Anonymous Transferable E-cash

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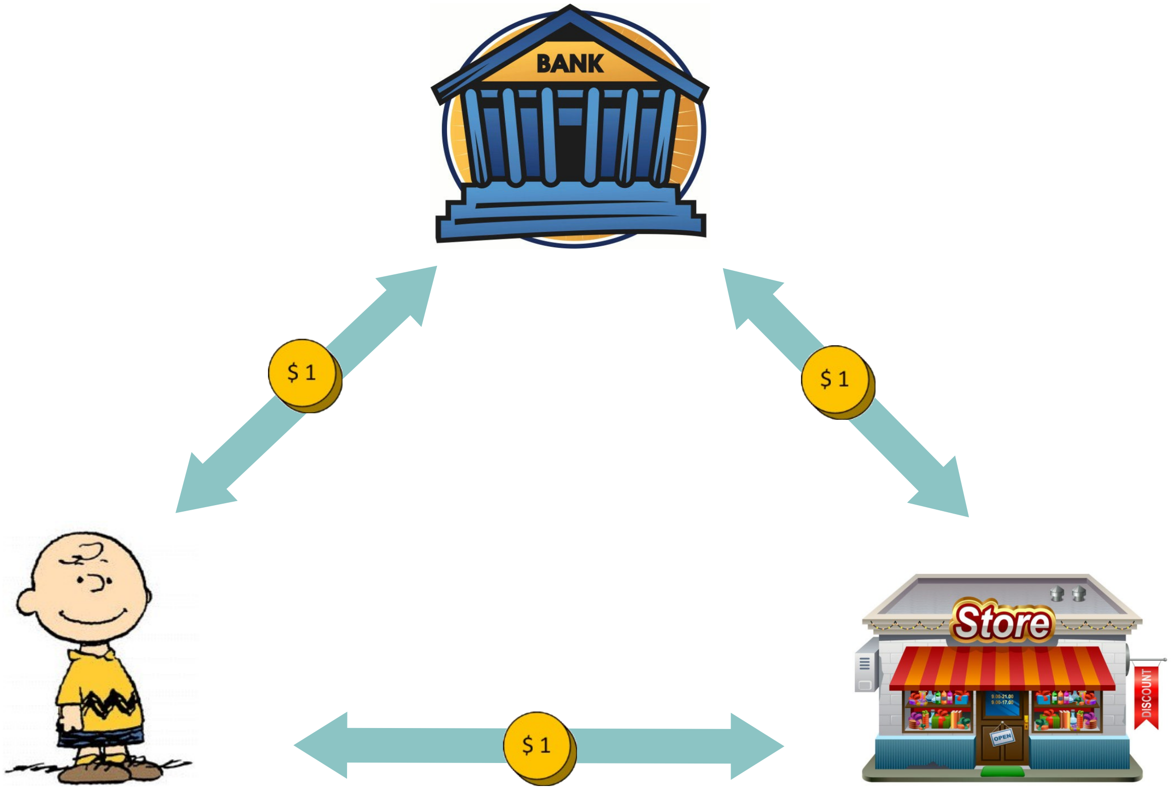
PKC'15, Maryland, USA

Electronic cash

Simulating traditional cash



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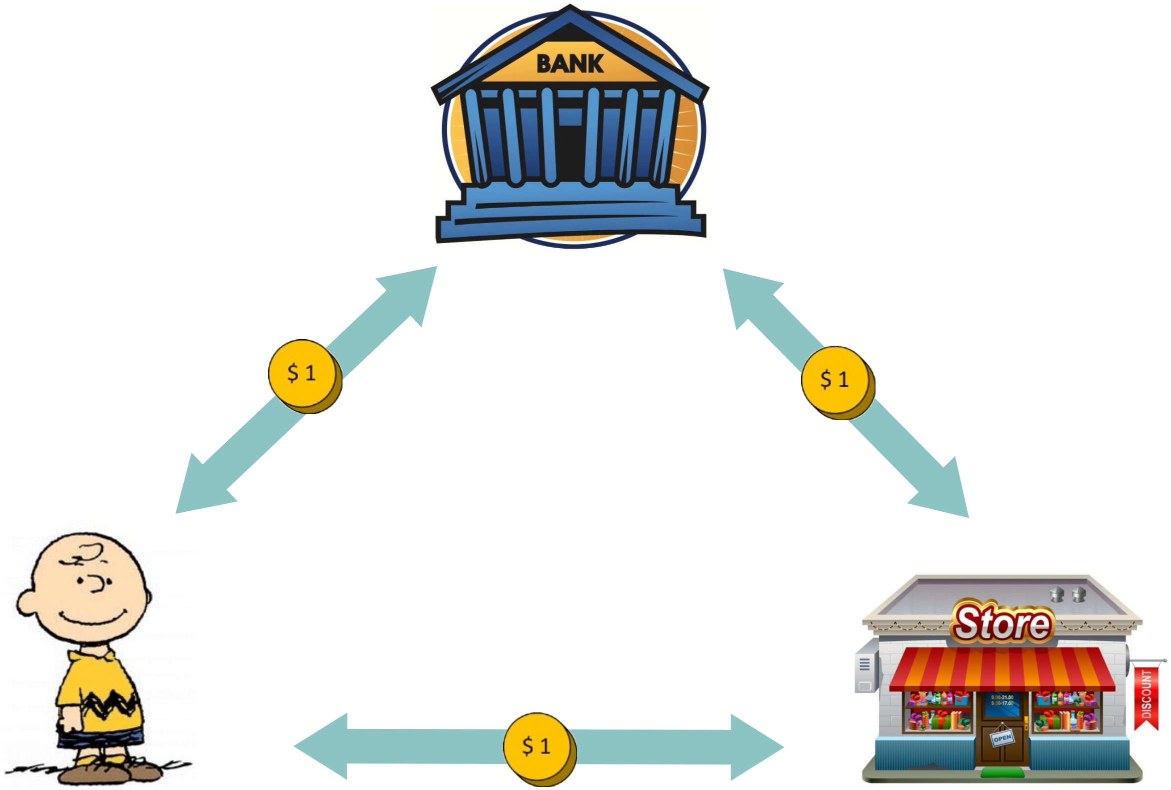

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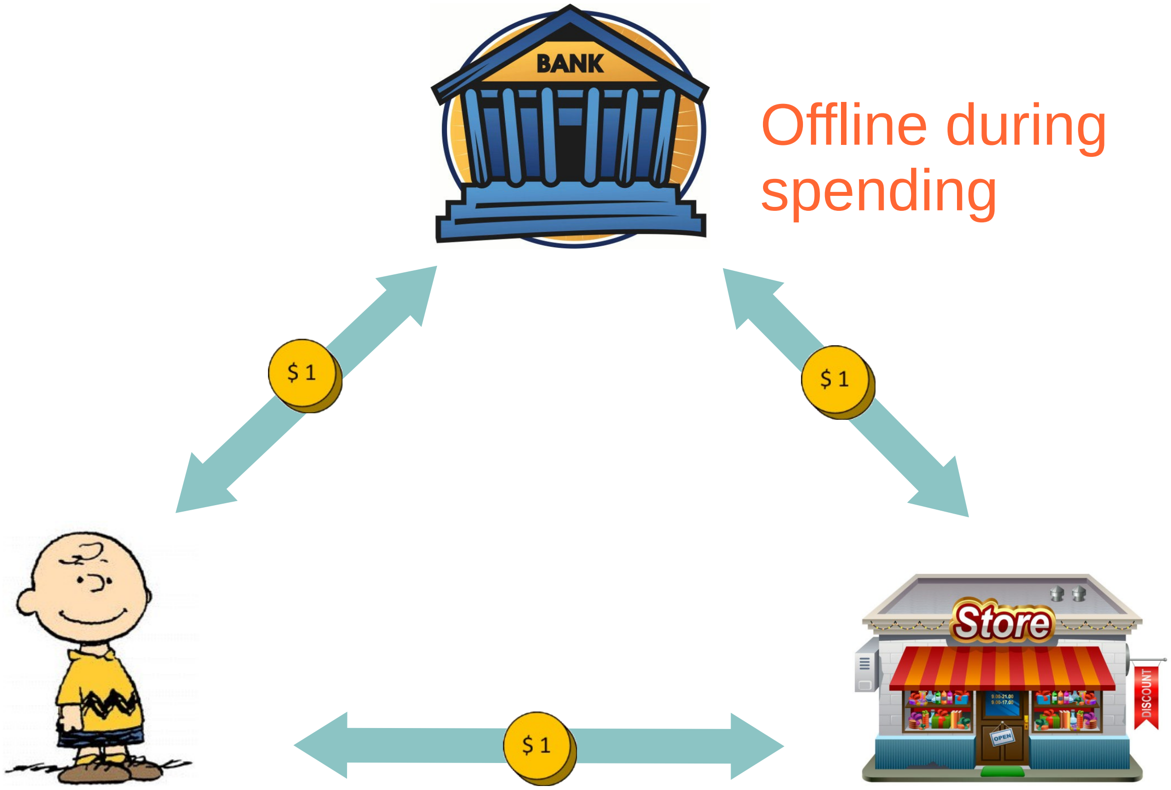

