ACHIEVING PRIVACY IN VERIFIABLE COMPUTATION WITH MULTIPLE SERVERS — WITHOUT FHE AND WITHOUT PREPROCESSING

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OUTSOURCING COMPUTATION

- Alice has a weak device and she wants to perform expensive computation

 

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Solution: Outsource to the cloud

CLOUD COMPUTING

- Commercial providers: Amazon, Microsoft Azure, Google Compute Engine etc.

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- Folding@Home: Stanford Project that uses computing resources of thousands of volunteer PCs/game consoles

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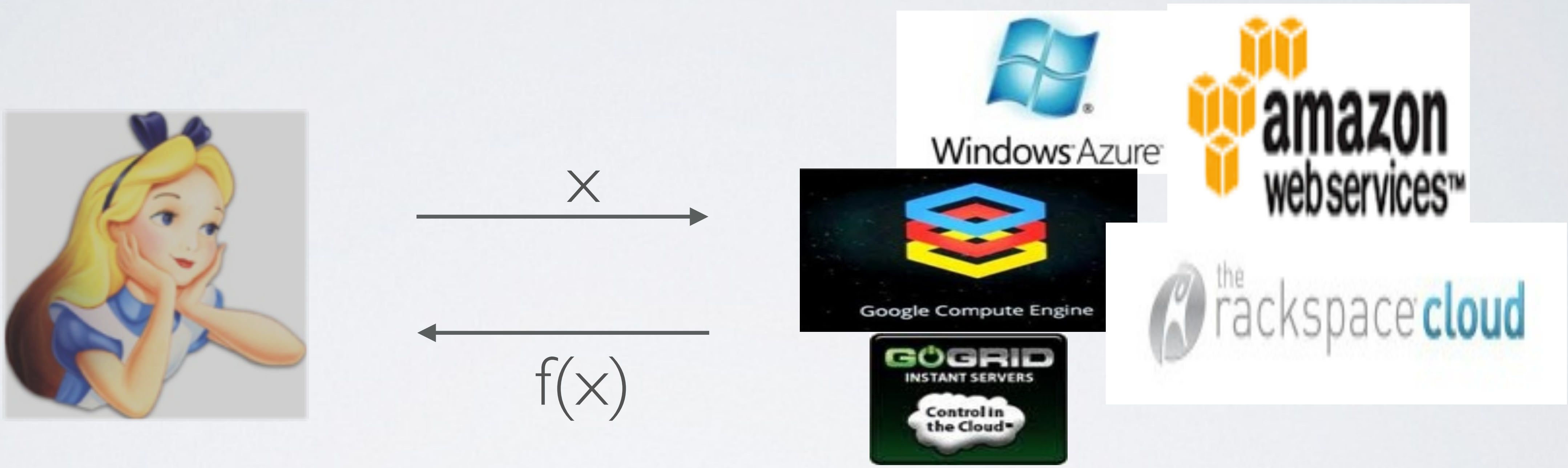

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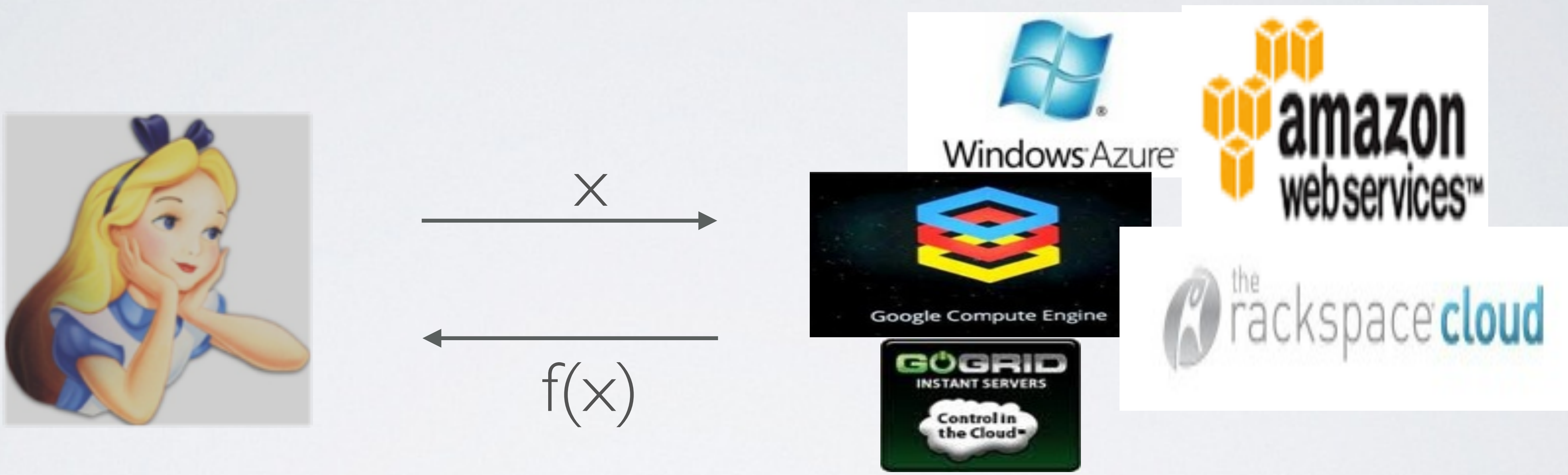

- Problem: Need to trust the companies that the computation was done correctly.

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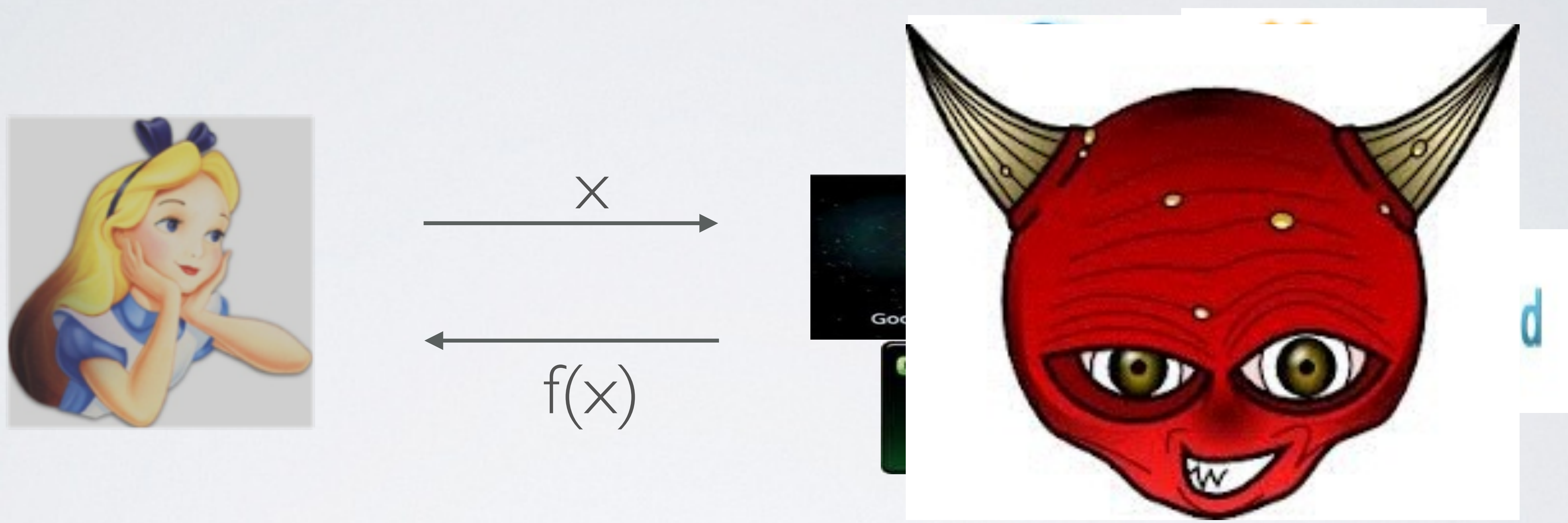

What if the cloud is malicious?

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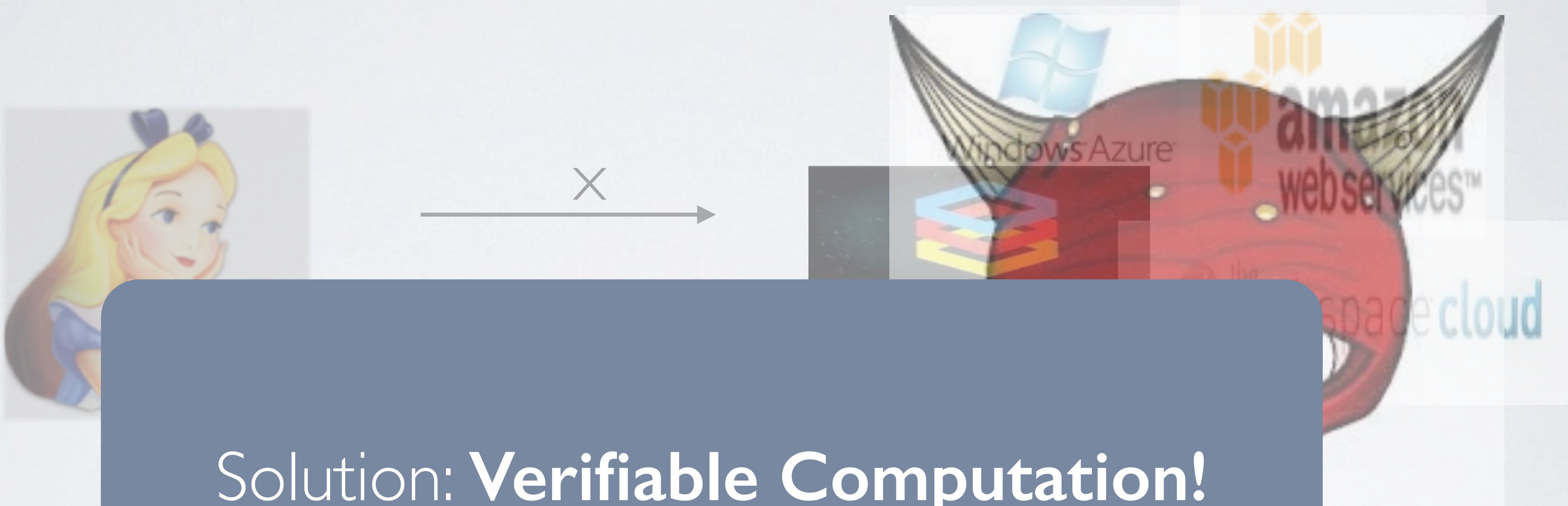
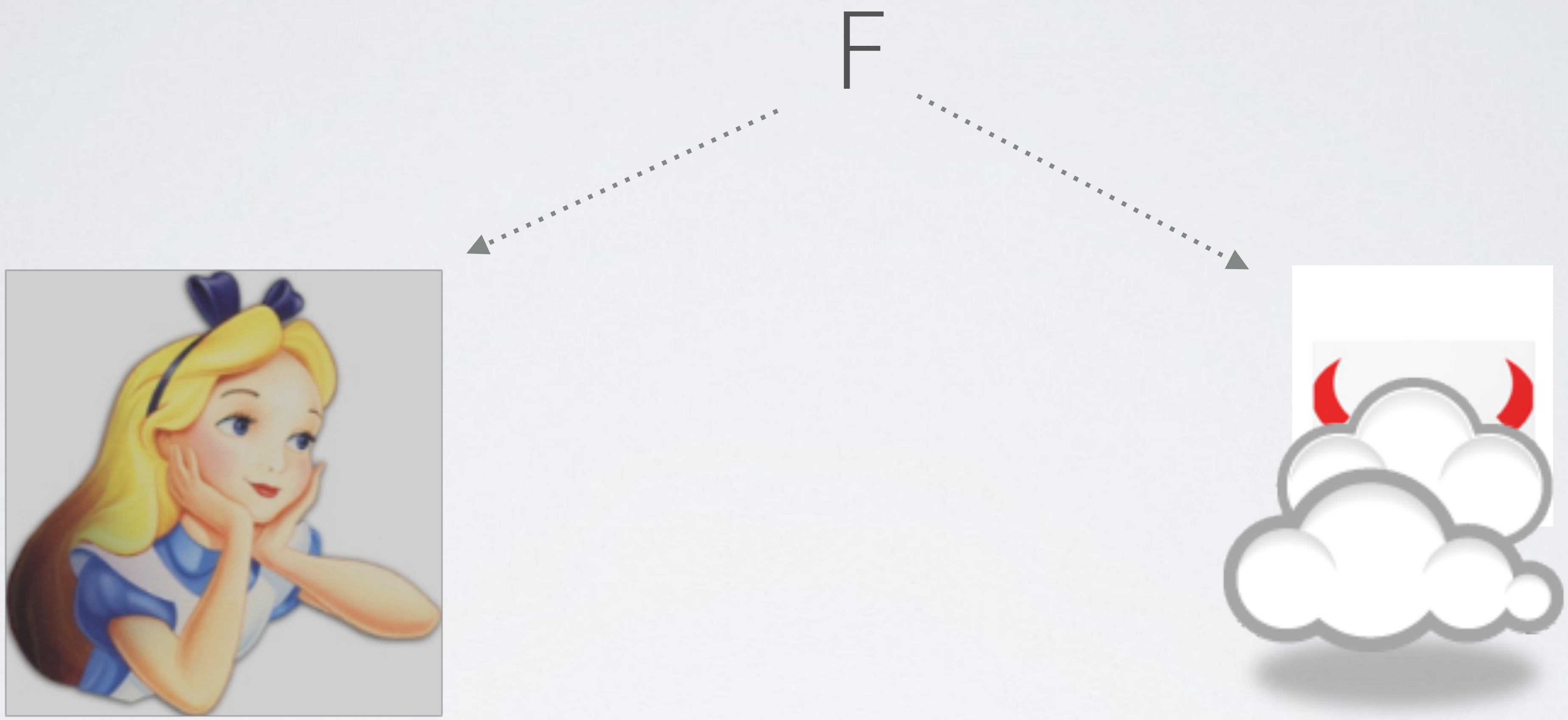


Solution: **Verifiable Computation!**

What if the cloud is malicious?

