Automatic Verification of Remote Electronic Voting Protocols

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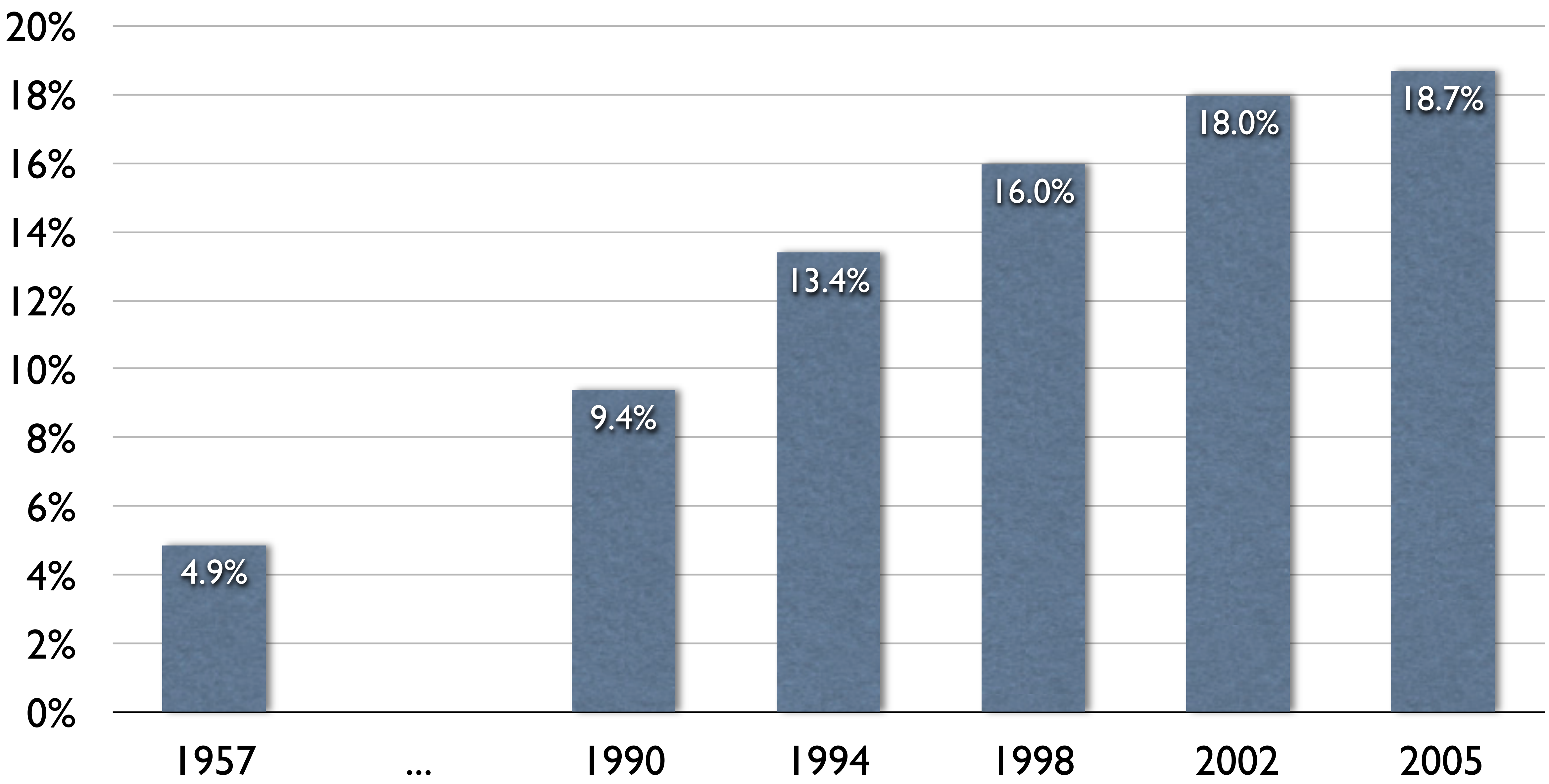
Joint work with: Michael Backes and Matteo Maffei

Did you know that ...

- ... in Germany, in the latest parliamentary elections **18.7%** of the votes were cast by post?



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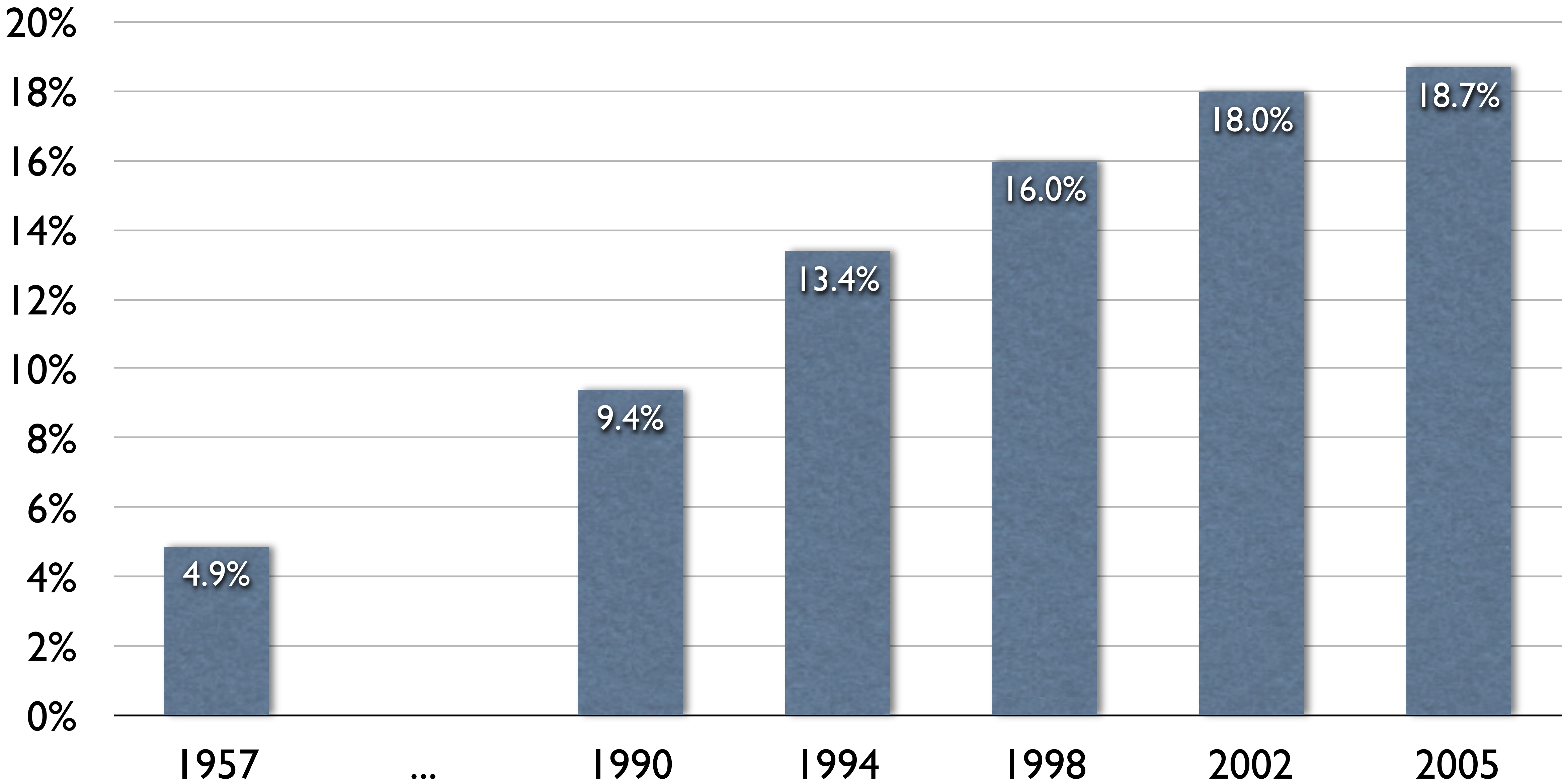
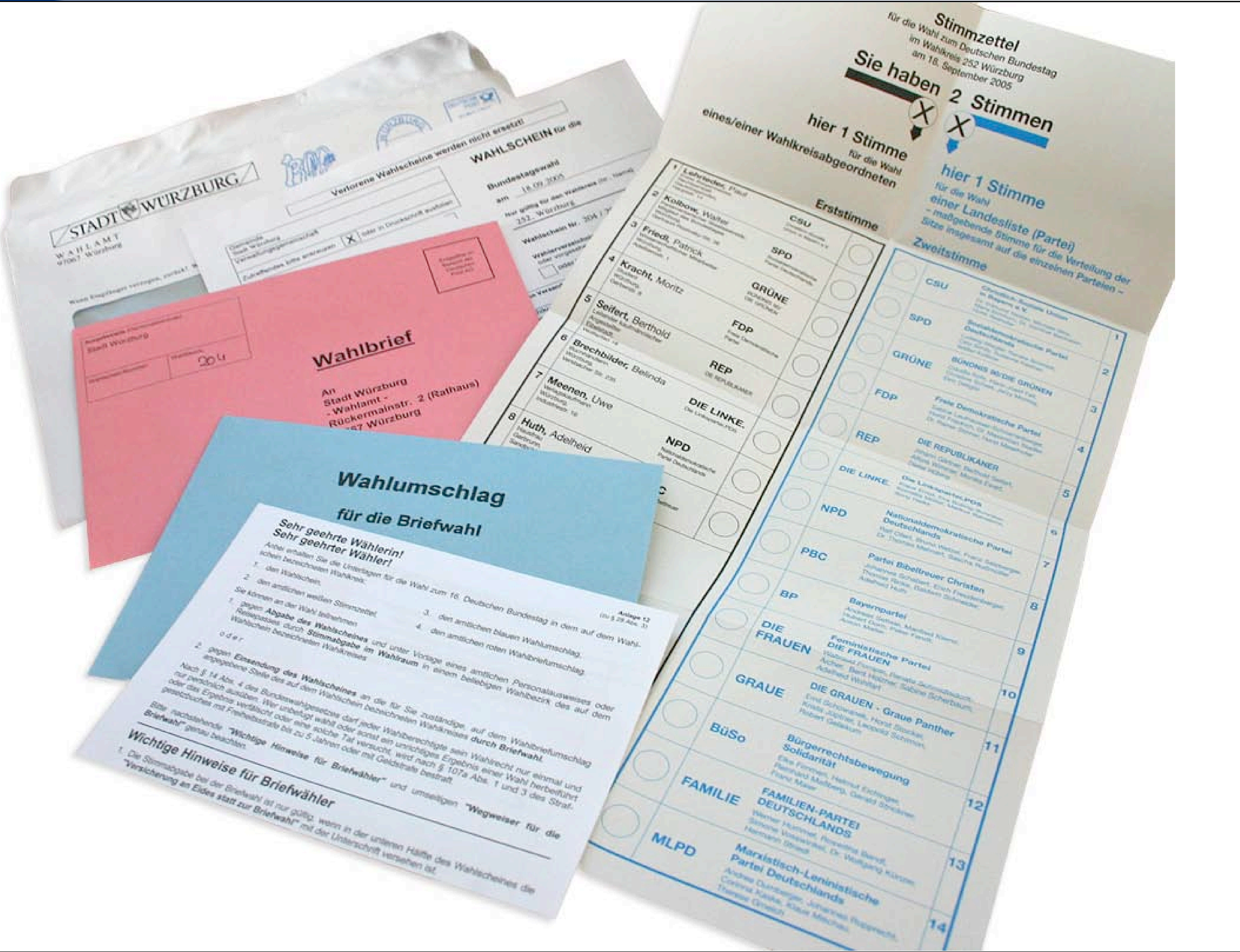
- this is a form of **remote voting**




