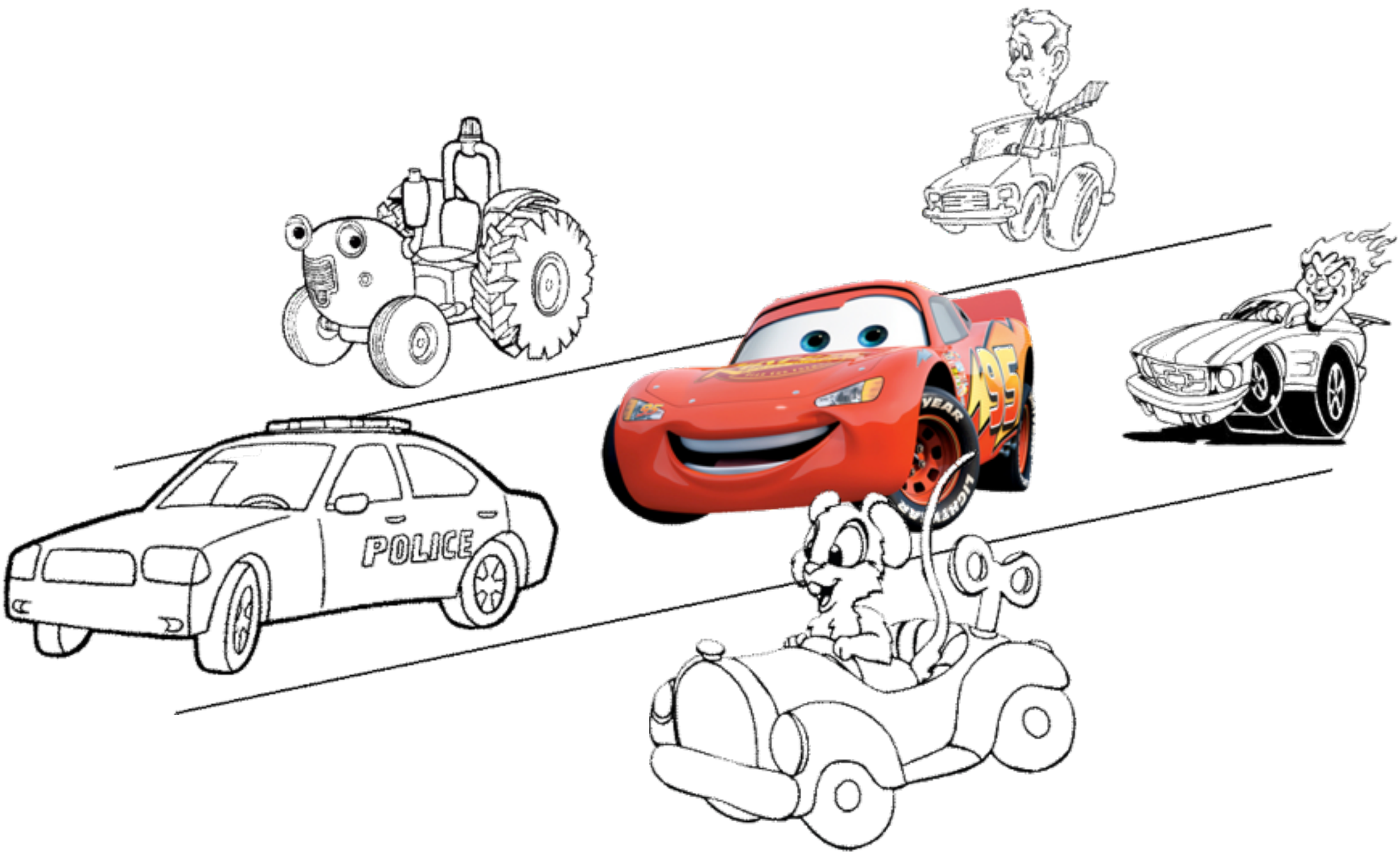
An Exploration of Group and Ring Signatures

Sarah Meiklejohn

UC San Diego Research Exam
4 February 2011

A real-world problem



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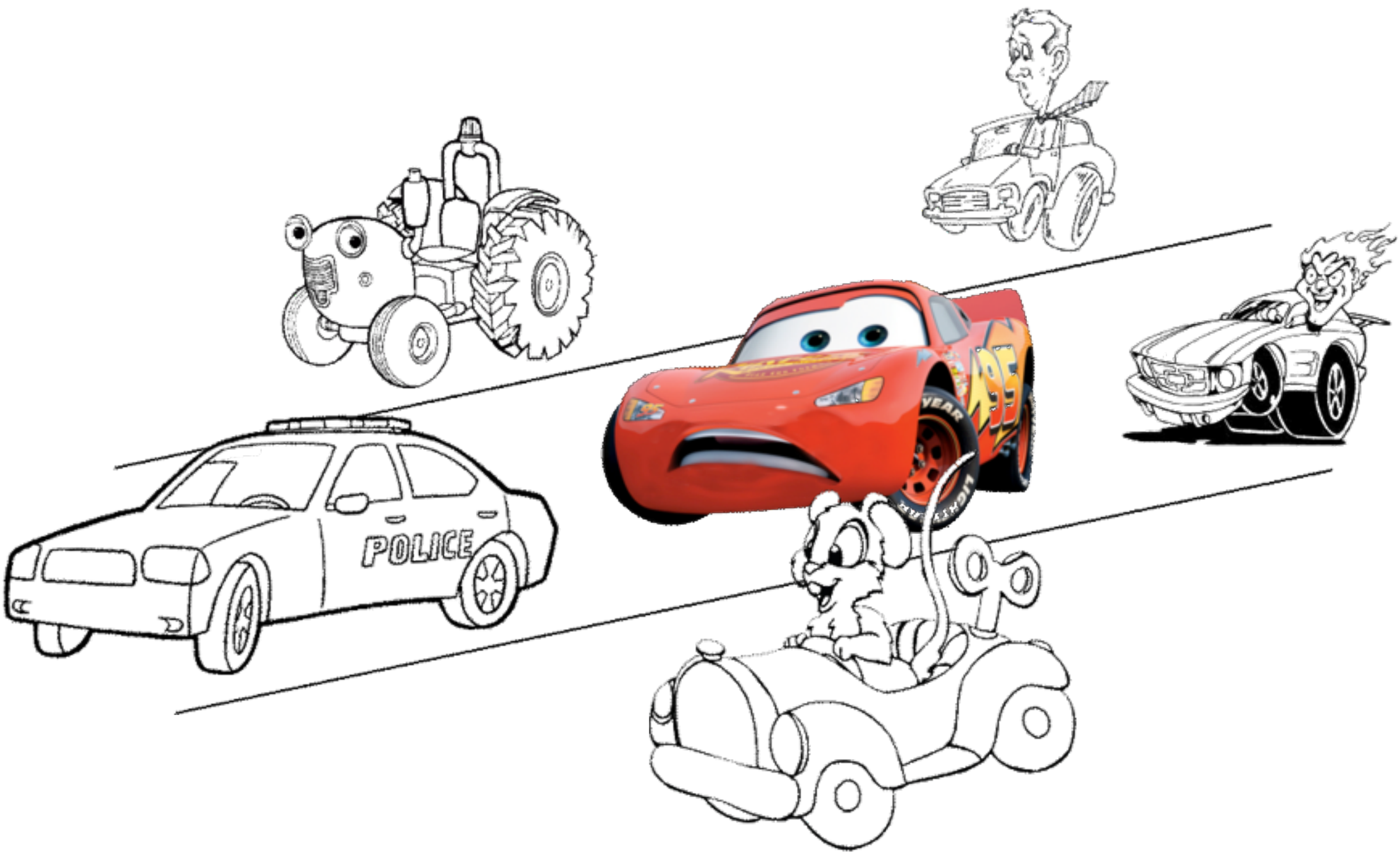

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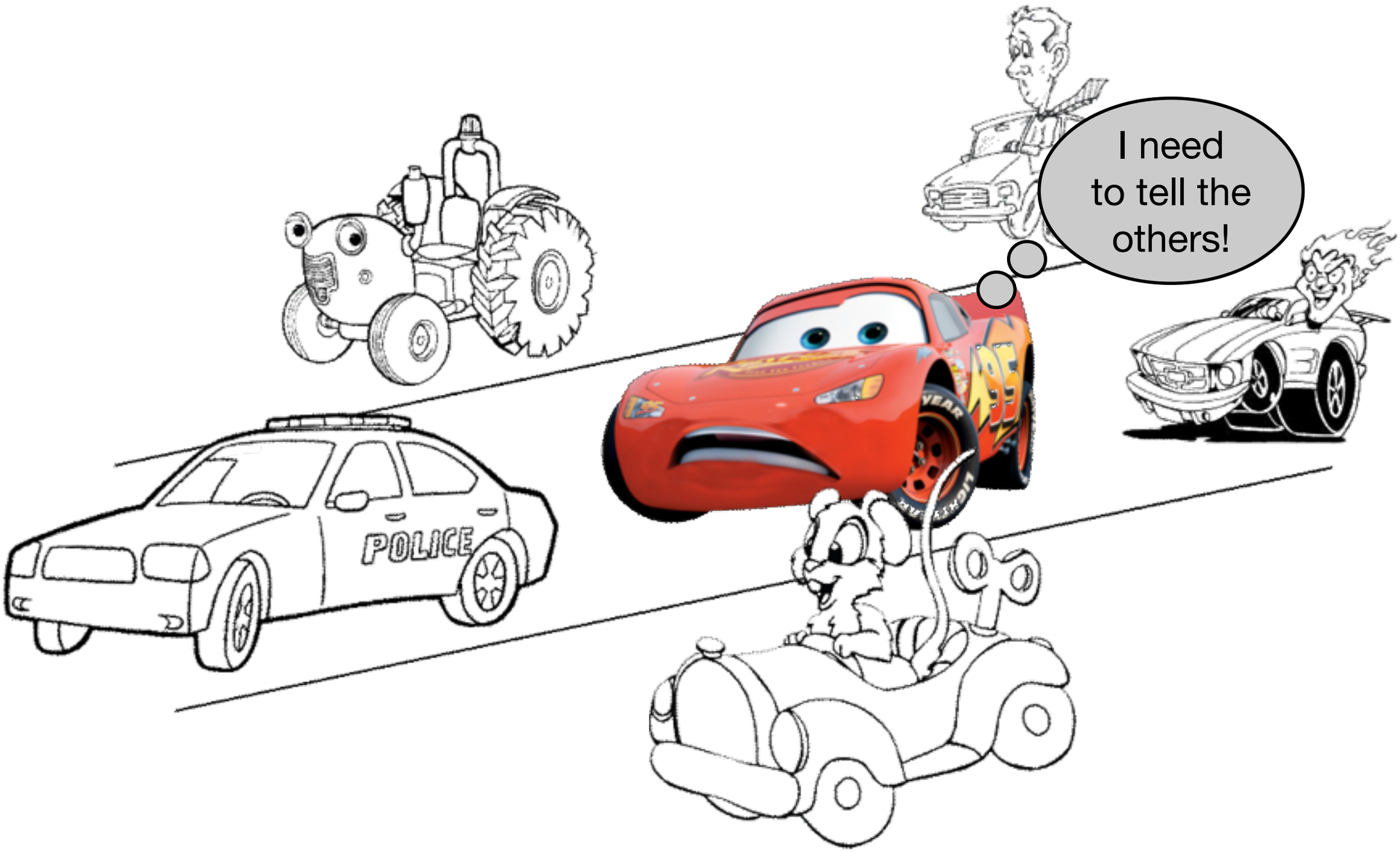

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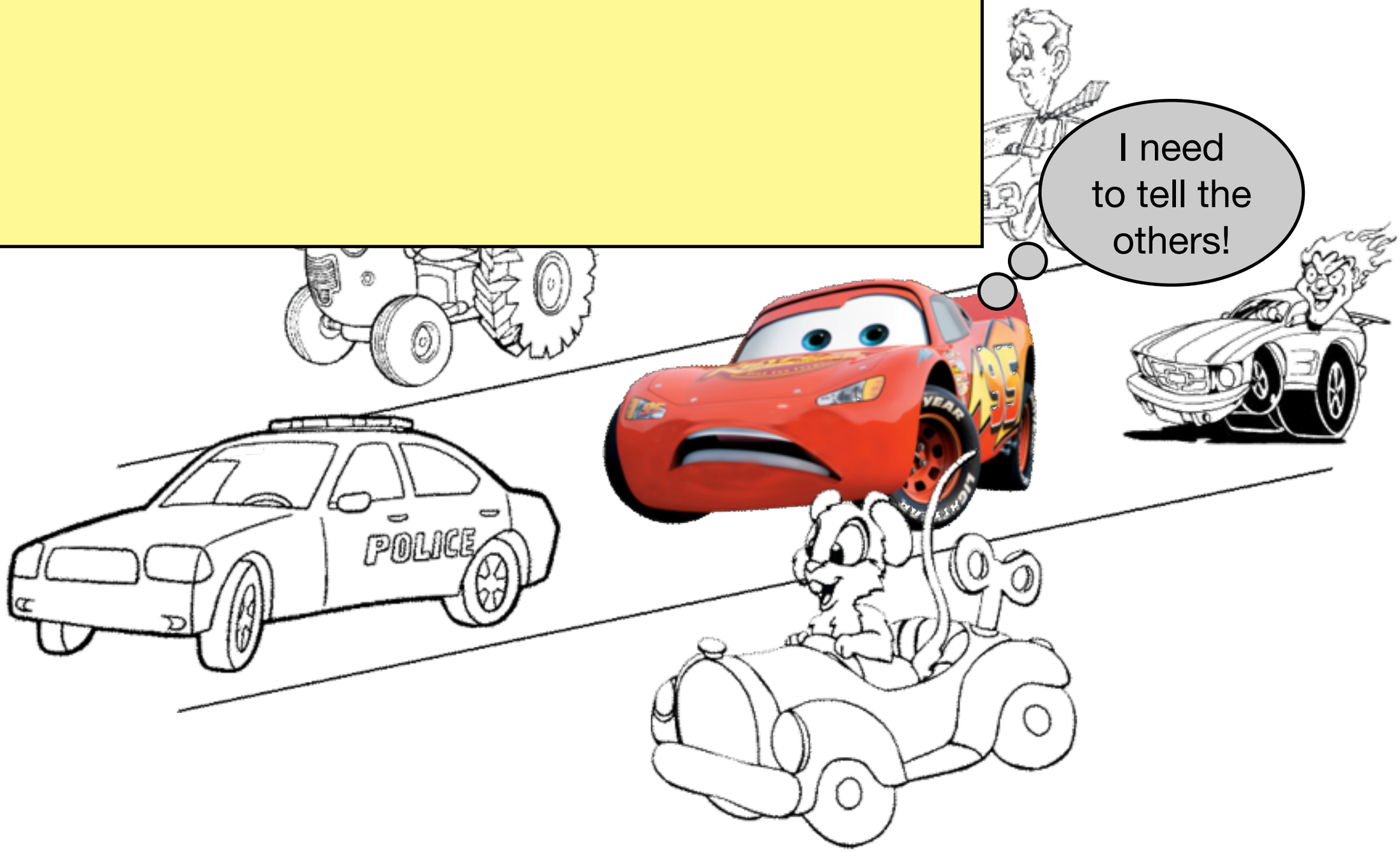

A real-world problem

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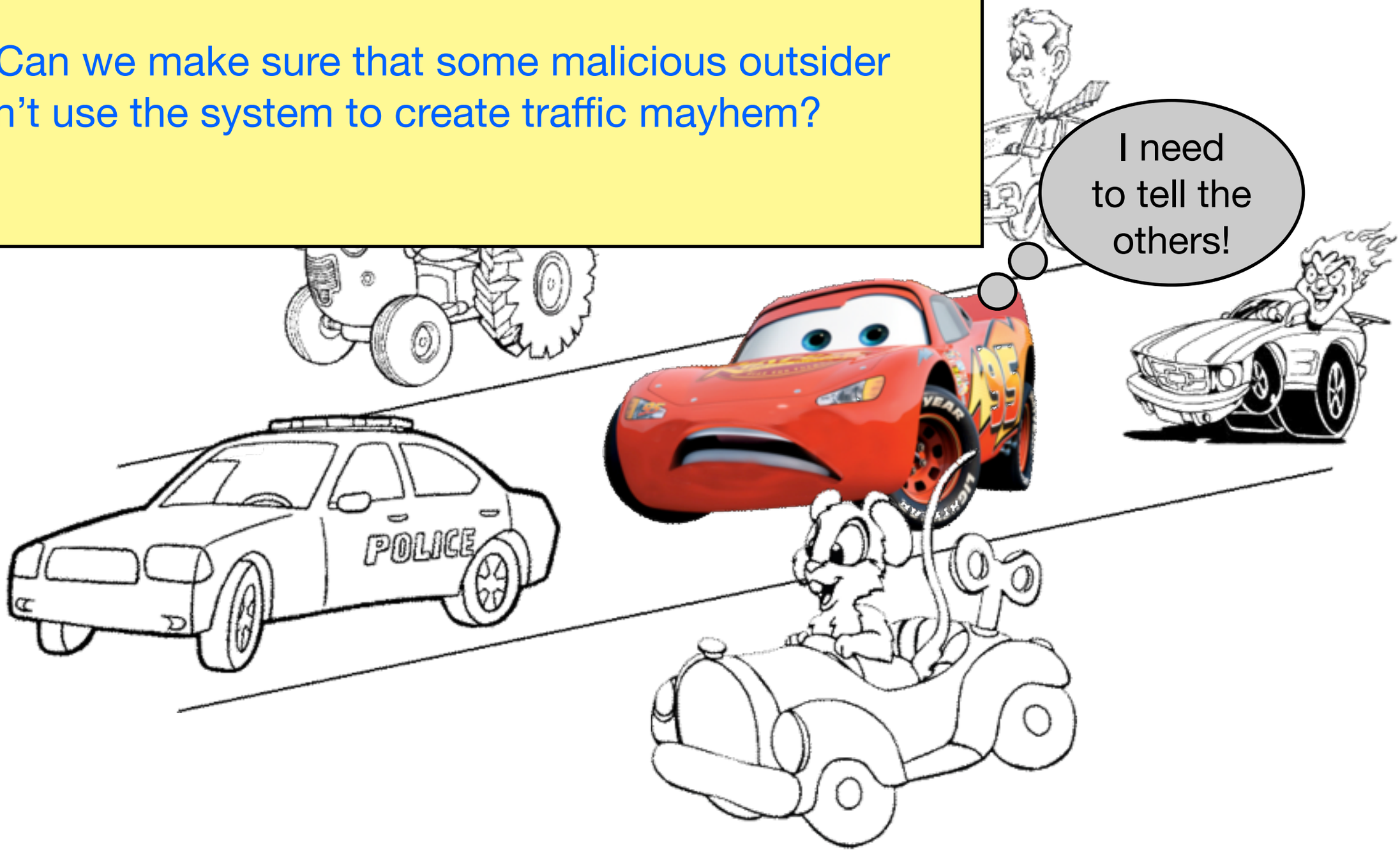
2. Can we make sure that some malicious outsider can't use the system to create traffic mayhem?



Outline

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Cryptographic background

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Group signatures

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Ring signatures

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- ...then he can compute σ = Sign(sk,m) for the desired message m, and ...
- Recipient can run Verify(pk,σ,m) to be sure σ was created by Signer

Digital signatures

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Signer

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- We need signatures to be unforgeable, which means an adversary cannot successfully pretend to be the Signer (without knowing sk)

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Group signatures

Intuition and motivation

Formal definitions

Extensions and variants

Comparison of existing schemes

Ring signatures

Open problems

Group signatures: why do we want them?

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Group 1

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pk_A, sk_A

pk_B, sk_B

pk_C, sk_C

pk_D, sk_D

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Alice: pk_A

Bob: pk_B

Charlie: pk_C

Dora: pk_D

Group signatures: why do we want them?

