Rational Broadcast Protocols against Timid Adversaries

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(Digital) Signature

Digital data for verifying the authenticity of messages

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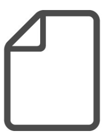
sk_A 

m

Verify with vk_A

(Digital) Signature

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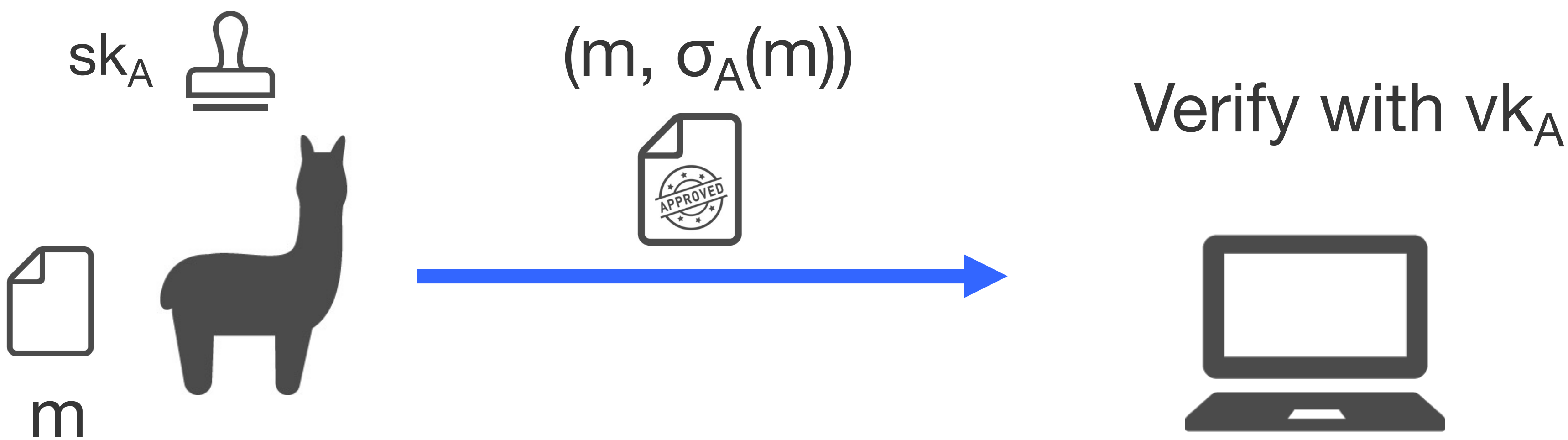

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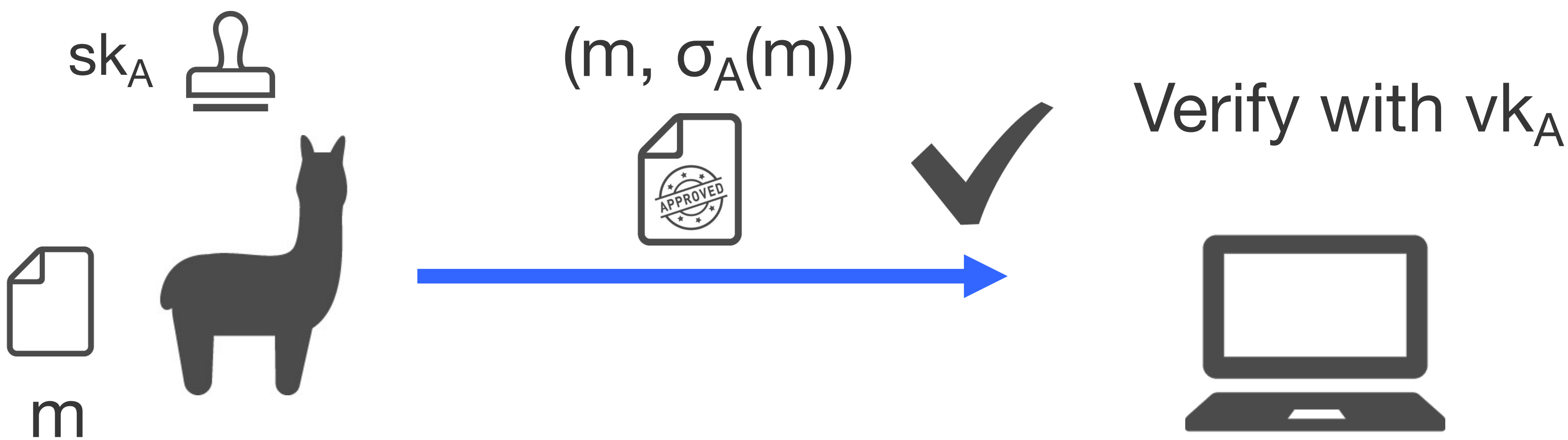

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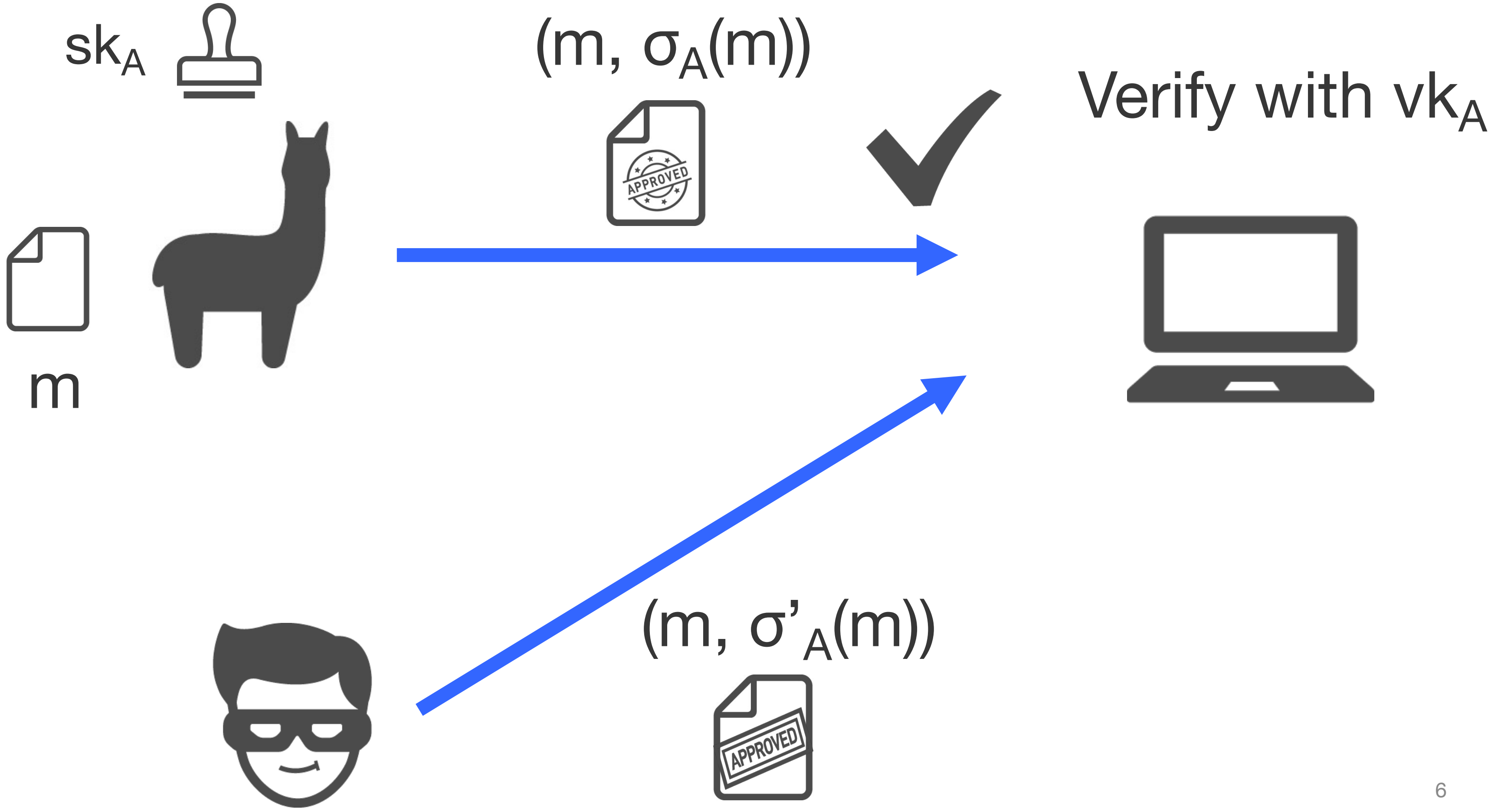

