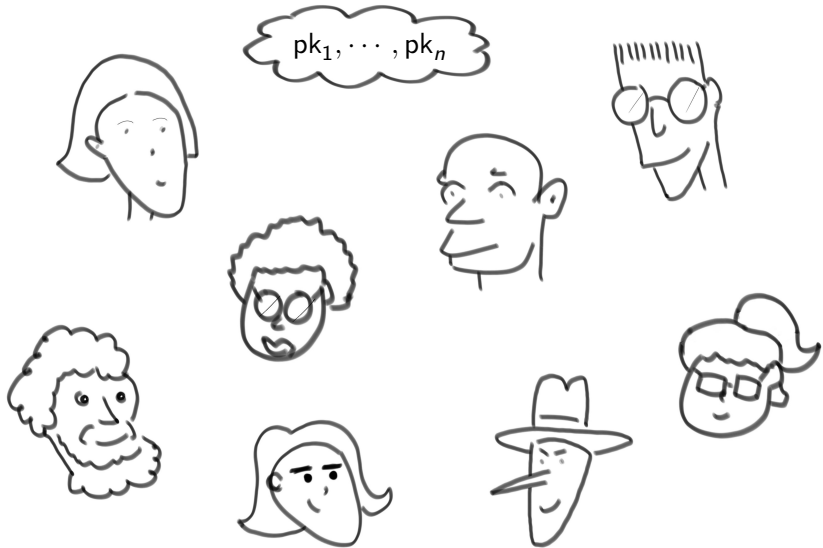
[DH76; CKS08]

$\mathbb{G}$ group, $\langle g \rangle = \mathbb{G}$, $p := |\mathbb{G}|$



Decisional DH: $a, b, c \leftarrow_R \mathbb{Z}_p$: $(g^a, g^b, g^{ab}) \approx_c (g^a, g^b, g^c)$

(Simplified) Security model



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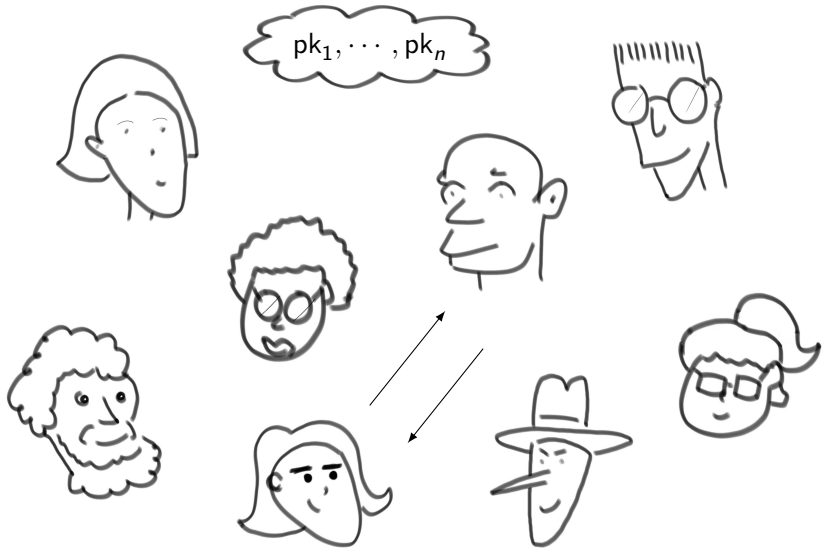

