There Is Always an Exception: Controlling Partial Information Leakage in Secure Computation

ICISC-2019

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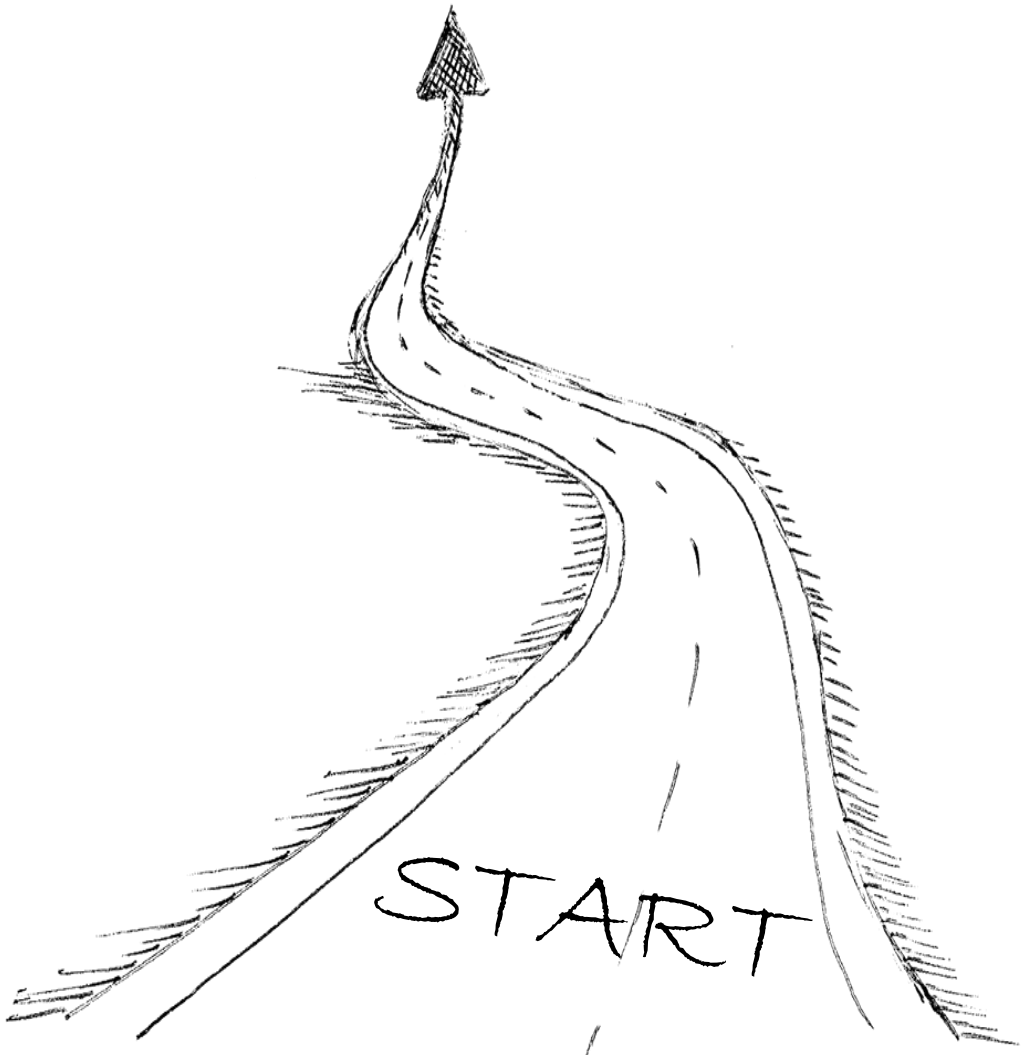
Roadmap



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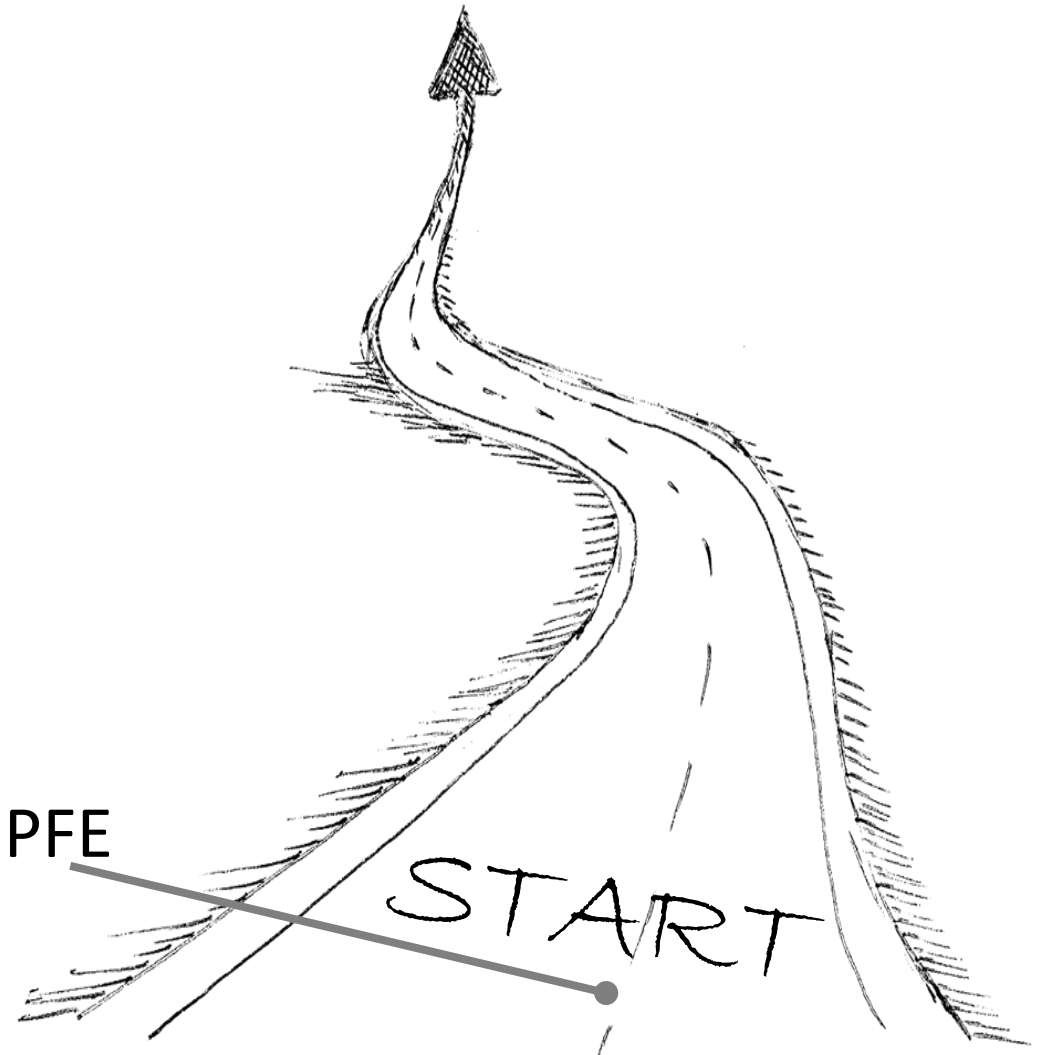

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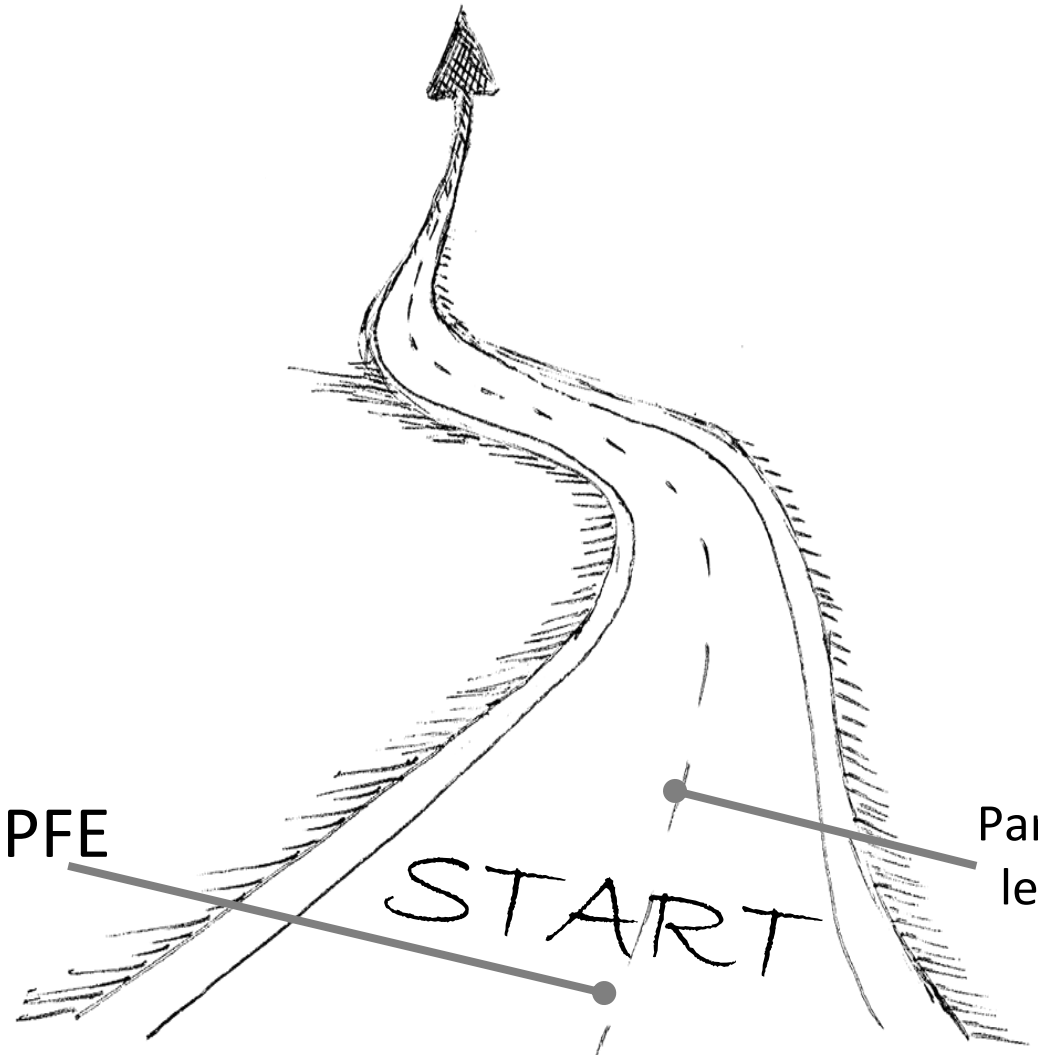

