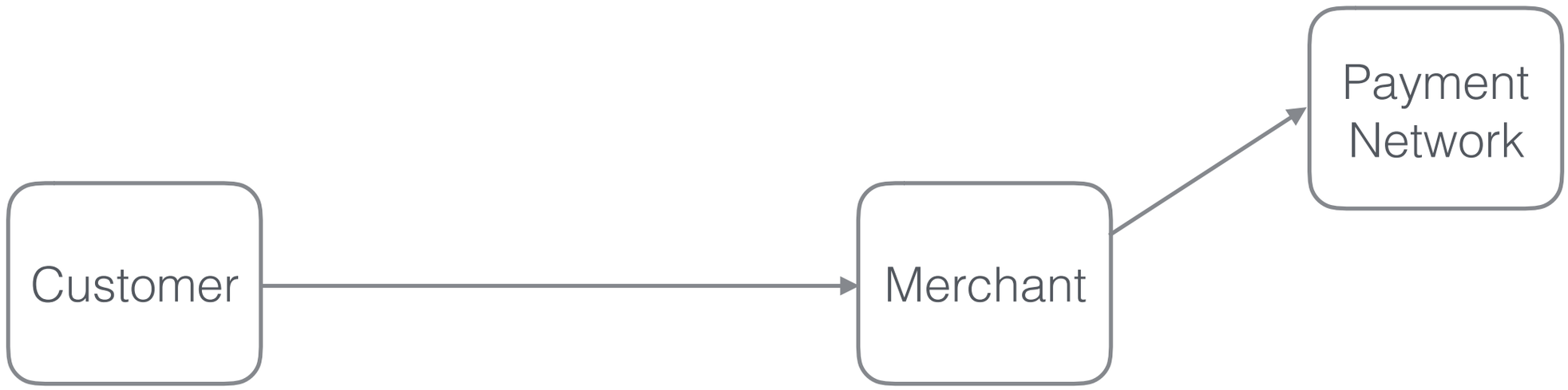
Decentralized
Anonymous
Micropayments

Alessandro Chiesa, Matthew Green, Jingcheng Liu,
Peihan Miao, Ian Miers, **Pratyush Mishra**

http://eprint.iacr.org/2016/1033

Digital Payments



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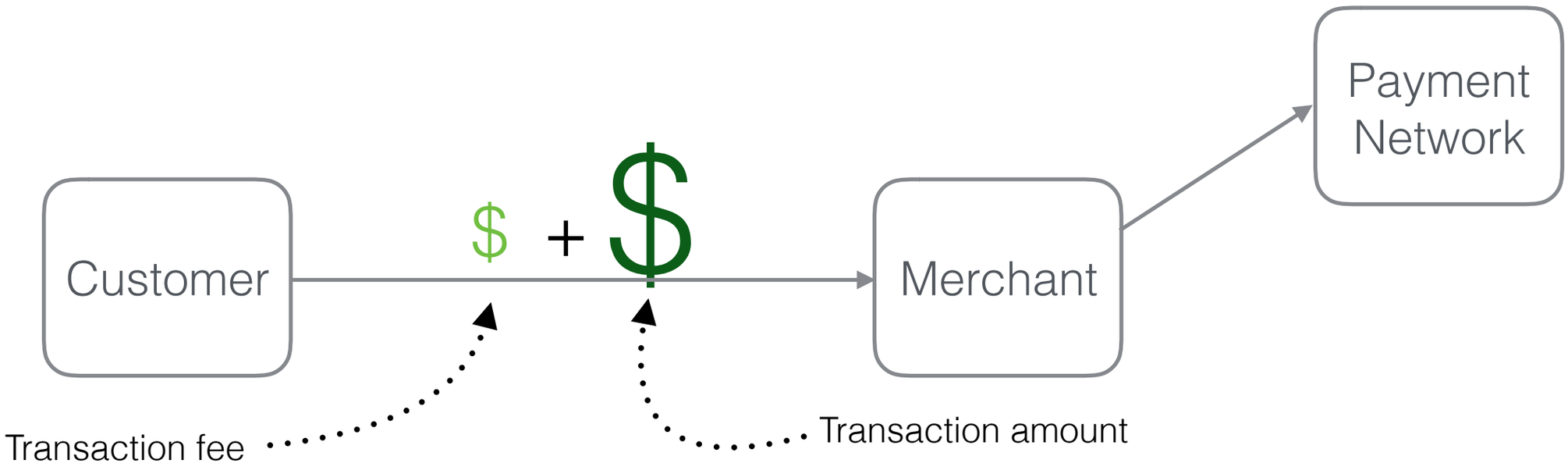

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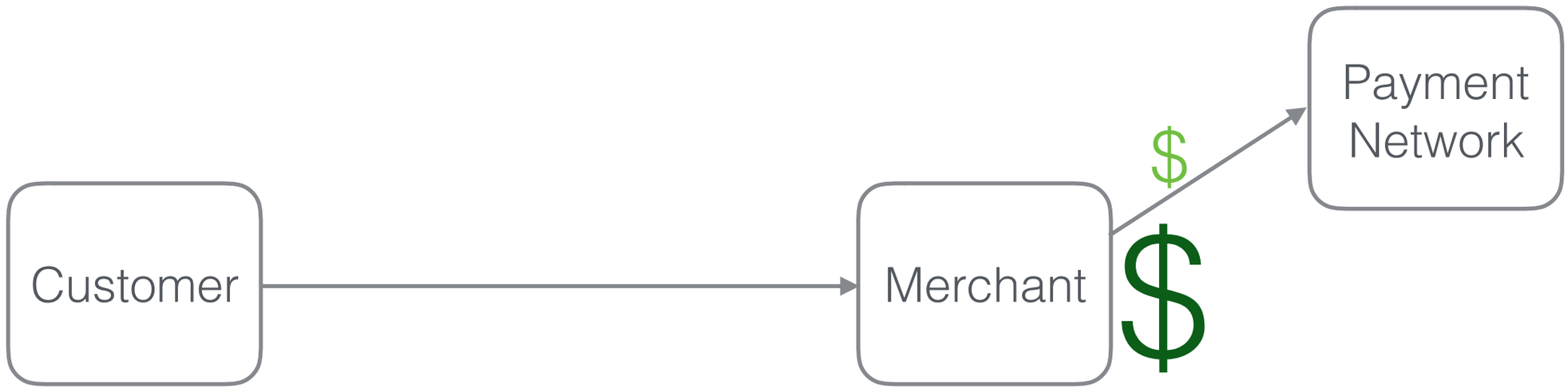

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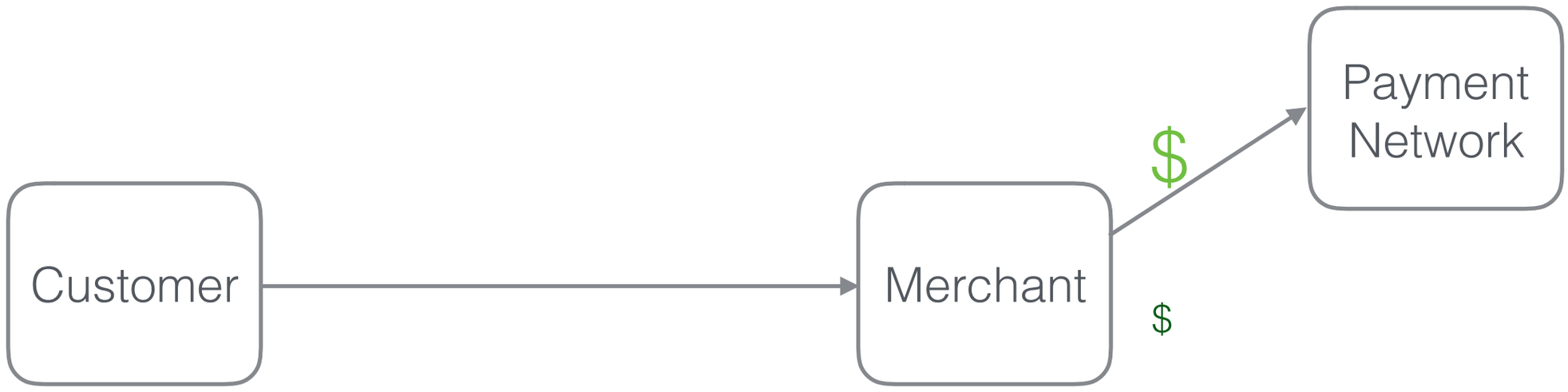

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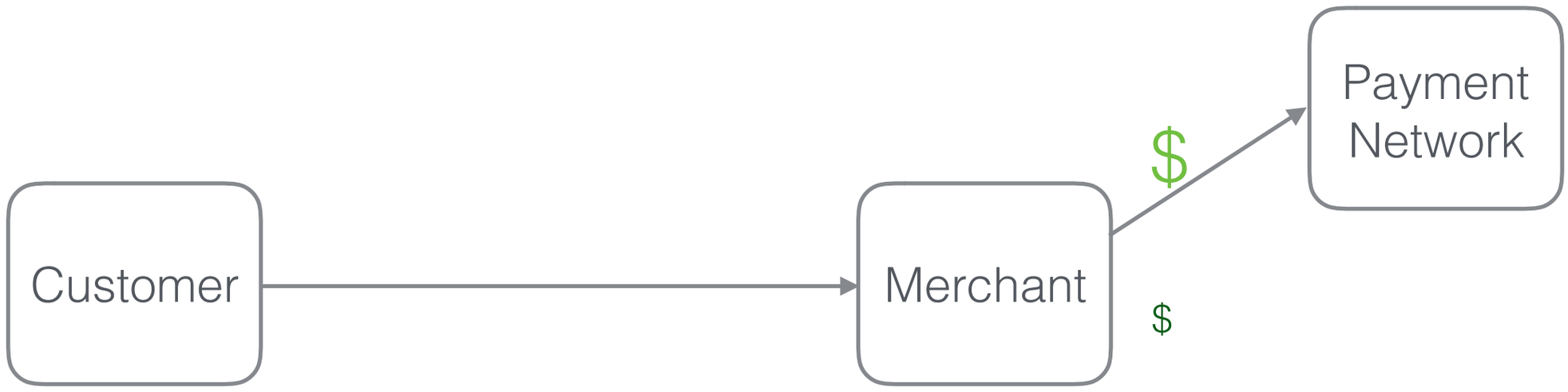

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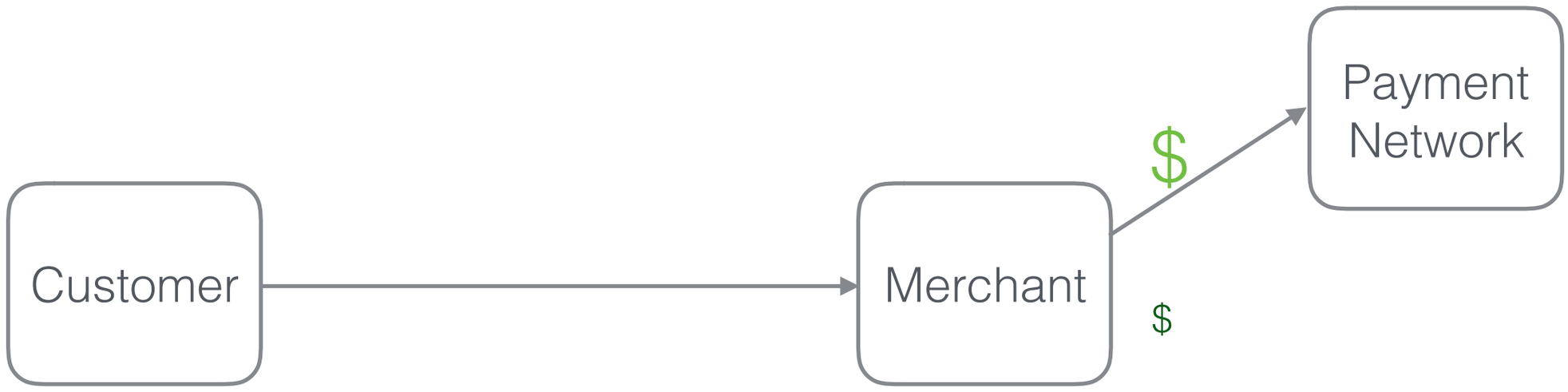

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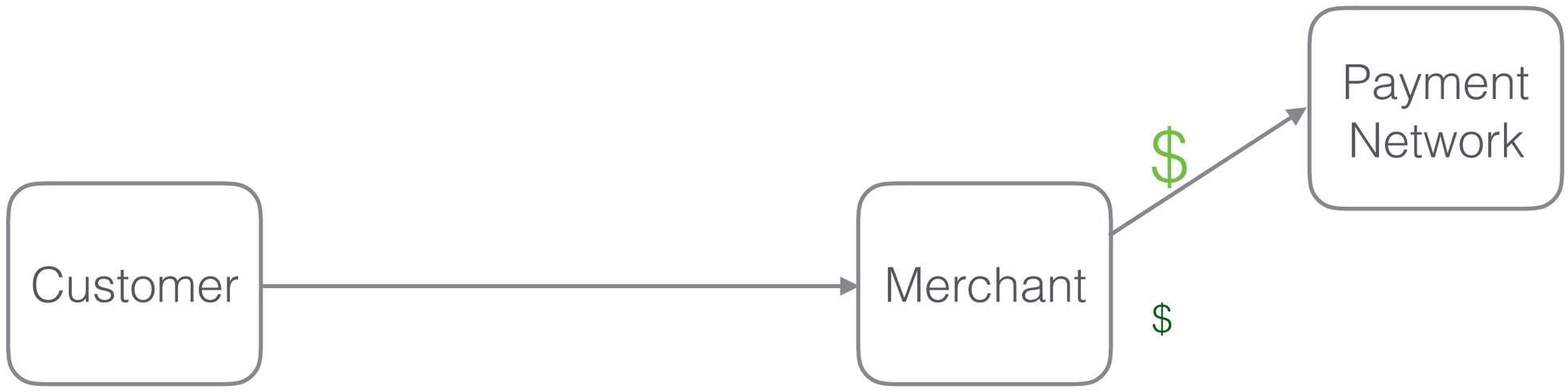

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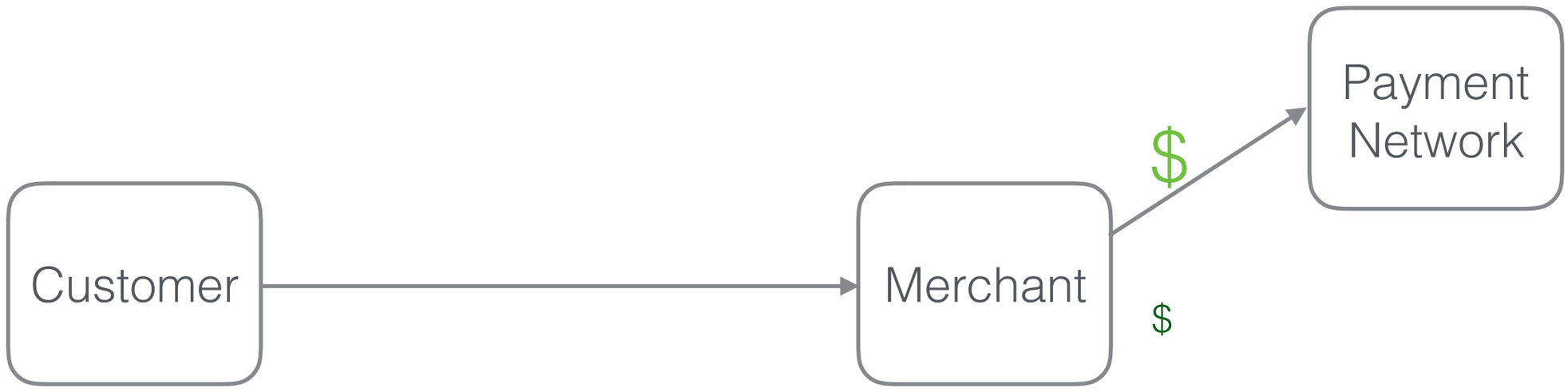

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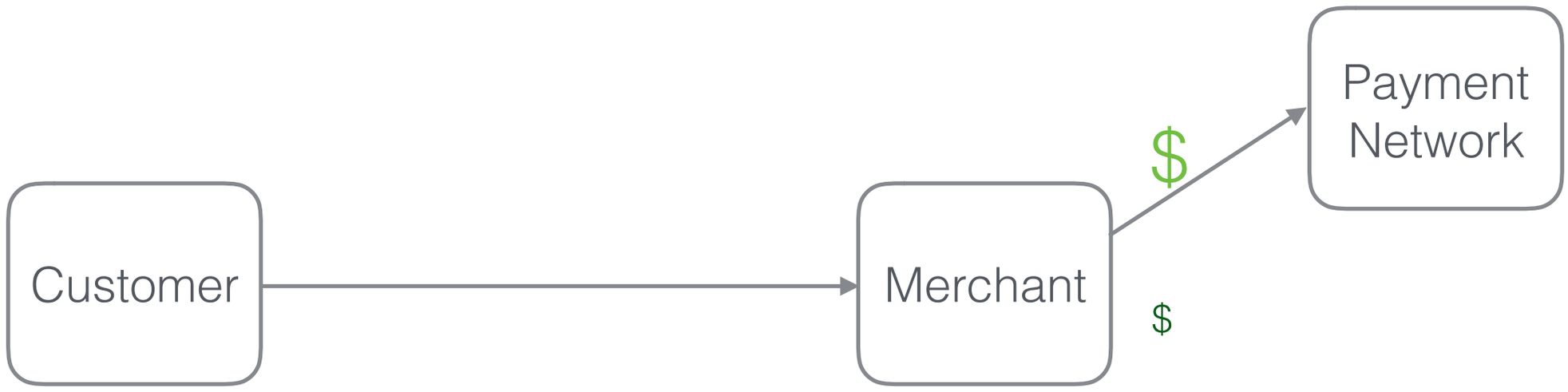

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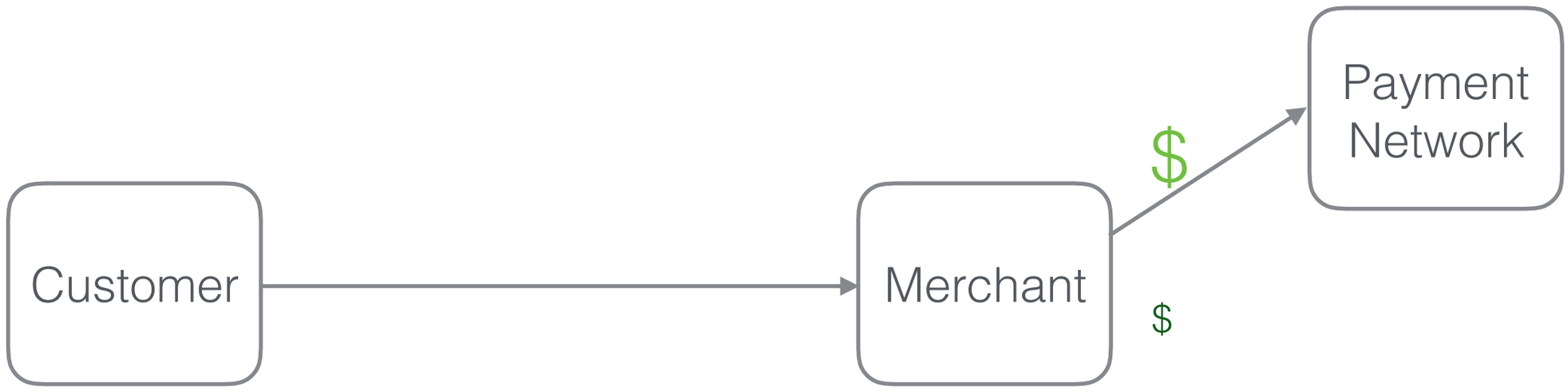

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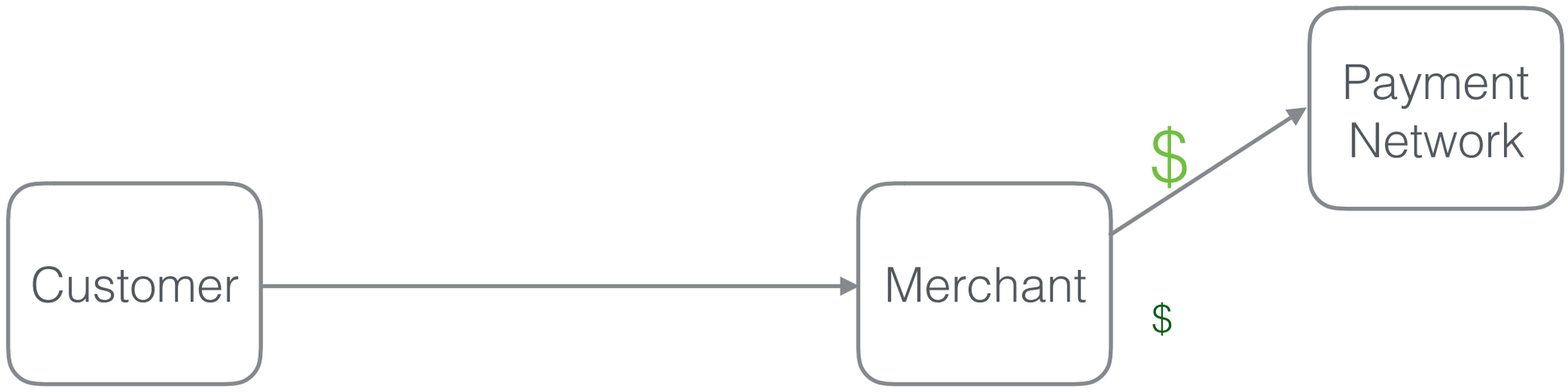

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Why? Requires creating financial relations, meeting regulations, etc.