Offline during spending

Anonymous

Electronic cash

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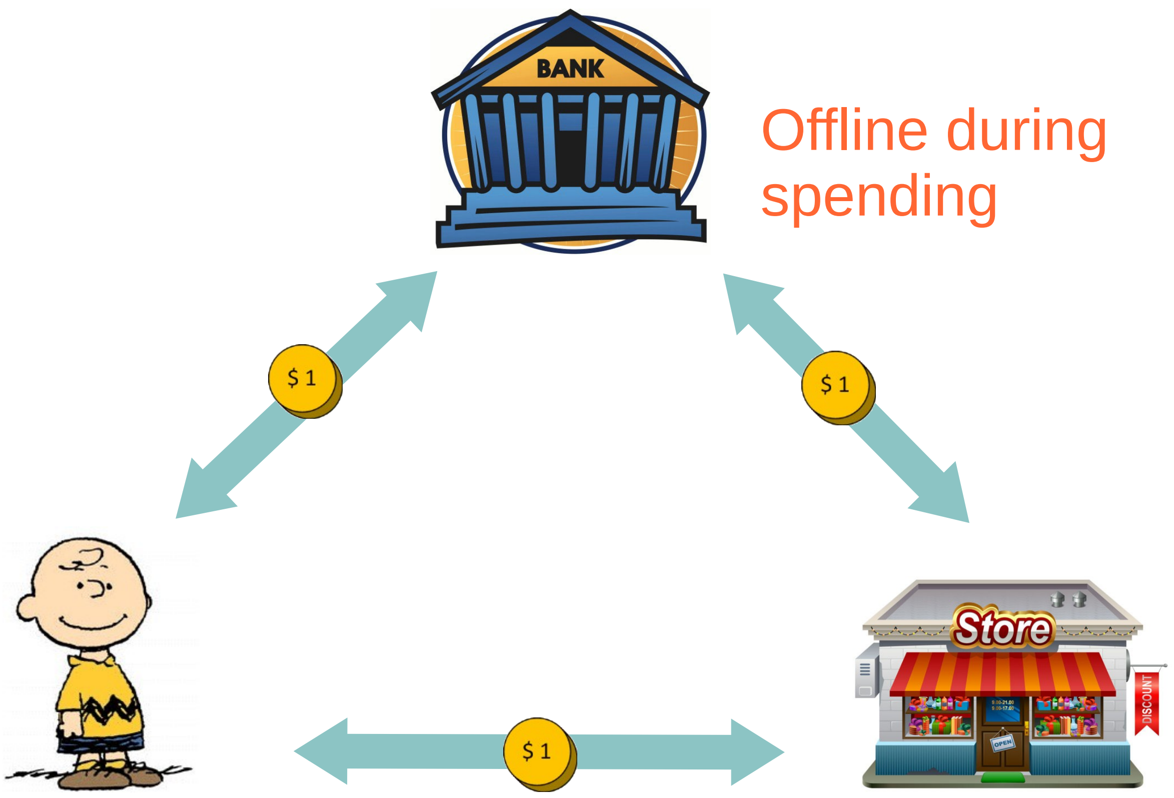
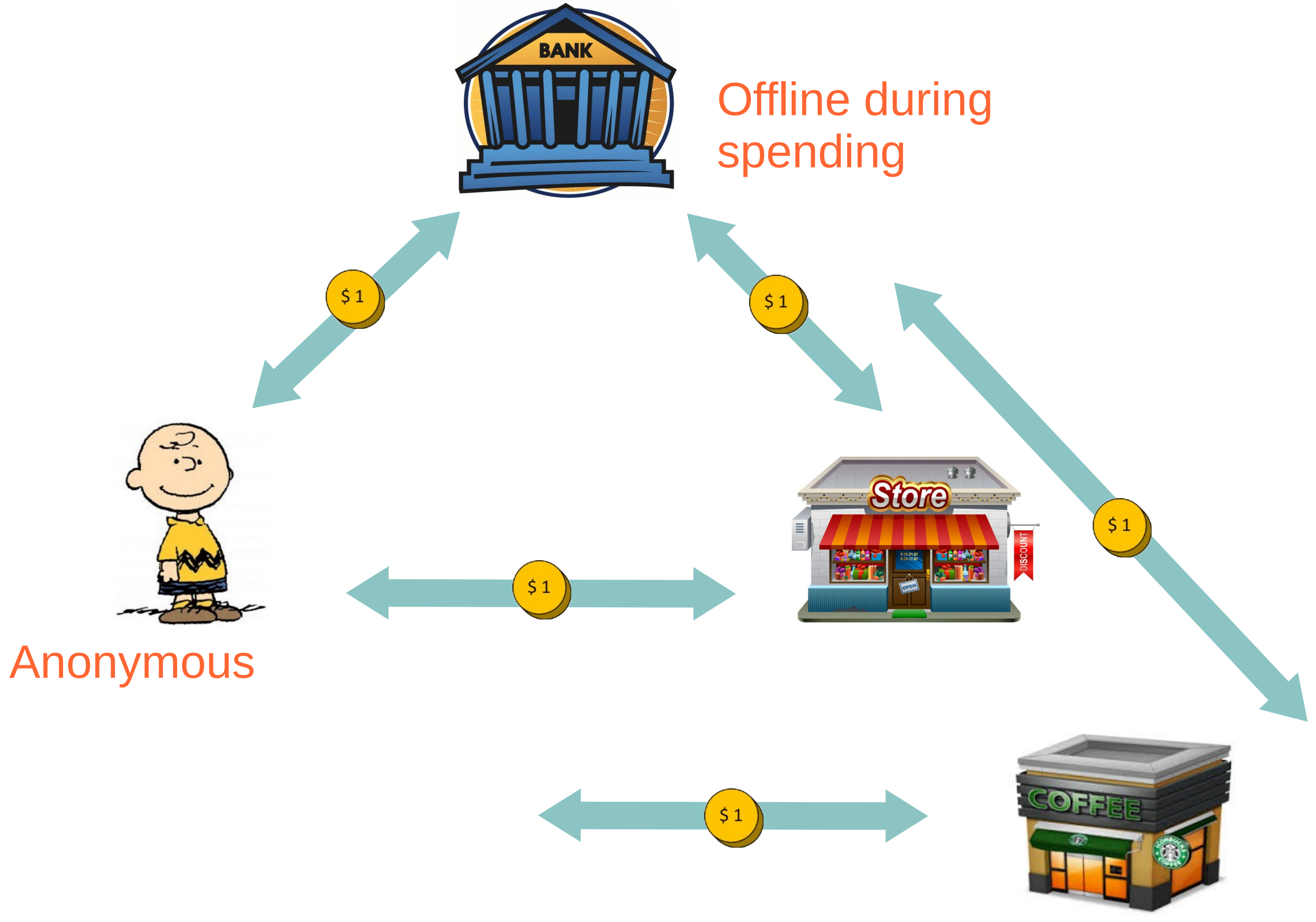