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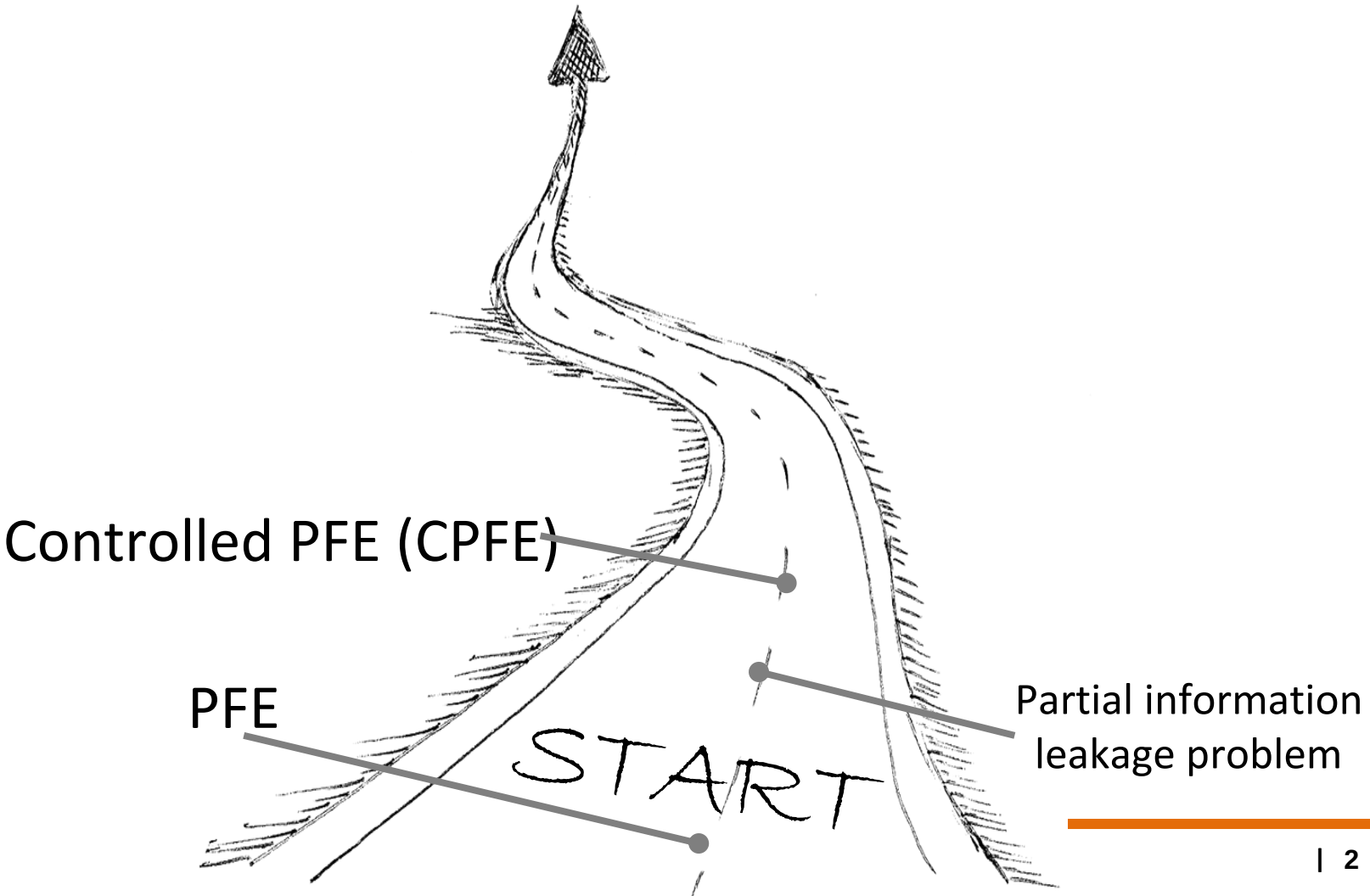
Controlled PFE (CPFE)
PFE
START
Partial information leakage problem