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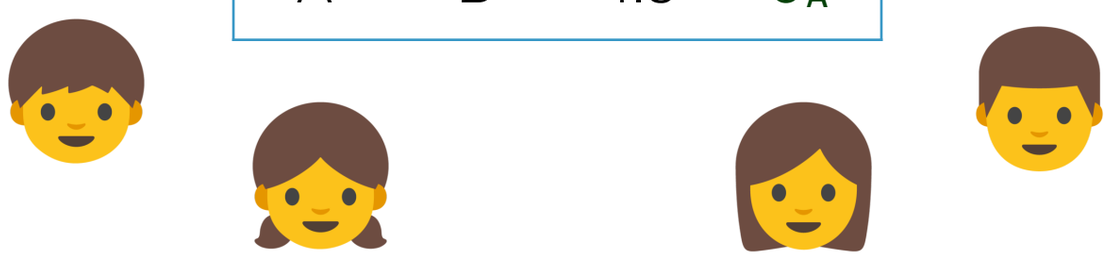

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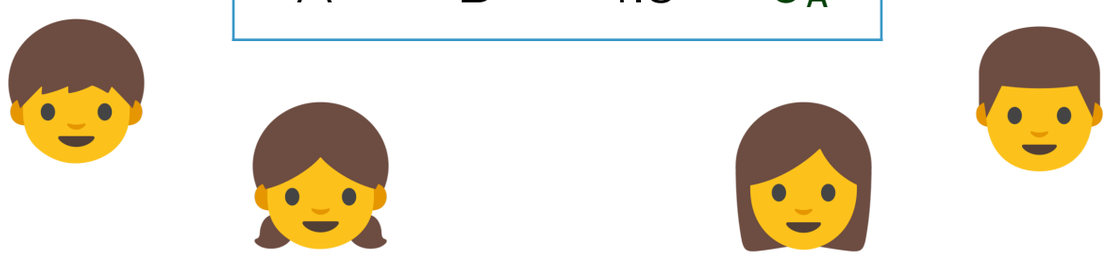

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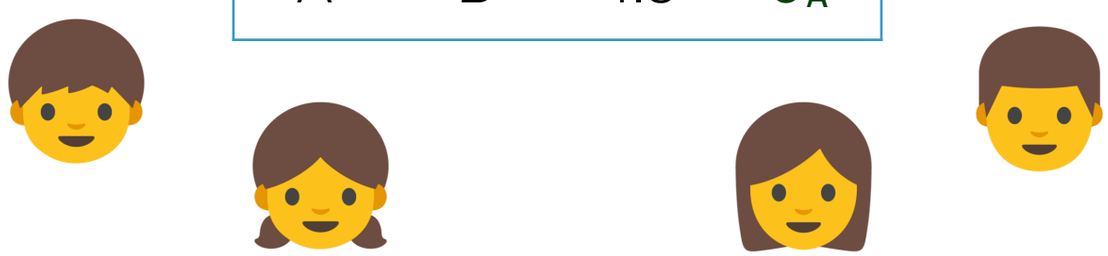

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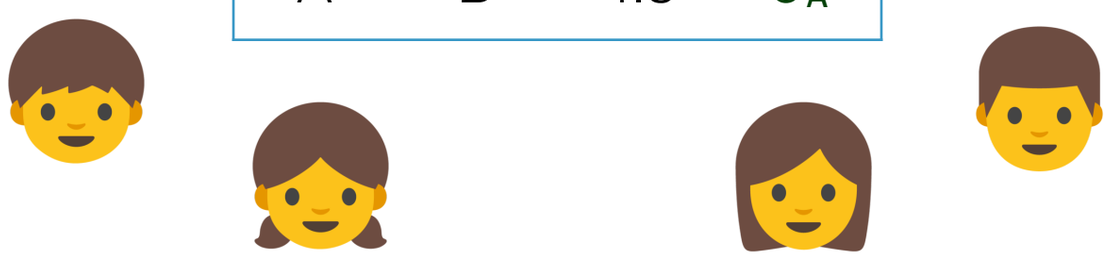

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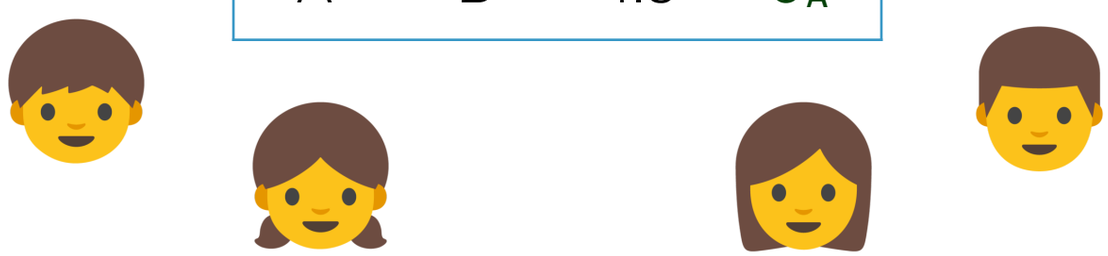

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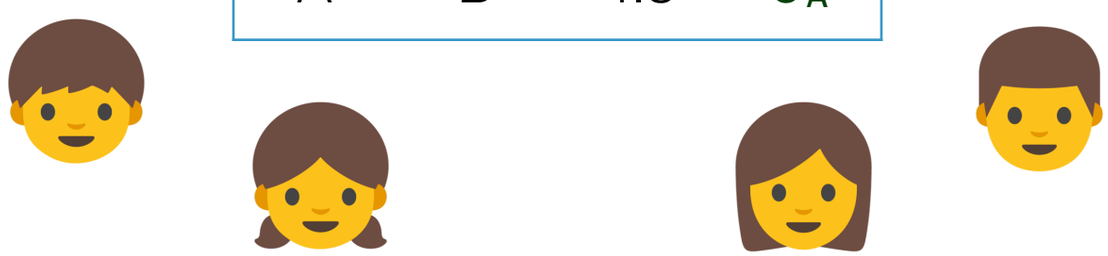

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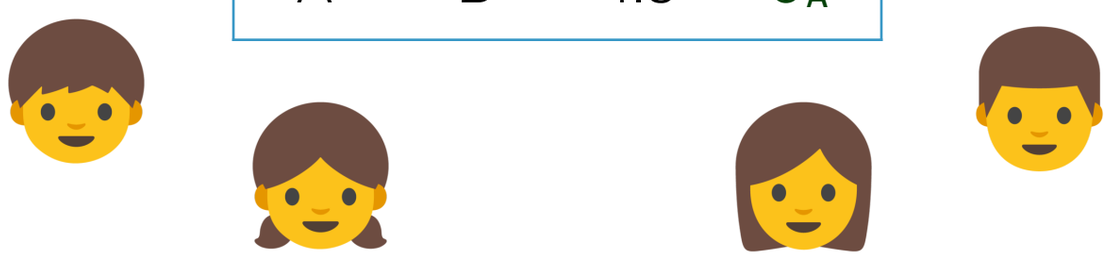

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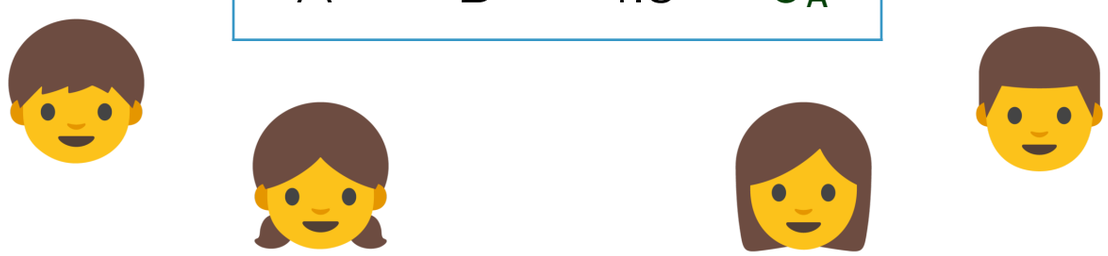

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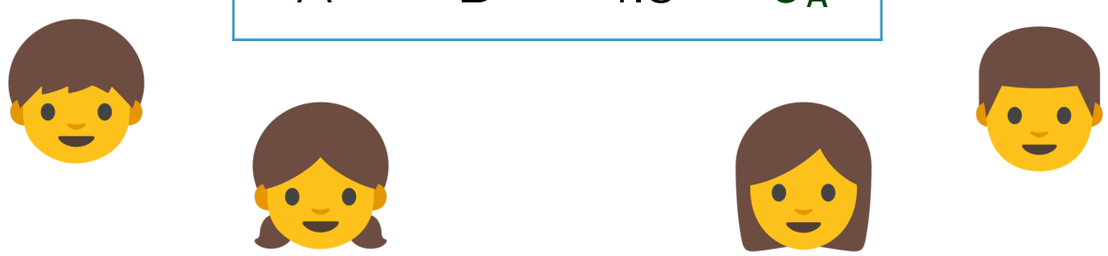

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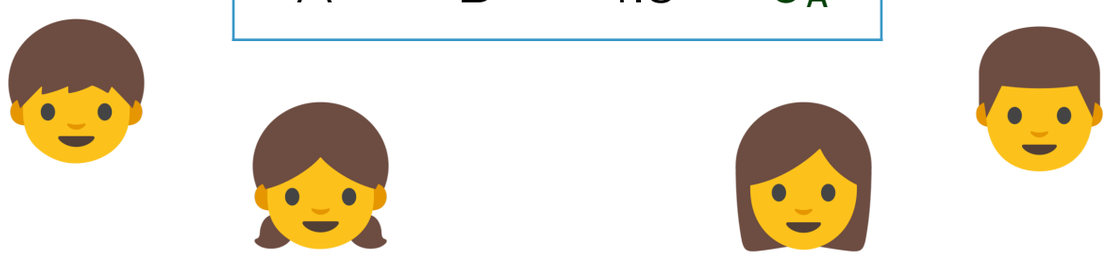

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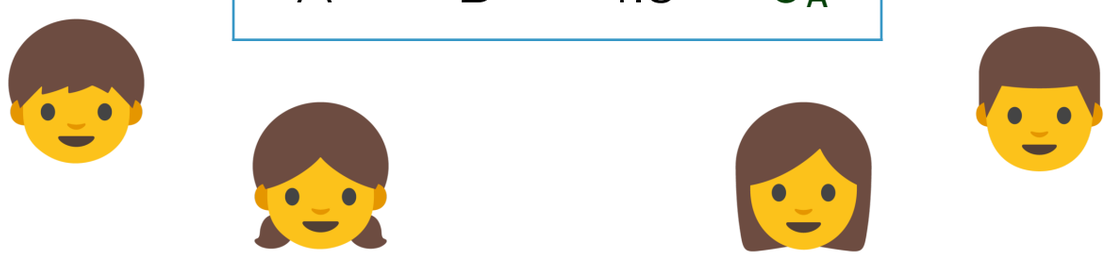

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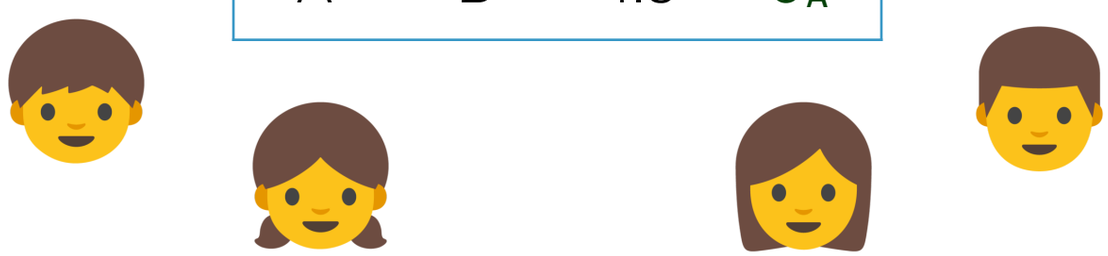

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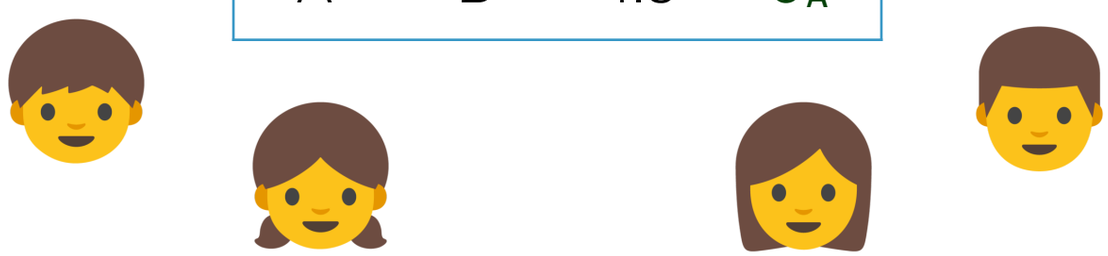

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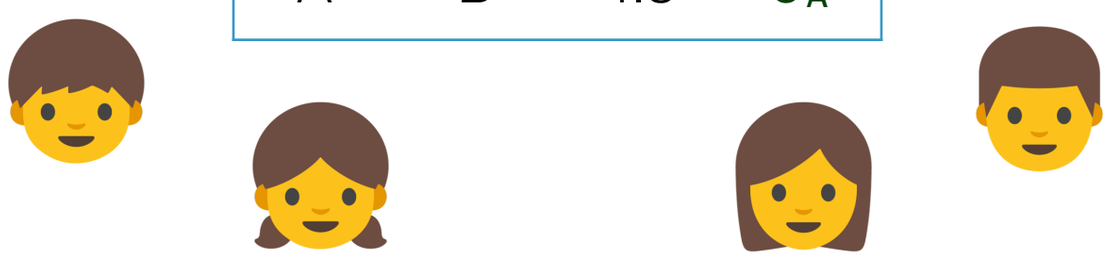

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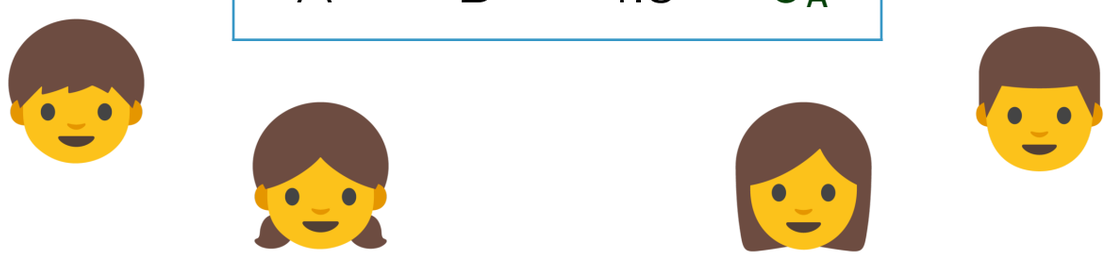

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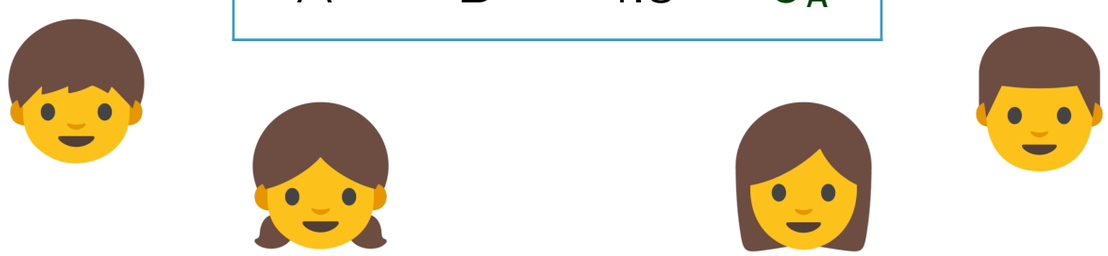

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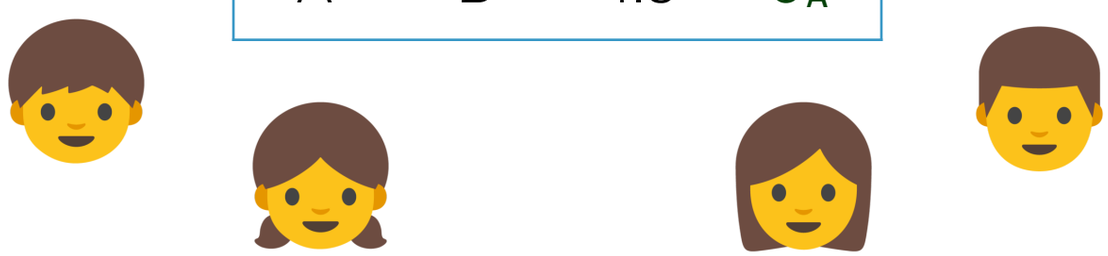

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Zerocash (Oakland 2014)

- Anonymous Bitcoin-like currency.
- **Solves problem 3:** Hides sender, receiver and amount.

Goal

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   - **translucent crypto**: new **fractional message transfer** protocol. (probabilistic)
   - **game theory**: characterization of double-spending.

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$1

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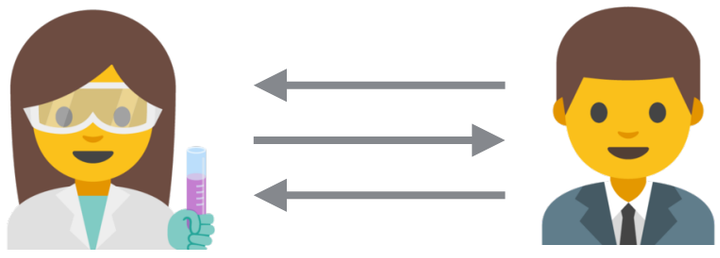

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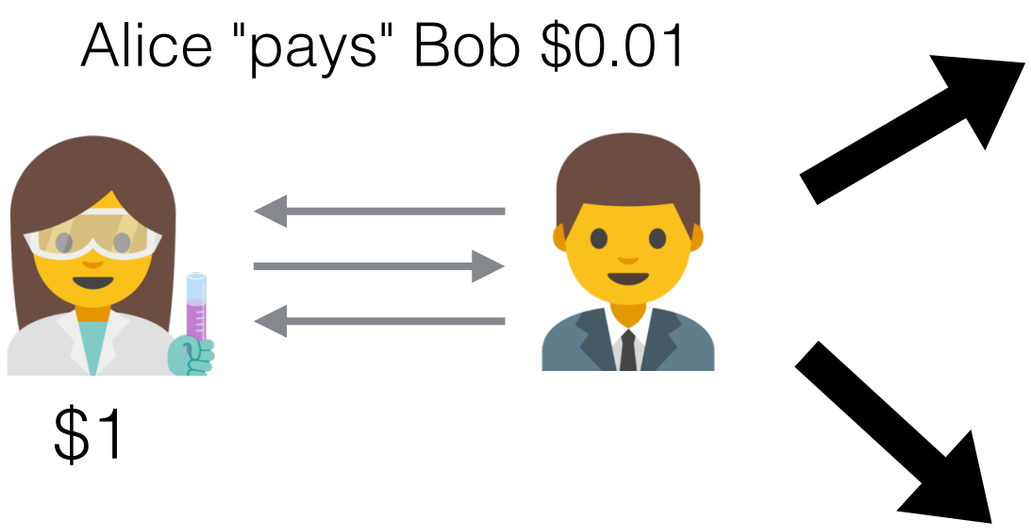