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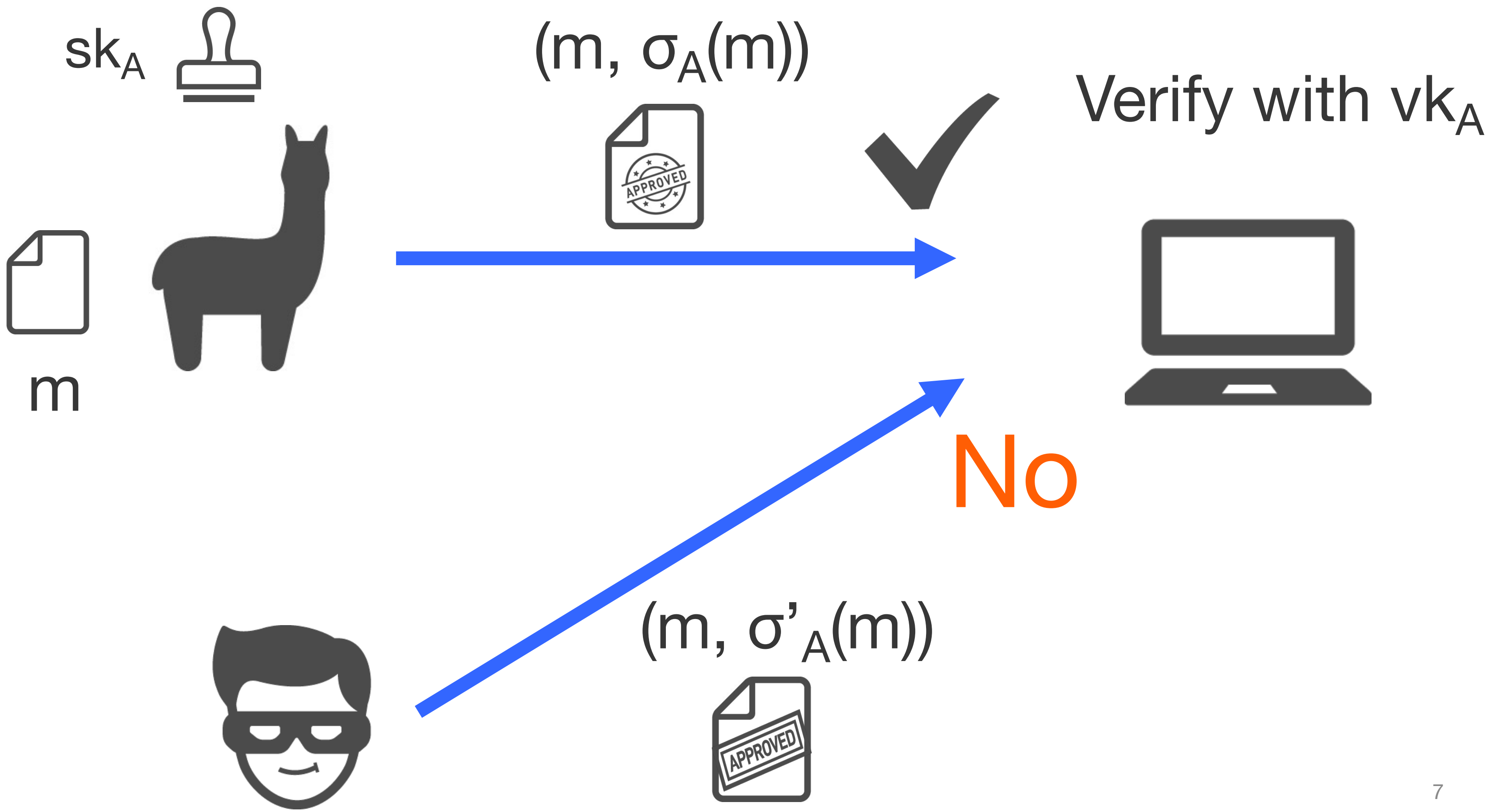

Role of Signature

B has a signature $(m, \sigma_A(m))$ of A

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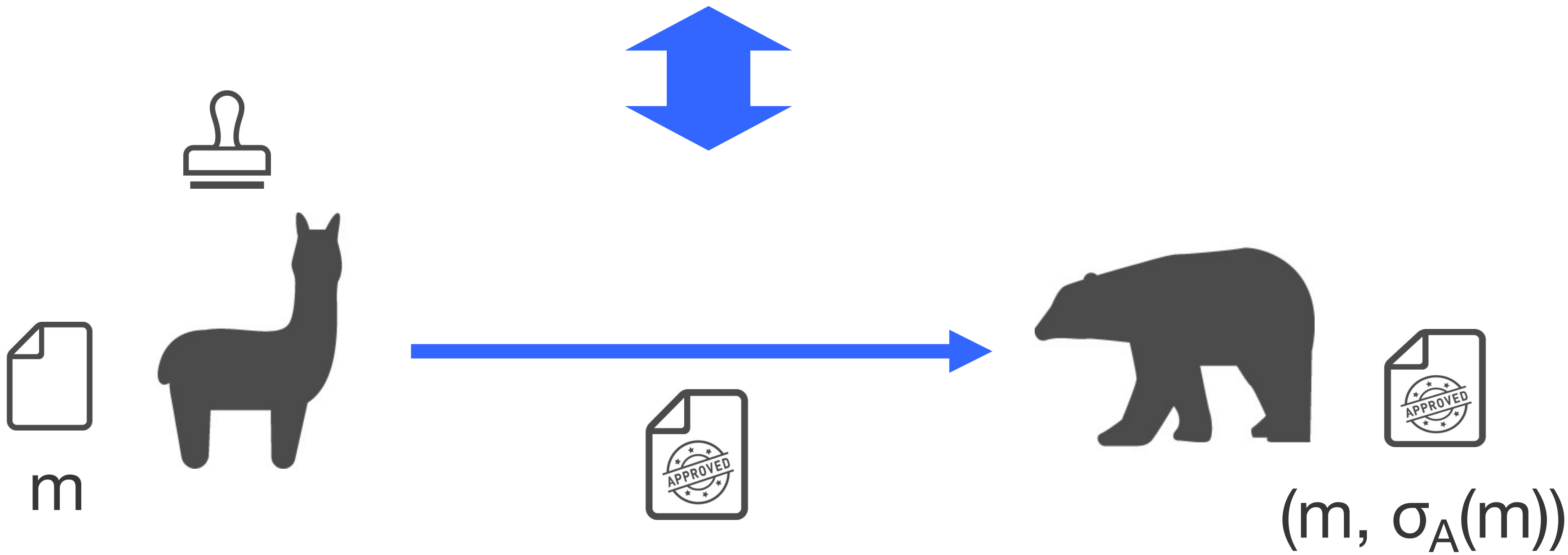

