Leakage-Resilient Public-Key Cryptography

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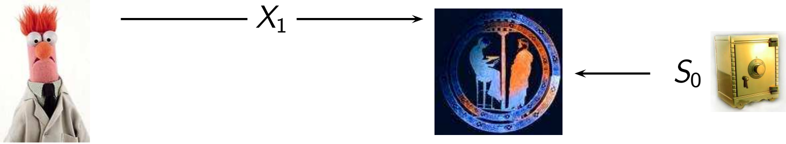
Black-Box Crypto

- Secret initial state S_0
- On query X_i
  - Compute $(Y_i, S_i) \leftarrow f(X_i, S_{i-1})$.
  - Output Y_i.



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$\xleftarrow{\quad Y_1 \quad}$

$\longrightarrow S_1$

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$\xrightarrow{X_2}$

$\longleftarrow$ S_1

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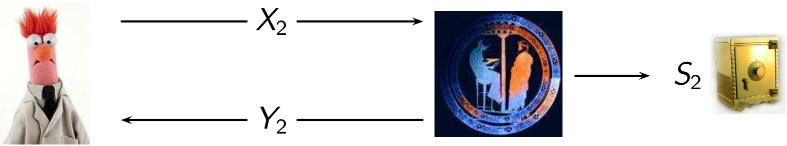

Real-World Crypto

$\xrightarrow{\quad X_i \quad}$

$\xleftarrow{\quad} S_{i-1}$

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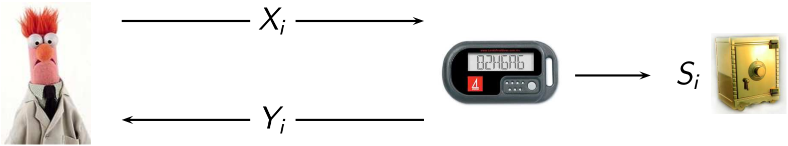

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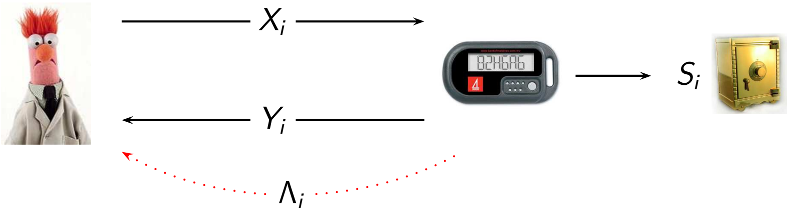

- Computation leaks information $\Lambda_1, \Lambda_2, \ldots$ on each invocation.

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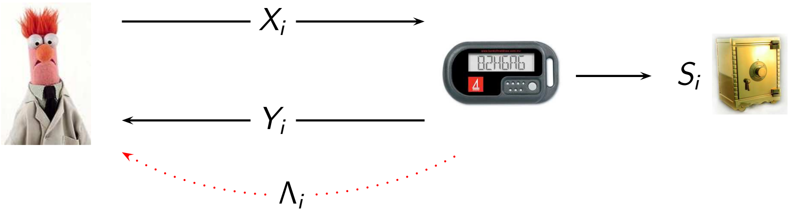
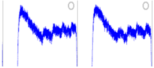


- Computation leaks information $\Lambda_1, \Lambda_2, \ldots$ on each invocation.
- Must prove security against side-channel attacks, but which?

Some Side-Channels

-  electromagnetic radiation [QuisquaterS01]
-  power consumption [KJJ99]
-  running-time [Kocher96]
-  sound [ShamirTromer]
  `people.csail.mit.edu/tromer/acoustic`
- . . .

Leakage-Resilience

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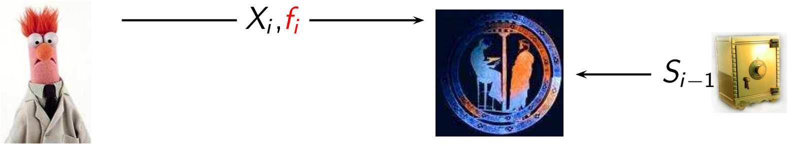
- Need security against all side-channel attacks under reasonable assumption on the underlying hardware.
- Leakage Resilience [DP07]: Security against all side-channel attacks where
  - The *amount* of information leaked is bounded.
  - Only computation leaks information [MR04].

Modelling Leakage Resilience



- f_i is any *efficient* function with range $\{0,1\}^\lambda$.

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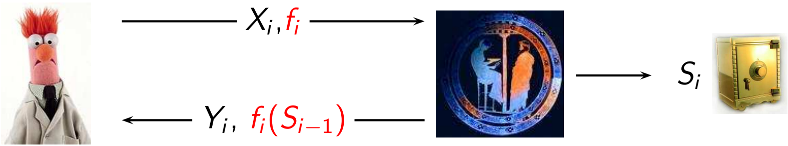

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Leakage-Resilient Primitives

- Leakage-resilient stream-cipher [DP FOCS'07].
- Leakage-resilient signatures (tree-based) [FKP09,???].

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State of leakage-resilient PKC:
"Tree-based" signatures not very practical, PKE open.
What we want:
Efficient leakage-resilient signatures/PKE.
Or even better:
Leakage-resilient instantiation of popular schemes.

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Leakage-Resilient instantiations of [with Eike Kiltz]

- *PKE: Bilinear ElGamal (CCA1,CCA2?).*
- *Signatures: Waters Signatures.*

security proof in the generic group model.

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- *PKE: ElGamal.*

under falsifiable assumption.

Bilinear ElGamal

- Cyclic groups $\mathbb{G}, \mathbb{G}_T$ of order p
- Bilinear map $e(g^x, g^y) = e(g, g)^{xy}$.
- Key Generation: $x \leftarrow \mathbb{Z}_p \qquad sk = g^x \qquad pk = e(g, g)^x$
- Key Encapsulation: $C \leftarrow g^r \qquad K \leftarrow e(g, g)^{xr}$.
- Key Decapsulation: $K \leftarrow e(C, g^x)$.

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Making Decapsulation Leakage Resilient

- Share $sk = g^x$ as: $\phi_0 = g^s$ and $\phi_1 = g^{x-s}$
- Leakage Resilient Key Decapsulation:
  1. $r \xleftarrow{*} \mathbb{Z}_p$
  2. $K' \leftarrow e(C, \phi_0) \quad \phi_0 \leftarrow \phi_0 \cdot g^r$
  3. $K'' \leftarrow e(C, \phi_1) \quad \phi_1 \leftarrow \phi_1 \cdot g^{-r}$
  4. $K \leftarrow K' \cdot K''$

"Standard" ElGamal Encryption

Assumption

- g generator of cyclic group of order p. Sample random $x \leftarrow \mathbb{Z}_p$, $\mathcal{A}$ gets g^x.
- Let $x_1, x_2, \ldots$ be random and $x_i' \leftarrow x_i / x$ ($x = x_i \cdot x_i' \mod p$)
- For $i = 1, 2, \ldots$, $\mathcal{A}$ chooses $f_i, g_i : \mathbb{Z}_p \rightarrow \{0,1\}^\lambda$ and gets

$$f_i(x_i) \quad \text{and} \quad g_i(x_i')$$

- $\mathcal{A}$ gets DDH challenge, i.e. must distinguish

$$g^x, g^r, g^{x \cdot r} \quad \text{from} \quad g^x, g^r, g^s$$

Any idea as to whether this problem is/isn't hard? (Easy if $\lambda > \log p/2$)