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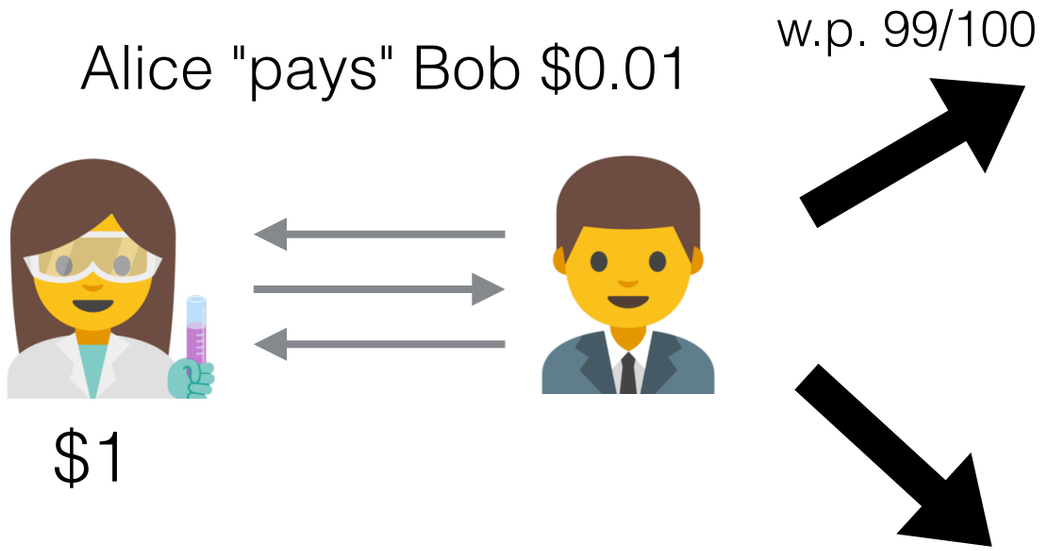
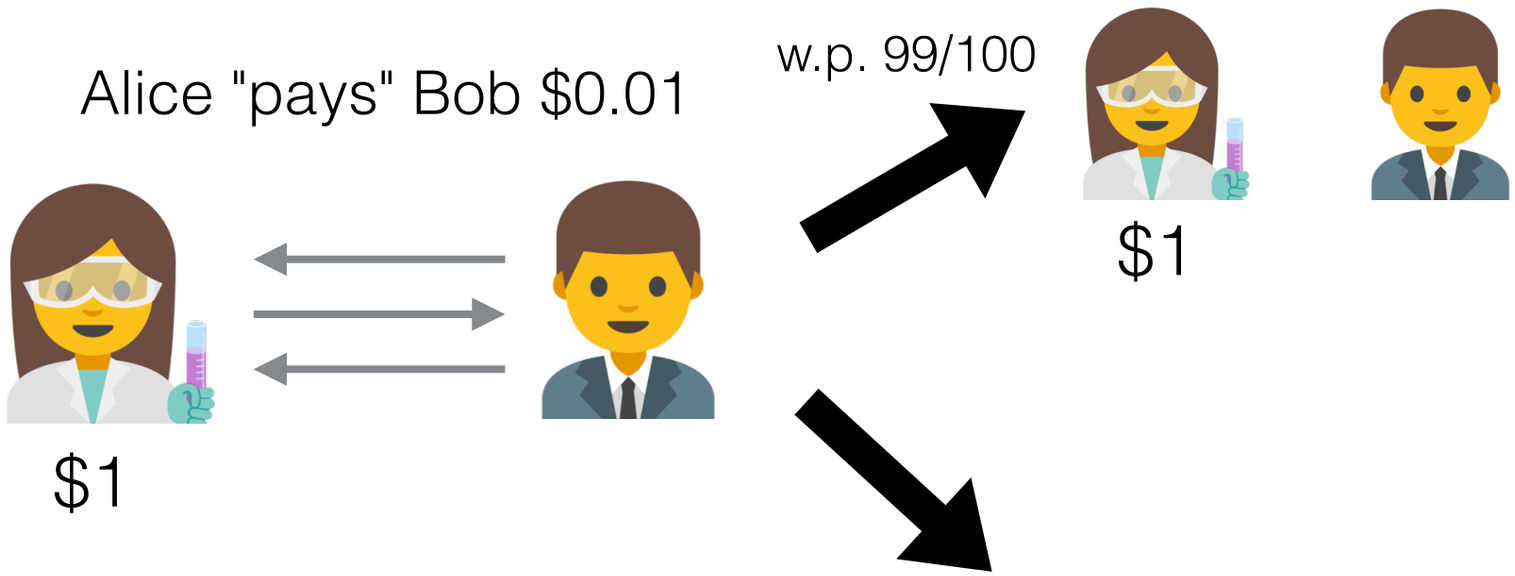


Probabilistic Payments



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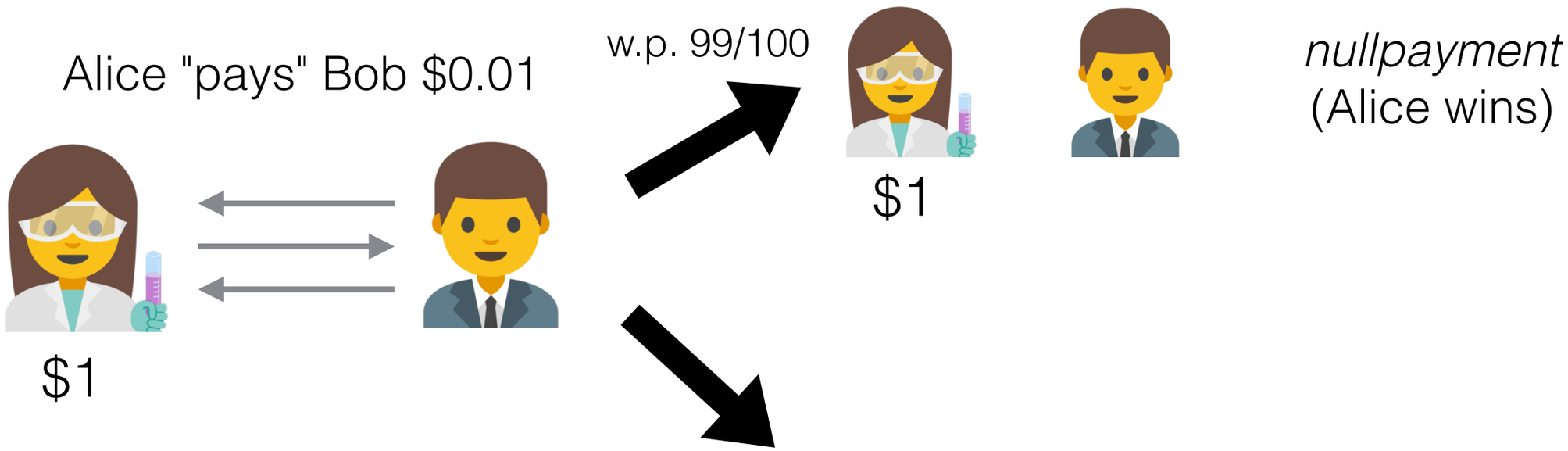
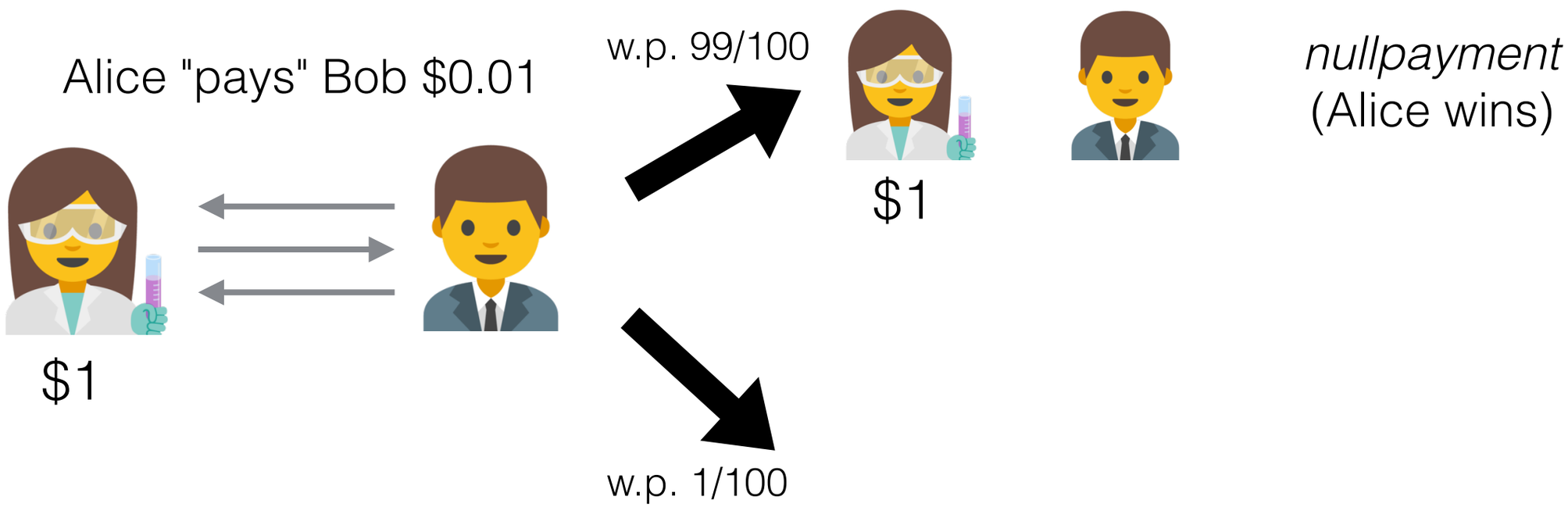
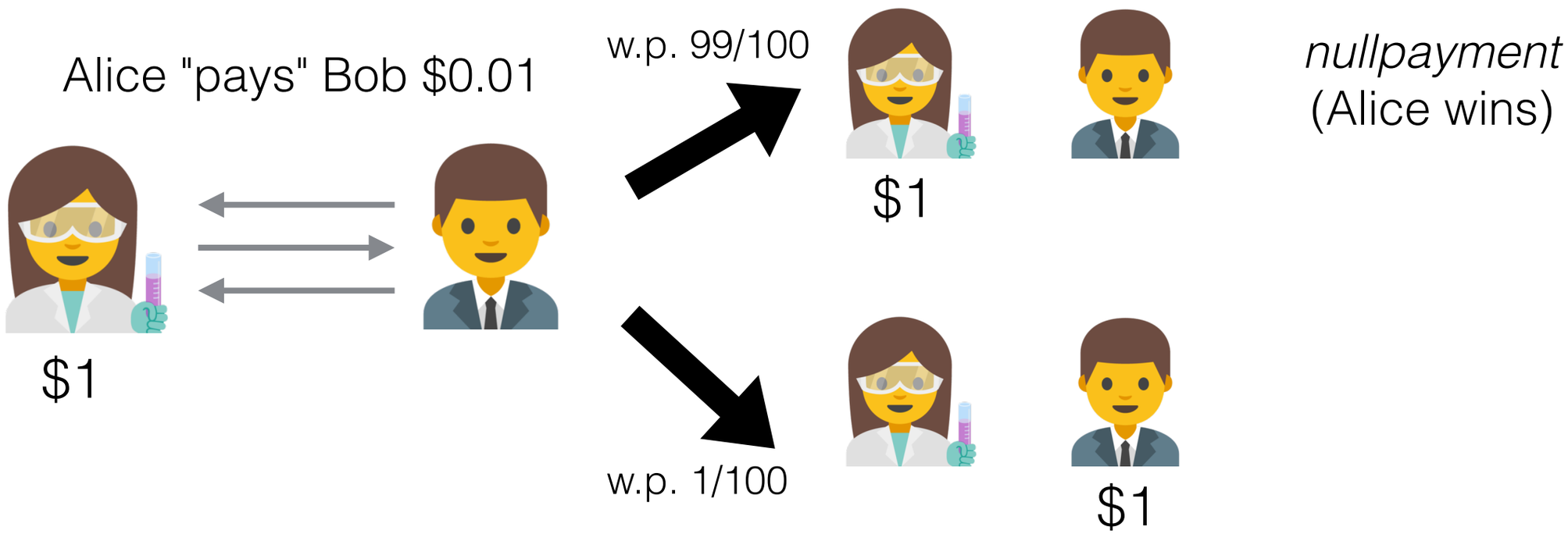


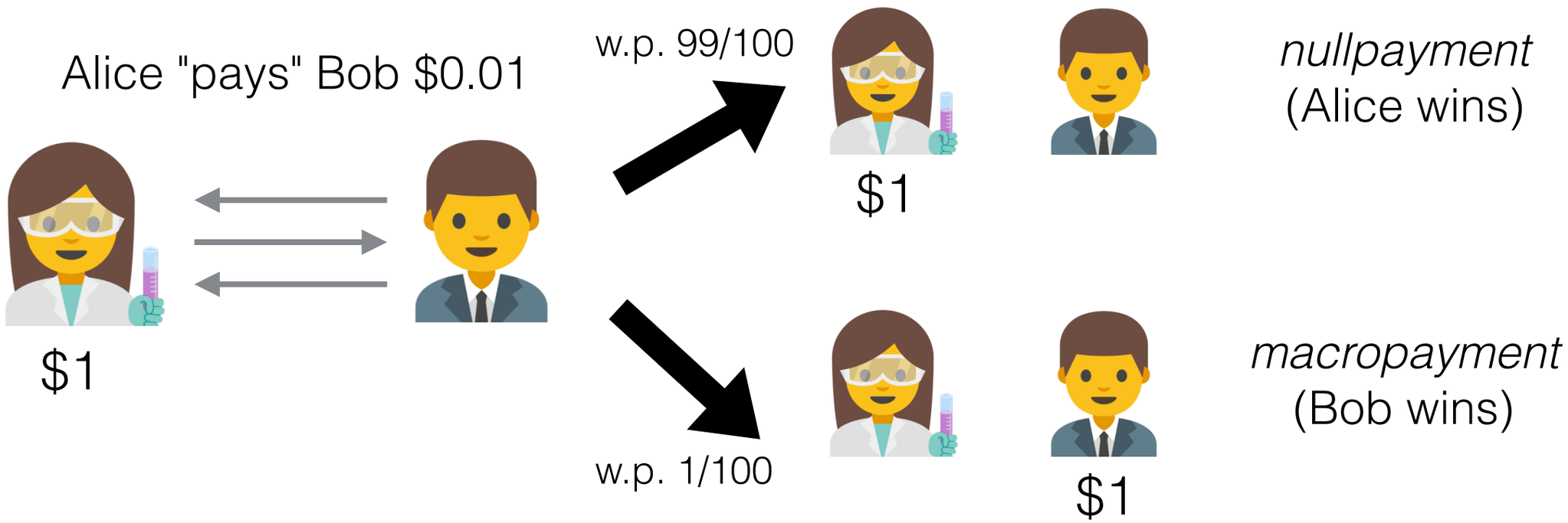
Probabilistic Payments



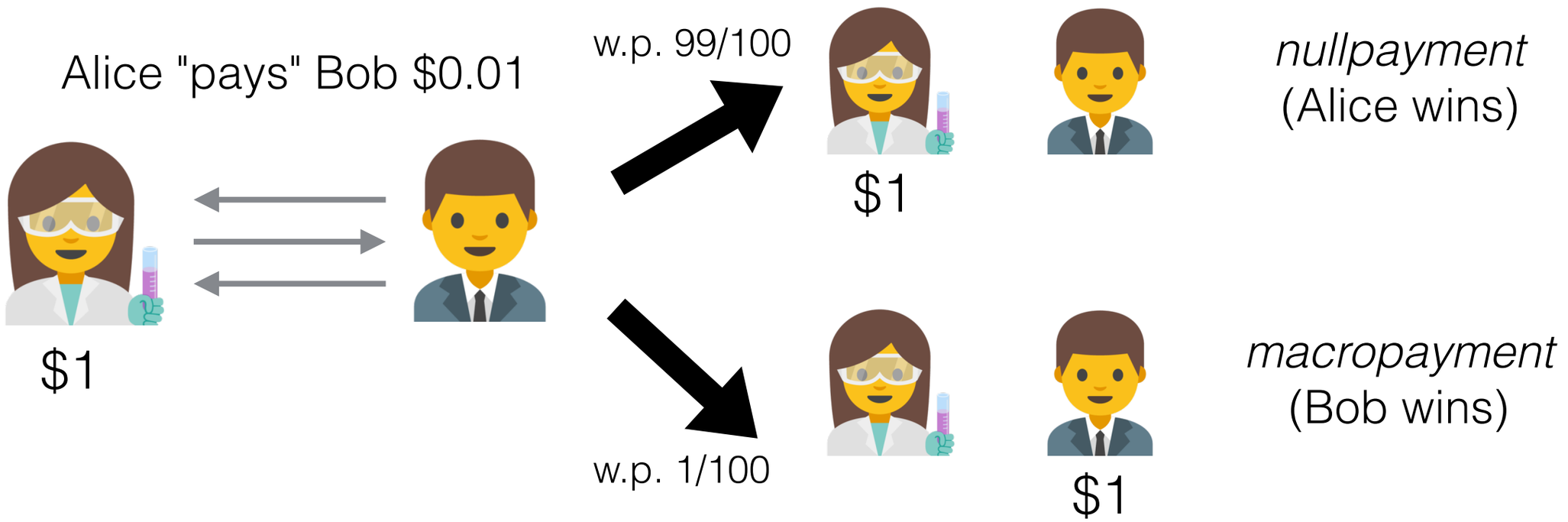
Probabilistic Payments



Probabilistic Payments

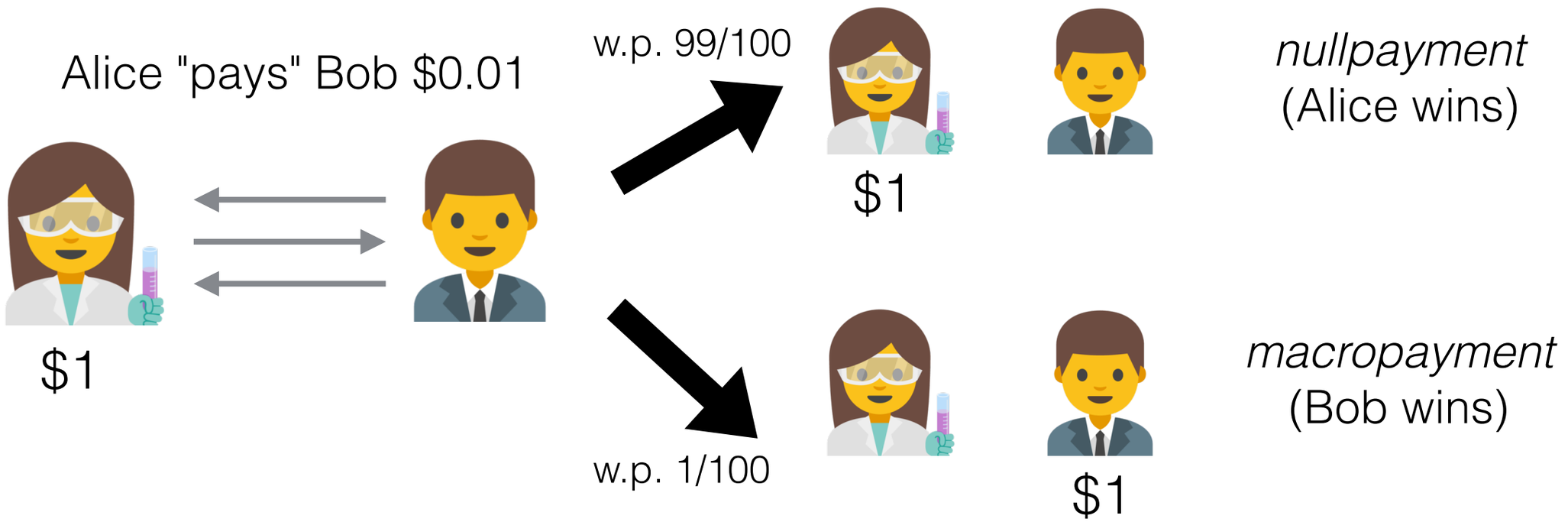


Probabilistic Payments



Probabilistic payments imply micropayments:

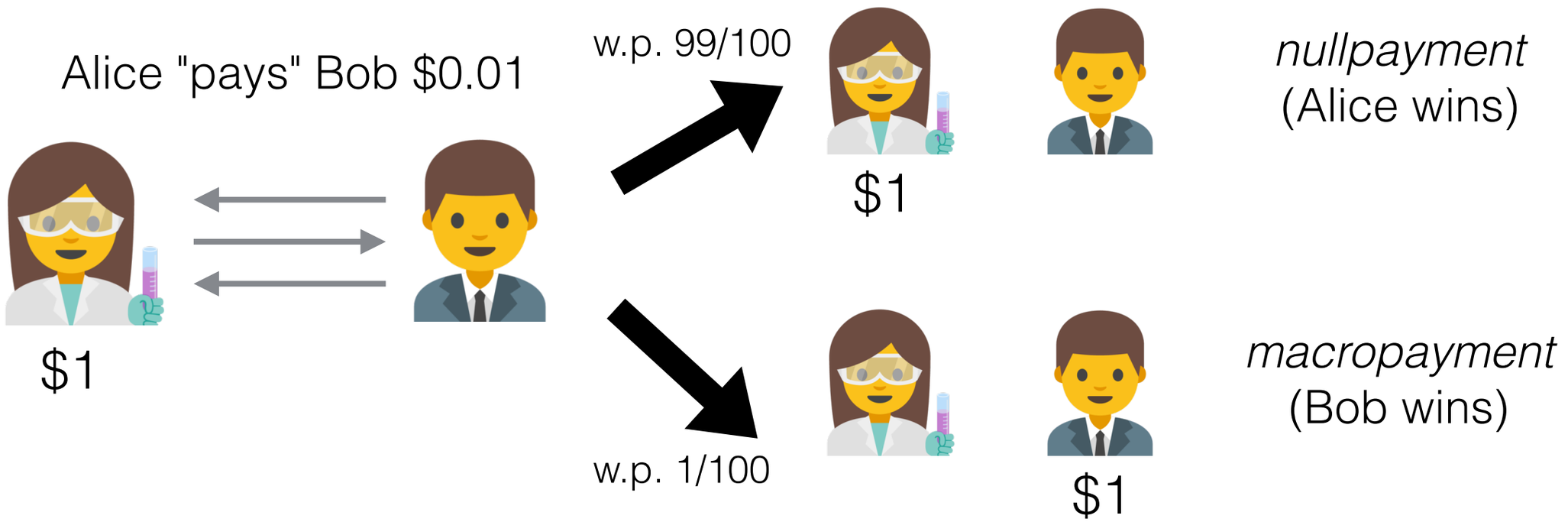
Probabilistic Payments



Probabilistic payments imply micropayments:

Transaction fee is amortized over many payments.

