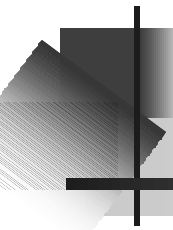
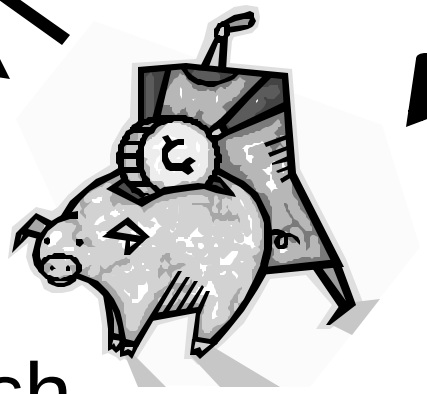


Electronic Cash

The Problem

Alice pays Merchant Bob with ecash



Alice opens account.

Withdraws ecash

Bob deposits ecash in his account

Ecash Requirements

- Maintain properties of physical cash
- Unforgeability
- Untraceability
  - Bank cannot link a deposit to a withdrawl
  - Required to maintain anonymity
- Double spending problem
  - A digital copy of ecash could be spent elsewhere

Blind Signature

- Recall RSA --signatures
  - (d,N) is private key and (e,N) public key
  - Signature: $m^d \bmod N$
  - Anyone can decrypt this with public key
  - Verify that only owner could sign it
- Blind signature
  - Sign a message without revealing the message to the signer

Blind signature

- Alice sends Bob $s = (r^e\ m) \bmod N$
  - r is a random number, not revealed to Bob
- Bob computes $t = s^d \bmod N$ and returns it to Alice
- Alice computes $t/r \bmod N = m^d \bmod N$
  - Obtains Bob signature on message m
  - Hasn’t revealed m to Bob

Ecash –blind signatures

- Alice and Bank work together to produce $1
  - Bank signs the $1 ecash certificate
  - Bank doesn't have information that this signed $1 belongs to Alice
- Valid $1 bill is a pair = (x, y)
  - $y = f(x)^d \bmod N$
  - f() is a one-way hash function

Ecash -protocol

- Alice withdraws $1 by
  - Picks x, computes f(x)
  - Gets a blind signature on f(x) from Bank
    - Alice sends bank $s = (r^e f(x)) \bmod N$
    - Bank sends Alice $t = s^d \bmod N$
    - Alice has $y = t/r = f(x)^d \bmod N$
- Alice pays Bob by sending (x,y)

Ecash --protocol

- Bob deposits (x,y) with the bank
- Bank can verify that $y^e = f(x)$
- Bank can check for double spending
  - Not on the list of previously deposited bills
- Bank cannot link this deposit to Alice
  - Blind signature on a random string s

Ecash –Forging

- Imagine $1 bill = (x,y), $y = x^d \bmod N$
- Alice can pick y
  - Then, compute $x = y^e \bmod N$
  - Now, has a feasible (x,y) pair
- By using, one-way hash function f()
  - Requires Alice to invert the one-way hash
  - Forging is difficult
    - Gets f(x), not x, from $y^e \bmod N$

Multiple denominations

- Choose multiple key pairs
  - One for each denomination
- A second approach, choose different encryption exponents
  - e = 3 for $1 bill, 5 for $5 bill, 7 for $10 bill
  - These exponents need to be mutually prime
  - If not, can forge bills

Ecash --offline

- The above scheme requires bank to be online all the time
- Not a problem now
- But, can we design a scheme that does not require bank to be online all the time?

Offline ecash

- Let bank detect double spending
  - Bank not online all the time to prevent
- If user doesn’t double spend, remains anonymous
- If user double spends, user ID is revealed
  - Take suitable action, charge a fine, put in jail etc..

Offline ecash --format

Bank Name
Random Serial Number
One Dollar
$f(x_1)$, $f(x_1 \oplus ID)$
$f(x_2)$, $f(x_2 \oplus ID)$
....
$f(x_k)$, $f(x_k \oplus ID)$

Offline ecash

- Alice generates k random numbers x_i for each bill
- Computes $f(x_i)$ and $f(x_i \text{ XOR ID})$
- Gets the bank to blind sign the bill with these numbers

Offline ecash

- Bank randomly picks N out of M bills it signs for Alice
- Asks Alice to “unblind” them to make sure Alice is actually including her ID in the bills
- Bank assumes that remaining N-M bills include Alice’s ID

Offline ecash

- Alice pays Bob, the Merchant with signed cash
- Bob sends a challenge bit stream b_i
- If $b_i = 0$, Alice reveals x_i , $b_i = 1$, Alice reveals (x_i XOR ID), for i = 1,...k
- Bob can verify each response from Alice
  - Against the information in the $1 bill

Offline ecash

- Bob sends ecash to Bank along with the challenge bit string and the revealed information from Alice –for deposit
- If Alice double spends, the challenge strings given by Merchants will differ in one bit position with a high probability
- Then, bank will have both x_i and (x_i XOR ID)
  - Revealing Alice's ID

Offline ecash

- Sequence number is needed
- Without it, Alice can double spend by permuting the $f(x_i)$, $f(x_i \text{ XOR } ID)$ pairs

Ecash Additional requirements

- Unlinkability: Given two bills, bank cannot tell if they come from the same user
- Divisibility: Bill can be broken up and spend at multiple merchants
- Anonimity Revocation: Based on Judge's orders, to trace illegal transfers
  - Money laundering –owner tracing
  - Blackmail –Bill tracing