Leakage-Resilient Circuits Revisited

-- Optimal Number of Computing Components without Leak-free Hardware

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Joint work with

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University of Maryland


TCC Test-of-Time Award

The *TCC Test of Time Award* recognizes outstanding papers, published in TCC at least eight years ago, making a significant contribution to the influence also in other area of cryptography, theory, and beyond. The inaugural TCC Test of Time Award was given in TCC 2015 for papers pu

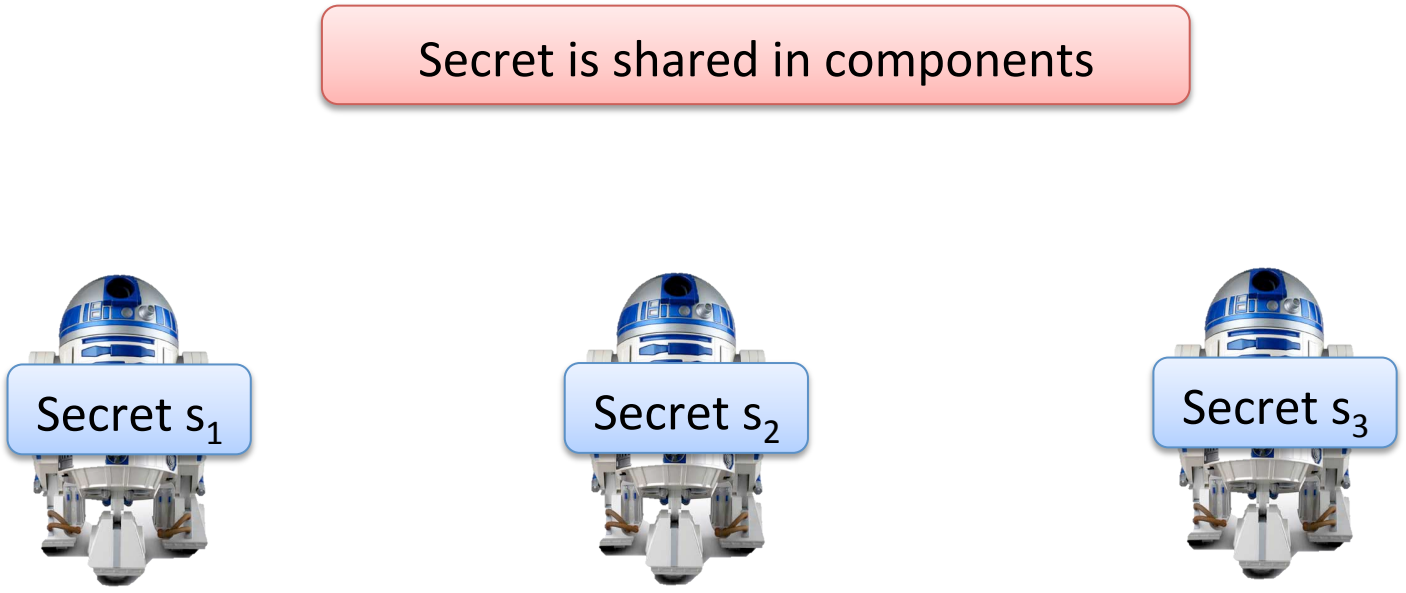
Award Recipients

2015:

- Physically Observable Cryptography by Silvio Micali (MIT) and Leonid Reyzin (Boston University), which was published in TCC 2004 award *for pioneering a mathematical foundation of cryptography in the presence of information leakage in physical systems*.

Only Computation Leaks (OCL) [MR]

- Idea: computation is performed by multiple components, where only the active ones are leaky.



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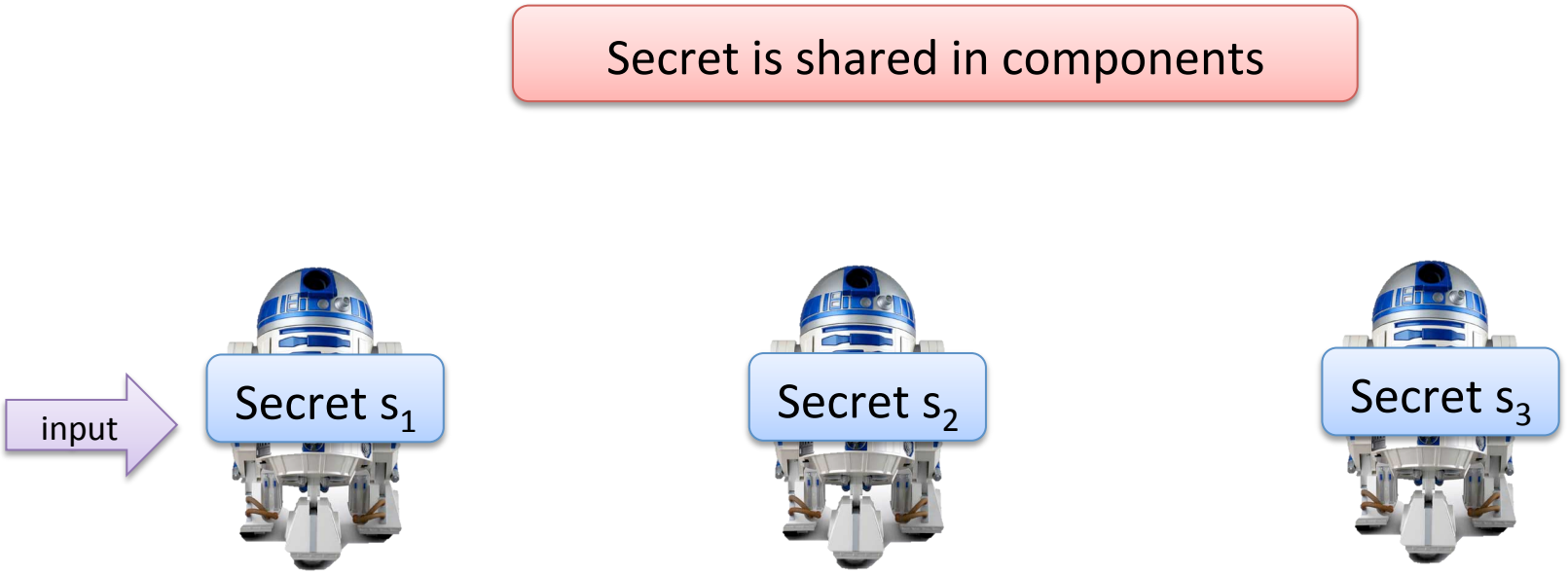

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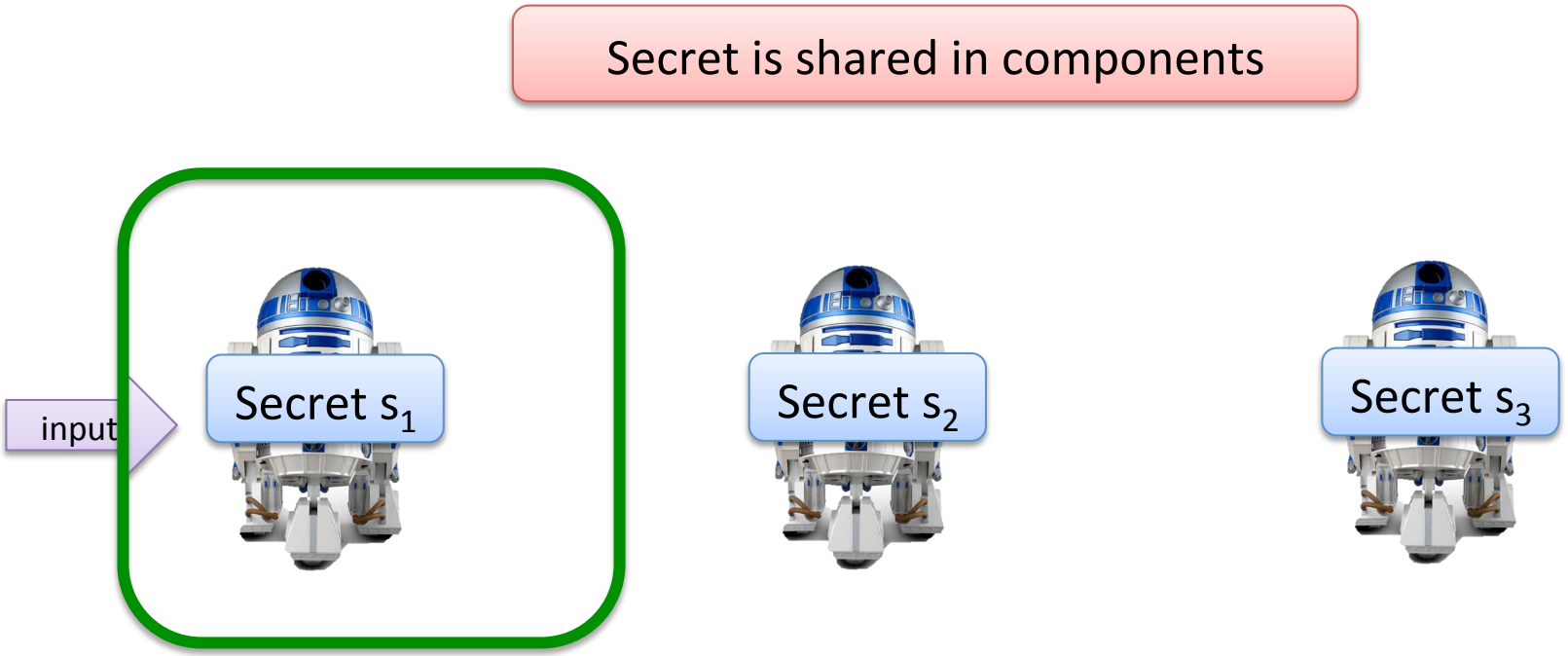

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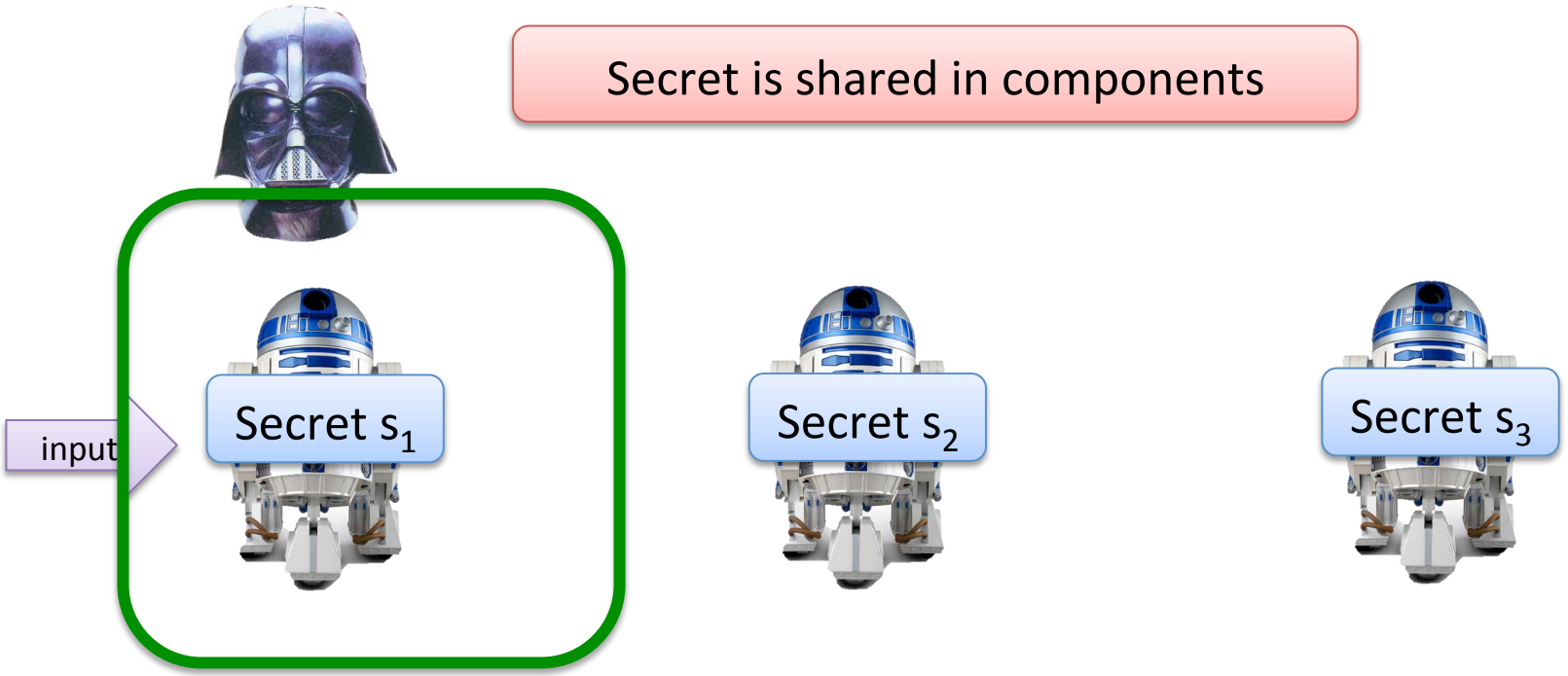

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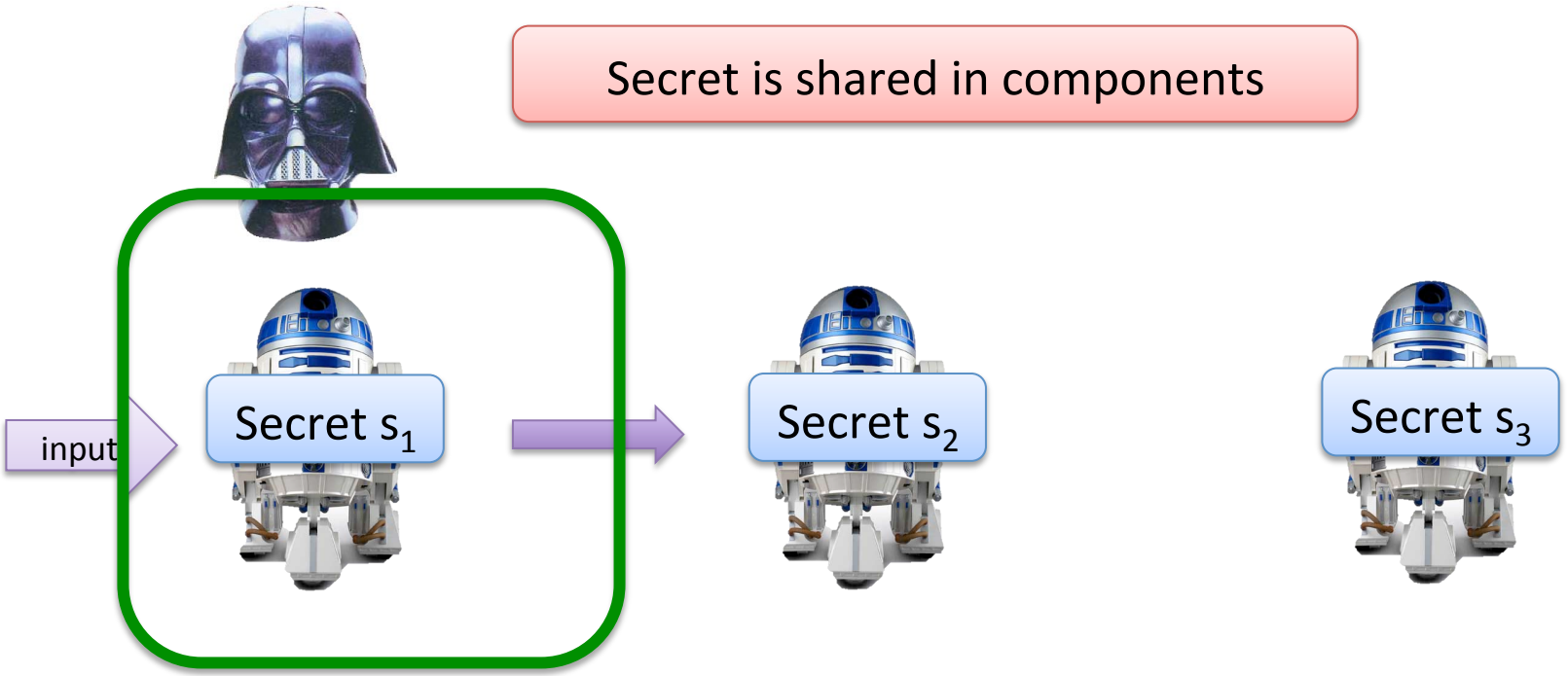