Offline during spending

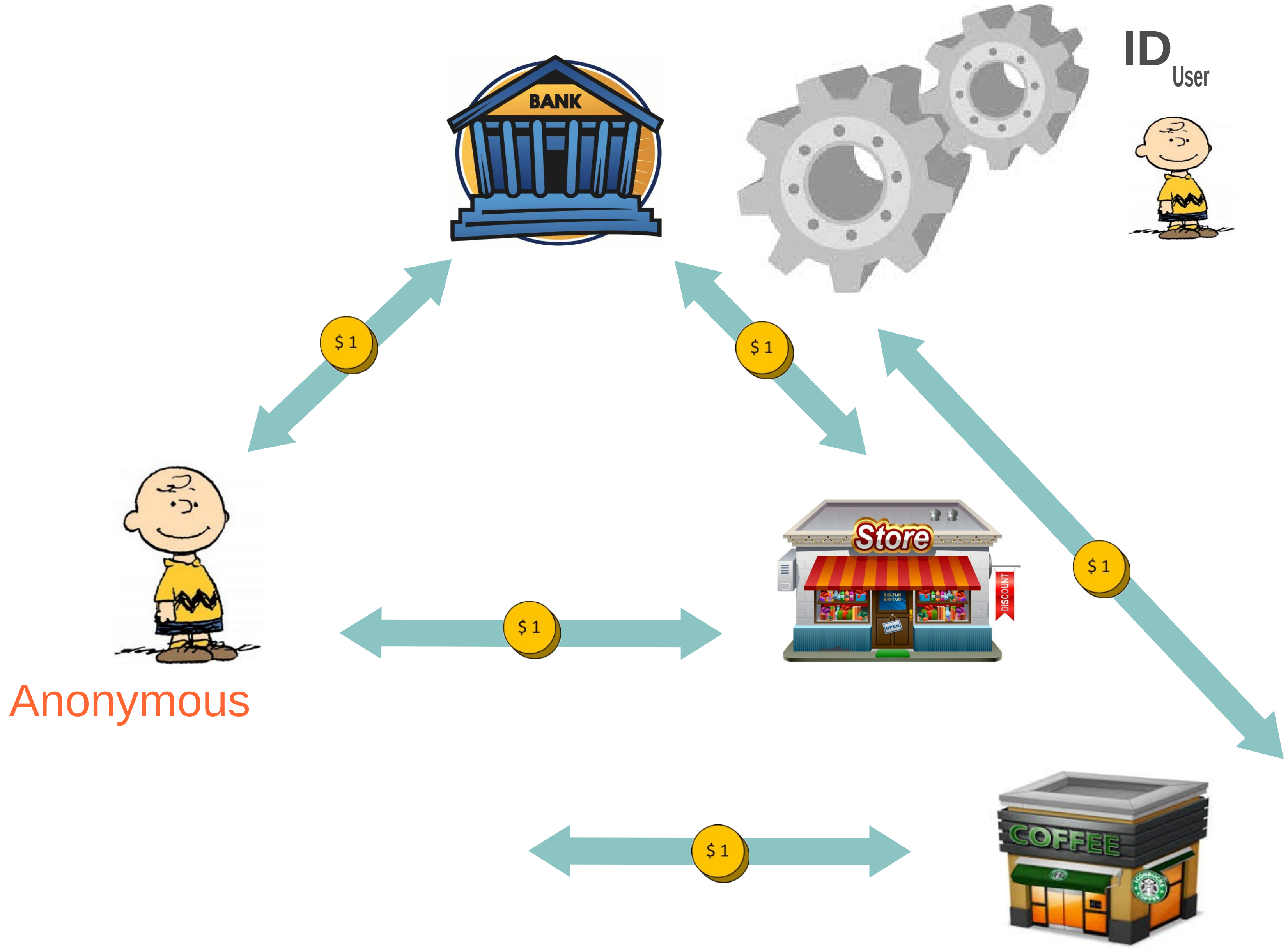
Anonymous

$ 1 unforgeable

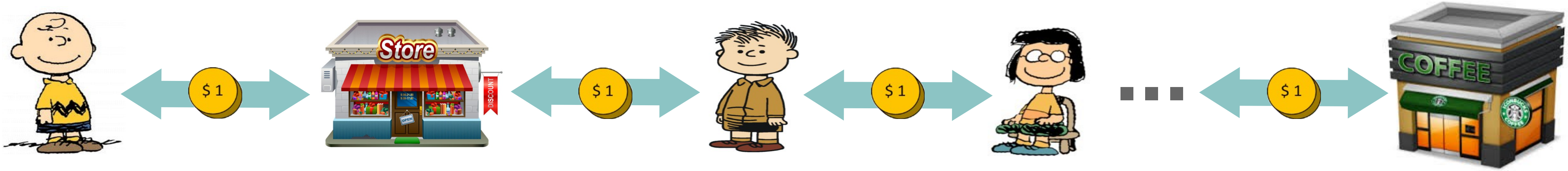
Double spending



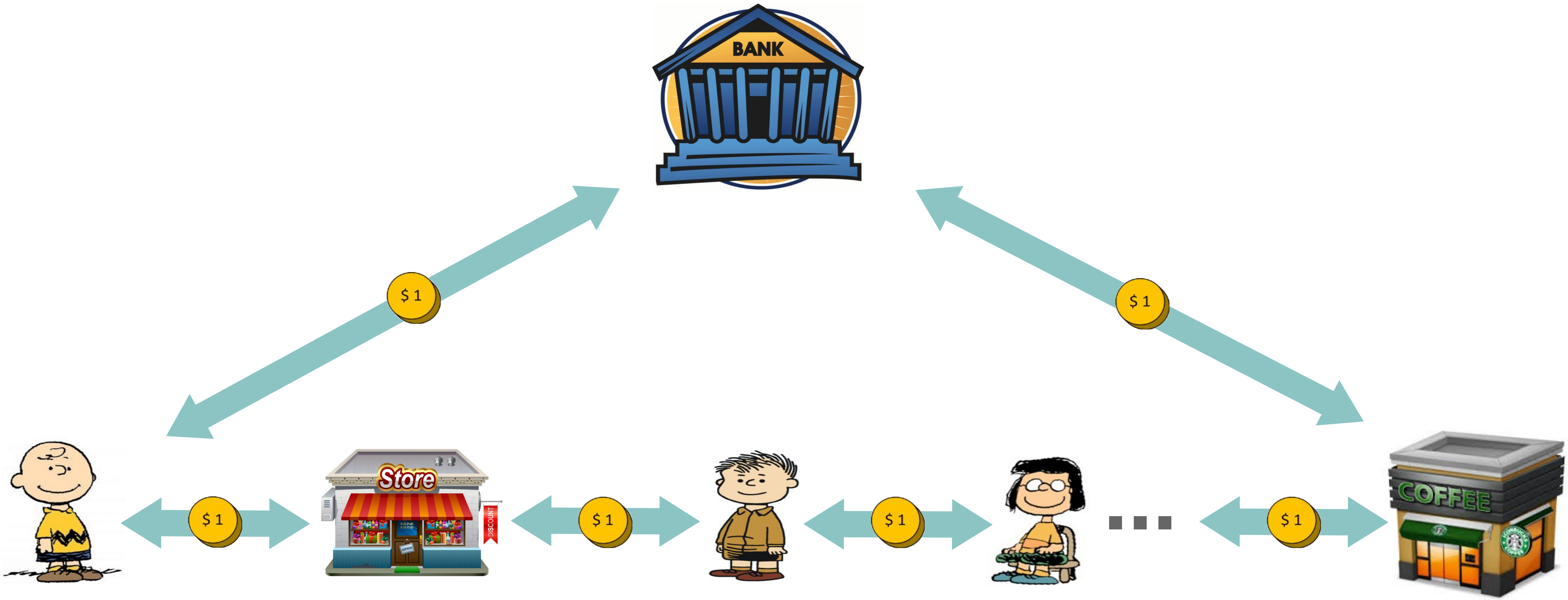
Double spending



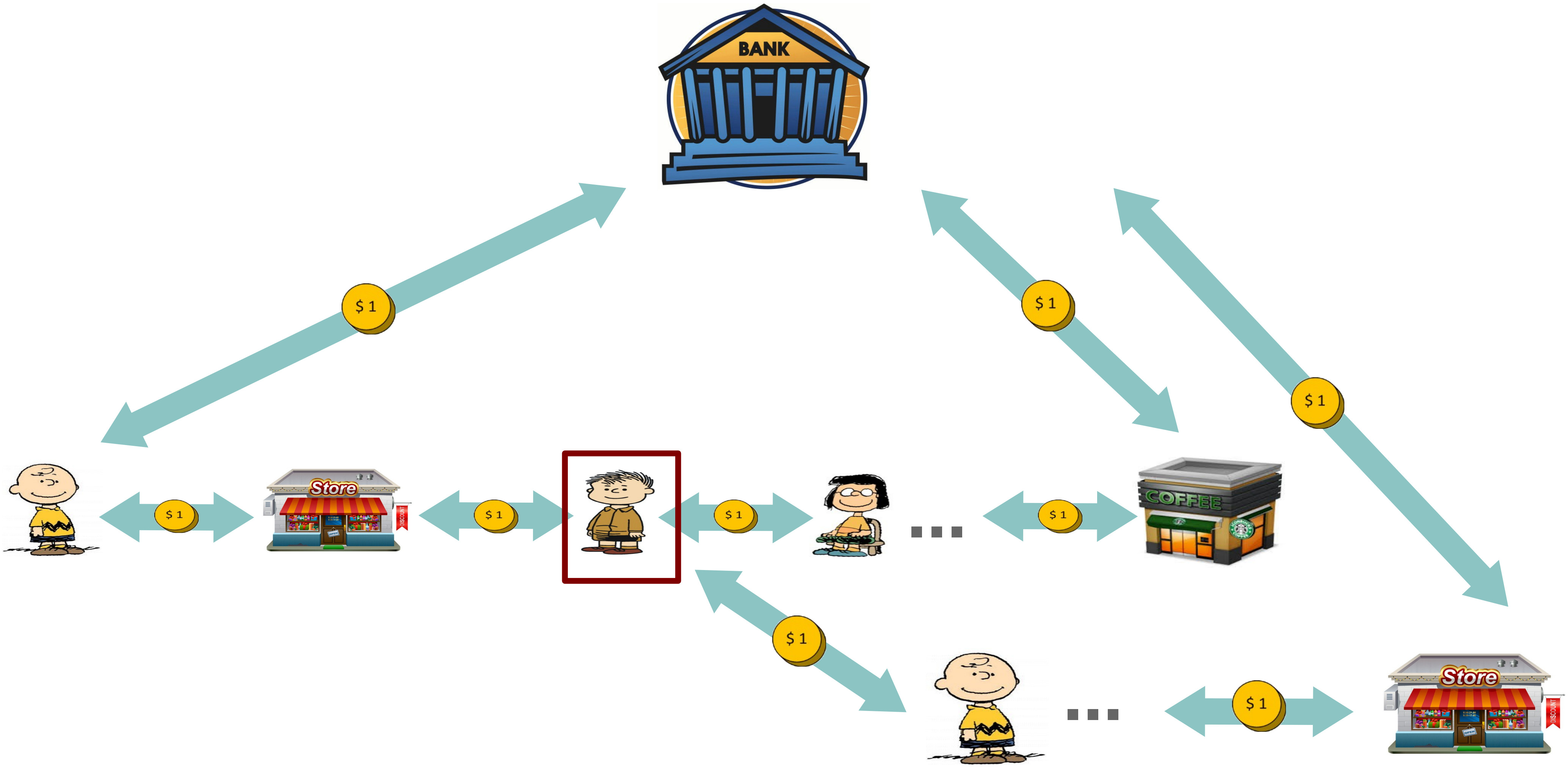
What if?