Probabilistic Payments



Probabilistic payments imply micropayments:

Transaction fee is amortized over many payments.

Nullpayments are offline and do not require interaction with payment network.

Building Blocks

Pass-Shelat

Zerocash

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

Zerocash

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

Ledger			
From	To	Amt	Sign
	⋮		
M	N	2.3	σ_M
A	M	10	σ_A

Zerocash

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A

Zerocash

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A

coin-flip

Zerocash

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A

coin-flip

Zerocash

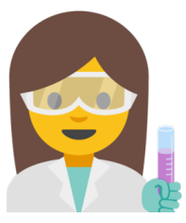
Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E



coin-flip

Zerocash

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

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2. Alice and Bob engage in coin-flip.
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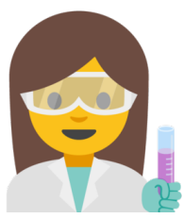
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E



coin-flip

Zerocash

zero knowledge proofs + Bitcoin

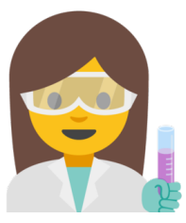
Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E



coin-flip

Zerocash

zero knowledge proofs + Bitcoin

pk_A, sk_A

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2

pk_B, sk_B

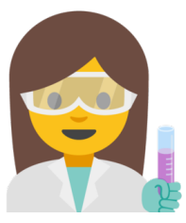
Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E



coin-flip

Zerocash

zero knowledge proofs + Bitcoin

1. Alice owns coin c_1 with comm cm_1.

pk_A, sk_A

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2

pk_B, sk_B

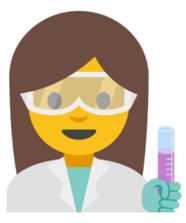
Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
	⋮		
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E



coin-flip

Zerocash

zero knowledge proofs + Bitcoin

1. Alice owns coin c_1 with comm cm_1.
2. To pay Bob, Alice:

pk_A, sk_A

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2

pk_B, sk_B

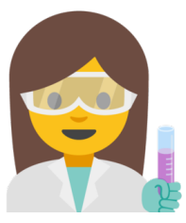
Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E



coin-flip

Zerocash

zero knowledge proofs + Bitcoin

1. Alice owns coin c_1 with comm cm_1.
2. To pay Bob, Alice:
   a) derives sn_1 from c_1 and sk_A.

sn_1

c_1

pk_A, sk_A

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2

pk_B, sk_B

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
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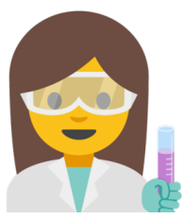


coin-flip

Zerocash

zero knowledge proofs + Bitcoin

1. Alice owns coin c_1 with comm cm_1.
2. To pay Bob, Alice:
   a) derives sn_1 from c_1 and sk_A.
   b) creates new coin c_3 with comm cm_3.

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2

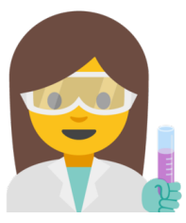
Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E



coin-flip

Zerocash

zero knowledge proofs + Bitcoin

1. Alice owns coin c_1 with comm cm_1.
2. To pay Bob, Alice:
   a) derives sn_1 from c_1 and sk_A.
   b) creates new coin c_3 with comm cm_3.
   c) creates ZK proof π_3 for above.

sn_1

c_1

pk_A, sk_A

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2

pk_B, sk_B

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
	⋮		
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E

coin-flip

Zerocash

zero knowledge proofs + Bitcoin

1. Alice owns coin c_1 with comm cm_1.
2. To pay Bob, Alice:
   a) derives sn_1 from c_1 and sk_A.
   b) creates new coin c_3 with comm cm_3.
   c) creates ZK proof π_3 for above.
   d) appends tx = (sn_1, cm_3, π_3).

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2
sn_1	cm_3	π_3

Building Blocks

Pass-Shelat

coin-flipping + Bitcoin

1. Alice escrows v.
2. Alice and Bob engage in coin-flip.
3. If Alice wins: she can reuse escrow.
4. If Bob wins: he gets v.

Ledger			
From	To	Amt	Sign
⋮			
M	N	2.3	σ_M
A	M	10	σ_A
A	E	4.3	σ_A
E	B	4.3	σ_E

coin-flip

Zerocash

zero knowledge proofs + Bitcoin

1. Alice owns coin c_1 with comm cm_1.
2. To pay Bob, Alice:
   a) derives sn_1 from c_1 and sk_A.
   b) creates new coin c_3 with comm cm_3.
   c) creates ZK proof π_3 for above.
   d) appends tx = (sn_1, cm_3, π_3).

Cannot link sn_1 with cm_1 without sk_A.

Ledger		
Old	New	Proof
⋮		
8436378	cm_1	π_1
6327690	cm_2	π_2
sn_1	cm_3	π_3

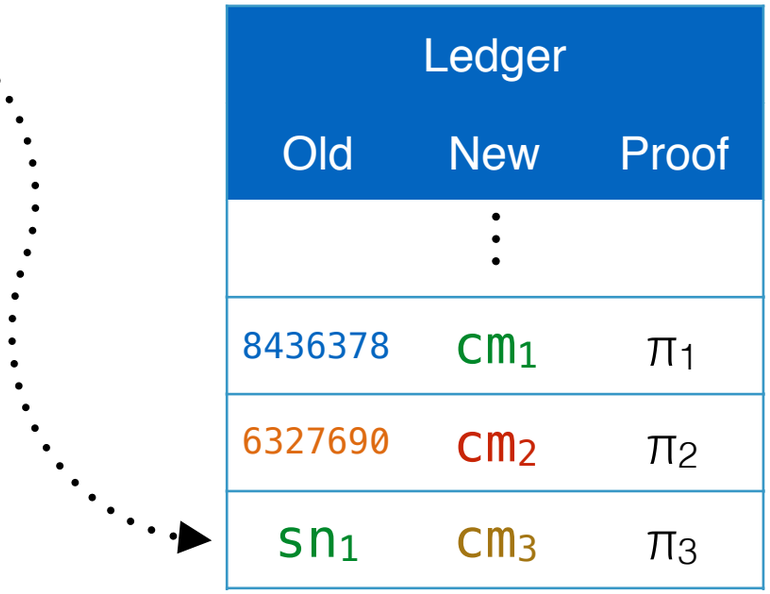
Naive Attempt: PS + Zerocash

Naive Attempt: PS + Zerocash

Ledger		
Old	New	Proof
	⋮	
8436378	cm_1	π_1
6327690	cm_2	π_2

Naive Attempt: PS + Zerocash

1. Alice escrows v in a Zerocash transaction.



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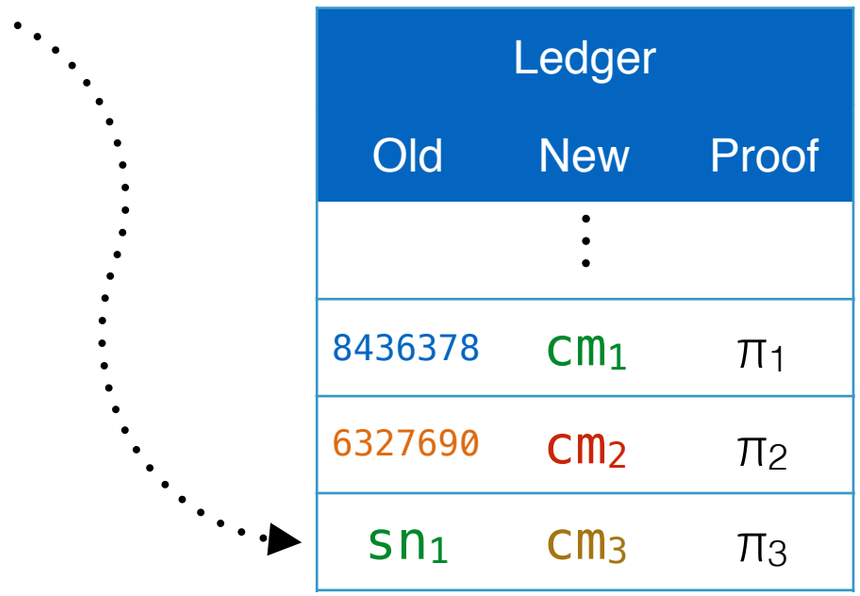

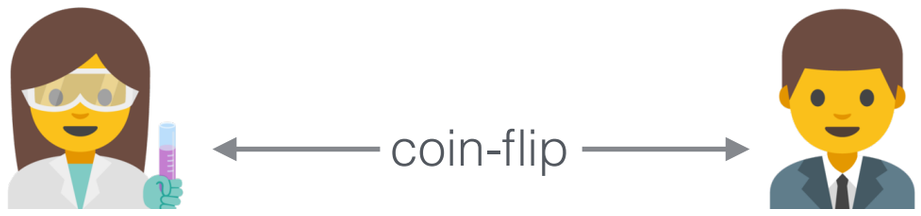

Naive Attempt: PS + Zerocash

1. Alice escrows v in a Zerocash transaction.
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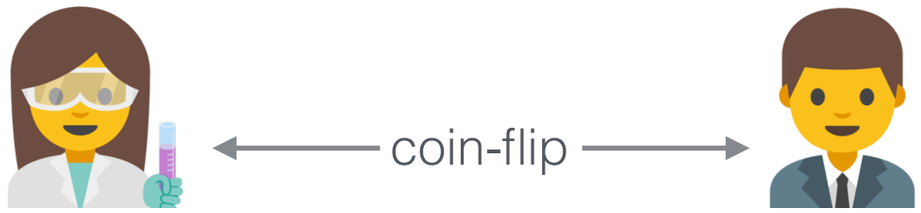
Ledger		
Old	New	Proof
	⋮	
8436378	cm_1	π_1
6327690	cm_2	π_2
sn_1	cm_3	π_3



Naive Attempt: PS + Zerocash

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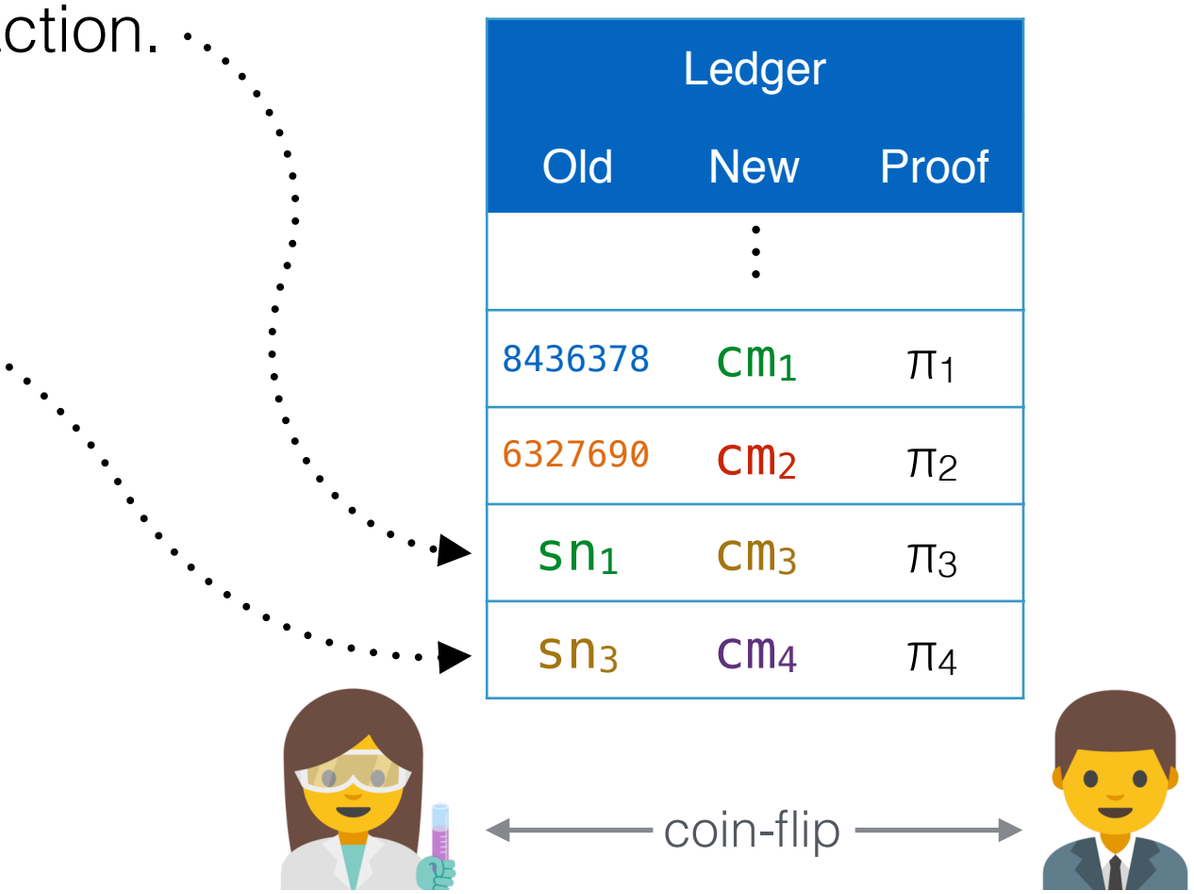

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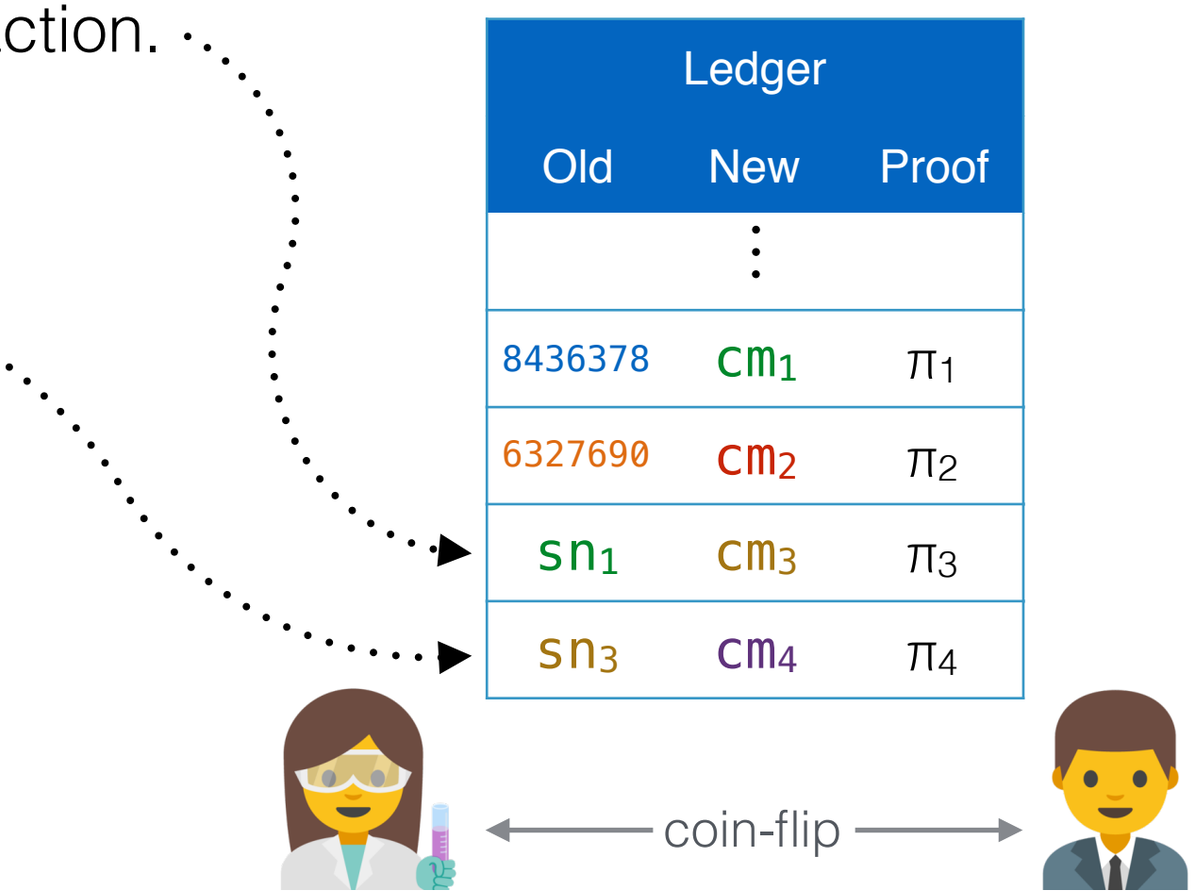


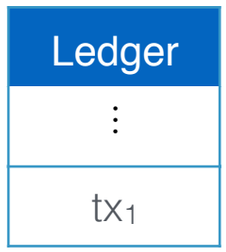
Major Issues:

Linkability

Double Spending

Problem 1: Linkability

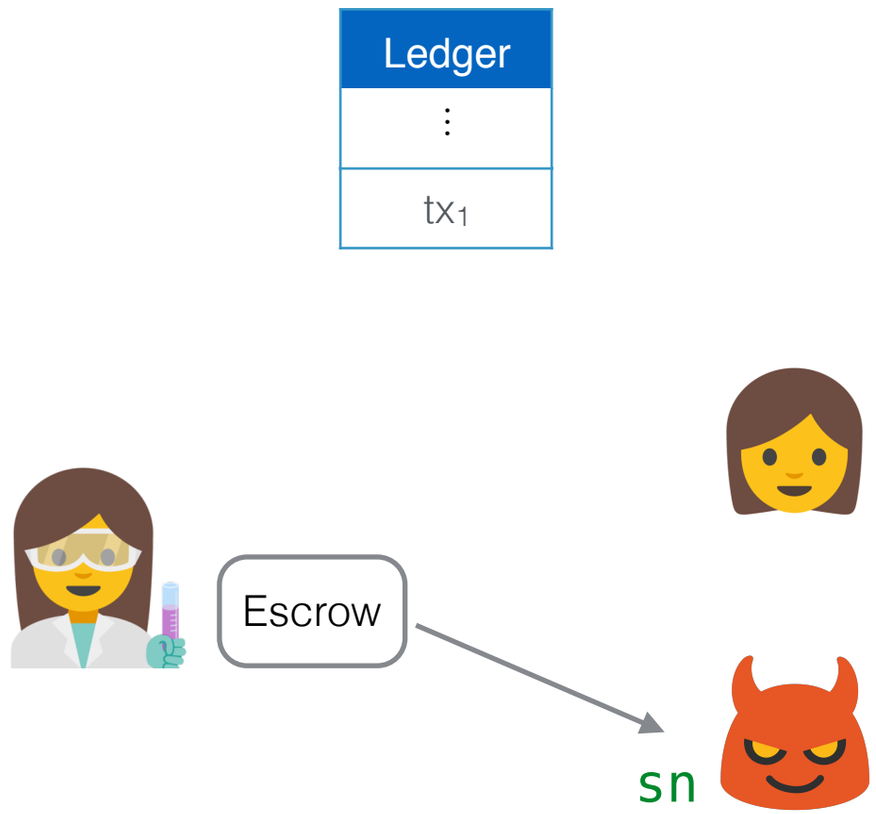
Problem 1: Linkability



Escrow

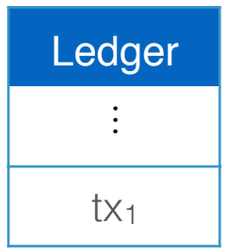
- To amortize transaction fees, Alice has to reuse escrow.
- Bob **always** learns serial number of escrowed coin.

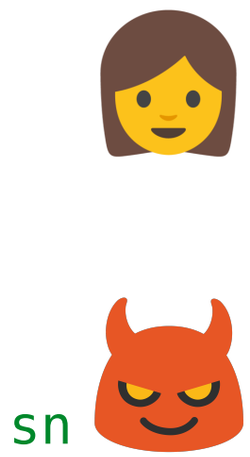
Problem 1: Linkability



- To amortize transaction fees, Alice has to reuse escrow.
- Bob **always** learns serial number of escrowed coin.
  - Can track Alice when she spends coin w/ others.