VERIFIABLE COMPUTATION



VERIFIABLE COMPUTATION

F

Input: x

Goal: Verifiably outsource computation of F on x to the cloud

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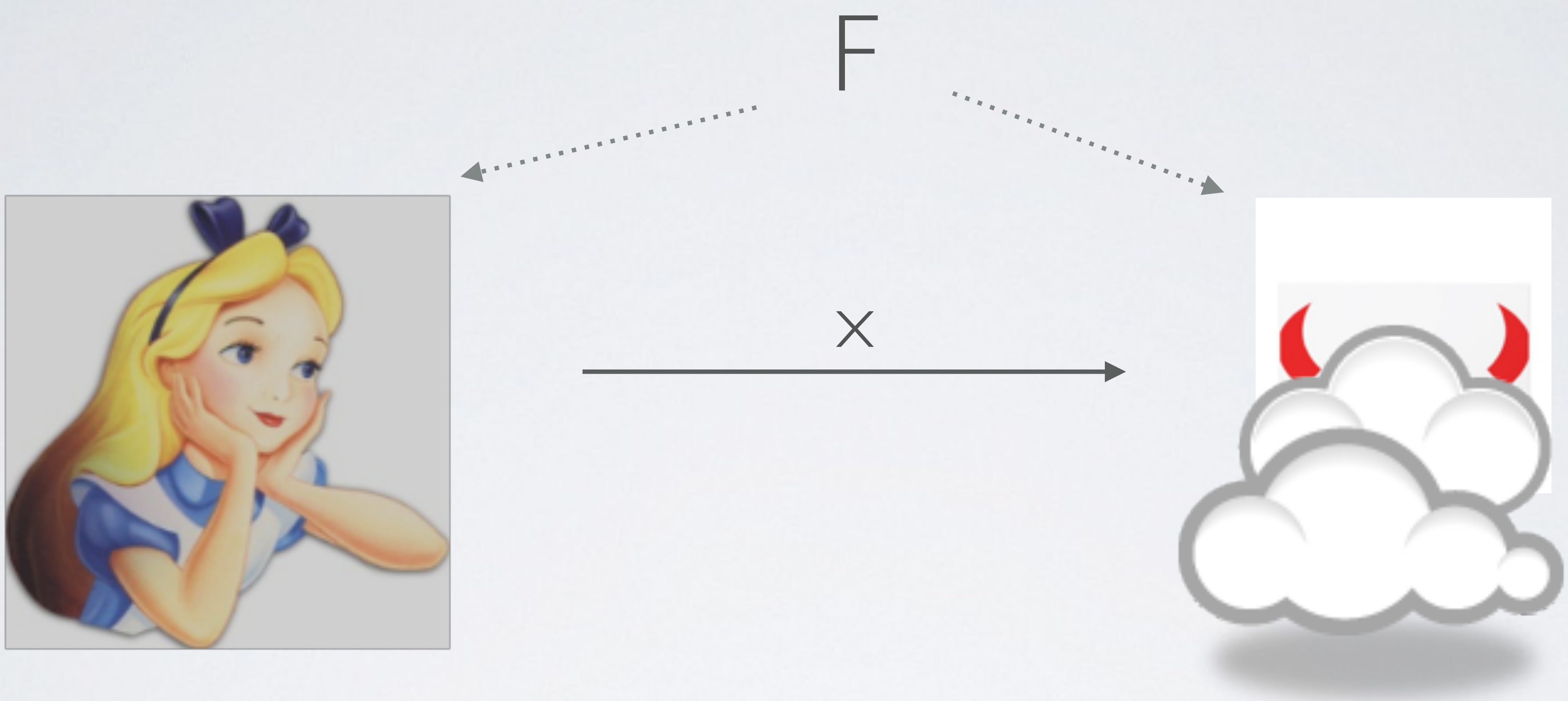

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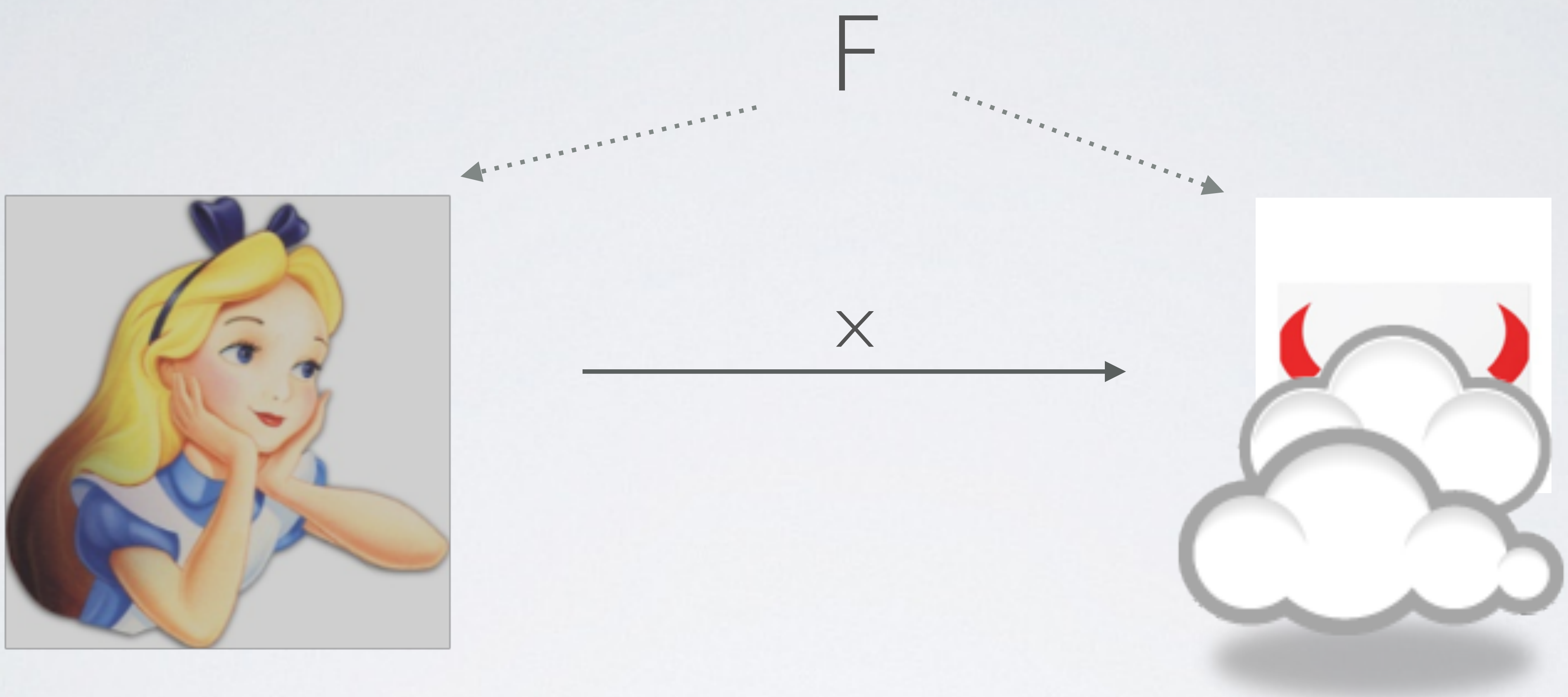

- Compute y=F(x)
- Generate proof z that the computation was done correctly

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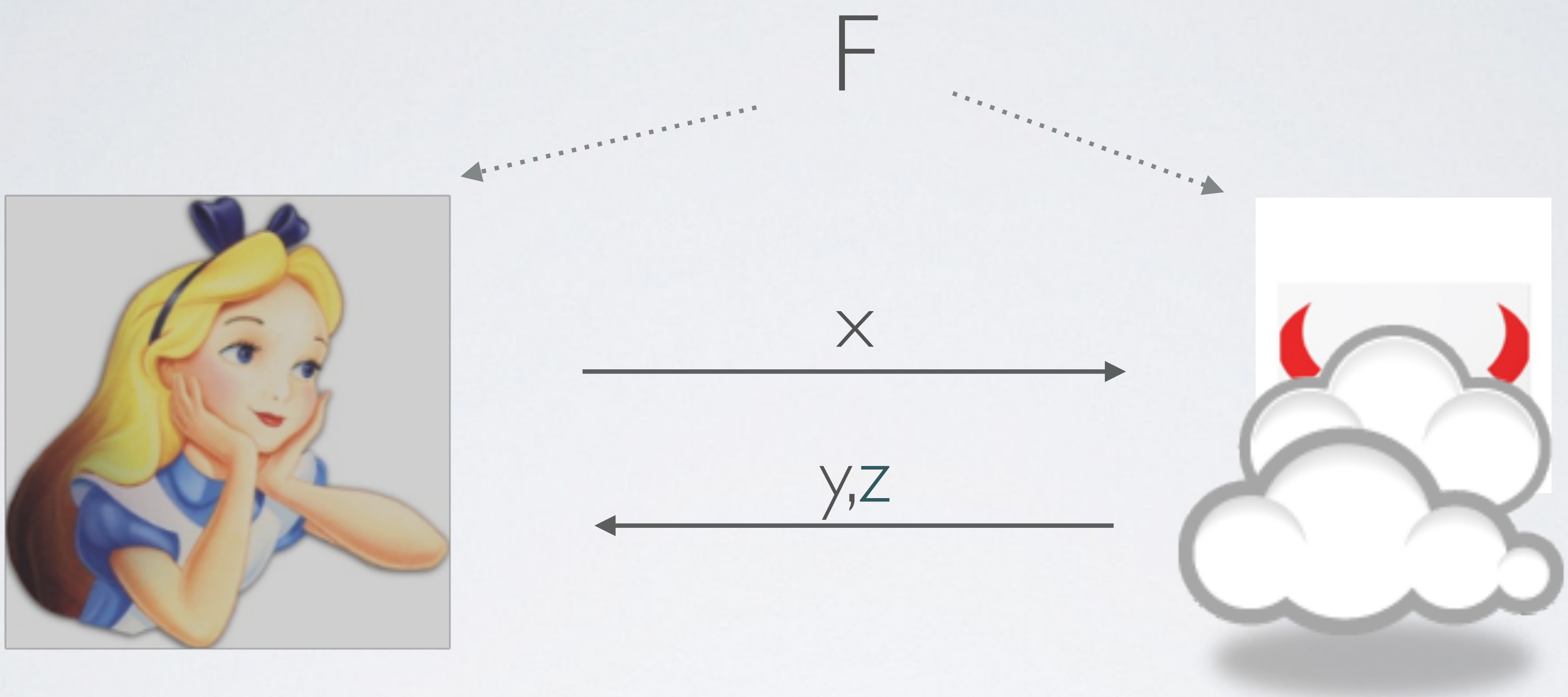

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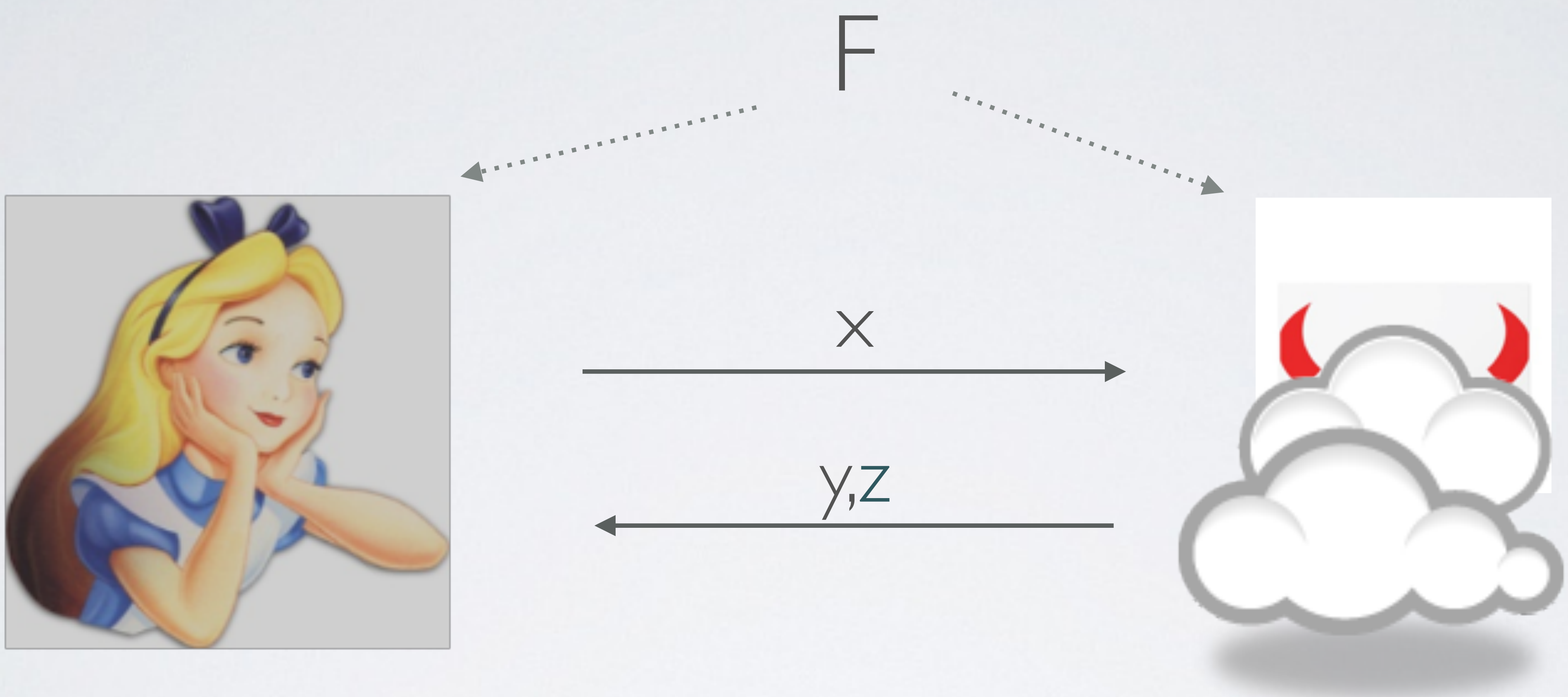


- Verify using proof z that y = F(x)

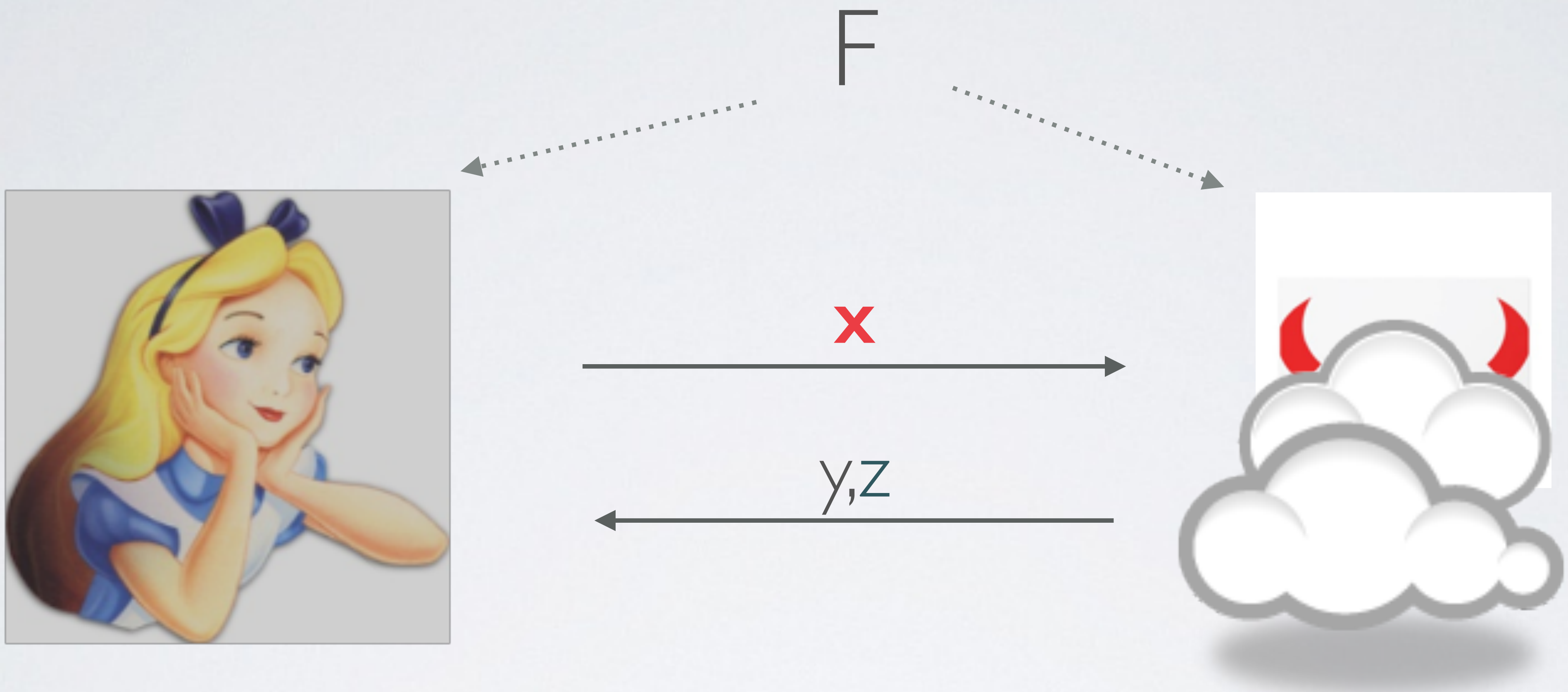
- Compute y=F(x)
- Generate proof z that the computation was done correctly

PROPERTIES OF VC PROTOCOL

- Verifiability: An adversarial cloud cannot make Alice accept an incorrect F(x).