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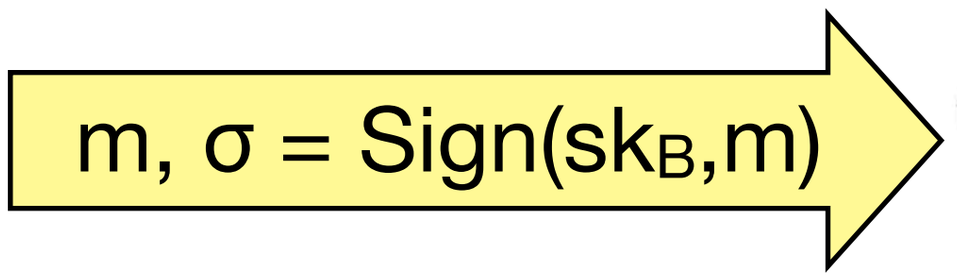

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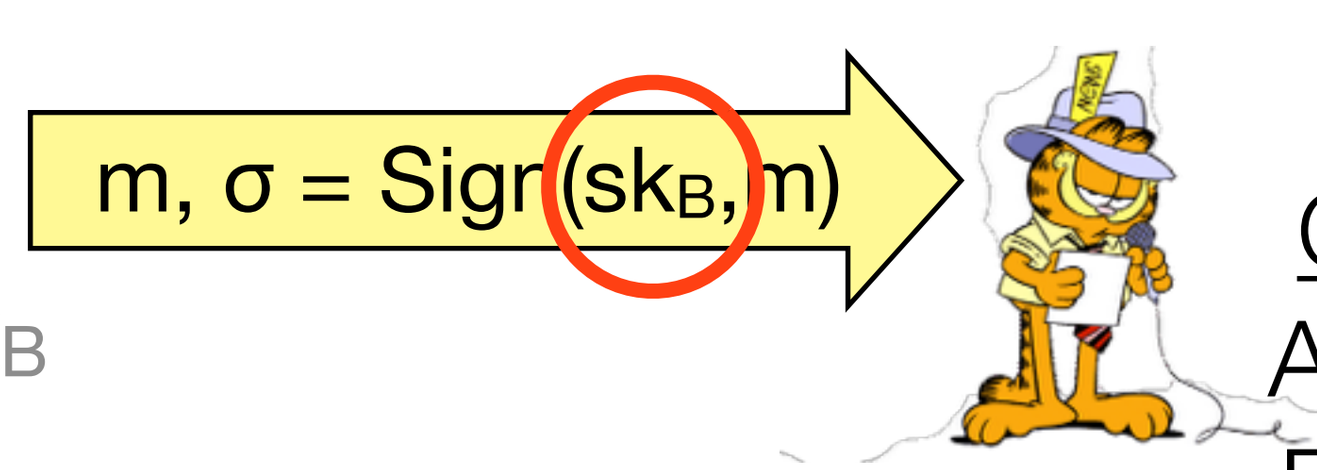

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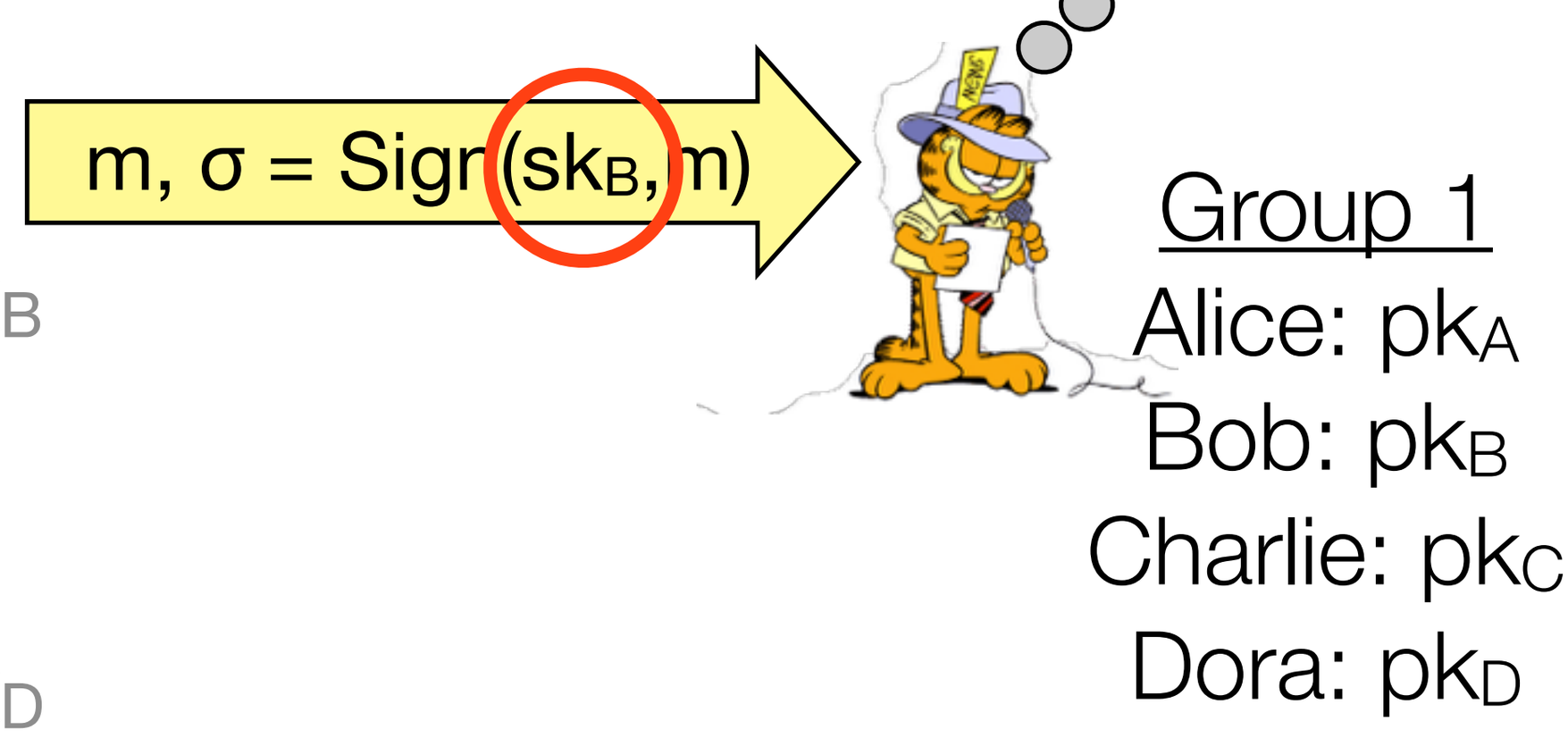

Group signatures: why do we want them?

pk_A, sk_A

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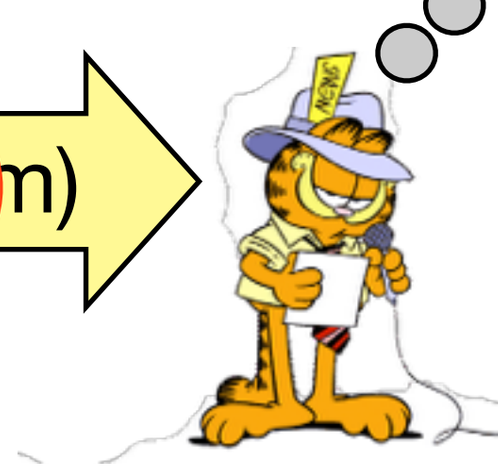
Group 1

$m, \sigma = Sign(sk_B, m)$



Verify(pk_B,σ,m) = 1... so Bob wrote the message!

<u>Group 1</u>

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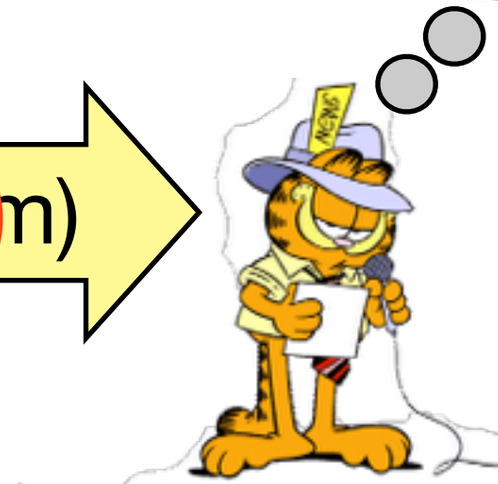

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<u>Group 1</u>

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Properties of group signatures: anonymity

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sk_A

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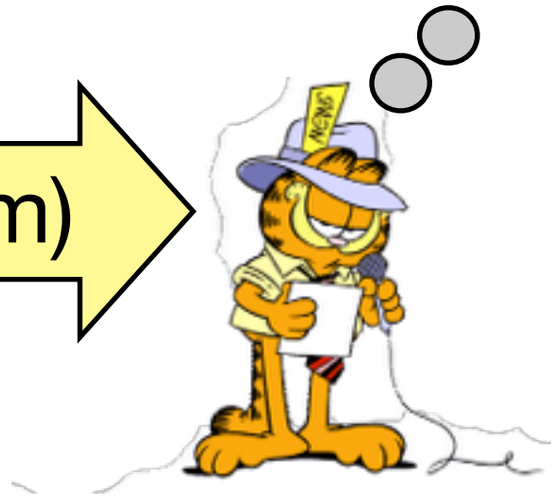

Verify(pk_{CIA},σ,m) = 1...
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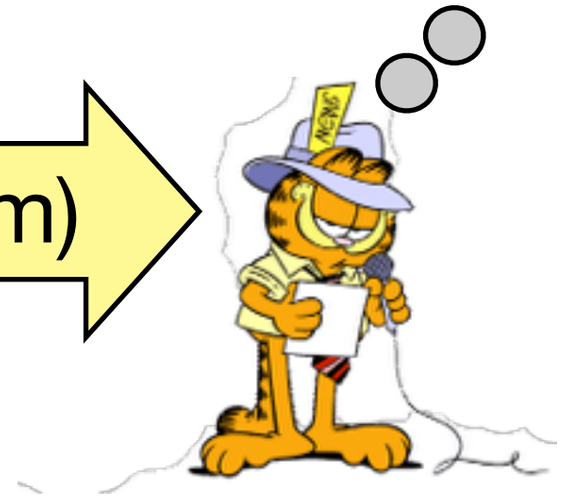

Verify(pk_{CIA},σ,m) = 1...
so someone from the CIA wrote the message.

- Given Sign(sk_B,m) and Sign(sk_D,m), recipient can't tell the difference
- This should be true even if he knows who has signed previous messages

Properties of group signatures: traceability

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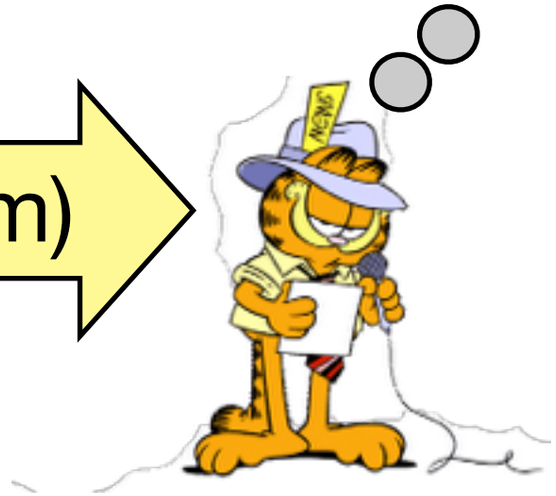

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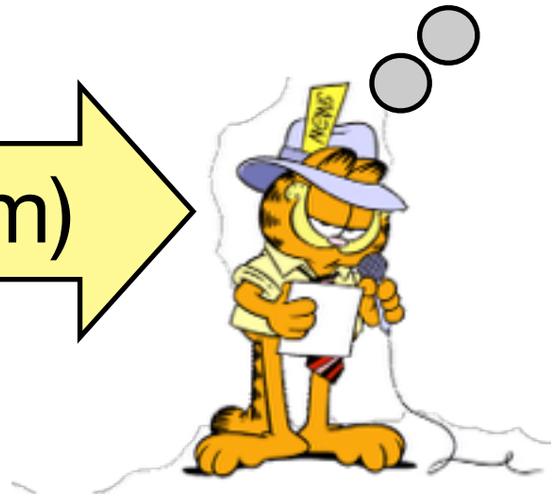

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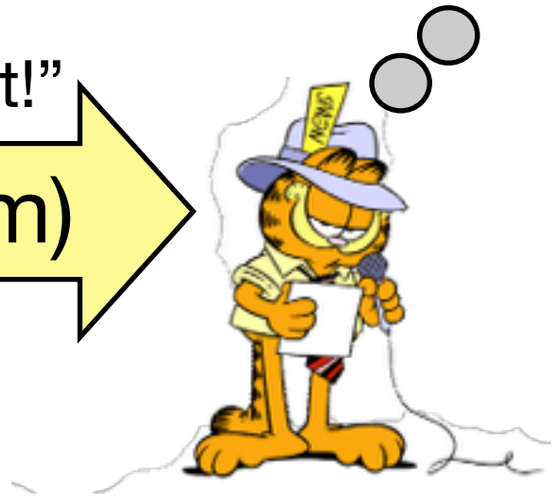

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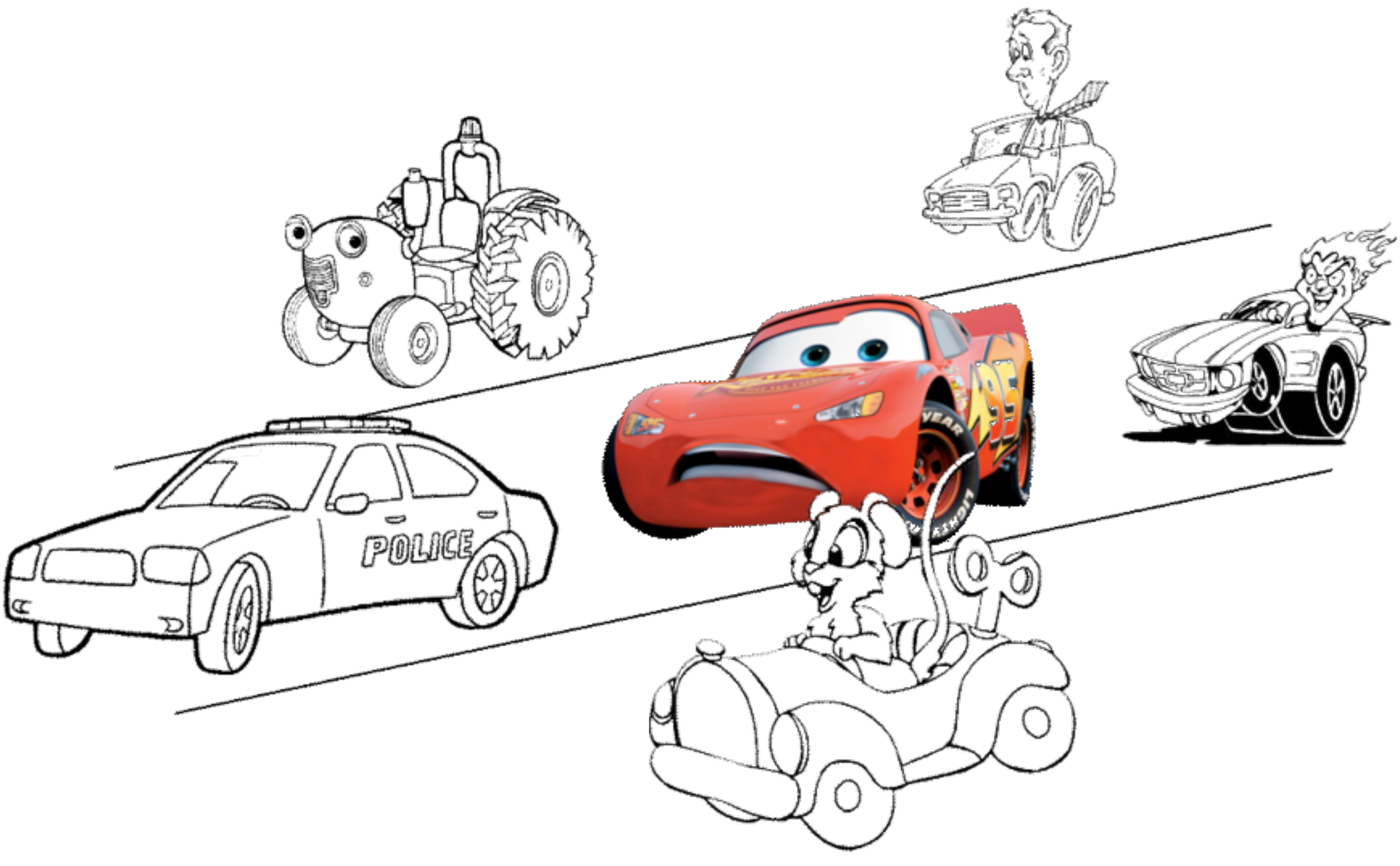
sk_D

- Want new algorithm Trace s.t. Trace(tk,σ) = Bob
- Whoever has access to tk breaks anonymity

Using group signatures with our real-world problem



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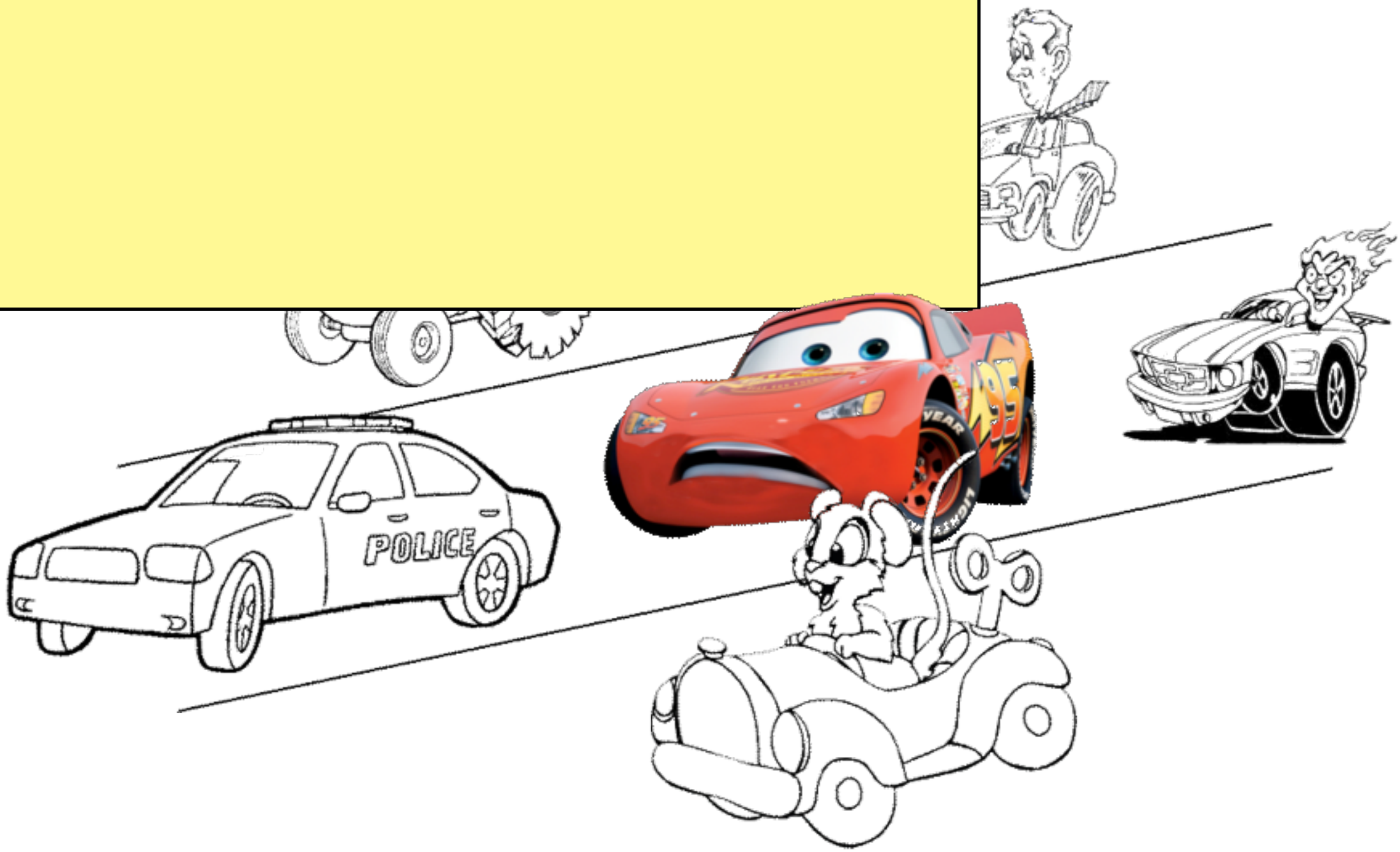