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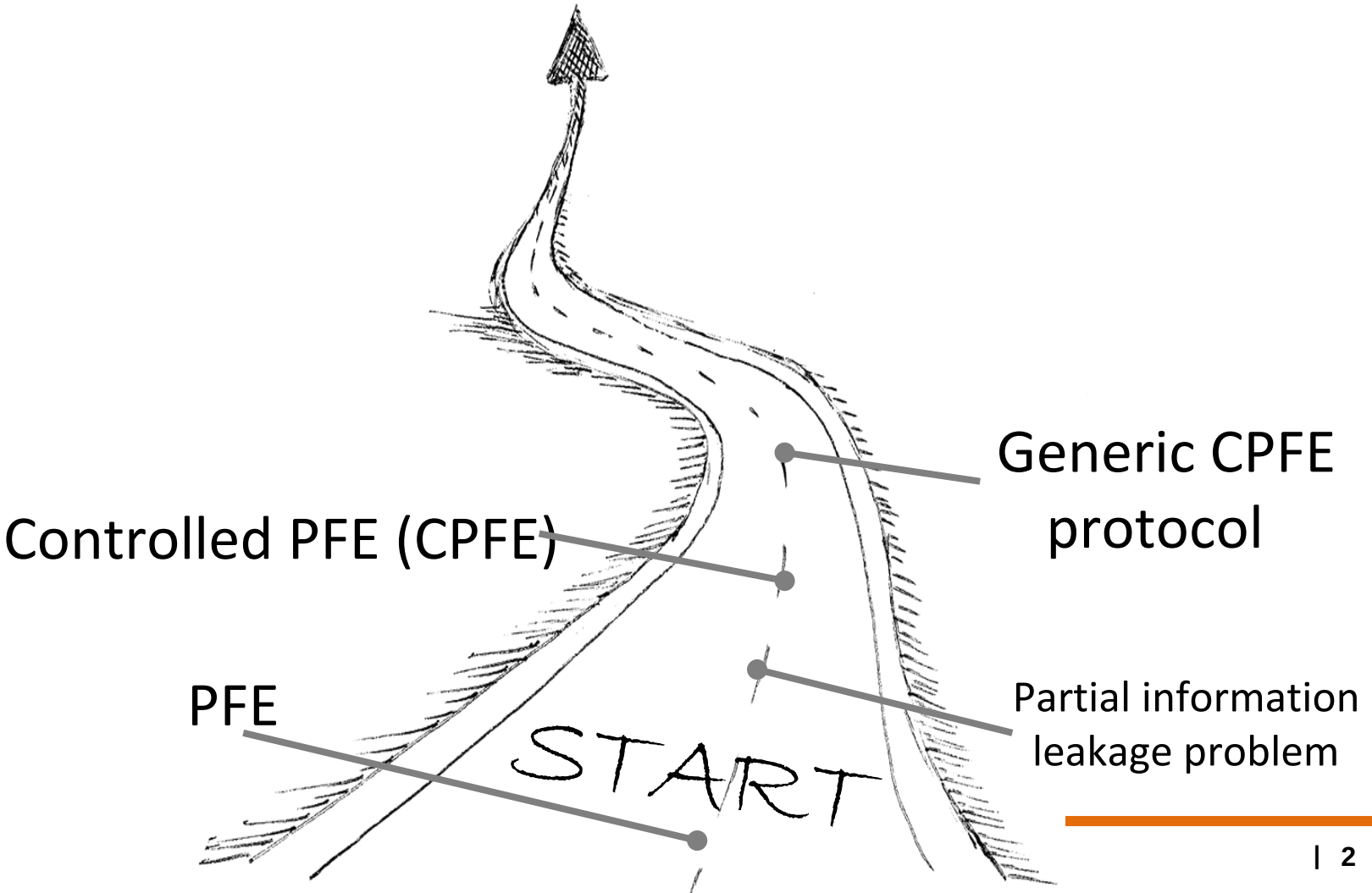
Generic CPFE protocol
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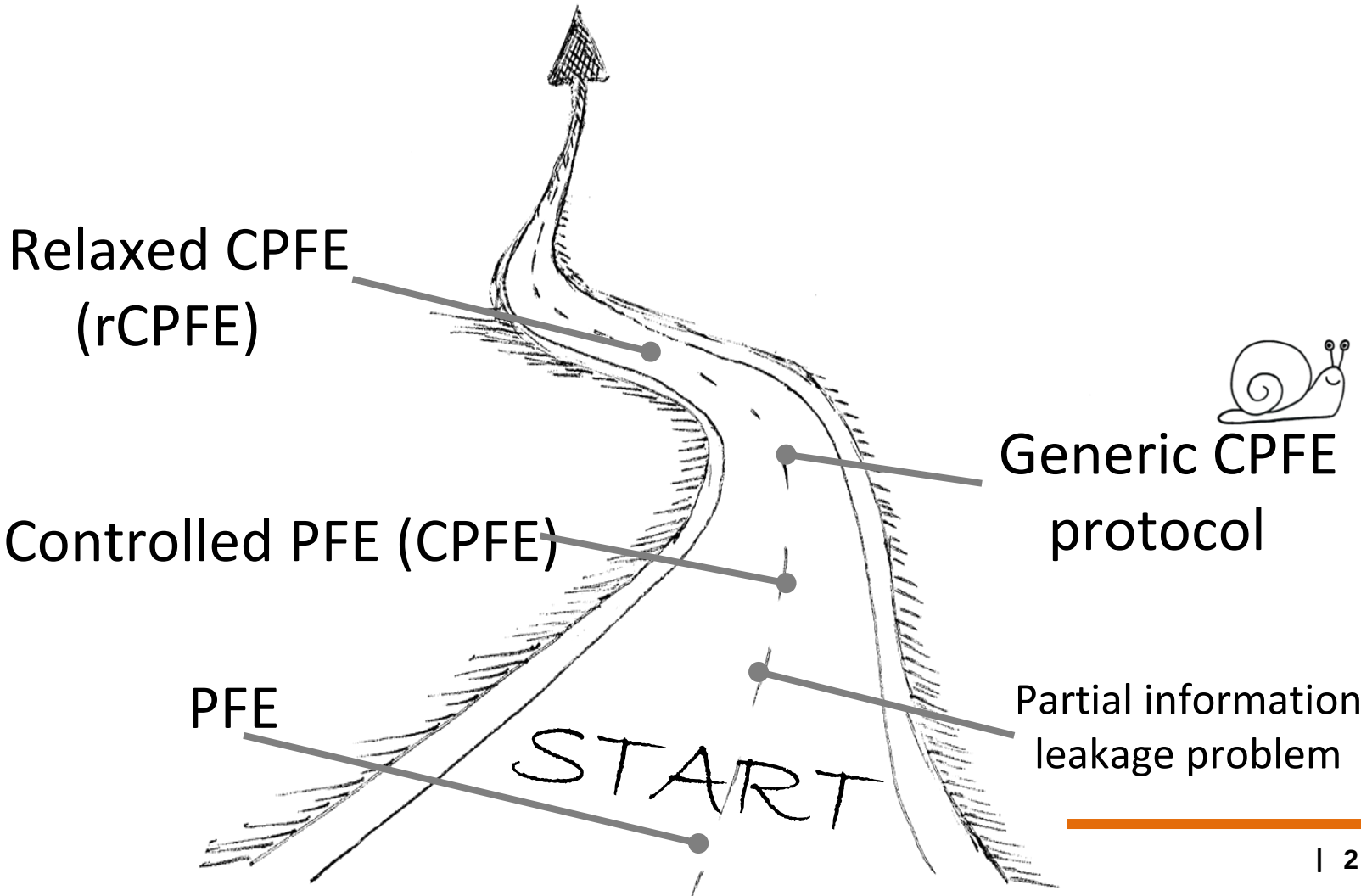
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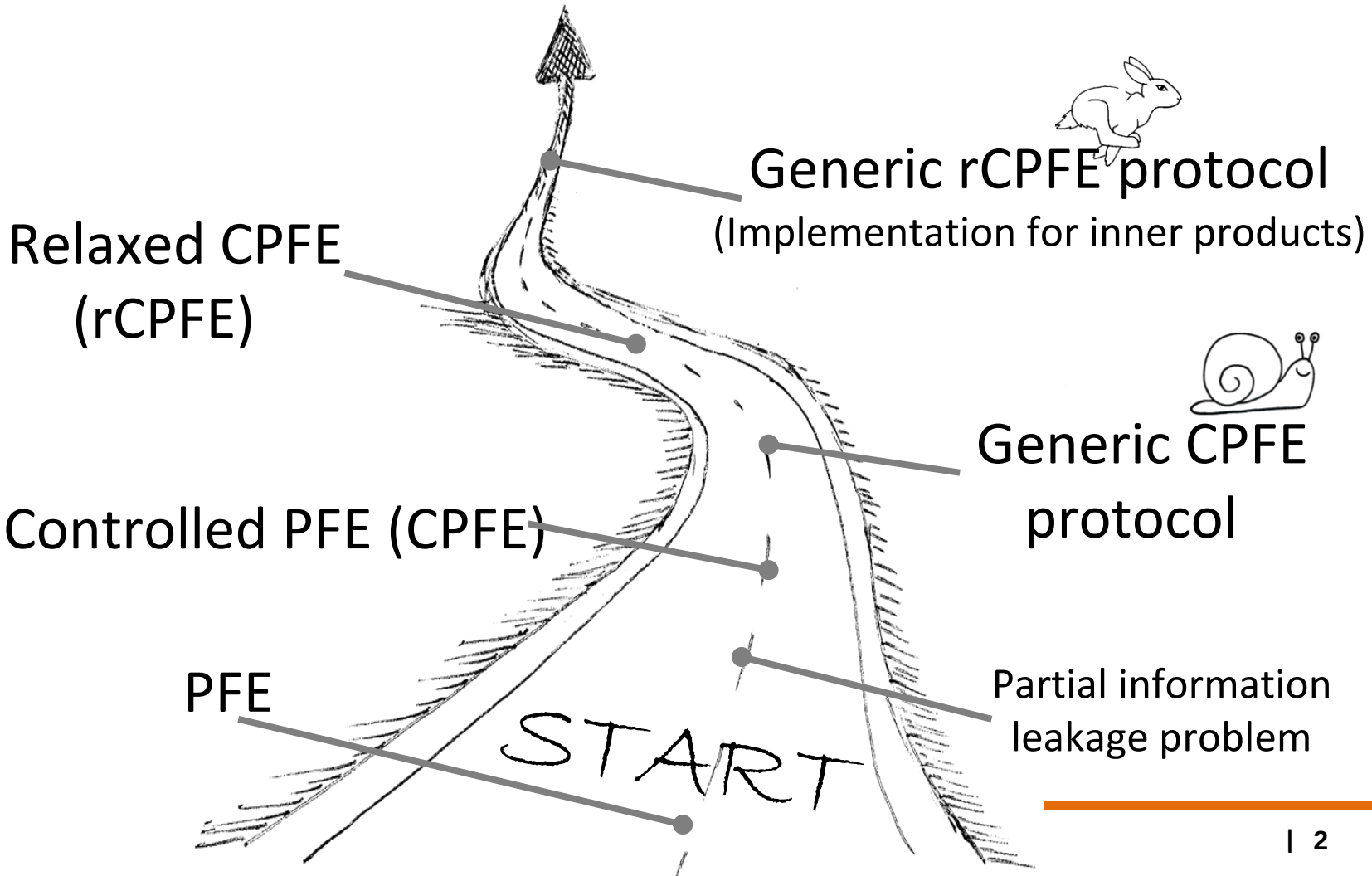
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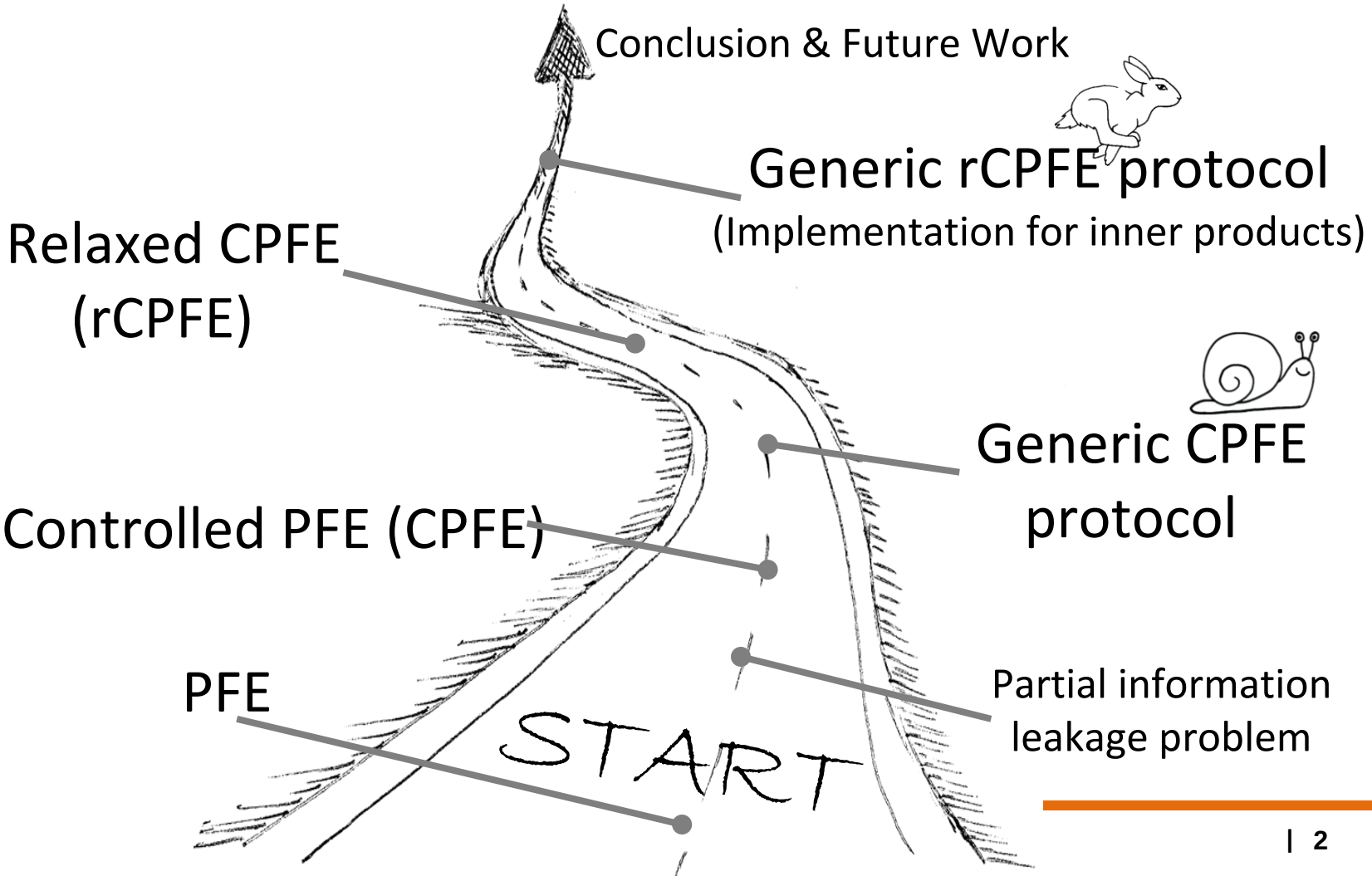
Conclusion & Future Work
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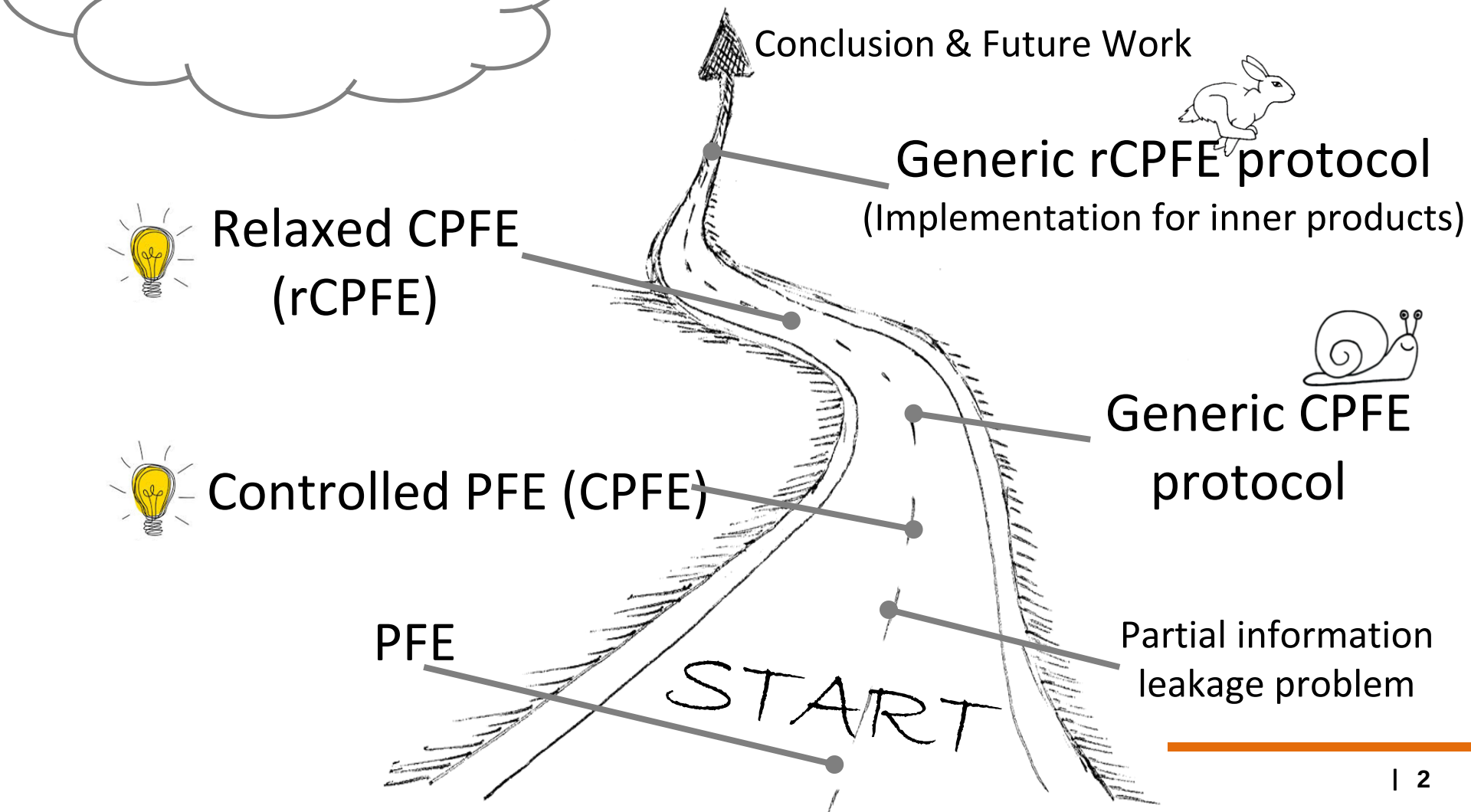
Contributions:

- Definitional framework



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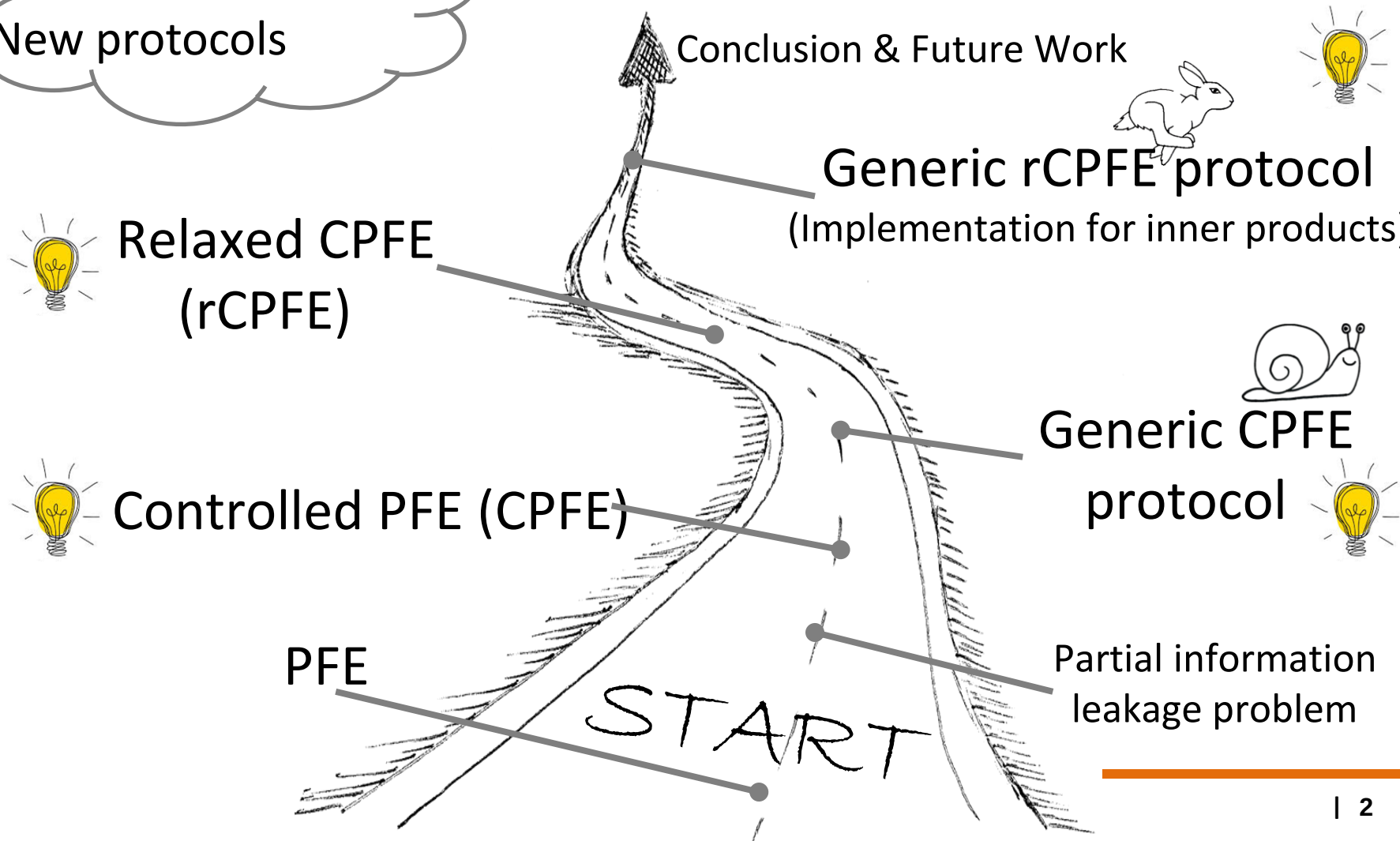
Contributions:

- Definitional framework
- New protocols



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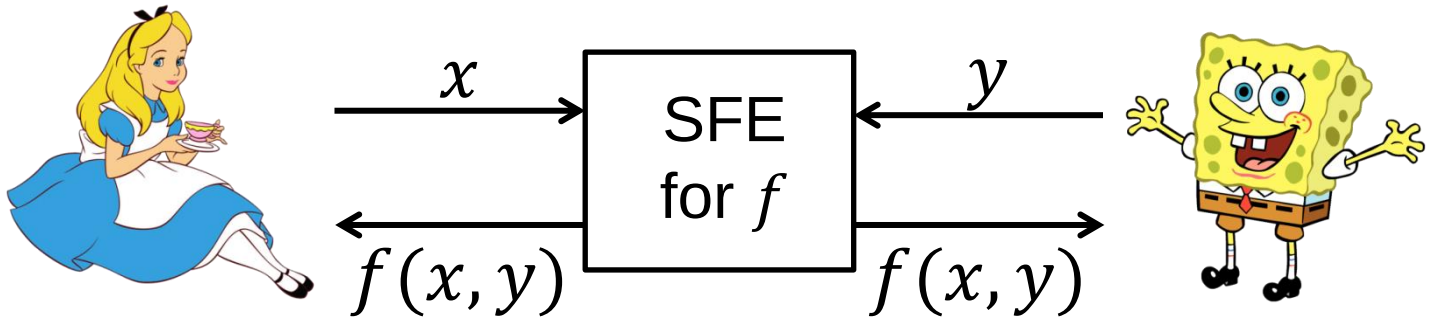
- *Secure* Function Evaluation (SFE or 2PC)



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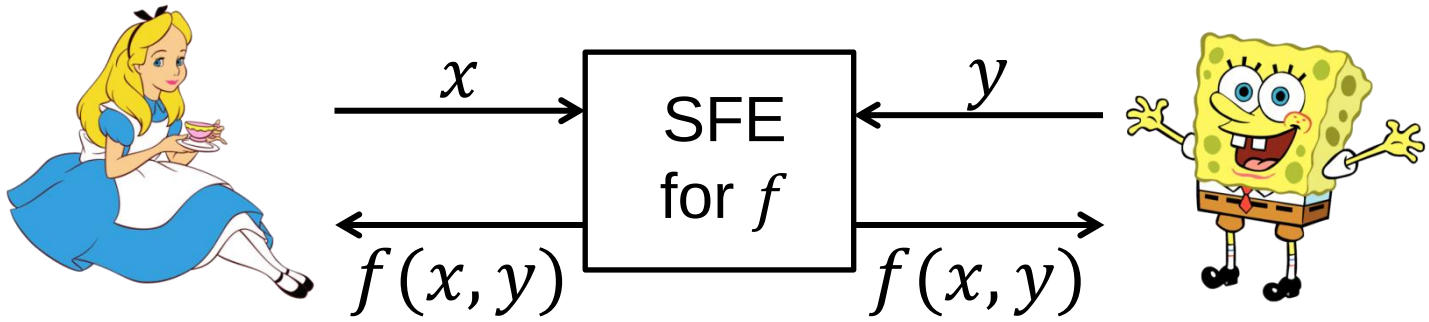

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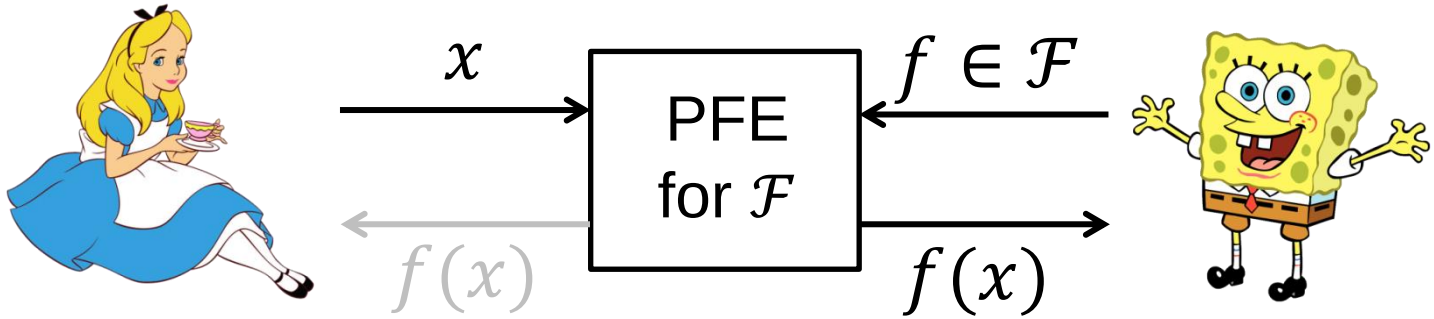

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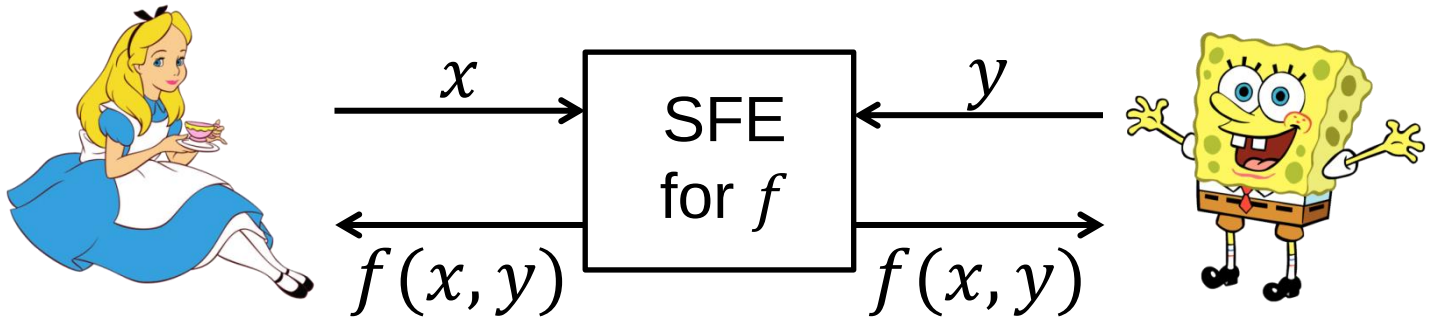

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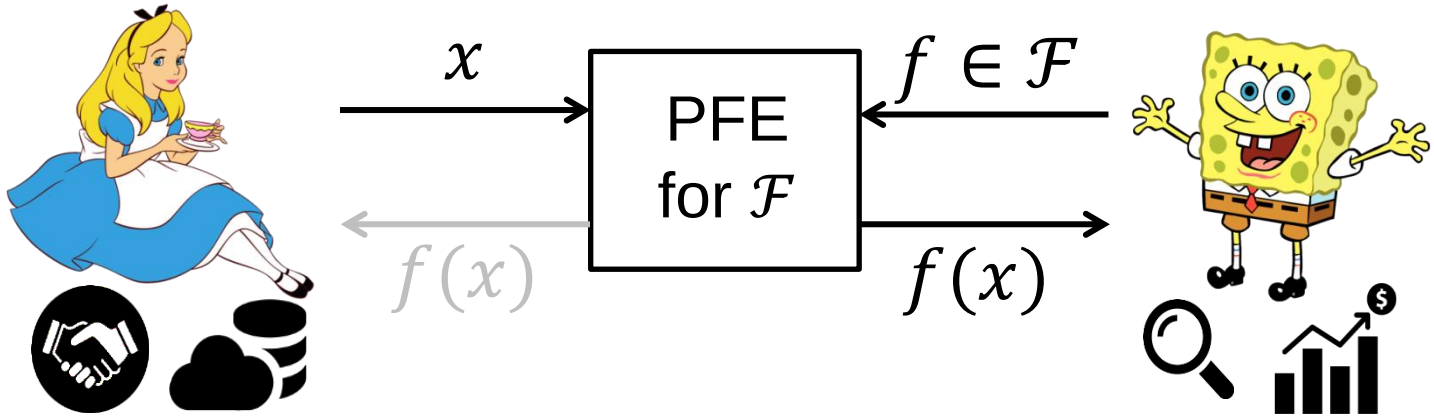
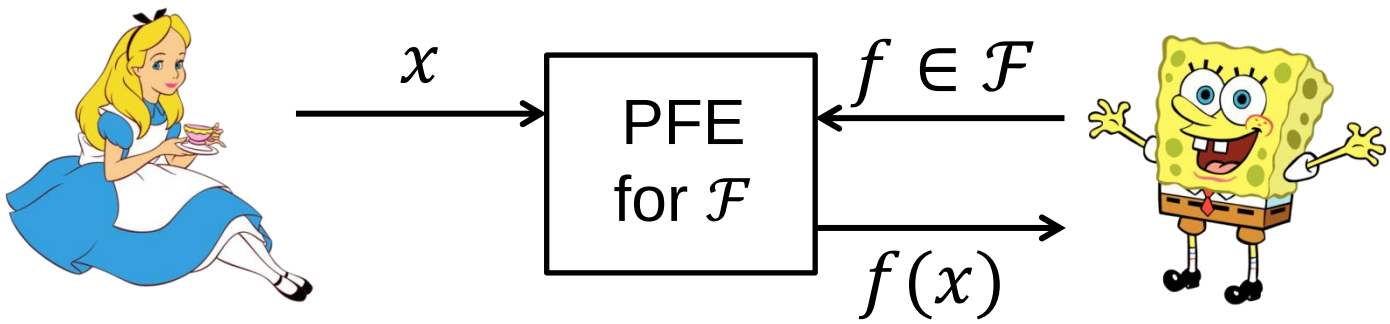