Transferable E-Cash



Double spending detection



Our Contributions

The first practical, truly anonymous transferable e-cash scheme

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- ✔ On double spending, only the identity of the malicious user is revealed [FPV'09]
- ✔ No trusted 3rd party that can de-anonymize users [BCFGST'11]

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The first practical, truly anonymous transferable e-cash scheme

- ✔ On double spending, only the identity of the malicious user is revealed [FPV'09]
- ✔ No trusted 3rd party that can de-anonymize users [BCFGST'11]

- New Detailed definitions of transferable e-cash security
- New Generic construction based on malleable signatures
- New An efficient double-spending detection technique

Transferable E-Cash Security

Unforgeability: An adversary cannot spend more coins than the number of coins he withdrew.

Double Spending: An adversary cannot spend a coin twice (double-spend) without his identity being revealed.

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Chaum & Pedersen '92:

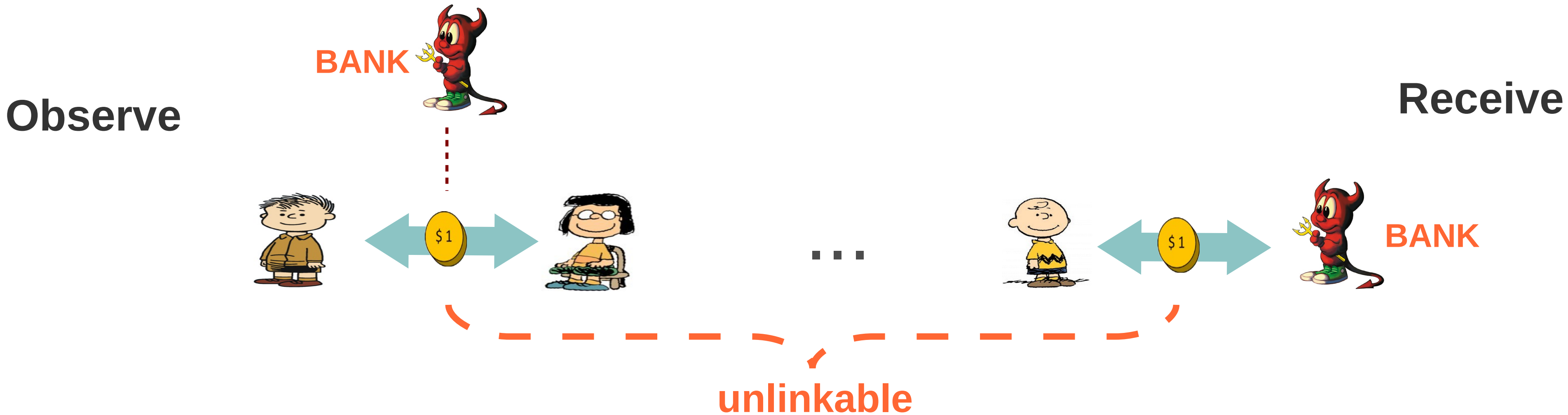
An unbounded adversary can always recognize coins he has already owned

Canard & Gouget '08:

A bounded adversary, impersonating the bank, can always recognize coins he has already owned (using the DS mechanism)

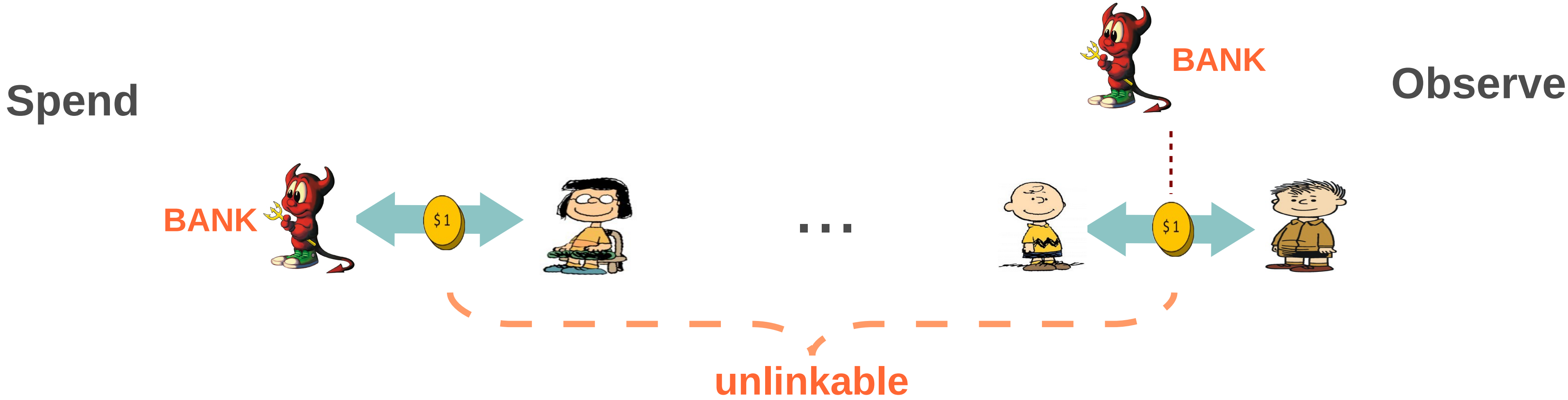
Transferable E-Cash Anonymity

- Observe-then-Receive (**OtR**): an attacker, impersonating the bank, cannot link a coin he receives to a previously (passively) observed transfer between honest users



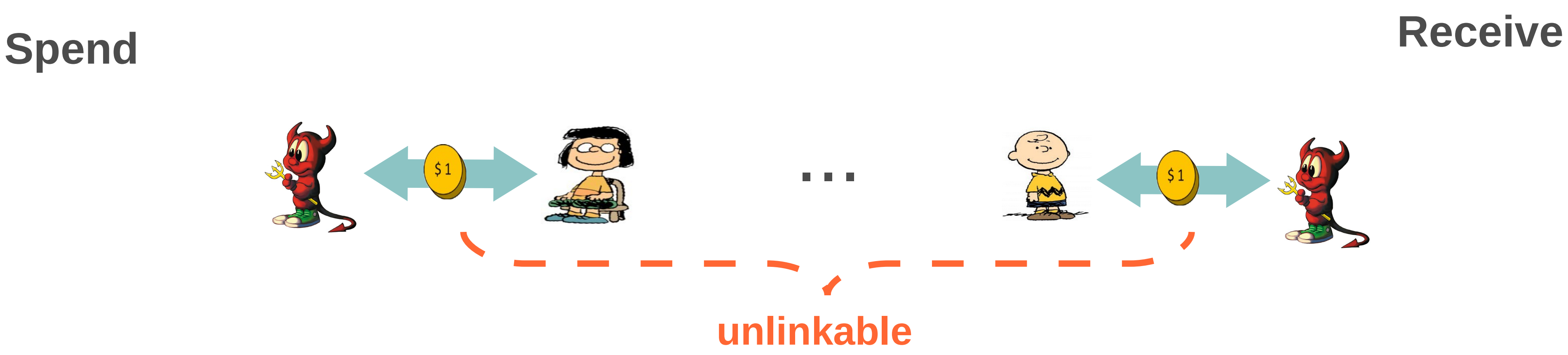
Transferable E-Cash Anonymity

- Observe-then-Receive (**OtR**)
- Spend-then-Observe (**StO**): an attacker (impersonating the bank) cannot link a passively observed coin transferred between two honest users to a coin he has already owned