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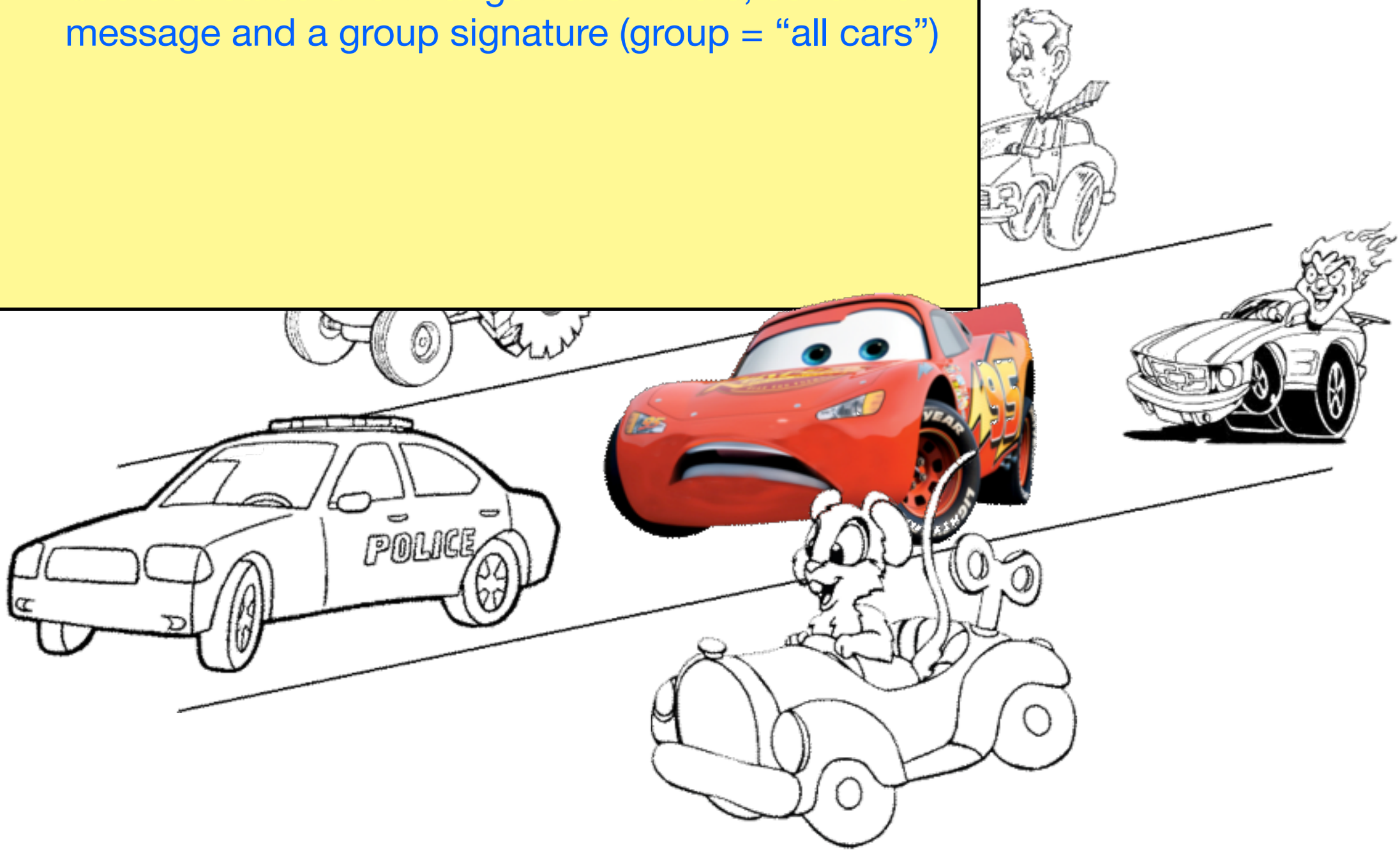

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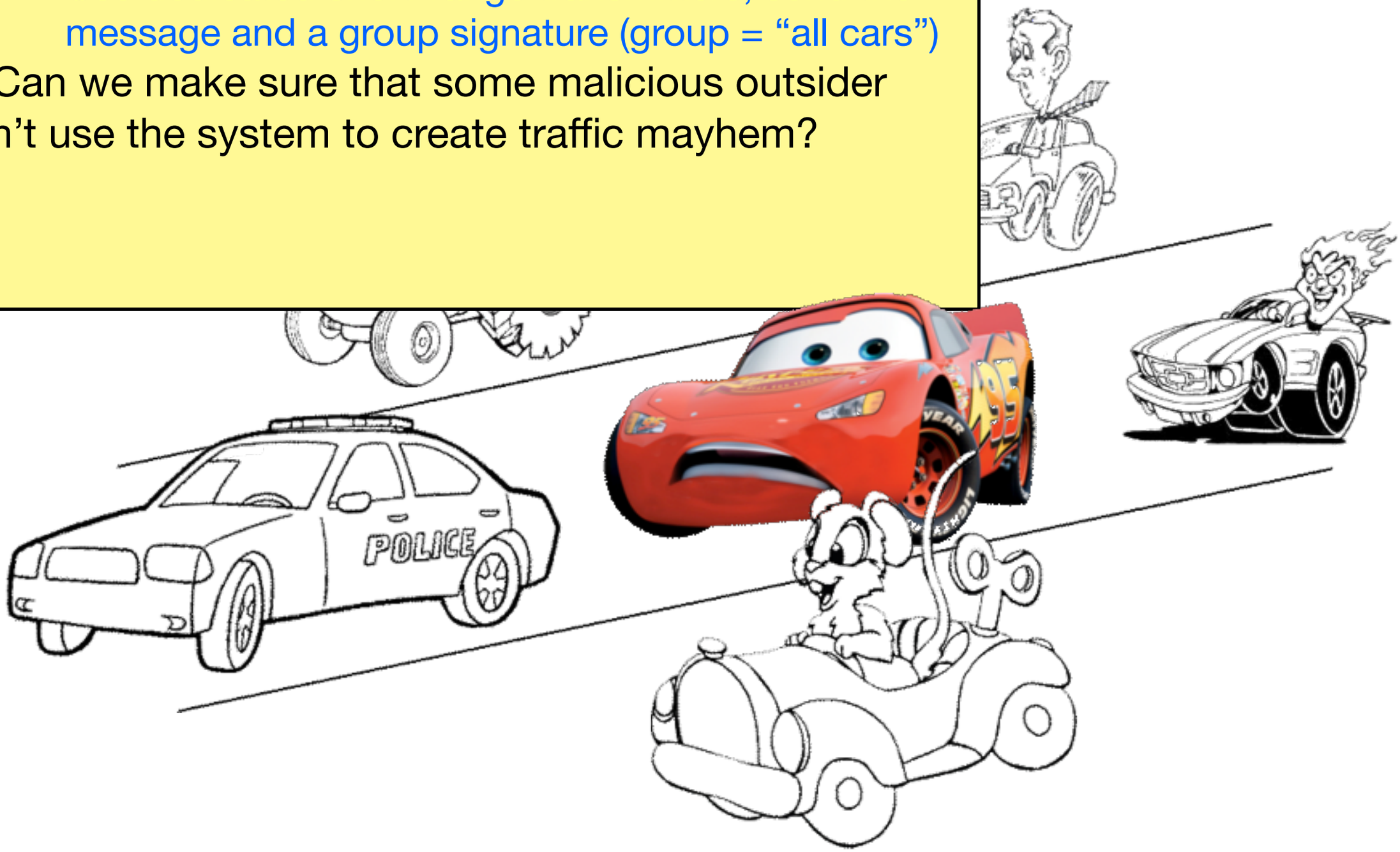

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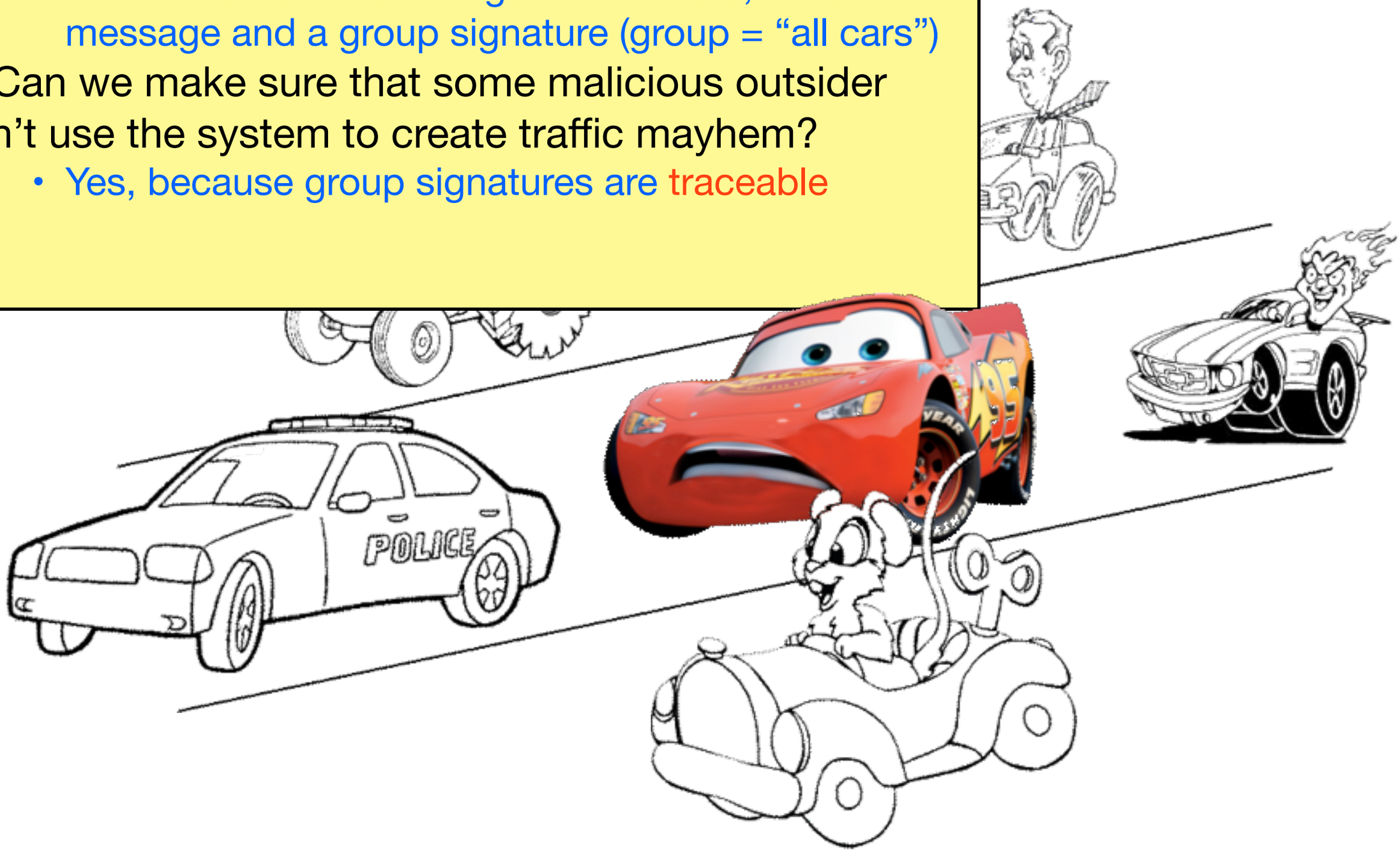

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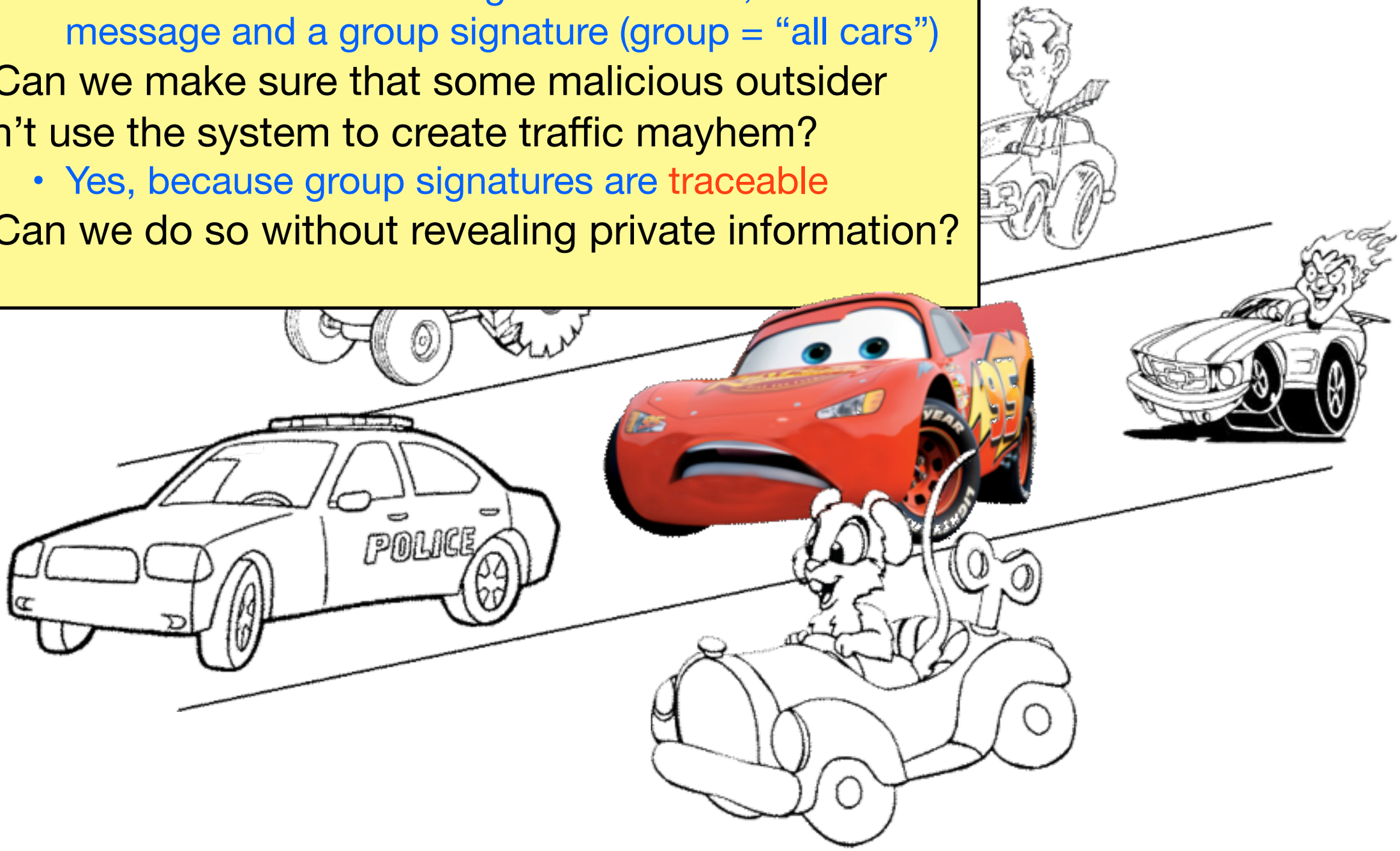

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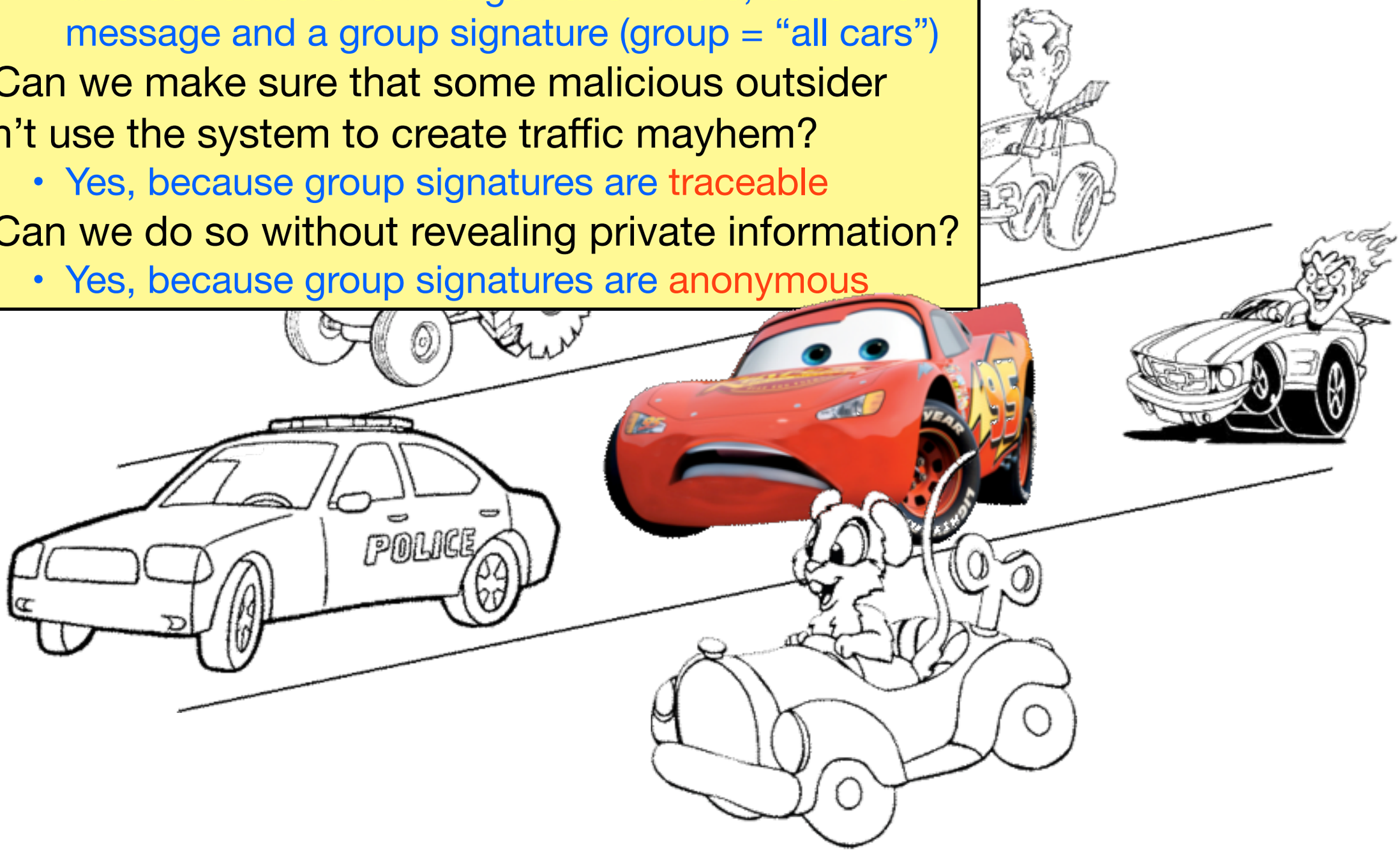

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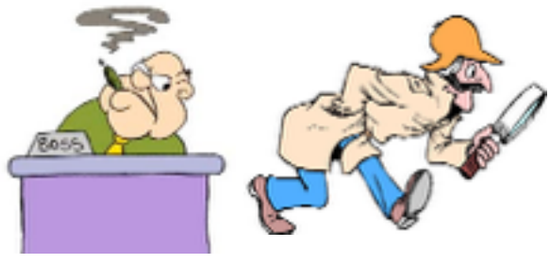

Anonymity: a more formal definition

Game **G**

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Phase 1: getting to see who signed which messages

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$pk, \{sk_i\}$

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msk

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Sign(sk_B,m)

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pk, {sk_i}

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pk, $\{sk_i\}$

Phase 2: picking identities and receiving a challenge

Anonymity: a more formal definition

m, i_0, i_1

$pk, \{sk_i\}$

Phase 2: picking identities and receiving a challenge

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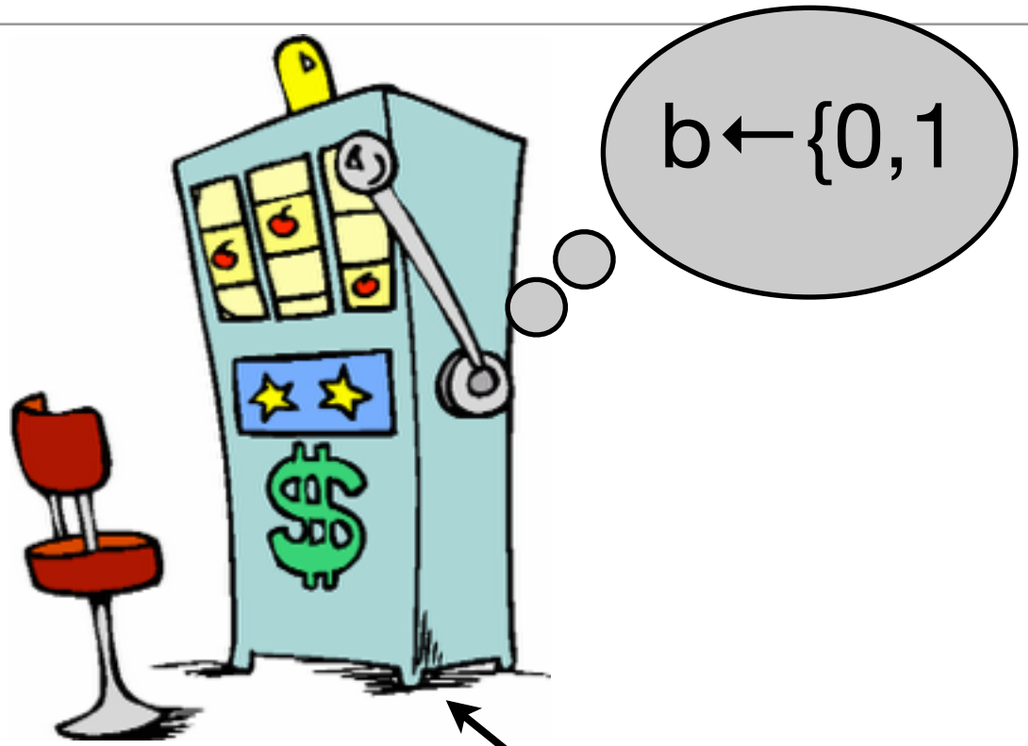