B has a proof that A sent m

Countersignature

C has a countersignature (m, $\sigma_B(\sigma_A(m))$)

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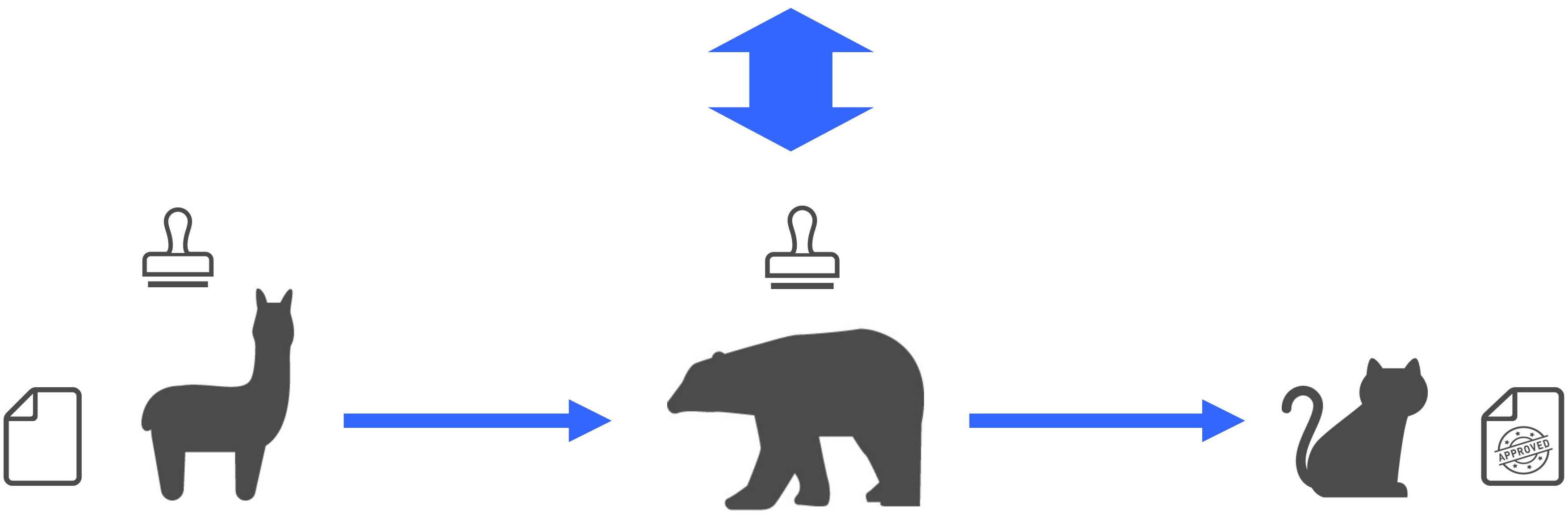


m

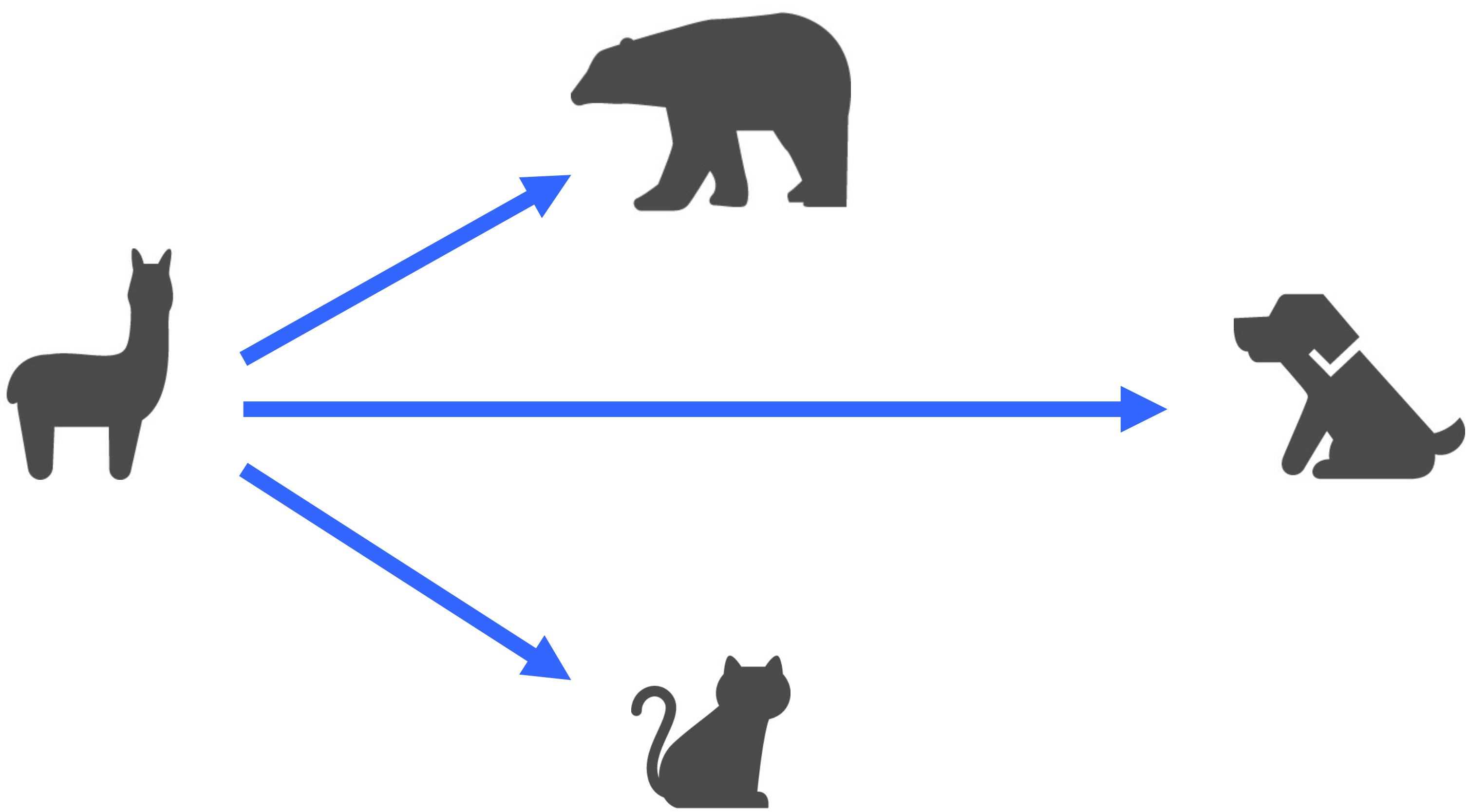
$(m, \sigma_B(\sigma_A(m)))$

C has a proof that B knows that A sent m

Broadcast Protocols

A sender sends the “same” message to all parties
even if the sender is malicious

- Building blocks for blockchains/multiparty computation



Broadcast Protocol (Setting & Requirements)