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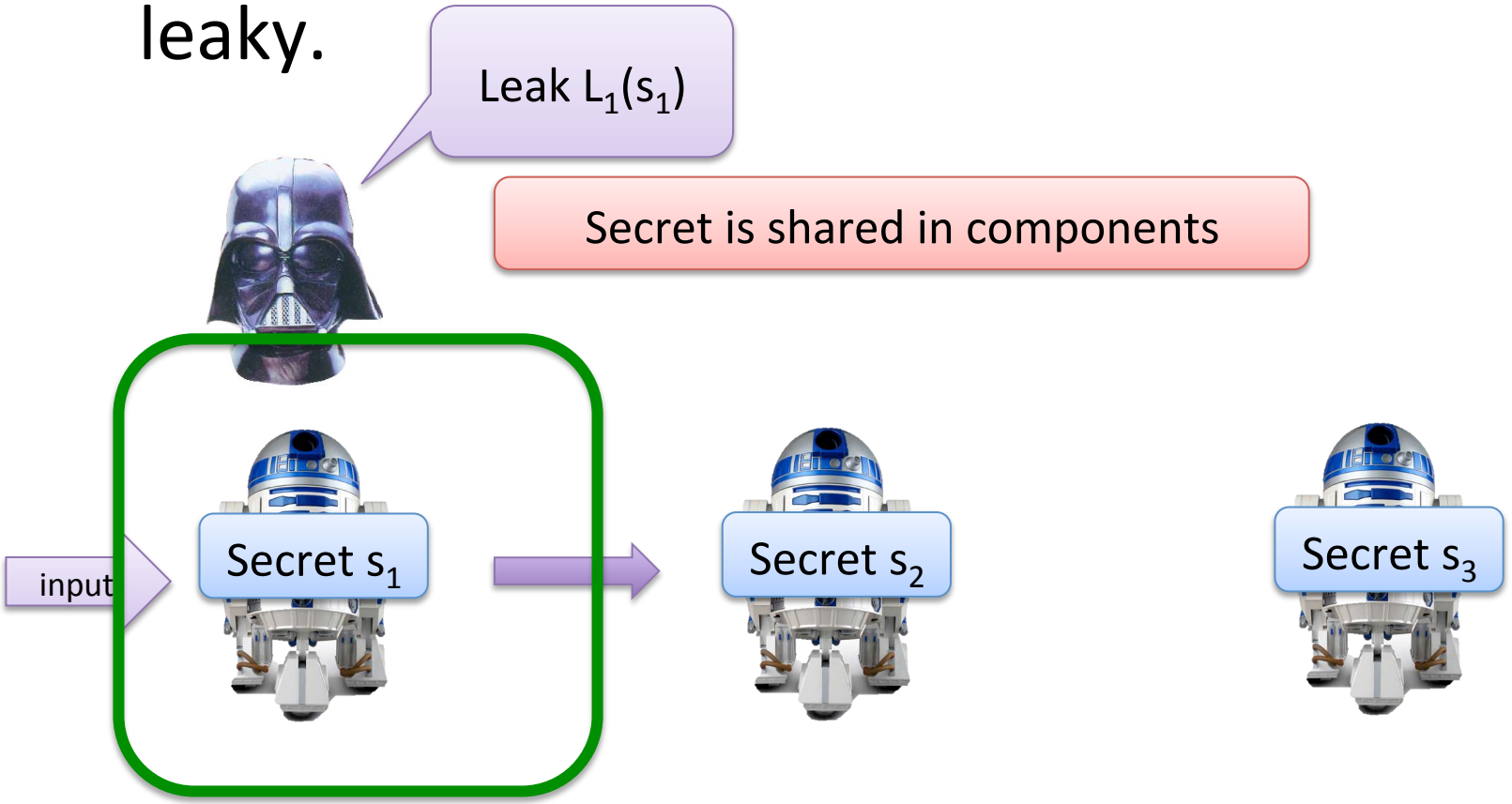

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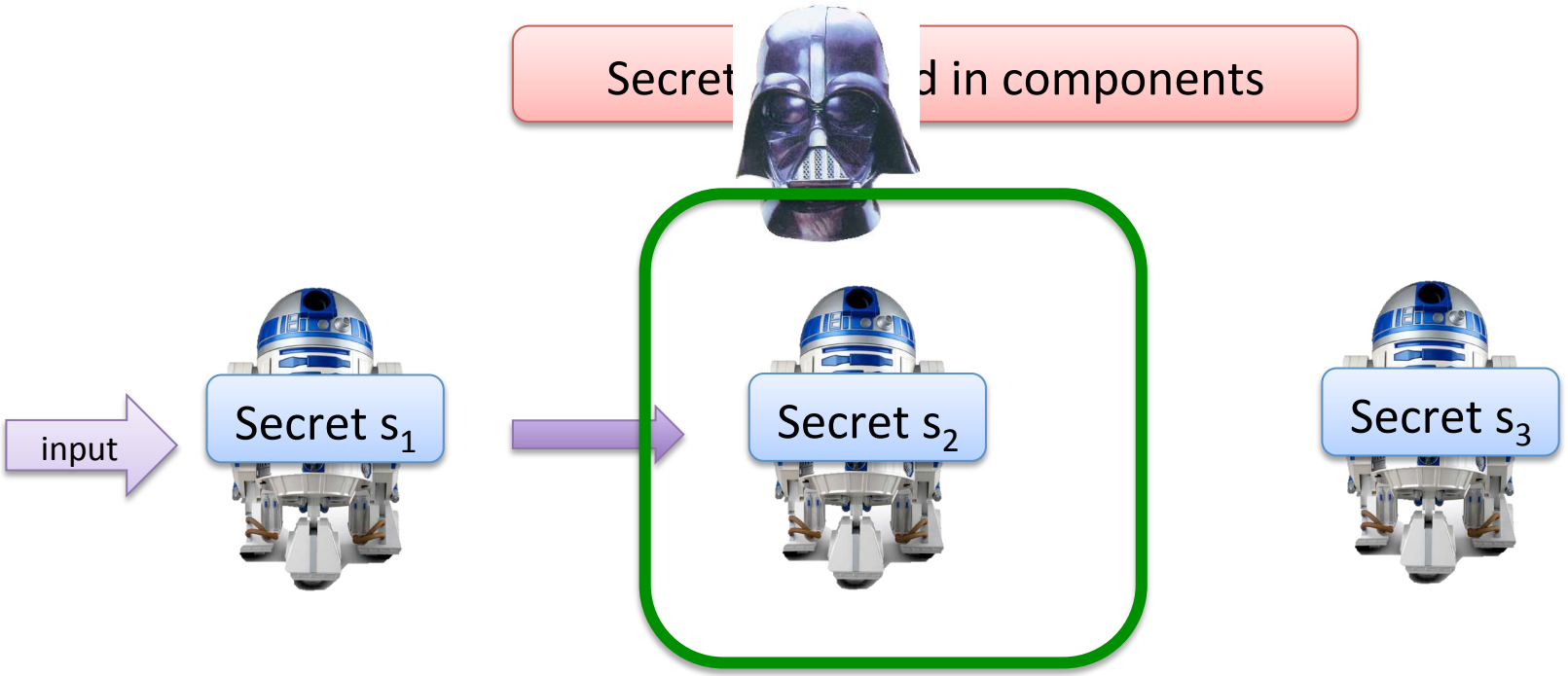

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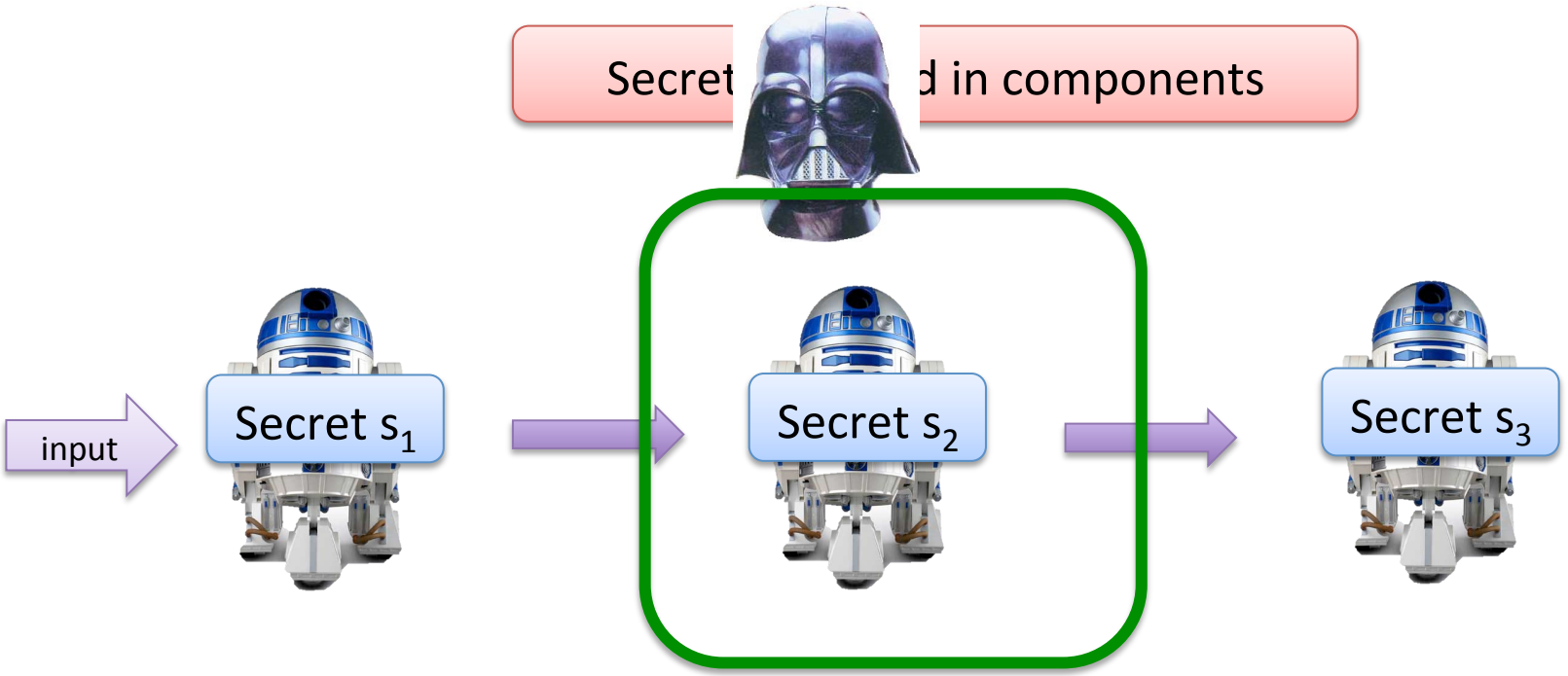

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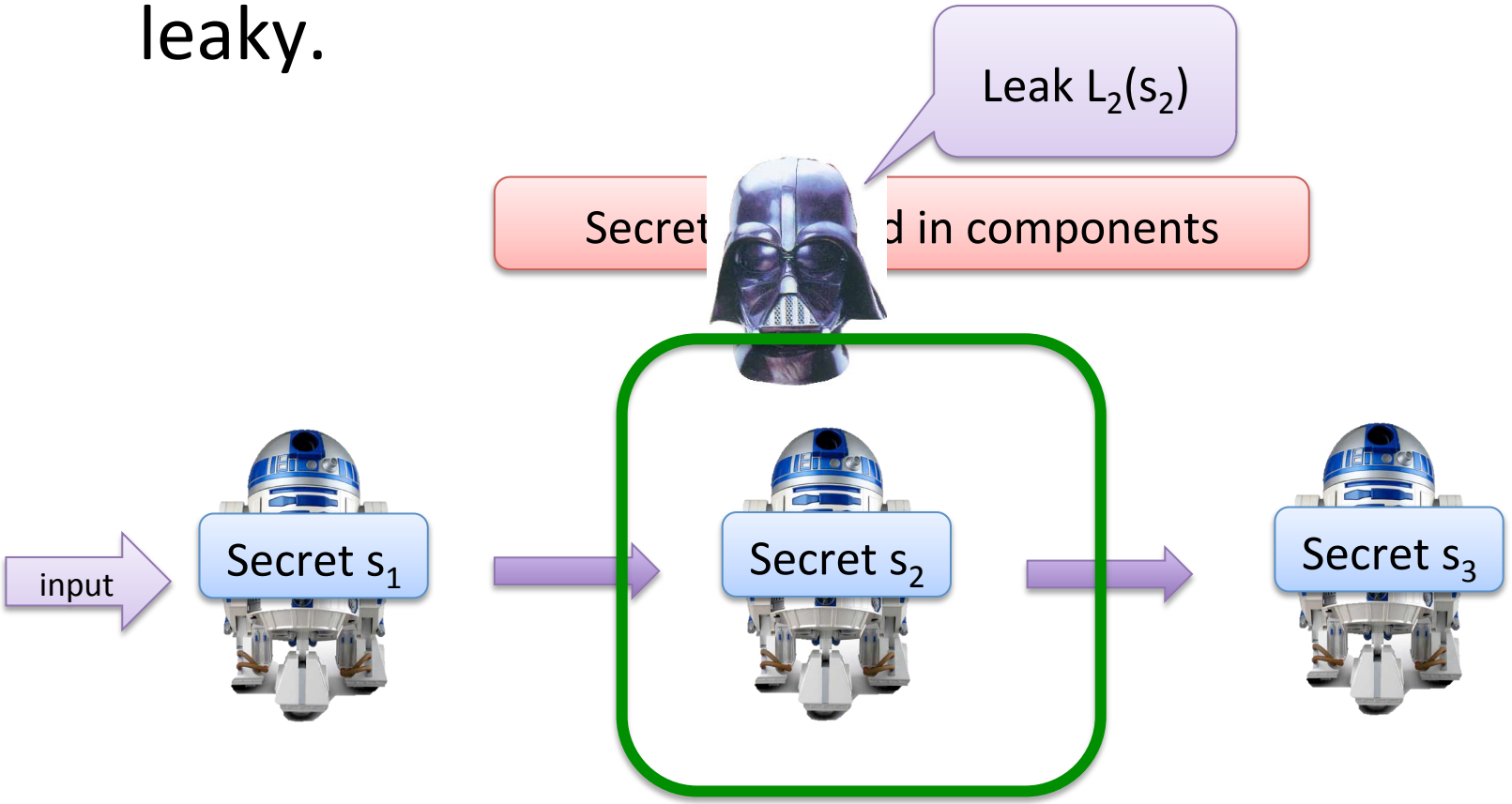

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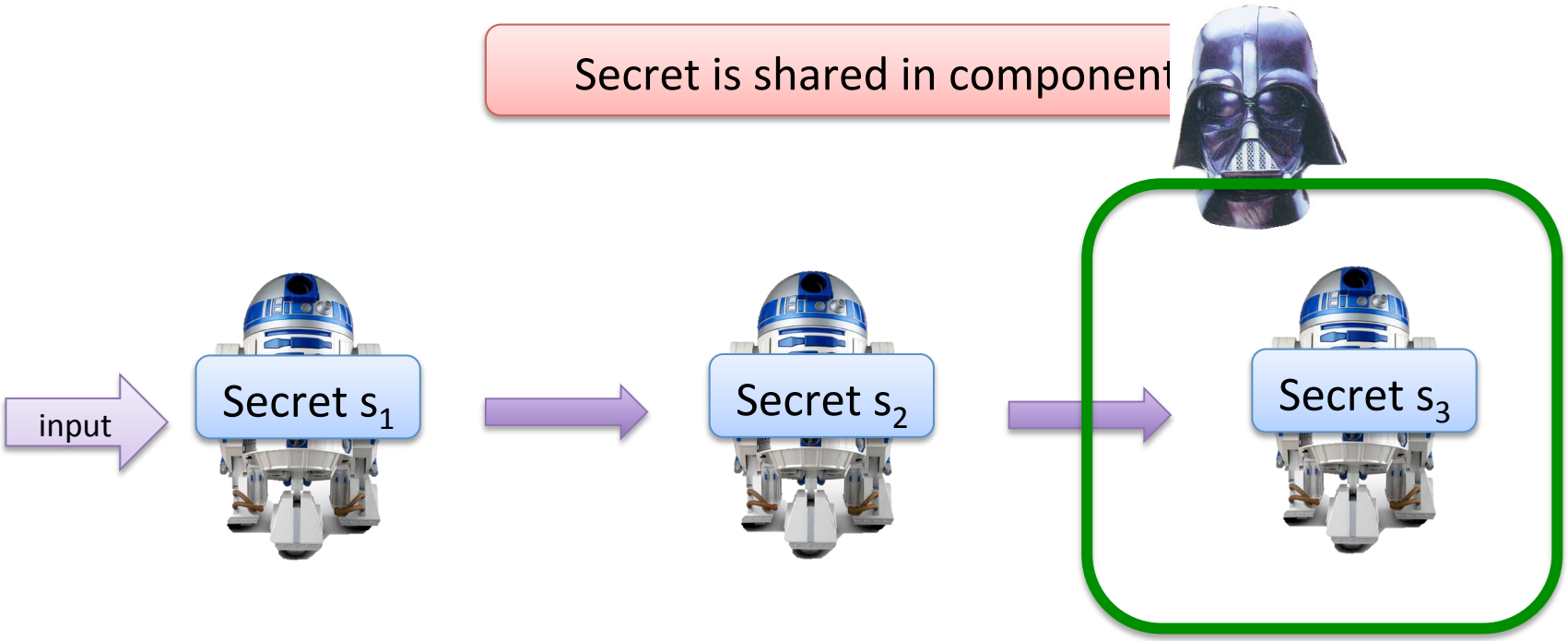