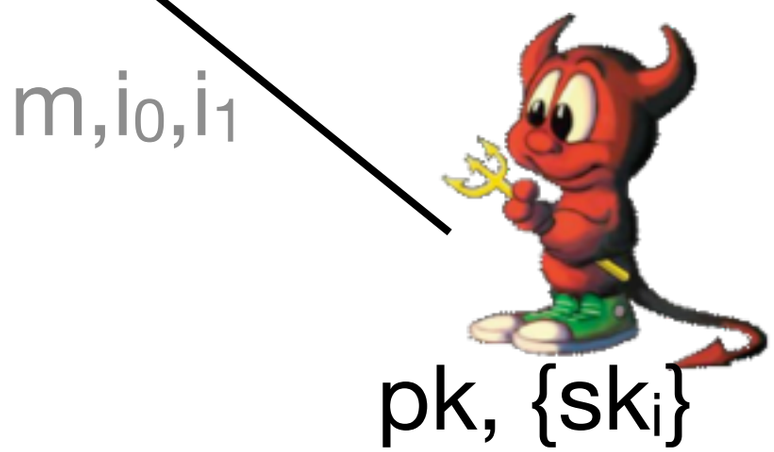

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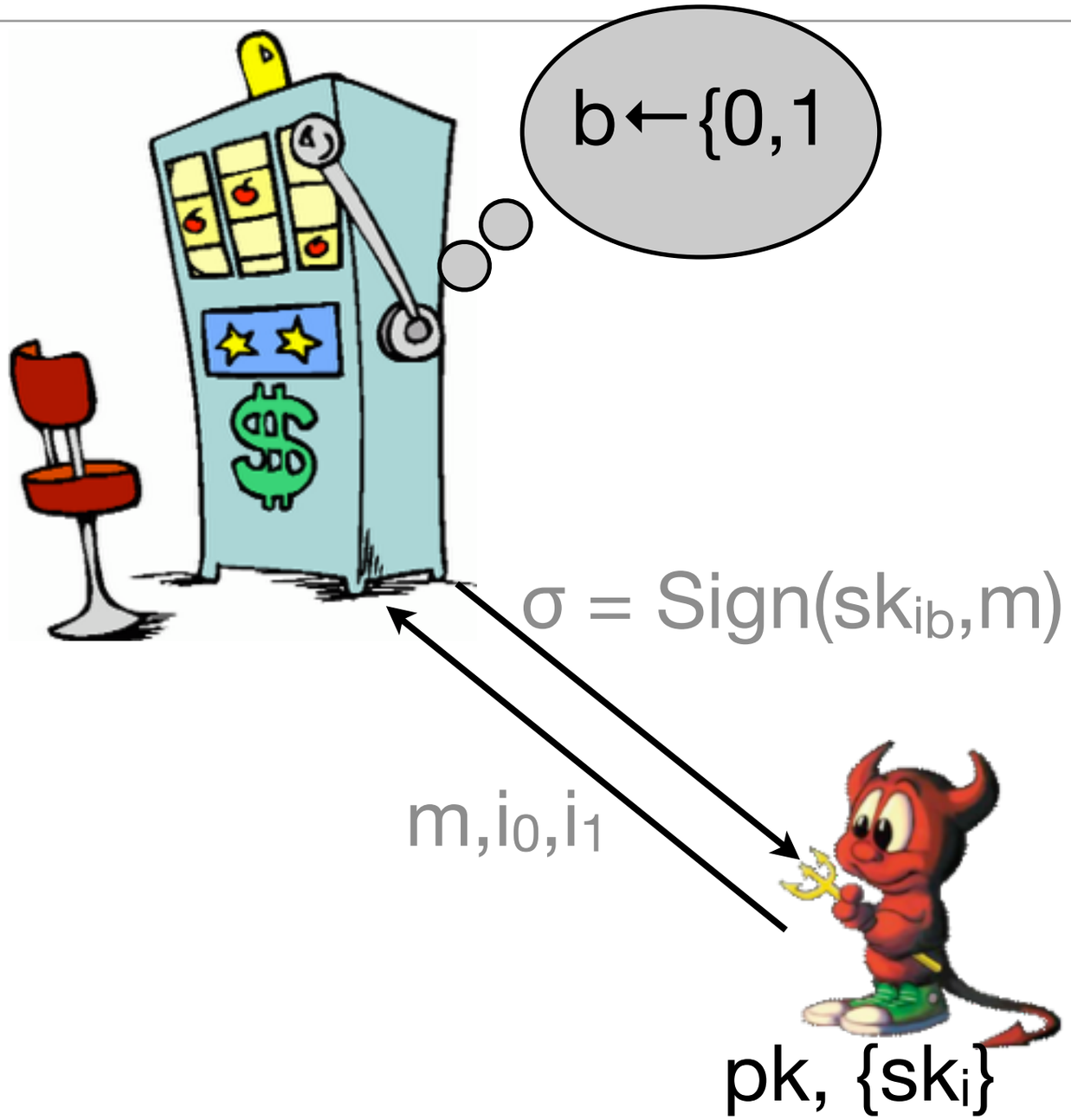

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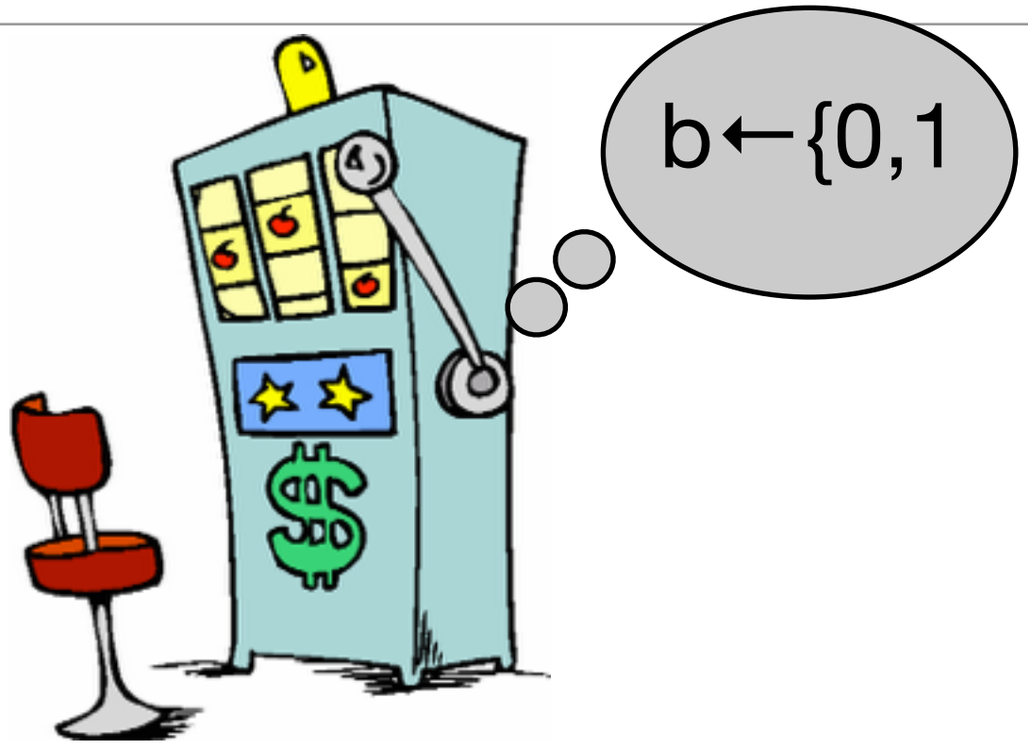

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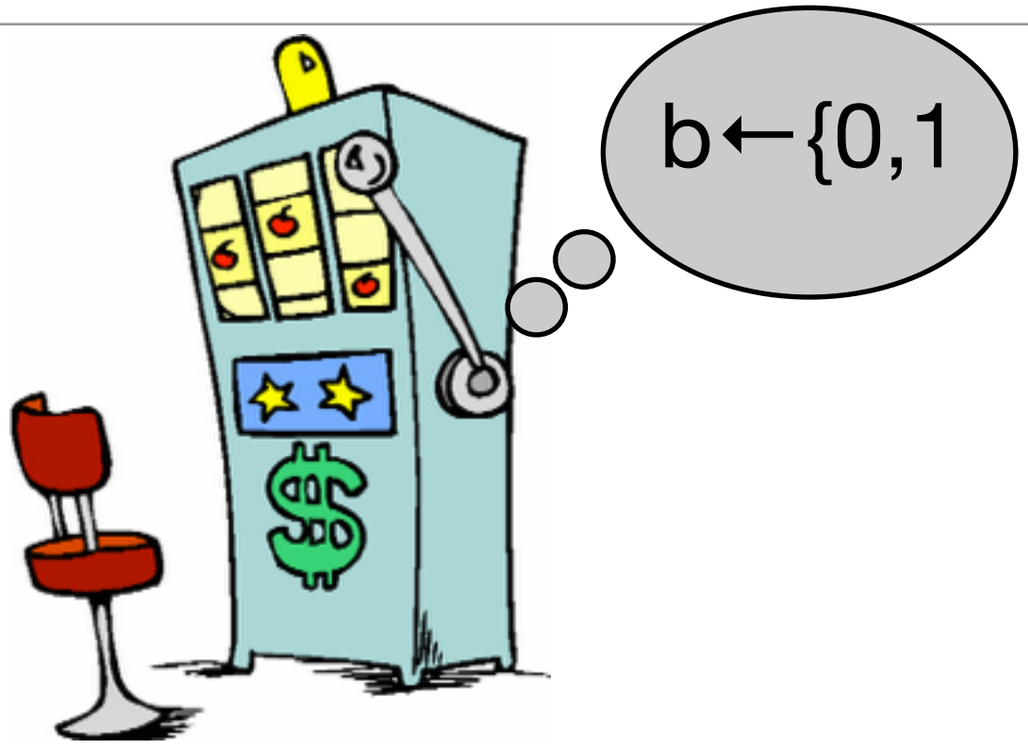

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Phase 3: getting to see who signed which messages (again)

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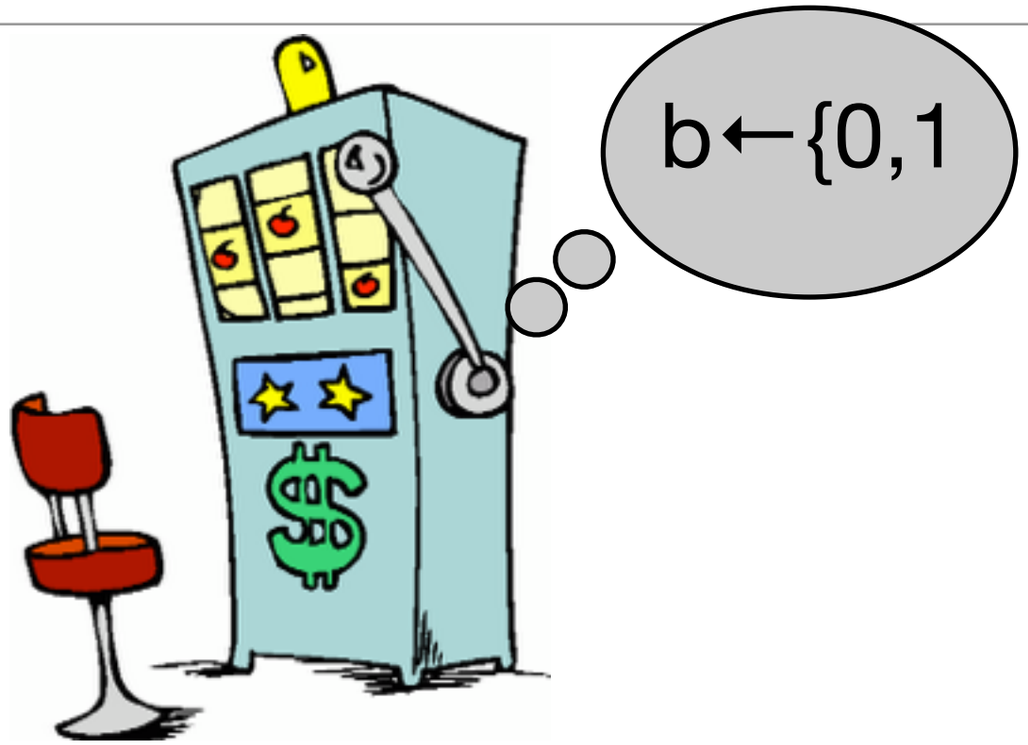

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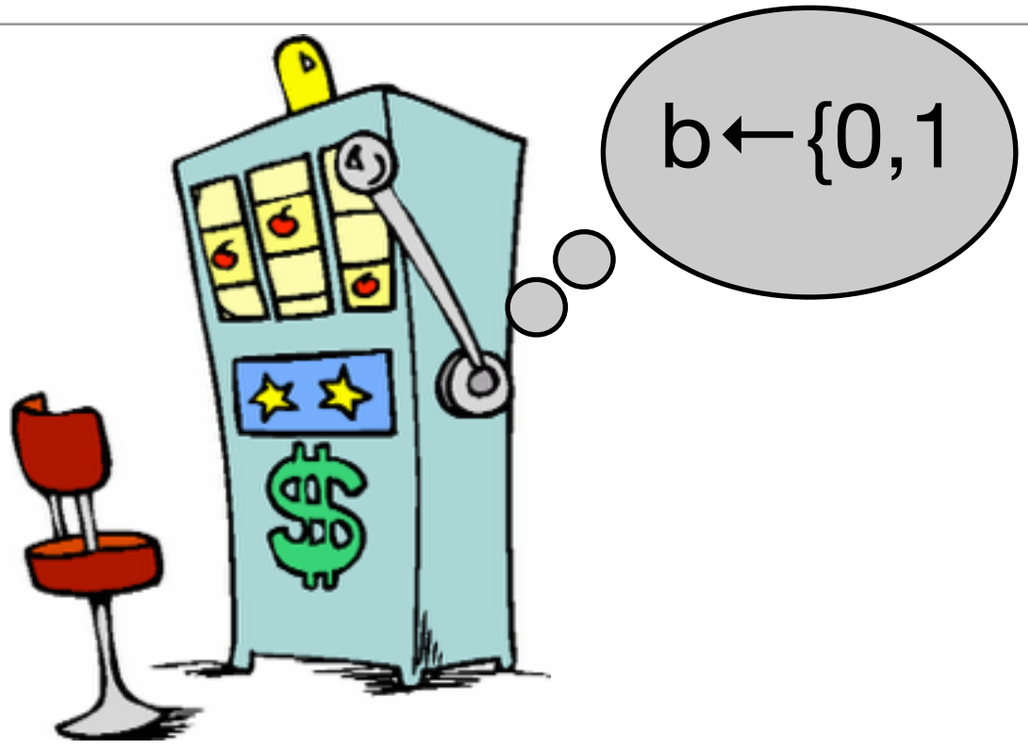

Sign(sk_i,m) ≠ σ

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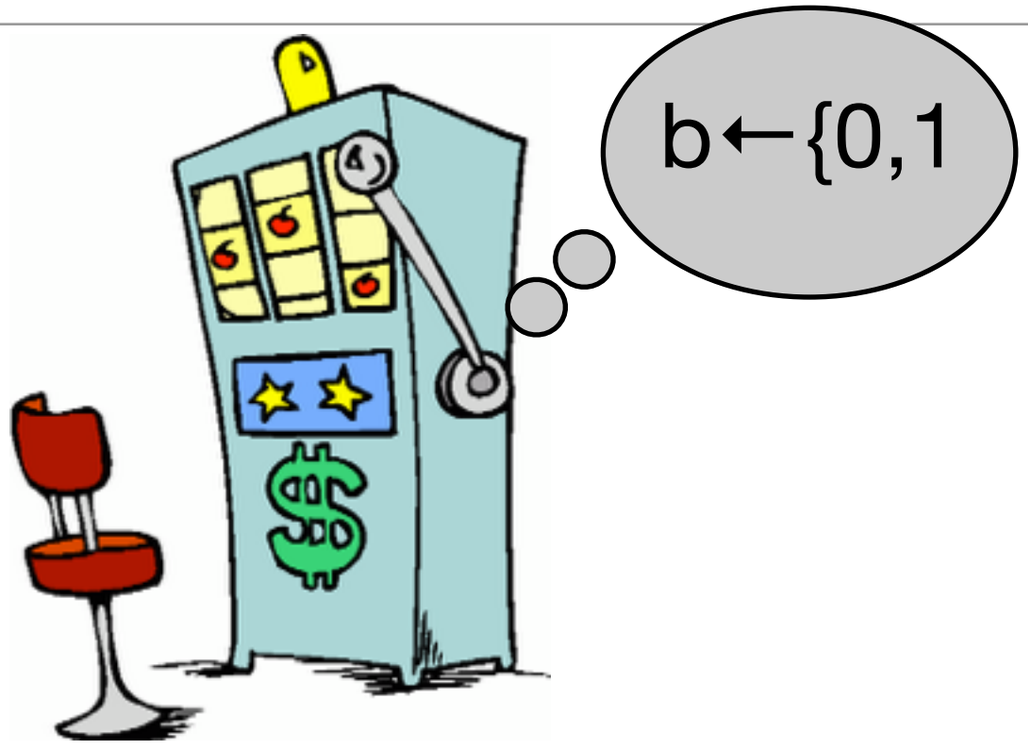

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$Sign(sk_i,m) \neq \sigma$

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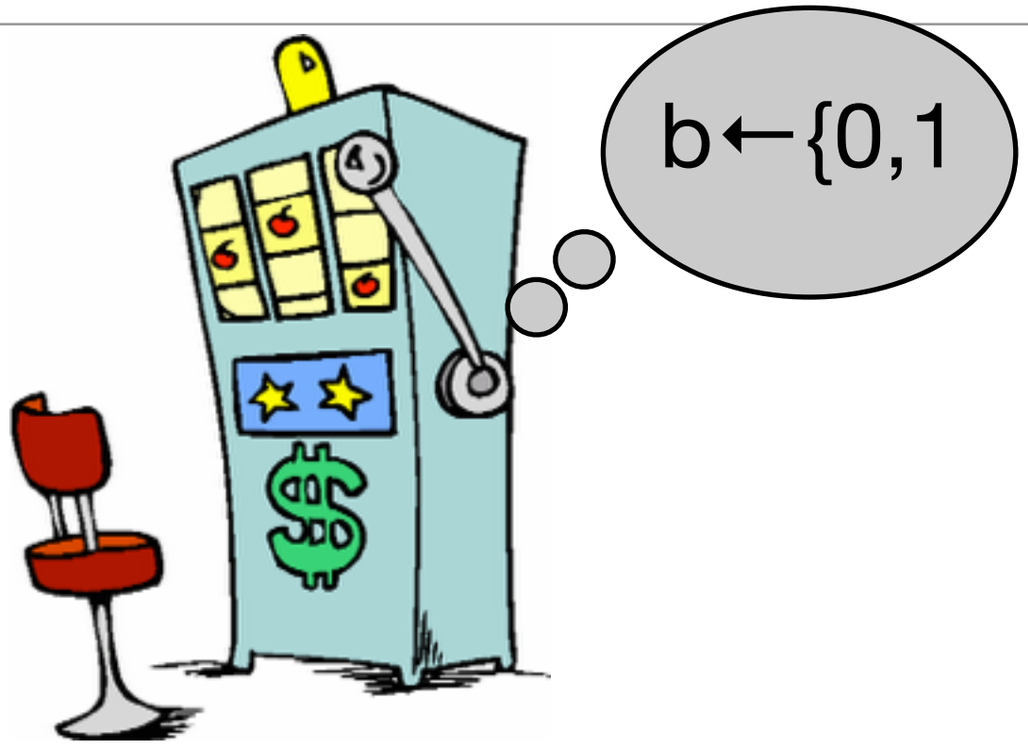