Data Broker

Value-Added Service Provider

Problem Statement



- Requirements from PFE:
  - **Function privacy**: *Alice does no learn anything about* f
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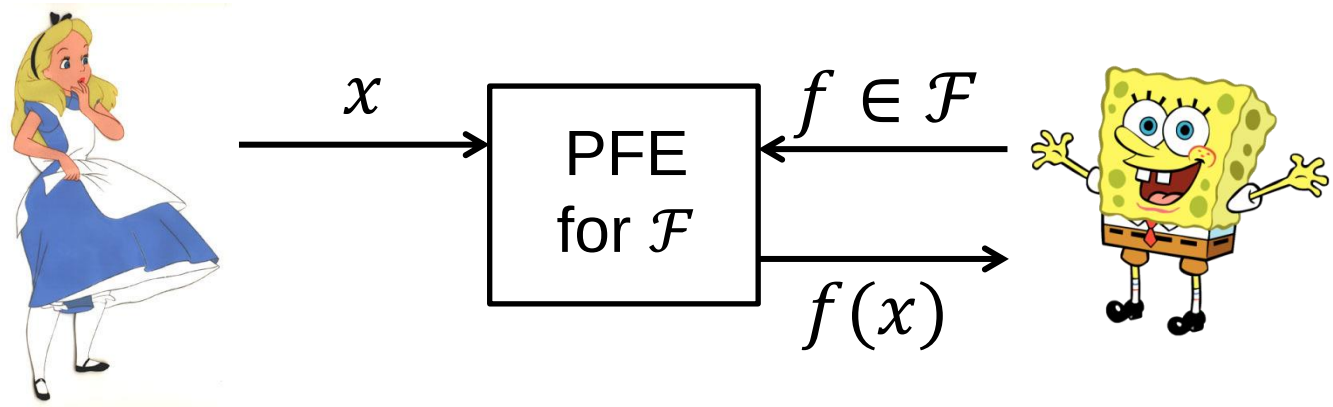

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  - **Data privacy**: *Bob does not learn more about x than what is already revealed by $f(x)$*

- What if besides x, some partial information $g(x)$ is also sensitive?
- In particular, what if $g \in \mathcal{F}$ as well?

Example: Privacy-Preserving Credit Checking

- Is Alice eligible for credit in the Bank of Korea? [PSS09]

한국은행
THE BANK OF KOREA

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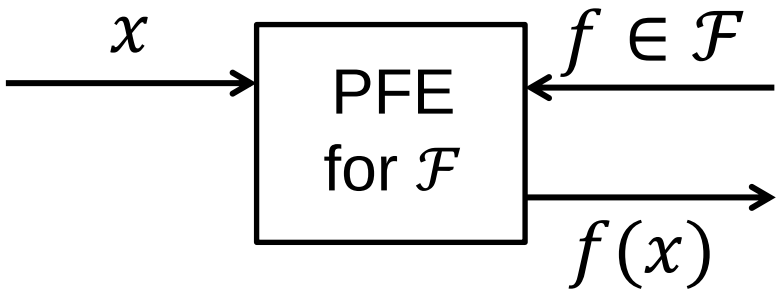

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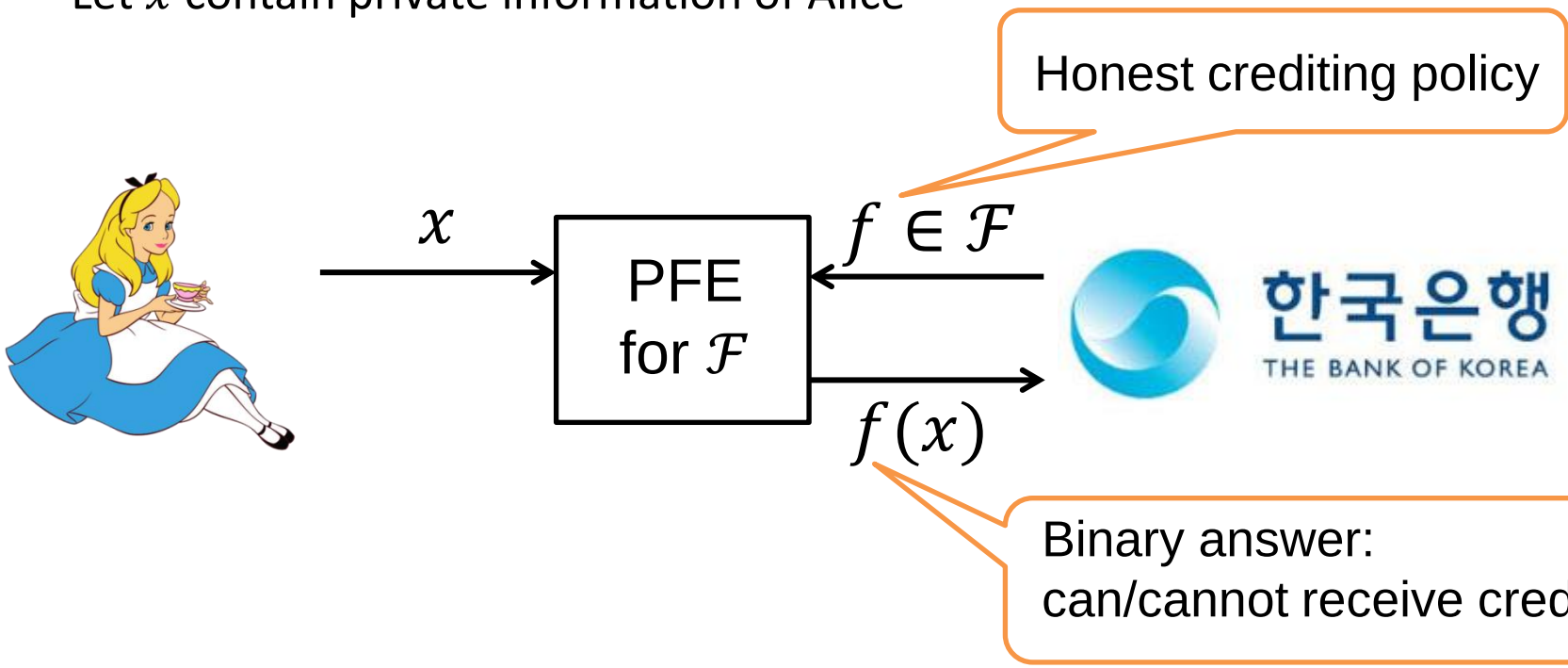

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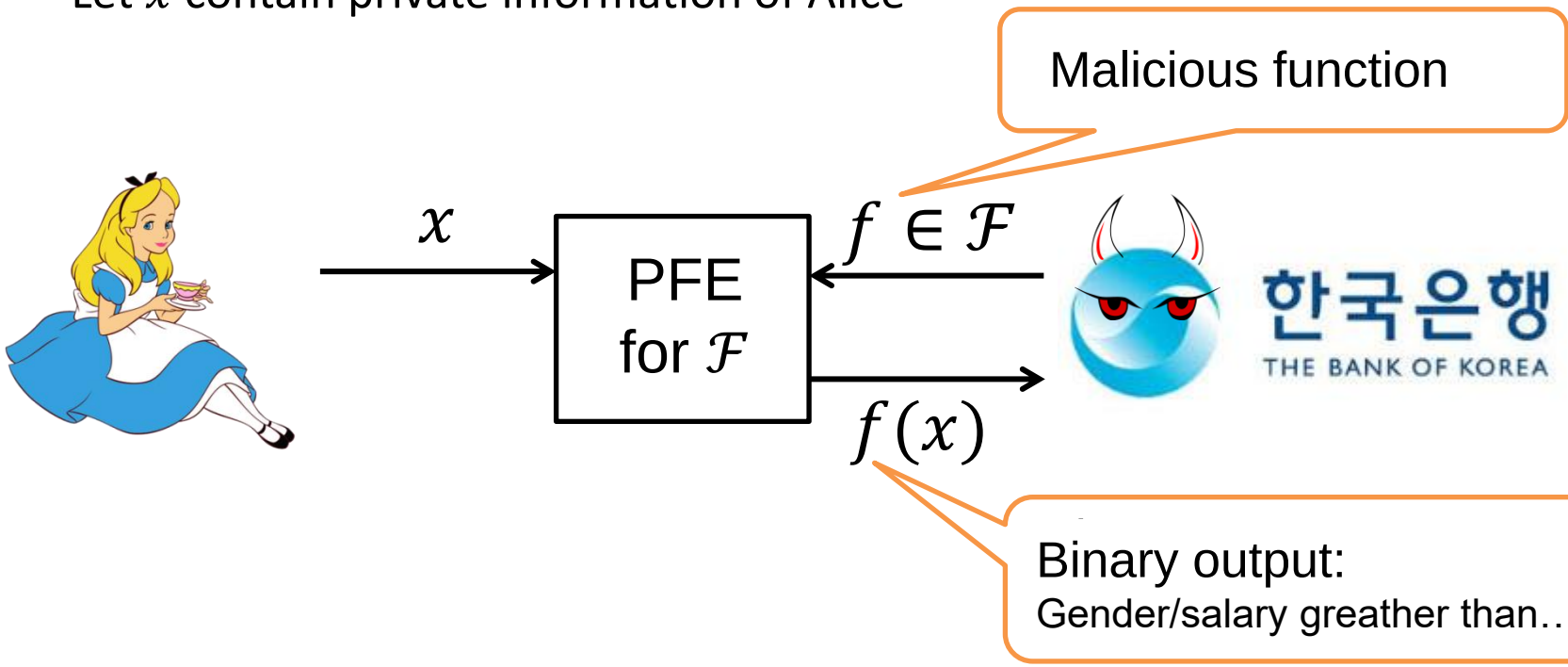

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- Goal: To enable Alice to make exceptions, i.e. to define a set of forbidden functions $\mathcal{F}_A \subset \mathcal{F}$

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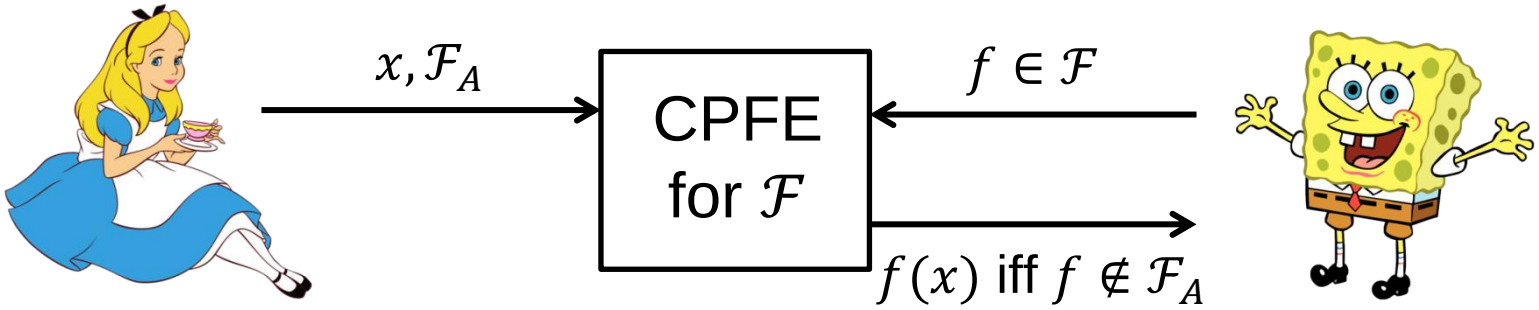