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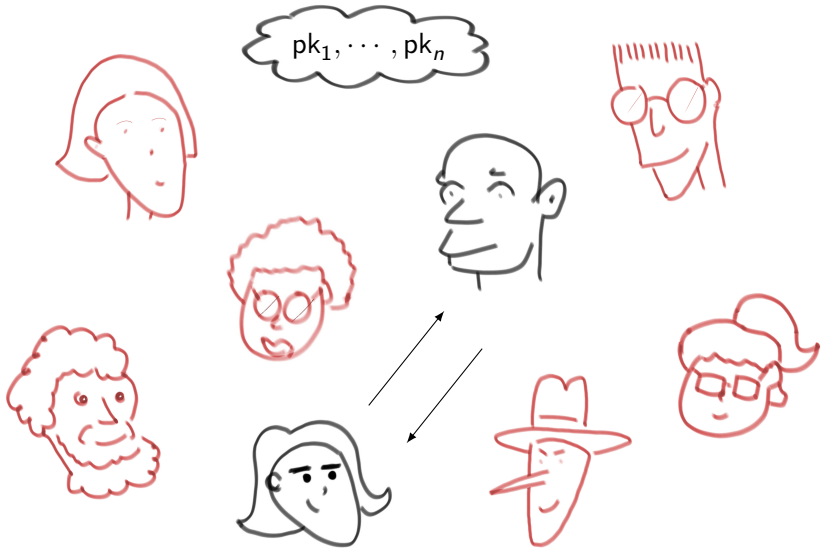
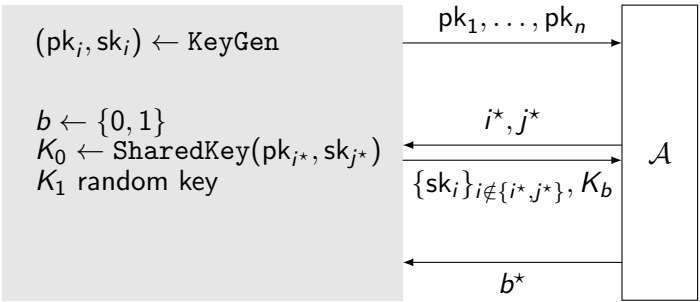


(Simplified) Security of NIKE w/ extractions



$$\mathsf{Advantage}^{\mathsf{nike}}_{\mathcal{A}} := |\Pr[b^\star = b] - 1/2|$$

Recap: DH Key Exchange - Security w/ extractions

Idea: $i^\star, j^\star \leftarrow_R \{1, \ldots, n\}$, embed DDH-challenge in $\mathsf{pk}_{i^\star}, \mathsf{pk}_{j^\star}$

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[BJLS16]: This loss is inherent!

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\+ **Generic transformation with tight instantiation:**

- NIKE with passive security $\rightsquigarrow$ NIKE with active security

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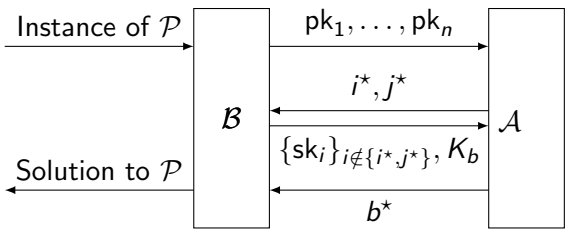

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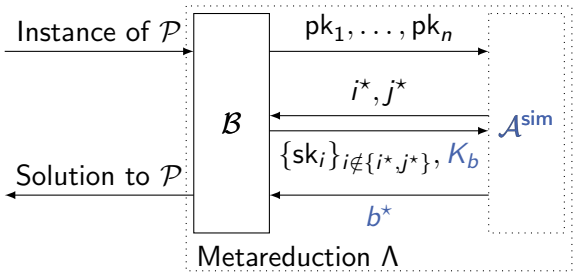

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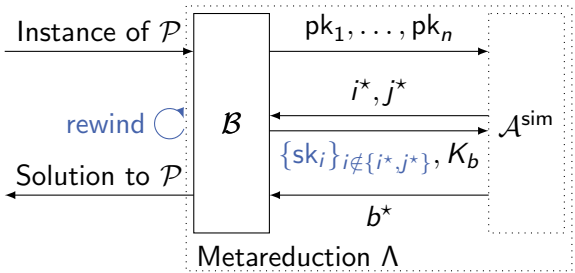