- Efficiency: Verifying y=F(x) should be significantly easier than computing F(x) itself.

A SECOND LOOK AT VERIFIABLE COMPUTATION



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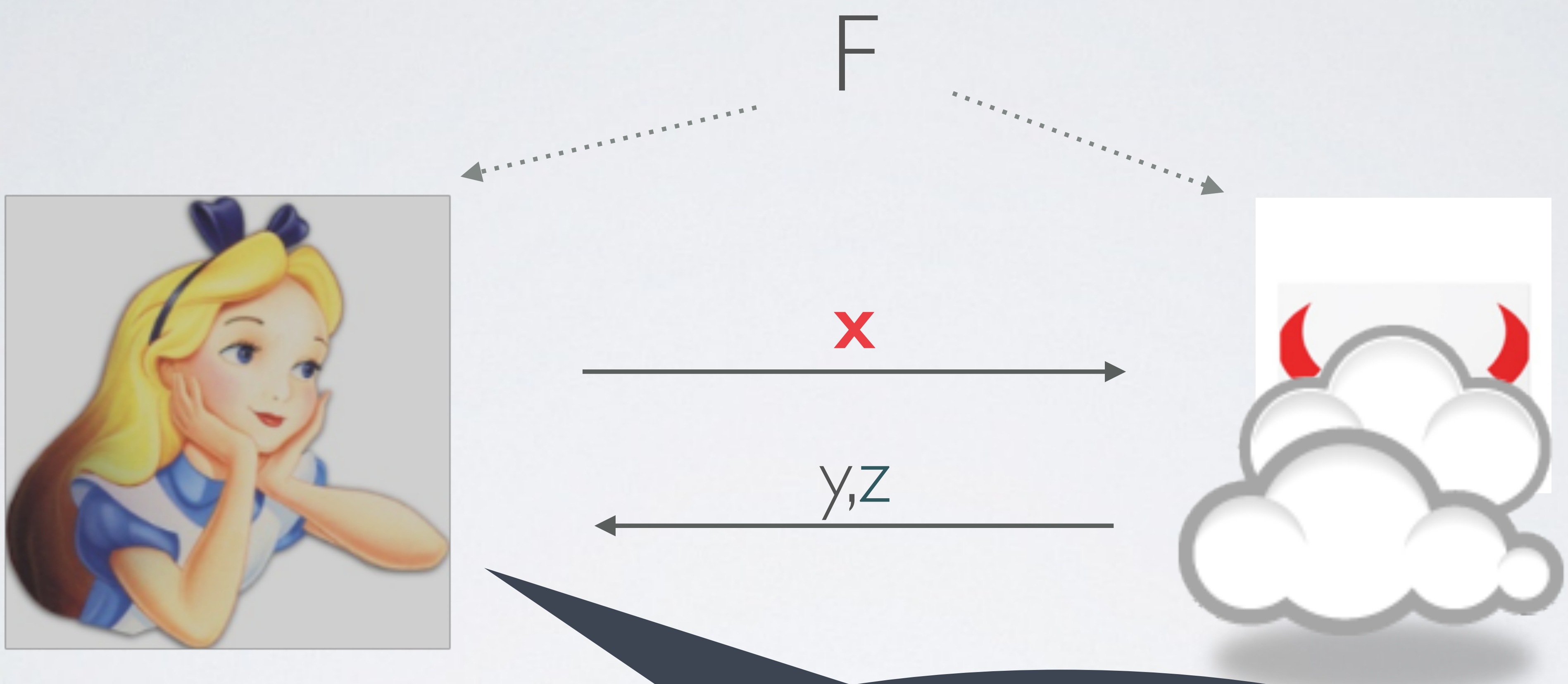

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Is it necessary that the cloud learns x?

F(x)
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A SECOND LOOK AT VERIFIABLE COMPUTATION

F

This work: Focus on achieving privacy

Is it necessary that the cloud learns x?

- Verify using proof z that y = F(x)

- Compute y=F(x)
- Generate proof z that the computation was done correctly

PRIOR WORK ON VC PROTOCOLS

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- No input-privacy:

- With input-privacy:

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- No input-privacy: CS proofs [Micali94], Extractable CRHF-based solutions [GLR11,BCCT11], ABE based solutions [PRV12], Quadratic Span programs [GGPR12], Information-theoretic protocols [CRR12]

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- With input-privacy: FHE-based solutions [GGP10,CKV10], Randomized-Encodings based solutions [AIK10]

PRIOR WORK ON VC PROTOCOLS

- No input-privacy: CS proofs [Micali94], Extractable CRHF-based solutions [GLR11,BCCT11], ABE based solutions ... n programs [GGPR1 ... protocols [CRR12]

Either use FHE or defined for specific functions.

- With input-privacy: FHE-based solutions [GGP10,CKV10], Randomized-Encodings based solutions [AIK10]

DRAWBACKS WITH FHE

- Computational assumption: constructions under standard assumptions known only for leveled-FHE

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- Efficiency: the computational overhead involved during evaluation is large.

DRAWBACKS WITH FHE

Can we achieve privacy in verifiable computation for all efficient functions without FHE?

- HE
- during evaluation is large.

ACHIEVING PRIVACY IN VC WITHOUT FHE

- Single server case: FHE seems to be inherently required.

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We focus on the case when Alice outsources her computation to many servers

RESULTS

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Many prior known protocols : expensive preprocessing

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In all prior known protocols : the client complexity depends on the function complexity

TECHNICAL DETAILS

VC IN THE MULTIPLE-SERVER MODEL

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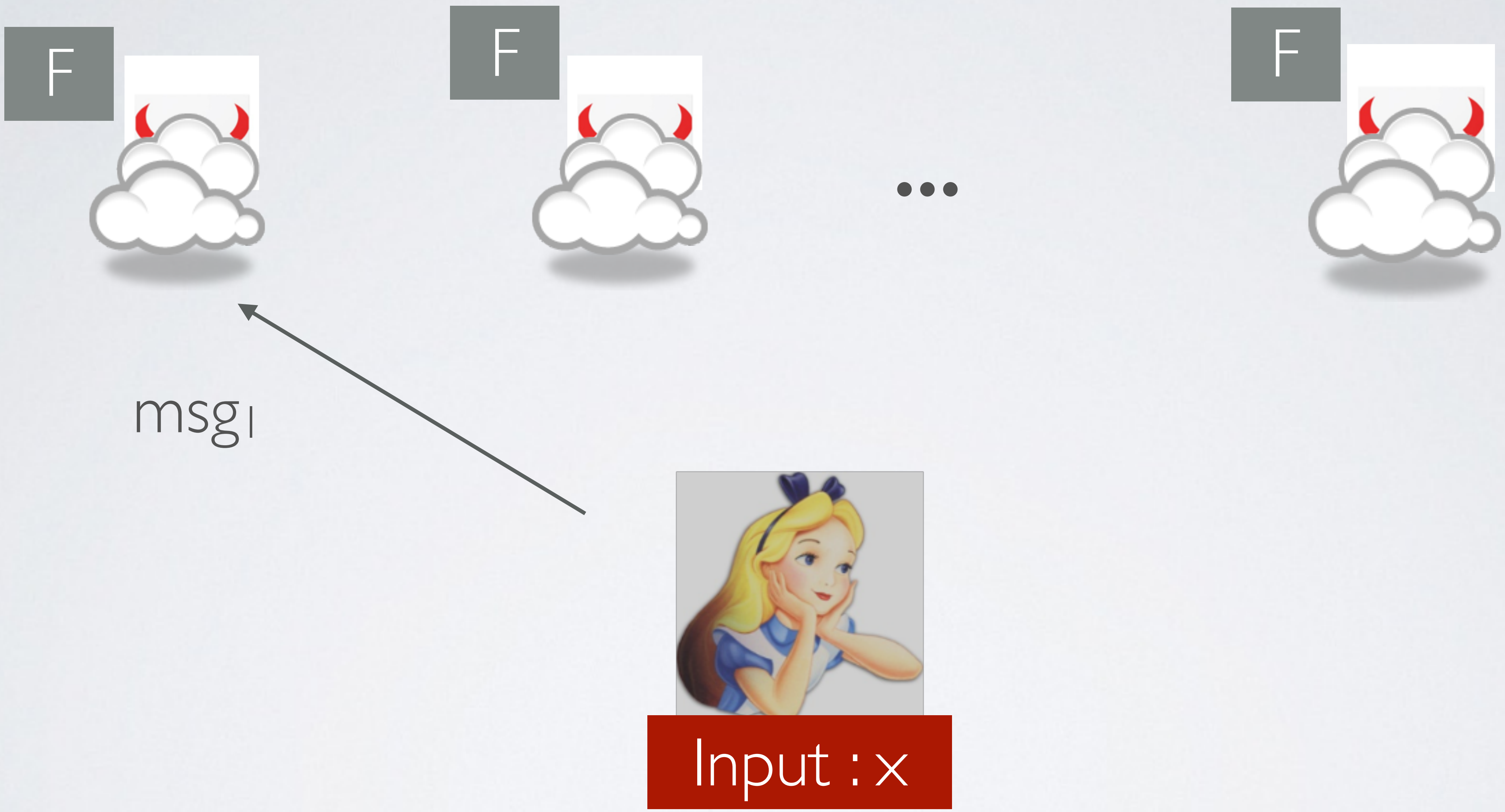

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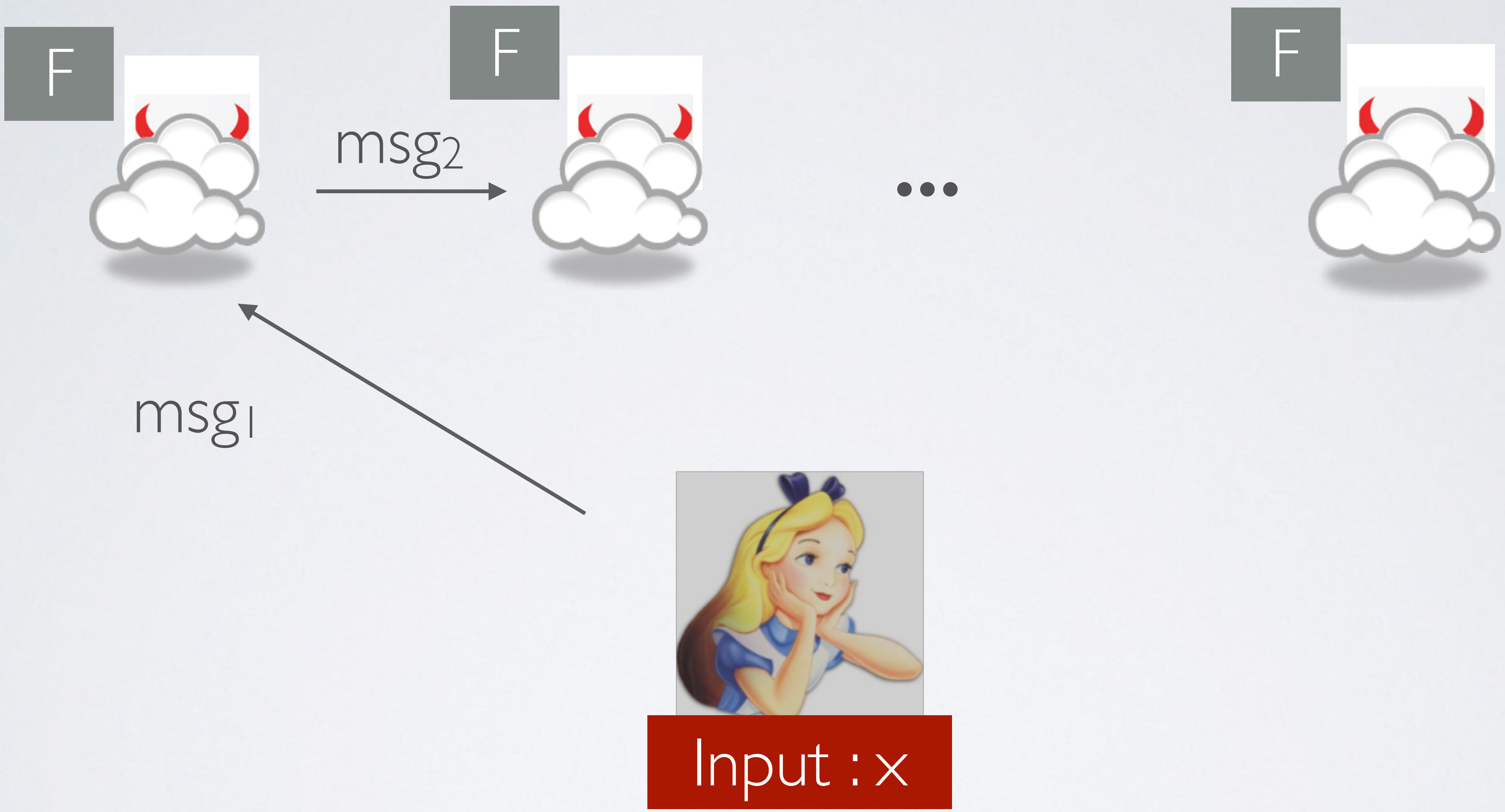

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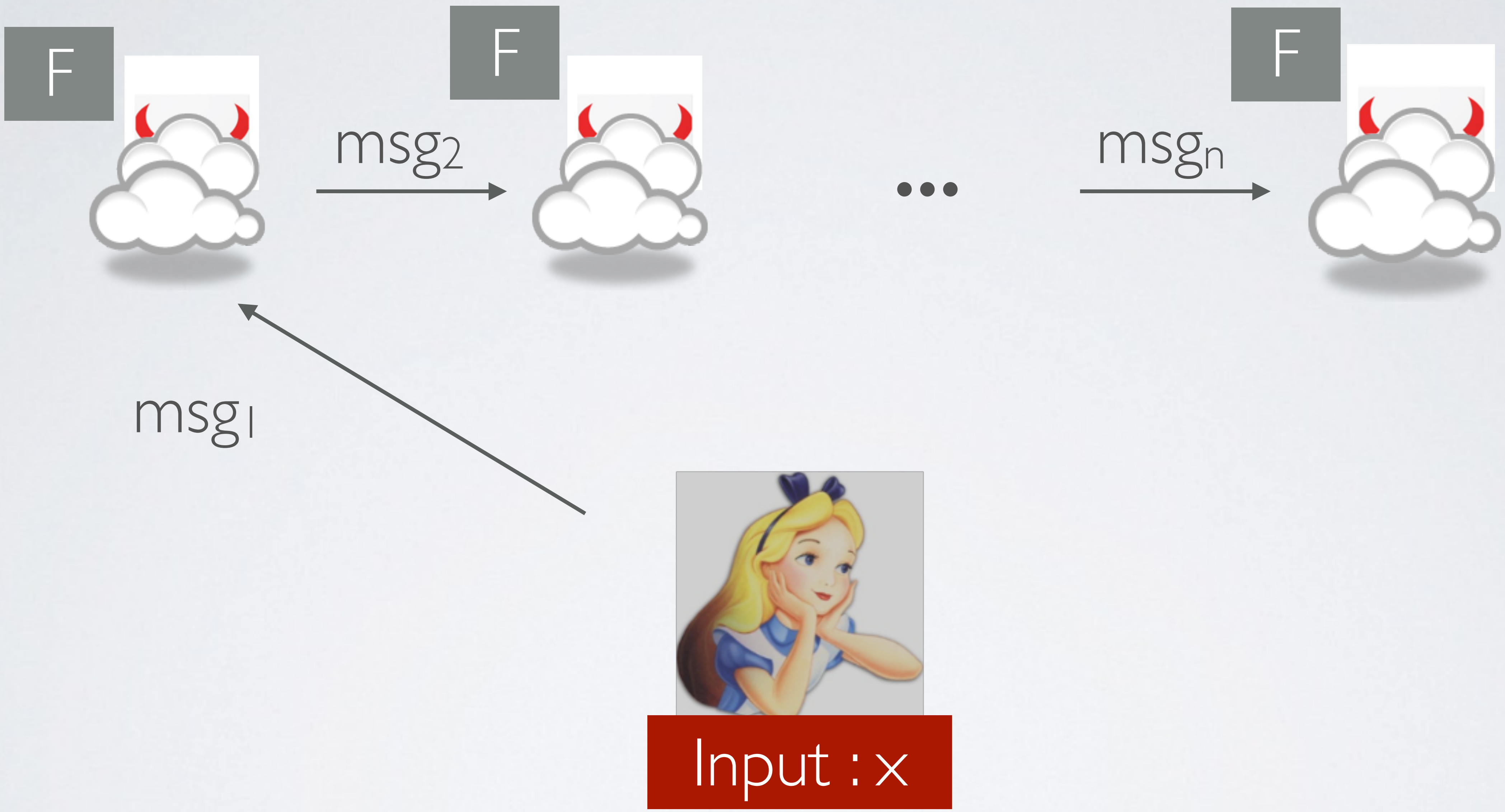