Stimmzettel
für die Wahl zum Deutschen Bundestag
im Wahlkreis 252 Würzburg
am 18. September 2005
Sie haben 2 Stimmen
hier 1 Stimme
für die Wahl
eines/einer Wahlkreisabgeordneten
hier 1 Stimme
für die Wahl
einer Landesliste (Partei)
Erststimme
Zweitstimme
CSU
SPD
GRÜNE
FDP
REP
DIE LINKE.
NPD
PBC
BP
DIE FRAUEN
GRAUE
BüSo
FAMILIE
MLPD
STADT WÜRZBURG
WAHLSCHEIN für die
Bundestagswahl
Verlorene Wahlscheine werden nicht ersetzt!
Wahlbrief
An
Stadt Würzburg
- Wahlamt -
Rückermainstr. 2 (Rathaus)
Wahlumschlag
für die Briefwahl
Sehr geehrte Wählerin!
Sehr geehrter Wähler!
Wichtige Hinweise für Briefwähler

Remote voting (by post)

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  - The post is not always a secure channel
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- Still, this has been used in Germany for 50+ years

Remote electronic voting

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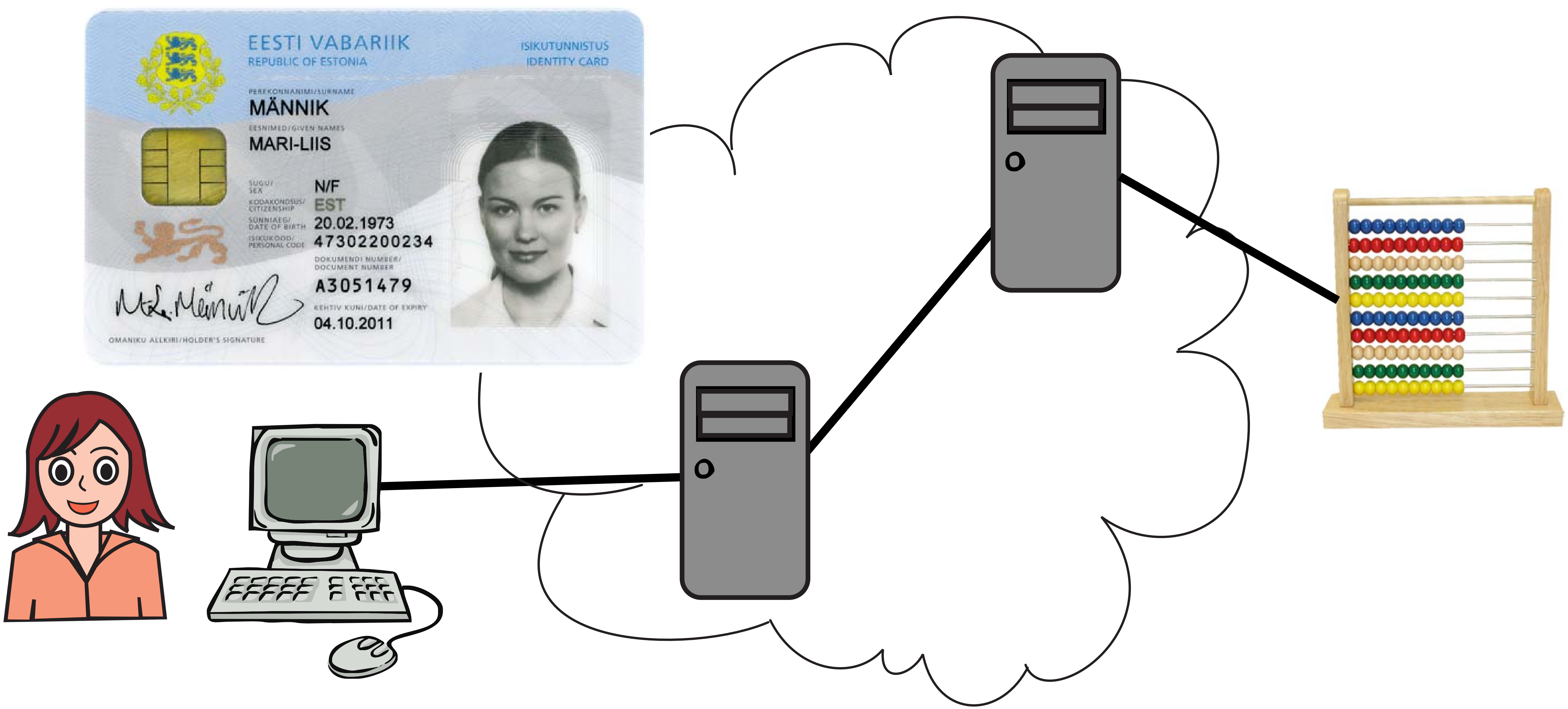
- Promises better security (than voting by post at least)
  - the security properties can be cryptographically enforced



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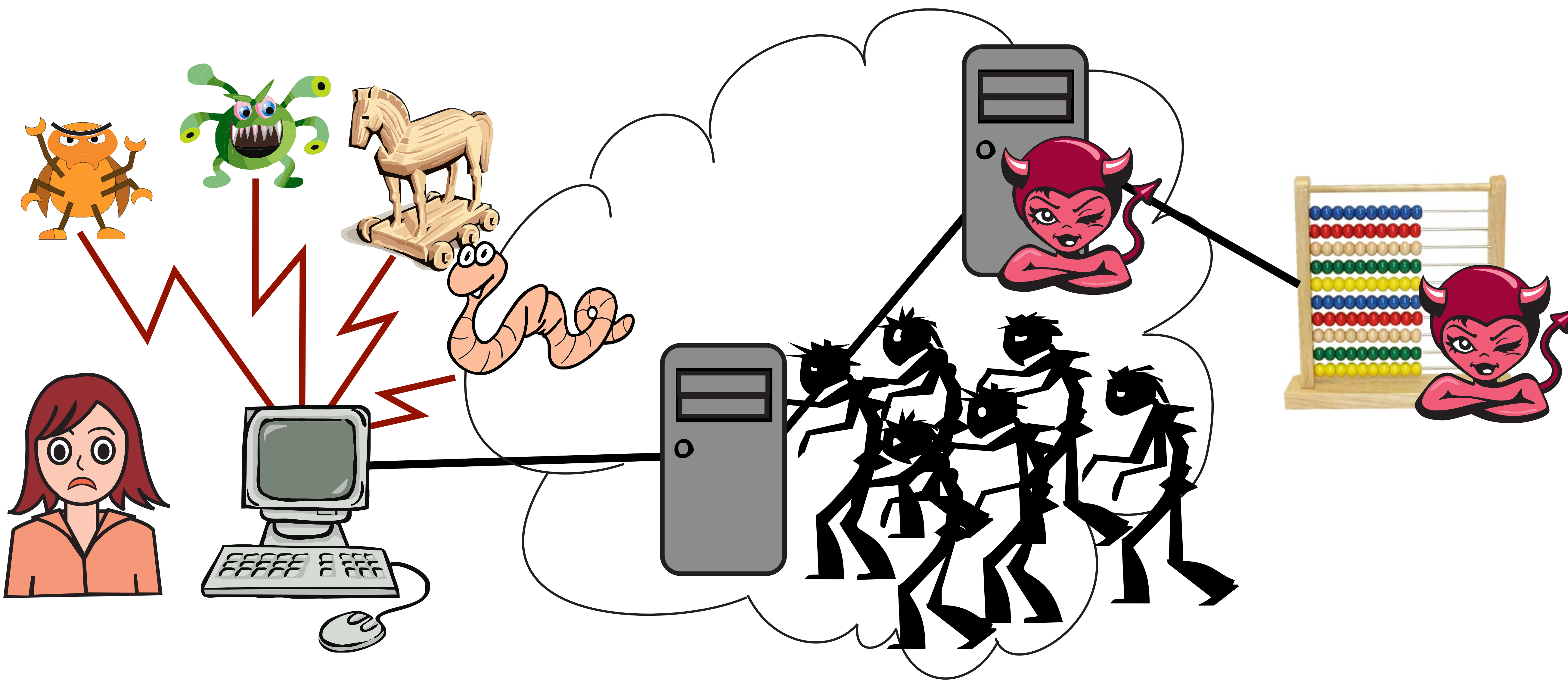