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Setting

- A set $[n] = \{1, \ldots, n\}$ of n parties on secure P2P network
- Adversary can corrupt $\leq t$ parties
- Synchronous communication ($\exists$ rounds)
- PKI (Signature) is available (Authenticated setting)

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Requirements

- Validity: If a sender $s \in [n]$ with input m is honest (= not corrupted), all honest parties output m
- Agreement: All honest parties output the same value

Previous & Our Results on Authenticated Broadcast

References	Resilience	# Rounds	Adversary	Results
Dolev-Strong (1983)	$t < n$	$t+1$	Malicious	∃deterministic BC
Dolev-Strong (1983)	$t < n$	t	Malicious	No deterministic BC
Katz-Koo (2006)	$t < n/2$	29	Malicious	∃randomized BC
Garay et al. (2007)	$t < n/2+k$	$O(k^2)$	Malicious	∃randomized BC
Garay et al. (2007)	$t < n$	$o(2n/(n-t))$	Malicious	No randomized BC
Micali-Vaikuntanathan (2017)	$t < n/2$	$2\lambda+3$ w.p. $1-2^{-\lambda}$	Malicious	∃randomized BC
Abraham et al. (2019)	$t < n/2$	10	Malicious	∃randomized BC
This Work	$t < n$	5	Rational	∃deterministic BC

Our protocol runs in $t+5$ rounds for malicious adversaries

Rational adversary tries to maximize utility

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Timid adversary prefers to attack the protocol without being detected

Our Protocol

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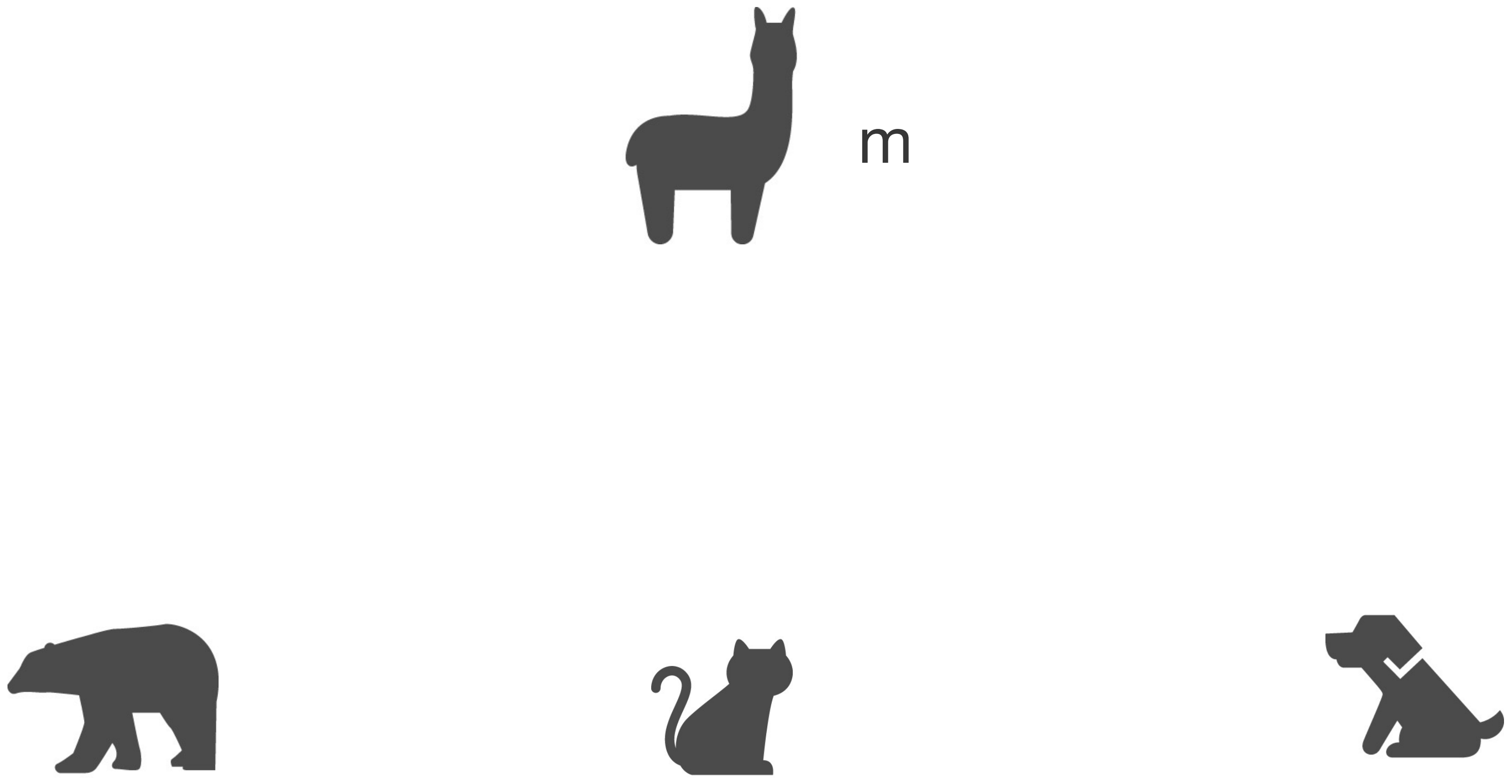
<u>Round 1:</u>