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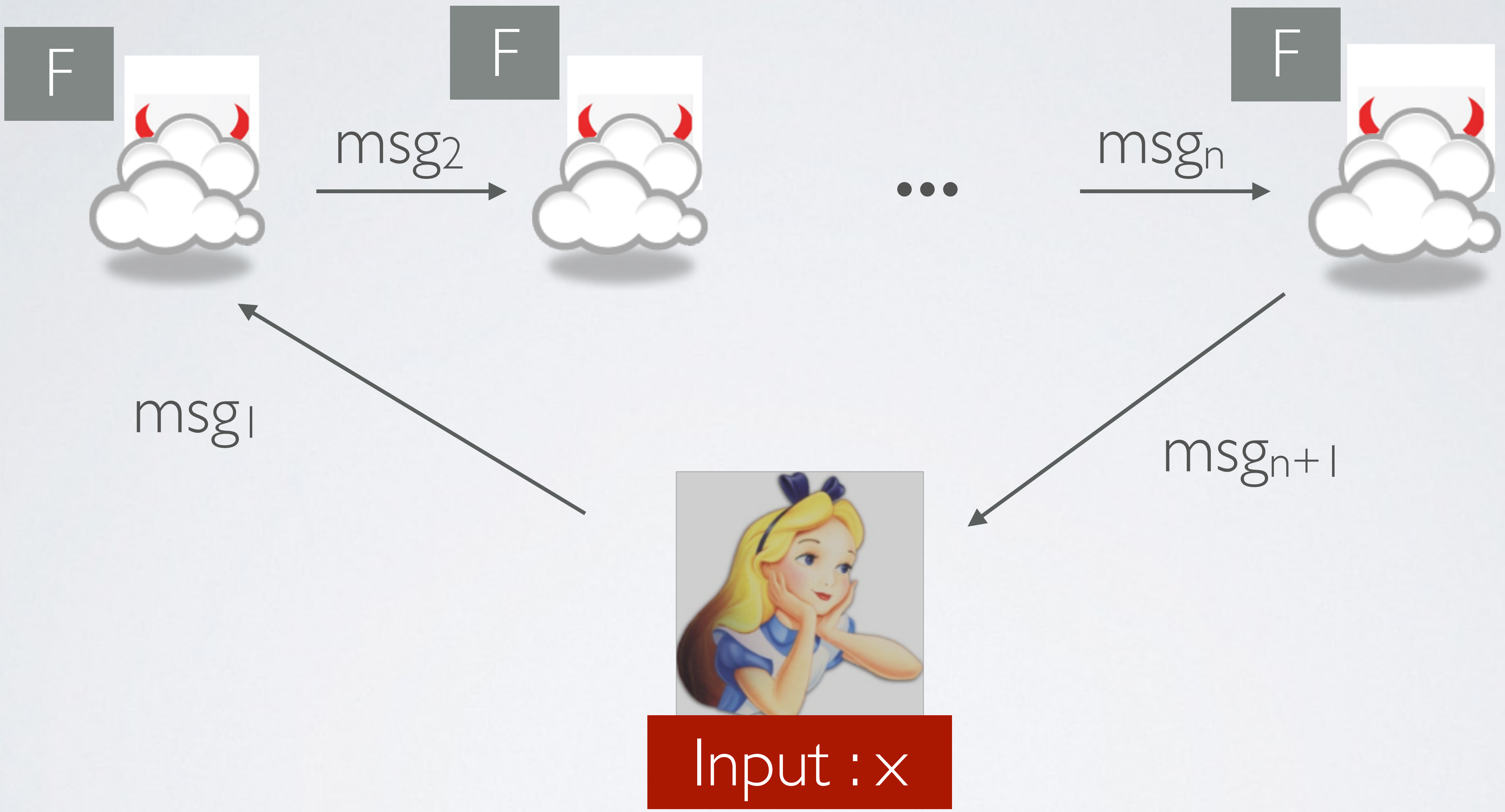

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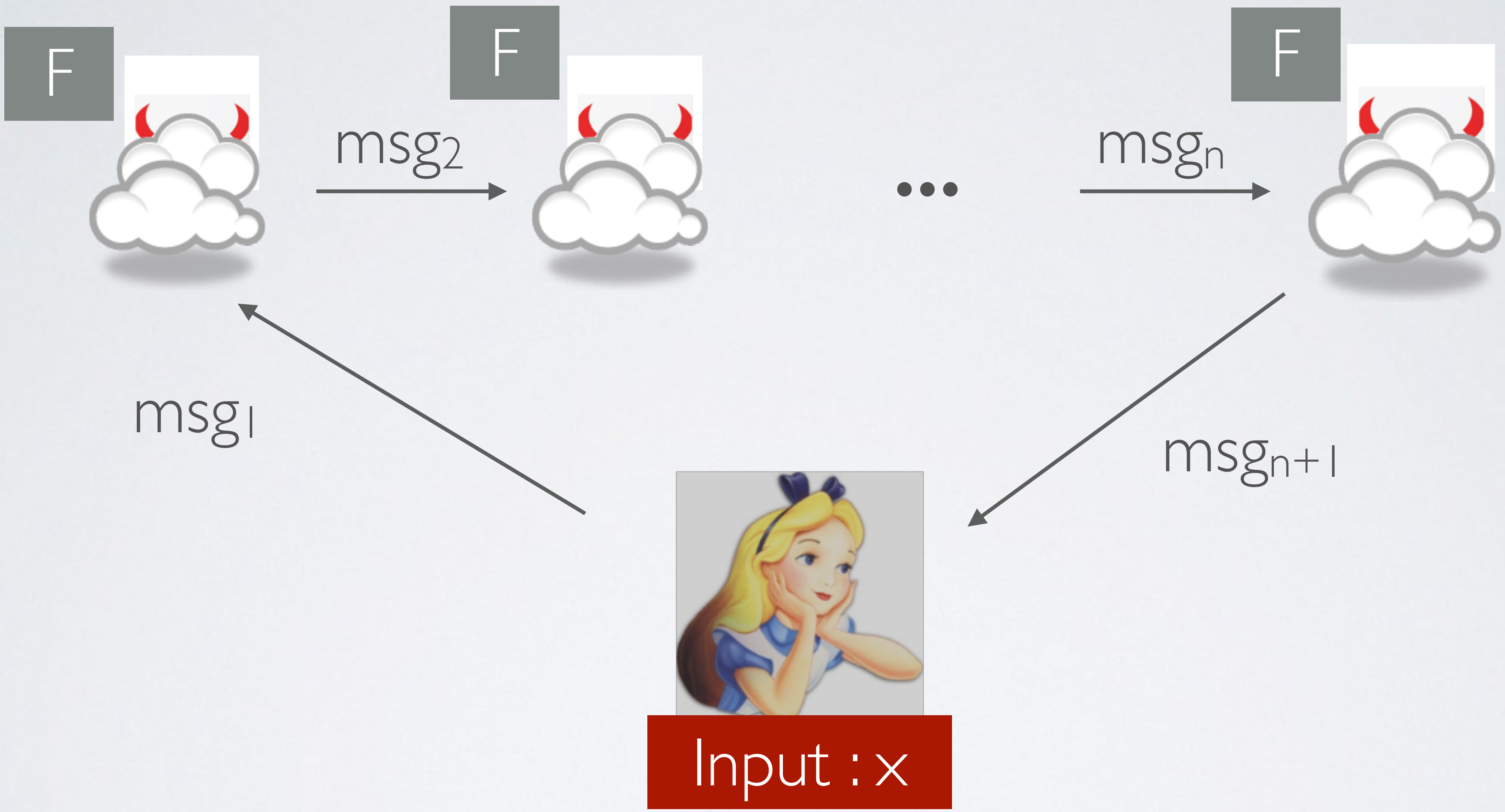

- Alice retrieves F(x) from msg_{n+1}

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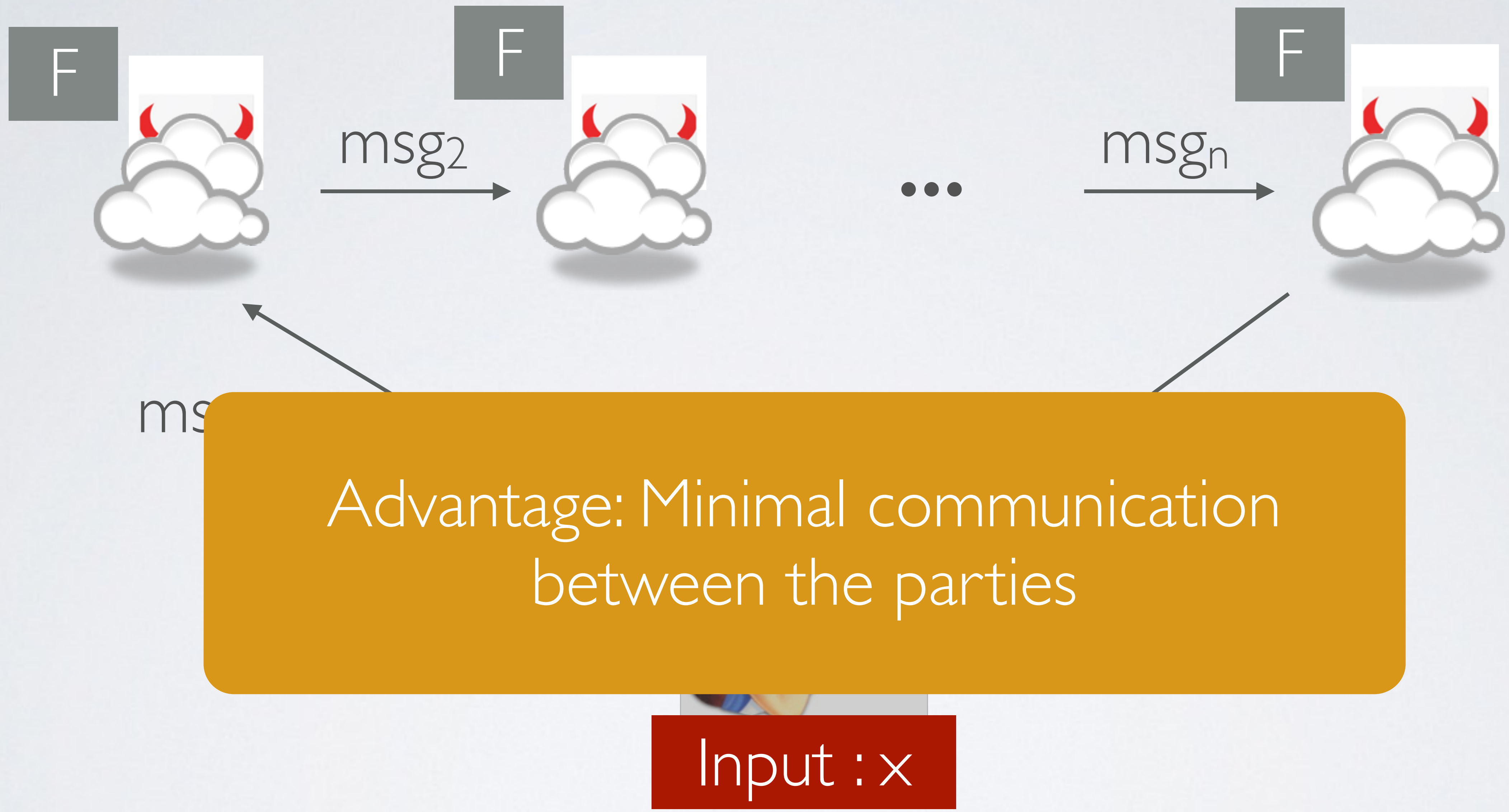
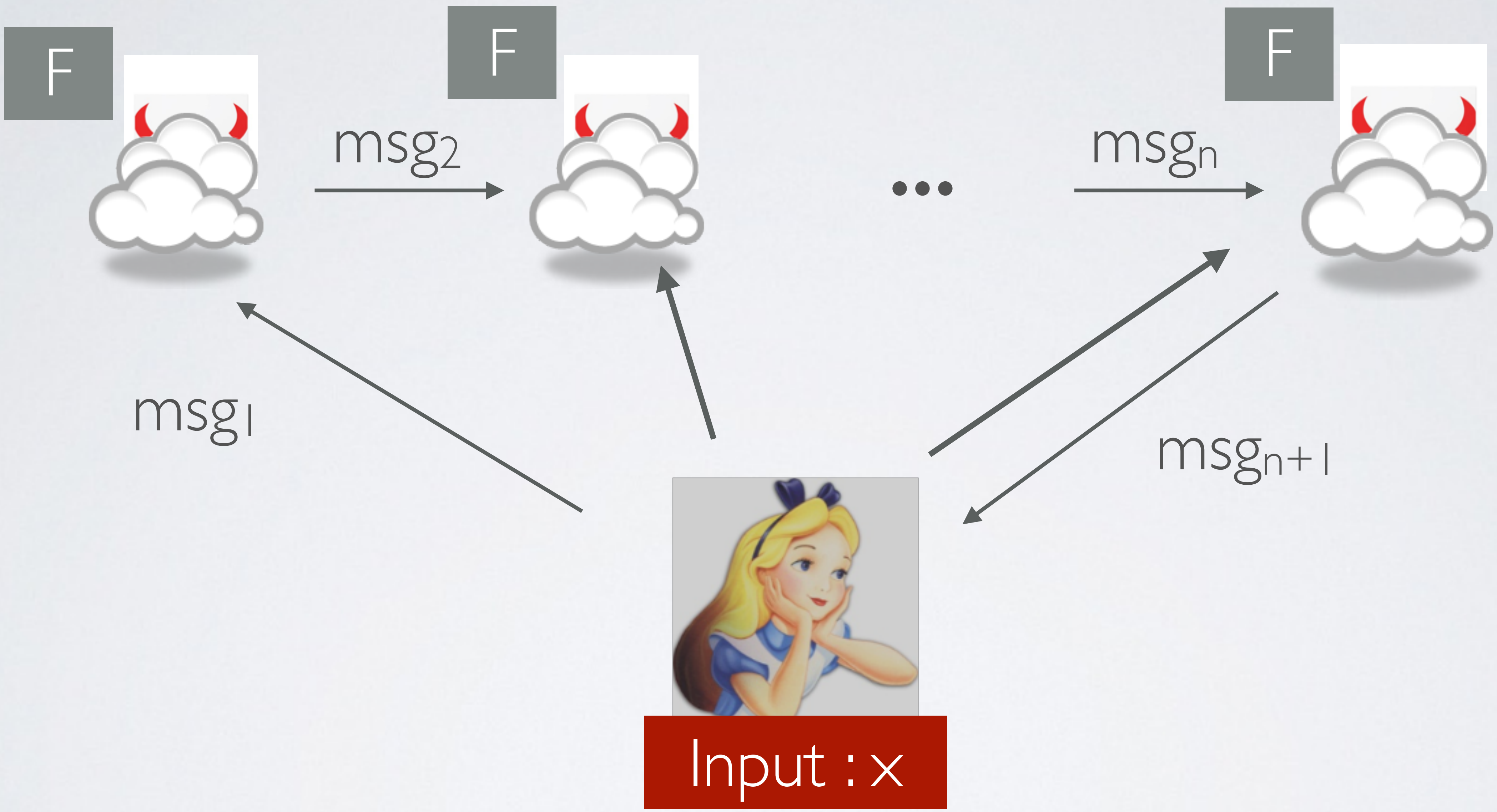


Advantage: Minimal communication between the parties

- Alice retrieves F(x) from msg_{n+1}

THIS TALK: EQUIVALENT MODEL



- Alice sends messages to intermediate servers

THIS TALK: EQUIVALENT MODEL

This is equivalent to the previous model:

- Client encrypts all the messages with public keys of servers
- Signs the ciphertexts
- Sends the ciphertexts to the first server.