accuracy eligibility democracy fault tolerance

inalterability non-reusability robustness

completeness correctness scalability availability

fairness **desired properties**

vote-privacy

universal verifiability no forced-abstention attacks

individual verifiability receipt-freeness

coercion-resistance

accuracy

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What we did

- General technique for modeling remote electronic voting protocols (in the applied pi-calculus) and automatically verifying their security
- New formal definitions of
  - soundness - trace property
  - coercion-resistance - observational equivalence
  - both definitions amenable to automation (e.g. ProVerif)
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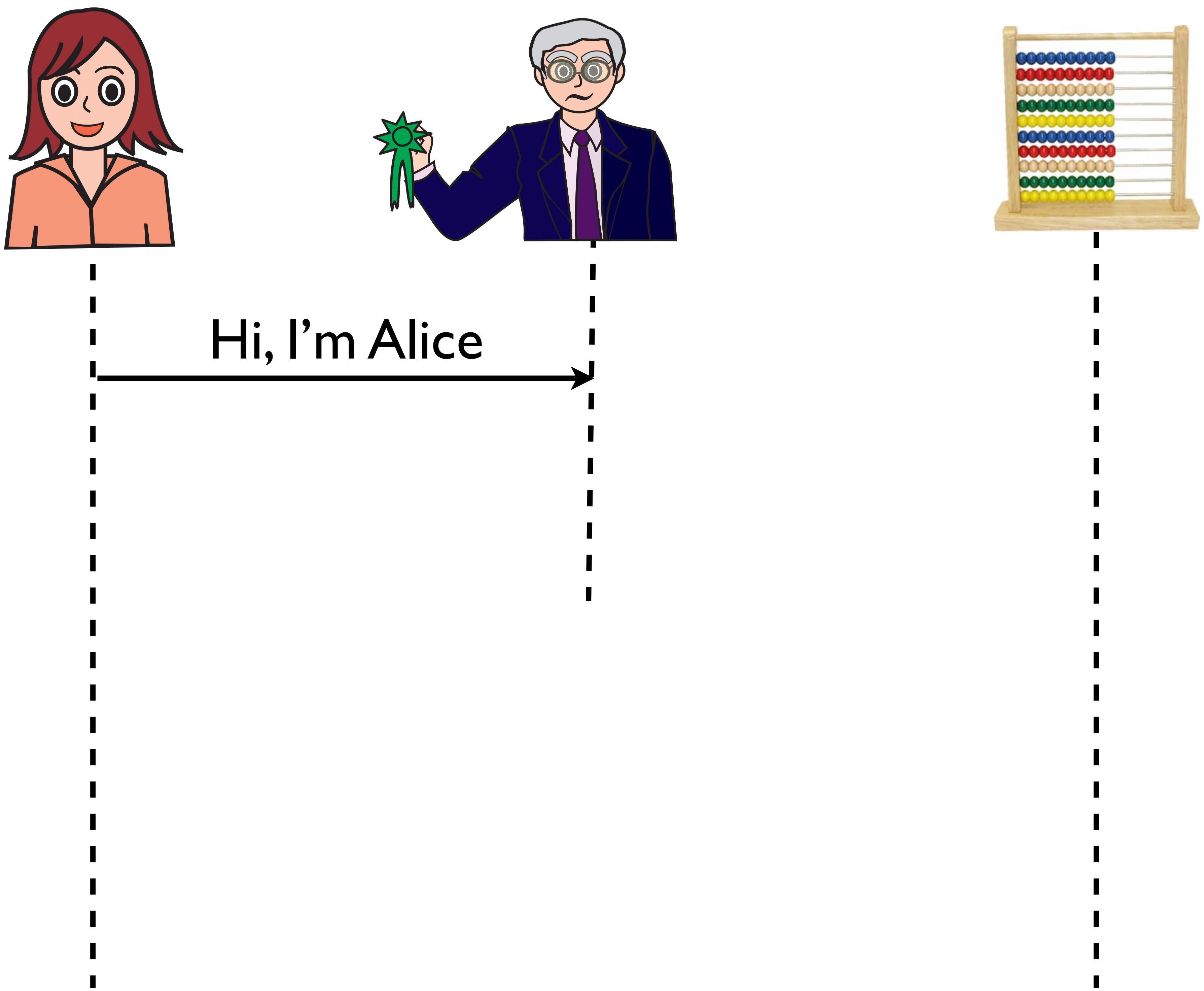
- Automatically verified the security of the JCJ protocol
- For all details see [Backes, Hrițcu & Maffei, CSF 2008]

The Big Picture

Soundness (eligibility, non-reusability, inalterability)



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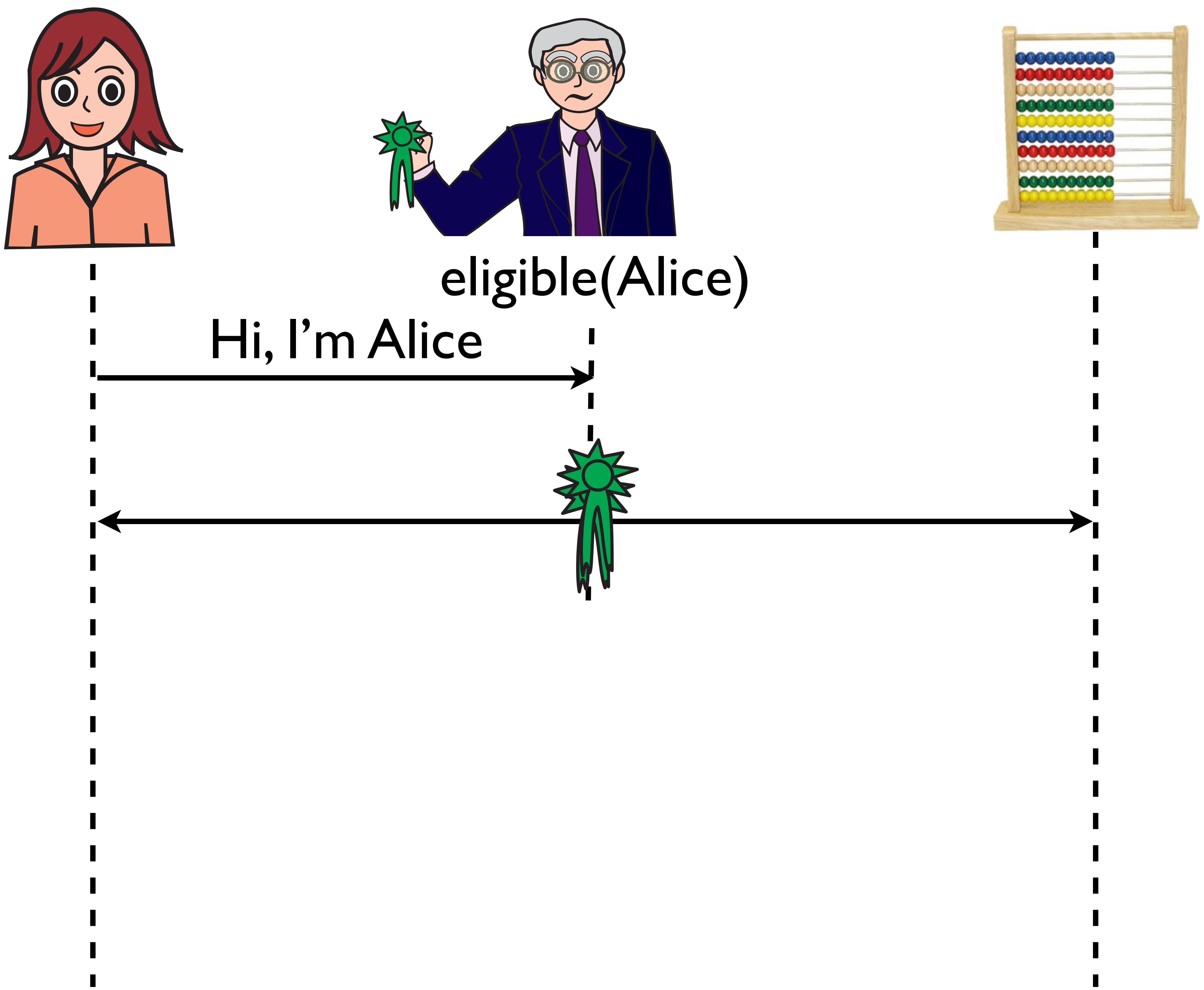