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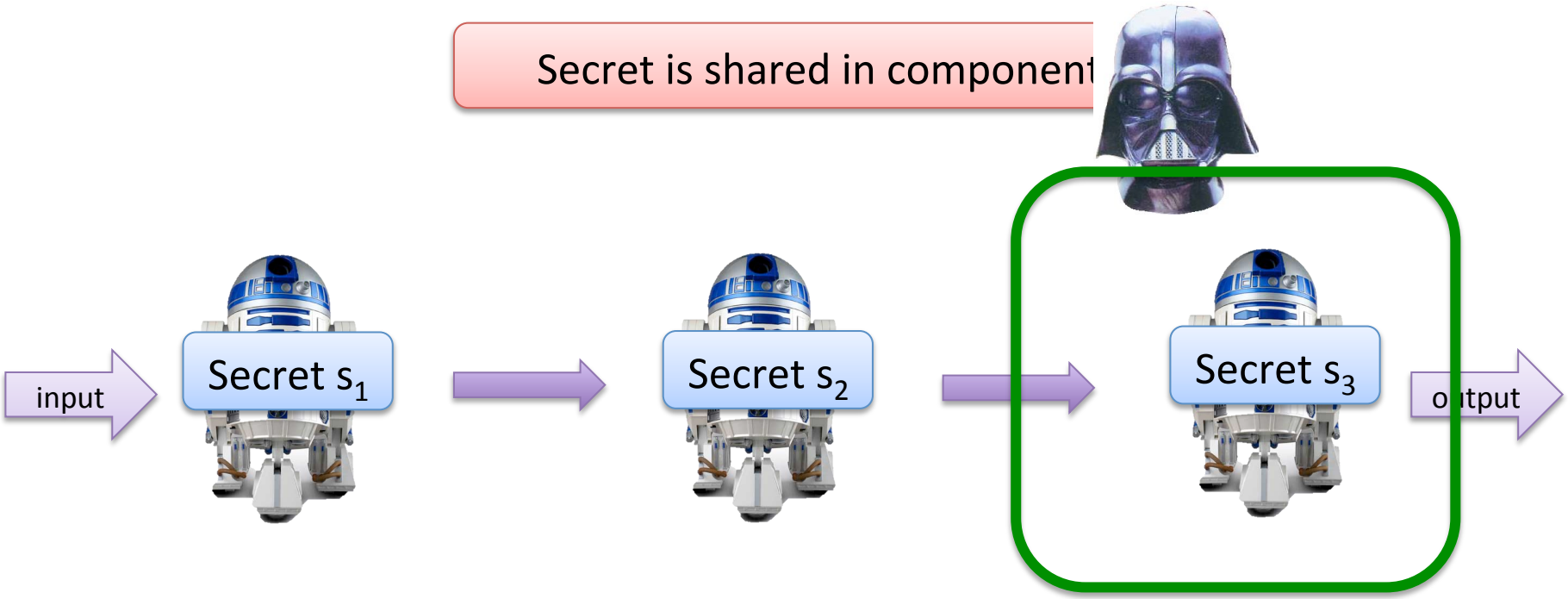

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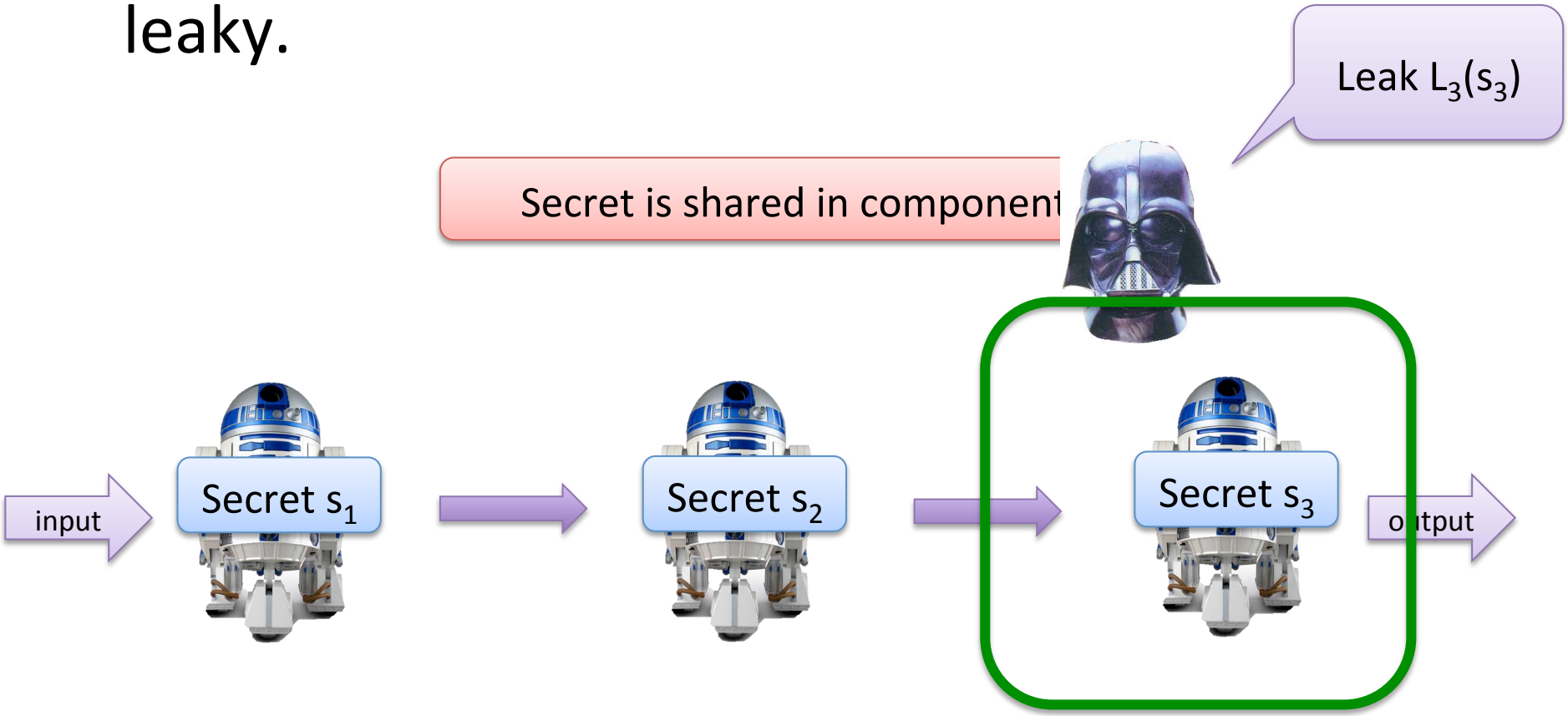
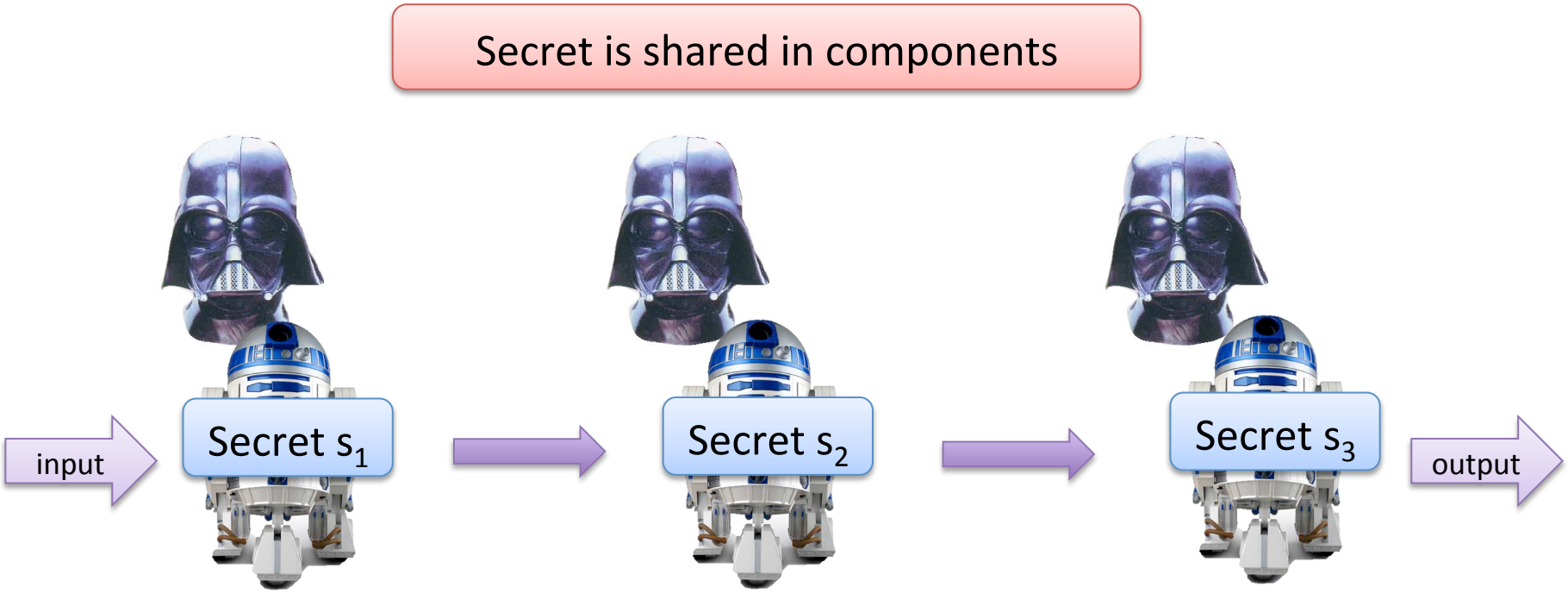


Generalized Model

- Adversary can leak on an arbitrary order of the component.



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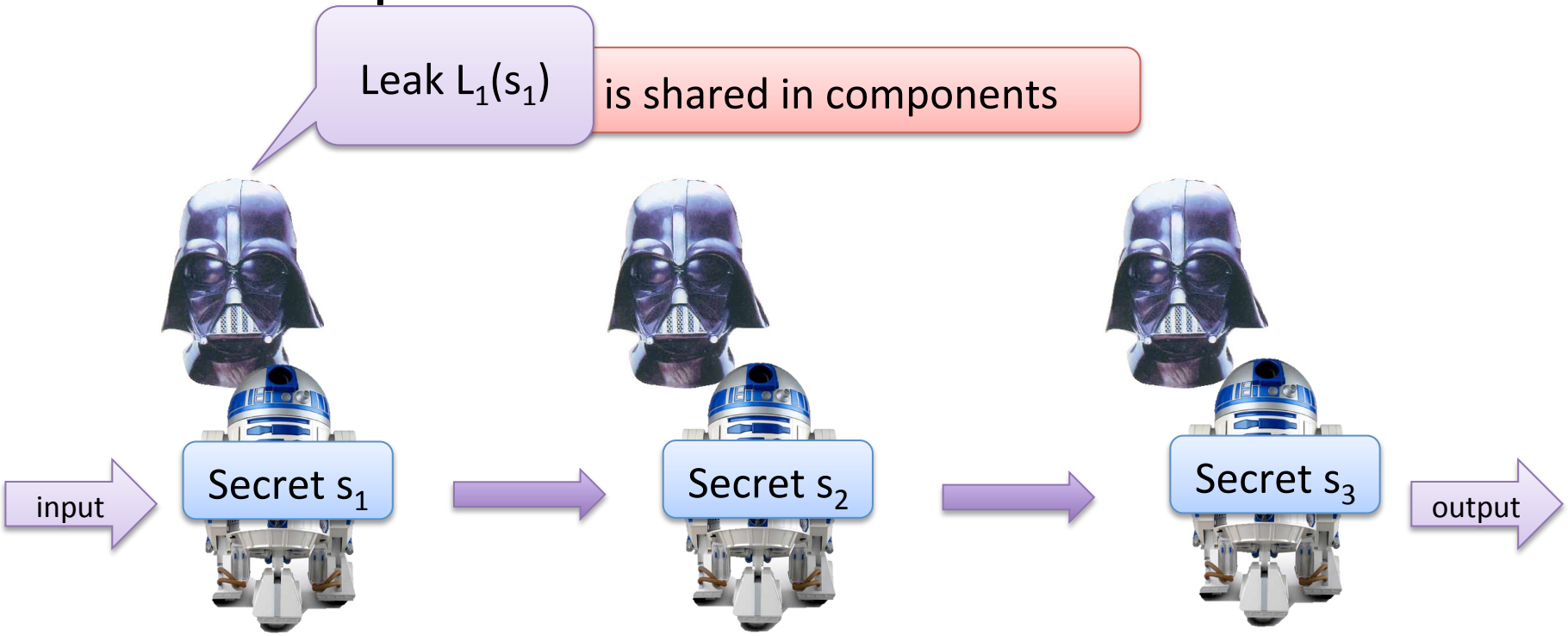

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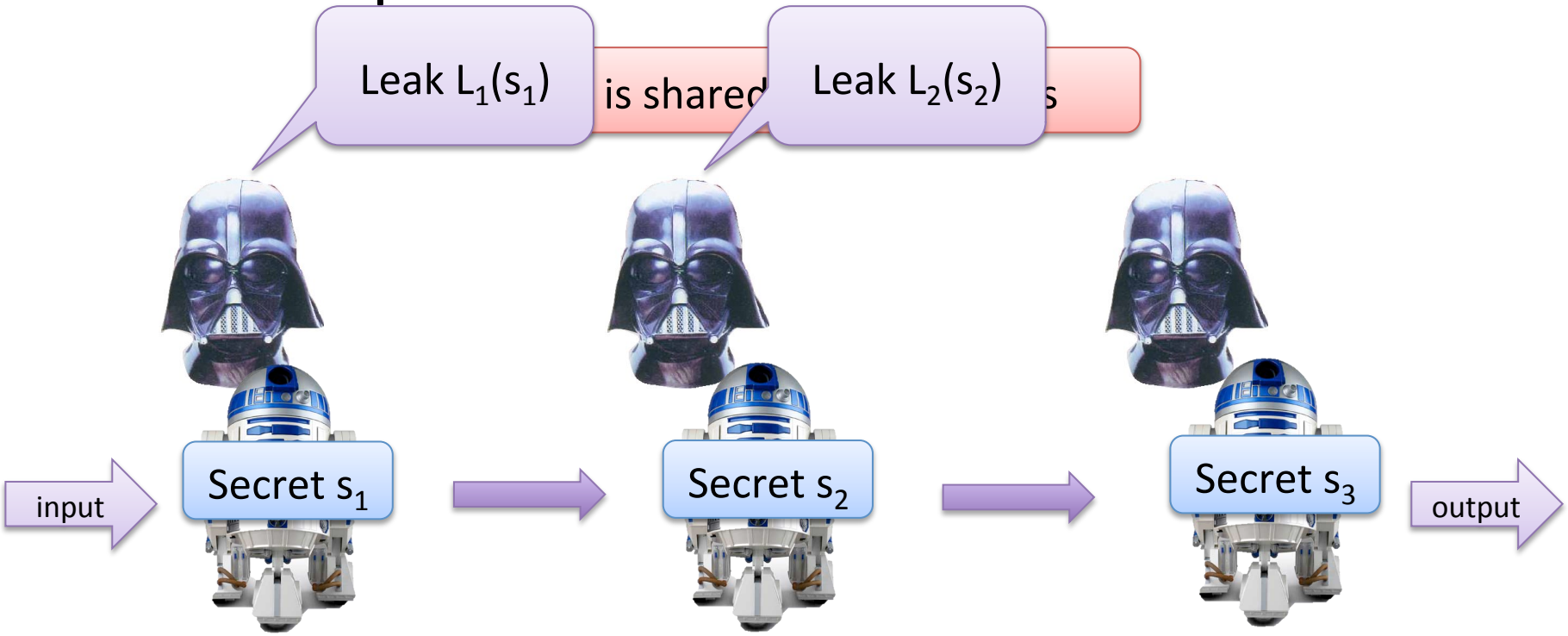

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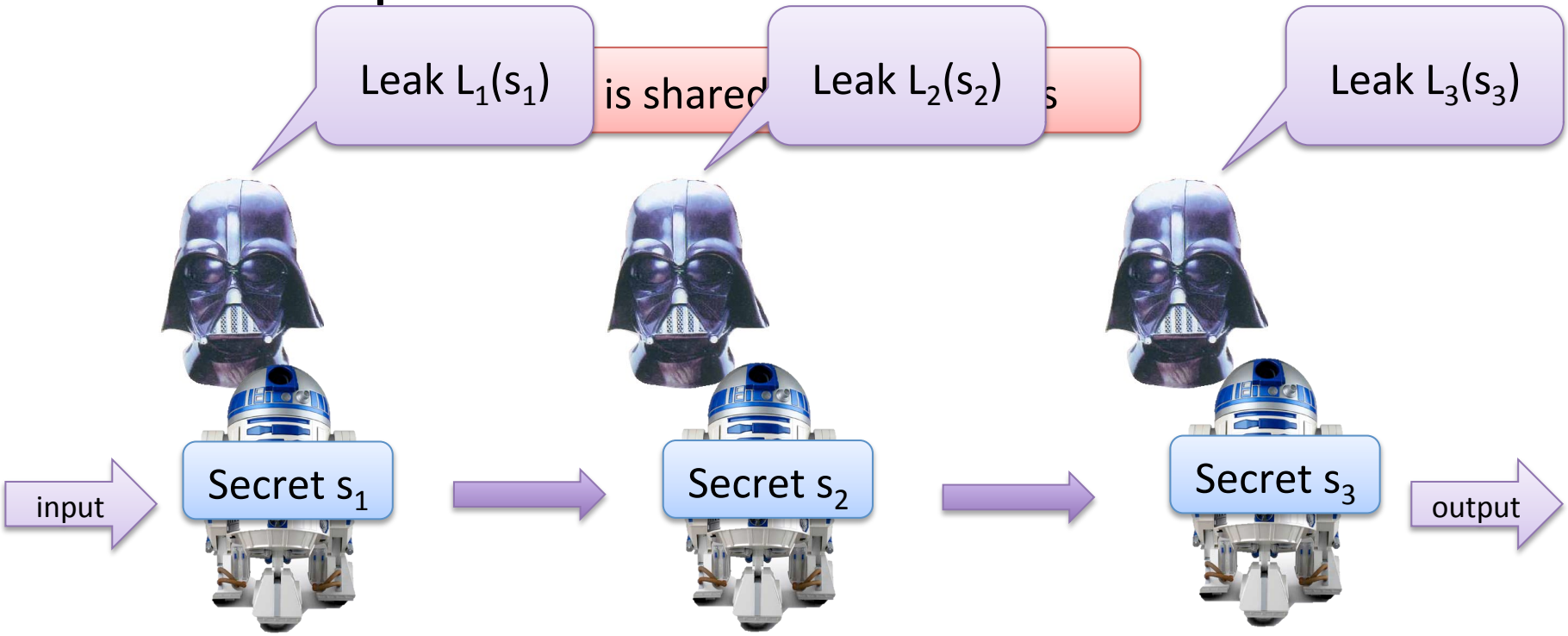