- Alice sends messages to intermediate servers

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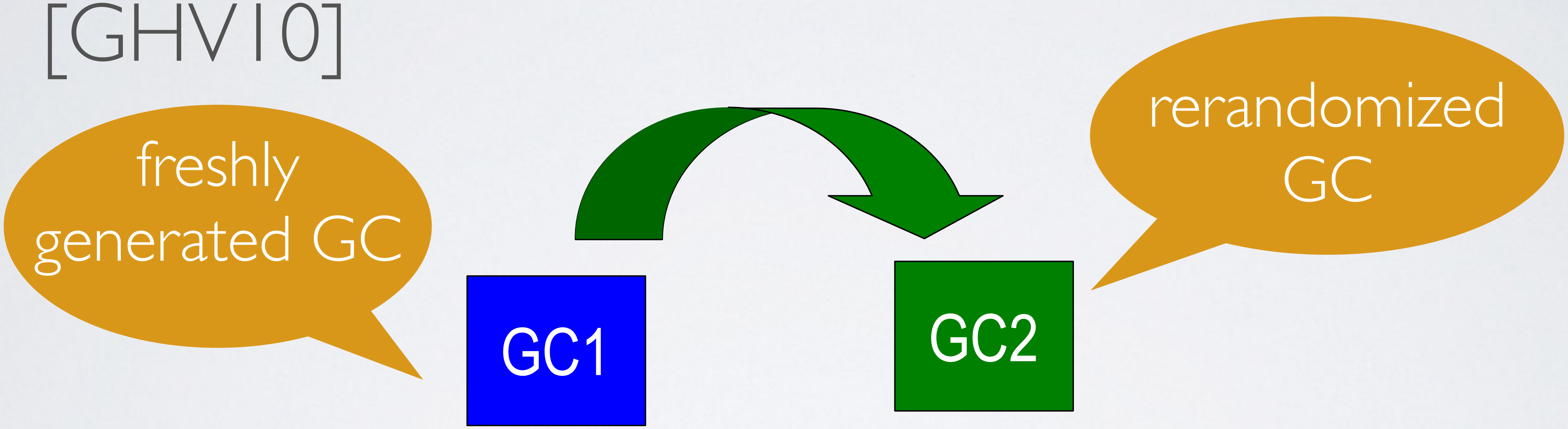

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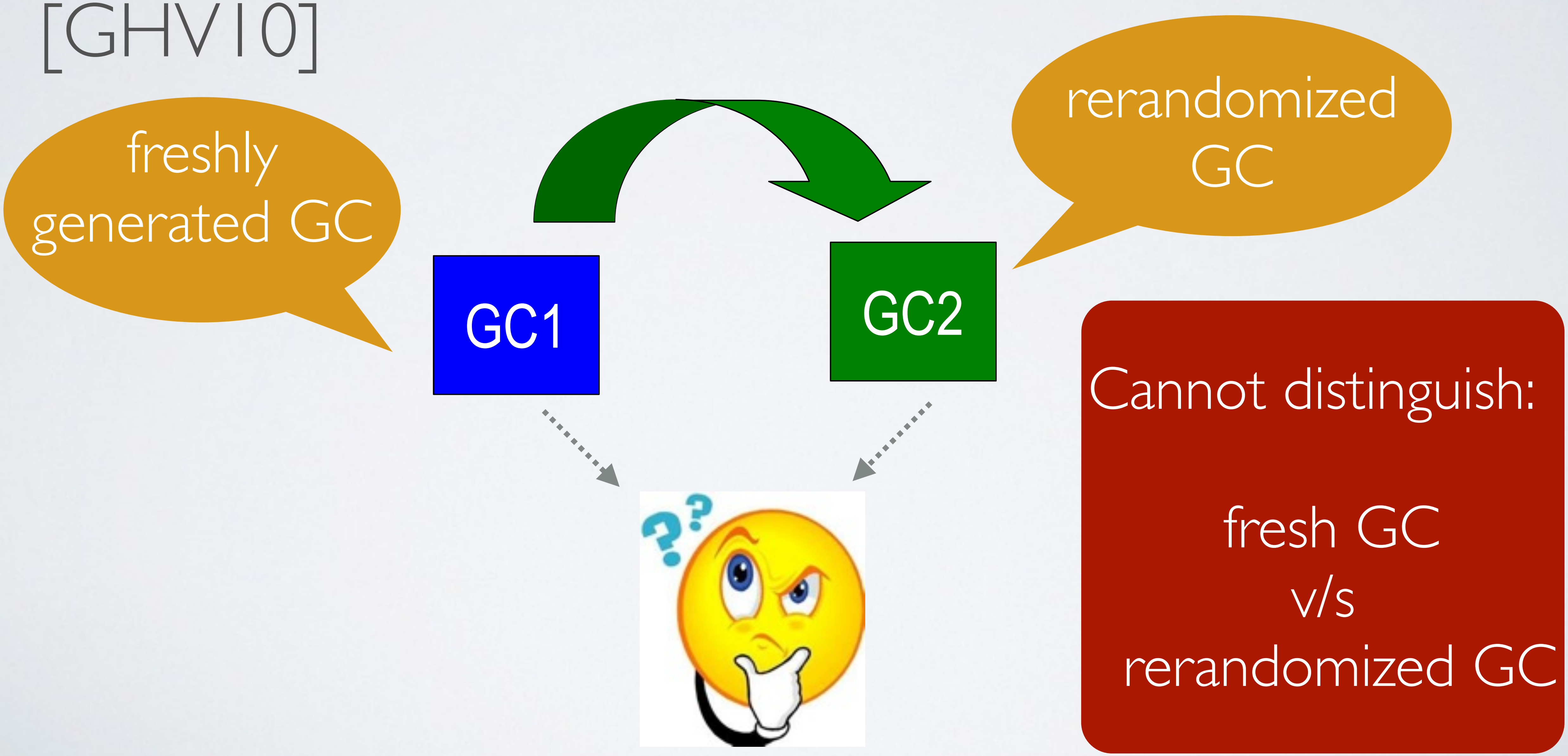

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Supports permutation and XOR

USING RERANDOMIZABLE GC

- First server: garbles the circuit F to obtain GC_1 and sends to second server.
- i^{th} server: rerandomizes the garbled circuit GC_{i-1} to obtain GC_i and sends to $i+1^{th}$ server.
- Last server: evaluates the garbled circuit to obtain F(x).

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wire keys supplied by the client

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  - Client gives PRF keys to the servers

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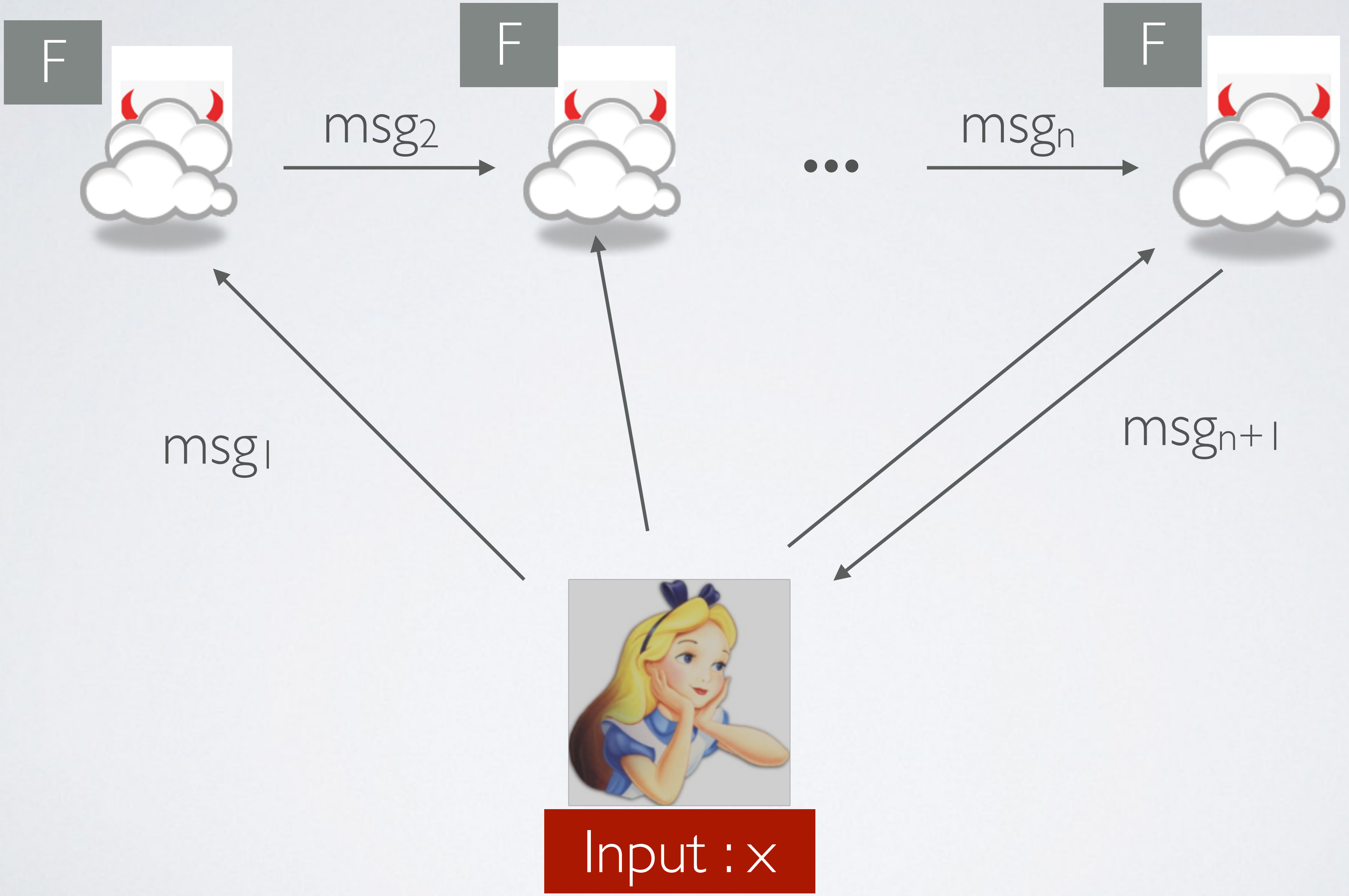

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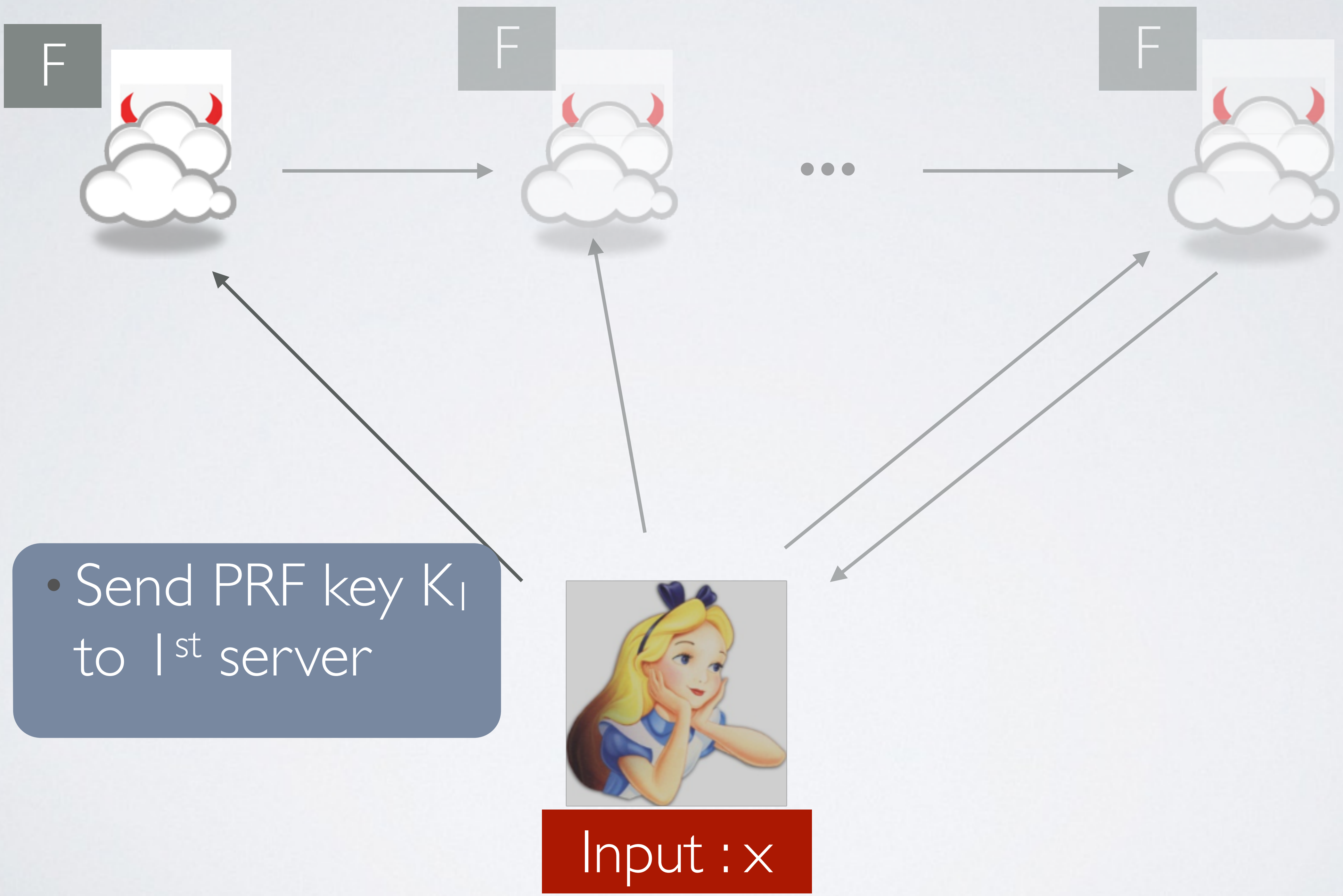