Problem 1: Linkability





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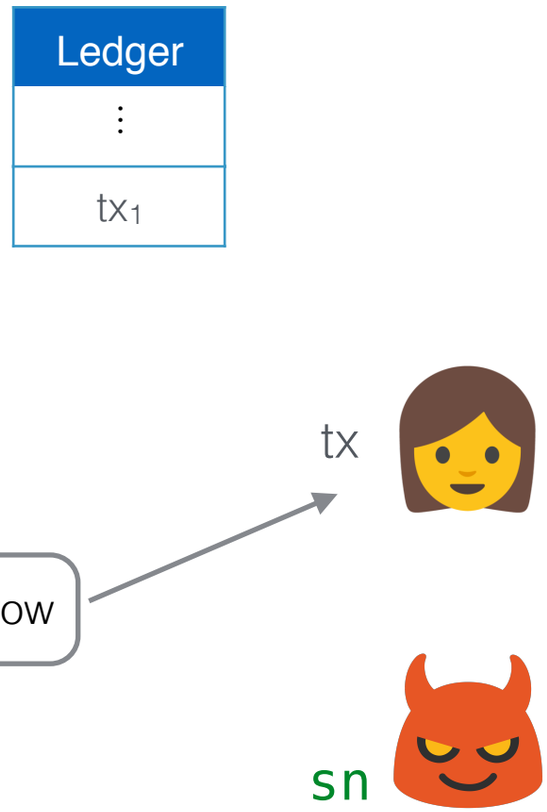

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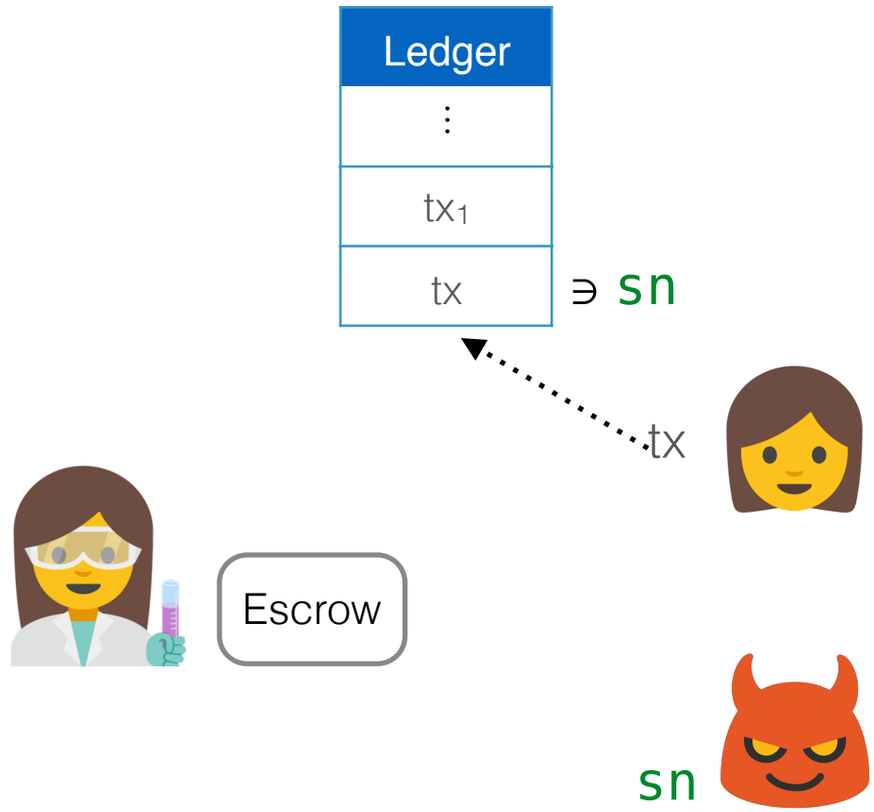
Problem 1: Linkability



- To amortize transaction fees, Alice has to reuse escrow.
- Bob **always** learns serial number of escrowed coin.
  - Can track Alice when she spends coin w/ others.
- Further attacks lead to loss of most privacy.

Solution: Make sn translucent

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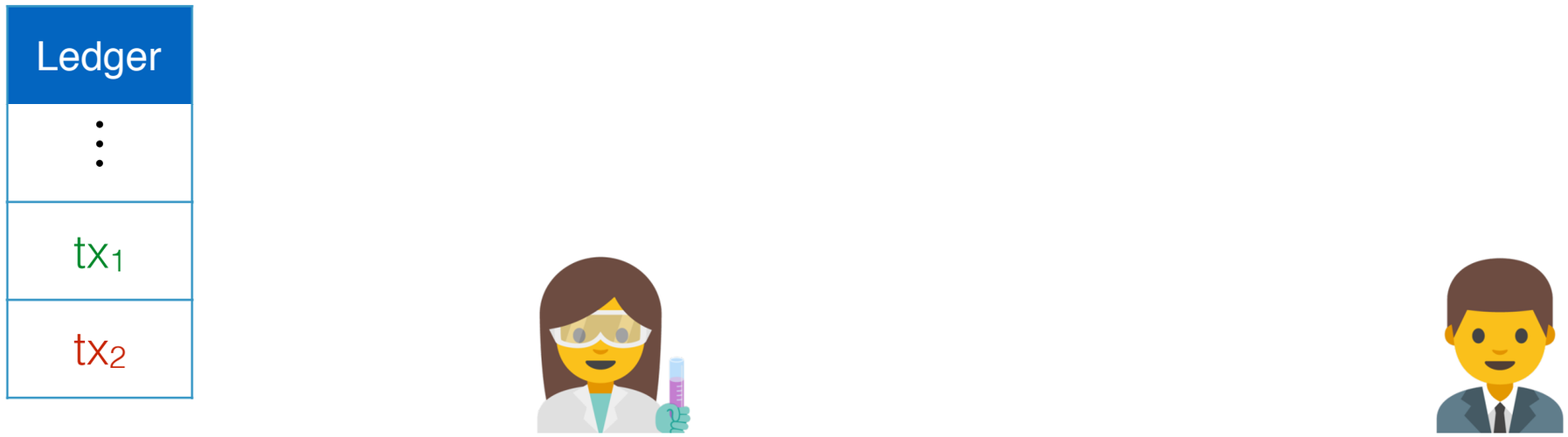
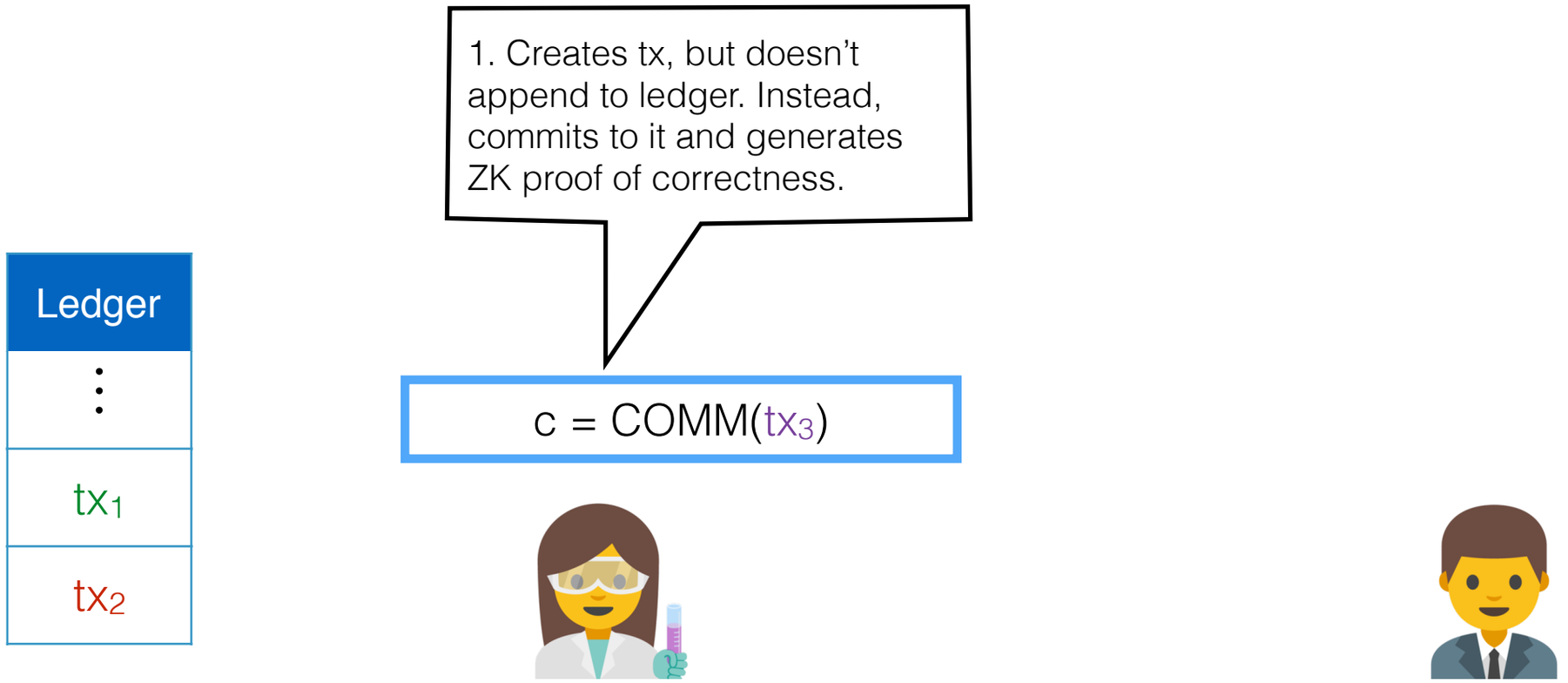
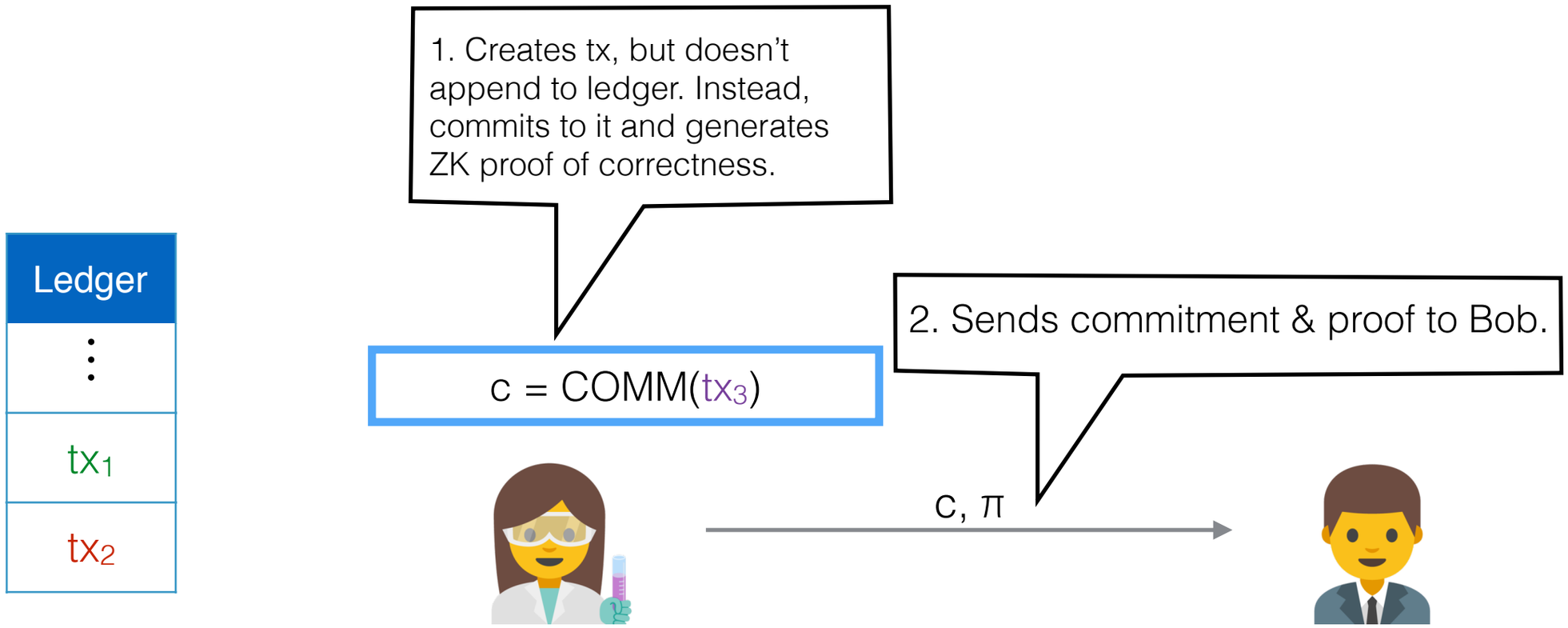


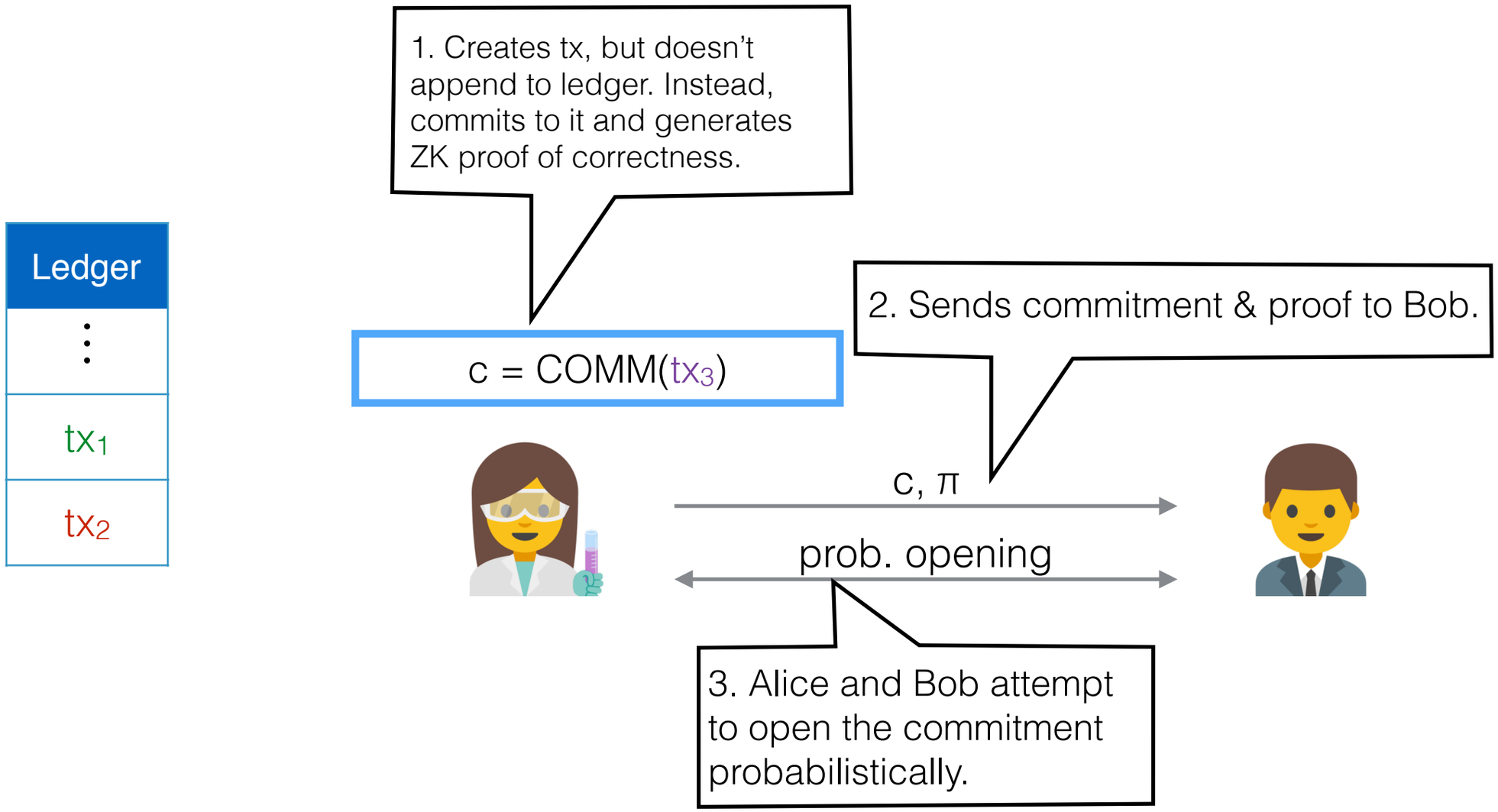
Solution: Make sn translucent



Solution: Make sn translucent



Solution: Make sn translucent



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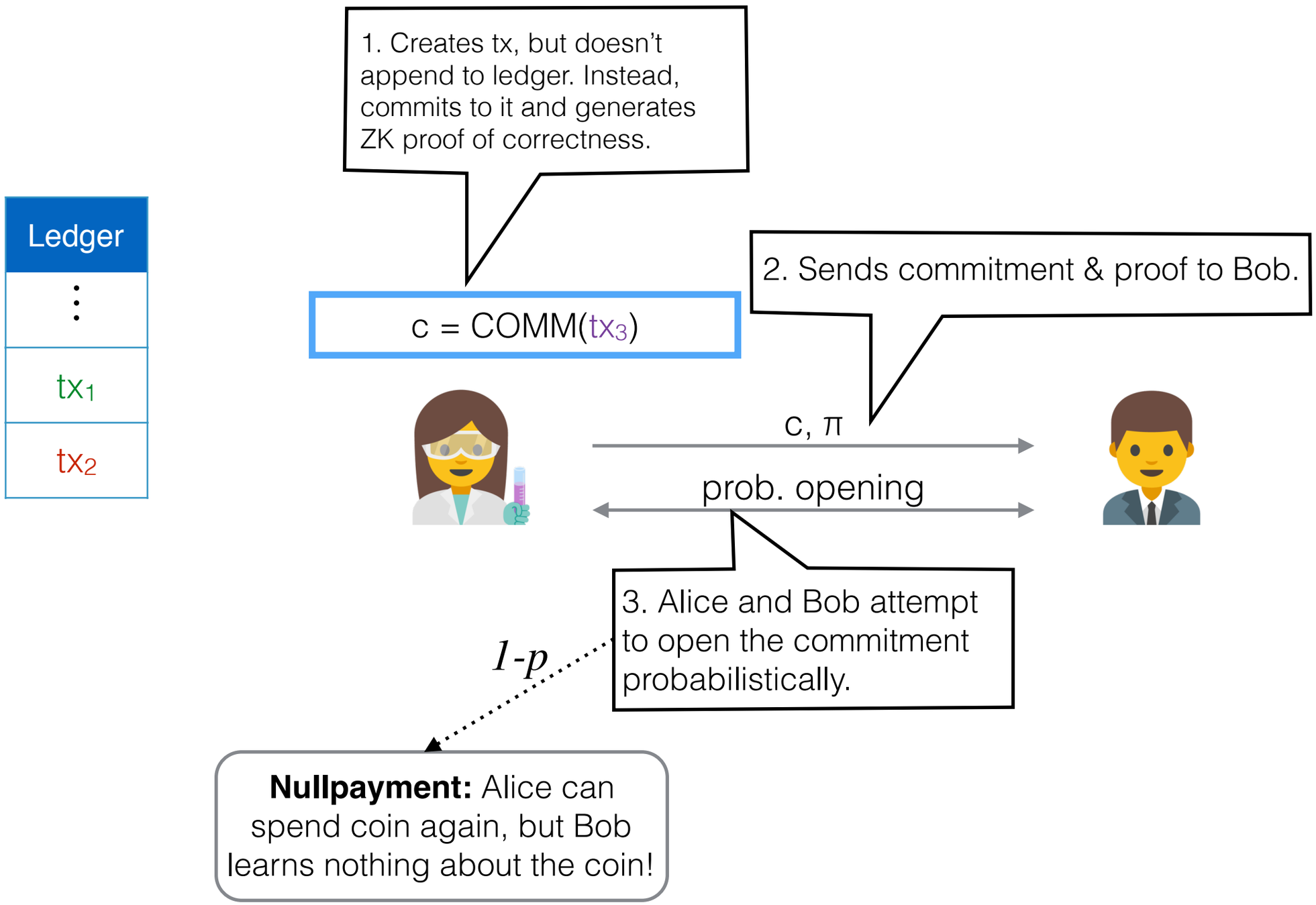
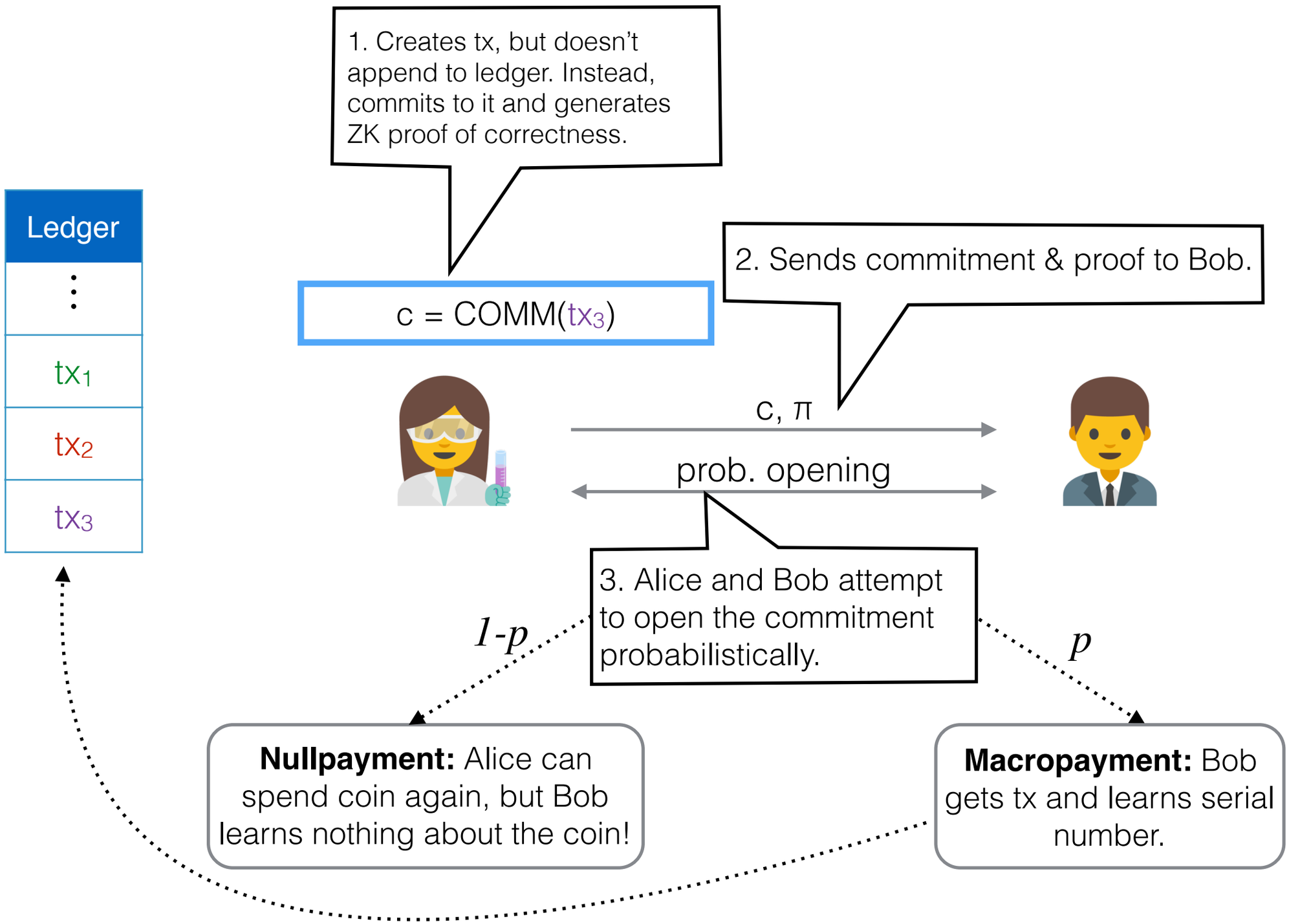
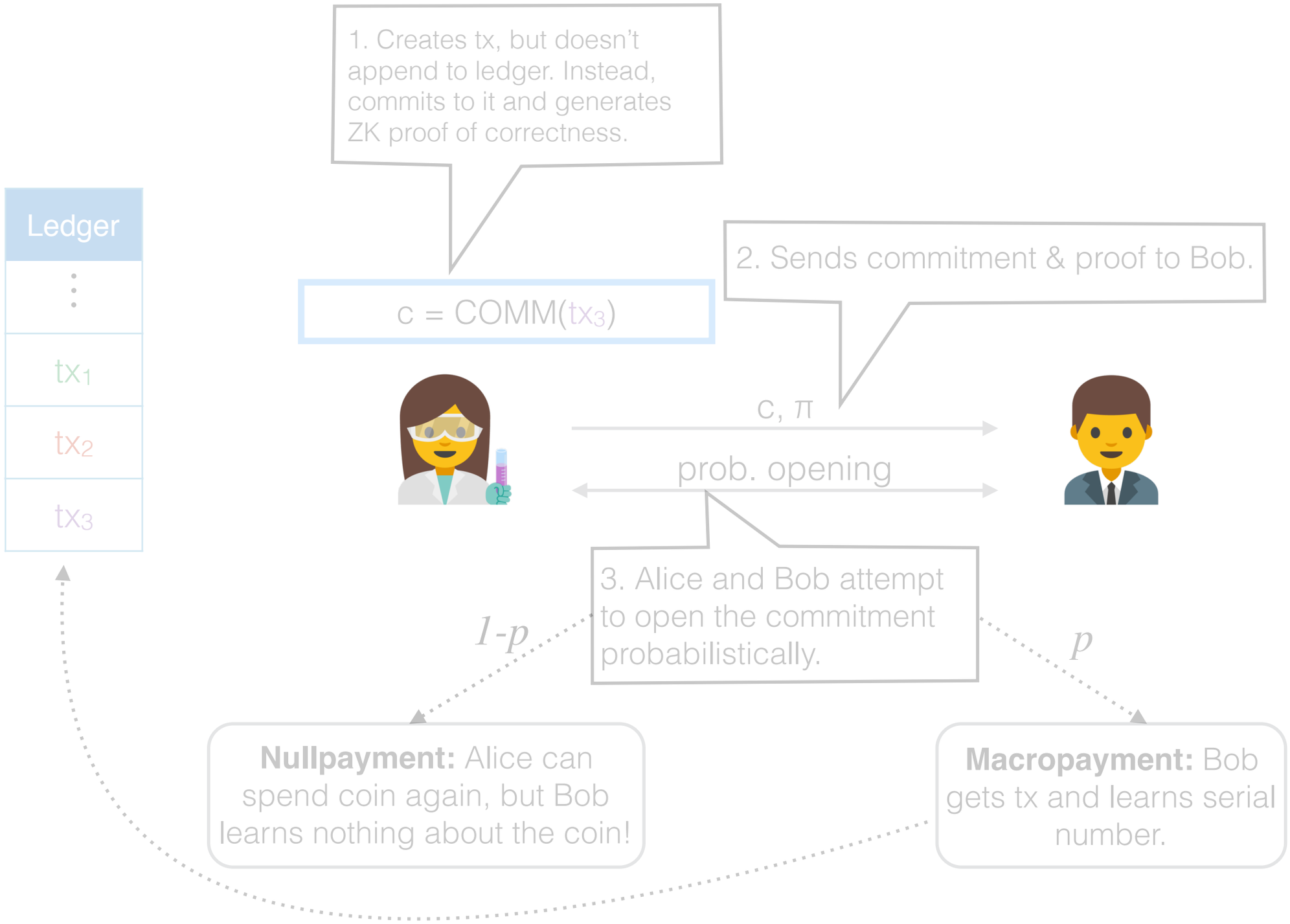