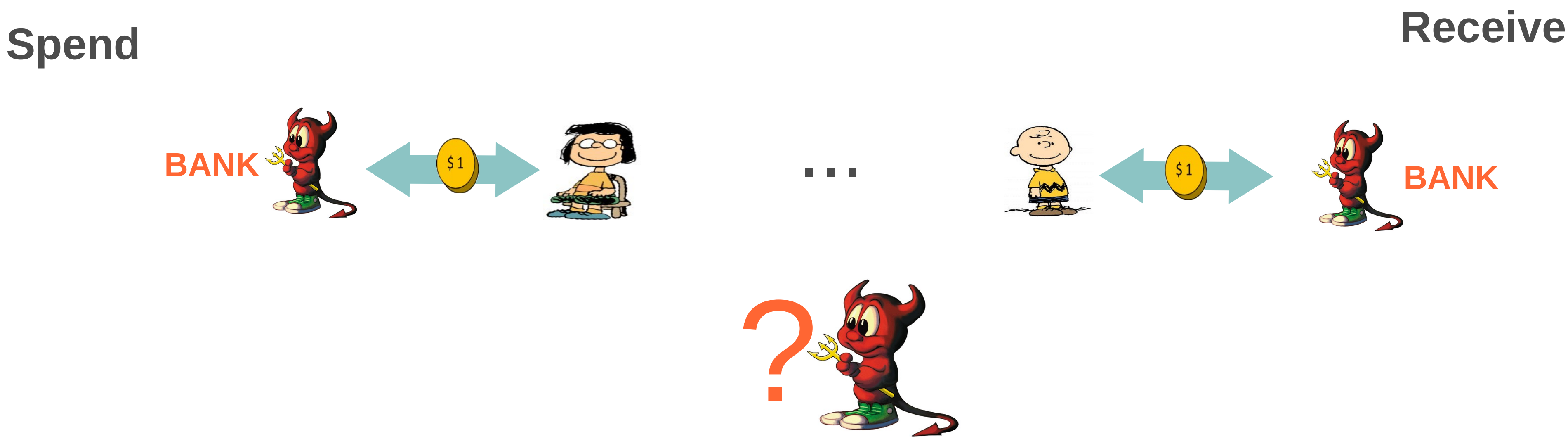
Transferable E-Cash Anonymity

- Observe-then-Receive (**OtR**)
- Spend-then-Observe (**StO**)
- Spend-then-Receive (**StR**): when the bank is honest, an attacker cannot link two transactions involving the same coin



Transferable E-Cash Anonymity

- Observe-then-Receive (**OtR**)
- Spend-then-Observe (**StO**)
- Spend-then-Receive (**StR**)
- Spend-then-Receive*(**StR***): an adversary, impersonating the bank, receives a coin he owned before he shouldn't be able to recognize the "chain" of honest users the coin followed



Our Construction

$U_1(ID_1,pk_1,sk_1)....U_n(ID_n,pk_n,sk_n)$

Coin List: CL

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where $SN=SN_1 || \ldots || SN_k$ & $DS=DS_1 || \ldots || DS_{k-1}$

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where $SN = SN_1 \,||\, \ldots \,||\, SN_k$ & $DS = DS_1 \,||\, \ldots \,||\, DS_{k-1}$

If a double-spending happened, then in CL there will be 2 coins where:

$$SN = SN_1 \,||\, \ldots \,||\, SN_j \,||\, \ldots \,||\, SN_k$$

$$=$$

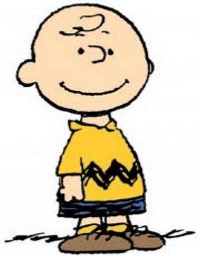
$$SN' = SN_1 \,||\, \ldots \,||\, SN'_j \,||\, \ldots \,||\, SN'_k$$

Double Spending Mechanism

$c = \sigma(SN, DS)$

sk_B, pk_B

(ID_1, pk_1, sk_1)



Withdrawal

Double Spending Mechanism

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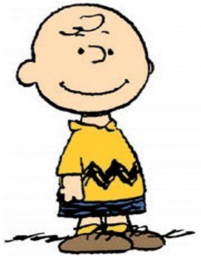

$com(SN_1)$

pick SN_1

Withdrawal

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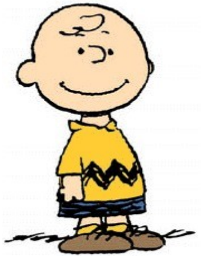
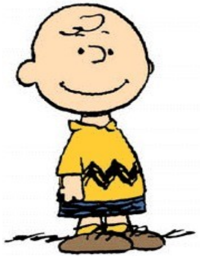


$com(SN_1)$ ←

pick SN_1

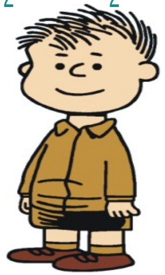
↔ $1

(ID_1, pk_1, sk_1)



$1 SN_1

(ID_2, pk_2, sk_2)