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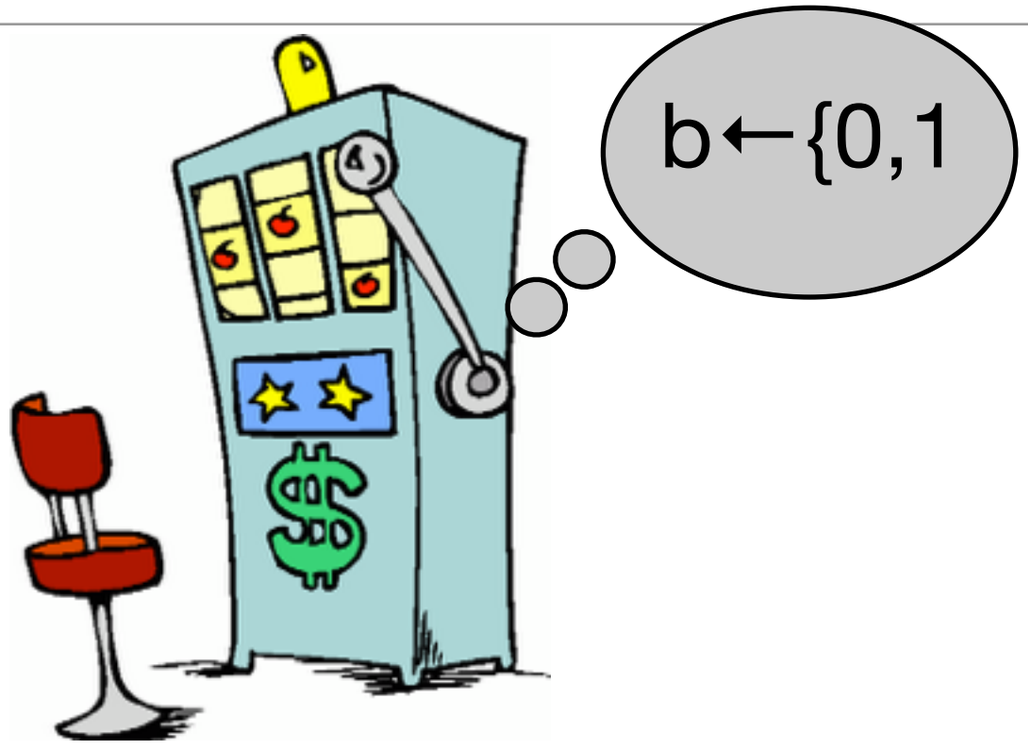

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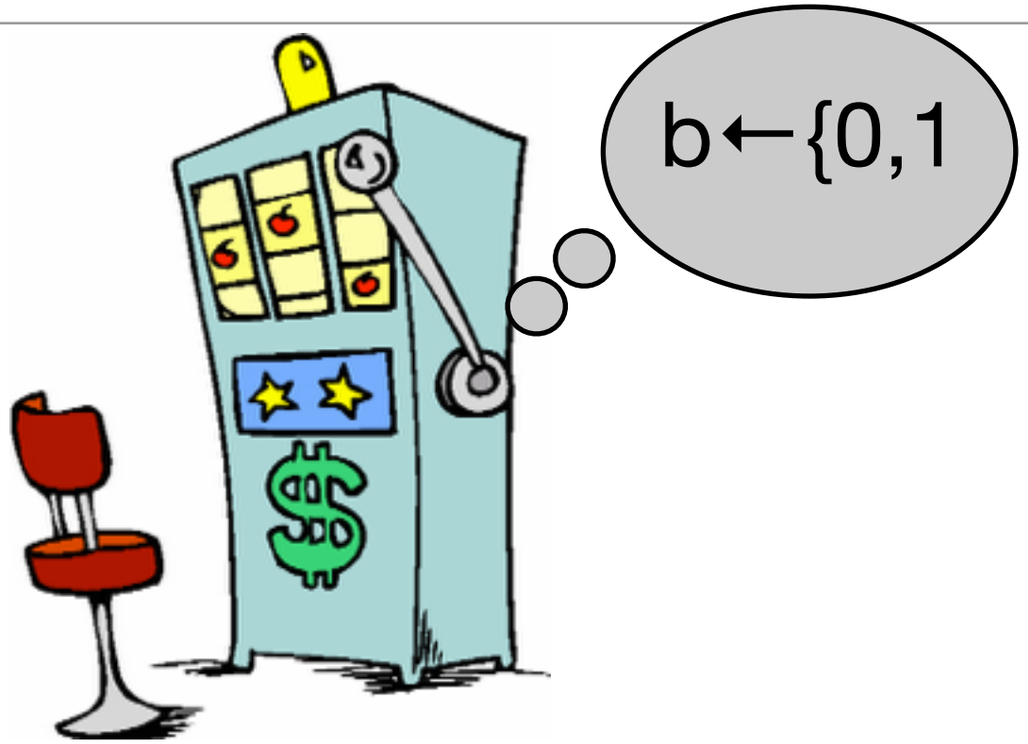

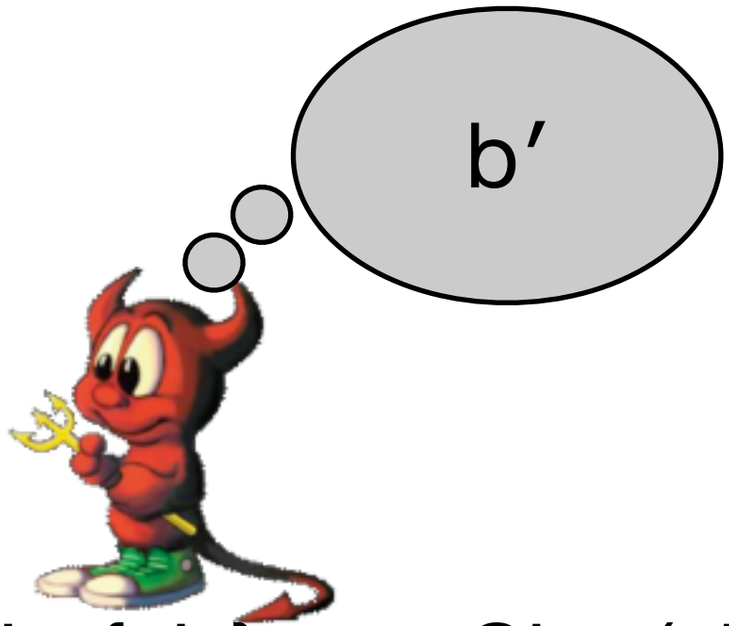

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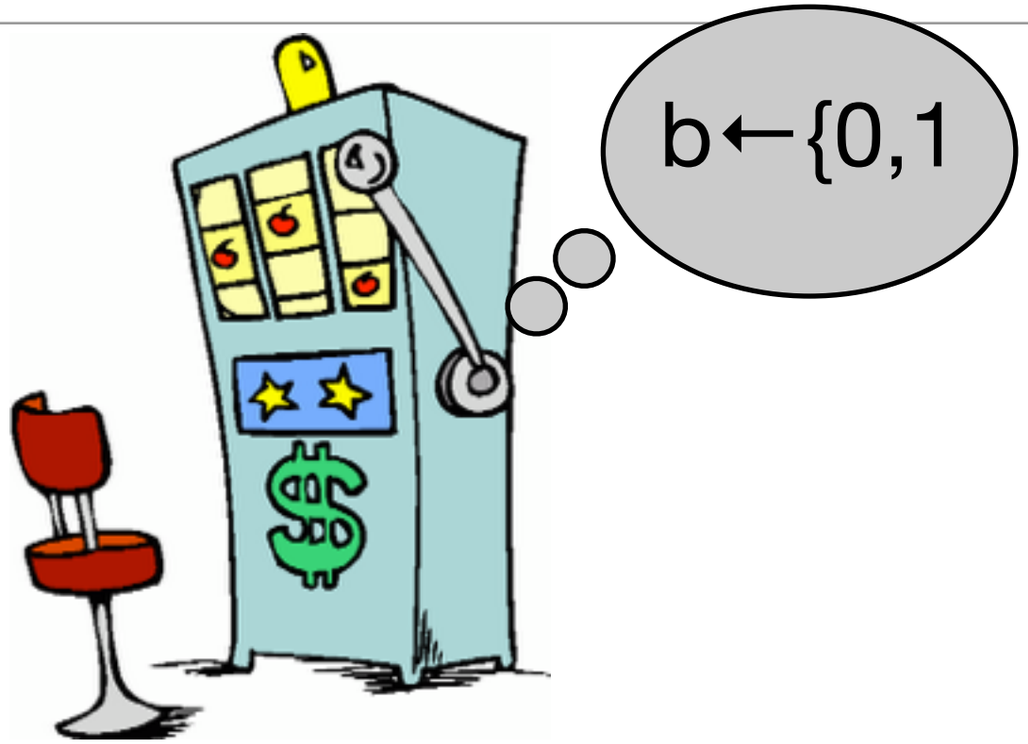

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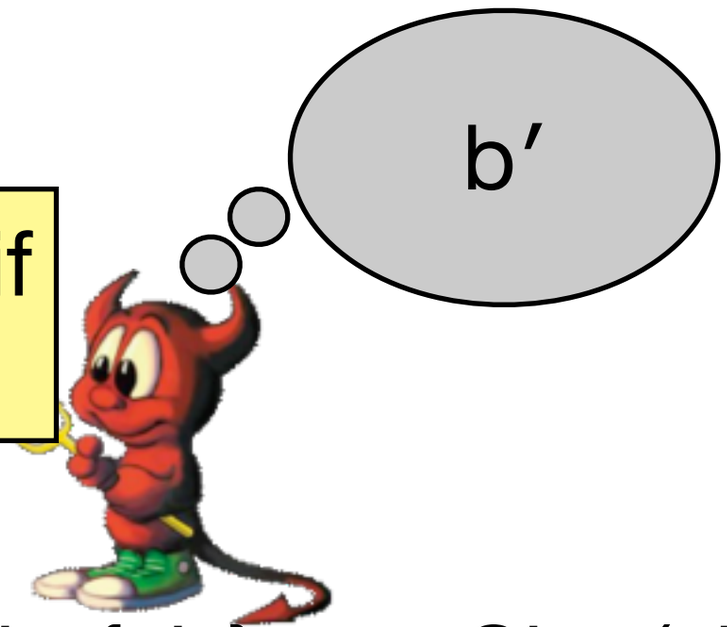

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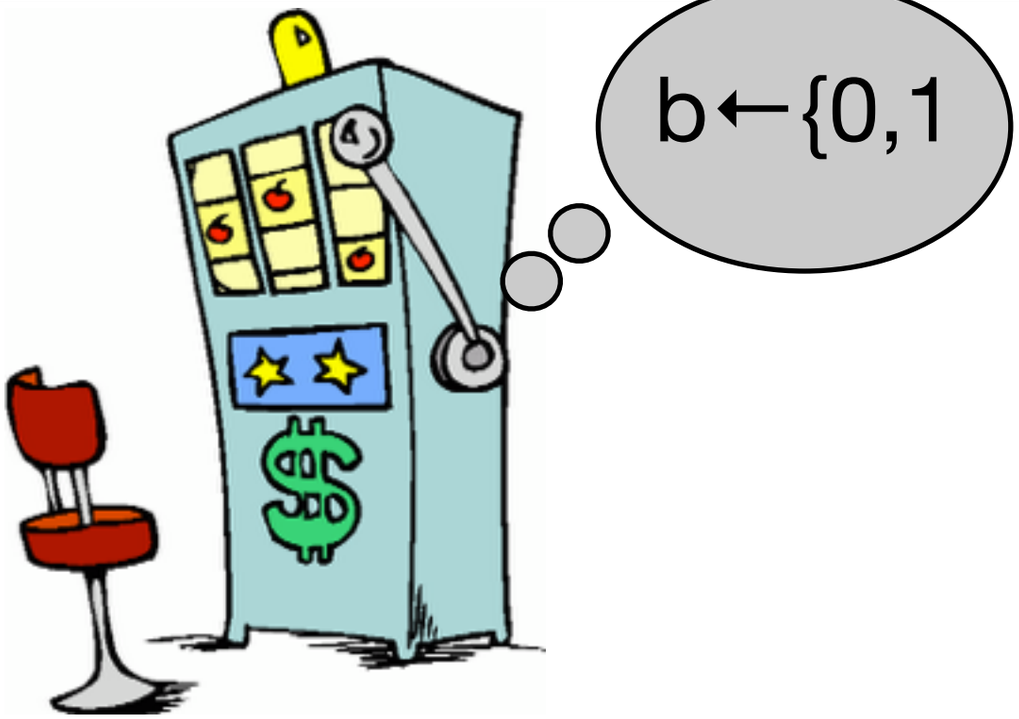

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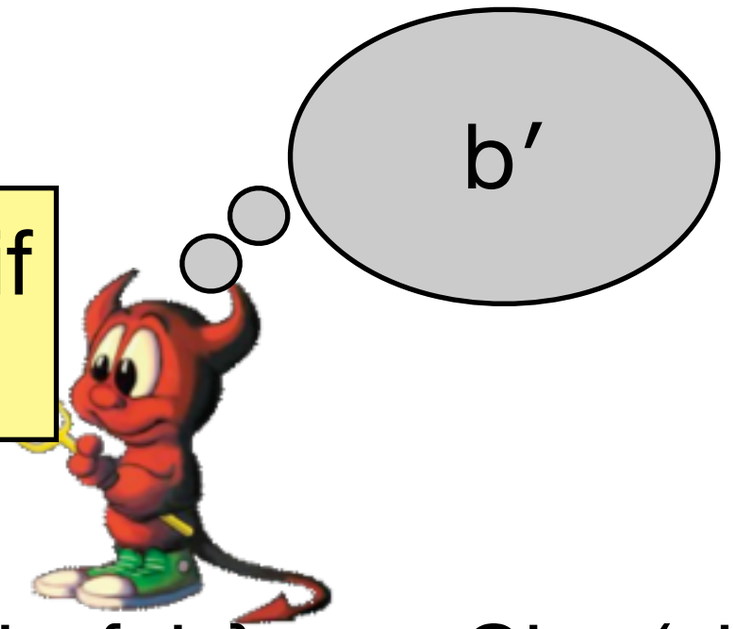

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Traceability: a more formal definition

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Phase 1: getting to pick a corrupt coalition

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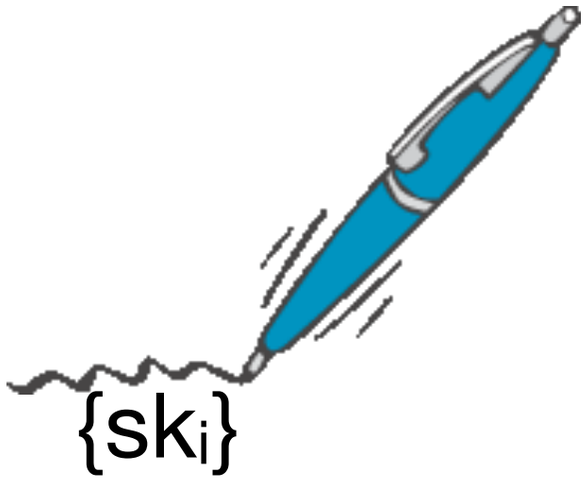

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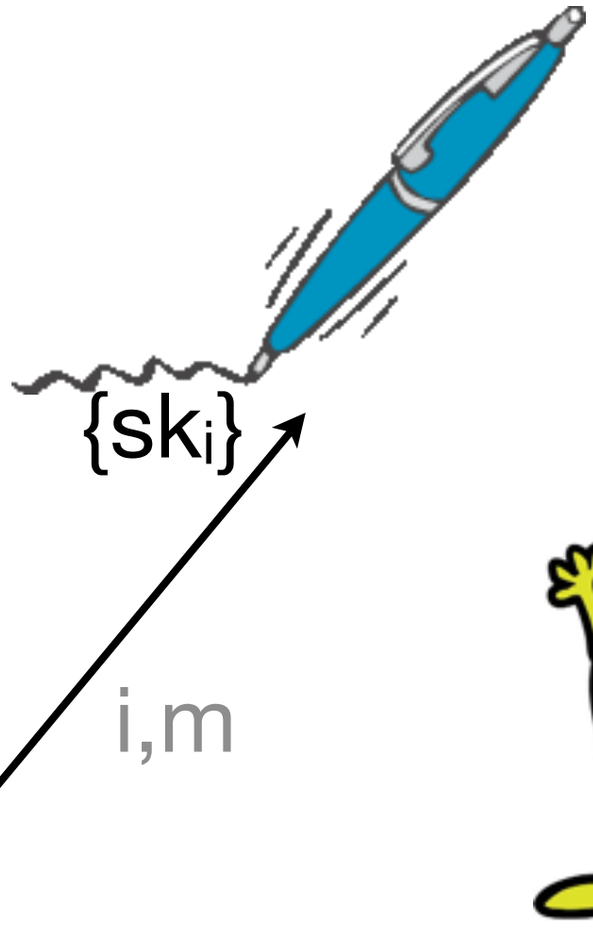

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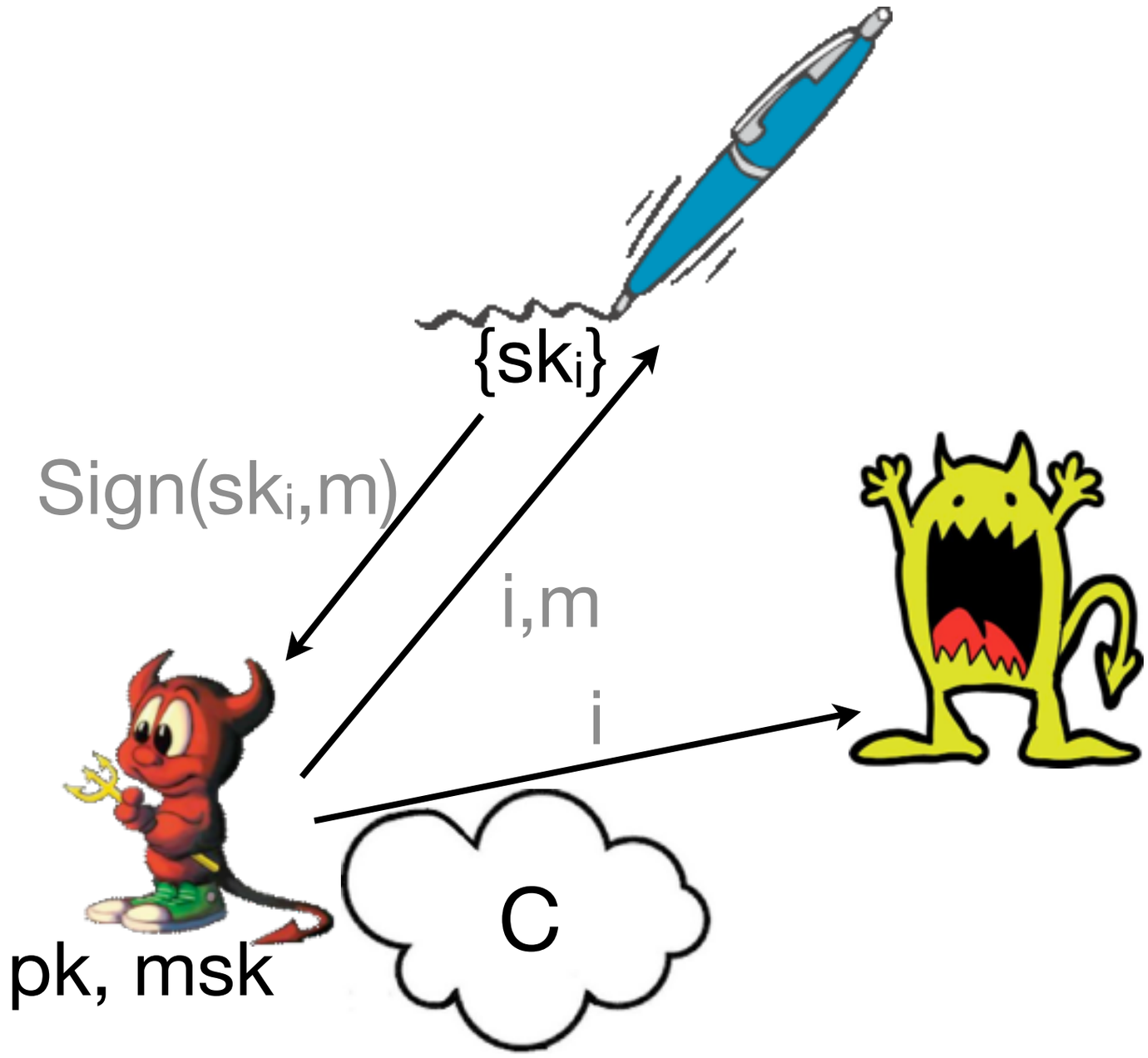