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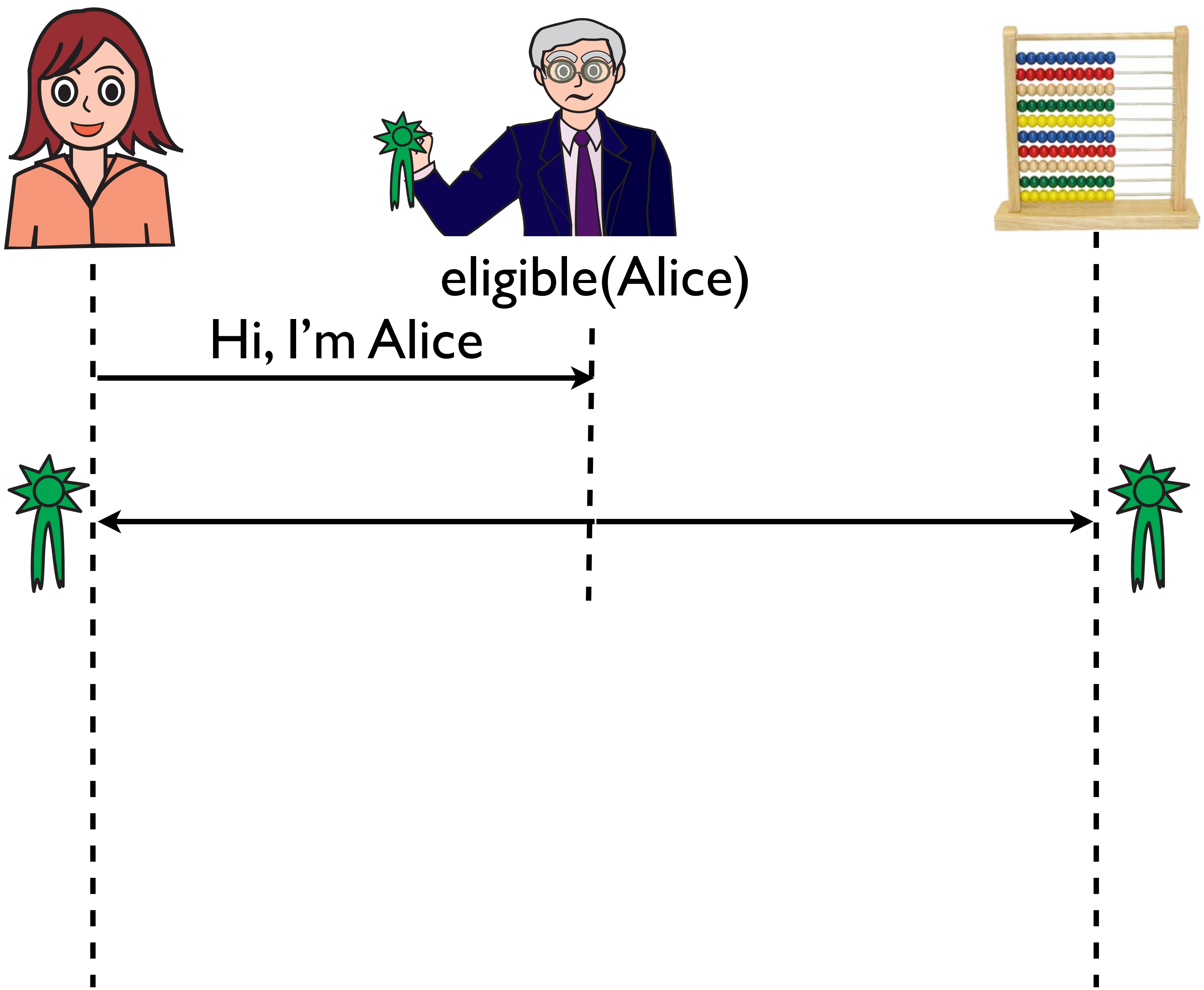

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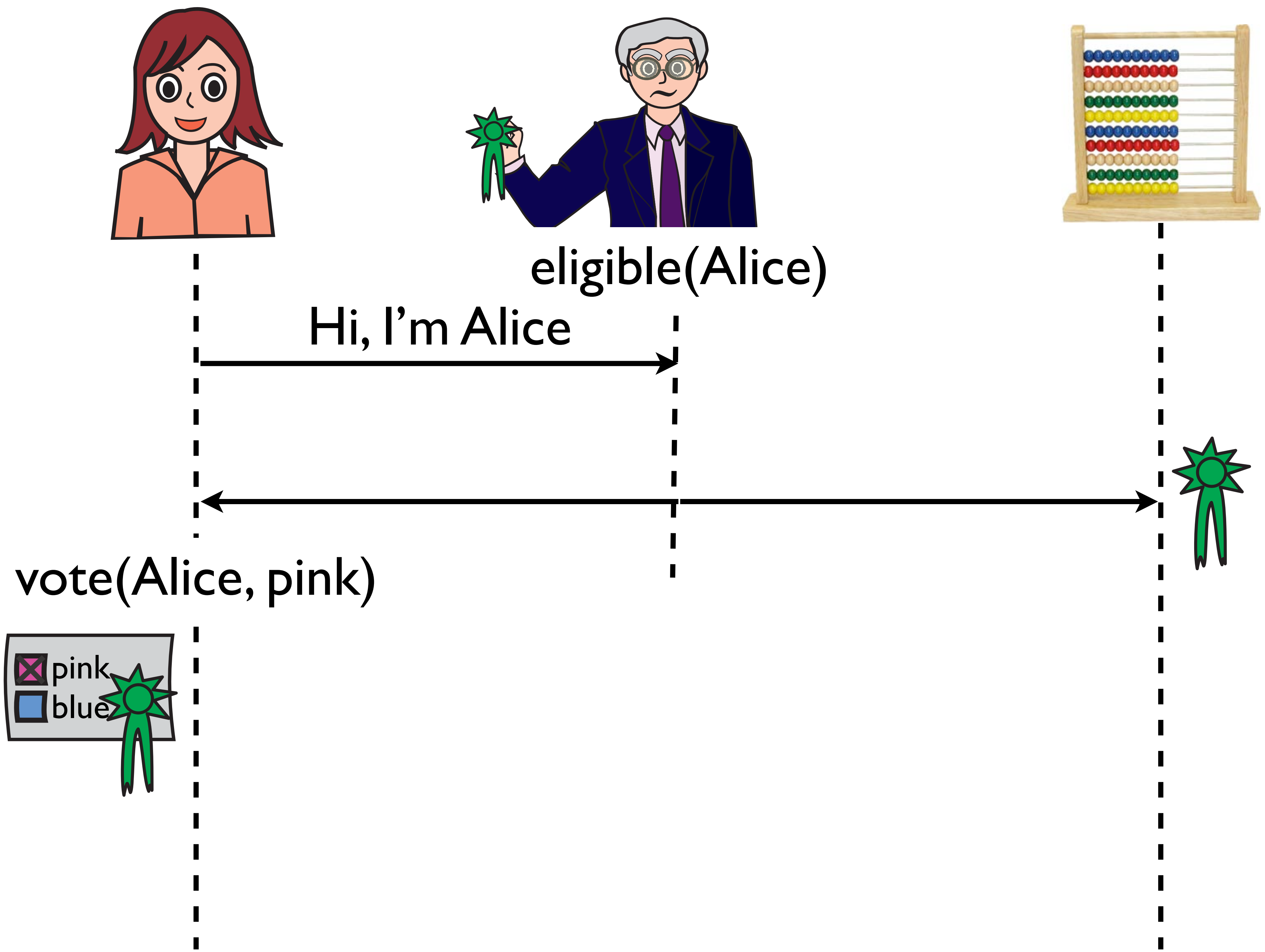

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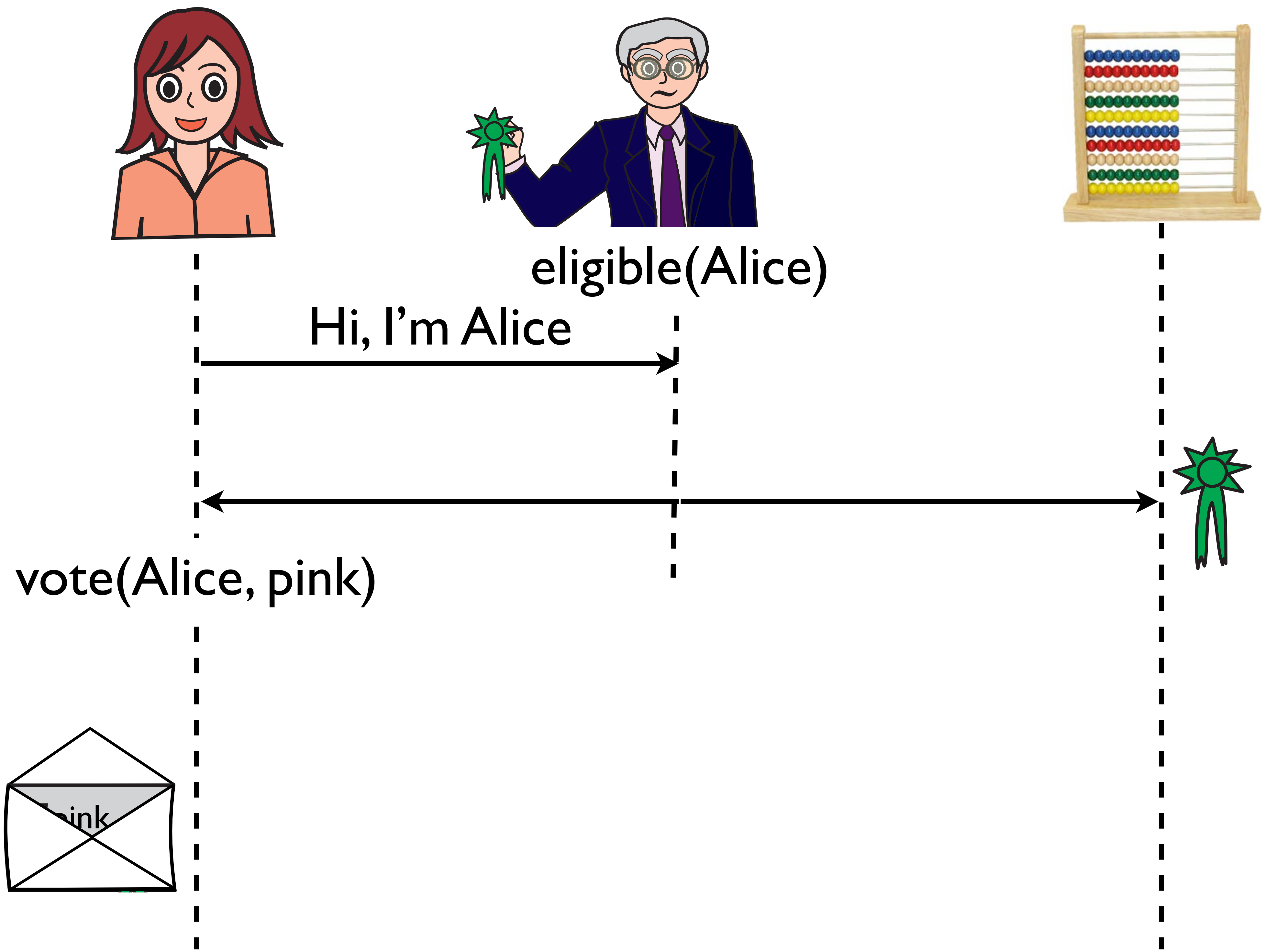