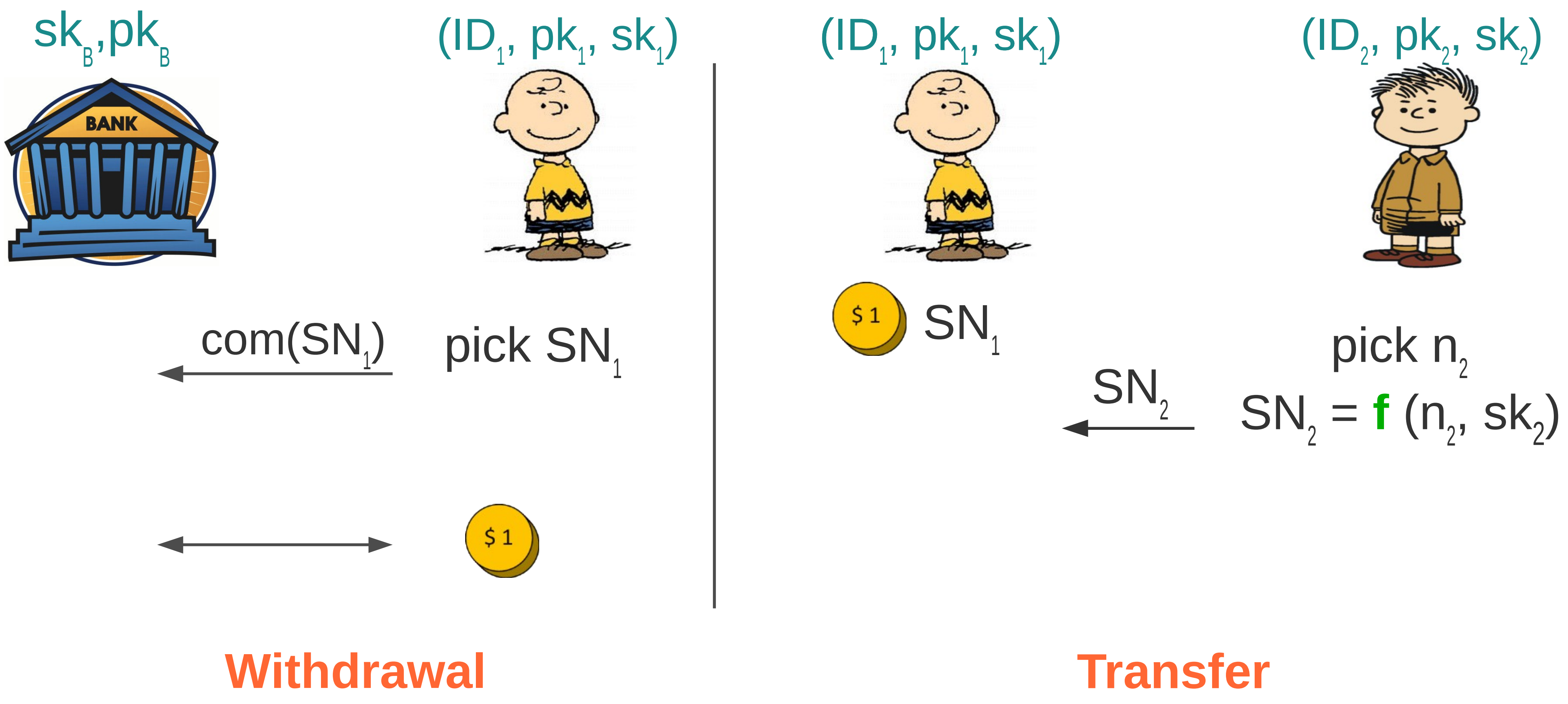


Withdrawal

Transfer

Double Spending Mechanism

$c = \sigma(SN, DS)$



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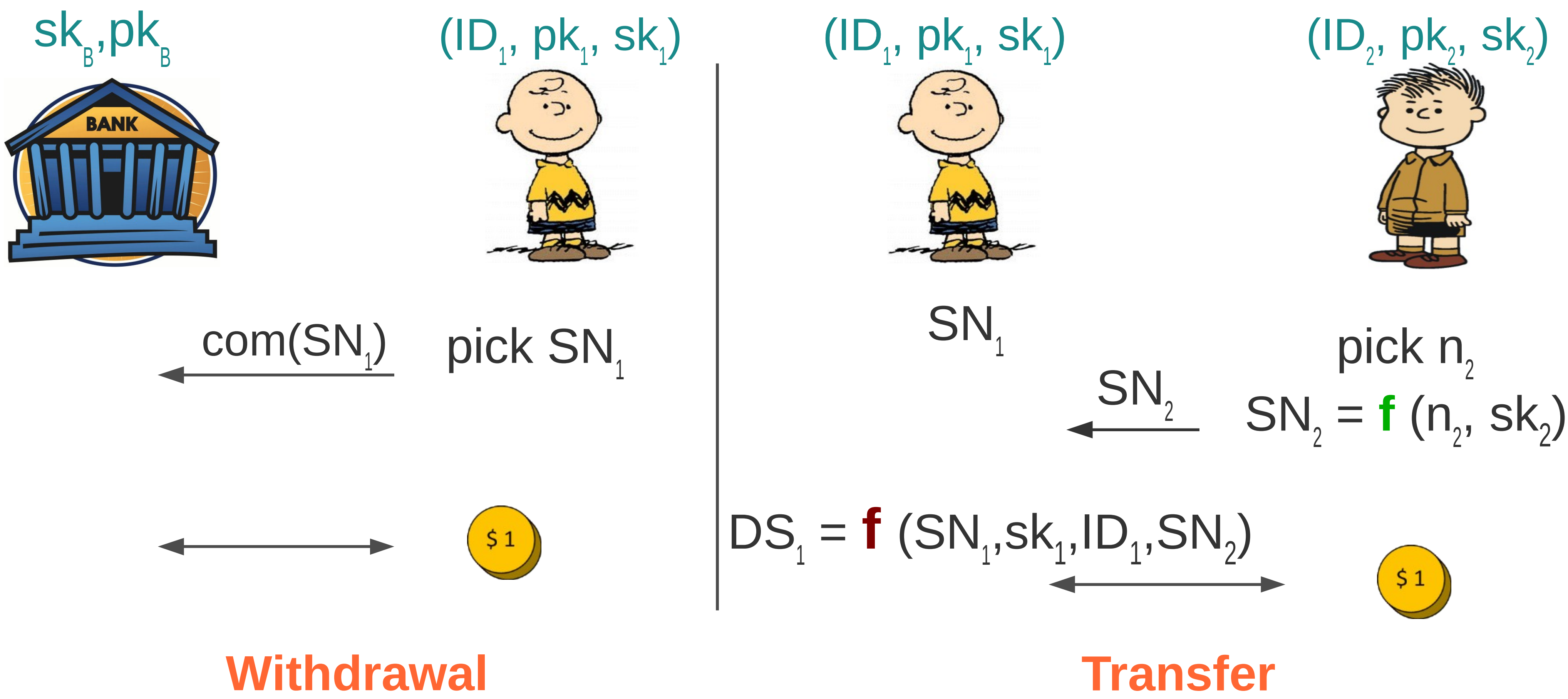
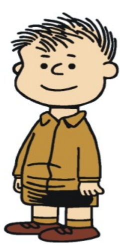


Double Spending Mechanism

(ID_1, pk_1, sk_1)

SN_1

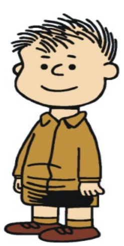
SN_2



Double Spending Mechanism

(ID_1, pk_1, sk_1)

SN_1



$\mathbf{SN_2}$

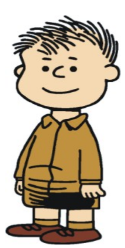
$DS_1 = \mathbf{f}\ (SN_1, sk_1, ID_1, \mathbf{SN_2})$

Double Spending Mechanism

(ID_1, pk_1, sk_1)

SN_1

$\mathbf{SN_2}$



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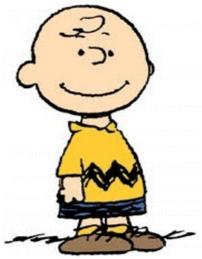

SN_1

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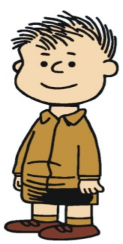
$DS_1 = \mathbf{f}\,(SN_1, sk_1, ID_1, \mathbf{SN_2})$

Double Spends



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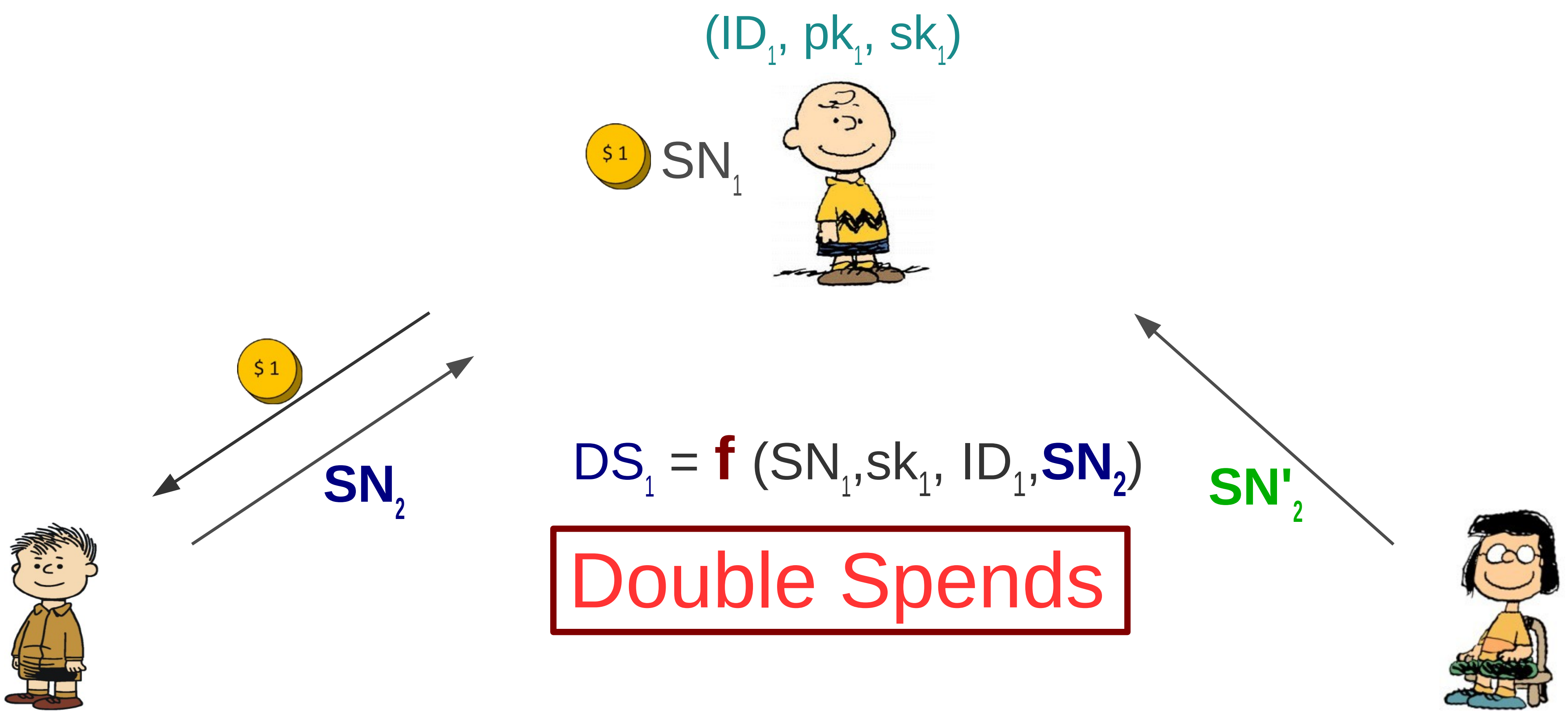