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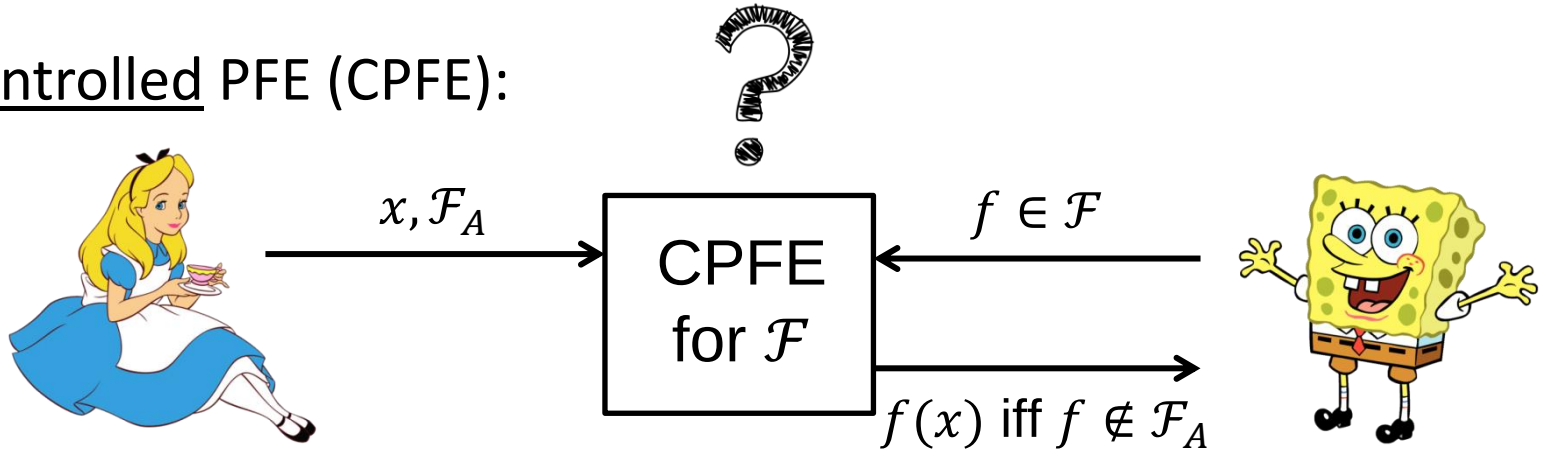

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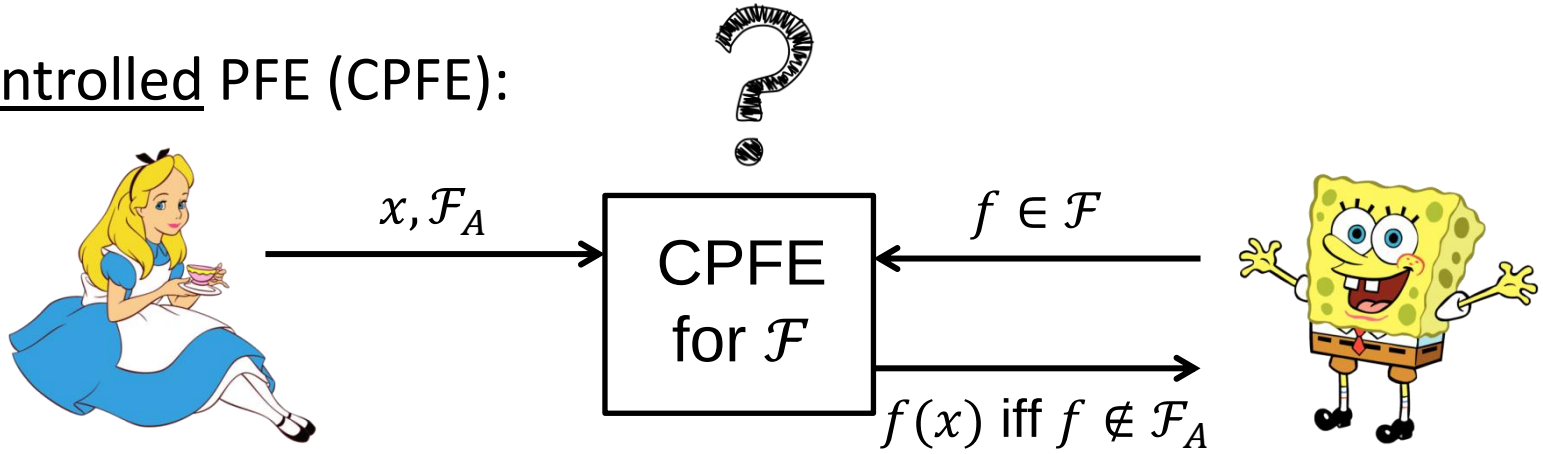

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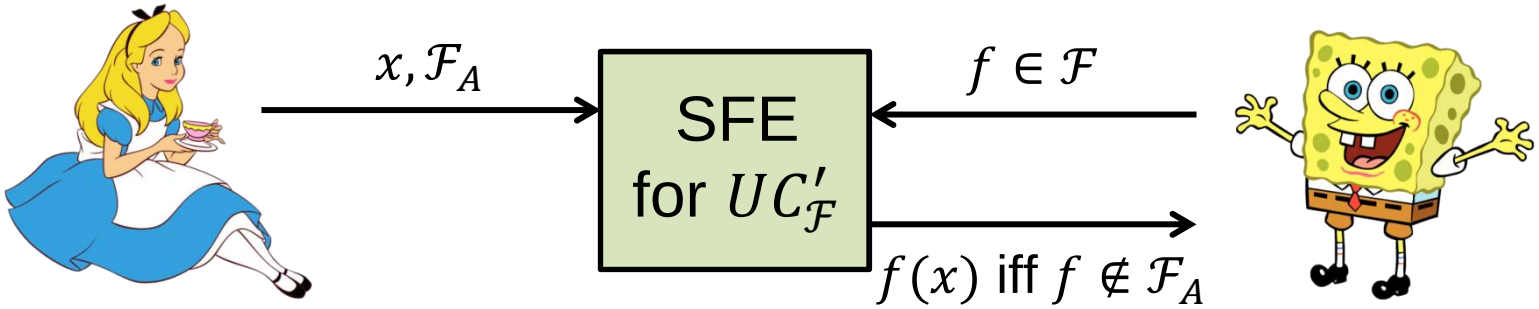

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- Conditional UC:

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Towards an Efficiency-Function Privacy Trade-off

- Drawbacks of the previous solution:
  - UCs are not efficient enough (even for a single evaluation)
  - Scalability: evaluating the same f on d different inputs costs d times more for both parties
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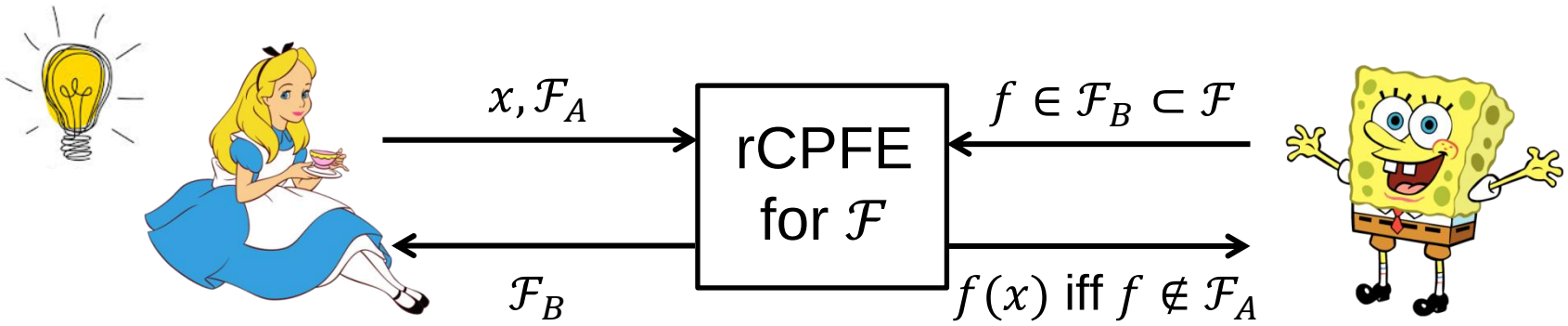

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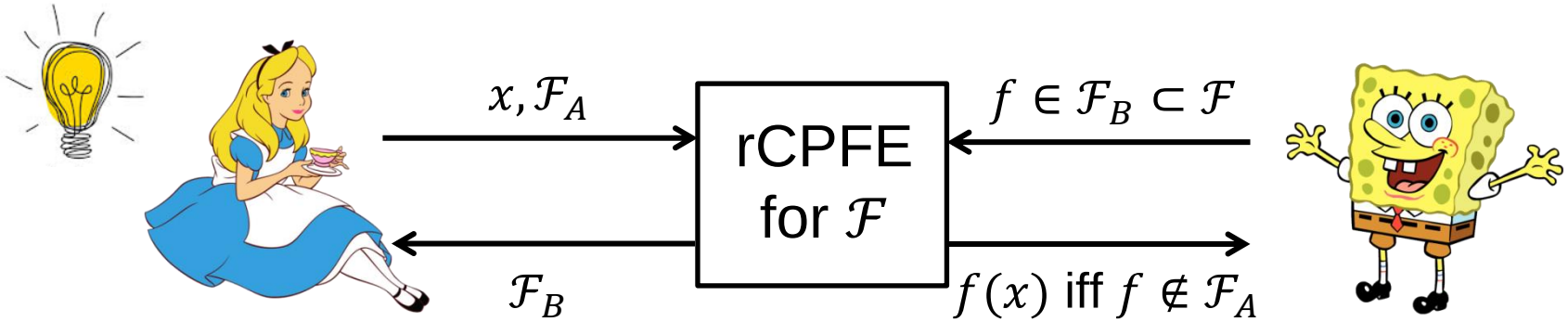

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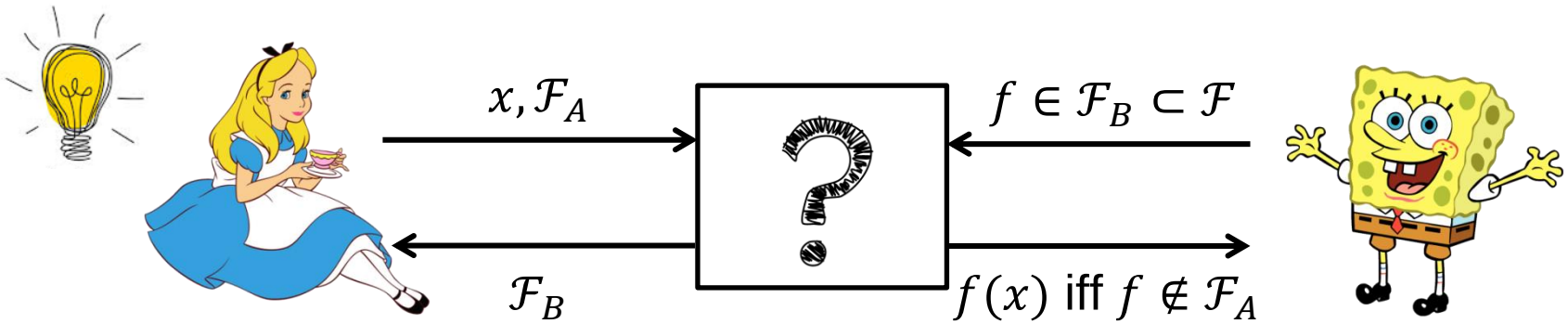