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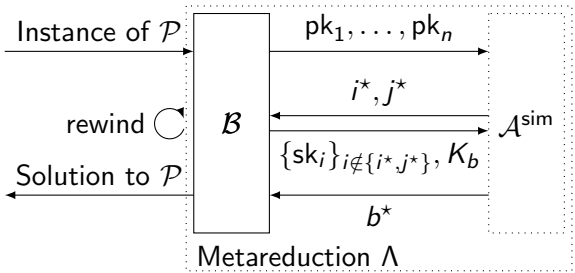

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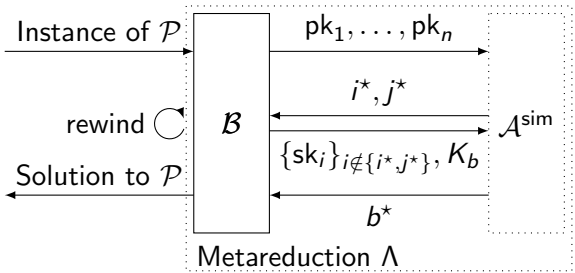

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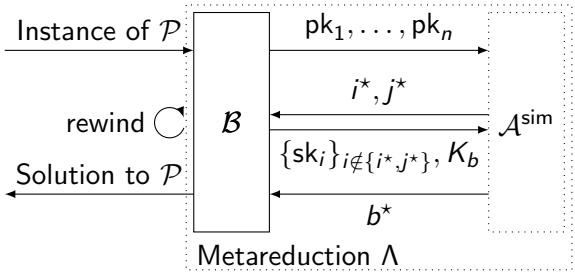

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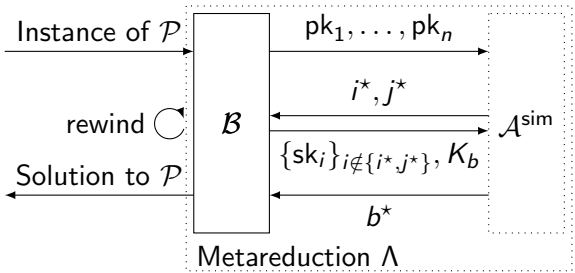

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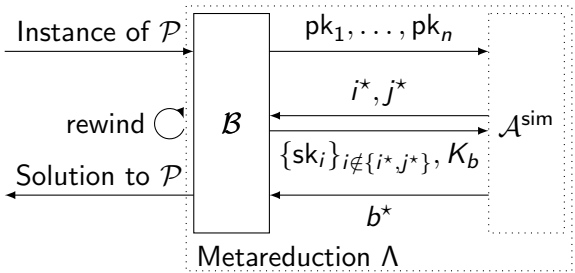

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Note: this requires entropy in sk_1 given pk_1 (and thus many secret keys)!

Recap: Subset membership problem (SMP)

X set, $L \subseteq X$ NP-language

Subset membership assumption for (X, L):

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Recap: Hash proof system

[CS98]

$\texttt{HPS} = (\texttt{Gen}, \texttt{PubEval}, \texttt{PrivEval})$ is HPS for language L if:

$$\left.\begin{array}{l}\texttt{PubEval}(hpk, x, w)\\ \texttt{PrivEval}(hsk, x)\end{array}\right\} \text{return } \textbf{the same} \text{ key } K \text{ for all } x \in L \text{ with witness } w$$

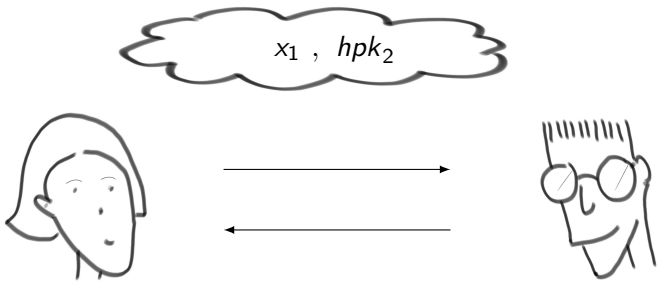
Universality: $\forall x \notin L$, $(hpk, hsk) \leftarrow \texttt{Gen}$:

$$(hpk, x, \texttt{PrivEval}(hsk, x)) \equiv (hpk, x, \texttt{random})$$

Our NIKE

Variation of the PAKE of [KOY01; GL03]