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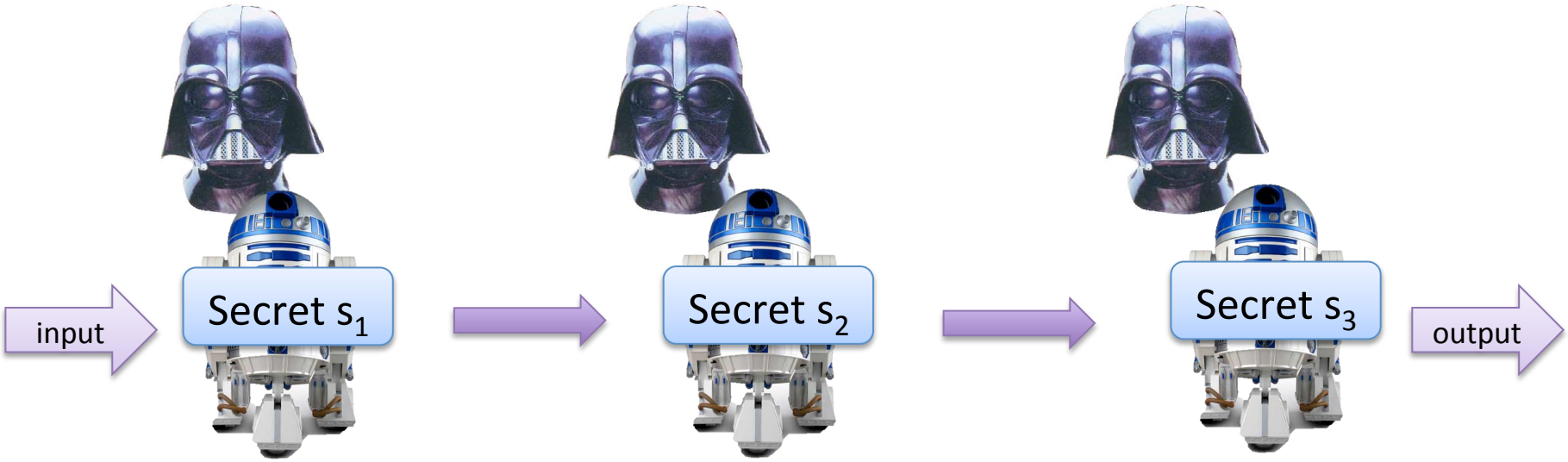

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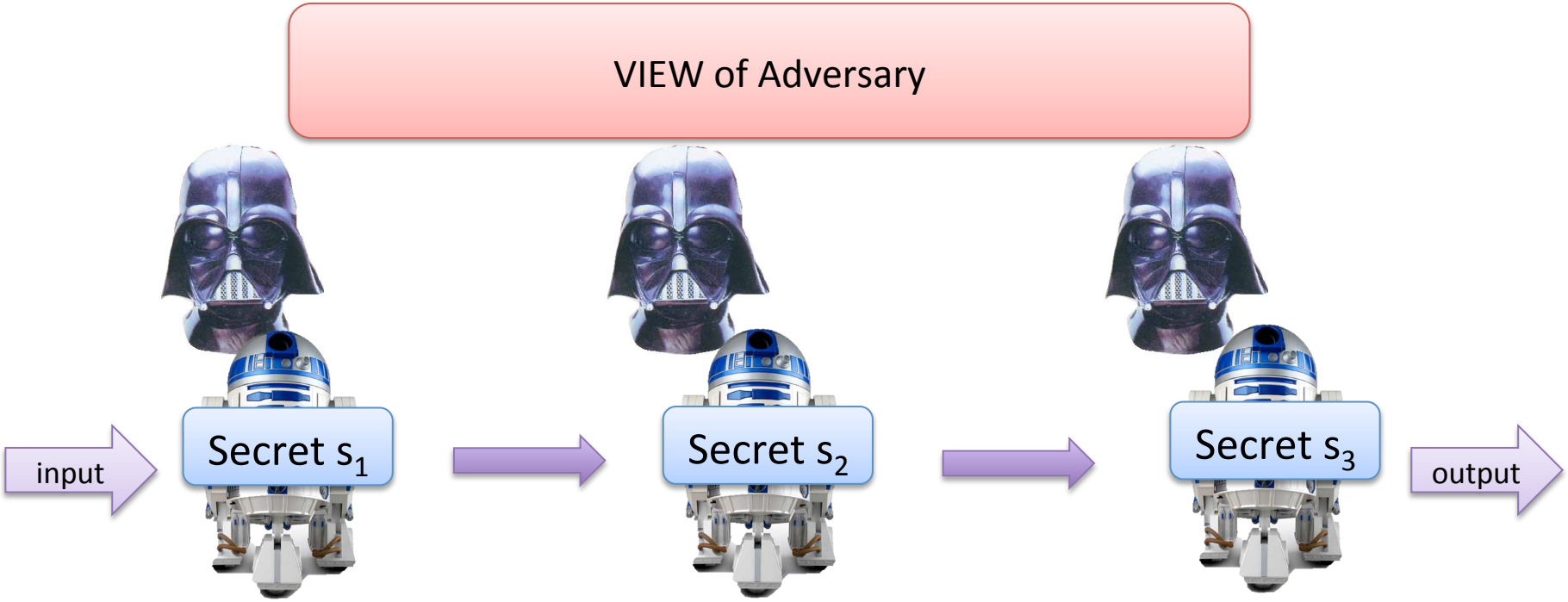

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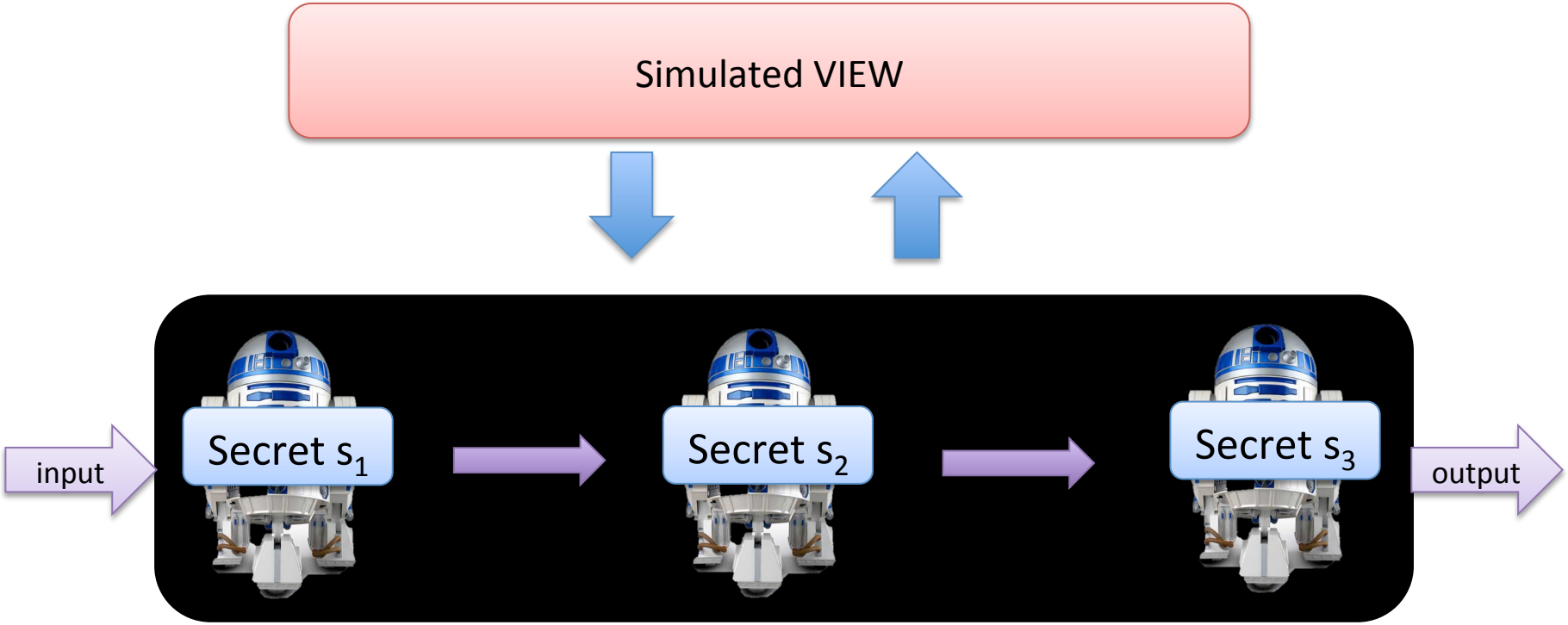

How to measure the “quality” of a construction

- Functionality

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- Functionality
- Number of components
- Extra Secure Hardware

Secure Hardware

Our Goal

- How do we secure general computation?
  - With the optimal number of components
  - Without secure hardware

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Function $D_s(\bullet)$

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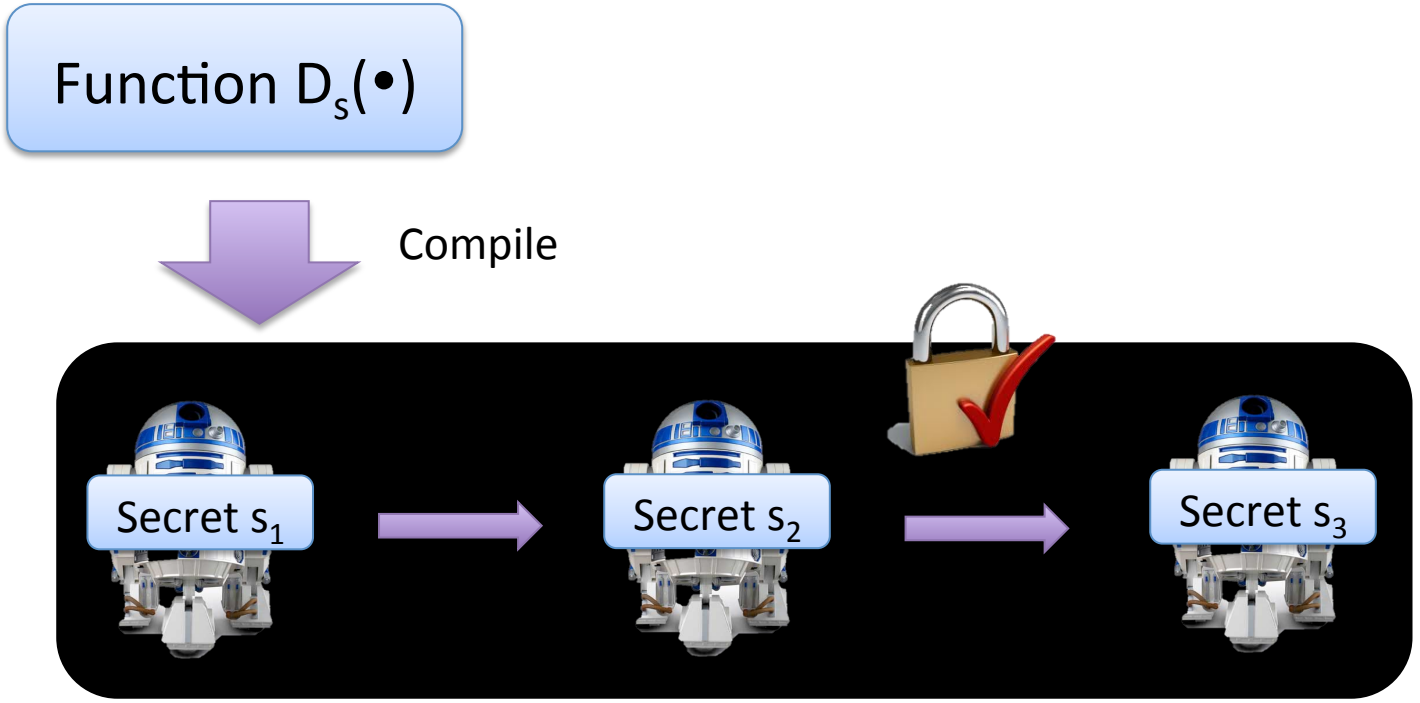

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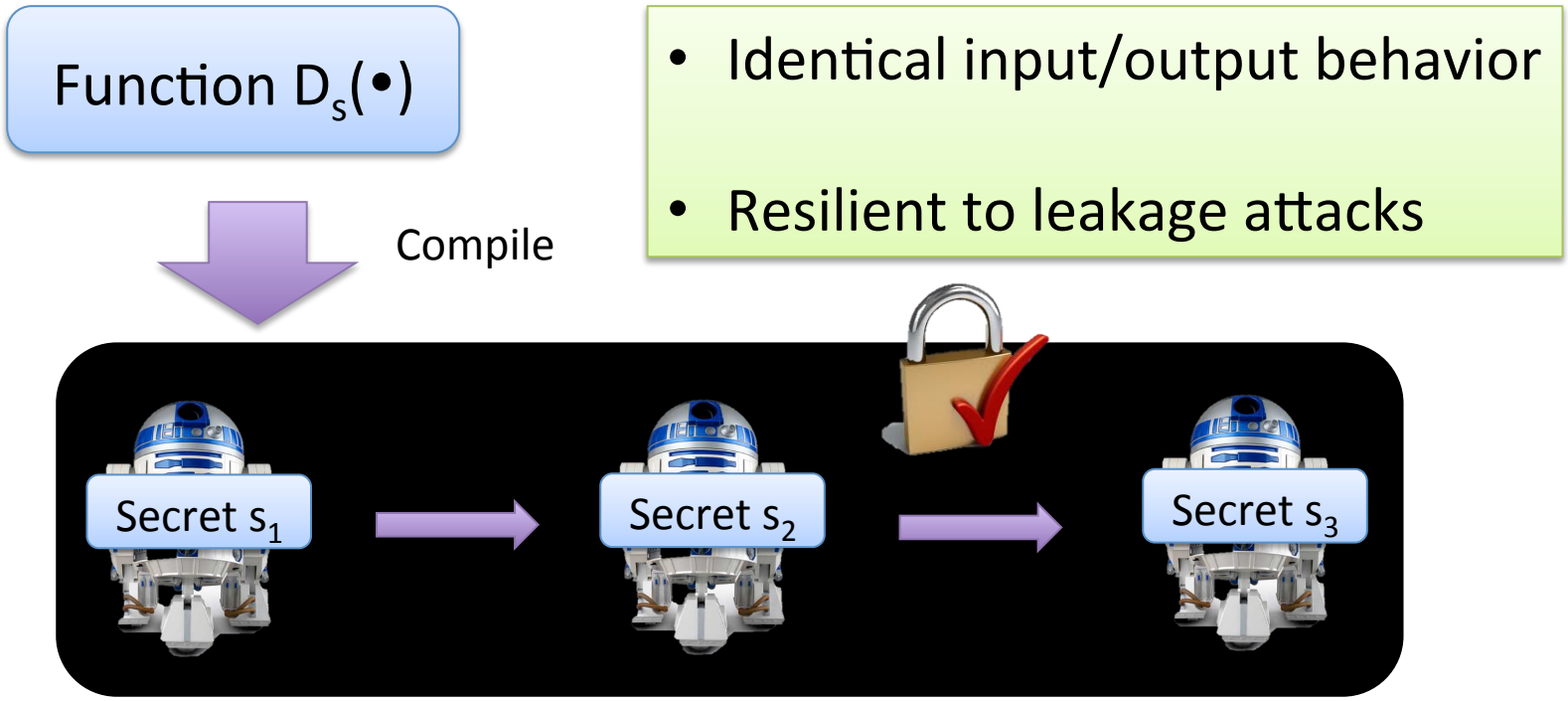

- Identical input/output behavior
- Resilient to leakage attacks

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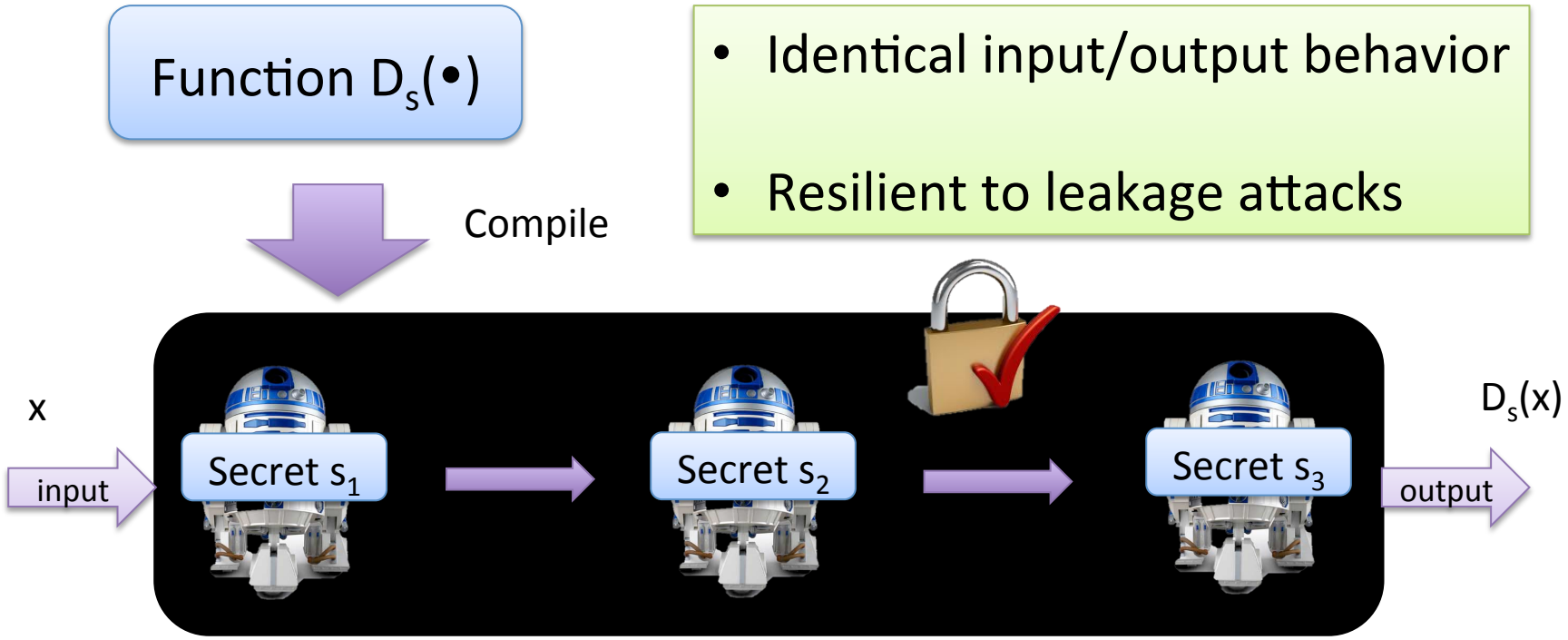

Previous Result

- It is impossible for one component (without secure hardware) [folklore,GR12]
- For multi-component constructions, we have:

Scheme	Hardware	Components
JV10	**Yes**	2
DF11	**Yes**	2
GR12	No	**|C|**
BDL14	No	**20**

Our Main Result

- Get best of the two: 2 components without hardware!