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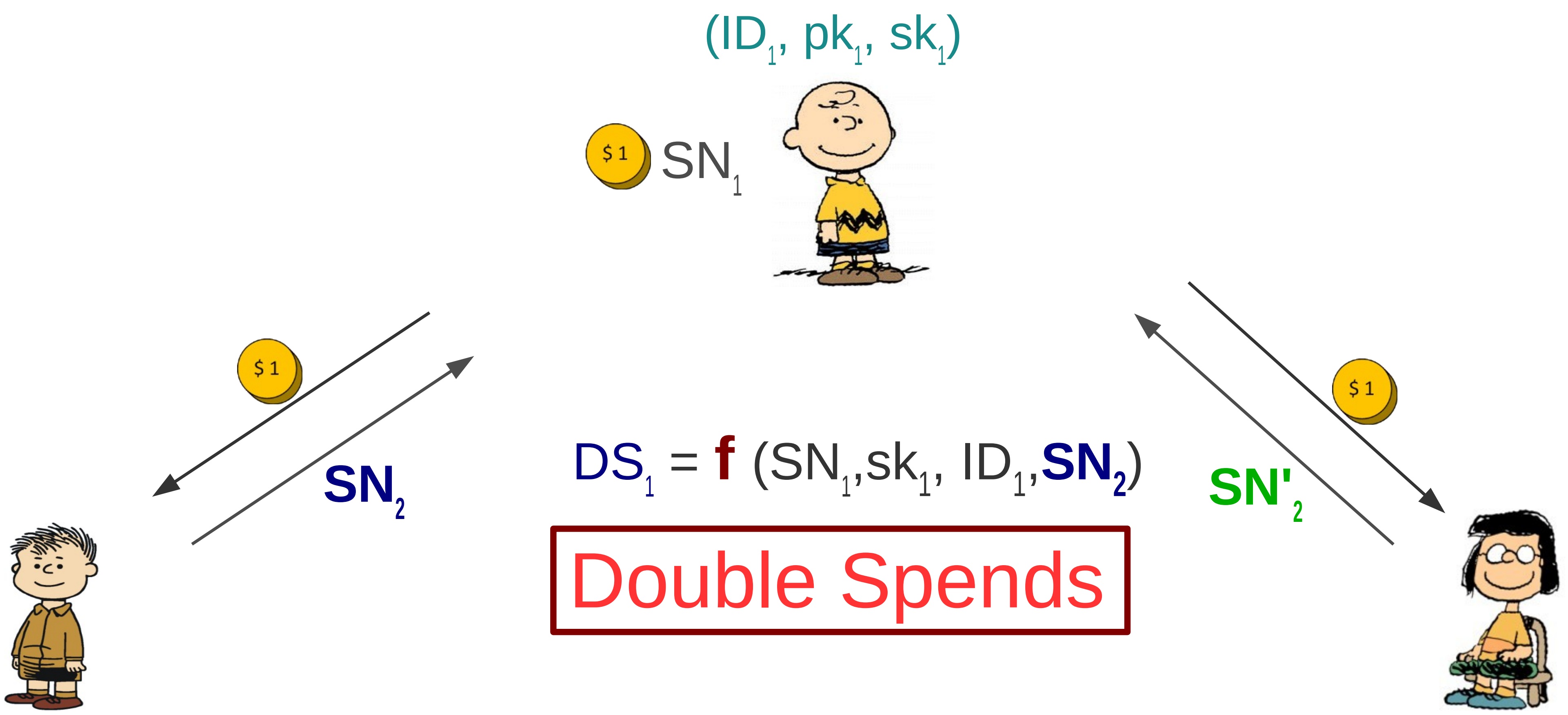

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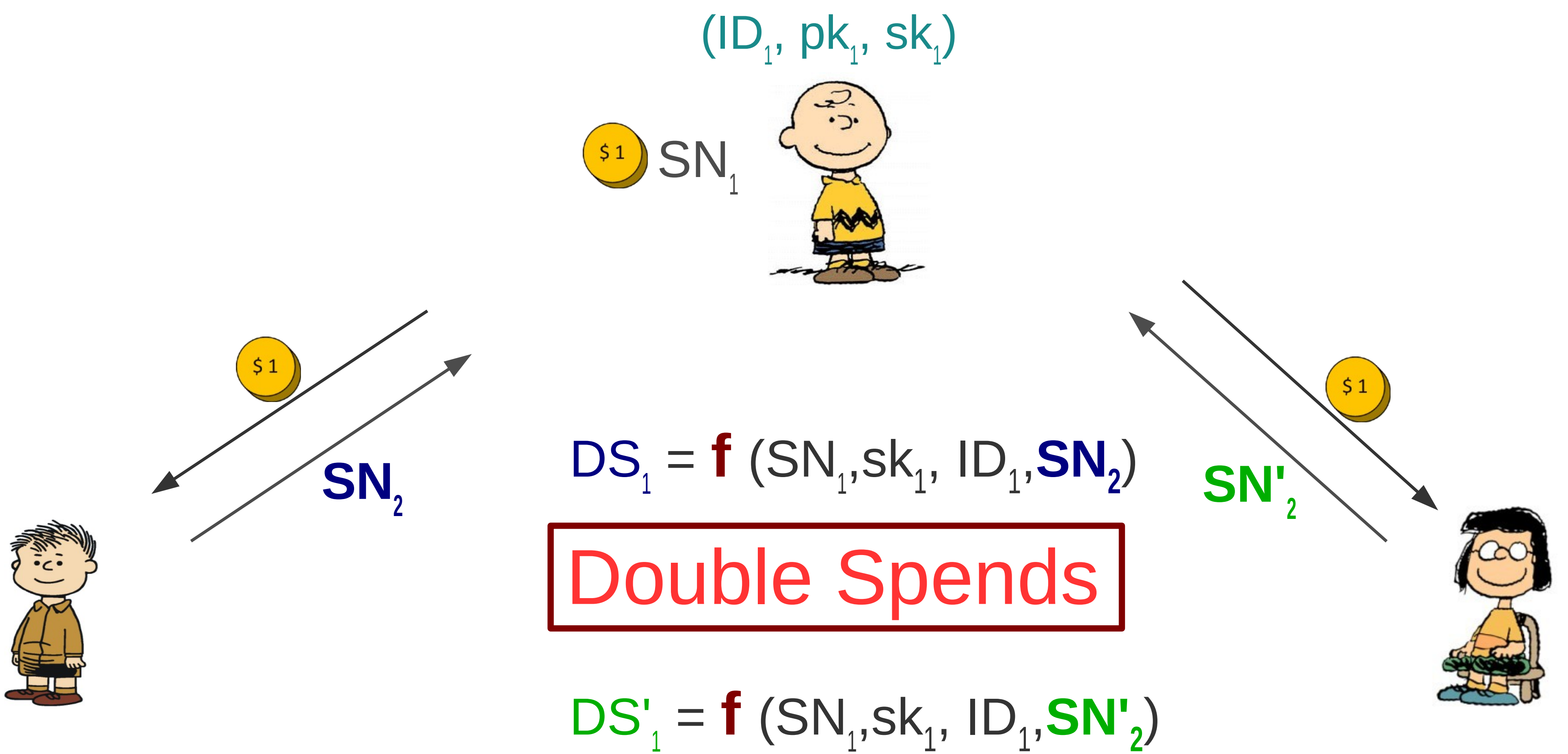

Double Spending Mechanism

SN' = SN_1 || **SN_2 || … || SN'_k**

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$\mathbf{ID_1}$

$\mathbf{DS'_1} = \mathbf{f}\,(SN_1, sk_1, ID_1, \mathbf{SN'_2})$

Double Spending Mechanism

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Bank needs to check:

$\mathbf{x = y^{ID}}$

for every ID registered

Thm. "*Our DS mechanism is anonymous under DDH.*"

Constructing transferable e-cash

- ✔ Ensure that coins contain all the valid information in order for double spending detection to be successful and correct.
- ✔ Need to encode all the identities of the users who ever owned the coin in a way that ensures anonymity.

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What is left?

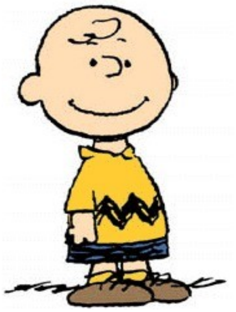
Make sure that coins are valid and unforgeable.