$\texttt{HPS} = (\texttt{Gen}, \texttt{PubEval}, \texttt{PrivEval})$ for L, SMP for $L \subseteq X$ hard



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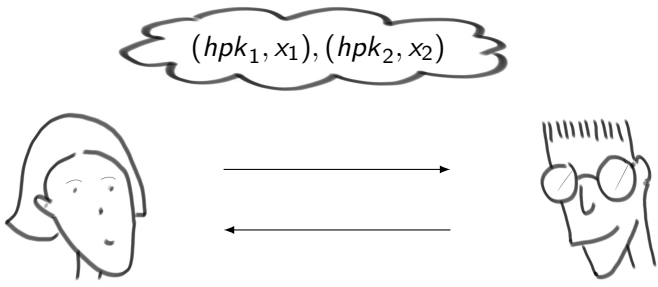

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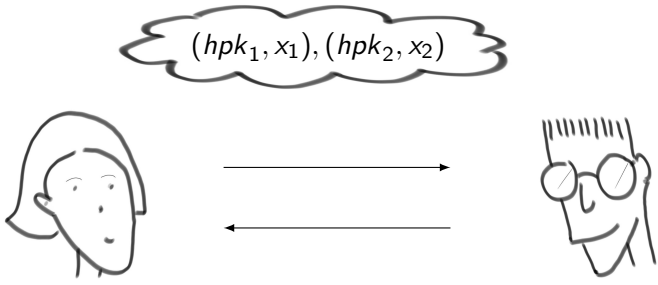

Note:

- hsk not unique
- can switch x to $X \backslash L$

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Towards a new lower bound

[BJLS16]:

- obtain $\mathsf{sk}_{i^\star}$ **or** $\mathsf{sk}_{j^\star}$ via rewinding to compute unique $K_{i^\star j^\star}$
- reduction aborts on all runs without $i^\star$ **and** all runs without $j^\star$ $\Rightarrow$ loss of $\Omega(n^2)$

Problem: $\mathsf{sk}_{i^\star}, \mathsf{sk}_{j^\star}$ not unique

Observation: uniqueness of $K_{i^\star j^\star}$ sufficient

- shared keys between valid public keys unique
- invalid public keys have no secret keys

Our metareduction:

- **Idea:** obtain $\mathsf{sk}_{i^\star}$ **and** $\mathsf{sk}_{j^\star}$ via rewinding to compute unique $K_{i^\star j^\star}$
- reduction aborts on all runs without $i^\star$ **or** on all runs without $j^\star$ $\Rightarrow$ loss of $\Omega(n)$

From passive to active security

Idea: add **unbounded simulation sound NIZK proof of knowledge** of secret key

- USS-NIZK allows to simulate during the reduction
- PoK allows to extract the secret key from corrupted users

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Instantiation:

- generic instantiation from standard components
- optimized tightly secure instantiation for our NIKE

Our results

Reference	$\lvert pk \rvert$	sec. model	sec. loss	assumption	uses
[DH76]	$1 \times \mathbb{G}$	passive	n^2	DDH	-
Ours	$3 \times \mathbb{G}$	passive	n	DDH	-
[CKS08]	$2 \times \mathbb{G}$	active*	2	CDH	ROM
[FHKP13]	$1 \times \mathbb{Z}_N$	active	n^2	factoring	ROM
[FHKP13]	$2 \times \mathbb{G} + 1 \times \mathbb{Z}_p$	active	n^2	DBDH	pairing
Ours	$12 \times \mathbb{G}$	active	n	DLIN	pairing

*w/o extractions

Modular constructions

New lower bound:

- applies to all schemes where invalid public keys have no secret keys
- yields a loss of $\Omega(n)$ for all simple black-box reductions

Generic transformation from passive to active secure NIKE **Thank you!!**

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