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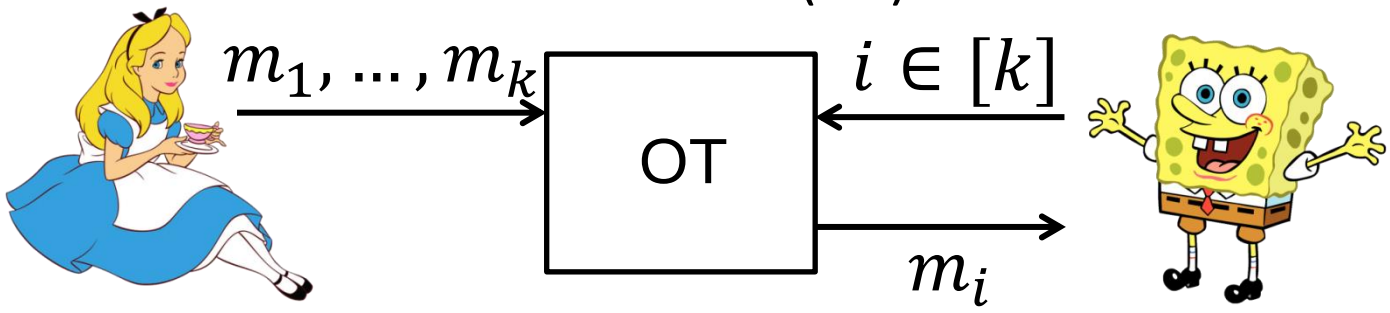
- A tool: 1 out of k Oblivious Transfer (OT):



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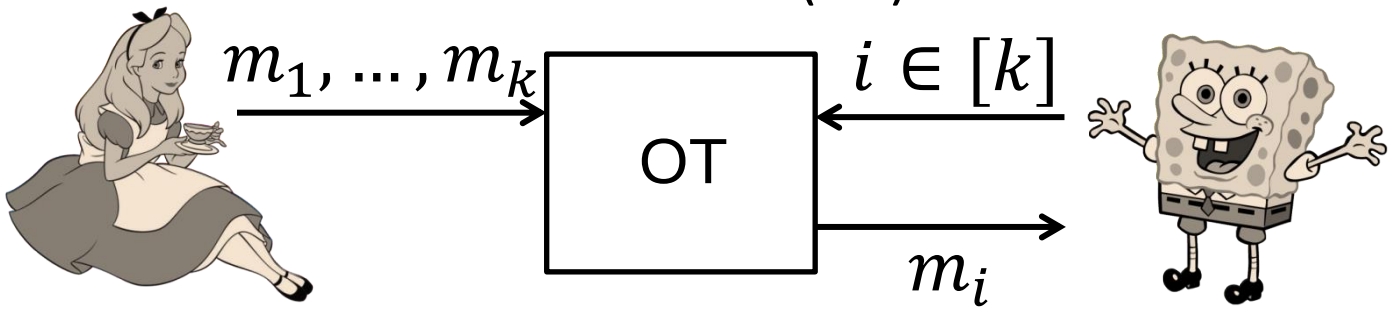

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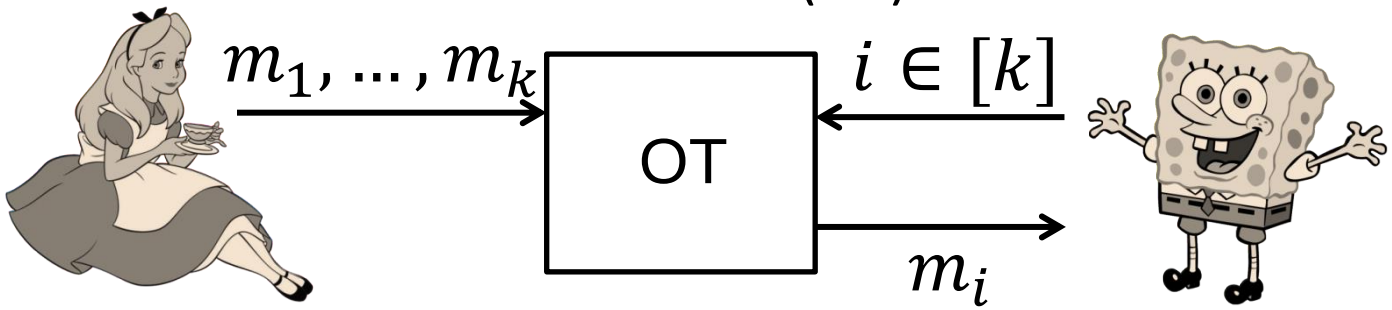

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$\mathcal{F}_B$ ←

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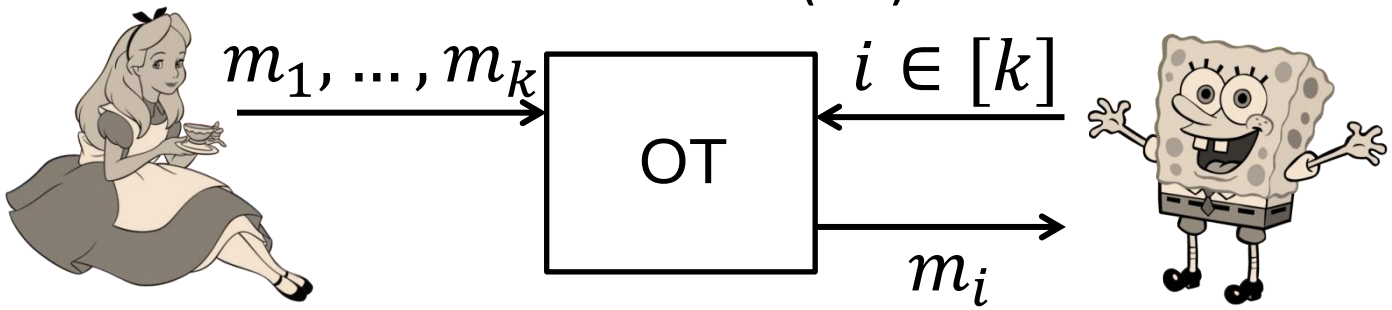

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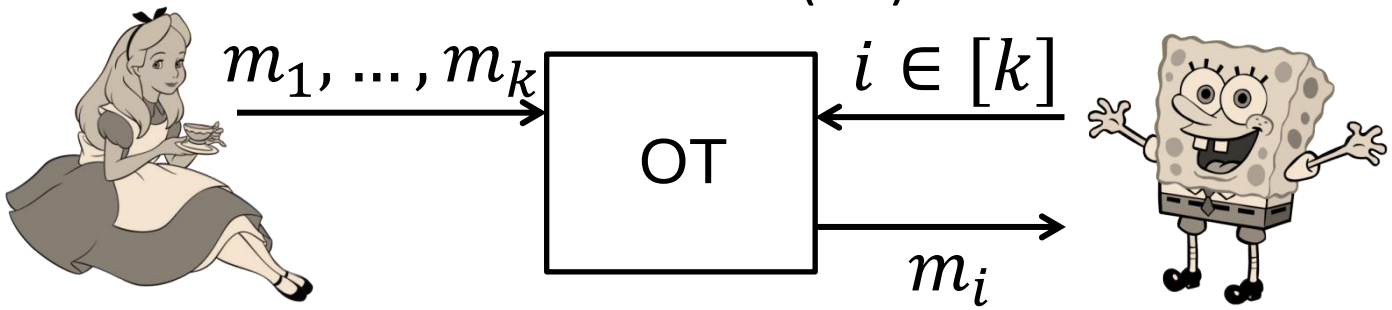

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OT

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Naive OT-based Idea to Realise rCPFE

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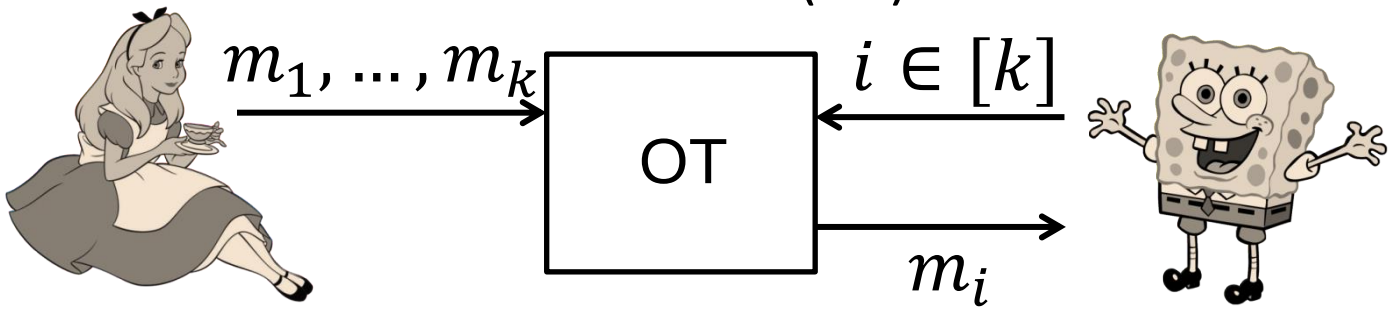

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Another Tool: Functional Encryption (FE)

- Recall traditional (secret key) encryption!

$Setup(\lambda) \rightarrow msk$

$Enc(msk, x) \rightarrow CT_x$

$Dec(CT_x, msk) \rightarrow x$

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$FE.Setup(\lambda) \rightarrow msk$

$FE.Enc(msk, x) \rightarrow CT_x$

$\boldsymbol{FE.KeyDer(msk, f) \rightarrow sk_f}$

$FE.Dec(CT_x, \boldsymbol{sk_f}) \rightarrow \boldsymbol{f(x)}$

- FE generalizes traditional encryption [BSW11]
- Decryption reveals about x no more than $f(x)$
- Arbitrary keys and ciphertexts can be combined in decryption
- To good to be true?
  - For **general** functions: impossibility/use of untested assumptions [BSW11]
  - For **restricted** functions: secure consructions, e.g. [GVW12, ALS16]

Generic rCPFE based on FE & OT

$x_1, \ldots, x_d, \mathcal{F}_A$ *INPUTS* $f \in \mathcal{F}$

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Runs $FE.Setup(\lambda) \rightarrow msk$

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Sample $f_i \in \mathcal{F}$ for $i \in [k-1]$

$\mathcal{F}_B \coloneqq (f_1, \dots, f_i, f, f_{i+1}, \dots, f_{k-1})$

$\mathcal{F}_B$ ←

Runs $FE.Setup(\lambda) \to msk$

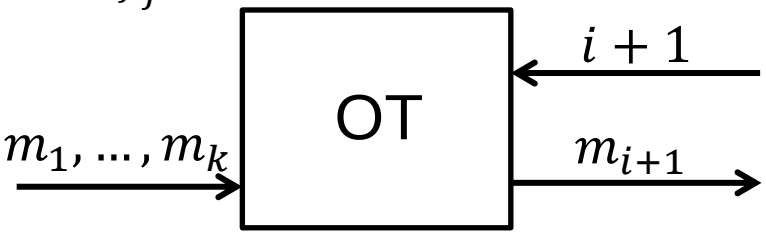
$\forall i \in [d]$: $FE.Enc(msk, x_i) = CT_{x_i}$