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- A modular approach:
  - Generic way to replace hardware in previous schemes [JV, DF]

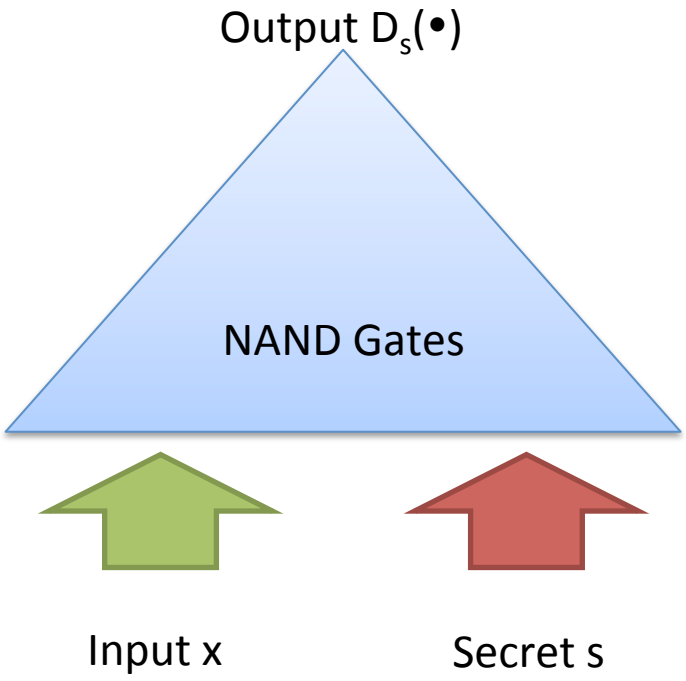
Scheme	Hardware	Components
JV-based	**No**	**2**
DF-based	**No**	**2**

Roadmap

- A generic design paradigm
  - Step1: design a hardware-based scheme
  - Step2: get rid of the hardware
    - Hardware replacement theorem
    - Implement sampling functionality

Original Dziembowski-Faust Scheme

- Given any $D_s(\bullet)$, we can express it as a circuit of NAND gates



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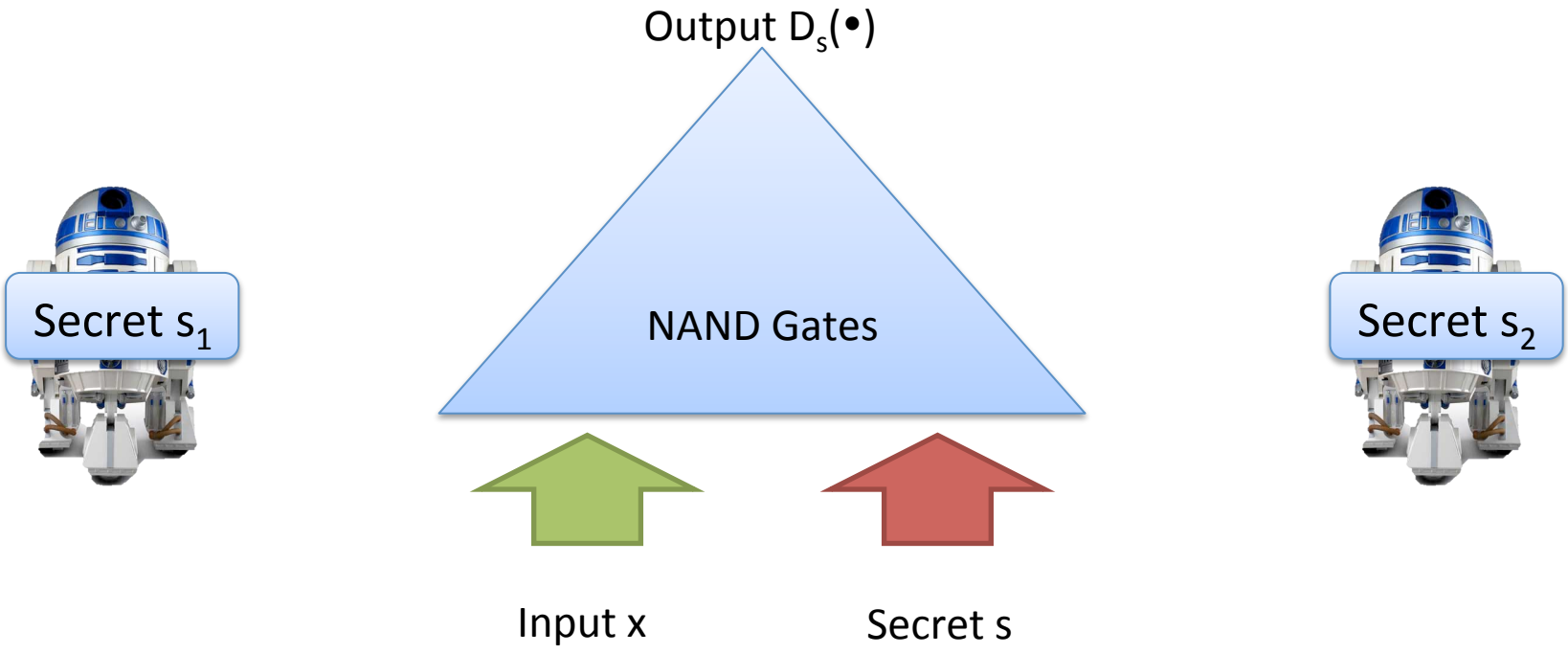

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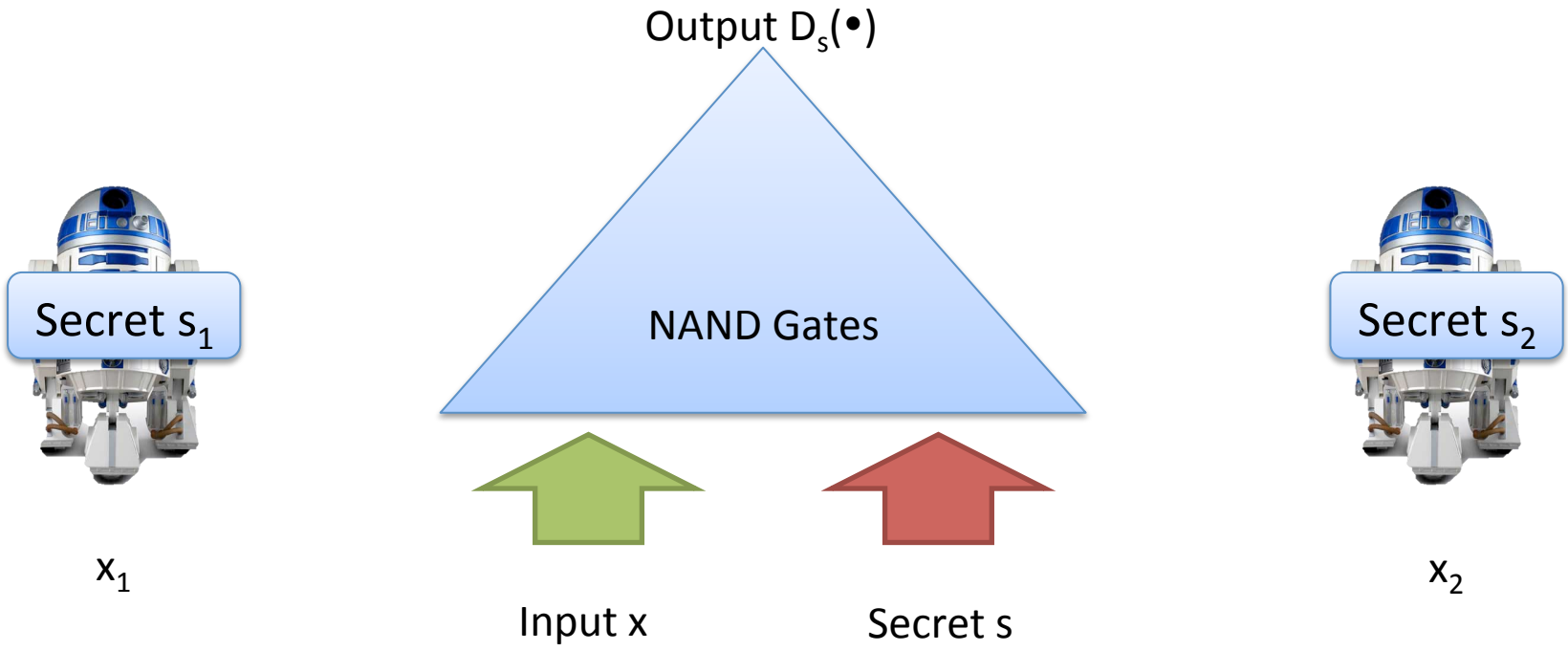
  - Initially, secret share s
  - On input x, secret share x



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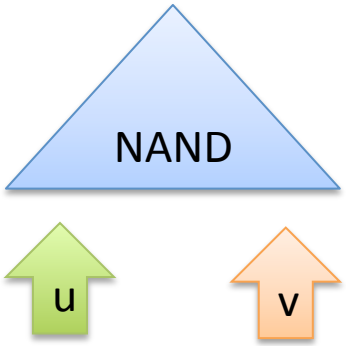
u_1 v_1



u_2 v_2

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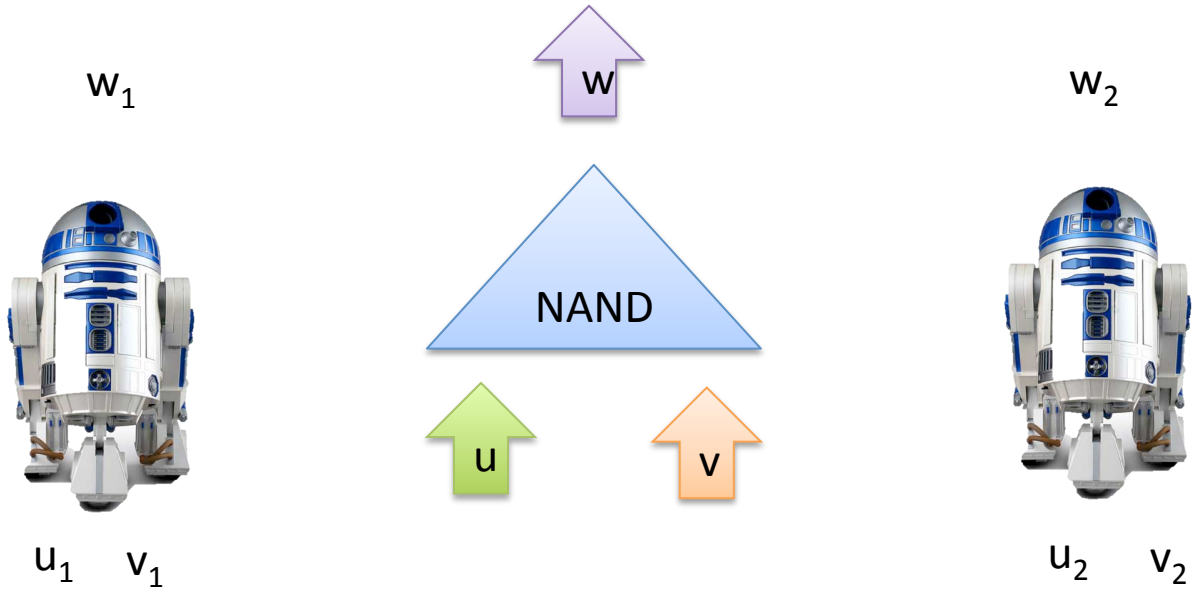
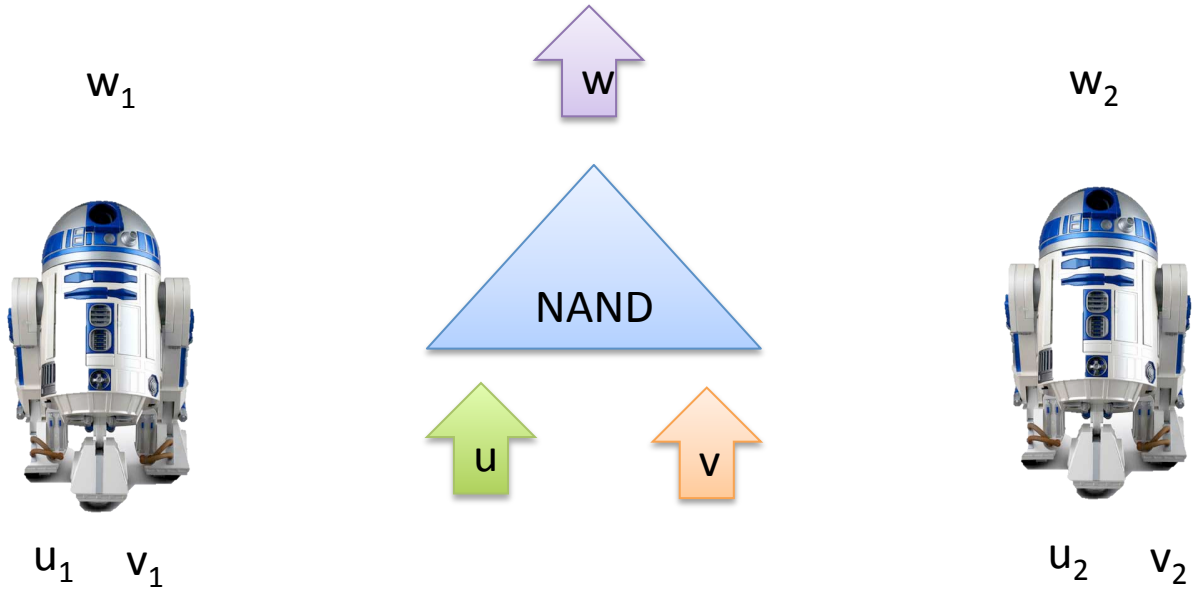


Original Dziembowski-Faust Scheme

Great property of shares

- Independent leakage on shares cannot reveal the underlying value!
- u is hidden given $L_1(u_1)$, $L_2(u_2)$, for bounded length functions



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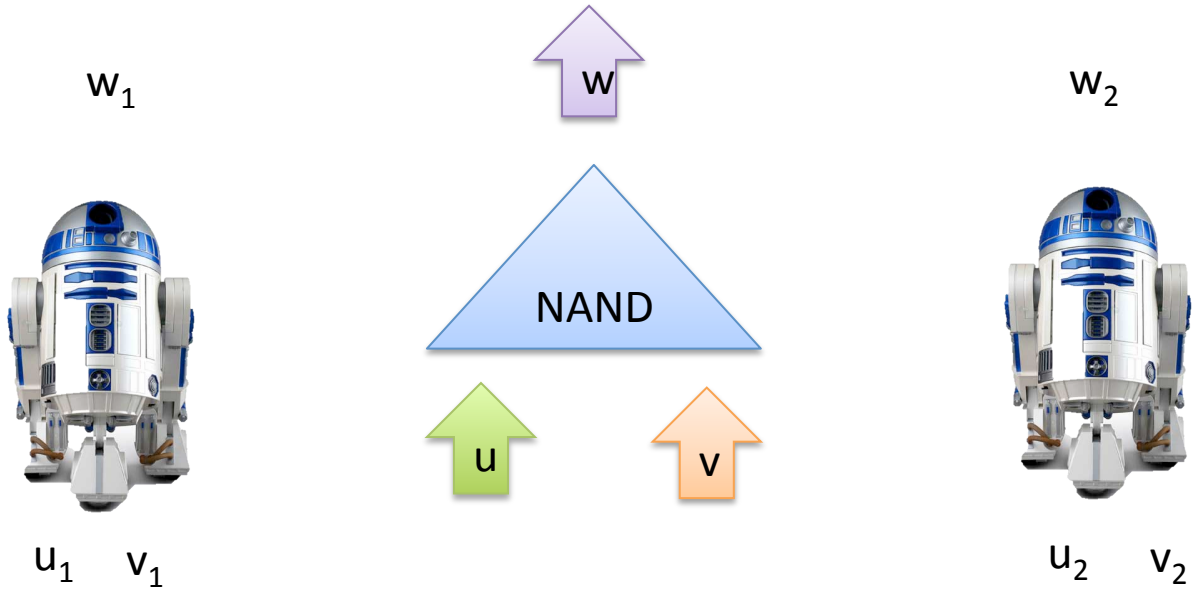