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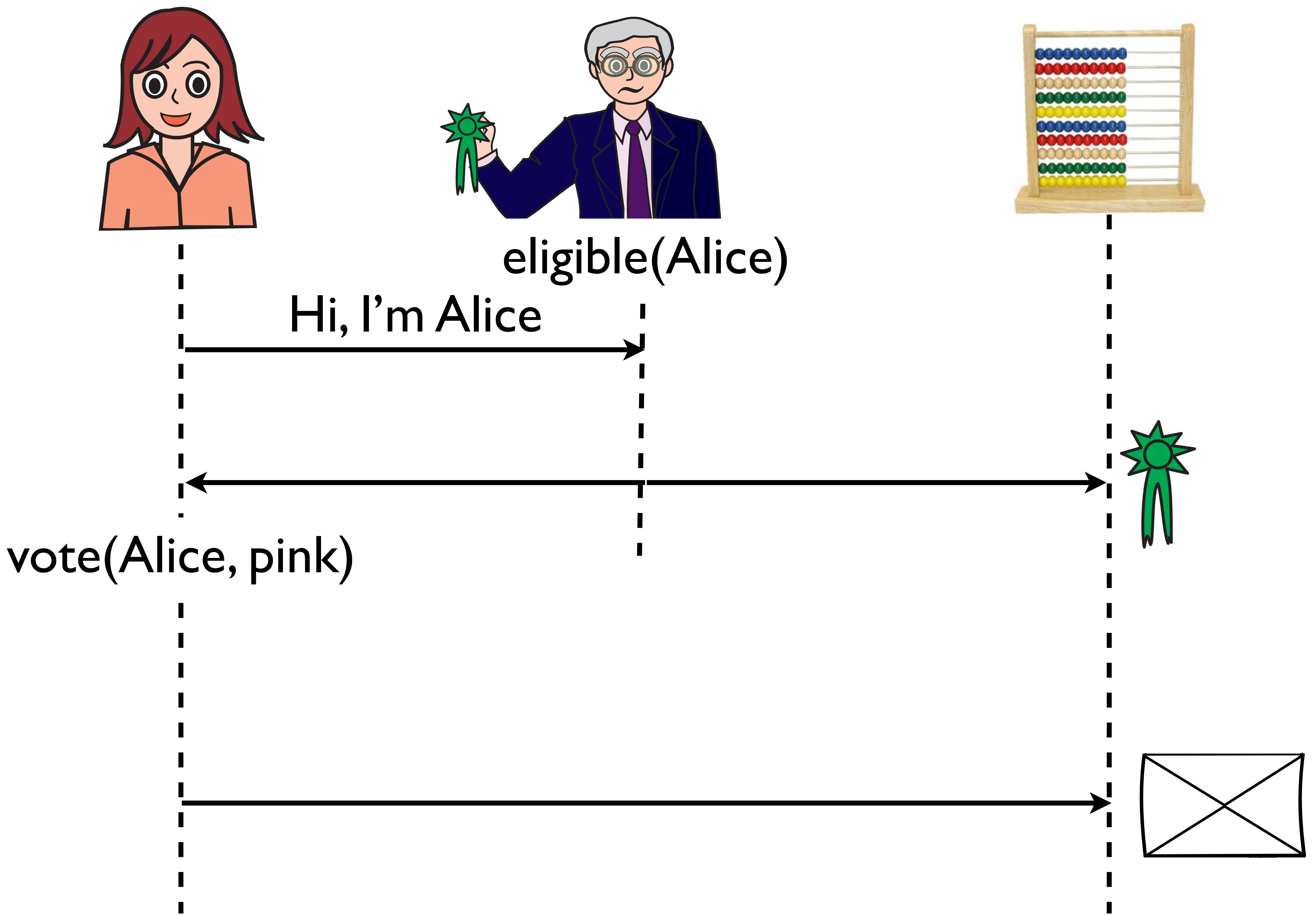

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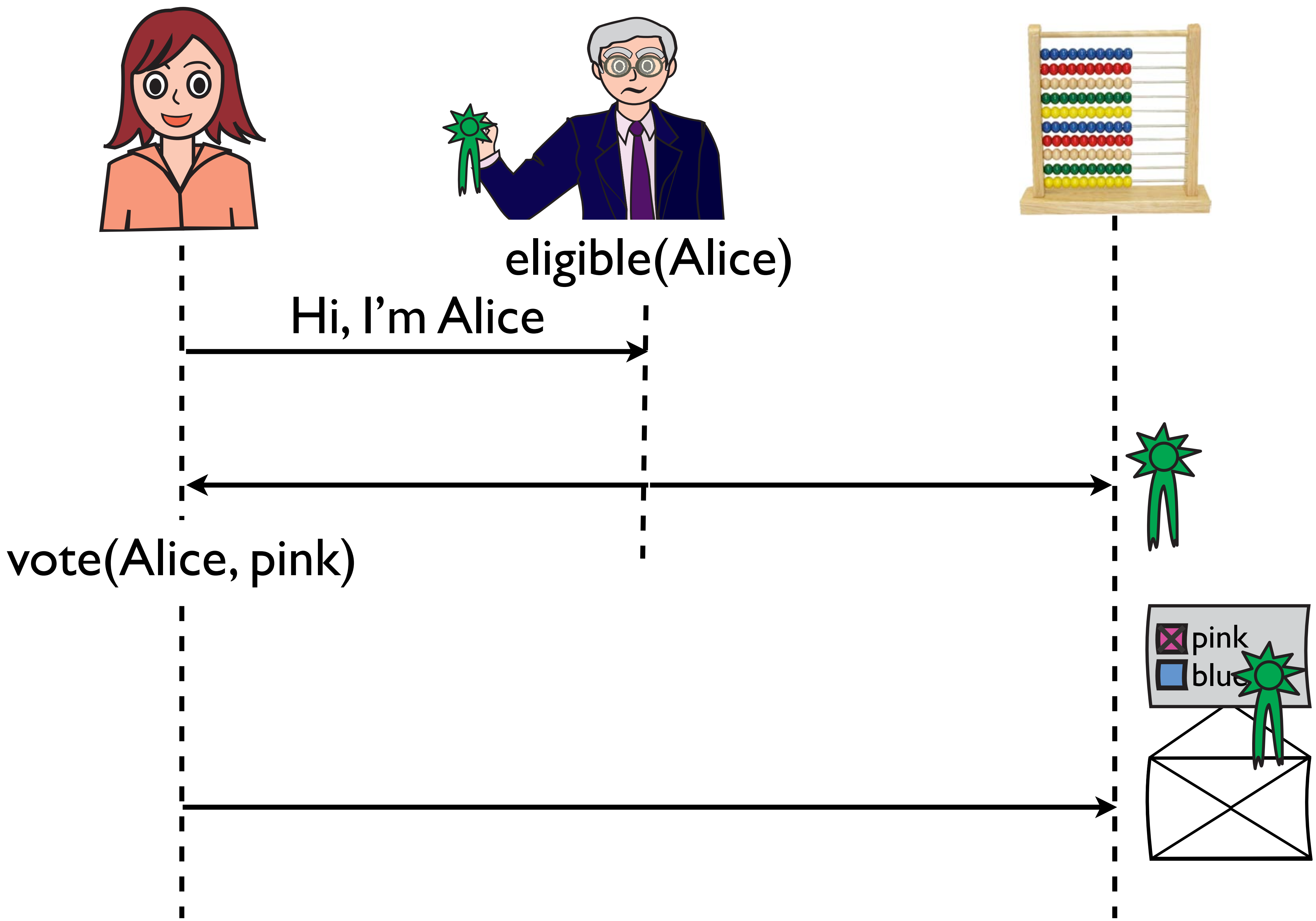

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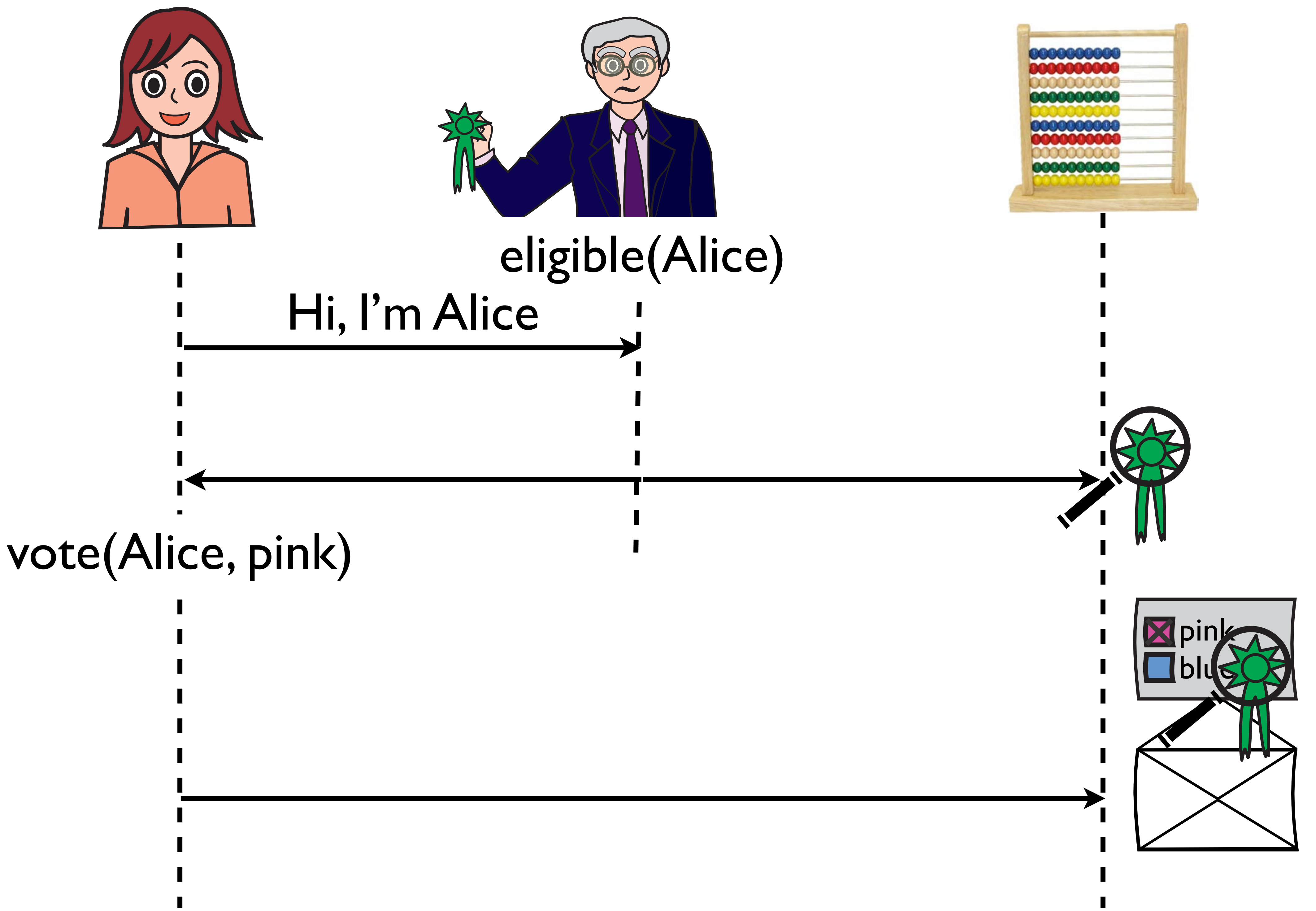