Sender s ∈ [n] sends (m, σ_s(m)) to all parties



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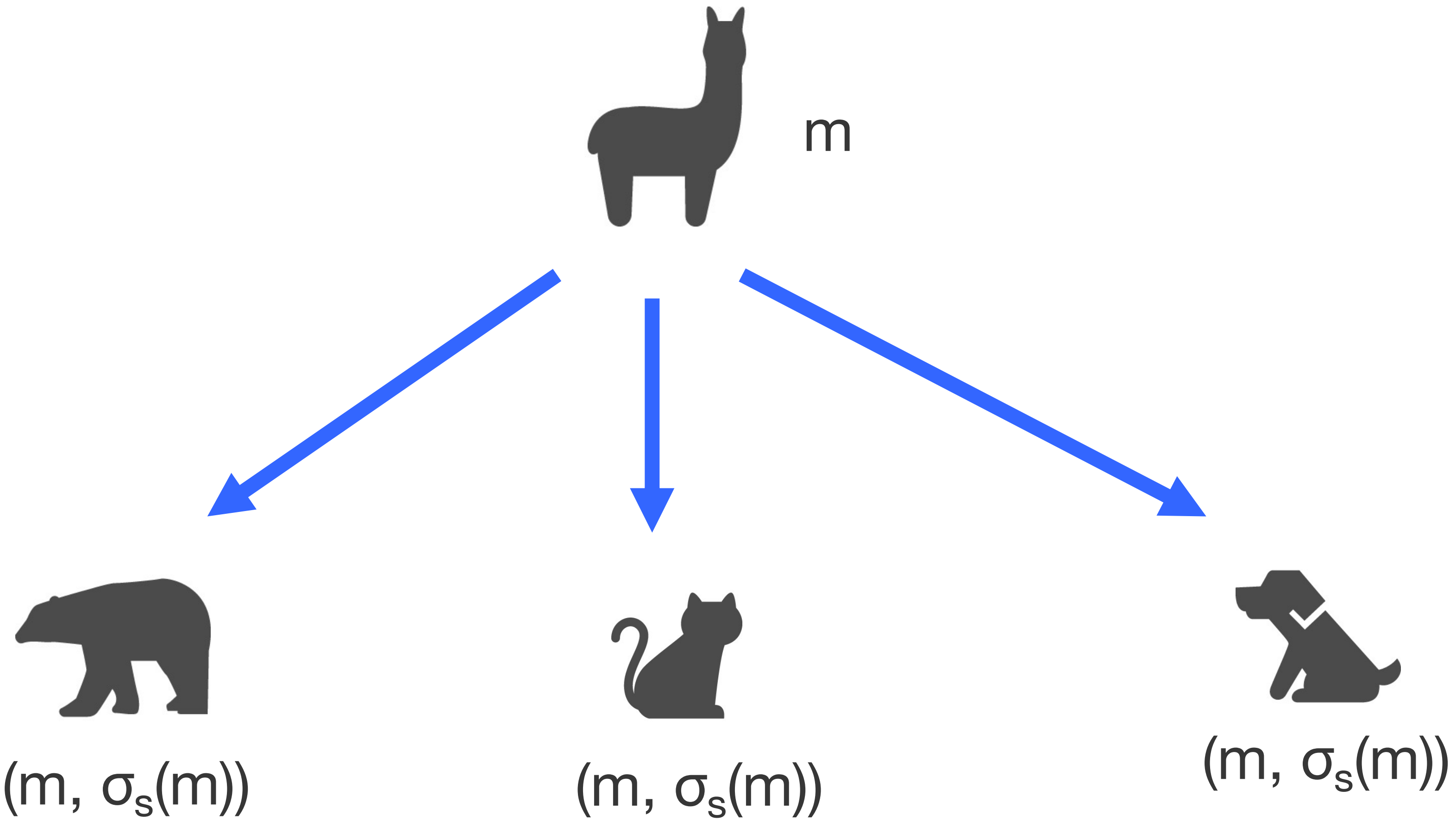
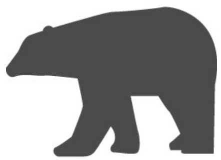


Round 2:

Each $i \in [n]$ sends countersig $(m, \sigma_i(\sigma_s(m)))$ to all parties



$(m, \sigma_B(\sigma_s(m)))$

$(m, \sigma_C(\sigma_s(m)))$

$(m, \sigma_D(\sigma_s(m)))$

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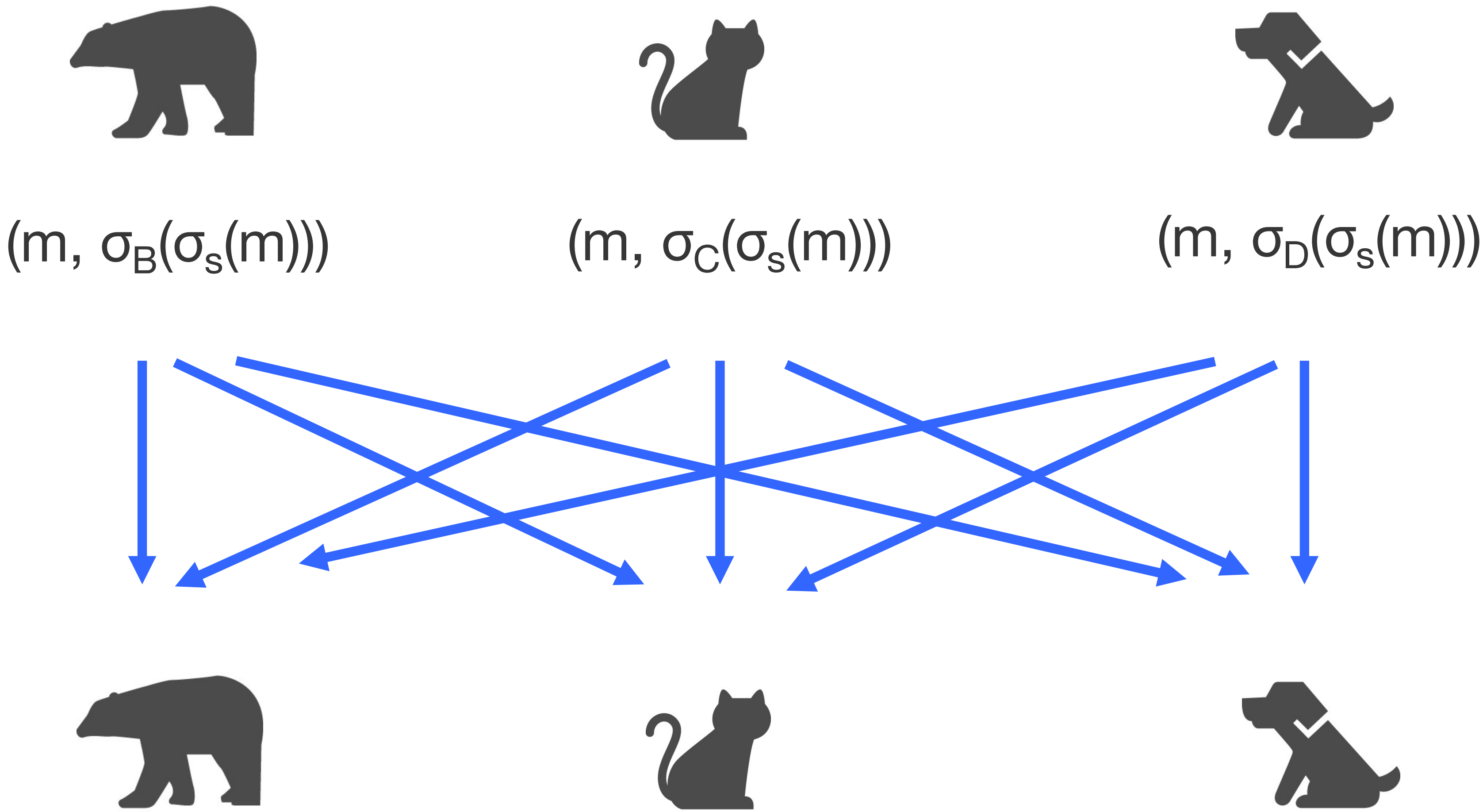
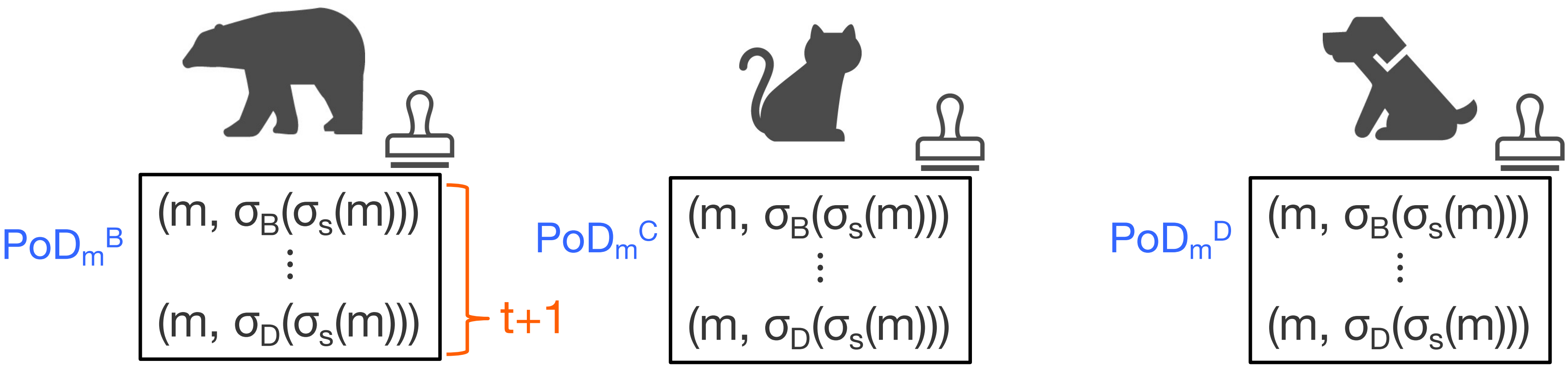