Solution: Make sn translucent



Solution: Make sn translucent



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Fractional hiding: w.p *1-p*, Bob learns nothing about message.
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Ledger
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tx_2
tx_3

c, π

prob. opening

3. Alice and Bob attempt to open the commitment probabilistically.

1-p

p

Nullpayment: Alice can spend coin again, but Bob learns nothing about the coin!

Macropayment: Bob gets tx and learns serial number.

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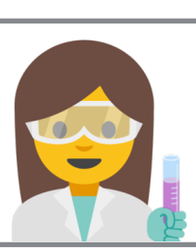

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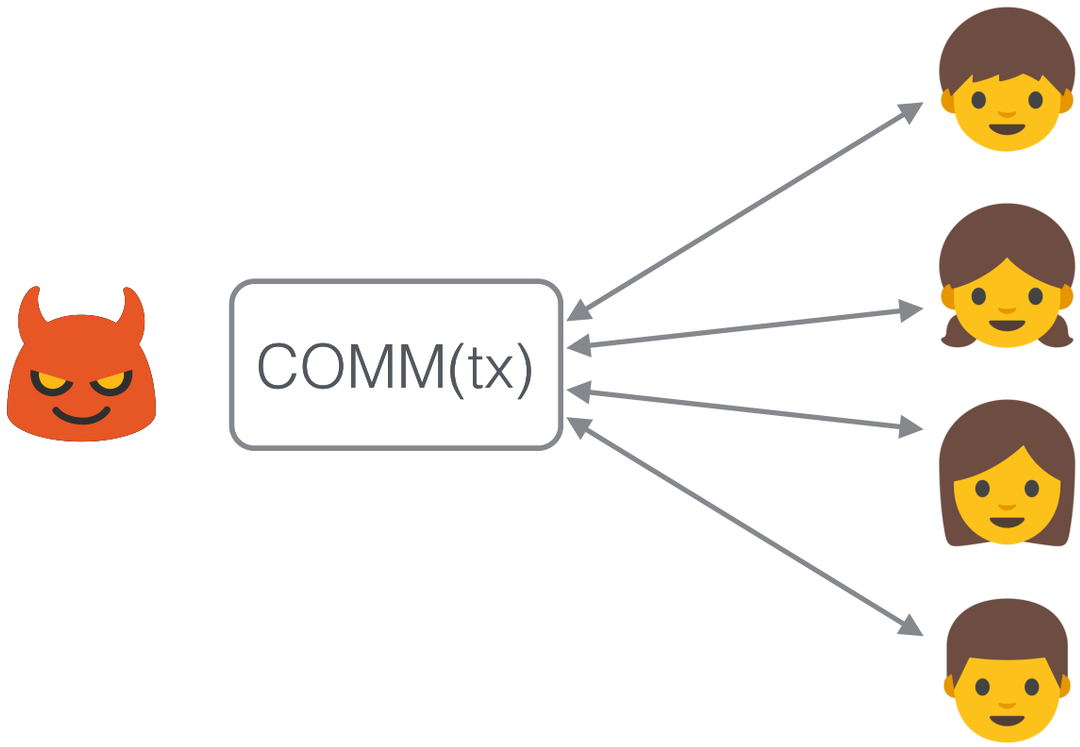

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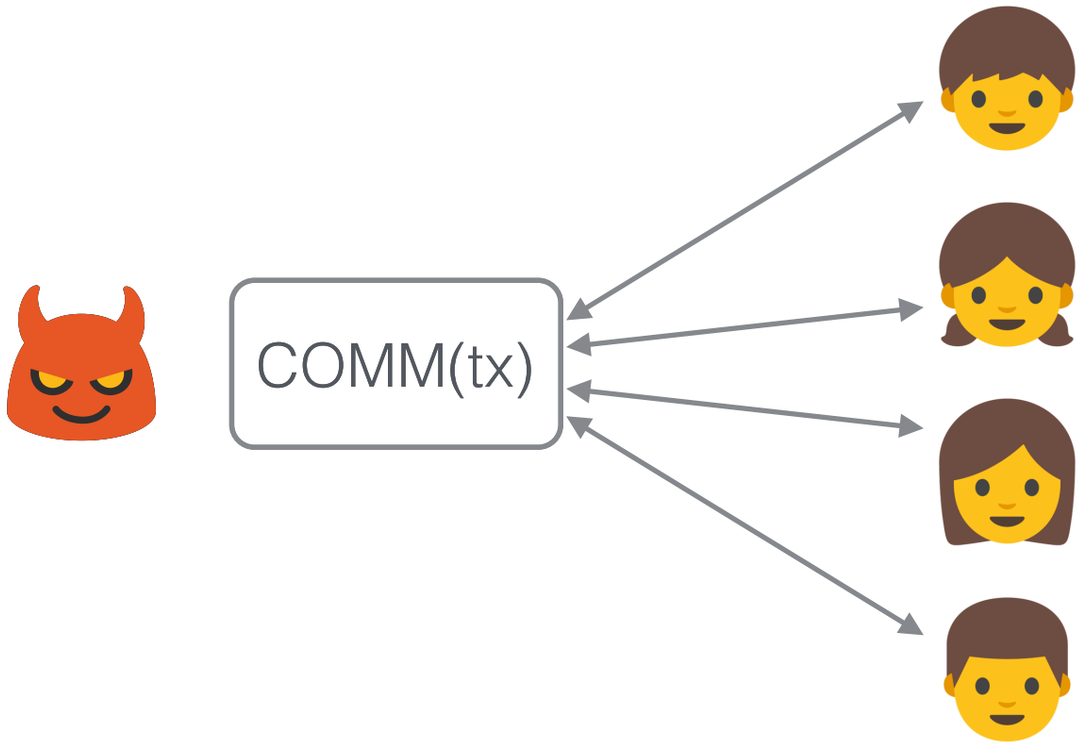

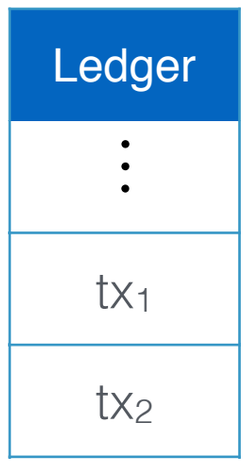

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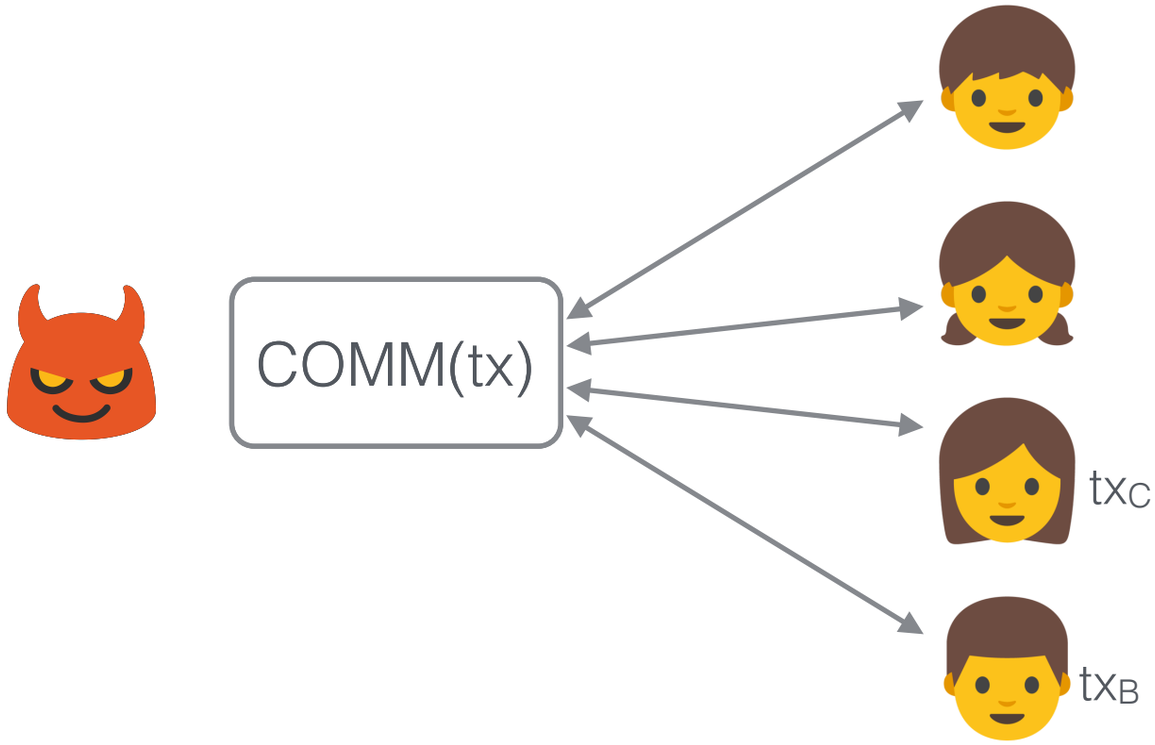

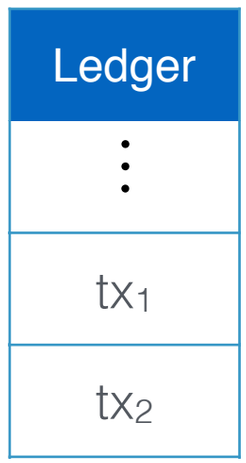

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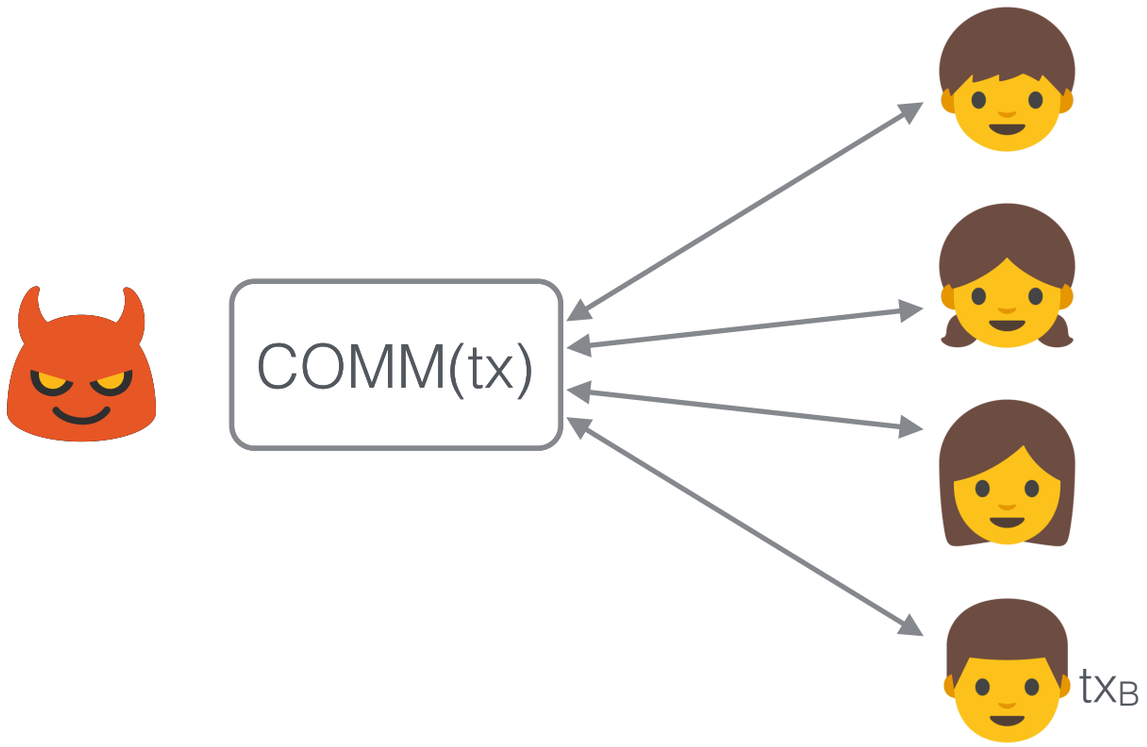

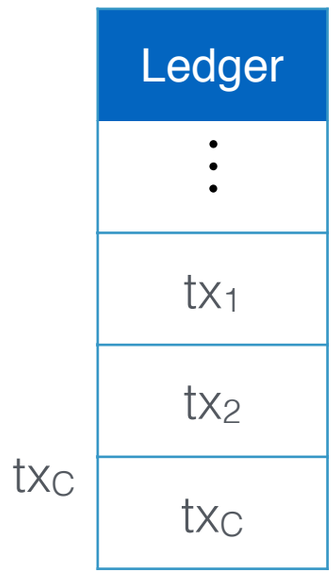

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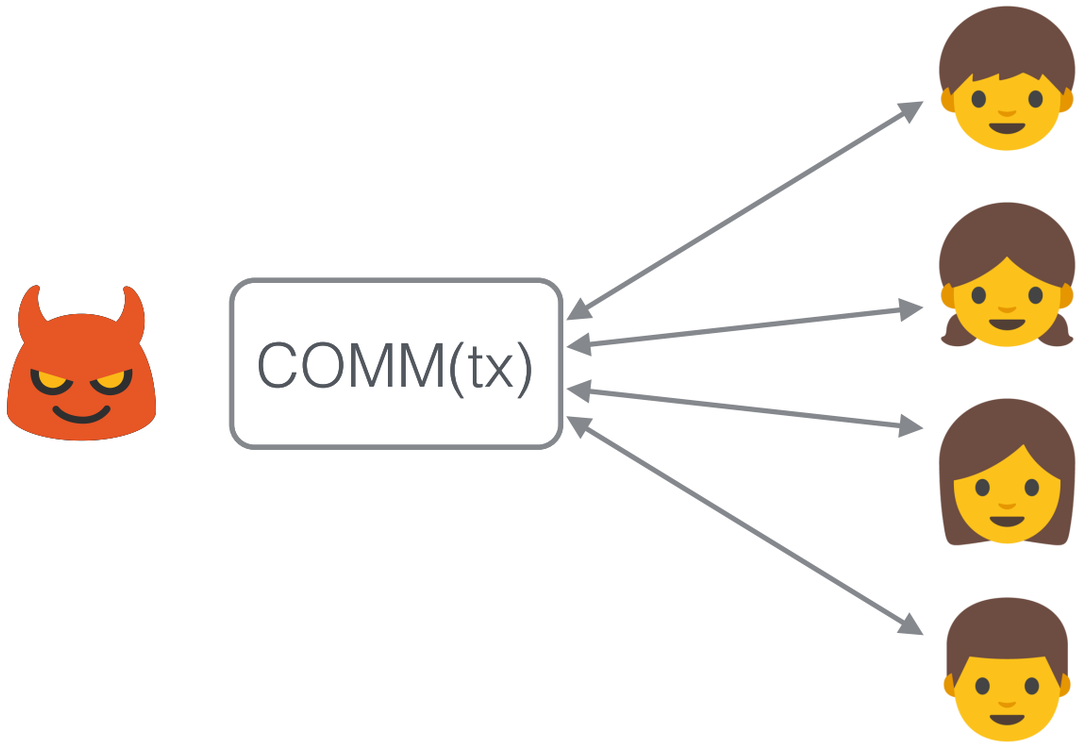

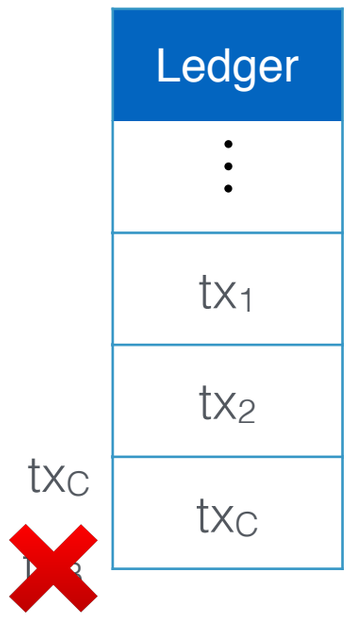

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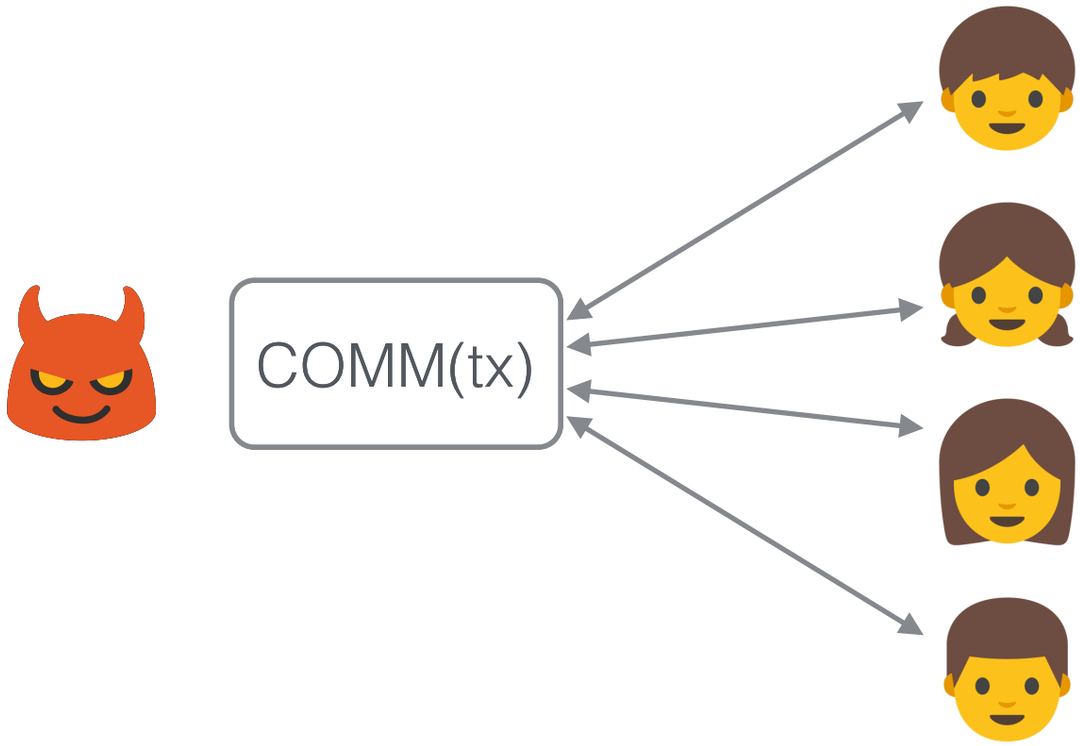
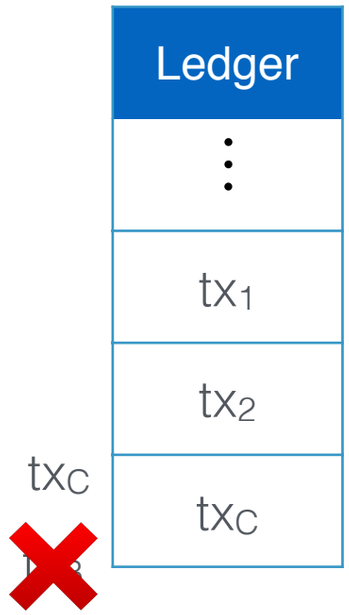
Offline setting ⇒ such attacks **cannot be prevented**.