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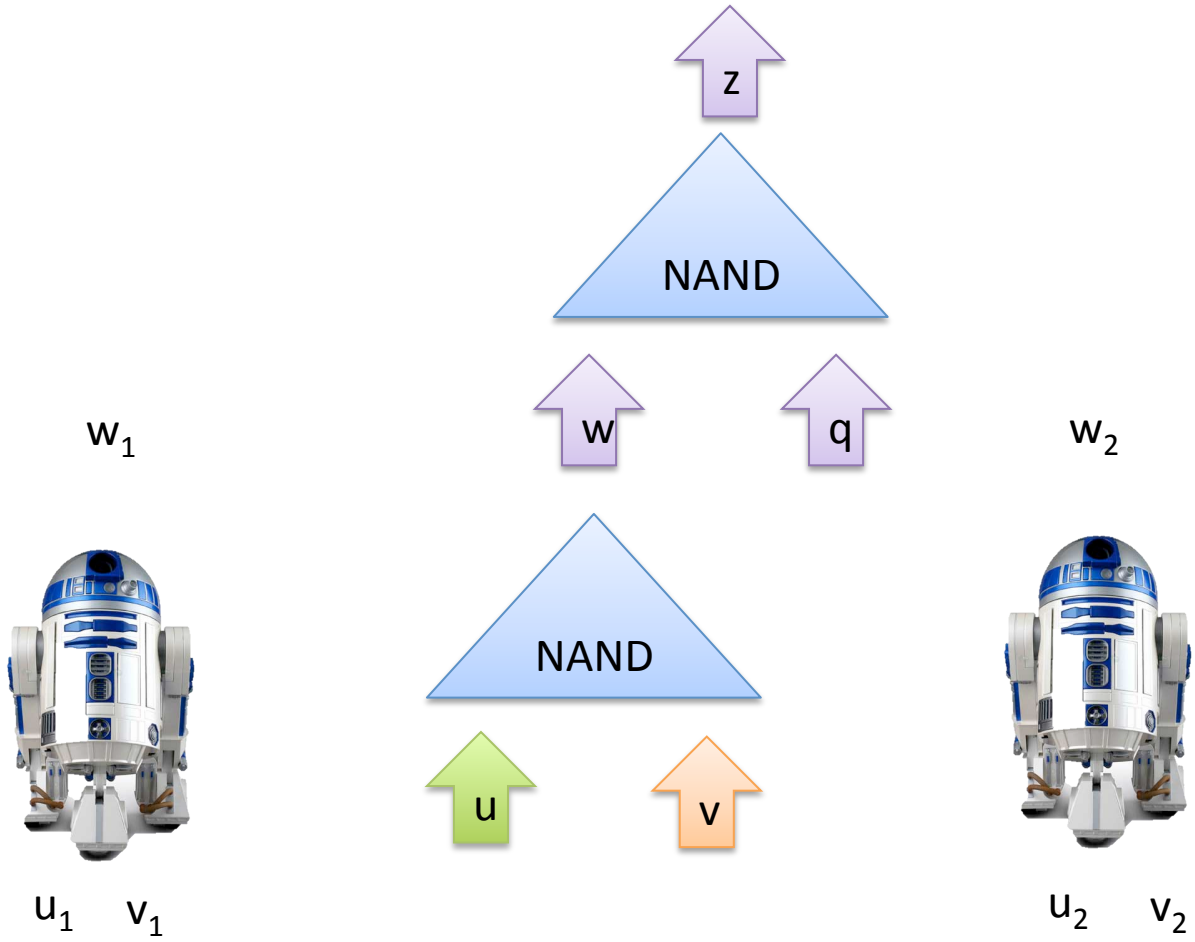

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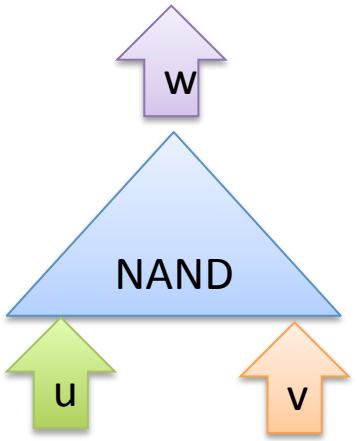

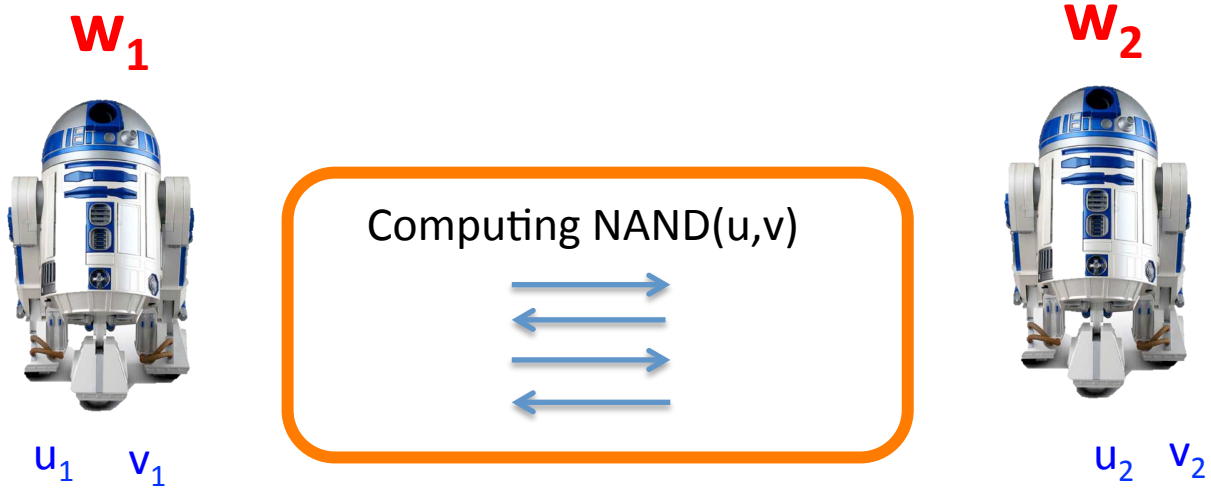

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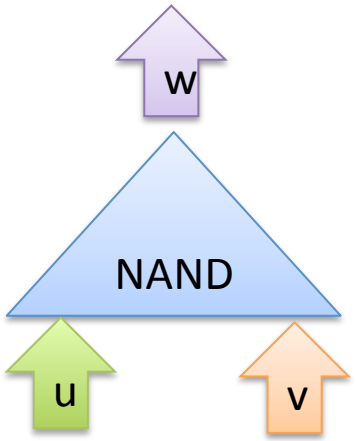

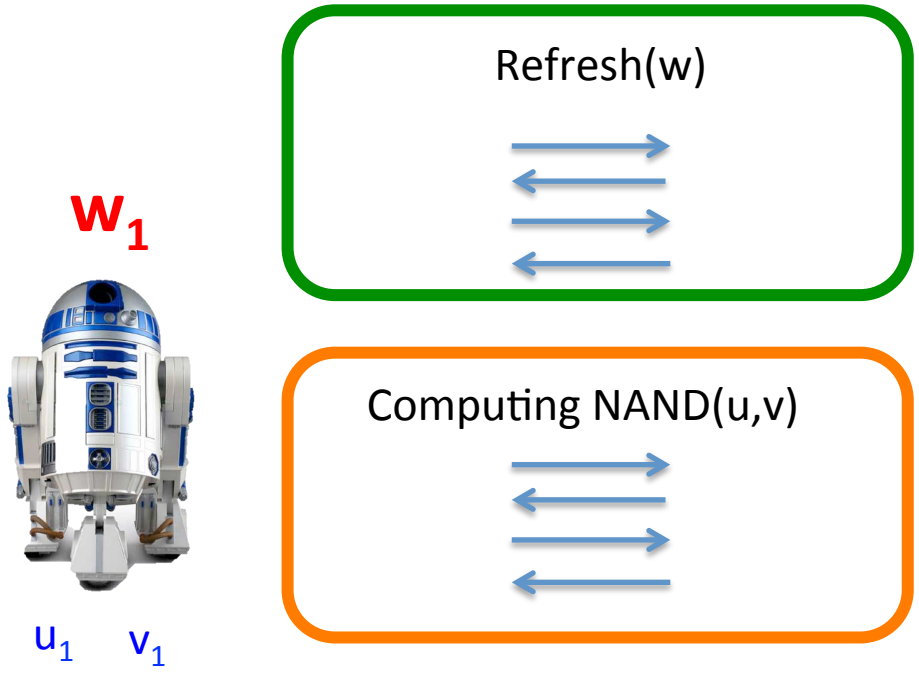

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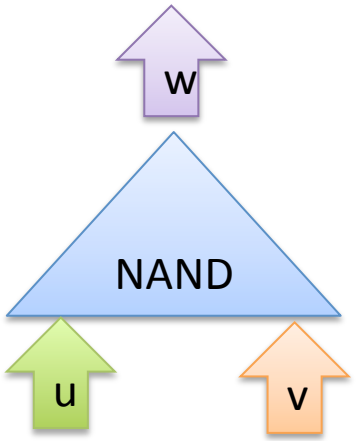
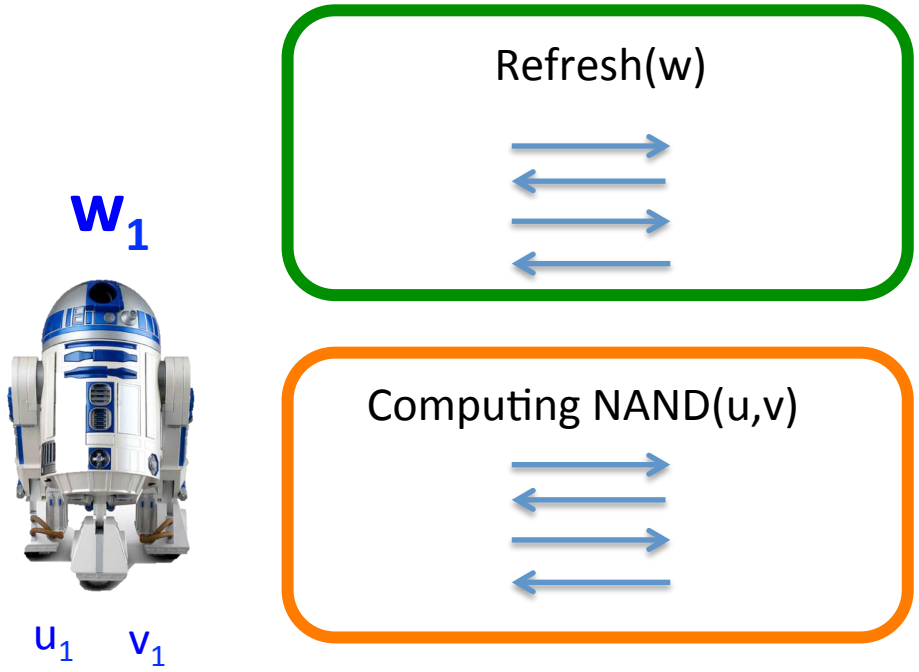


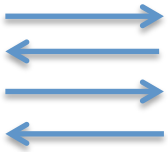


Original Dziembowski-Faust Scheme

- Refresh needs hardware

Secure Hardware

Refresh(w)



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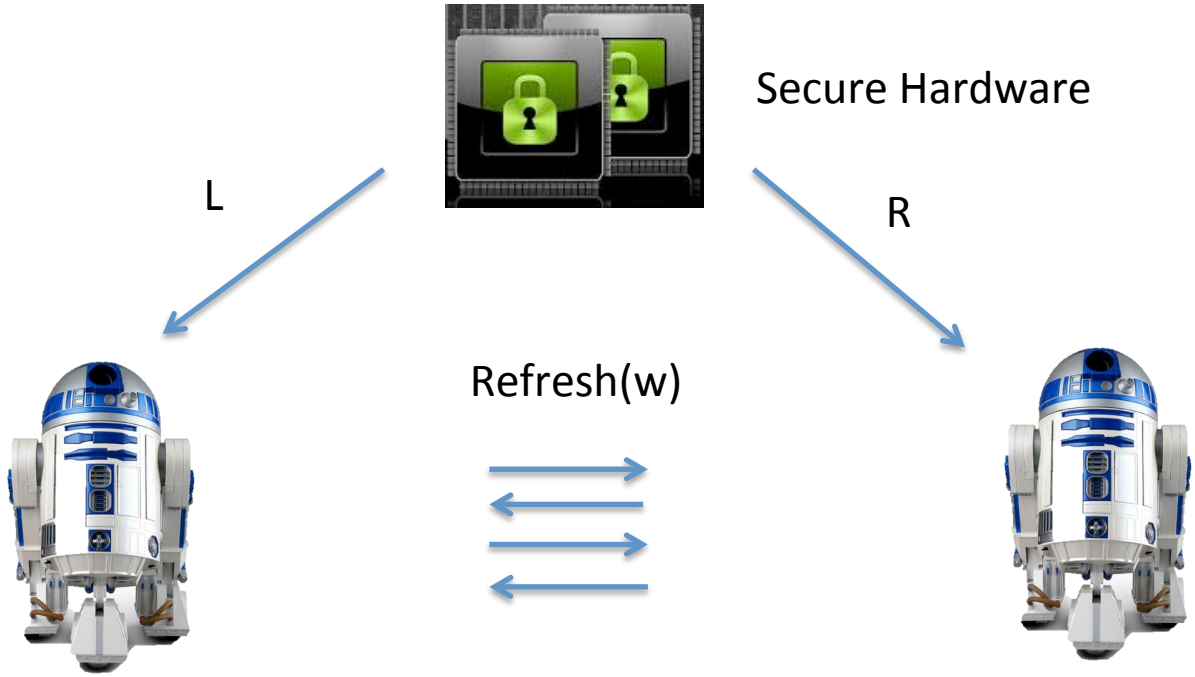

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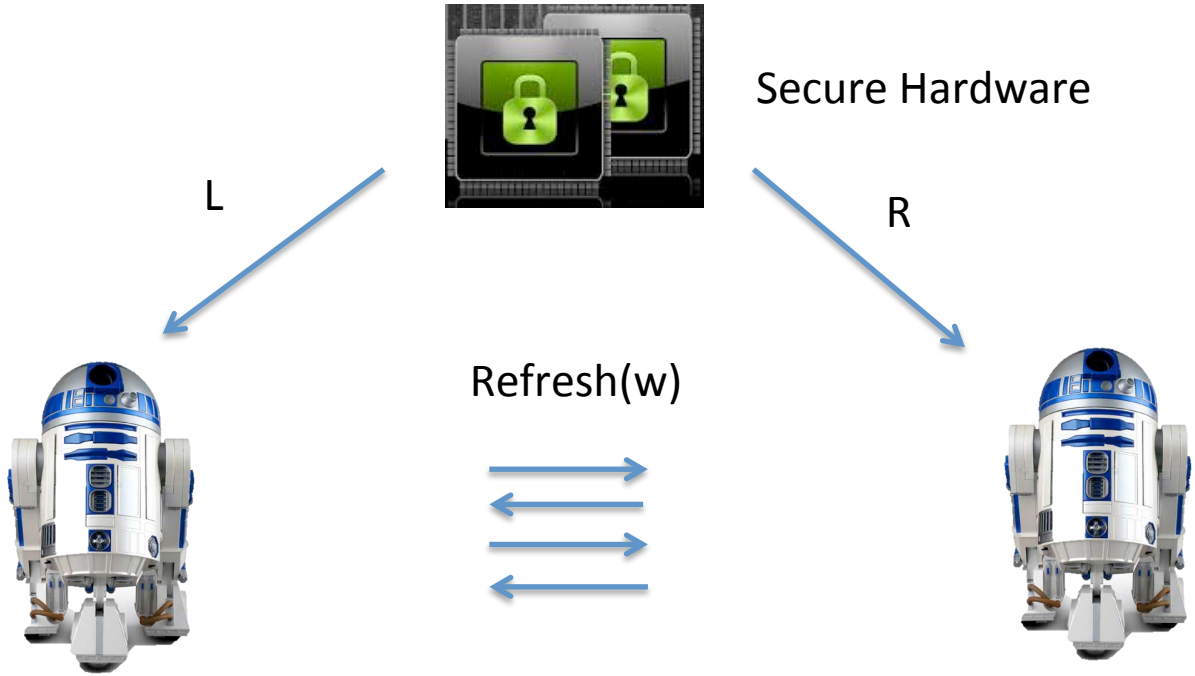

- L and R are vectors such that <L, R> = 0
- It is fine to leak on L and R separately, but NOT jointly