- Send PRF key K_1 to 1^{st} server

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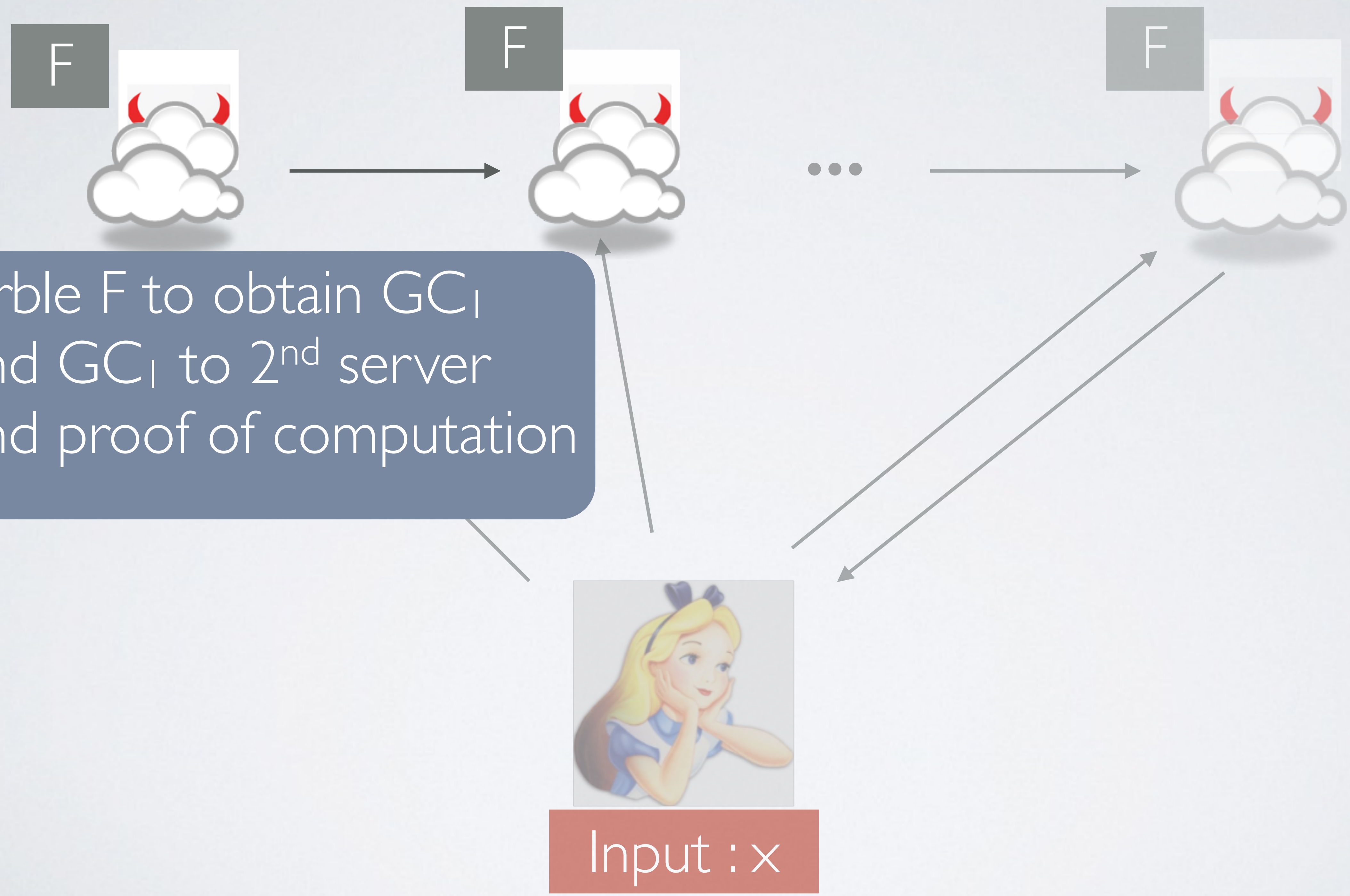

- Garble F to obtain GC_1
- Send GC_1 to 2^{nd} server
- Send proof of computation

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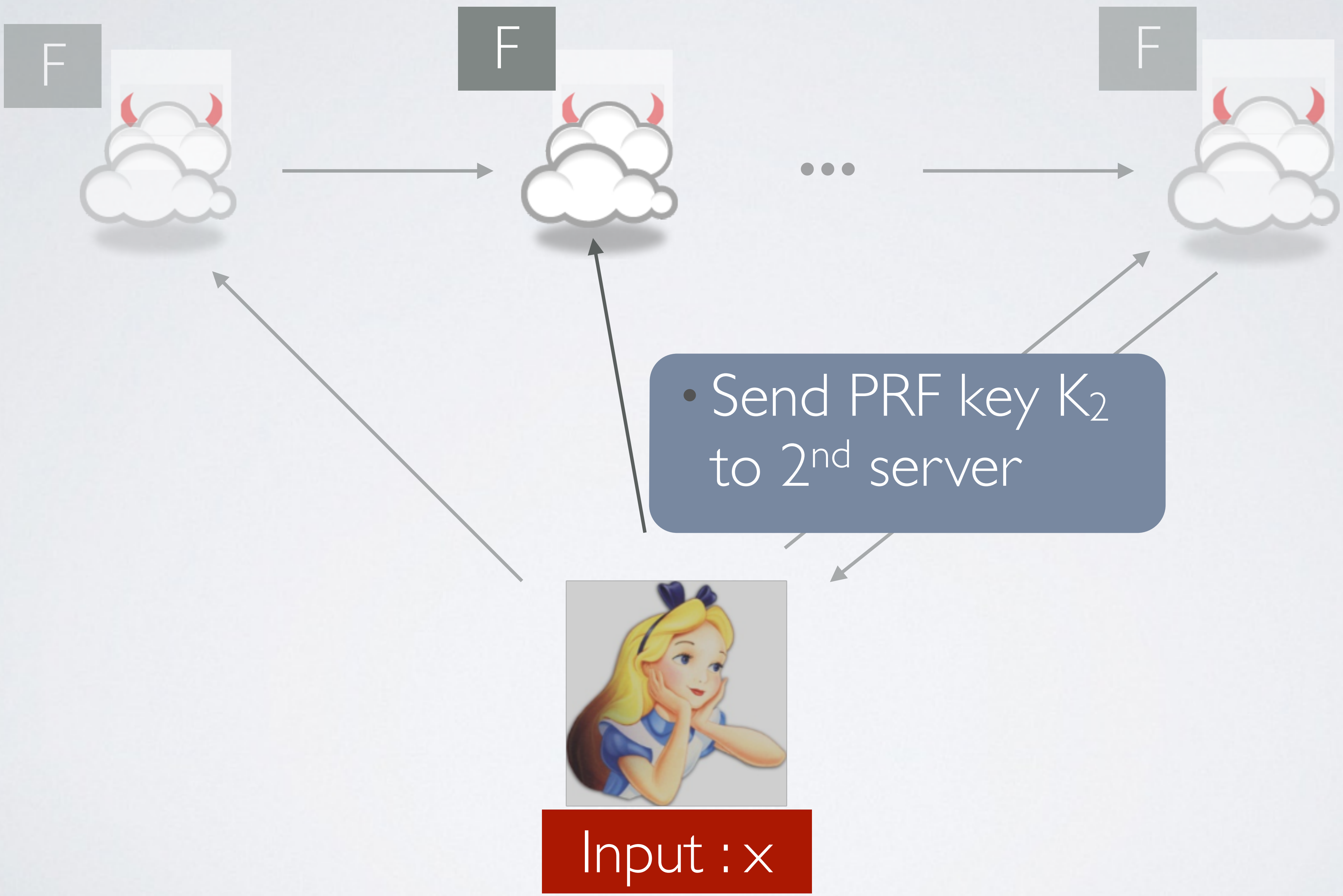

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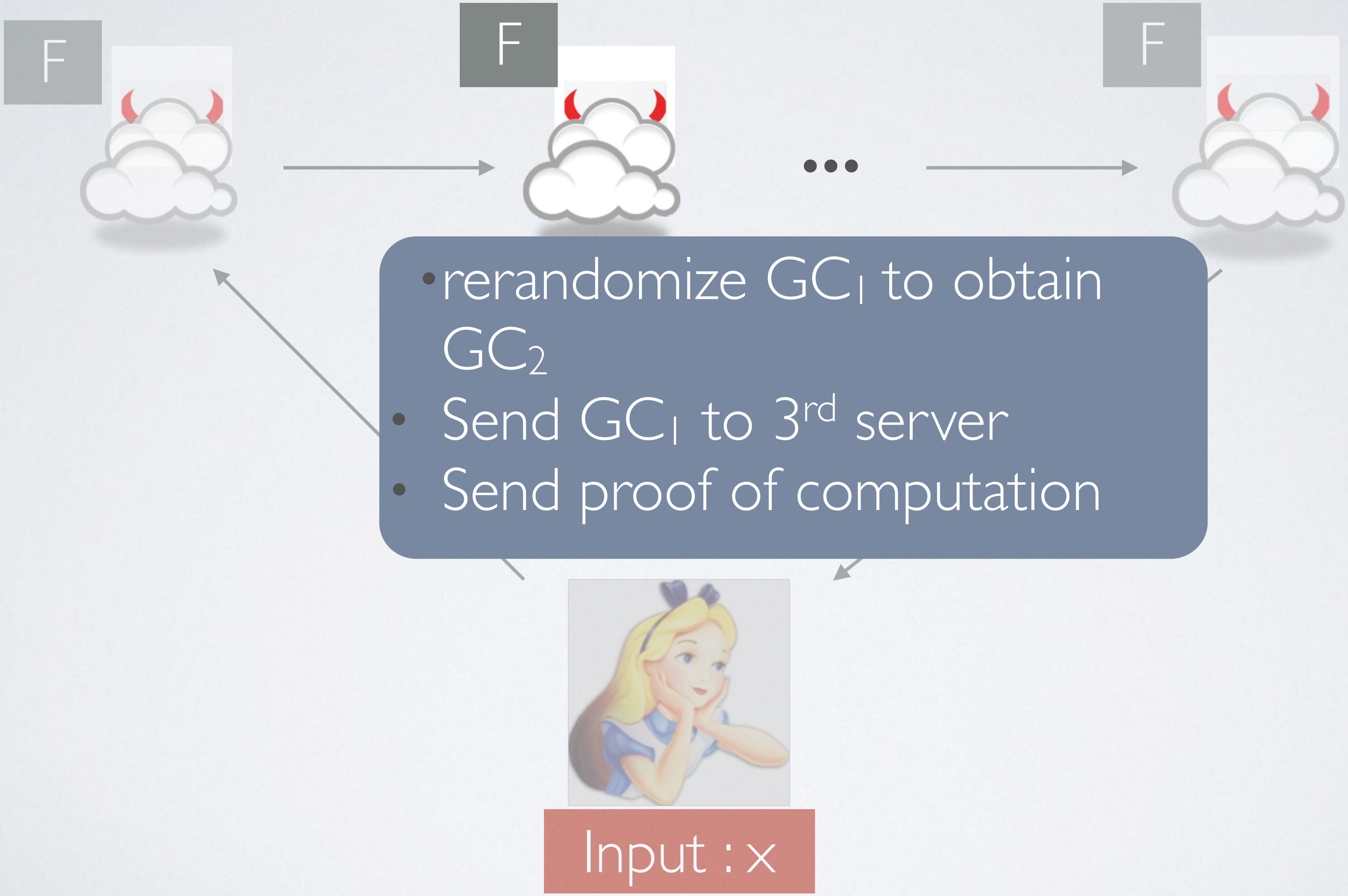

- rerandomize GC_1 to obtain GC_2
- Send GC_1 to 3rd server
- Send proof of computation

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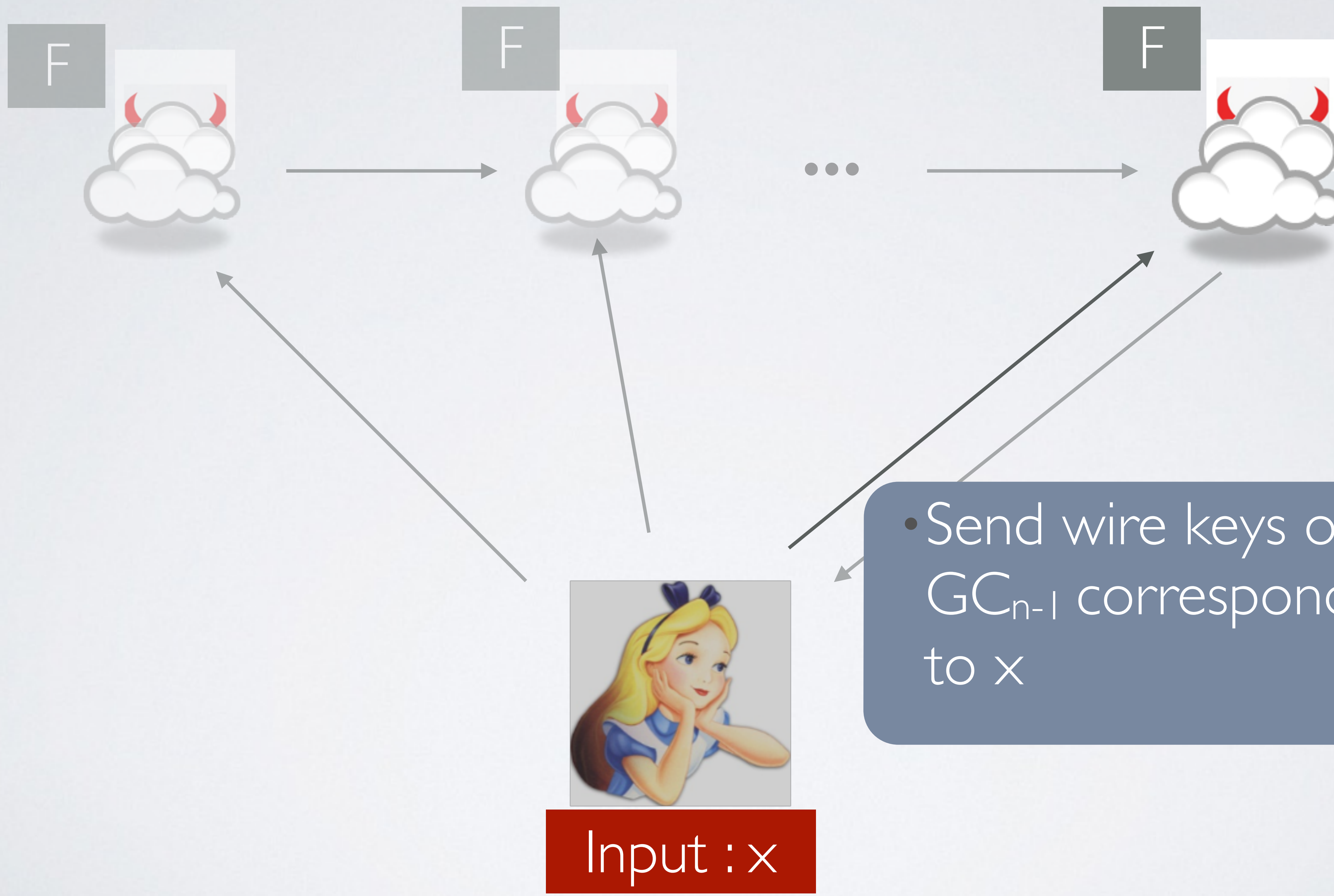