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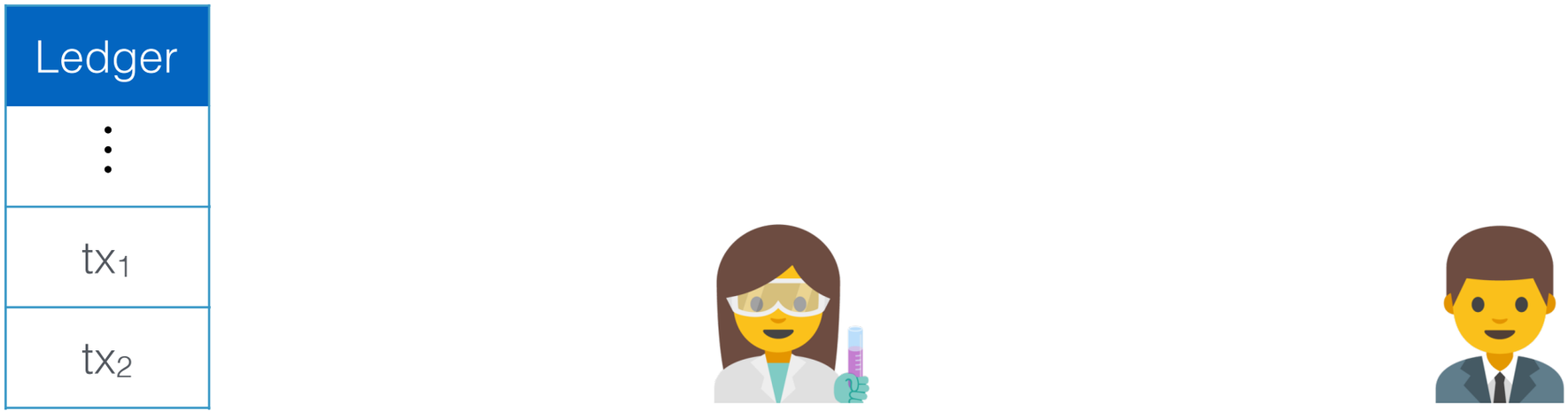

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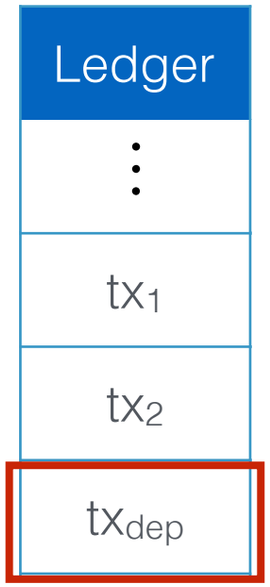

1. Before any probabilistic payments, Alice creates a deposit coin.

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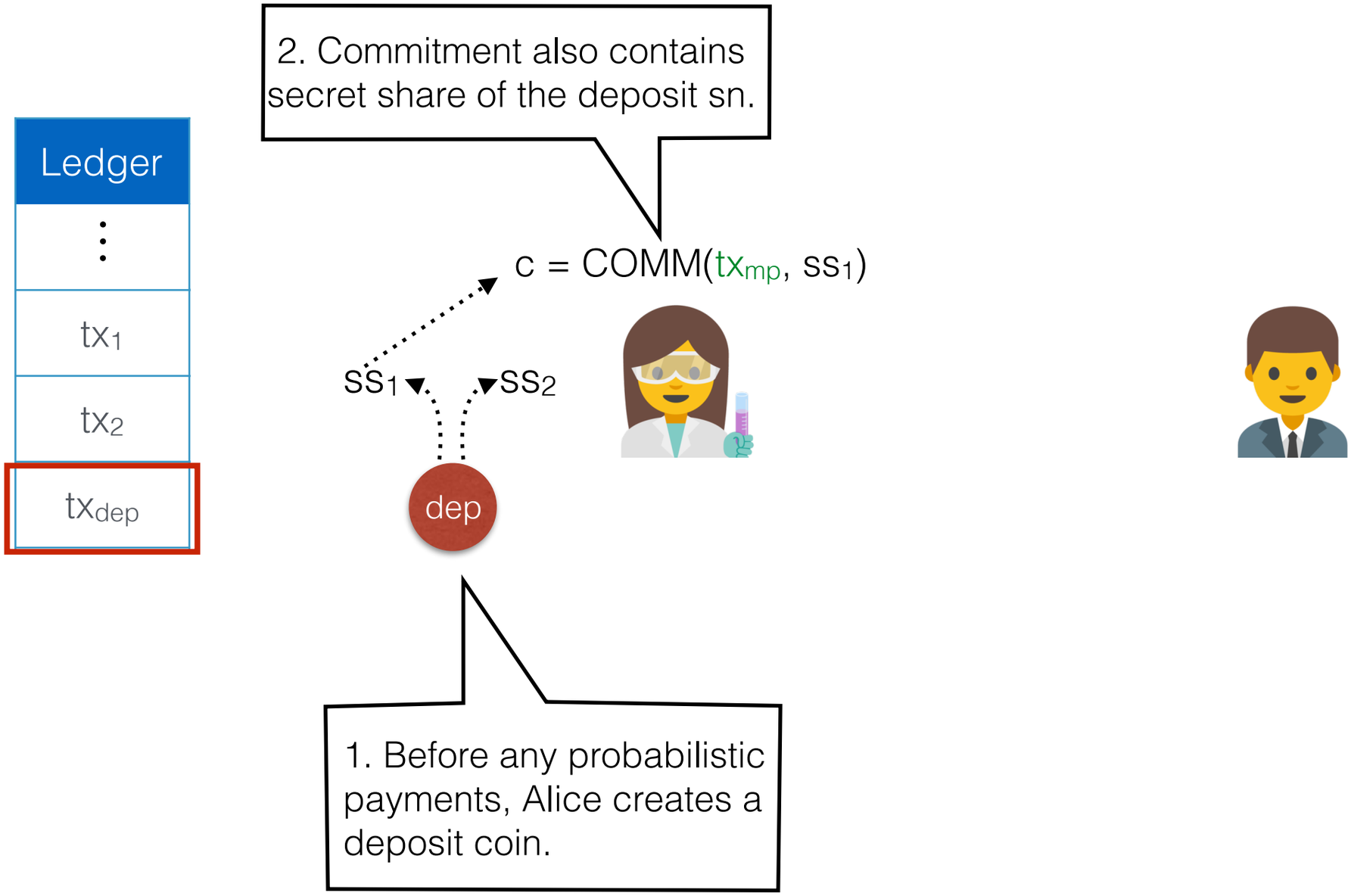

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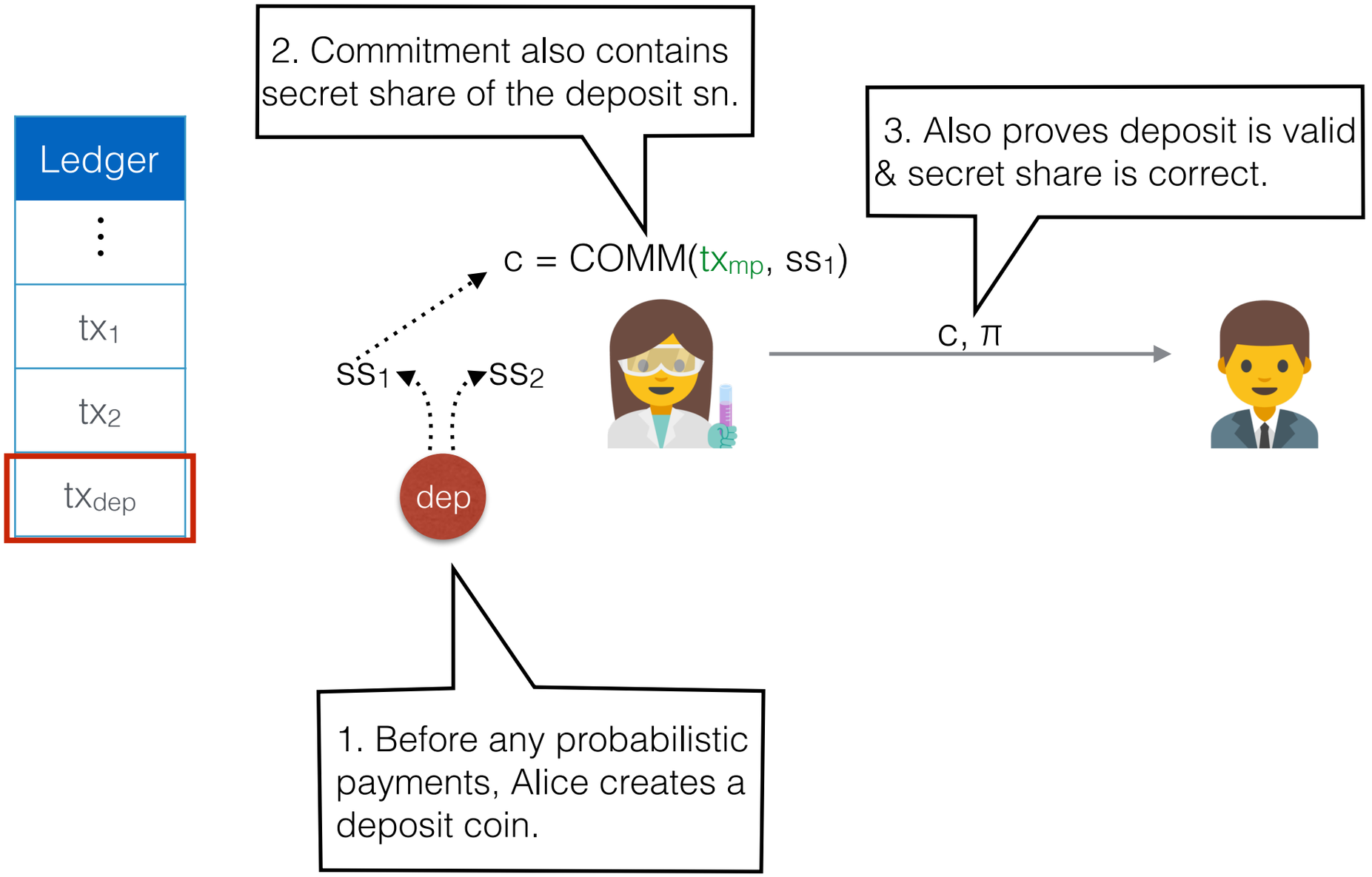

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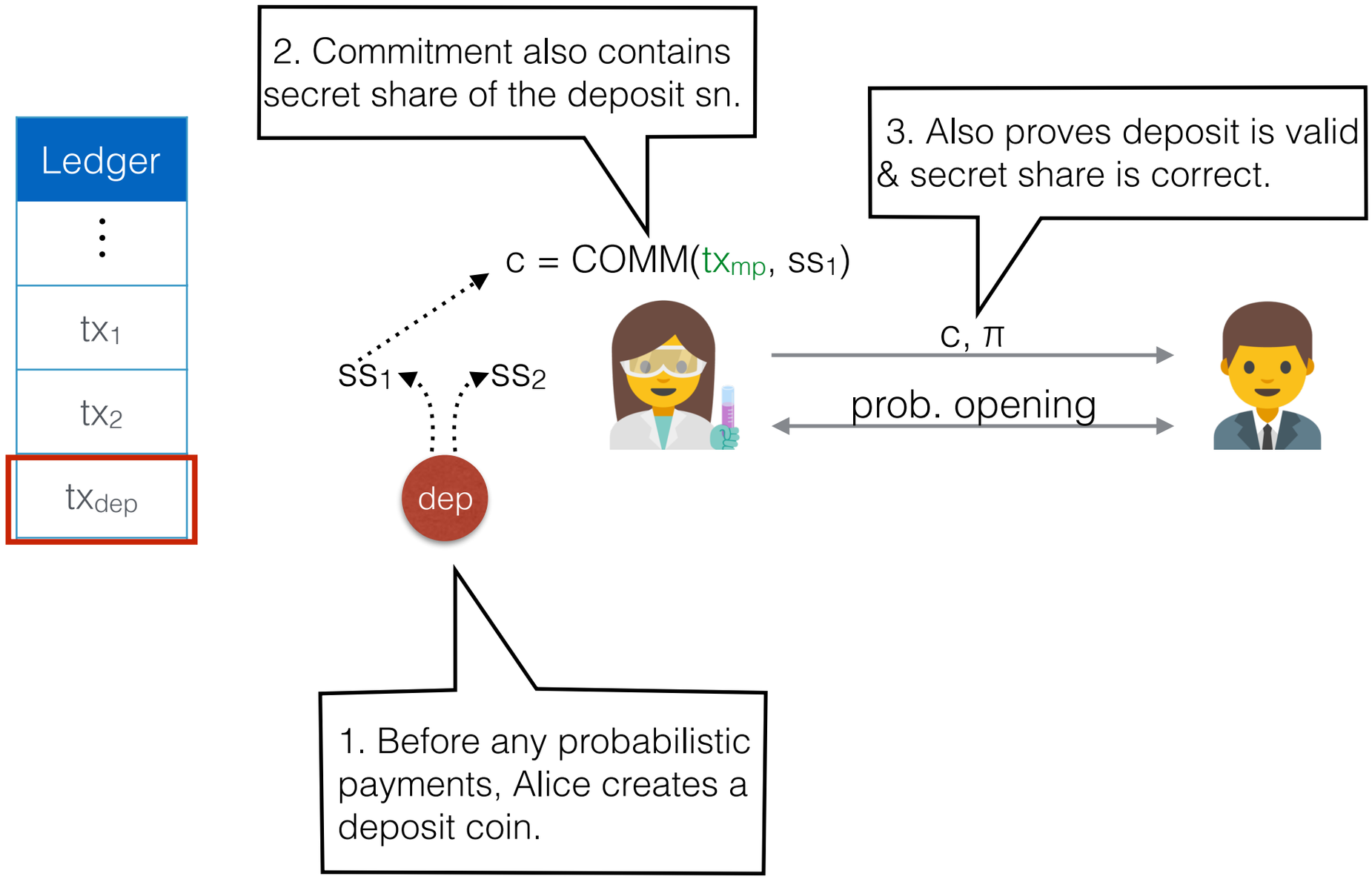

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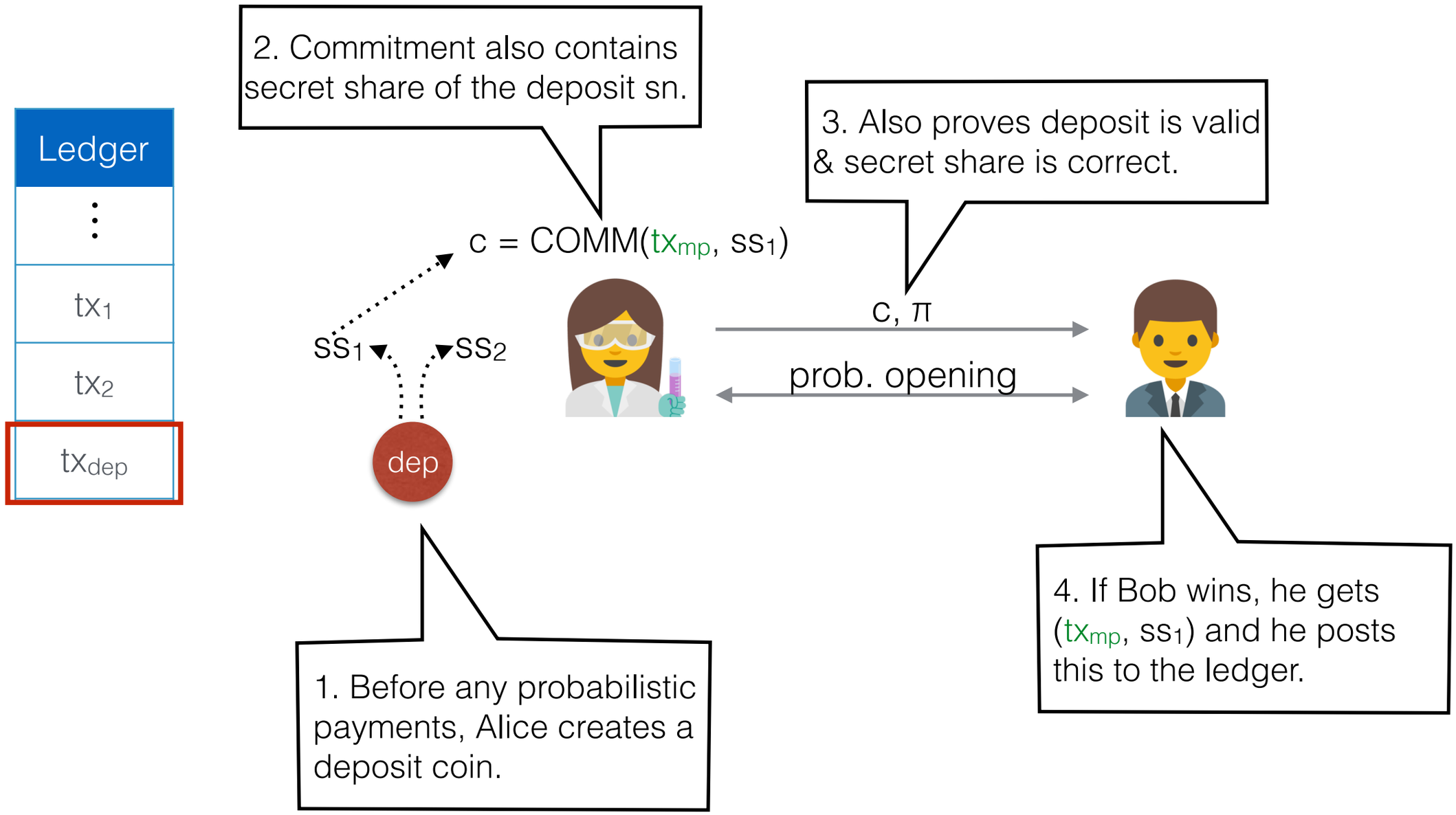