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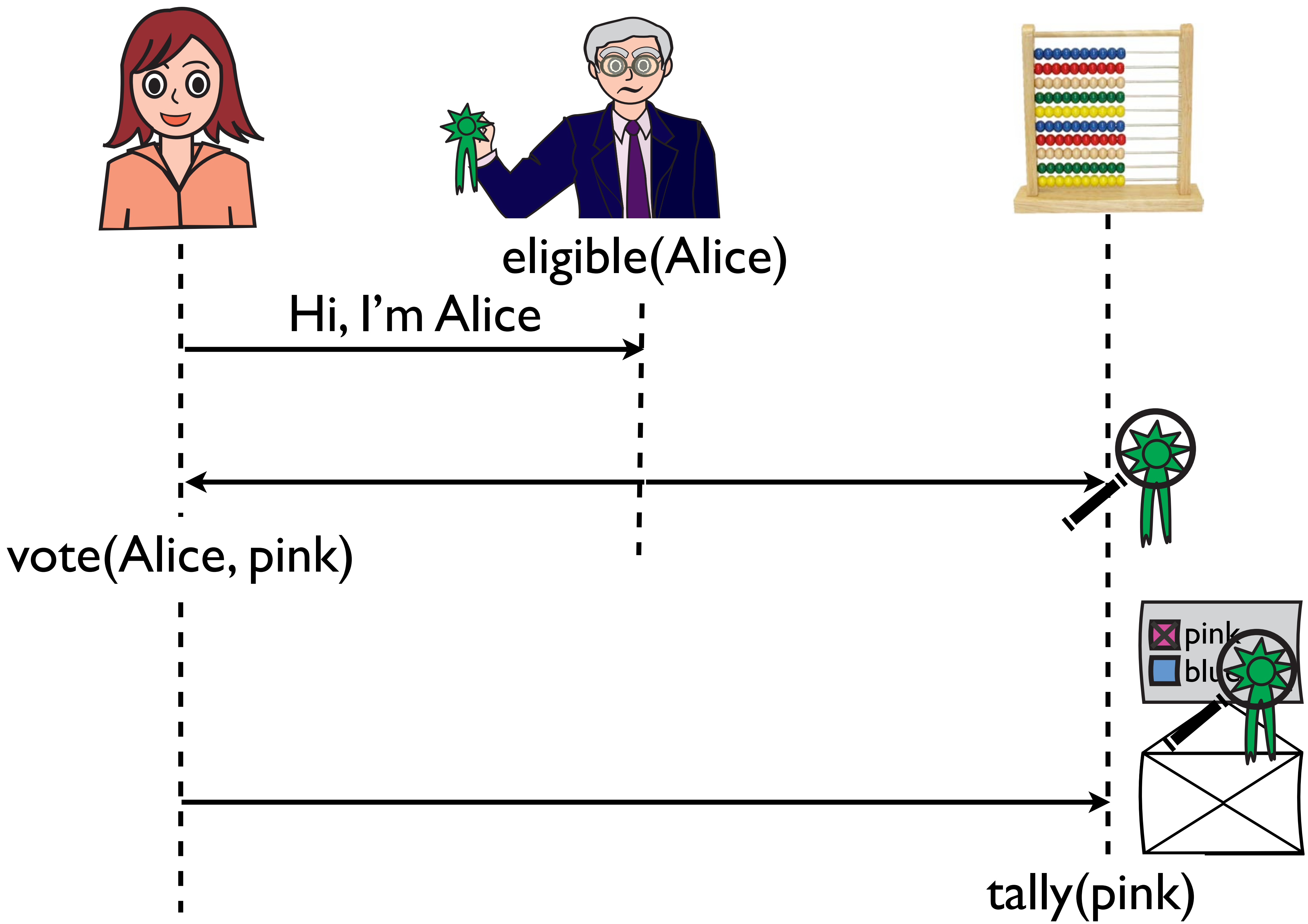

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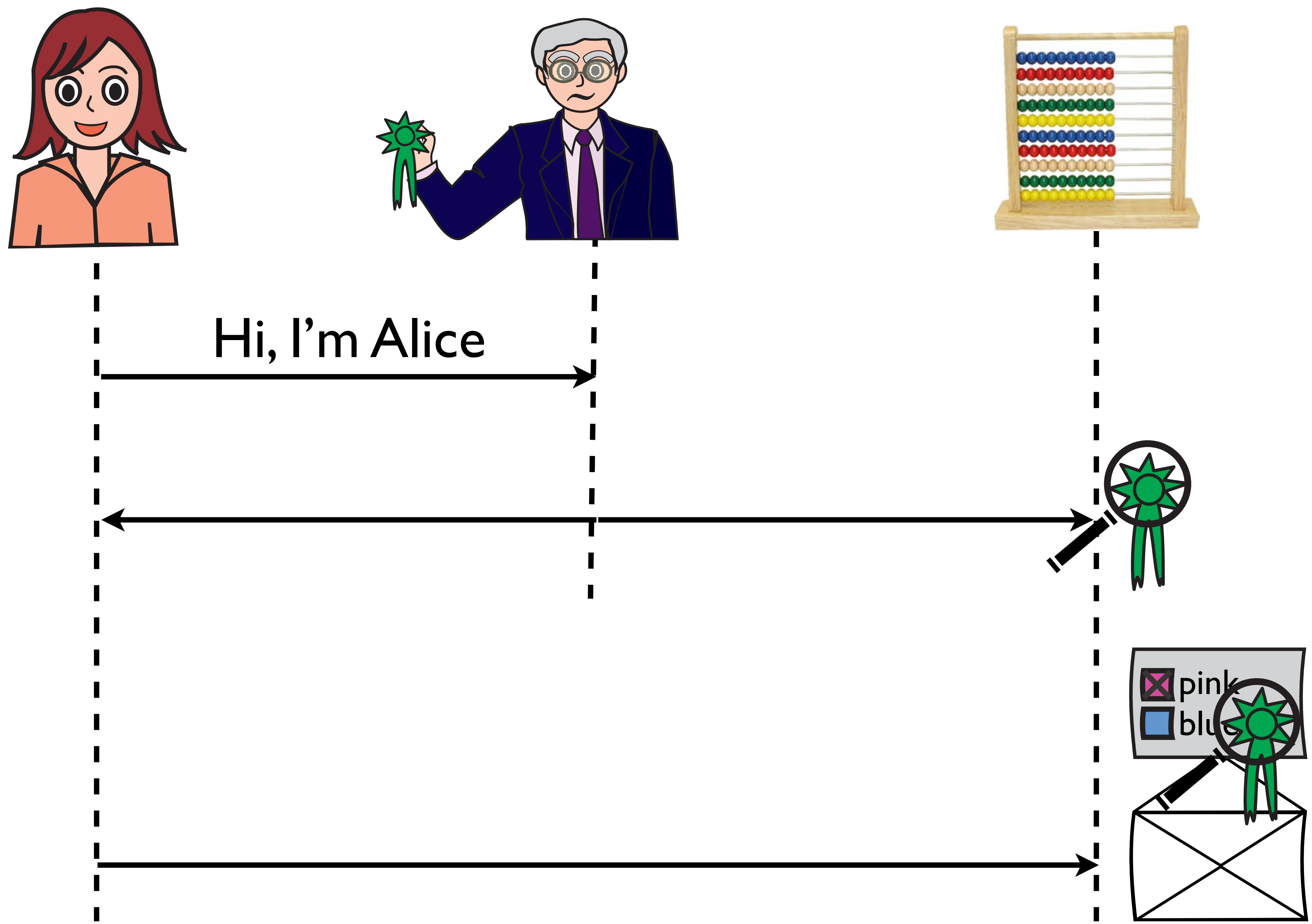

Trace: t_1 eligible(Alice) t_2 vote(Alice, pink) t_3 tally(pink)