- Send wire keys of GC_{n-1} corresponding to x

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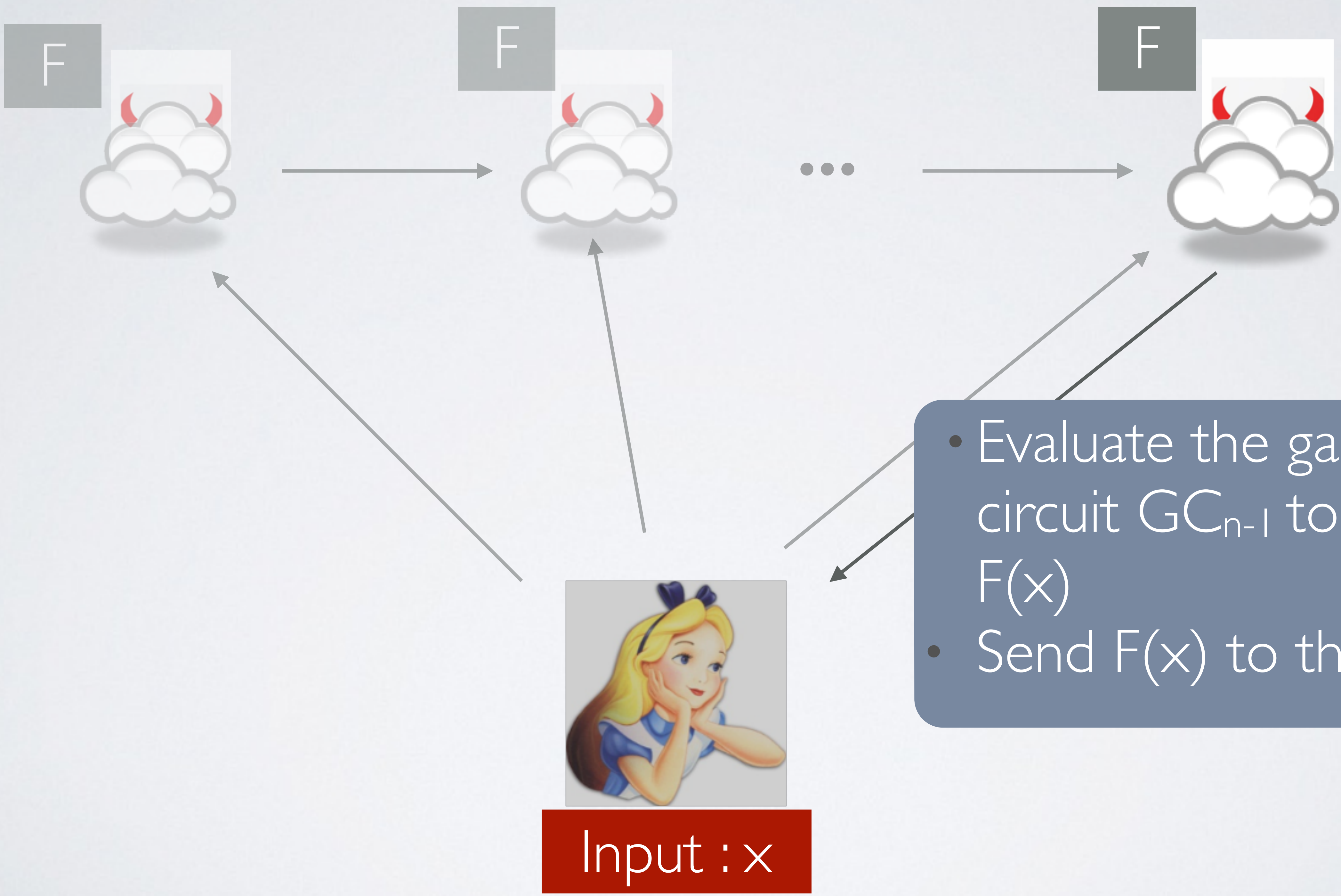

- Evaluate the garbled circuit GC_{n-1} to obtain F(x)
- Send F(x) to the client

OUR CONSTRUCTION: PROPERTIES

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OUR CONSTRUCTION: PROPERTIES

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The last server might send an incorrect value as F(x)

ENSURING VERIFIABILITY

- Consider the function $G(\cdot,\cdot)$:

$$G(x,K) \text{ outputs } \big(F(x), MAC(K,F(x))\big)$$

ENSURING VERIFIABILITY

- Consider the function G(·,·):

$$G(x,K) \text{ outputs } \big(F(x), MAC(K,F(x))\big)$$

- Modify our construction as follows:

  - Garble G(·,·) instead of F

  - Client sends wire keys corresponding to x and K instead of just x

REMARK ON CLIENT COMPLEXITY

- Client complexity depends on the number of servers

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Using preprocessing: generate all PRF keys during preprocessing phase

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???

IMPROVING CLIENT COMPLEXITY

- Warmup attempt: Using encryption scheme having homomorphic properties.

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Supporting permutation and XOR operations.

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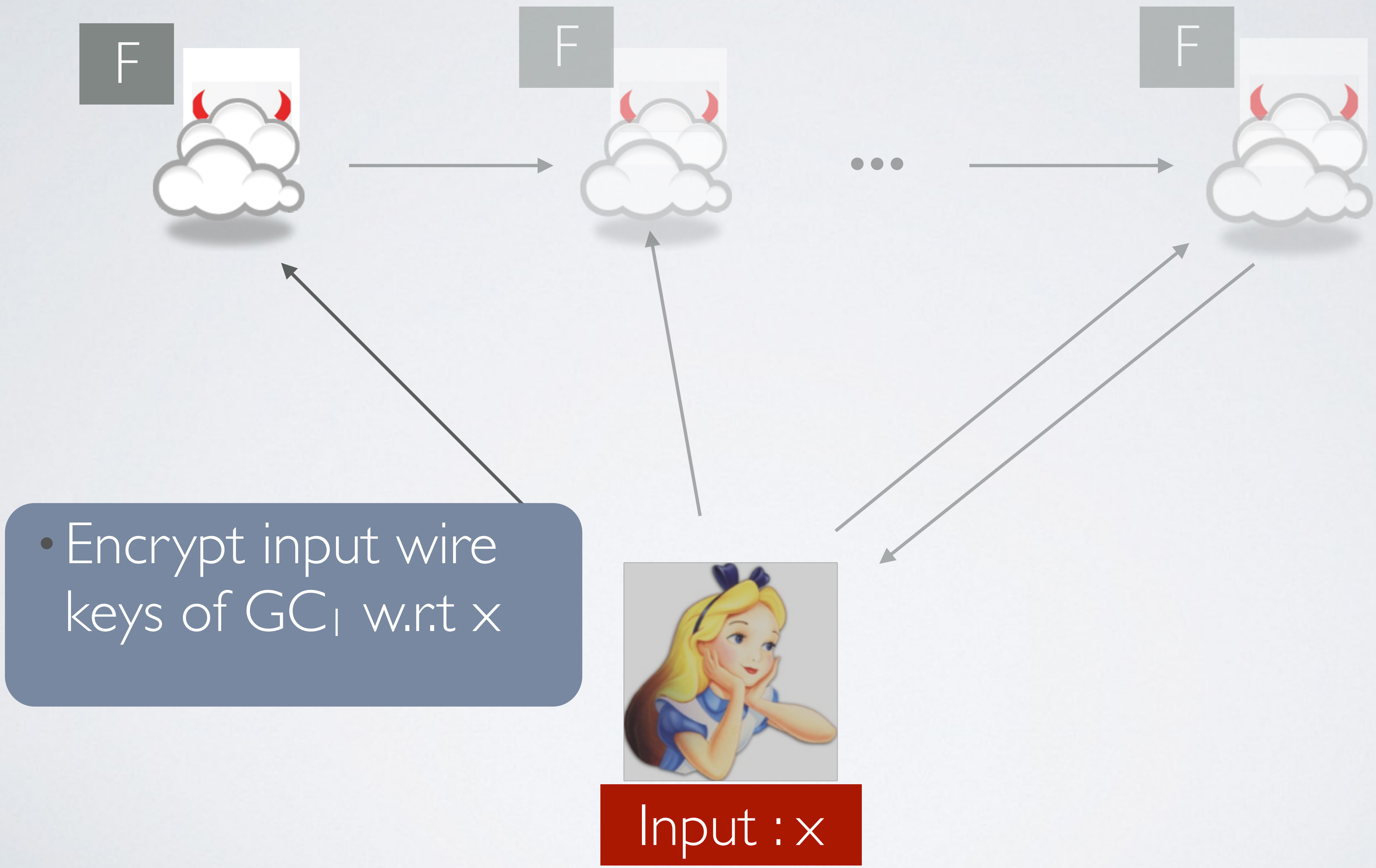

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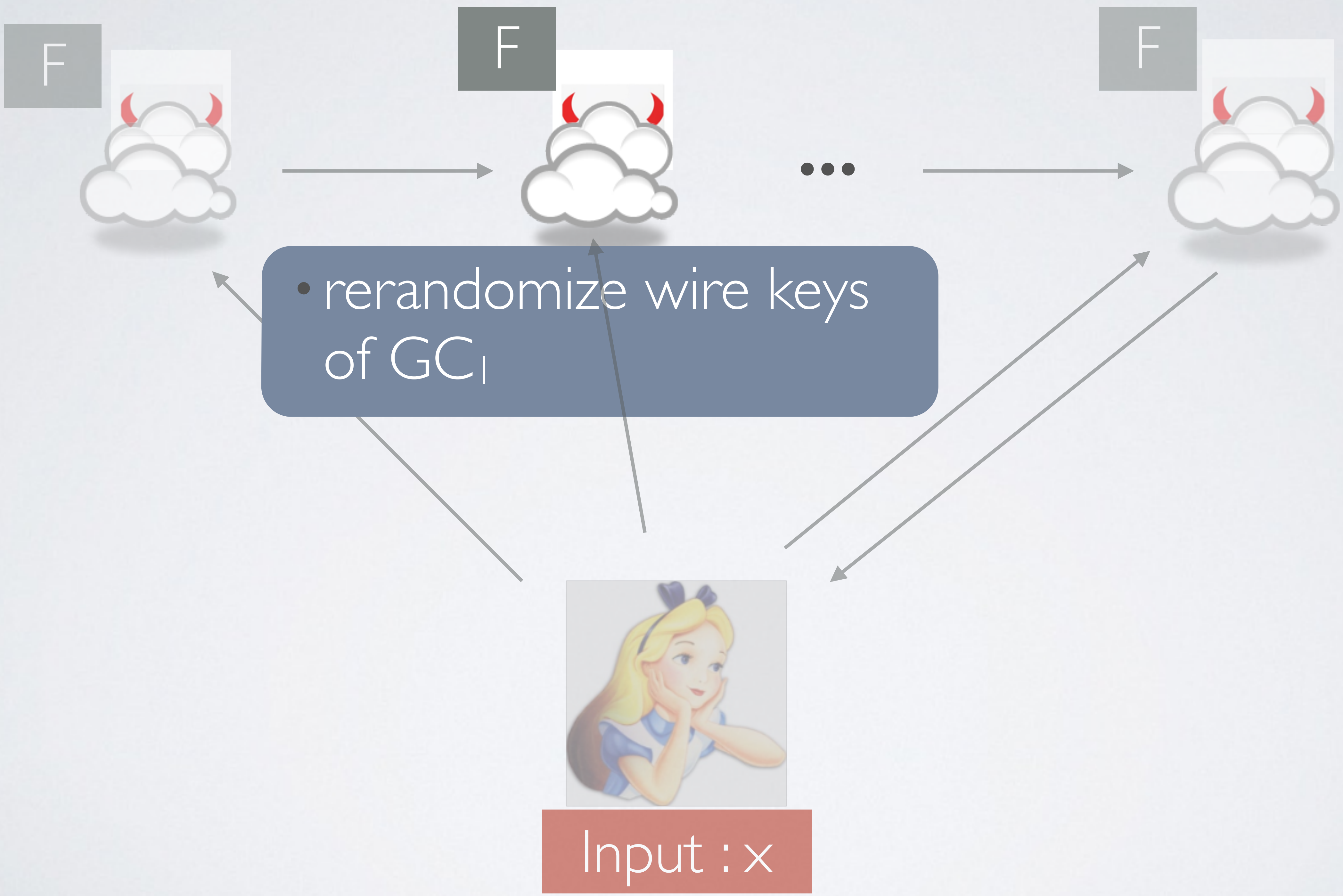

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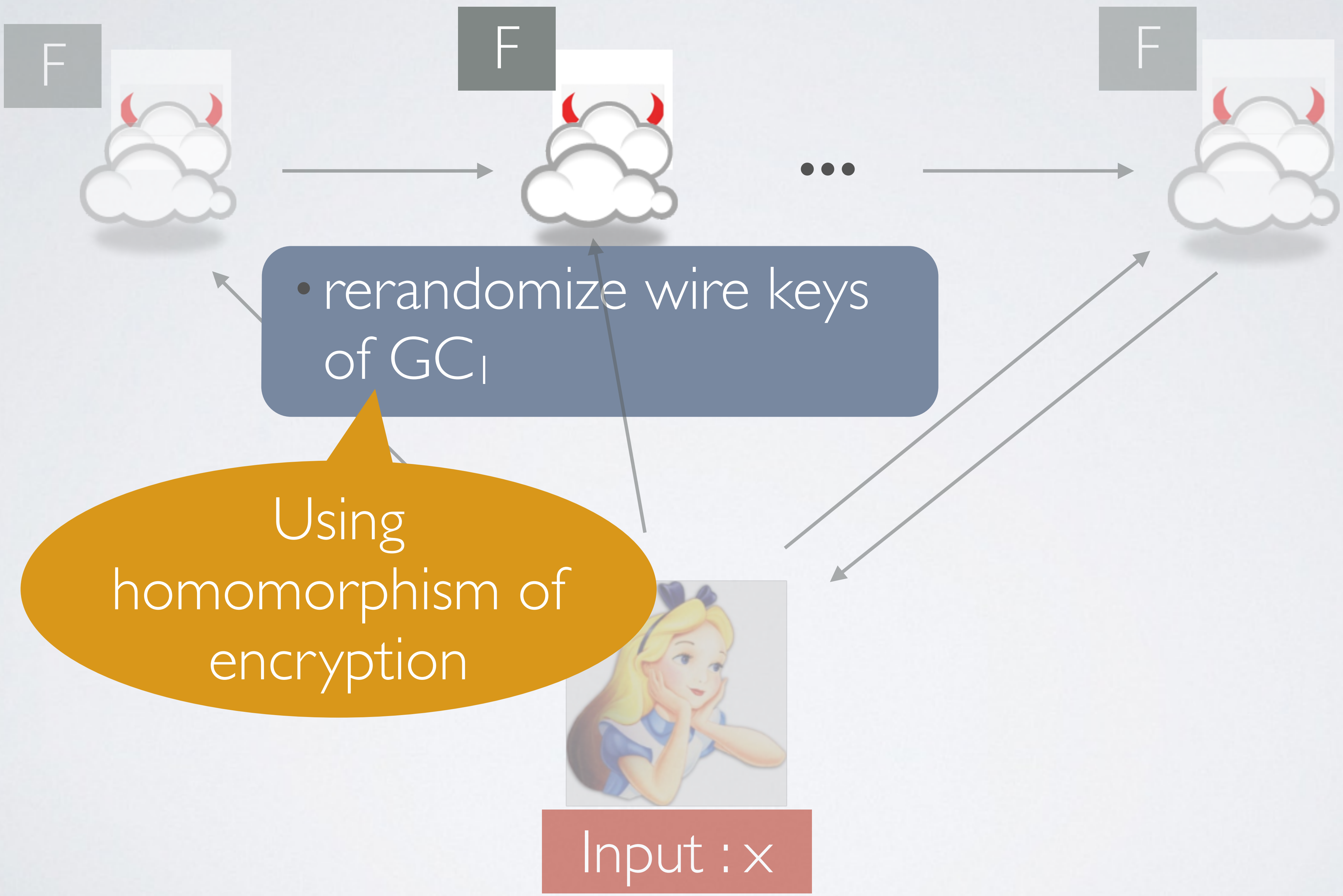