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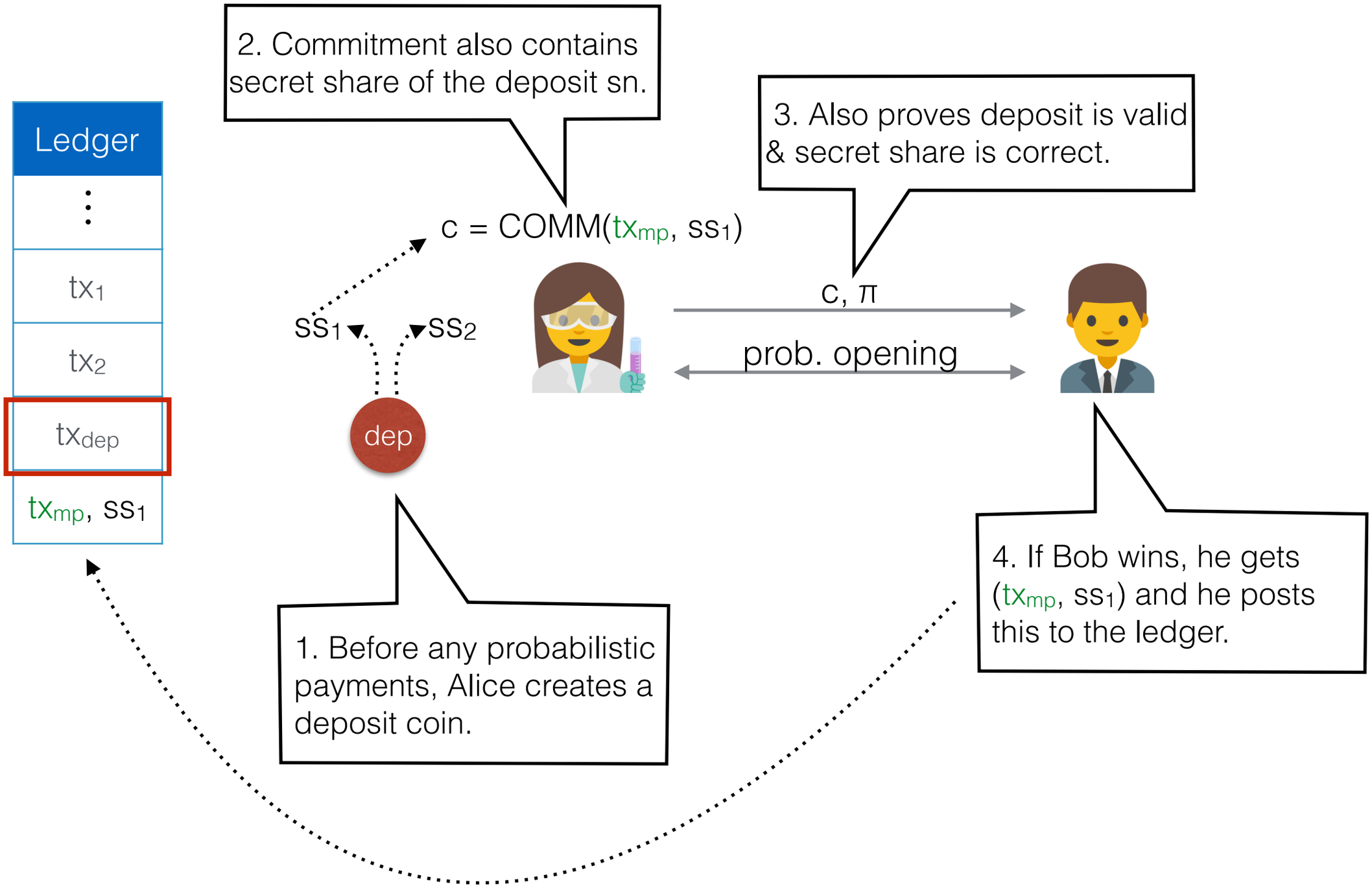

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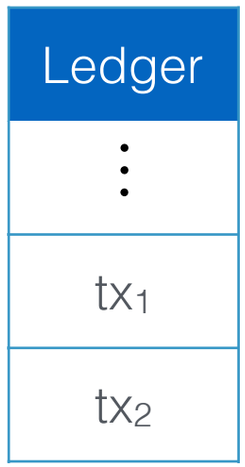

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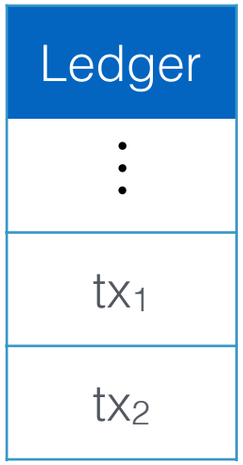

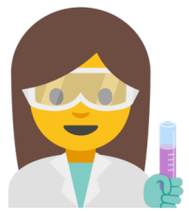

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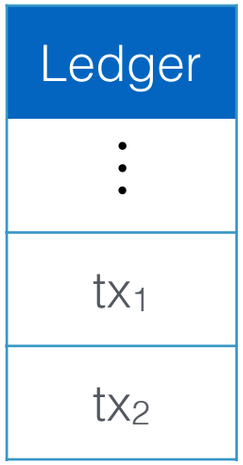

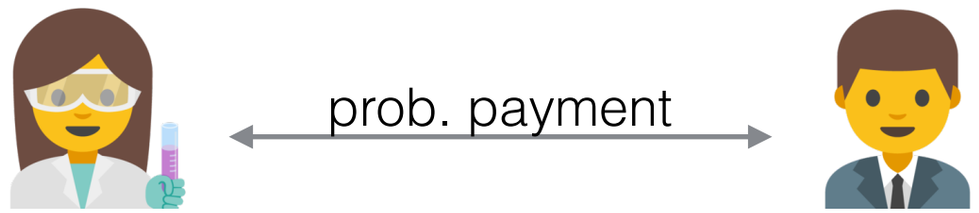

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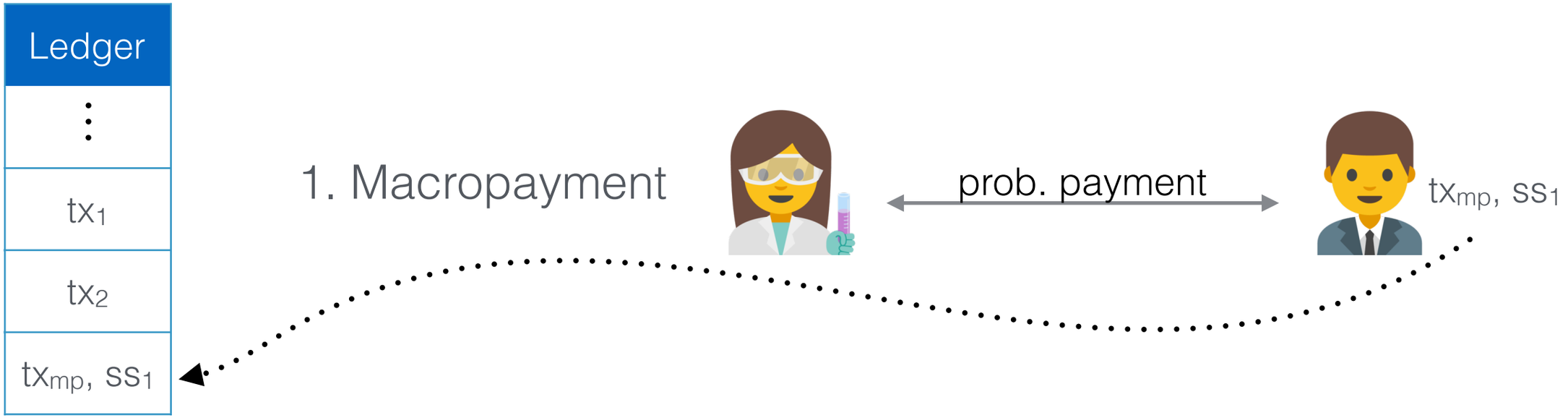

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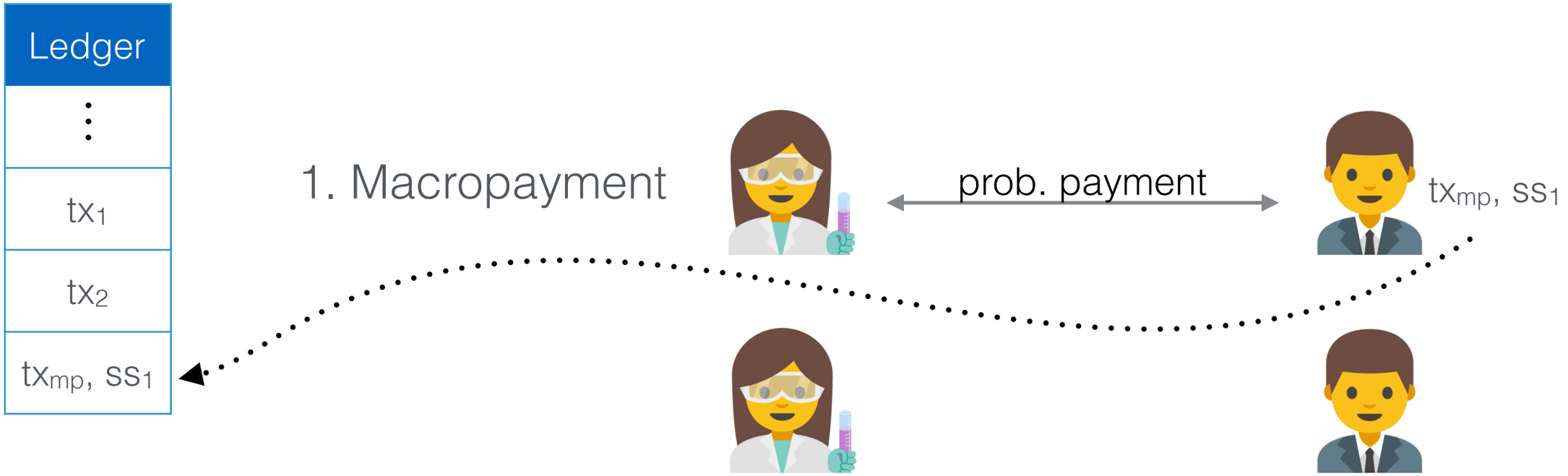

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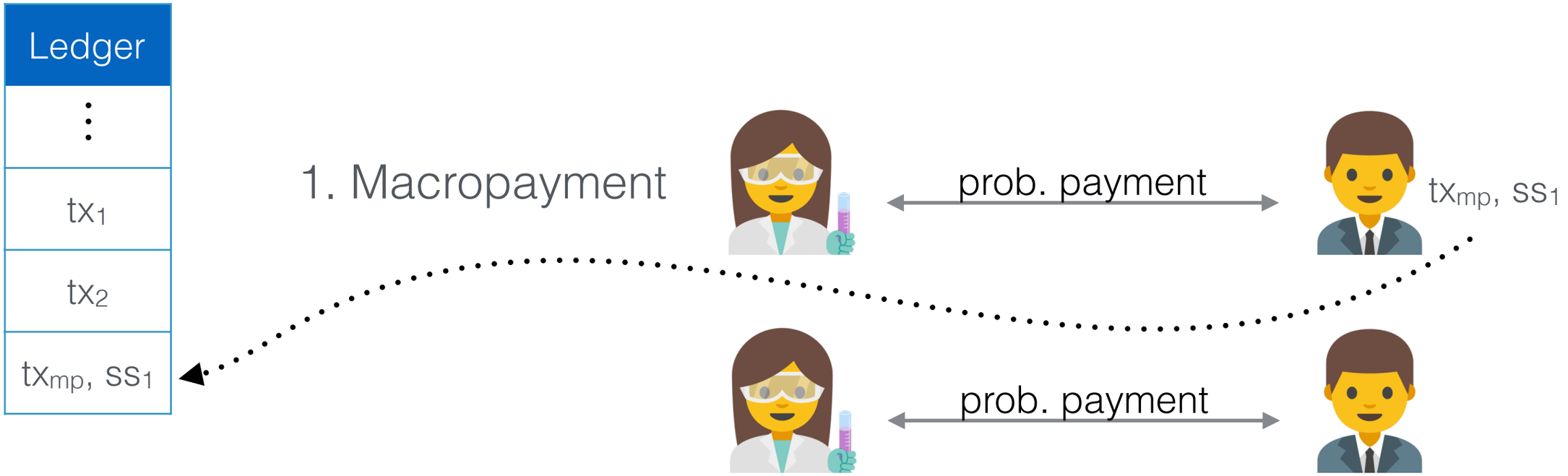

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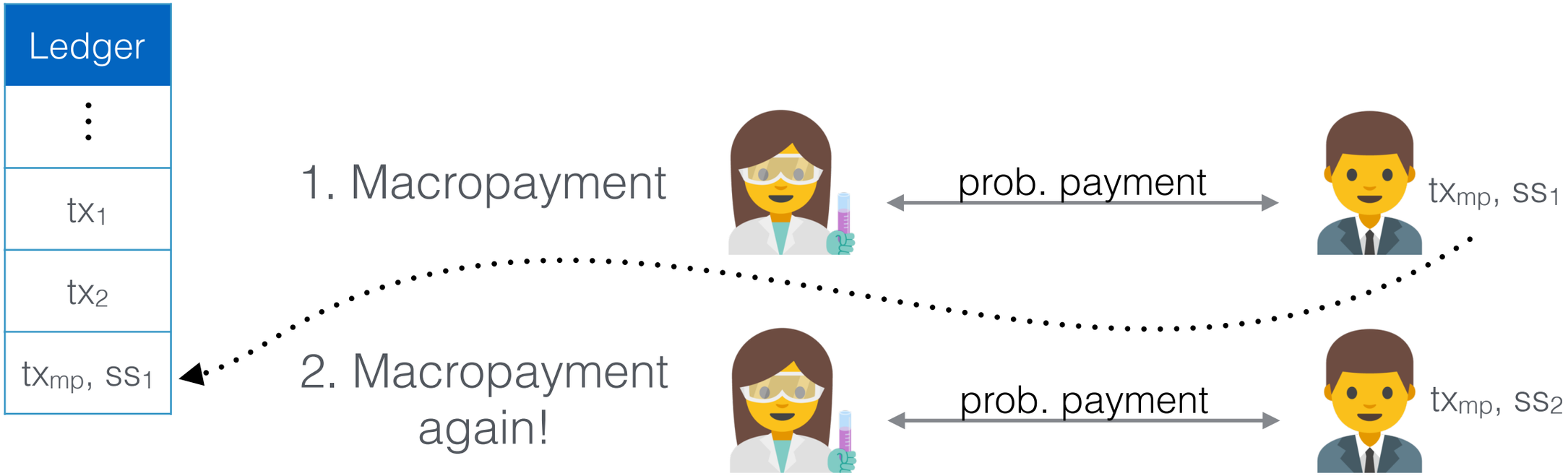

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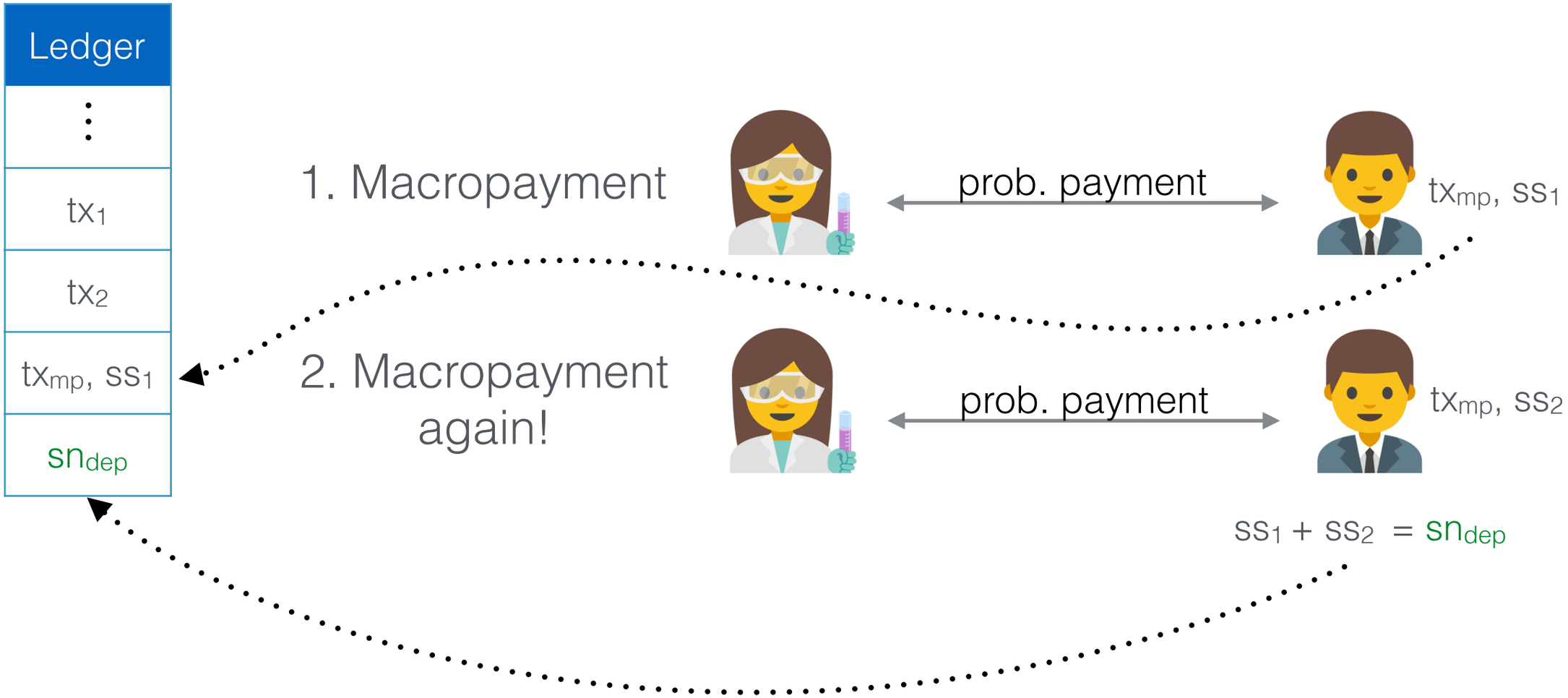

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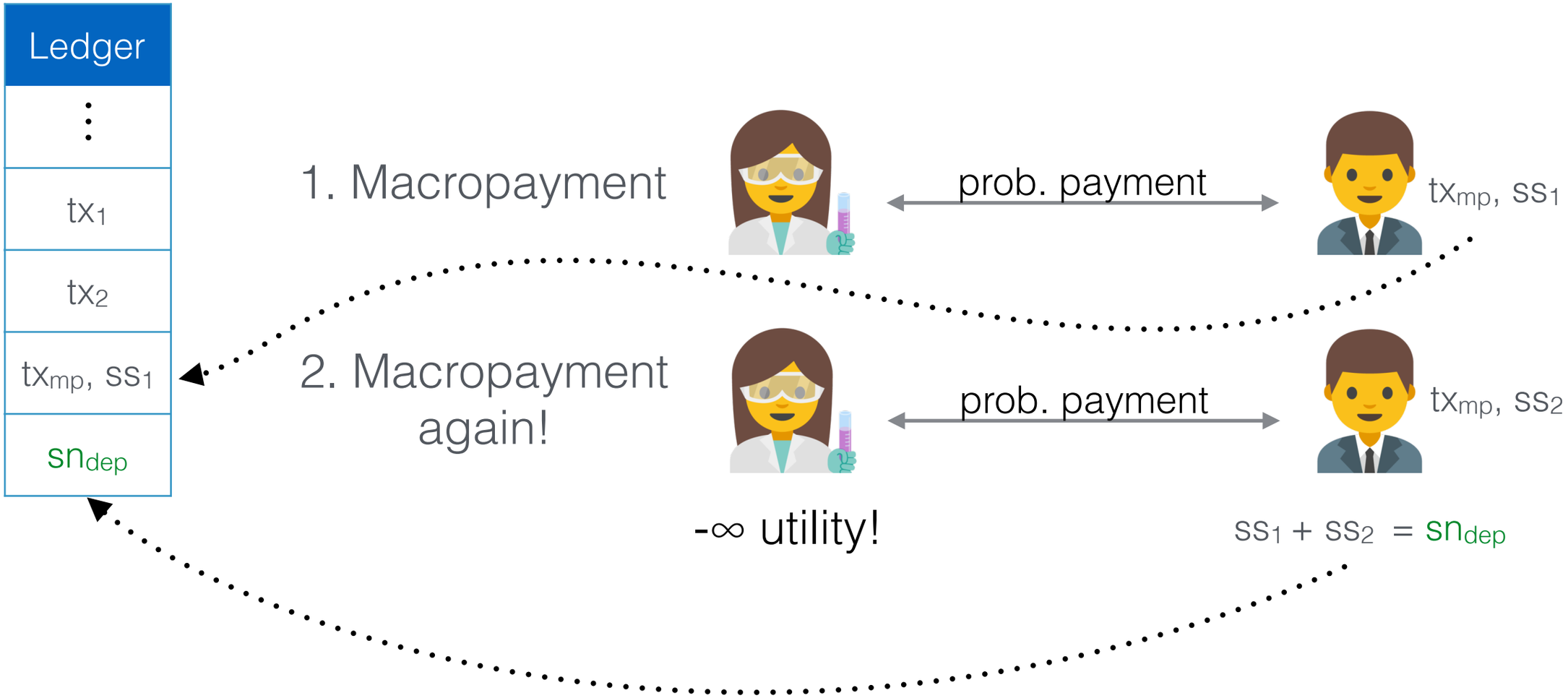

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See paper for solutions!

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Thanks!

http://eprint.iacr.org/2016/1033