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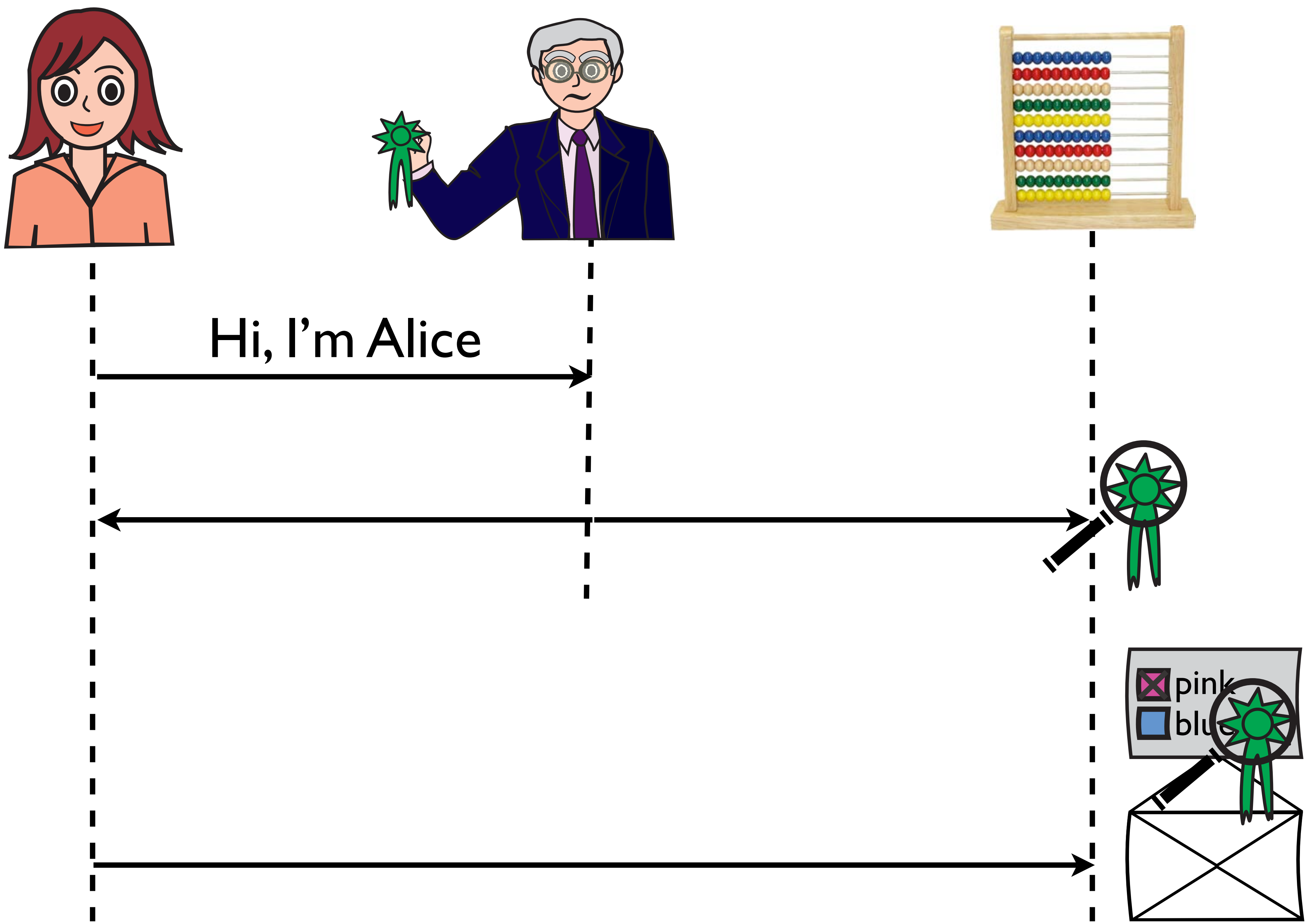

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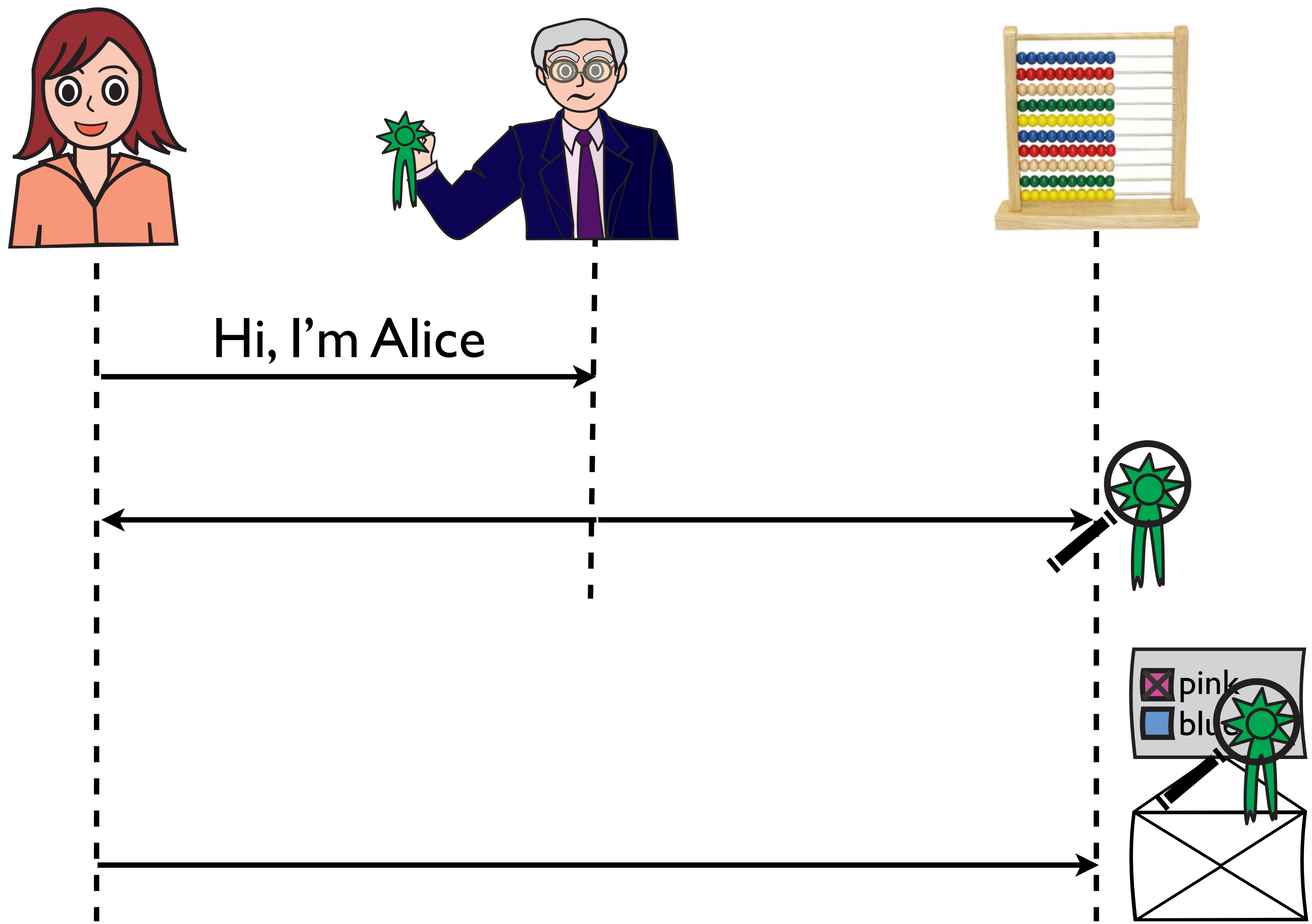
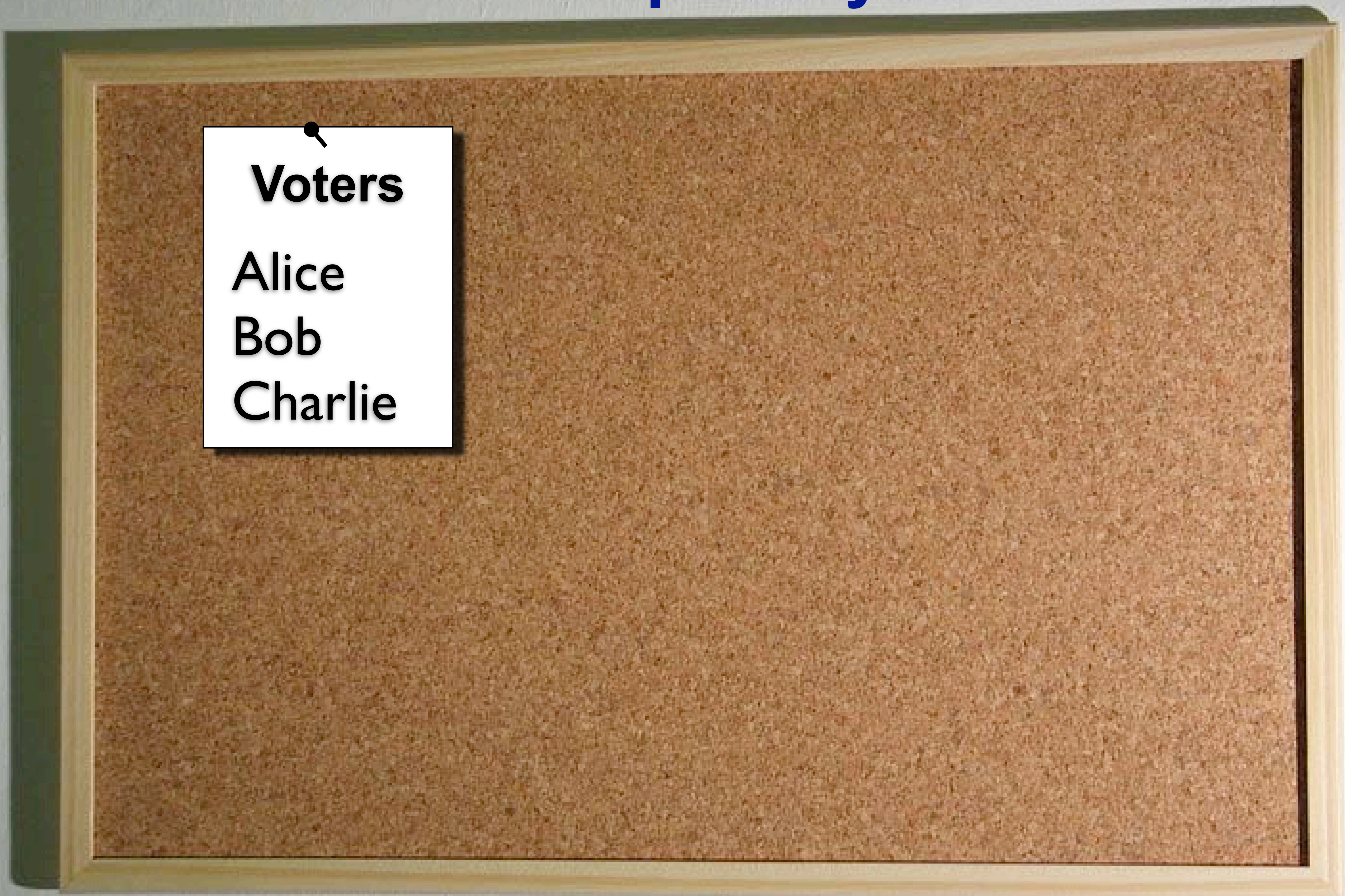