Round 3:

Each $i \in [n]$ collects t+1 valid countersigs to generate a signed "proof of dissemination" (PoD_m^i) and sends it to all parties



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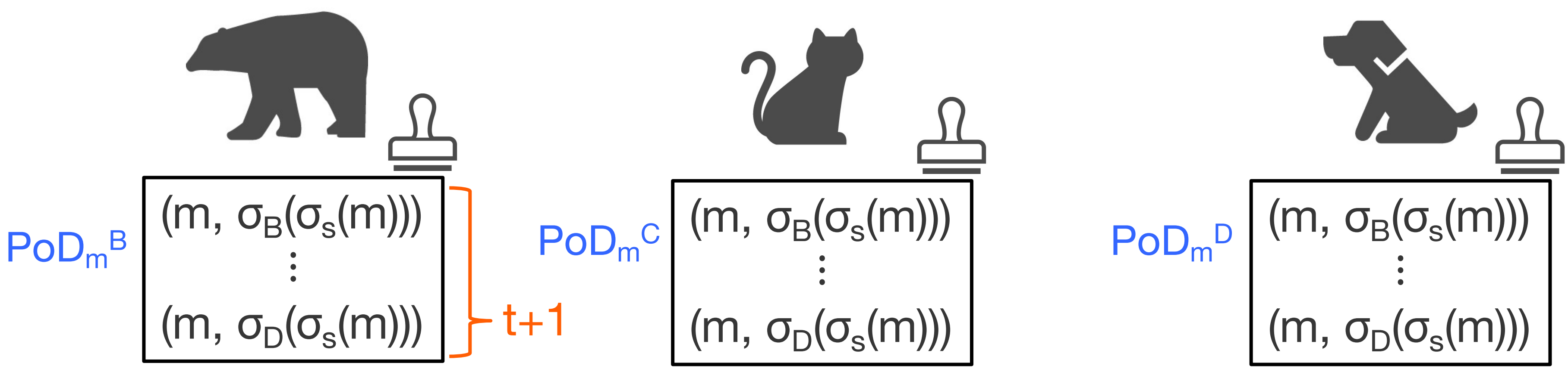

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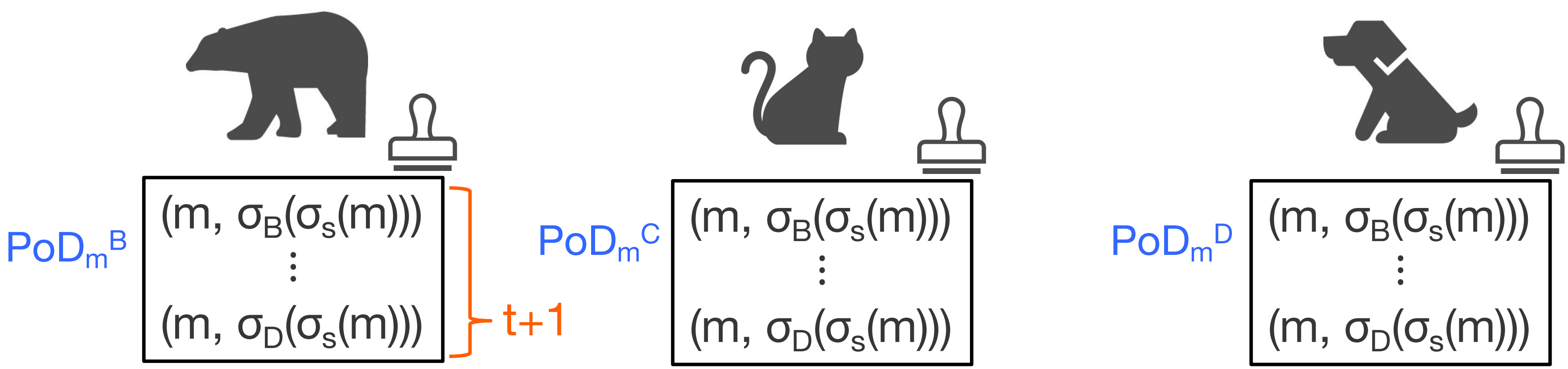
PoD_m^i = i knows that everyone got a countersig for m