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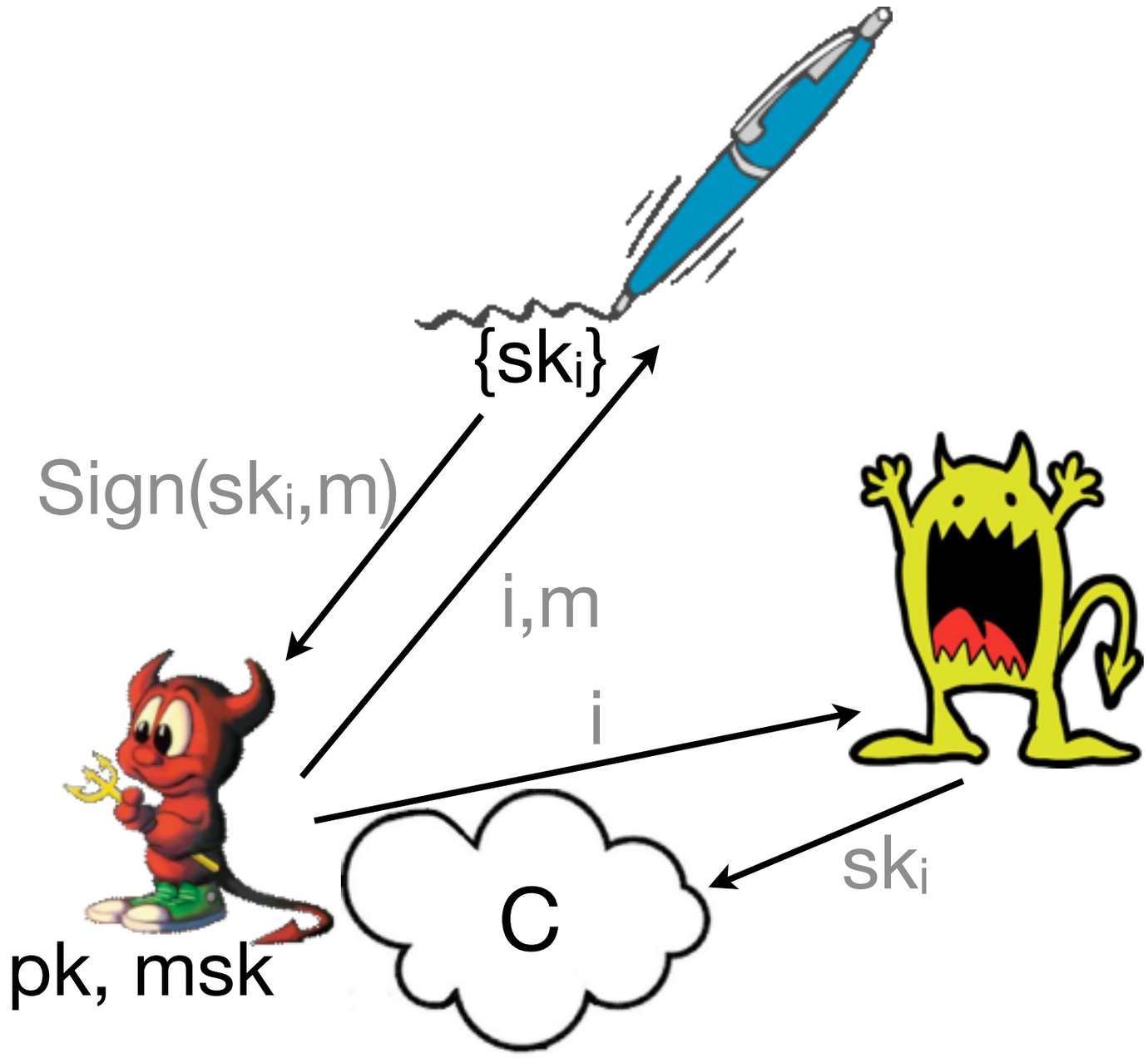

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Phase 2: outputting a forgery

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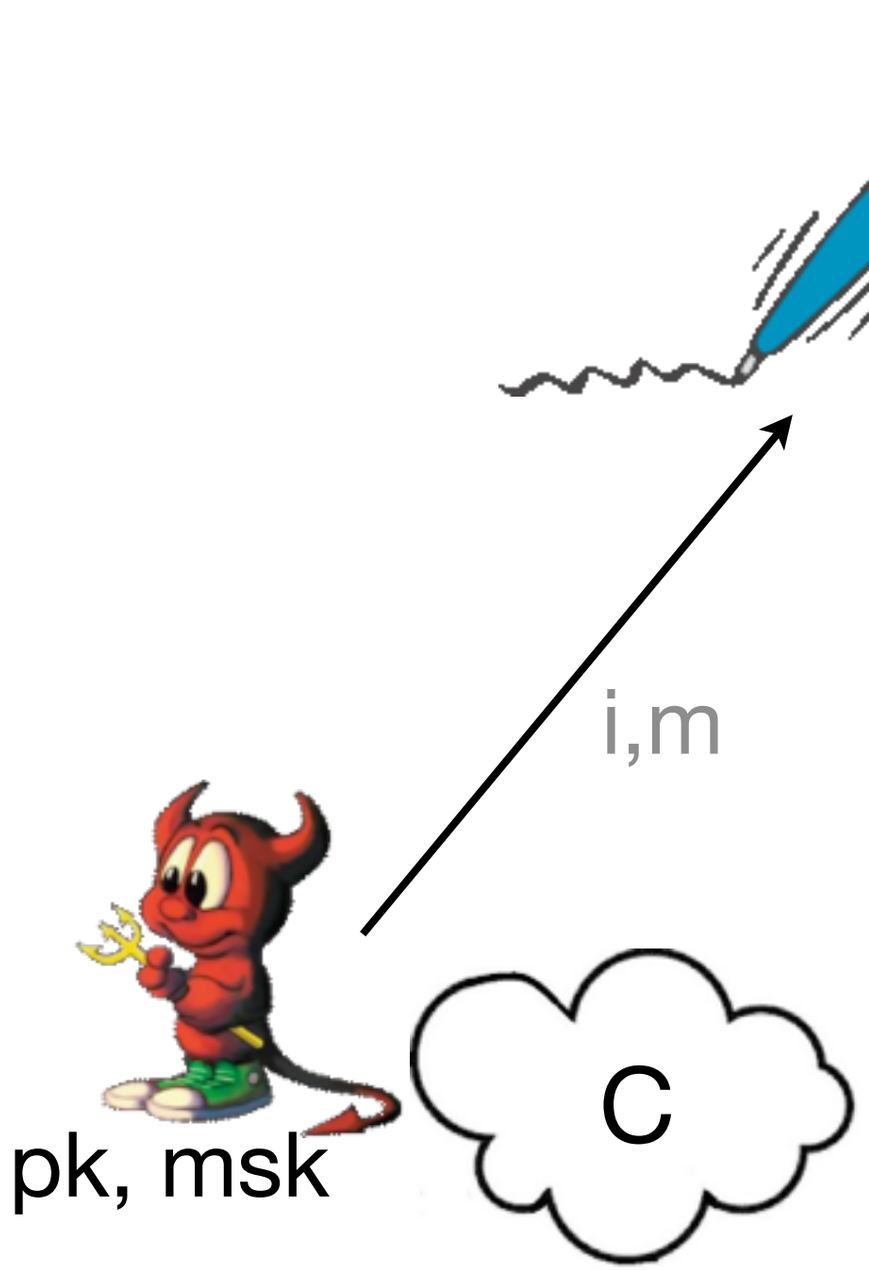

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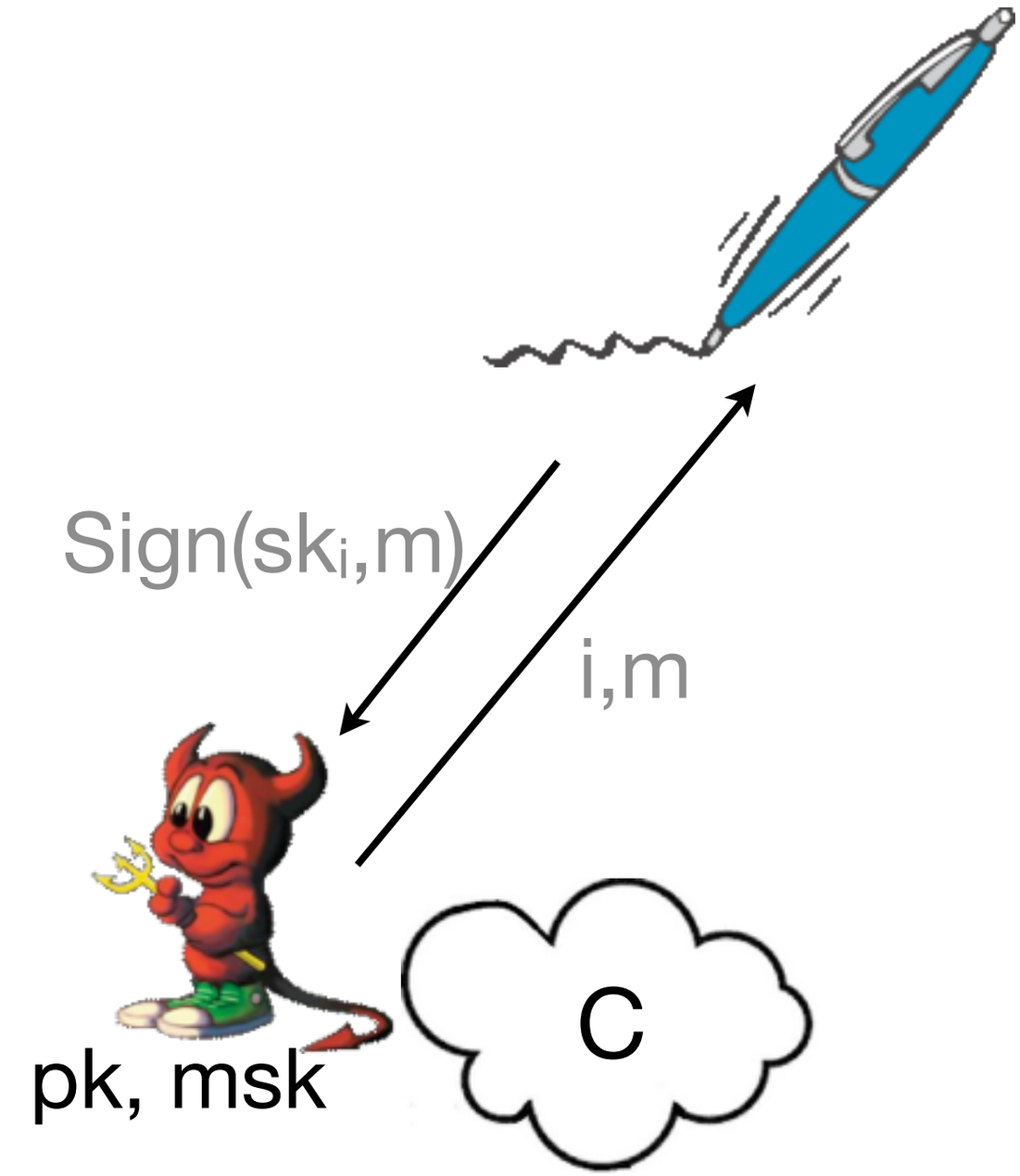

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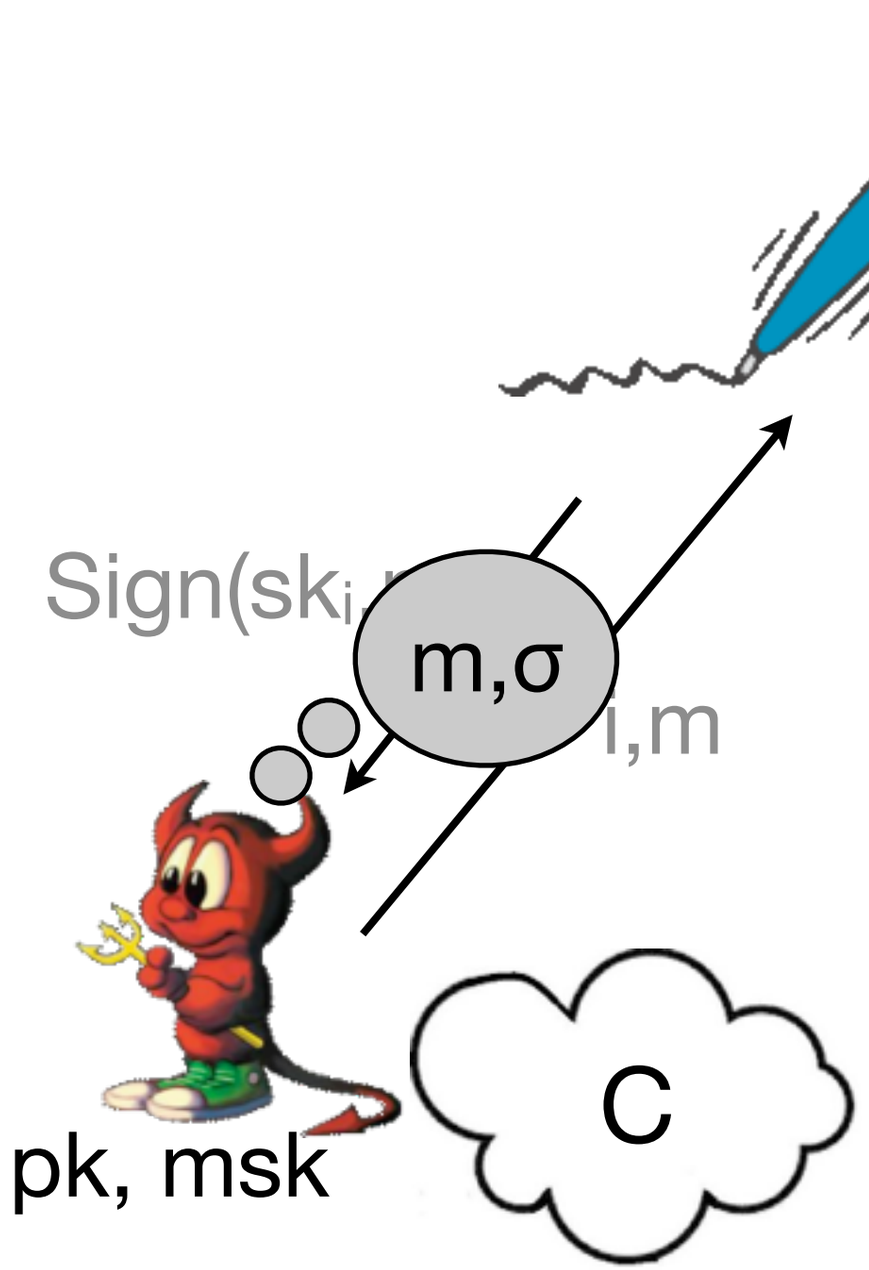

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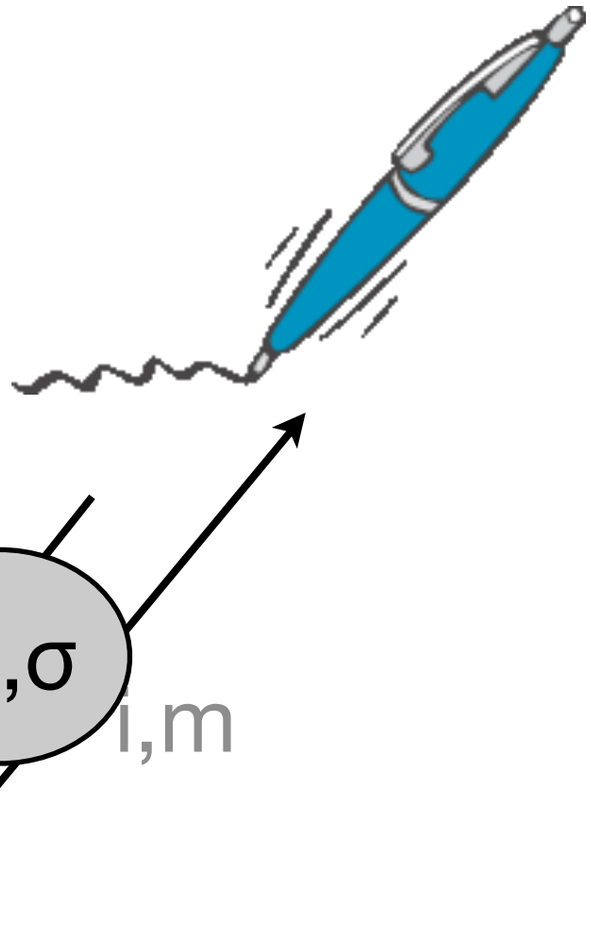

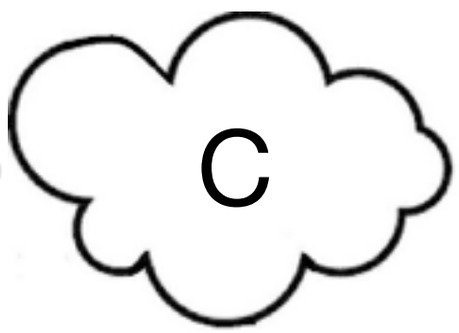

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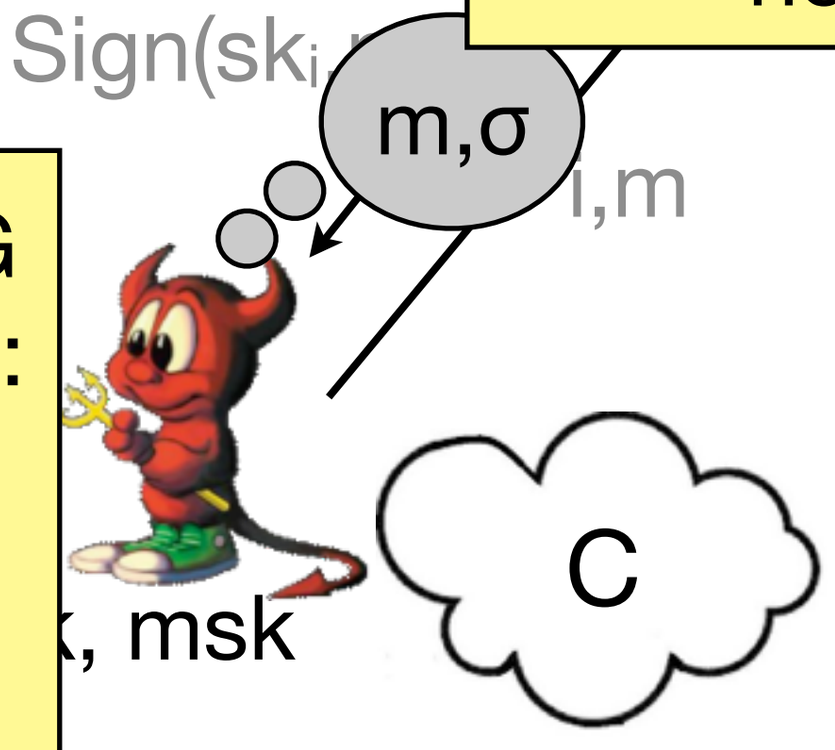
Say that scheme is traceable if the probability that A wins at G is very small (i.e., negligible)



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In practice, this approach could be emulated by a group master who simply runs KeyGen(1^k,1^N) for some N >> n, stockpiles extra keys for later

Using group managers instead of masters

Now, we have group manager who doesn't know your secret key

So Join() ↔ Enroll(msk) is a secure two-party computation at the end of which

the member learns their secret key and nothing else, and the group manager learns nothing (except that the member successfully enrolled)

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We can further talk about notions of non-frameability, in which corrupt coalition might also involve the group manager

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This is often accomplished using a revocation list (RL)

- In verifier-local revocation, RL is sent to all verifiers, who then perform some additional checks using Verify(pk,RL,σ,m)
- We could also have remaining signers update their keys to match some updated public key using KeyUpdate(pk′,pk,RL,sk_i) → sk_i'

How do we evaluate group signature schemes?