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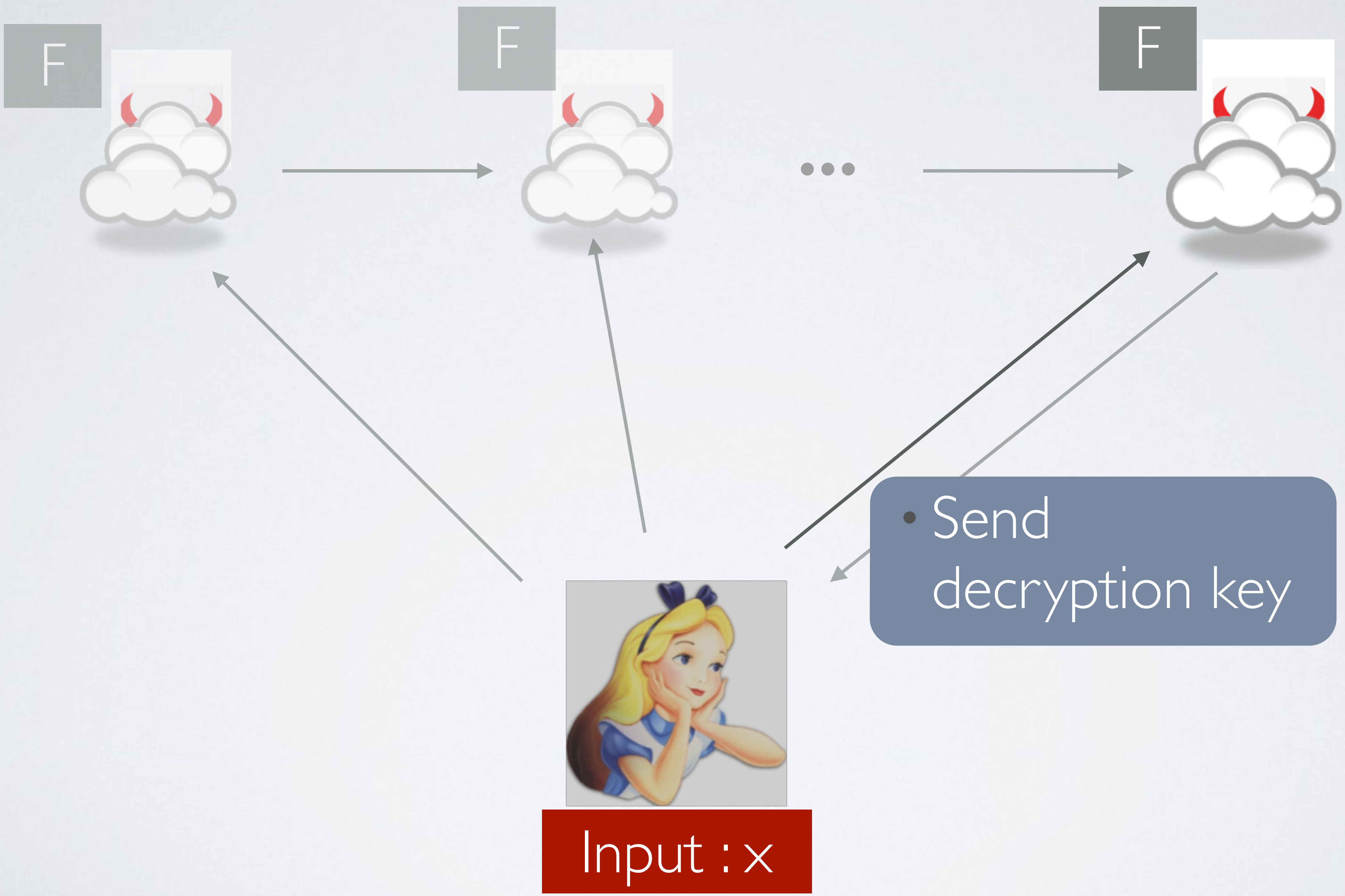

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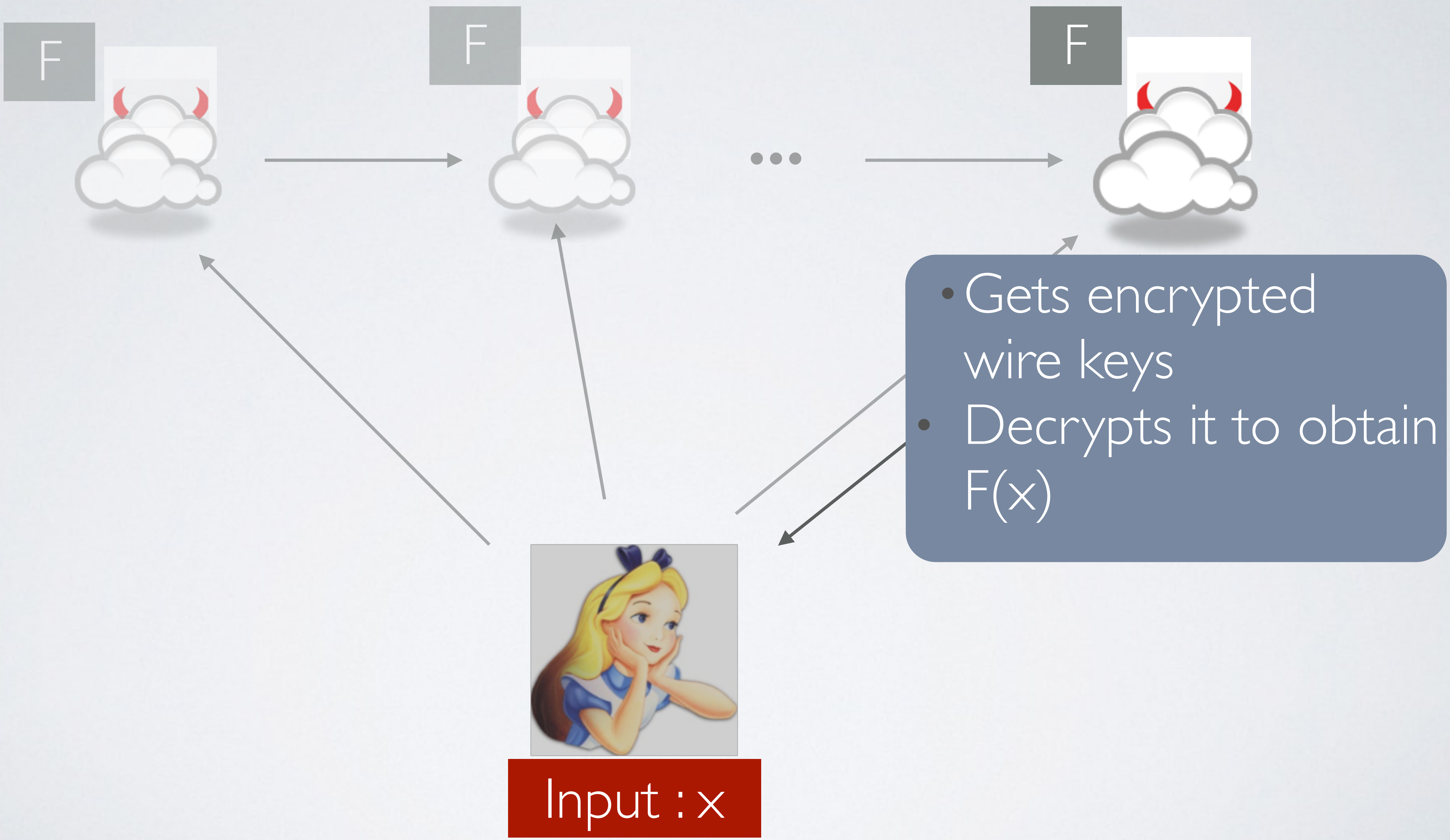

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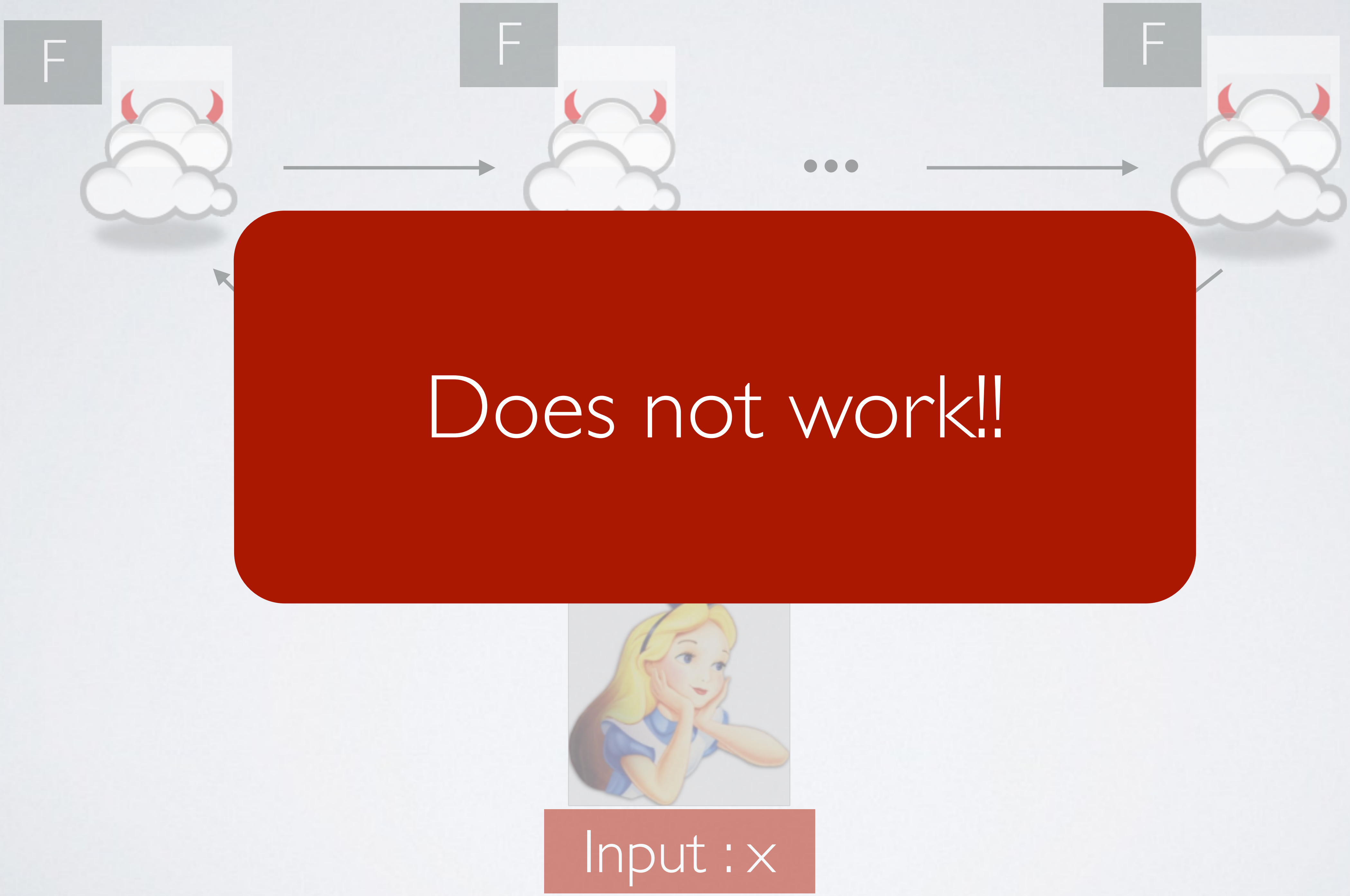

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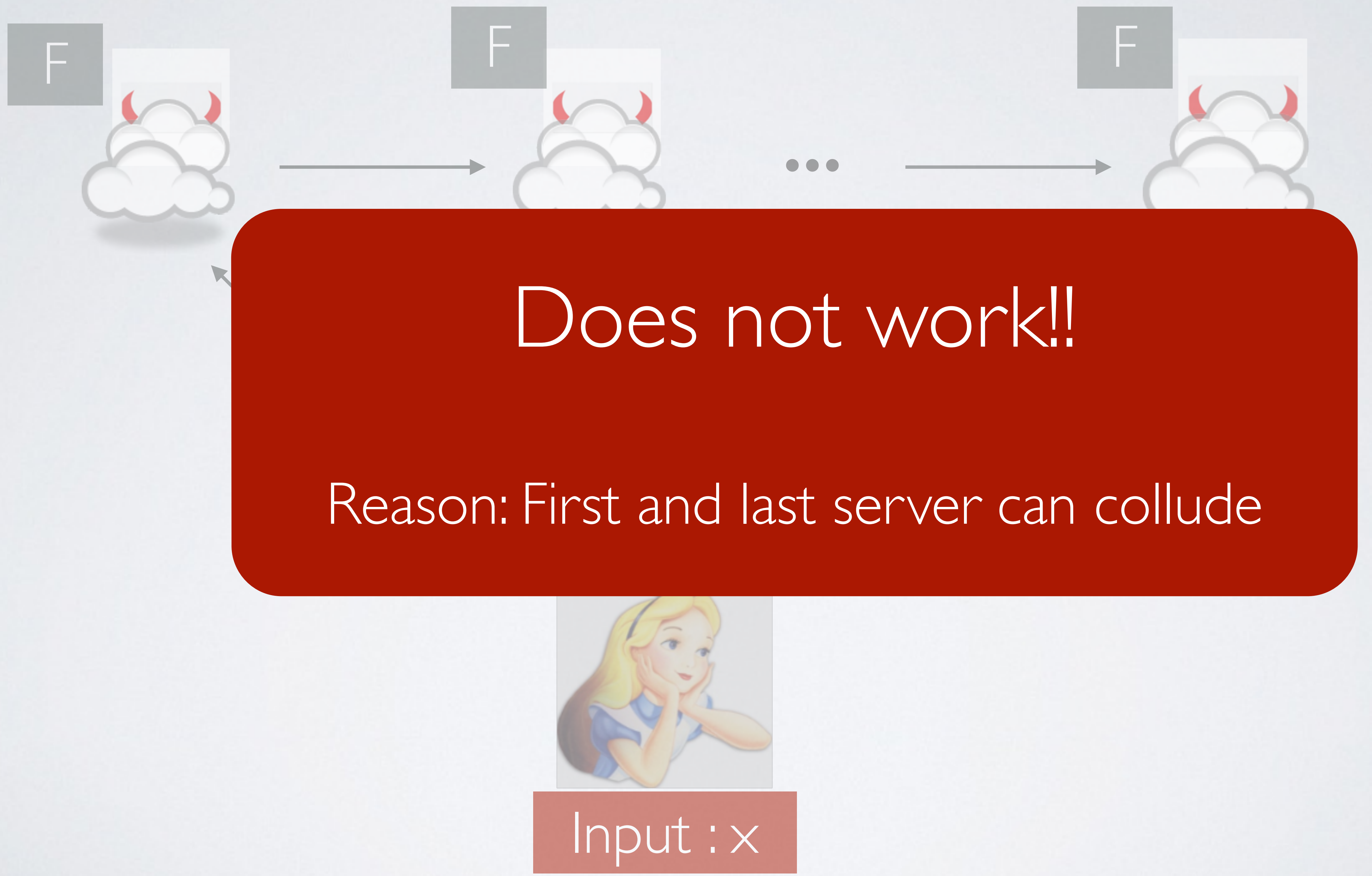

Does not work!!

Reason: First and last server can collude

FIXING THE CONSTRUCTION

- Use re-encryption!

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FIXING THE CONSTRUCTION

- Use re-encryption! : can re-encrypt a ciphertext corresponding to a different public key.

Details in the paper!

- We use an encryption scheme that supports re-encryption and homomorphism.

OPEN PROBLEMS

- Replacing NIZKs in our construction.
- VC protocol in the multiple-server model based on one-way functions?
- More efficient VC protocols for specific functions?

QUESTIONS?

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THANKS!