$CT_{x_1}, \dots, CT_{x_d}$ →

For $\mathcal{F}_B \setminus \mathcal{F}_A$ compute:

$FE.KeyDer(msk, f_j) = sk_{f_j}$

$$m_j \coloneqq \begin{cases} sk_{f_j} \text{ if } f_j \notin \mathcal{F}_A \\ \perp \text{ otherwise} \end{cases}$$



$m_{i+1} = sk_f$

Generic rCPFE based on FE & OT

$x_1, \dots, x_d, \mathcal{F}_A$ *INPUTS* $f \in \mathcal{F}$

ONLINE PHASE

Sample $f_i \in \mathcal{F}$ for $i \in [k-1]$

$\mathcal{F}_B \coloneqq (f_1, \dots, f_i, f, f_{i+1}, \dots, f_{k-1})$

$\mathcal{F}_B$ ←

Runs $FE.Setup(\lambda) \to msk$

$\forall i \in [d]$: $FE.Enc(msk, x_i) = CT_{x_i}$

$CT_{x_1}, \dots, CT_{x_d}$ →

For $\mathcal{F}_B \setminus \mathcal{F}_A$ compute:

$FE.KeyDer(msk, f_j) = sk_{f_j}$

$$m_j \coloneqq \begin{cases} sk_{f_j} \text{ if } f_j \notin \mathcal{F}_A \\ \perp \text{ otherwise} \end{cases}$$

$m_1, \dots, m_k$ →

OT

$i+1$ ←

m_{i+1} →

$m_{i+1} = sk_f$

OFFLINE PHASE

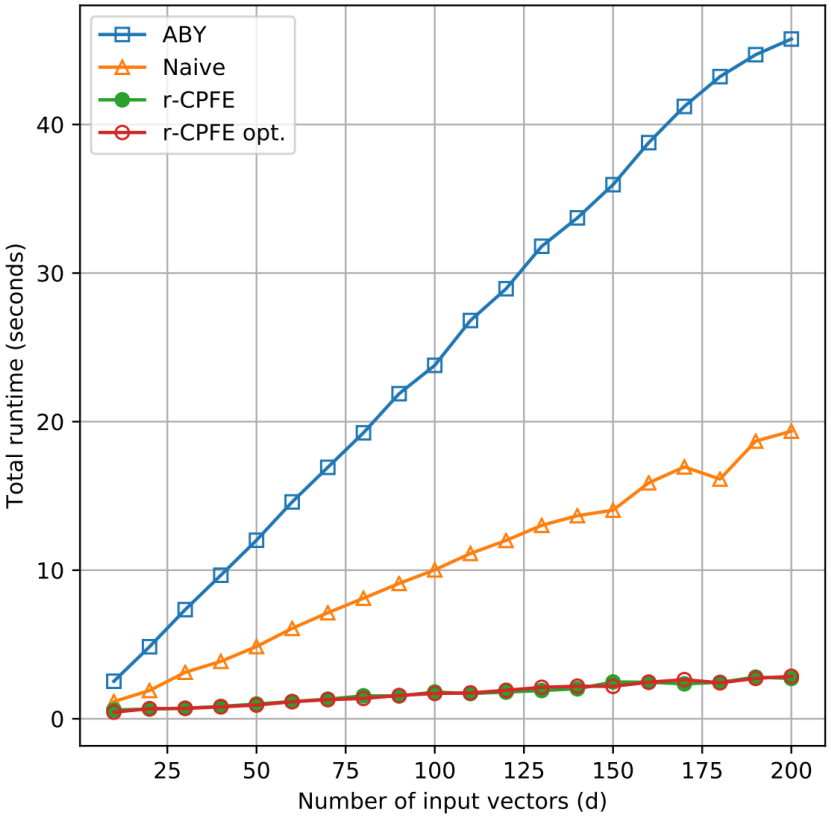
$\forall i \in [d]$: $FE.Dec(CT_{x_i}, sk_f) \to f(x_i)$

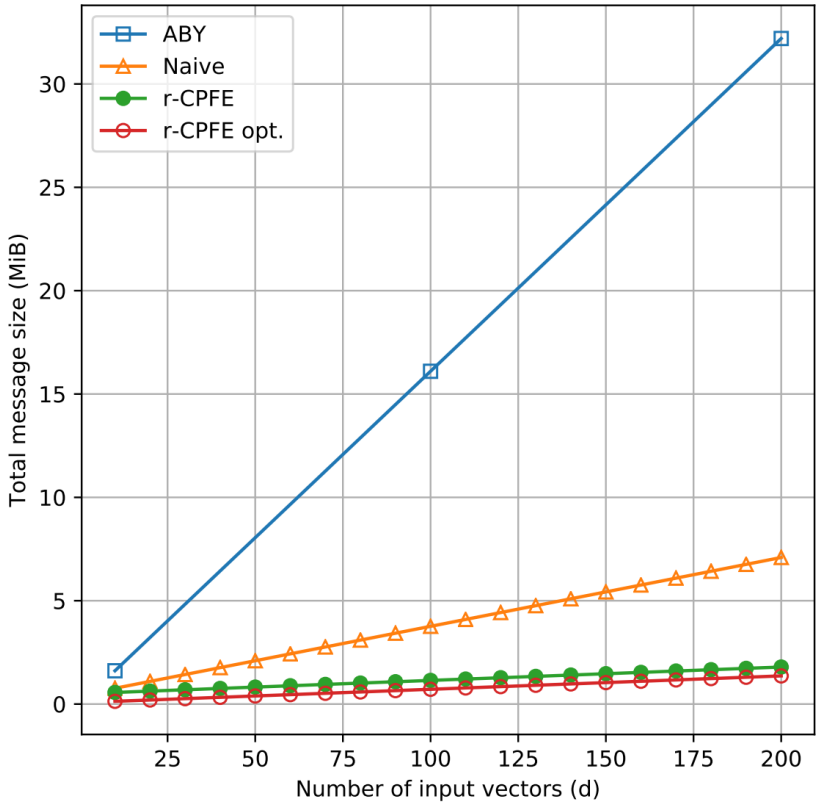
Generic rCPFE based on FE & OT

- Theorem. /informal/
  The protocol is SIM secure against semi-honest adversaries, if the underlying *FE scheme is k-query non-adaptive SIM secure for a single message* and the used *OT protocol is SIM secure against semi-honest adversaries*.
- Corollary.
  The protocol achieves *strong relaxed function privacy* if all dummy functions are sampled from the same distribution as f and $aux = \perp$.
- Instantiations:
  - Using FE of [GVW12] → rCPFE for $P/poly$ (in theory!)
  - Using inner product FE [ALS16] → inner product rCPFE from the DDH assumption
    Application: statistical analysis, e.g. logistic regression, etc.

Performance of Our Inner Product rCPFE

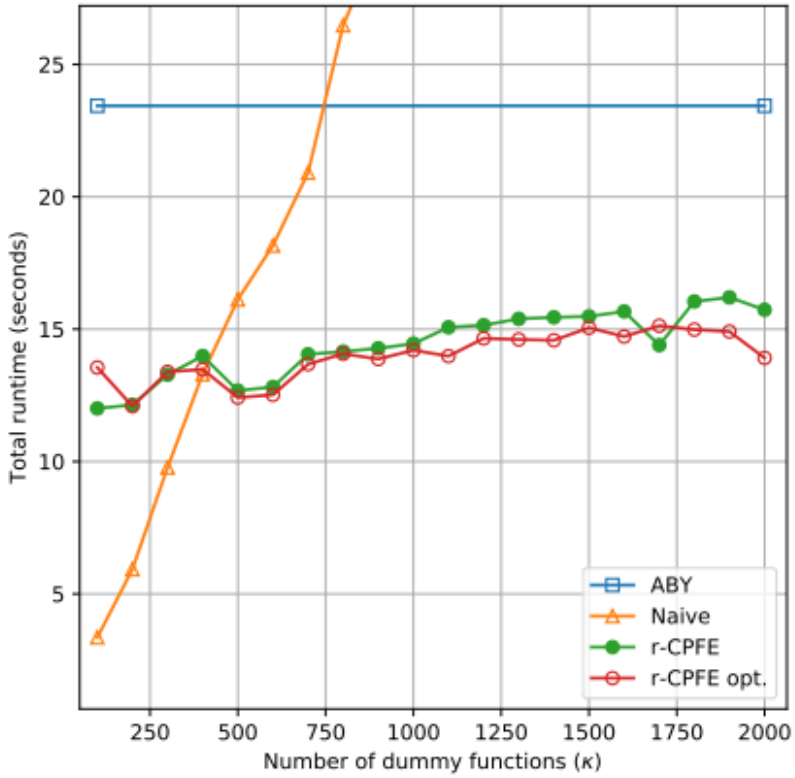
- Comparison with the state of the art secure inner product protocol (ABY framework) [DSZ15]:
  - Vector dimension: 100
  - Number of dummy functions: 1000

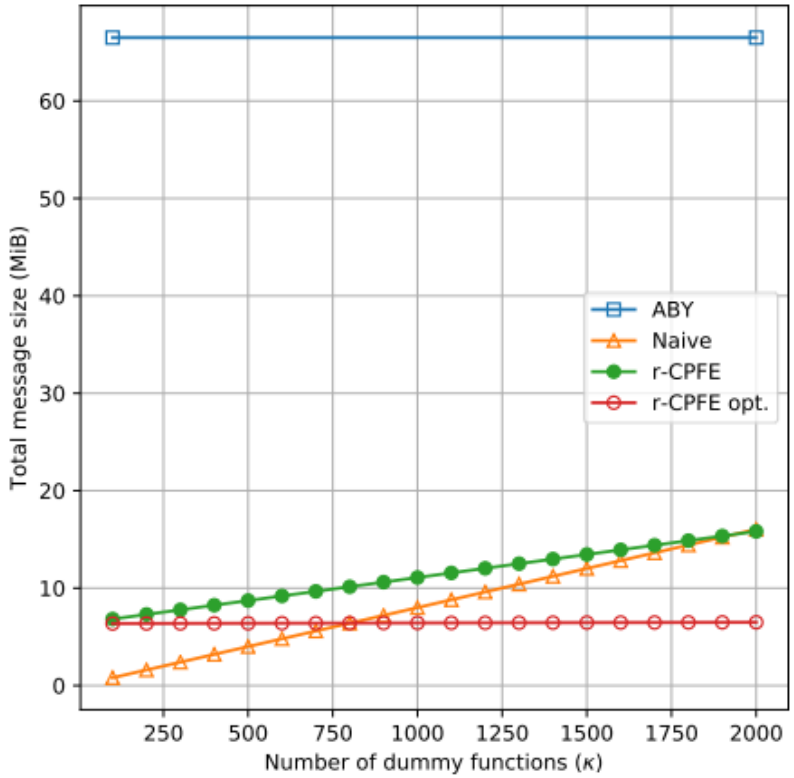




Performance of Our Inner Product rCPFE

- Representating the cost of our dummy functions
  - Vector dimension: 1000
  - Number evaluations with different inputs: 100
  - Approx equality of running time (with ABY) is for k=6200





Summary & Open Directions

- We initiate the study of partiol information leakage in PFE
- Defined variants of CPFE
- Generic realizations
  - Focus on scenarios where multiple evaluations occur
  - Trade-off to achieve better performance
- Inner Product rCPFE is practical

Future work

- Non-zero auxiliary info?
- How to get rid of dummy functions?
- Different trade-offs?

Take-home message

- Parital information can be sensitive and can leak easily!

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Thank you for the attention!

Q&A

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