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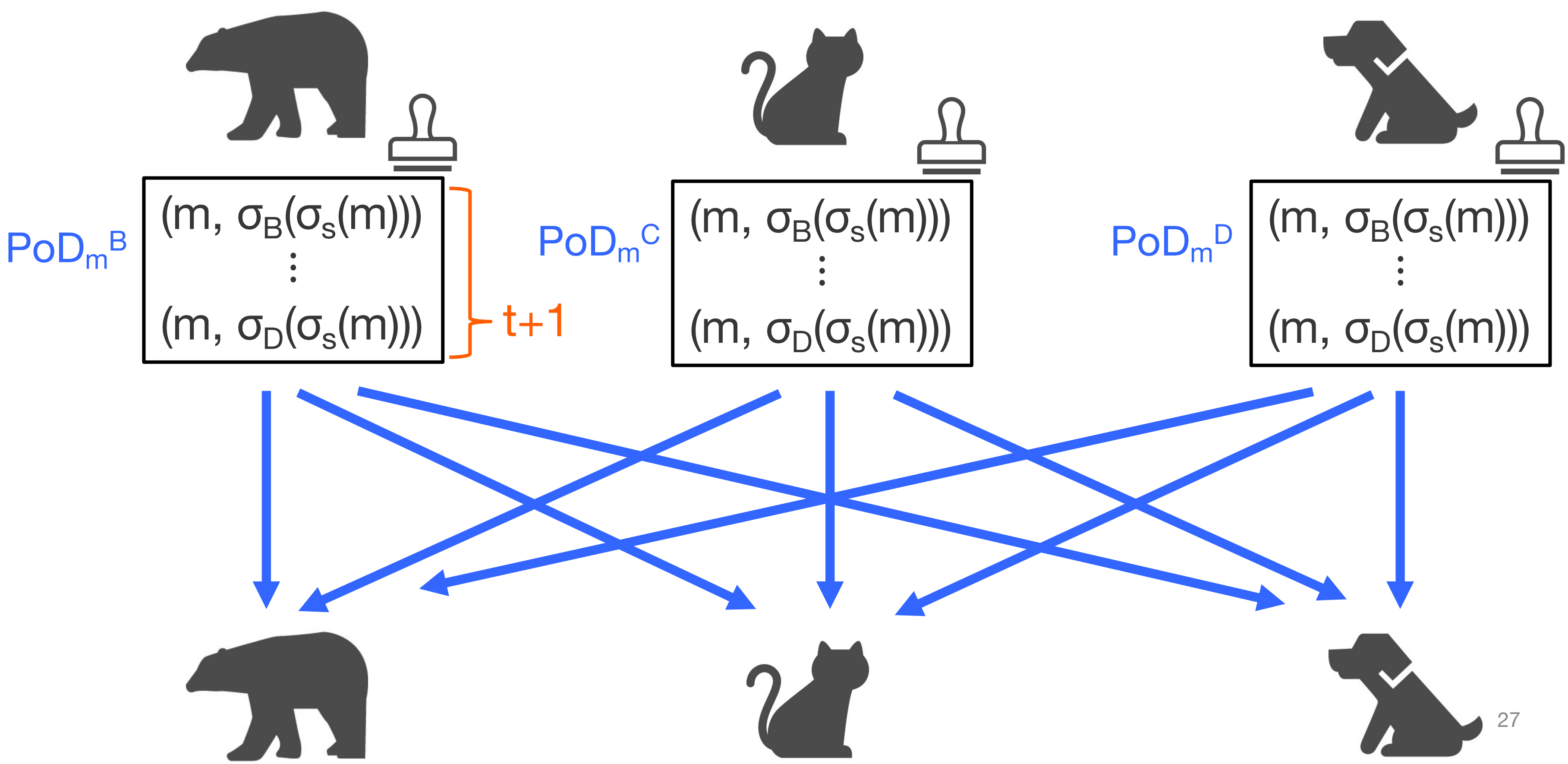
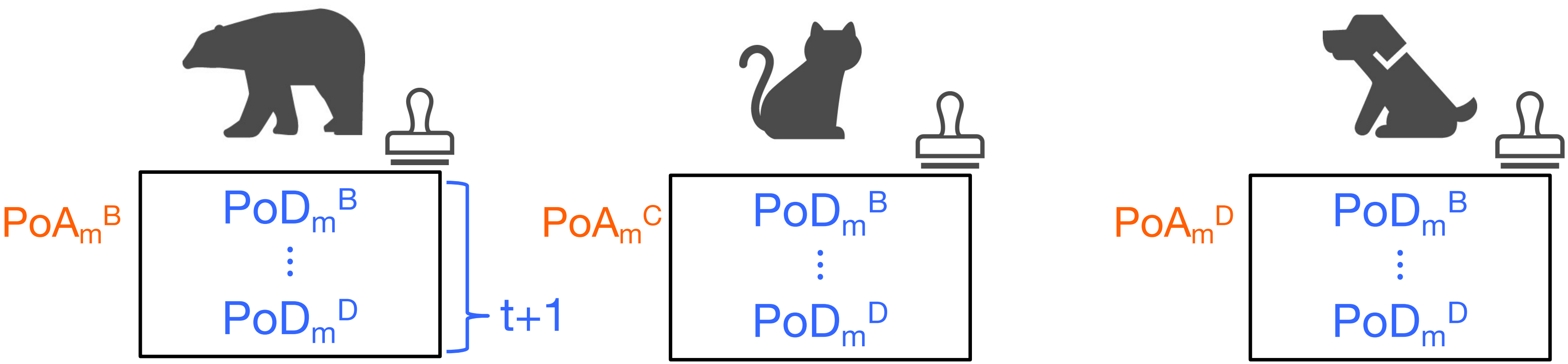


Round 4:

Each i ∈ [n] collects t+1 valid PoD_m^j to generate a signed "proof of agreement" (PoA_m^i) and sends it via Dolev-Strong protocol

(If i sees valid PoD_m & $PoD_{m'}$ for distinct m & m', i does nothing)



Round 4:

Each $i \in [n]$ collects $t+1$ valid PoD_m^j to generate a signed "proof of agreement" (PoA_m^i) and sends it via Dolev-Strong protocol

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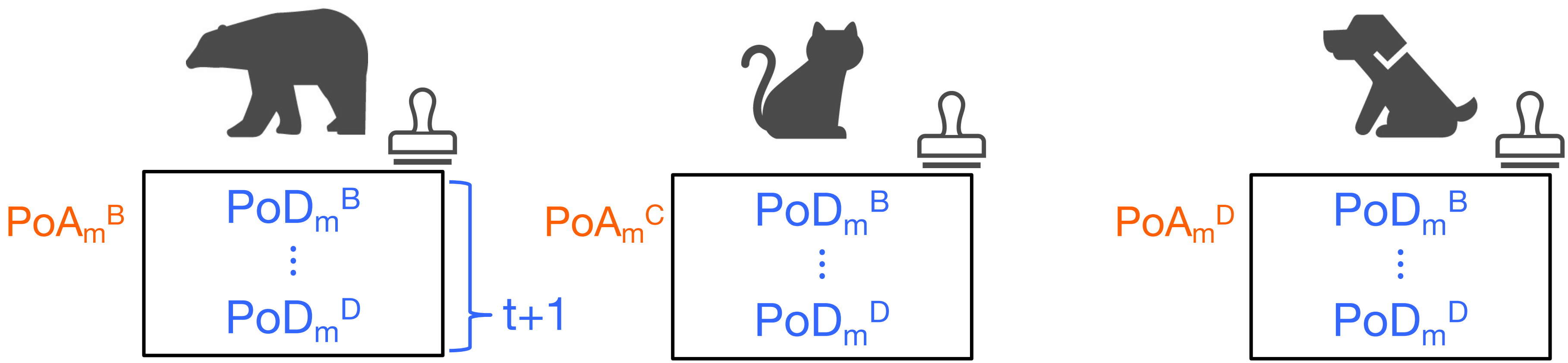
> PoA_m^i = i knows that everyone knows that everyone got a countersig for m