- Efficiency: want really fast Sign and Verify
- Size of the signatures: want them to be independent of the group size
- Security: want highest level of security (CCA-style anonymity, full traceability)
- Flexibility: group manager? dynamic addition? revocation?
- Uses reasonable assumptions: random oracles? crazy weird-looking assumptions?

Comparison of group signature schemes

	Efficiency	Size	Security	Flexibility	Assumptions	R.O.?
CS'97			CPA-A, PT	manager, +	DLP + strong RSA	
BMW'03		C*	CCA-A, FT	master	TDP	
DKNS'04			CPA-A, FT	manager, +	Strong RSA	
BBS'04			CPA-A, FT	master, -	q-SDH + DLIN	
BSZ'05		C*	CCA-A, FT	master, +	TDP	
BW'06		lg(N)	CPA-A, FT	master, +/-	CDH + SGH	
Groth'06		C*	CCA-A, FT	manager, +	DLIN	
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- Holy grail: Efficient, CCA-A and FT secure, fully dynamic but short signatures, secure under mild assumptions and without random oracles

- There's no clear winner here!

Outline

Cryptographic background

Group signatures

Ring signatures

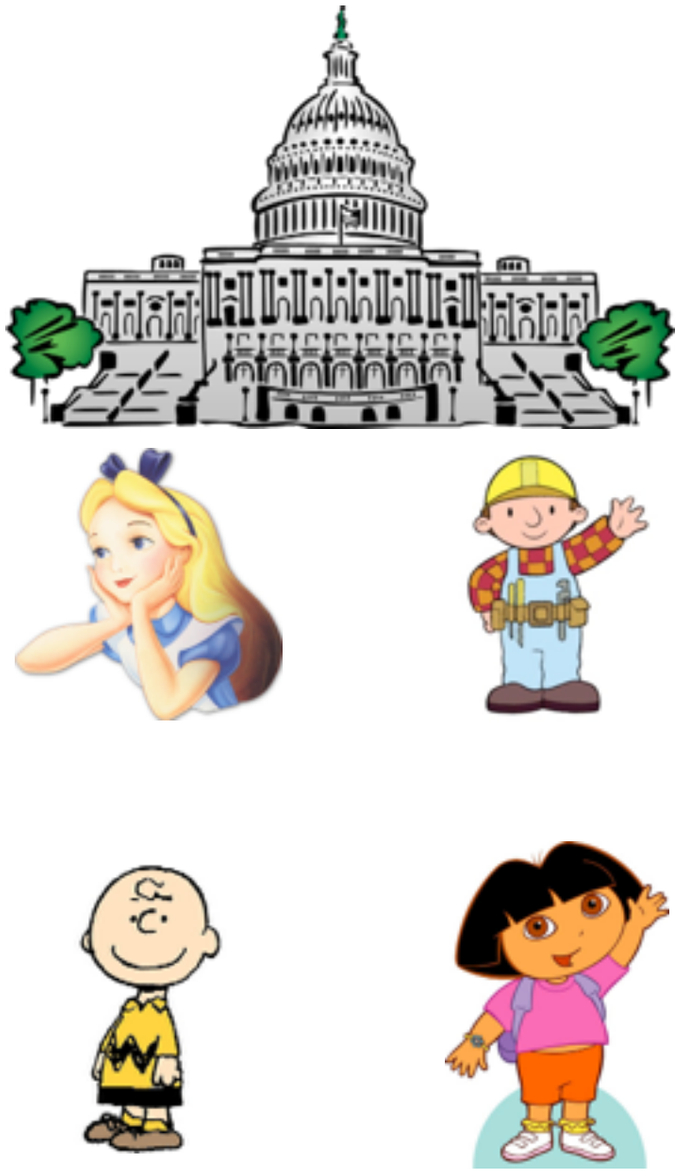
Intuition and motivation

Formal definitions

Comparison of existing schemes

Open problems

Ring signatures: why do we want them?



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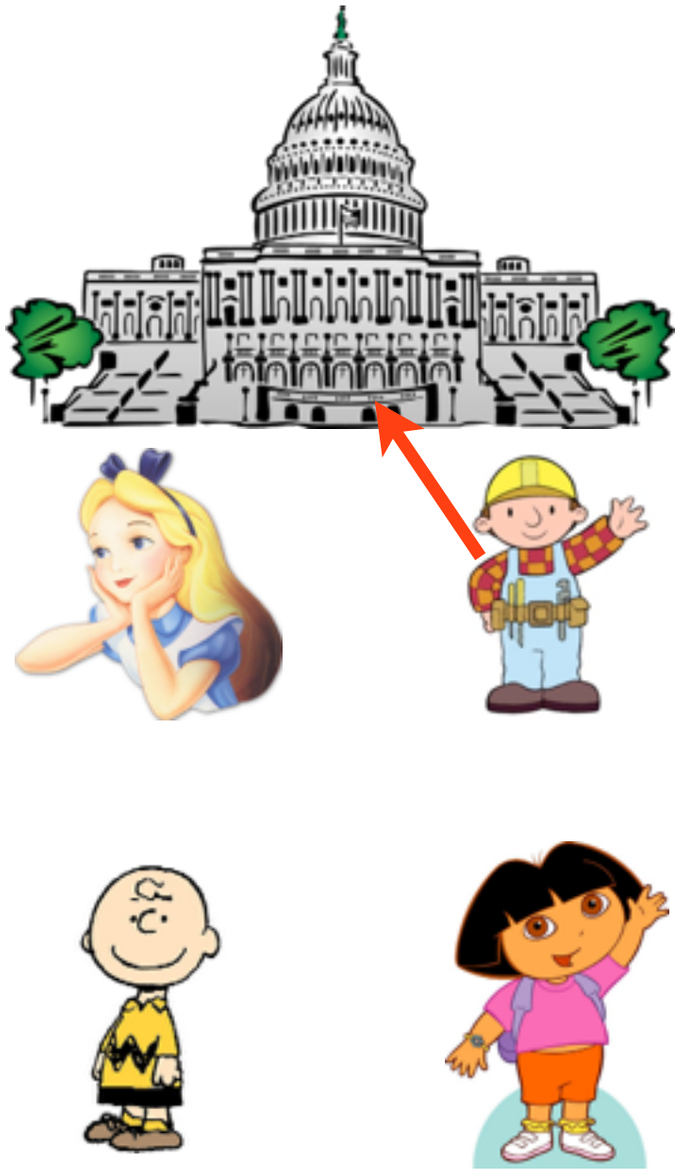

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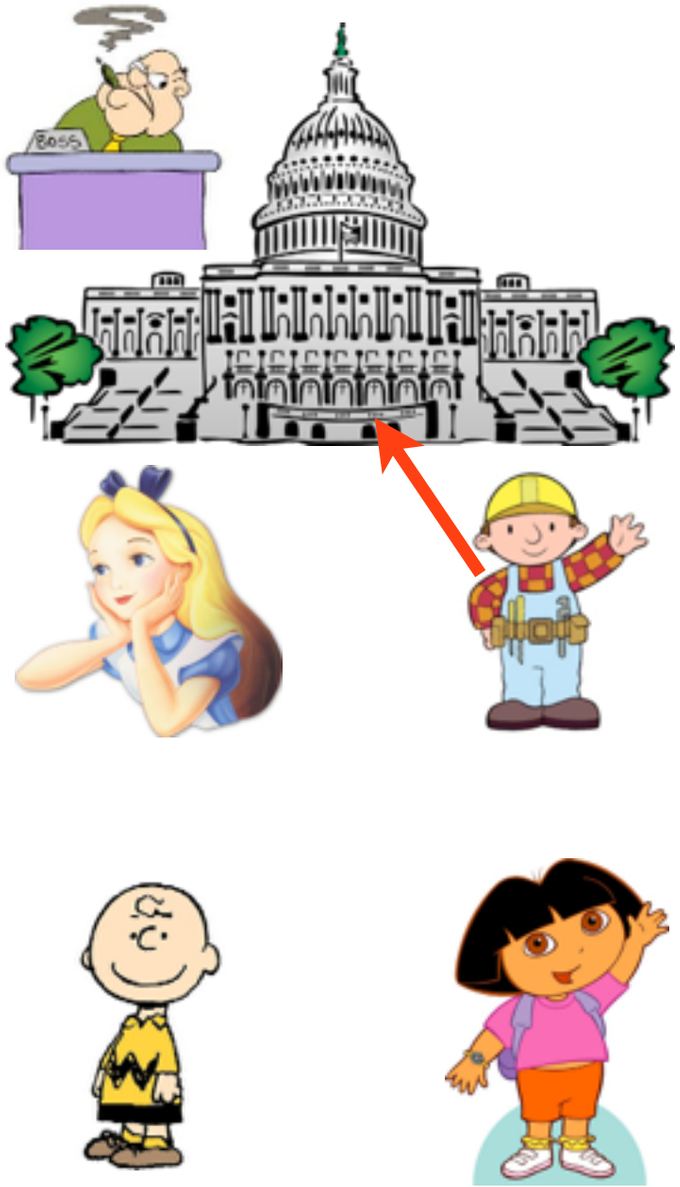

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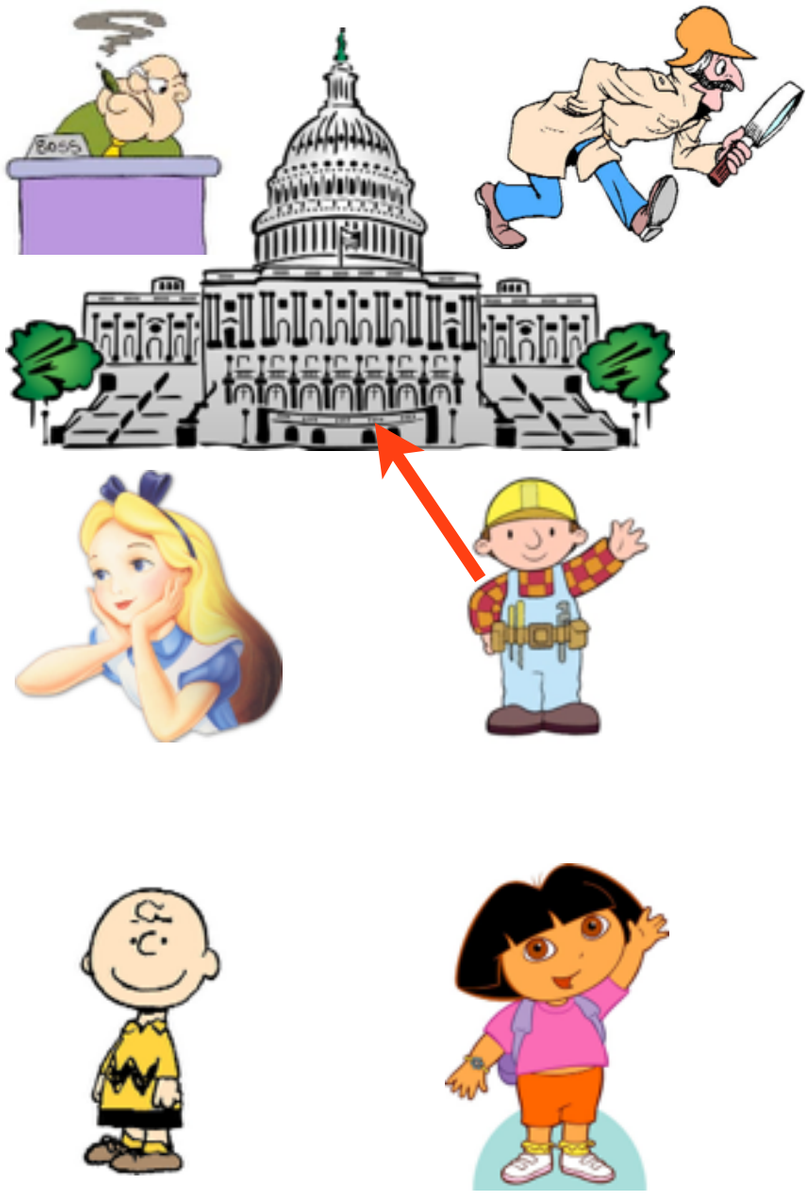

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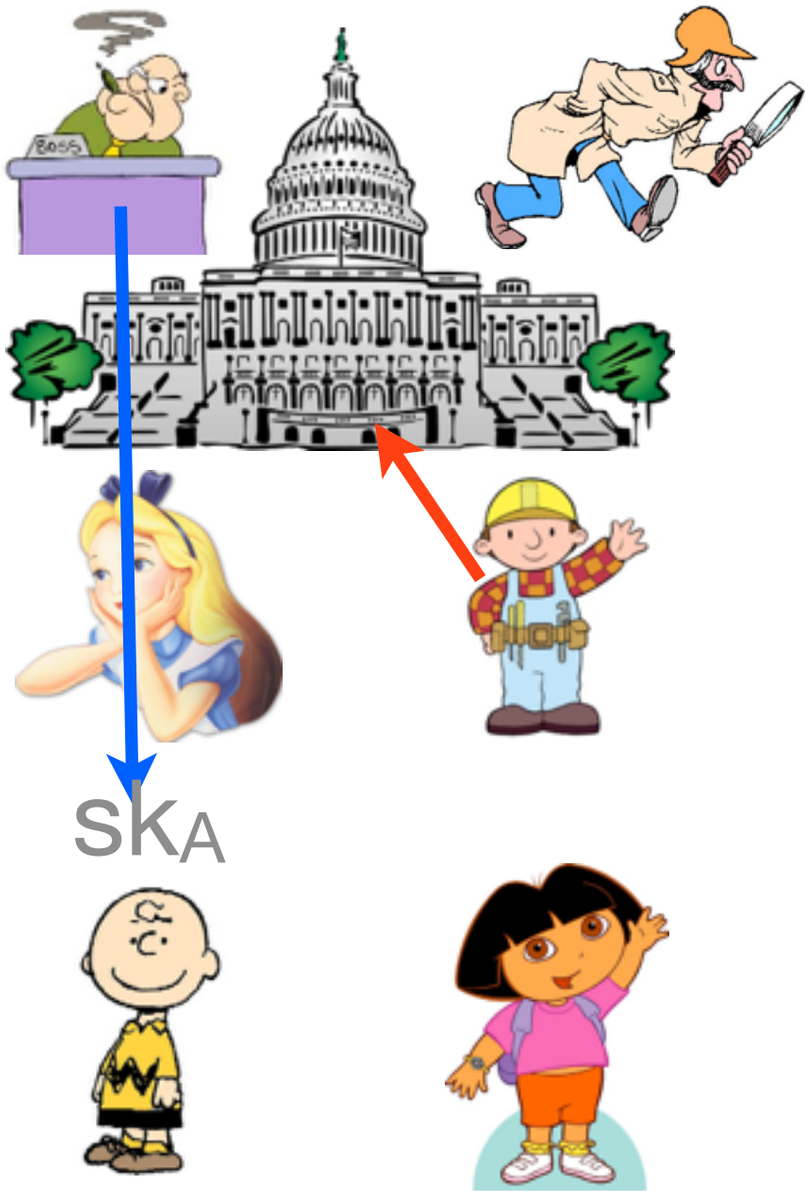

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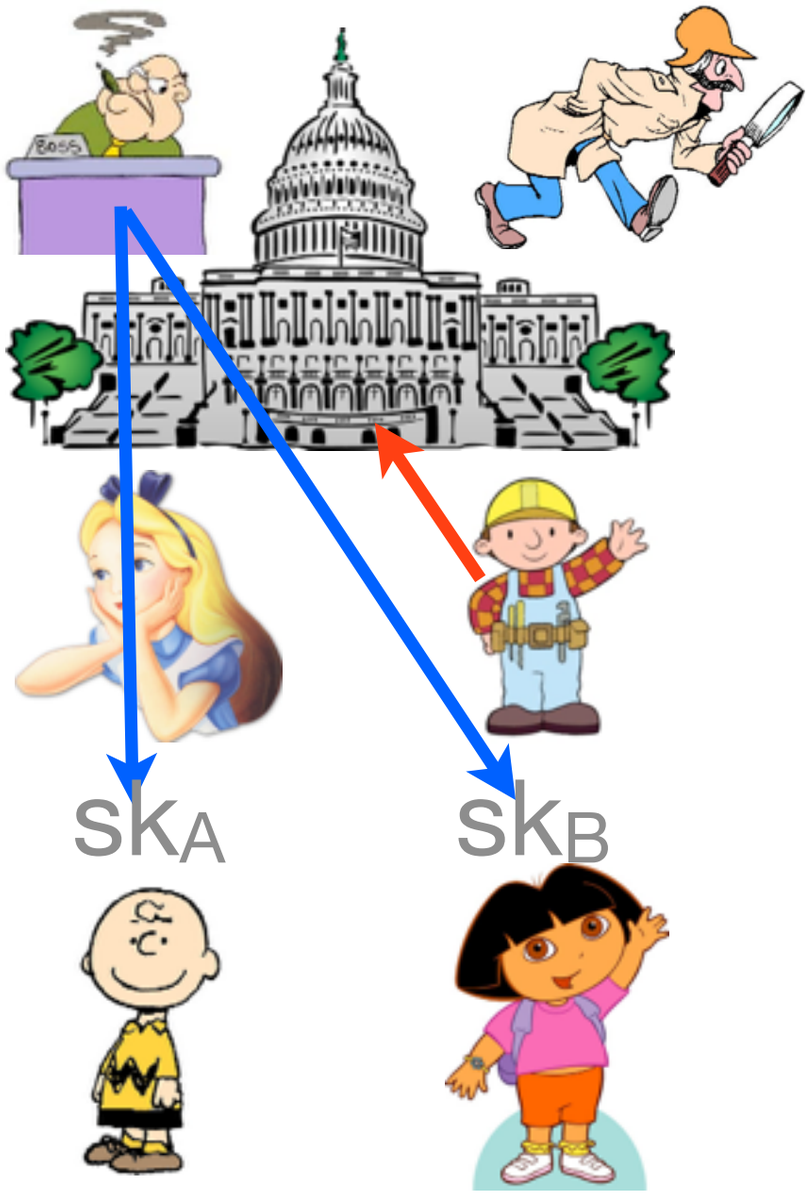

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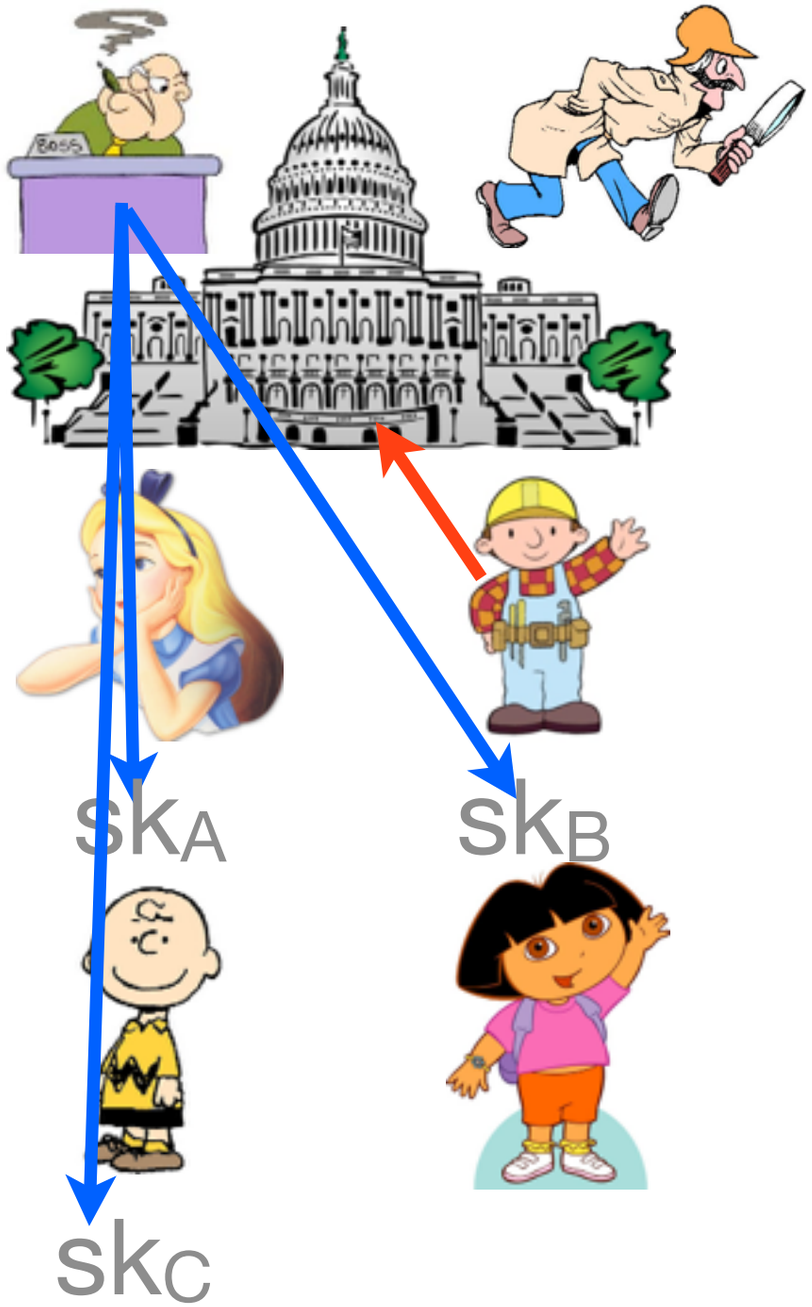