Malleable Signatures

sk,vk

$\sigma_{sk}(m)$

MSign



[ABCSsW'12, ALP'12,CKLM'13]

Malleable Signatures

sk,vk

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$m^* = T(m)$

Where T is an allowed transformation

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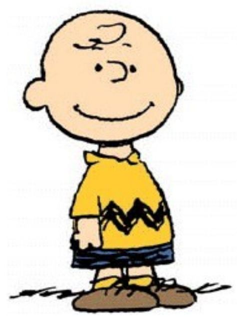
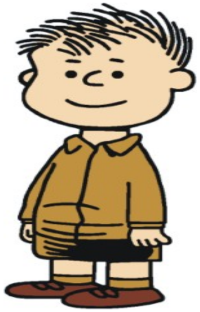


$\sigma^*_{sk}(m^*)$

MSigEval



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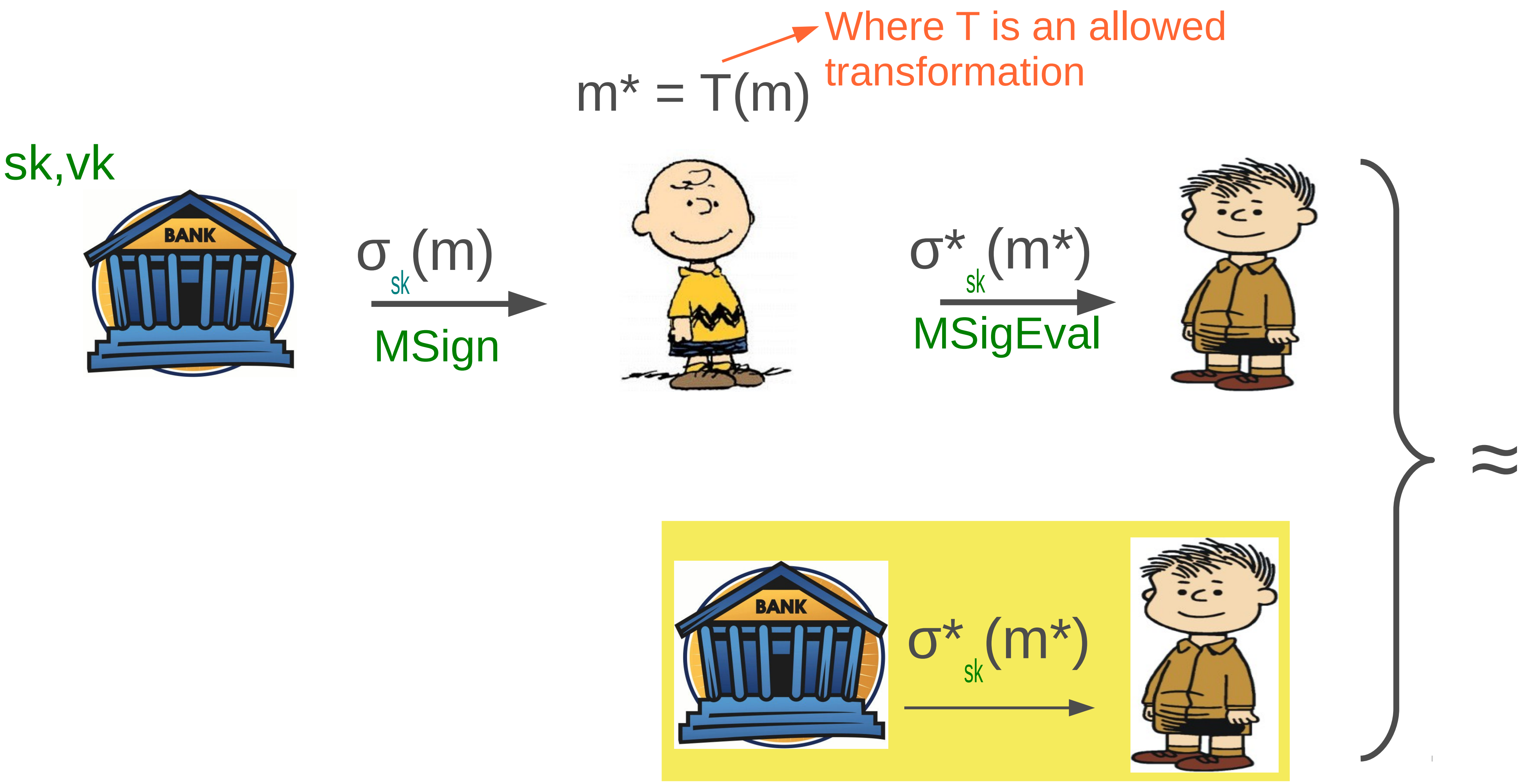
Malleable Signatures



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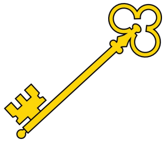
Our Construction – Withdrawal

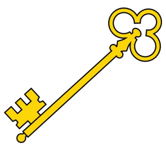
 

com ←

pick SN_1

com = Commit(SN_1)

Our Construction – Withdrawal



com

pick SN_1

σ = MSign(com)

com = Commit(SN_1)

σ

Our Construction – Withdrawal

σ = MSign(com)

com ←

σ →

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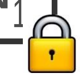
σ^* = MSigEval(T, com, σ)

for T(com) = $\boxed{SN_1}$ 

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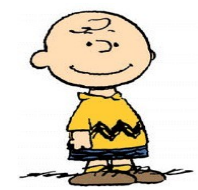

com

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σ

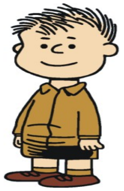
σ* = MSigEval(T, com, σ)

for T(com) = $\boxed{SN_1}$

 = ($\boxed{SN_1}$, σ*)

Our Construction - Spending

= (SN , DS , σ)



Our Construction - Spending

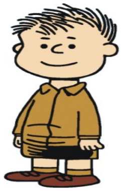
 = (SN, DS, σ)

SN= $SN_1 \,||\, SN_2 \,||\, \ldots \,||\, SN_j$

DS= $DS_1 \,||\, DS_2 \,||\, \ldots \,||\, DS_{j-1}$

Our Construction - Spending

 = (SN, DS, σ)

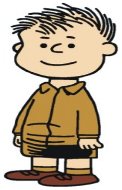


SN_{i+1} ←

pick SN_{i+1}

Our Construction - Spending

 = (SN, DS, σ)



compute DS_i

pick SN_{i+1}

Our Construction - Spending

= (SN, DS, σ)

compute DS_i

SN_{i+1} ←

pick SN_{i+1}

σ^* = MsigEval(T, SN, DS, σ)

Our Construction - Spending

 = (SN, DS, σ)

compute DS_i ← SN_{i+1} — pick SN_{i+1}

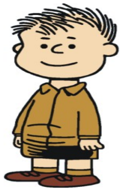
$\sigma^* =$ MsigEval(T, SN, DS, σ)

where T (SN, DS) =

($SN||SN_{j+1}$, $DS||DS_j$)

Our Construction - Spending

= (SN , DS , σ)



compute DS_i

SN_{i+1} ←

pick SN_{i+1}

σ* = MsigEval(T, SN , DS ,σ)

σ*, ($SN||SN_{j+1}$, $DS||DS_j$) →

where T (SN DS) =

($SN||SN_{j+1}$, $DS||DS_j$)

Our Construction - Spending

= (SN, DS, σ)

compute DS$_i$

SN$_{i+1}$ ←

pick SN$_{i+1}$

σ* = MsigEval(T, SN, DS, σ)

σ*, (SN||SN$_{j+1}$, DS||DS$_j$) →

where T (SN, DS) =

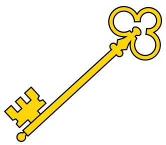
(SN||SN$_{j+1}$, DS||DS$_j$)

= (SN||SN$_{j+1}$, DS||DS$_j$, σ*)

Our Construction - Deposit

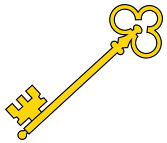
$\$1 = (\mathbf{SN}||SN_{j+1}, \mathbf{DS}||DS_j, \sigma')$

Run Spending



Our Construction - Deposit

$= (\mathbf{SN}||SN_{j+1}, \mathbf{DS}||DS_j, \sigma')$



Run Spending

Decrypt

$\mathbf{SN}=SN_1 \;||\; \dots \;||\; SN_{i+1}$

$\mathbf{DS}=DS_1 \;||\; \dots \;||\; DS_i$

If there exists a coin with same SN_1 then a double spent happened!

Our Construction - Security

We rely on the security properties of the underlying schemes:

1) Malleable signatures
2) Signature scheme
3) Commitment scheme
4) Randomizable encryption scheme

Exact assumptions depend on the instantiation!

Conclusion

The first practical, truly anonymous transferable e-cash scheme

- ✔ No trusted 3rd party that can de-anonymize users
- ✔ On double spending, only the identity of the malicious user is revealed

Possible instantiation:

Groth-Sahai proof system + El Gamal encryption/commitments + ACDKNO'12 structure preserving signatures

Secure under the Decision Linear (DLIN) and Symmetric External Decision Diffie-Hellman (SXDH) assumptions

thank you!

foteini@bu.edu

Additional Slides

Anonymity for transferable e-cash is more complicated [CG'08]...

- **Full anonymity (FA)**: an attacker, impersonating the bank, cannot recognize a coin he has already observed (observe-then-receive)
- **Perfect anonymity (PA):** an attacker cannot decide whether he has already owned a coin he is receiving (impossible)

[CP'92] An unbounded adversary will always recognize his own coins if he seems them later

What about a bounded adversary A, acting as the bank?