Another party may not know PoA_m



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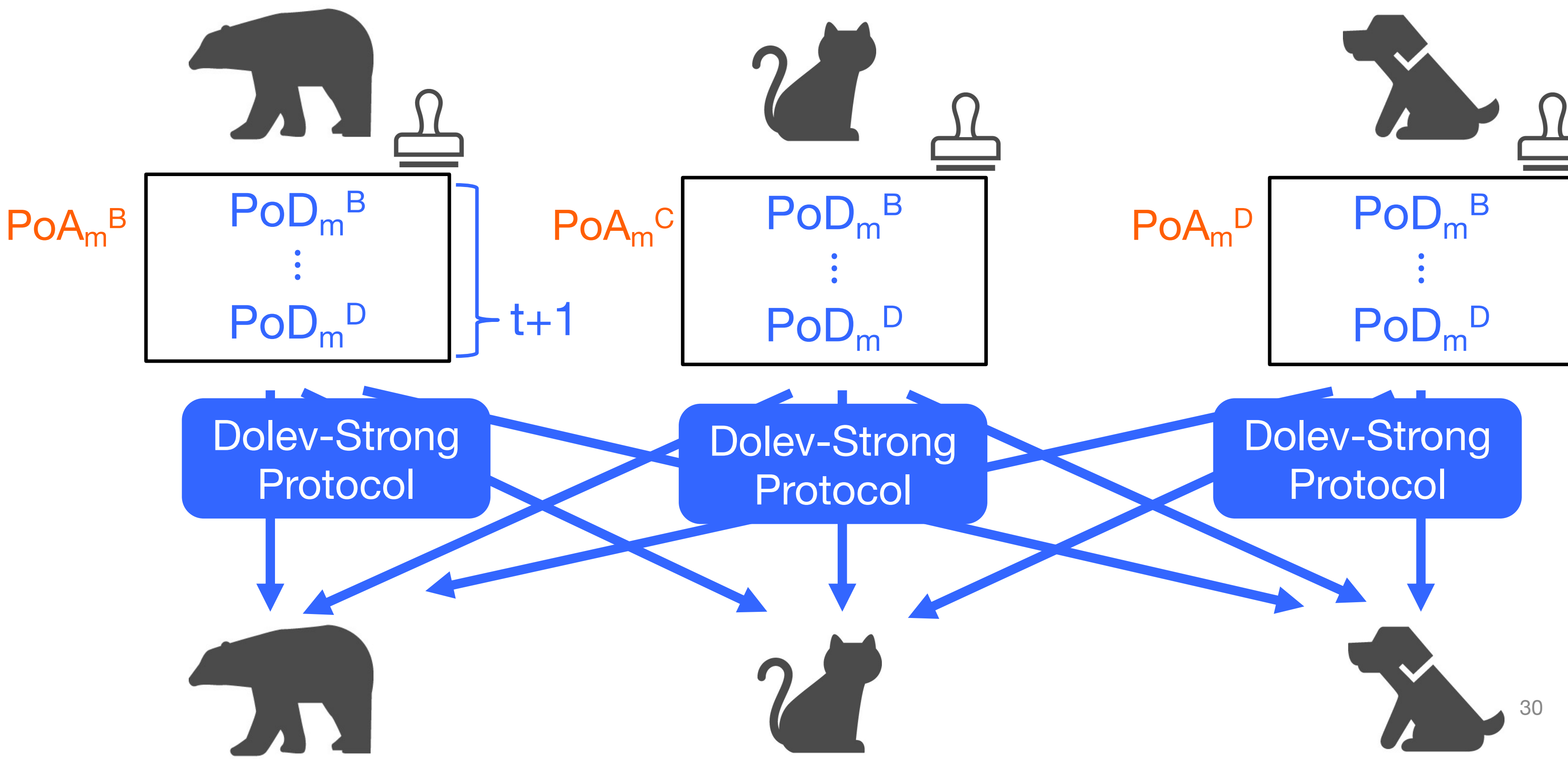

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If i ∈ [n] collects t+1 valid PoA_m^j (= “proof of termination” (PoT)), outputs m and halts.

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Round t+5:

If DS protocol outputs valid PoA_m, i outputs m.
Otherwise i outputs $\perp$ and sends "DETECT s" (s is cheating)

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Key Observations:

No party can obtain PoA_m & $PoA_{m'}$ for $m \neq m'$ simultaneously
(If so, every honest party sees PoD_m & $PoD_{m'}$ ➔ No PoA exists)

1. Honest party i output $m \neq \perp$ ➔ i obtained PoA_m
2. Honest party i output $\perp$ ➔ Every honest party failed to get PoA

Theorem

For any adversary corrupting t ($< n$) parties, our protocol satisfies

- weak validity
- agreement

The protocol finishes in round 5 for timid adversaries

- If finishes in round $t+5$ (output $\perp$), the sender's cheating is detected.

Requirements:

- Weak validity: If a sender $s \in [n]$ with input m is honest, all honest parties output m or $\perp$
- Agreement: All honest parties output the same value

Proof Overview

1. When violating weak validity:

   Sender s with input m is honest & Honest party i output $m'(\neq m)$

   → i got $PoA_{m'}$, but s never generates a signature for m'

   → Contradiction

2. When violating agreement with $(out_i, out_j) = (m, m'(\neq m))$:

   → i got PoA_m & j got $PoA_{m'}$ **→ Contradicting the observations**

3. When violating agreement with $(out_i, out_j) = (m, \perp)$:

   "$out_i = m$" → Honest i got PoA_m

   "$out_j = \perp$" → Every honest party failed to get PoA

   Contradiction

Discussion (False Detection)

When $t \geq n/2$,
honest sender s may be falsely detected as a cheater

- If $t = n/2$ parties do nothing, valid PoD cannot be generated

  → Honest party outputs $\perp$ (and s is declared cheating)

When $t < n/2$,
honest sender s can never be detected as a cheater

Conclusions

Construct a 5-round deterministic broadcast protocol against timid adversaries for $t < n$

- Avoiding DS lower bound by rationality
- Round complexity is $t+5$ in the worst (malicious) case

Future Work

- Improve the round complexity
- Construct a protocol without false detection for $t \geq n/2$ (or prove its impossibility)
- Achieve (standard) validity for $t \geq n/2$

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Broadcast Game for protocol Π

1. Set incorrect = disagree = undetect = 0
2. Adversary A chooses sender $s \in [n]$, message m, corrupted parties $C \subseteq [n]$ with $|C| \leq t$
3. Run Π where s is the sender with message m and A controls parties in C
4. After running Π, each $i \in [n]$ outputs v_i. Let $H = [n] \setminus C$.

   If $s \in H$ & $\exists\ i \in H$ s.t. $v_i \notin \{m, \perp\}$, set incorrect = 1
   If $\exists i, j \in H$ s.t. $v_i \neq v_j$, set disagree = 1
   If no party sent "DETECT", set undetect = 1
5. Outcome is out = (incorrect, disagree, undetect)

Utility of Timid Adversary

- For two outcomes out = (incorr, disag, undet) and out' = (incorr', disag', undet'),

1. U(out) > U(out')
   if incorr > incorr', disag = disag', undet = undet'
2. U(out) > U(out')
   if incorr = incorr', disag > disag', undet = undet'
3. U(out) > U(out')
   if incorr = incorr', disag = disag', undet > undet'

- By definition,

$$U(1,1,1) > \max\{ U(0,1,1), U(1,0,1) \}$$
$$\geq \min\{ U(0,1,1), U(1,0,1) \} > U(0,0,1) > U(0,0,0)$$

Security of Rational Broadcast

Protocol Π is secure against rational t-adversaries with U

⇔

∃(harmless) adversary B controlling ≤ t parties s.t.

1. Security: Π satisfies validity and agreement for B
2. Nash equilibrium:
   For every A controlling ≤ t parties, u(A) ≤ u(B).
   - u(A) := E[U(out_A)] is the expected value of U(out) for A

Dolev-Strong Protocol

Round 1:

Sender $s \in [n]$ sends $(m, \sigma_s(m))$ to all parties

Round $r = 2, \ldots, t+1$:

Each party $i \in [n]$, on receiving $c = (c_1, c_2)$,
if c_2 is a $(r - 1)$-fold valid signature of distinct signers $\neq i$,
then sends $(c, \sigma_i(c))$ to all parties. (Once for each m)
Otherwise, i sends nothing.

The end of round t+1:

Let V be the set of values of $(t+1)$-fold valid signatures.
If $|V| = 1$, output the value in V. Otherwise, output $\perp$.

$(t+1)$-fold valid signature of m
= everyone got the proof that s sent m