Roadmap

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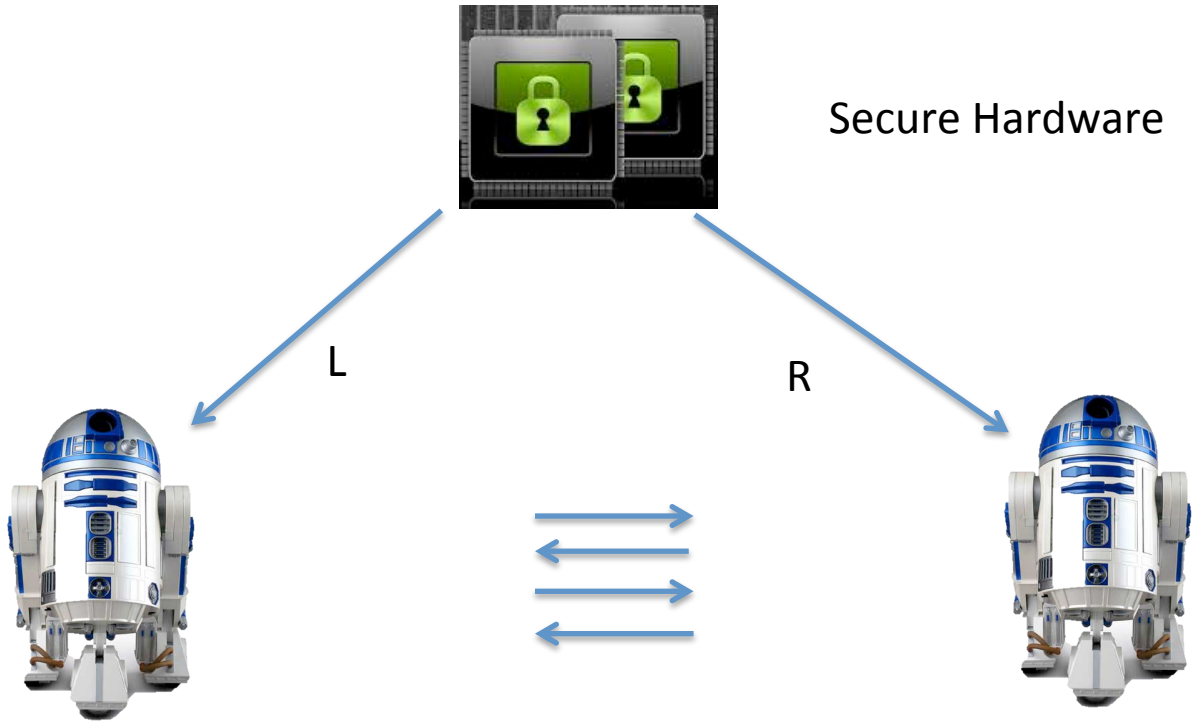

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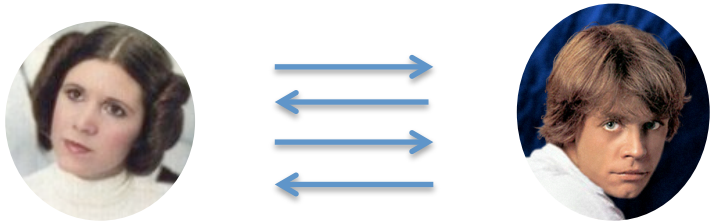

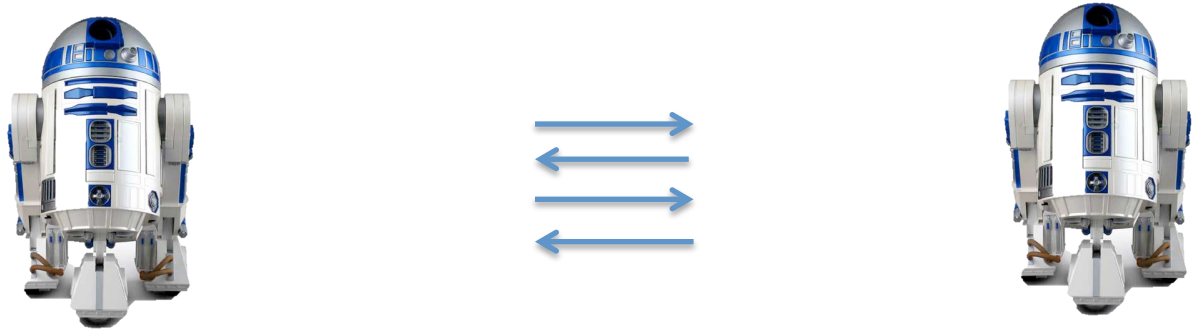

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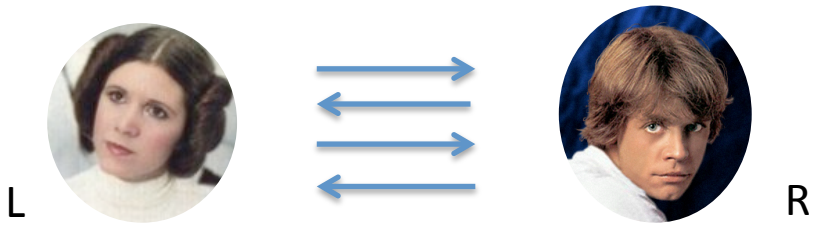

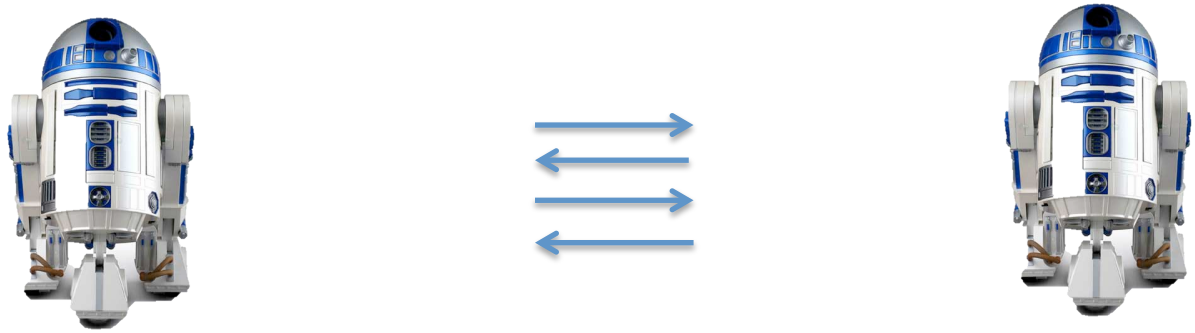

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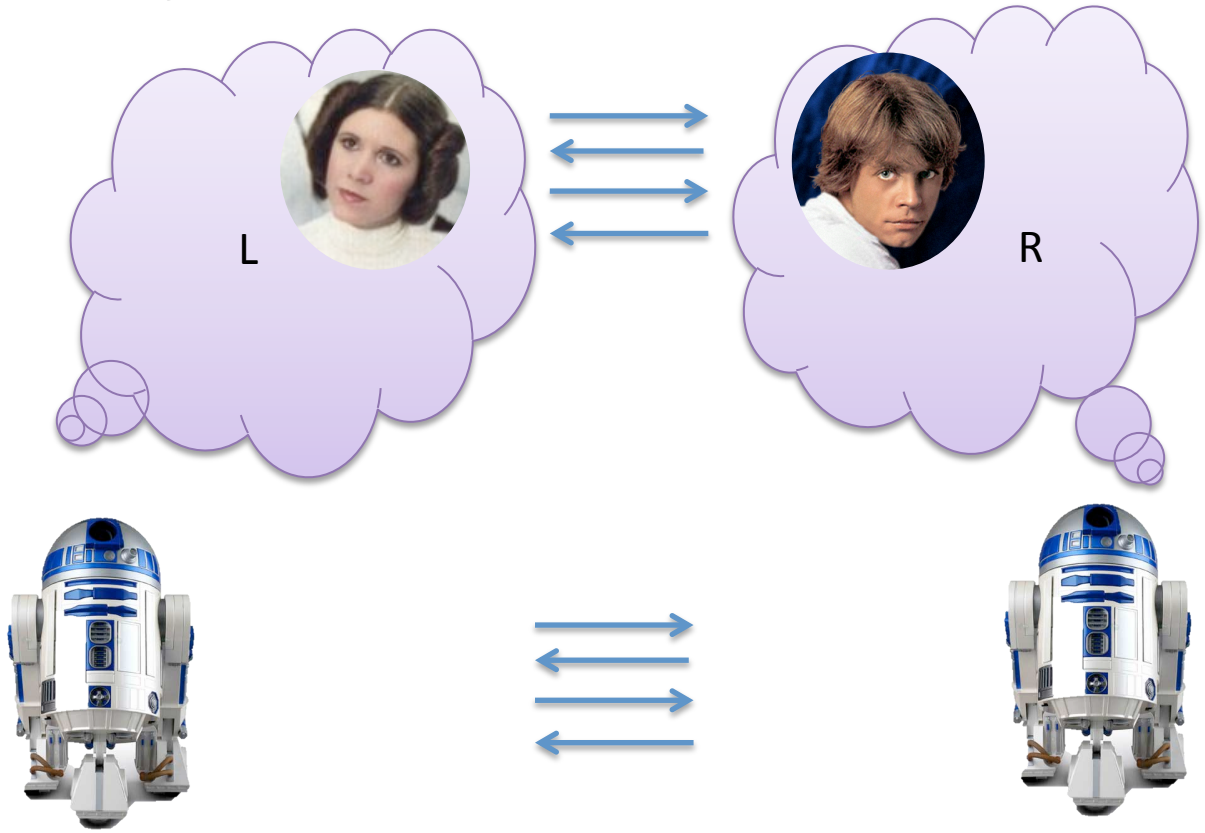

Similar to UC, leaky UC [BCH12]

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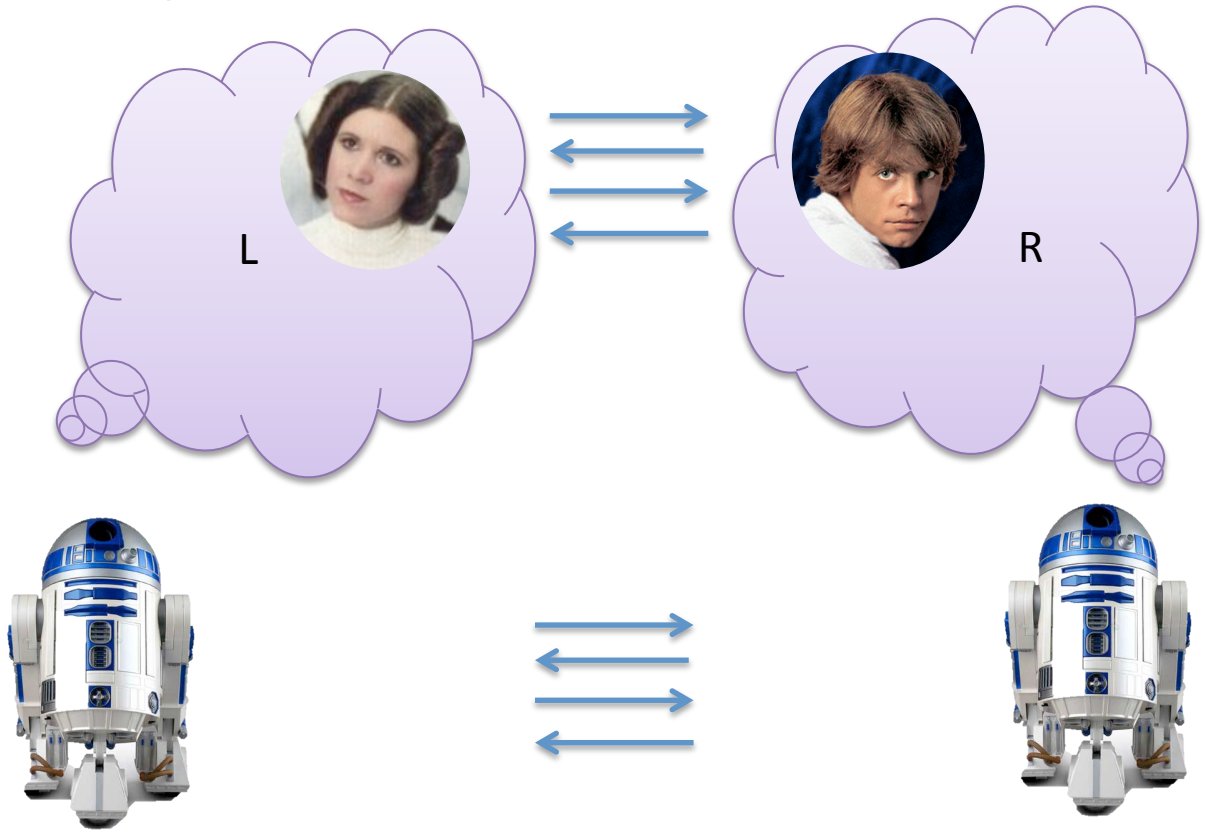

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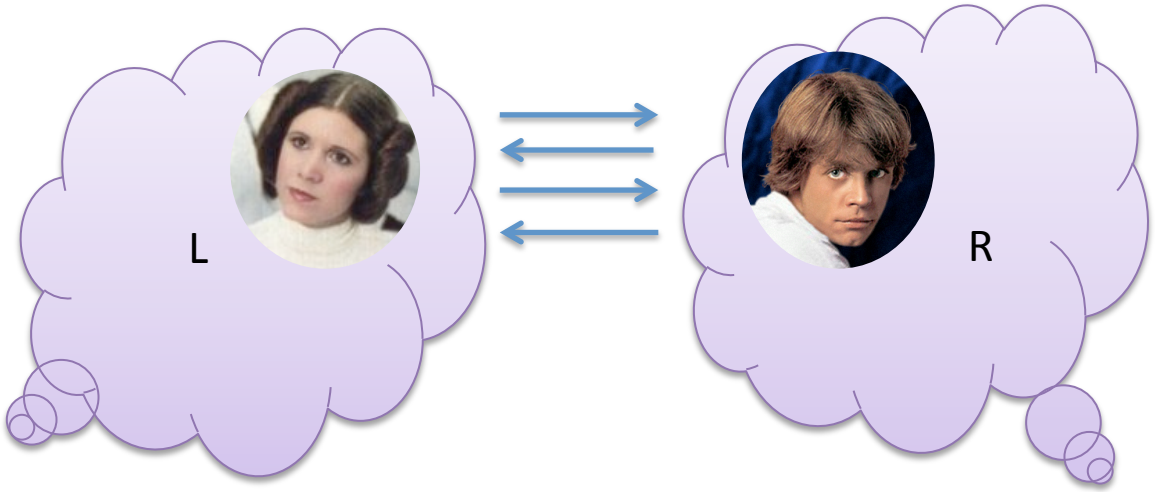
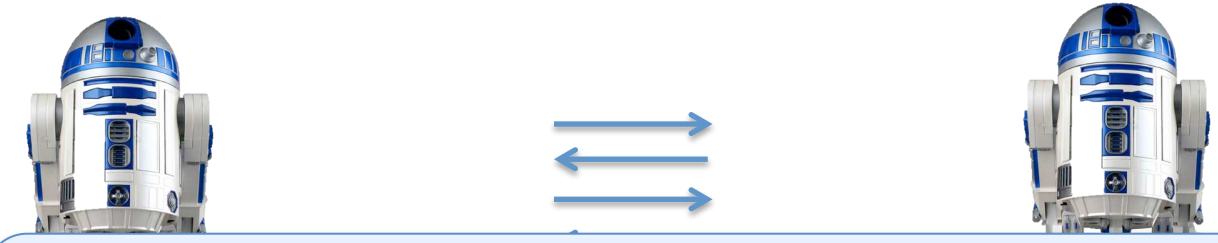




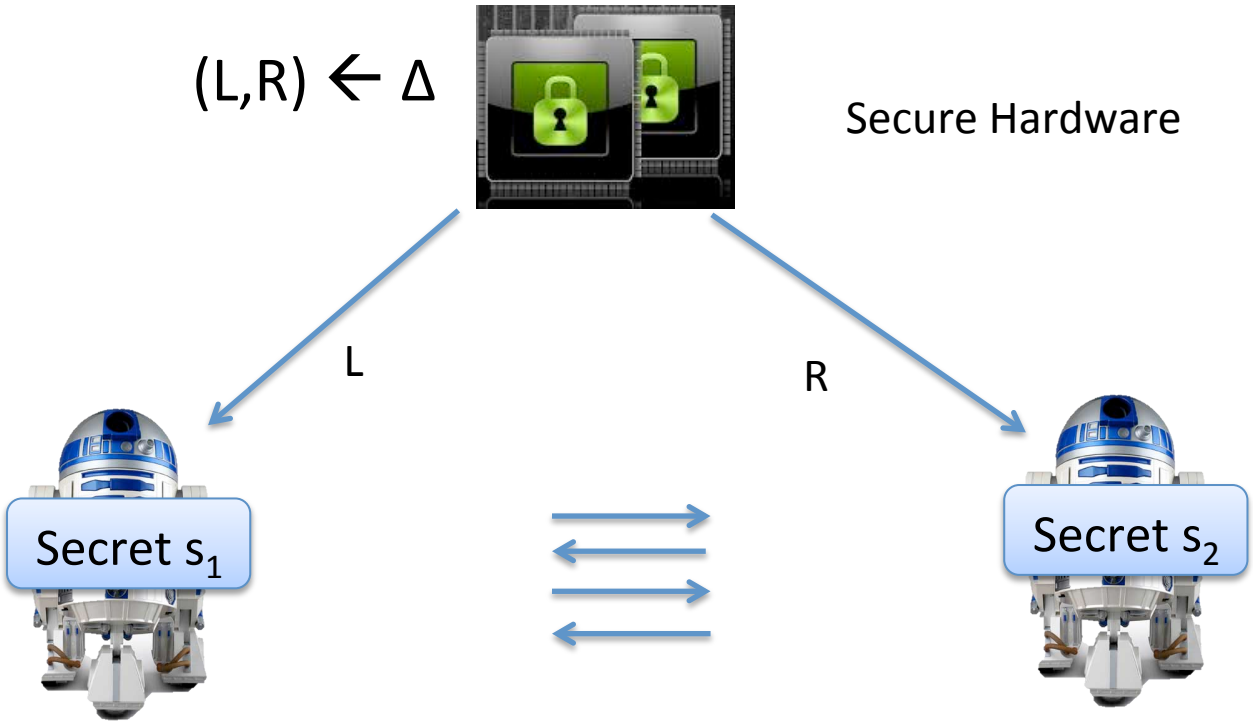
Challenge: Need to make sure Adv can not learn joint leakage of L and R !