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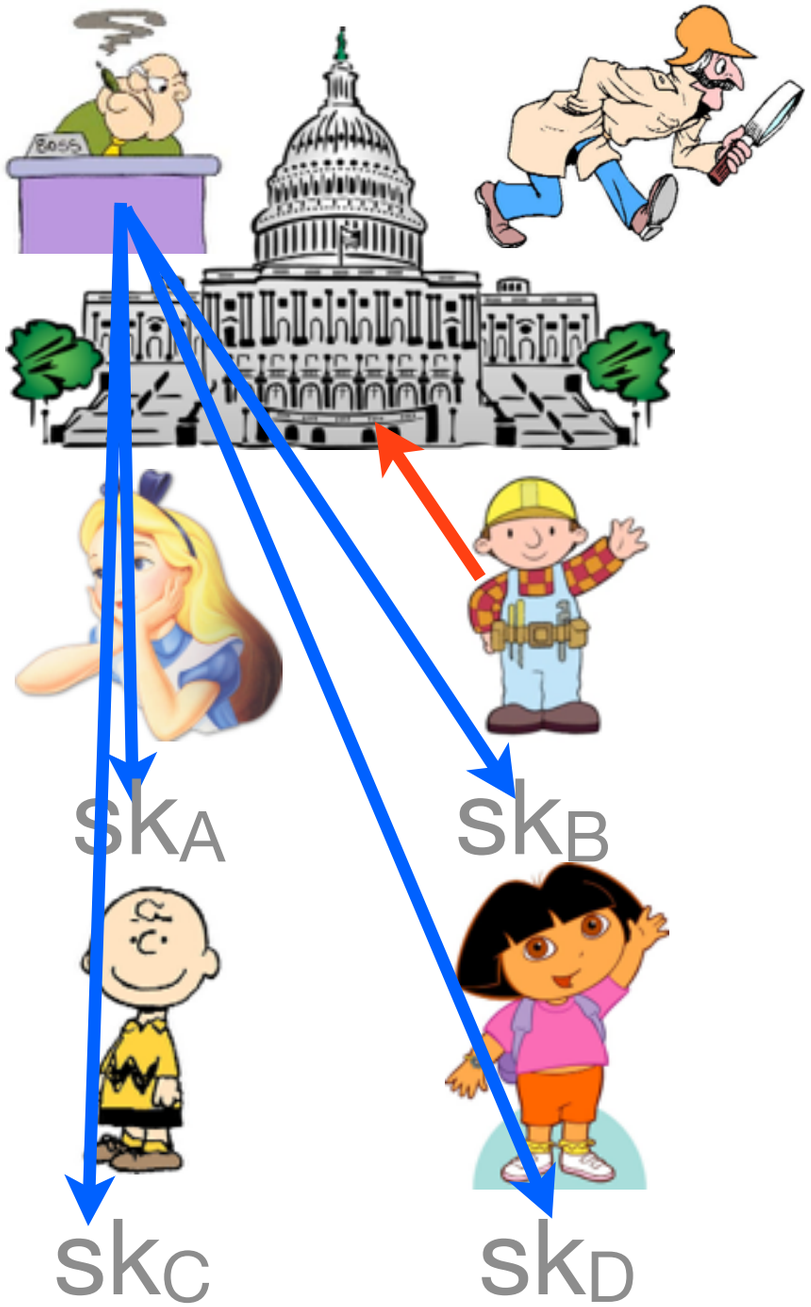

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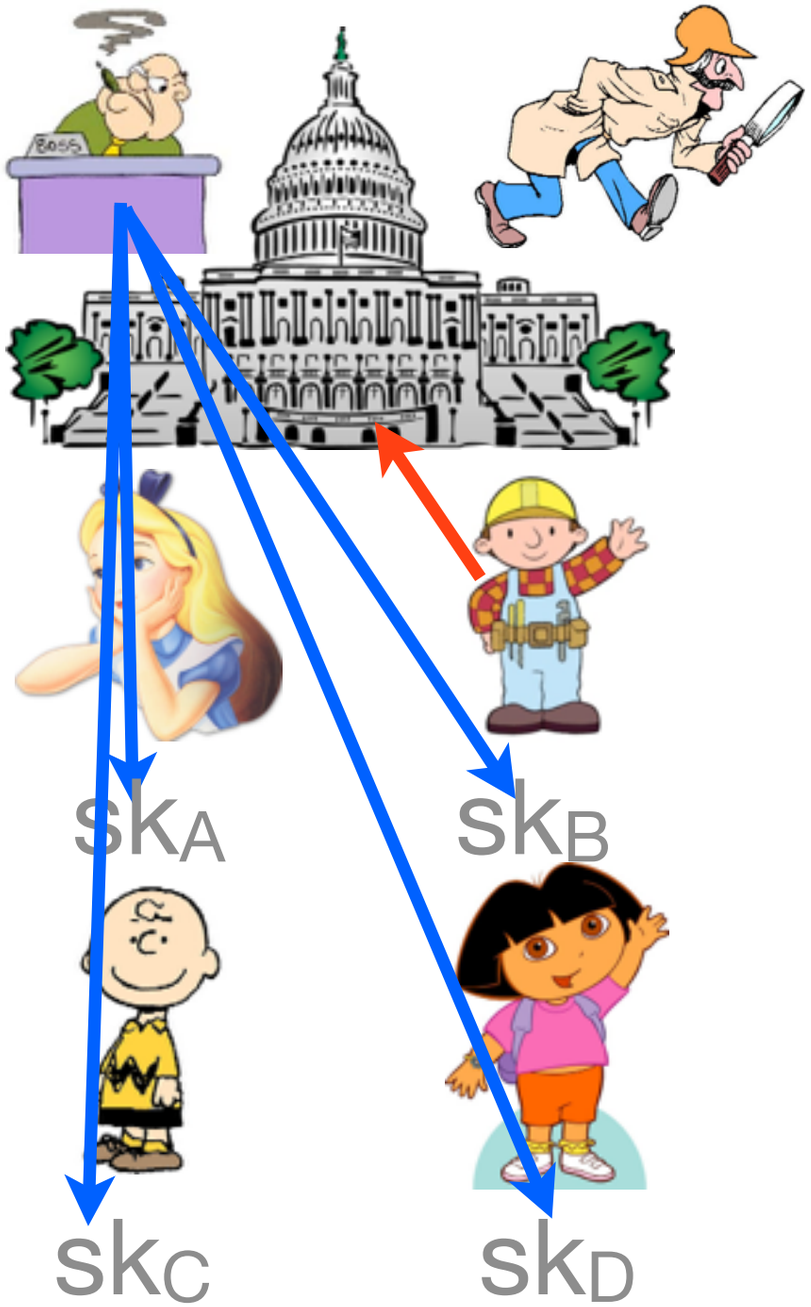

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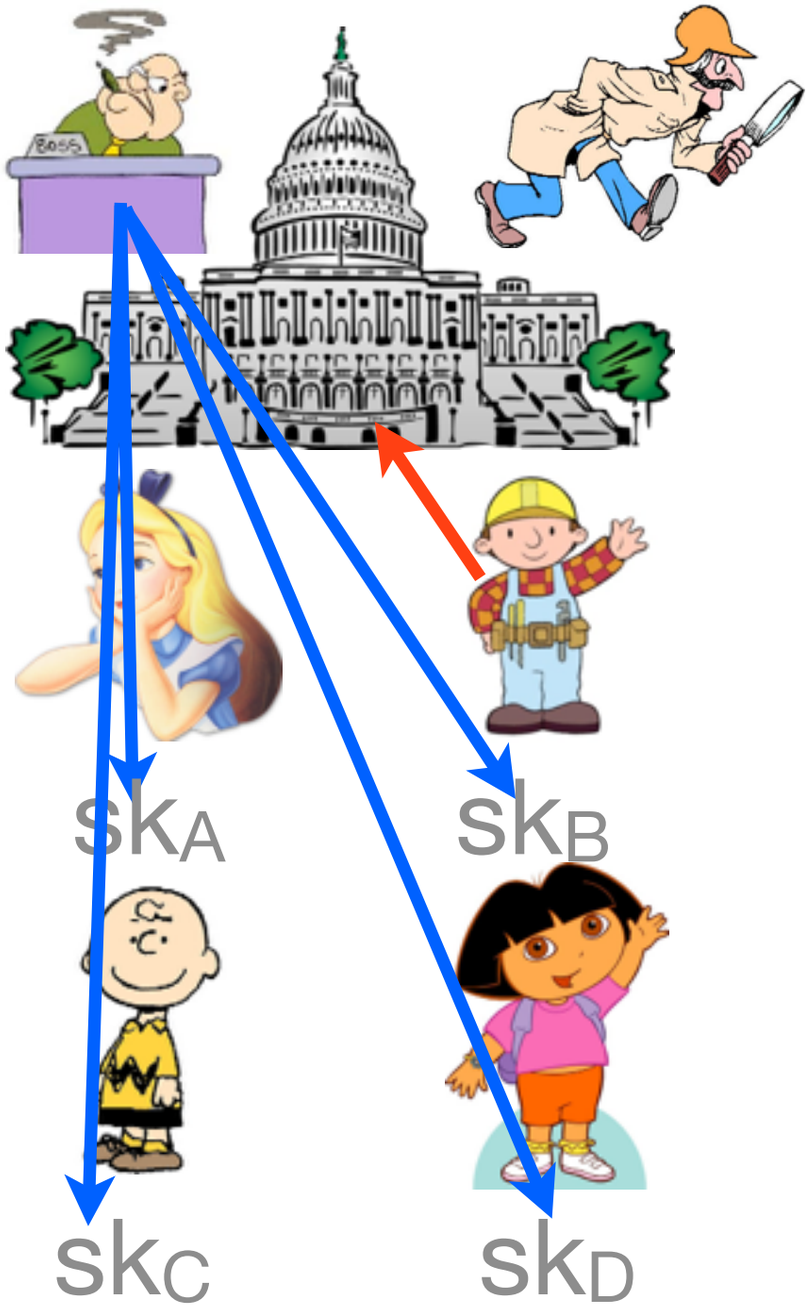

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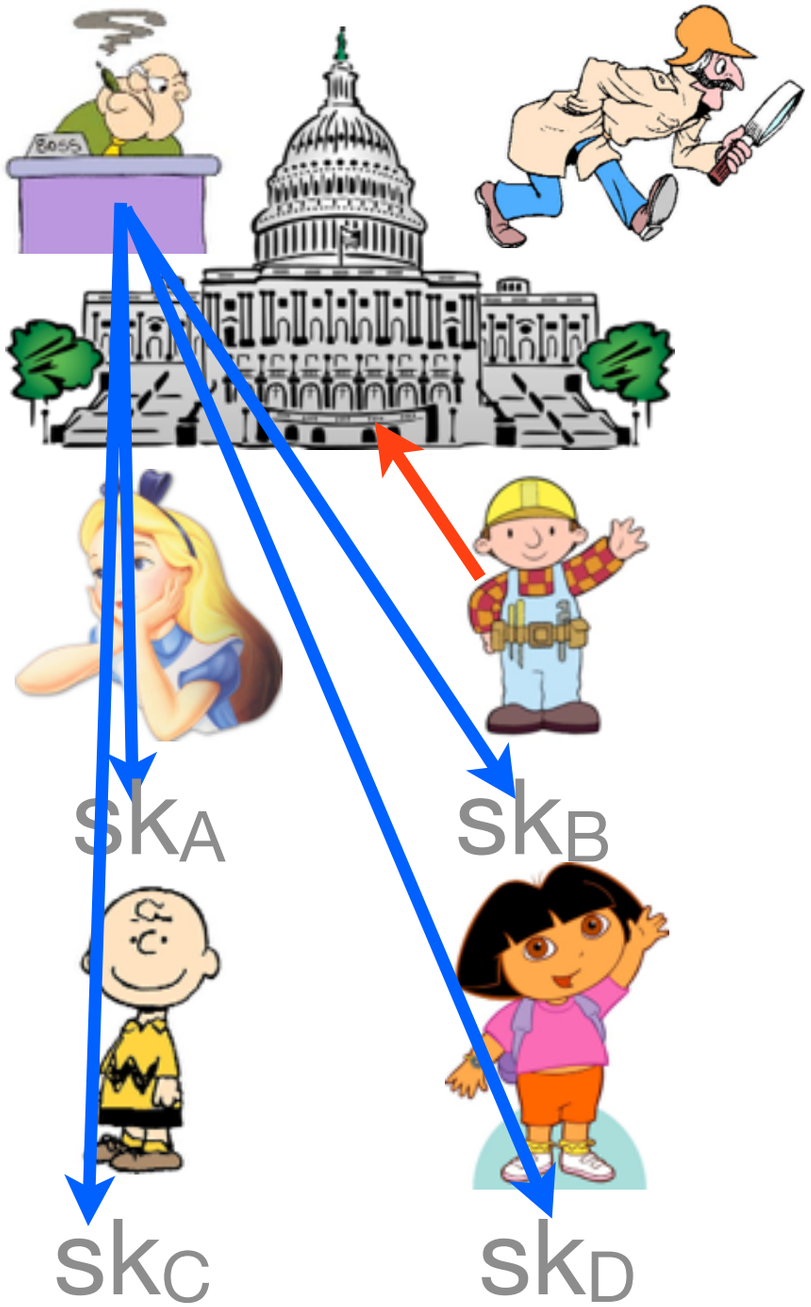

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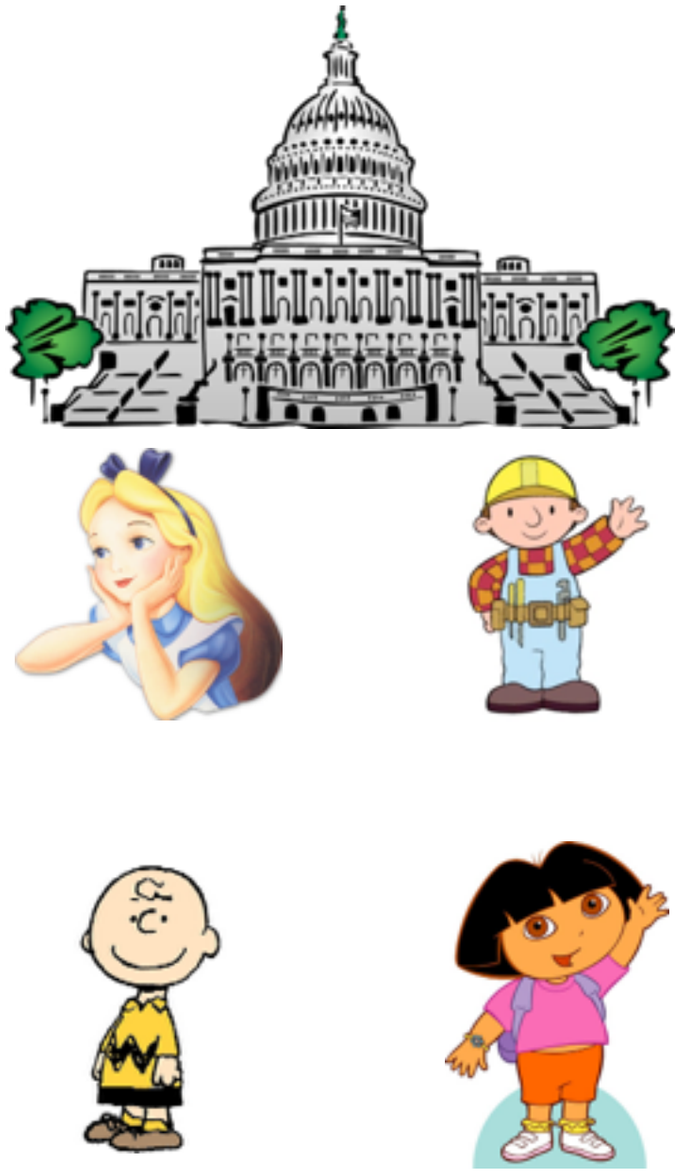

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pk_A, sk_A pk_B, sk_B

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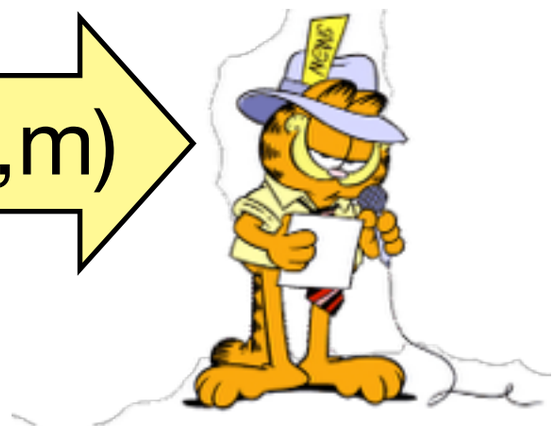
pk_B, sk_B

$m, \sigma = \mathrm{Sign}(sk_B, R, m)$



pk_C, sk_C

pk_D, sk_D

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pk_A, sk_A

pk_B, sk_B

pk_C, sk_C

pk_D, sk_D

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R = “US senators”

$\{pk_A, pk_B, pk_C, pk_D, \ldots\}$

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pk_A, sk_A pk_B, sk_B

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- KeyGen(1^k): outputs public key pk and secret key sk

- Sign(sk_i,R,m): outputs signature σ on message m

- Verify(R,σ,m): checks that σ is a valid signature on m formed by some member of the ring defined by R (and outputs 1 if yes and 0 if no)

Ring signature anonymity

Anonymity against full key exposure:

Ring signature anonymity

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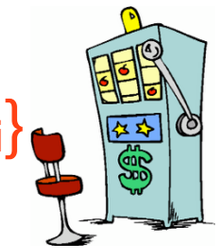
- Phase 1: KeyGen(1^k) is run m times to get $\{pk_i, sk_i\}$



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Ring signature anonymity

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- Phase 4: A now gets to see all $\{sk_i\}$, eventually outputs a guess bit b′

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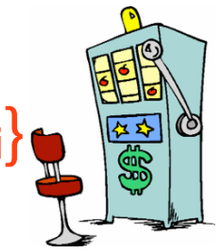

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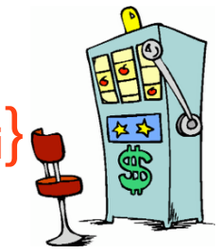

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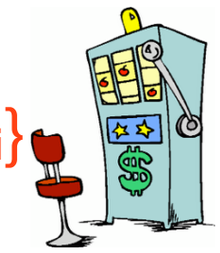

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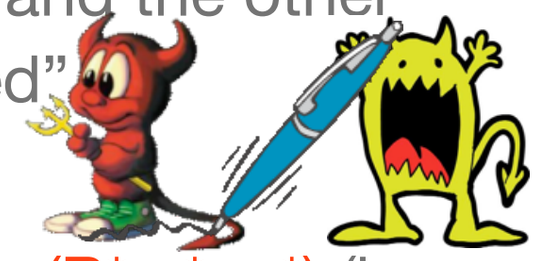

- Phase 3: A at some point has to output a successful forgery (R*,σ*,m*) (i.e., such that Verify(R*,σ*,m*) = 1)

How do we evaluate ring signature schemes?

- Efficiency: want really fast Sign and Verify
- Size of the signatures: want them to be independent of the ring size
- Security: want highest level of security (full anonymity, full unforgeability)
- Flexibility: can users pick their own signature schemes?
- Uses reasonable assumptions: random oracles? crazy weird-looking assumptions?

Comparison of ring signature schemes

	Efficiency	Size	Security	Flexibility	Assumptions	R.O.?
RST'01		linear	UFA		TDP	
DKNS'04		C	CFA		Strong RSA	
BKM'06		linear	CFA, FU		TDP	
SW'07		linear	CFA, FU		CDH + SGH	
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- Holy grail: Efficient, CFA and FU secure, flexible but short signatures, secure under mild assumptions and without random oracles

- Again, there's no clear winner!

Outline

Cryptographic background

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Ring signatures

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- Better definitions and formalizations for revocation

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Any questions?