Roadmap

- A generic design paradigm
  - Step1: design a hardware-based scheme
  - Step2: get rid of the hardware
    - Hardware replacement theorem
    - Implement sampling functionality

Sampling Functionality

- Let Δ be some distribution that samples (L, R)



How to Implement Sampling Functionality

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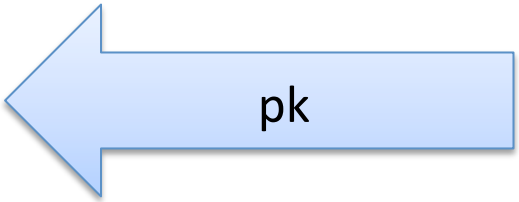


(pk,sk) <- Gen

How to Implement Sampling Functionality

- Let Δ be a distribution that hardware samples, i.e. (L,R)←Δ
- Simple idea: let one party samples Δ and use encryption to protect the communication

pk

Enc(pk,R)

1. Sample coins
2. Compute (L, R) = Δ(coins)
3. Compute Enc(pk, R)

(pk,sk) <- Gen

How to Implement Sampling Functionality

- Let Δ be a distribution that hardware samples, i.e. (L,R)←Δ

Can obtain joint leakage on L and R if can leak on coins

Big Issue!!!

pk

Enc(pk,R)

1. Sample coins
2. Compute (L, R) = Δ(coins)
3. Compute Enc(pk, R)

(pk,sk) <- Gen

[JL00,CHK05]

Receiver Non-committing Encryption

pk

c = Enc(pk,m; r)

Sender

Receiver

(pk,sk) <- Gen

[SW14]

Univeral Deniable Encryption

Public Parameter PP

pk

c = Enc(PP, pk,m; r)

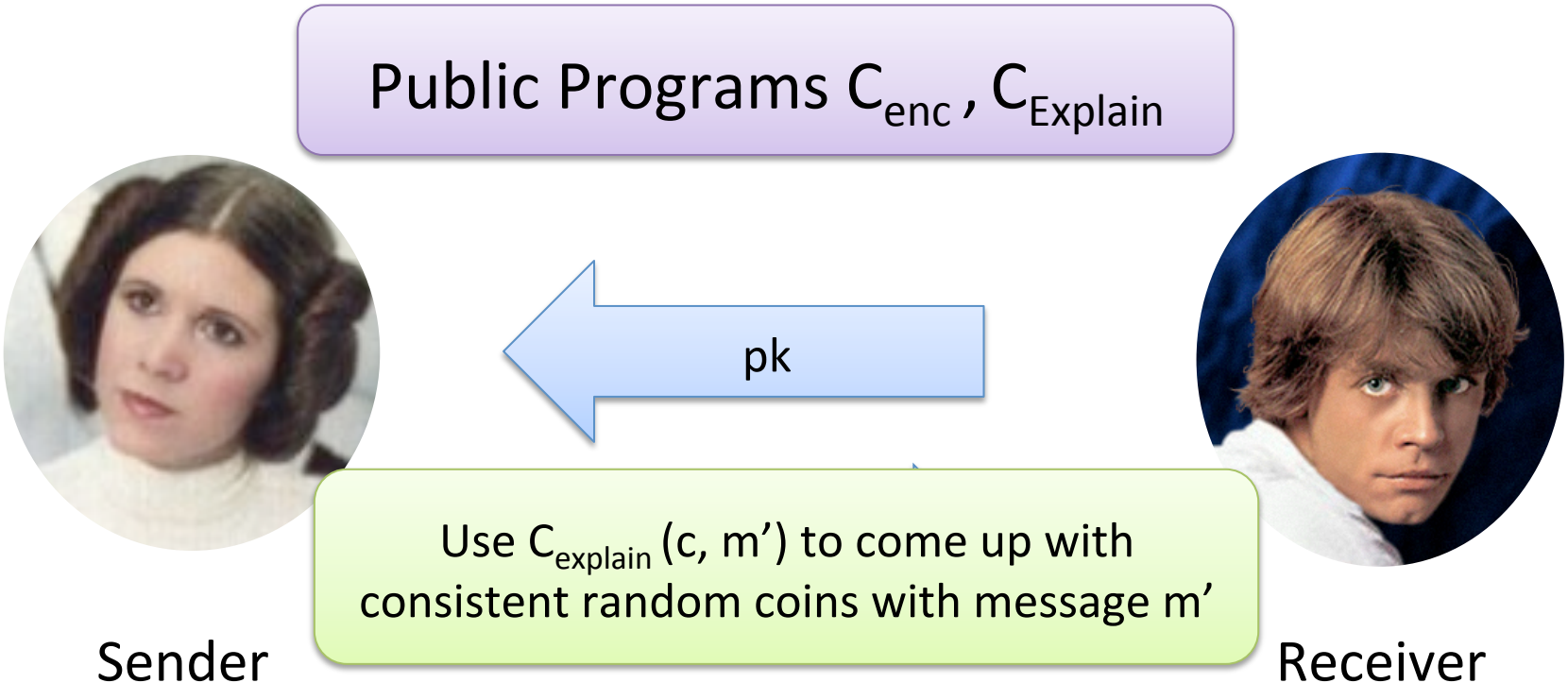
Sender

Receiver

For any m' in the message space, sender can produce a fake opening r' that is consistent with the transcript, i.e. c= Enc(PP, pk,m'; r')

Sahai-Waters' Transformation

- Theorem [SW] Given any encryption E, there exists an upgraded E* that is deniable.



How to Implement Sampling Functionality

- Let Δ be a distribution that hardware samples, i.e. (L,R)←Δ

pk

c_2 = Enc(pk,R)

(pk,sk) <- Gen

How to Implement Sampling Functionality

- Let Δ be a distribution that hardware samples, i.e. (L,R)←Δ

Public Program C_{enc} : on input (pk, r),

1. Sample (L, R) ← Δ
2. Output (c_1,c_2) = (L, Enc(pk, R))

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1. Sample r
2. Run Program C_{enc}(pk, r) and obtain (c_1,c_2) = (L, Enc(pk, R))

(pk,sk) <- Gen

How to Implement Sampling Functionality

- Let Δ be a distribution that hardware samples, i.e. (L,R)←Δ

1. Sample r
2. Run Program C_{enc}(pk, r) and obtain (c_1,c_2) = (L, Enc(pk, R))

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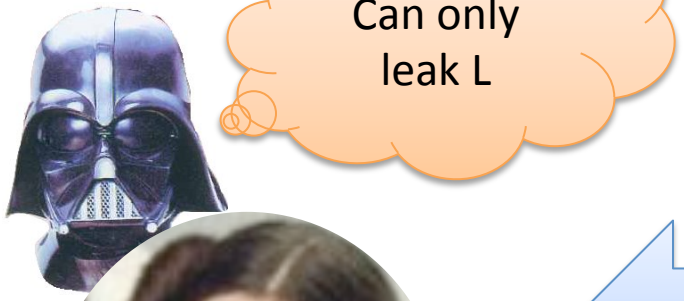
Can only leak R

(pk,sk) <- Gen

How to Implement Sampling Functionality

- Let Δ be a distribution that hardware samples, i.e. (L,R)←Δ



Can only leak L

Can only leak R

pk

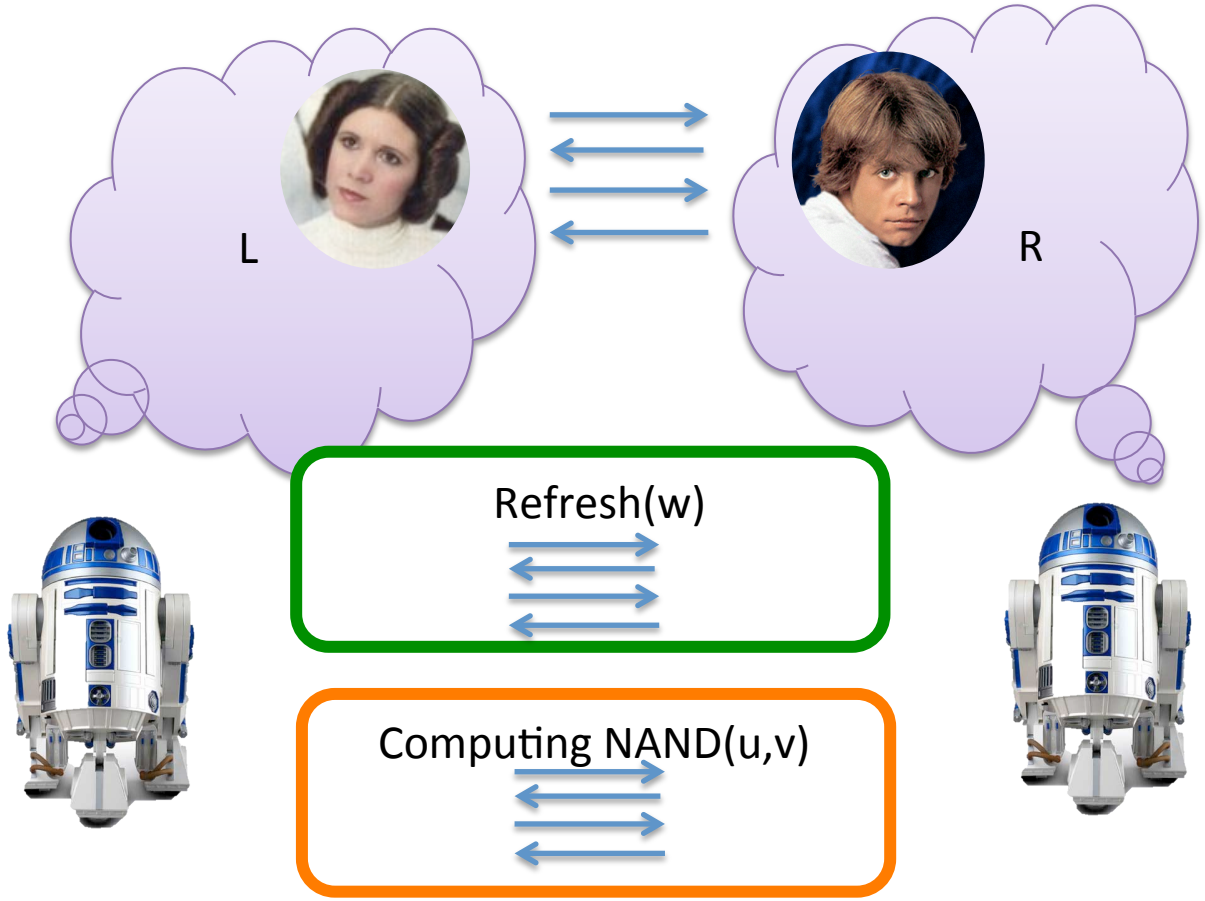
1. Sample r
2. Run Program C_{enc}(pk, r) and obtain (c_1,c_2) = (L, Enc(pk, R))

c_2 = Enc(pk,R)

(pk,sk) <- Gen

Final Scheme

- Replace hardware in DF by the protocol



Conclusion

- A generic design paradigm
  - Step1: design a hardware-based scheme
  - Step2: get rid of the hardware

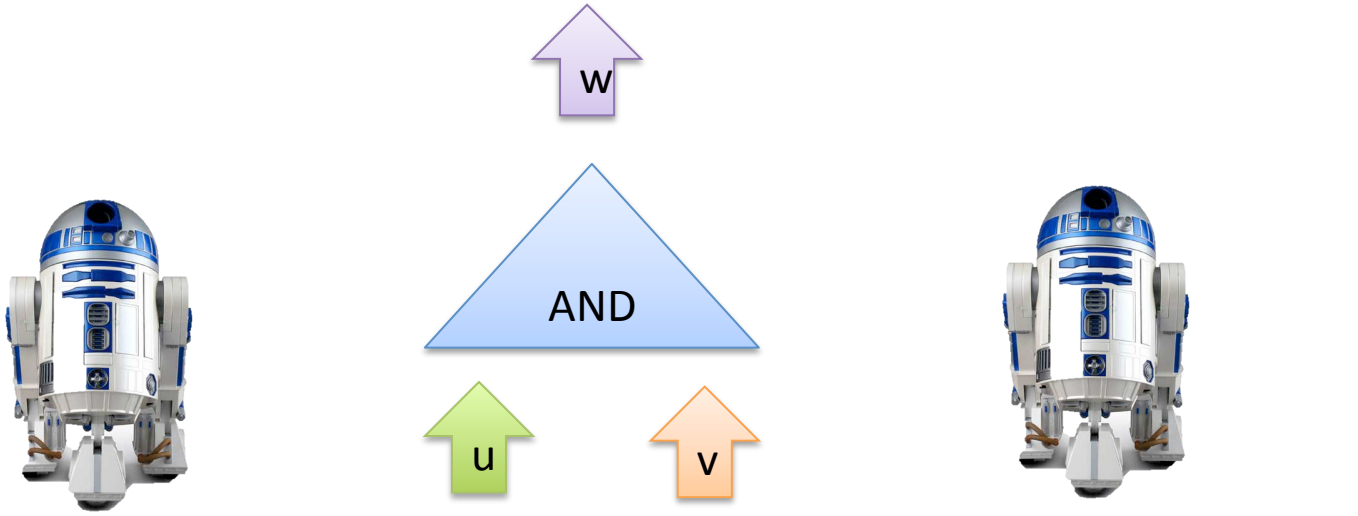
- New techniques to protect computation

Questions?

Thanks!

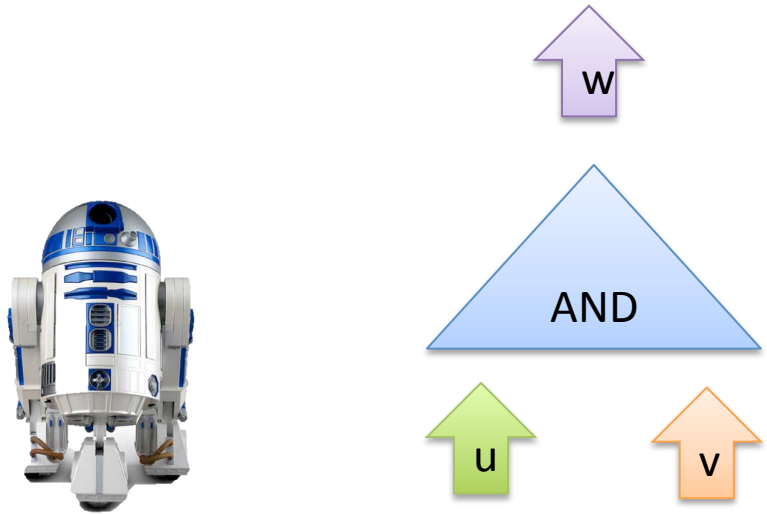
More Concretely

- The sharing is an inner product scheme
  - $u = (u_1, u_2)$ such that their inner product is u



More Concretely

- The sharing is an inner product scheme
  - $u = (u_1, u_2)$ such that their inner product is u
- Getting partial information of the shares does not leak the inner product



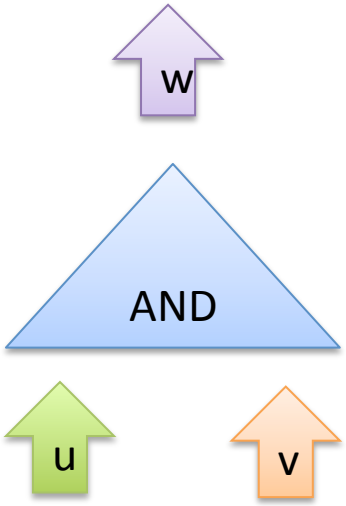
$u_1 = (110)$ $v_1 = (100)$ $u_2 = (111)$ $v_2 = (101)$

More Concretely

- The sharing is an inner product scheme
  - $u = (u_1, u_2)$ such that their inner product is u
- $\langle u_1 \otimes v_1, u_1 \otimes v_2 \rangle = \langle u_1, u_2 \rangle * \langle v_1, v_2 \rangle$

$w_1 = (100\ 100\ 000)$

$u_1 = (110)$ $v_1 = (100)$



$w_2 = (101\ 101\ 101)$

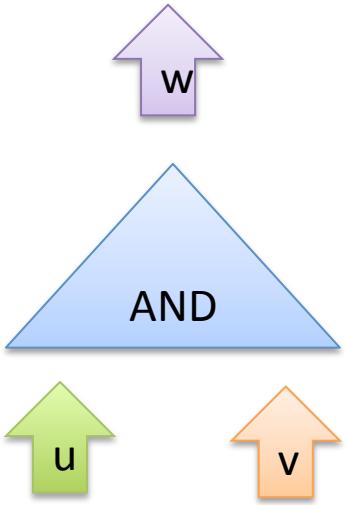
$u_2 = (111)$ $v_2 = (101)$

However…

- Dimension blows up…
- Shares of w are not fresh …

w_1 = (100 100 000)

u_1 = (110) v_1 = (100)



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