Trace: t_1 eligible(Alice) t_2 vote(Alice, pink) t_3 tally(pink)

$\exists \longleftarrow \exists \Longleftarrow \forall$

and the trace t_1 t_2 t_3 is also sound (injective matching)

Vote-privacy



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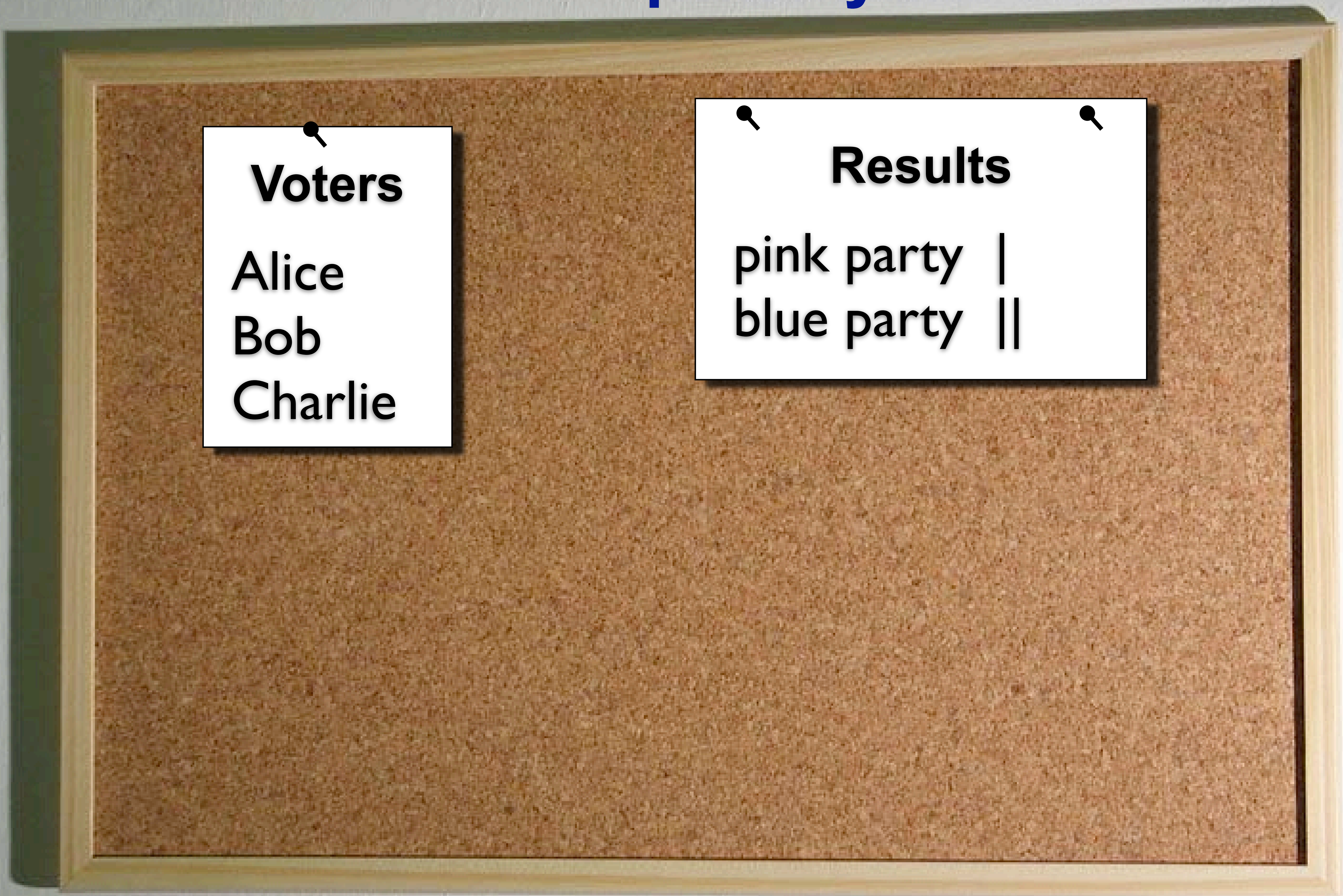


Vote-privacy

Voters

Alice
Bob
Charlie

Results

pink party |
blue party ||

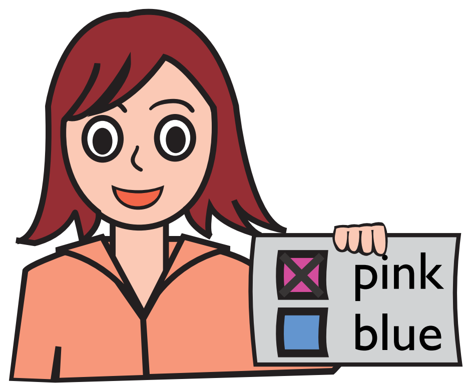
"Detailed" results

Alice .... pink party
Bob .... blue party
Charlie .... blue party

Vote-privacy

Definition of vote-privacy

[Delaune, Kremer & Ryan; CSF '06]

S[

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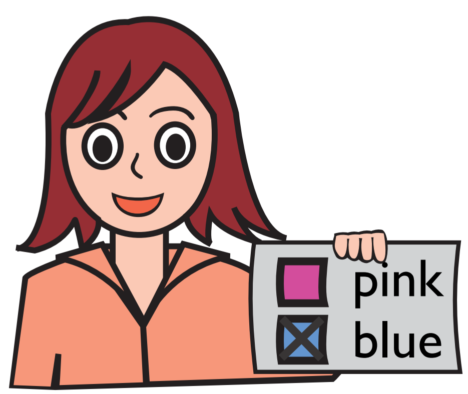
S[

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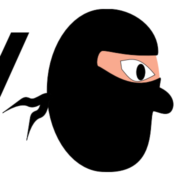
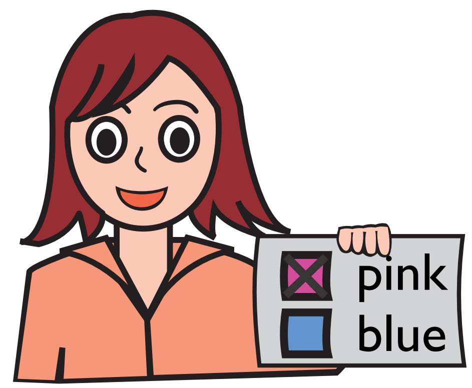
∀ 

 [S[

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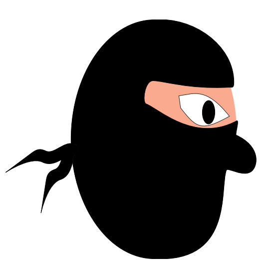
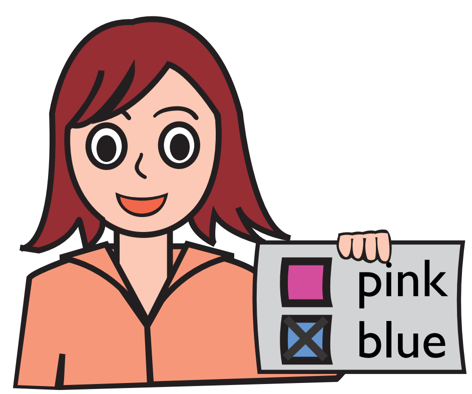
indistinguishable from

 [S[

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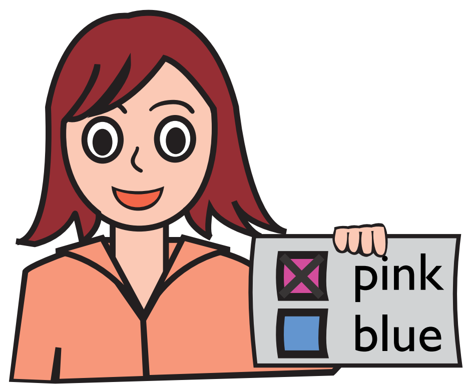
S[

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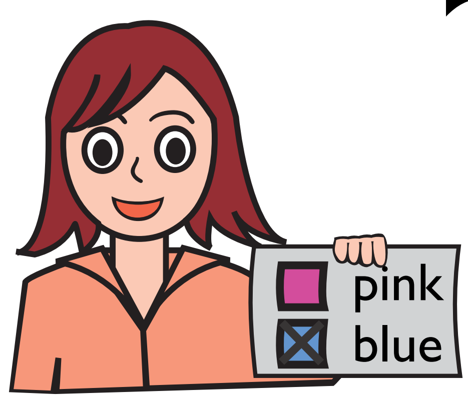
S[

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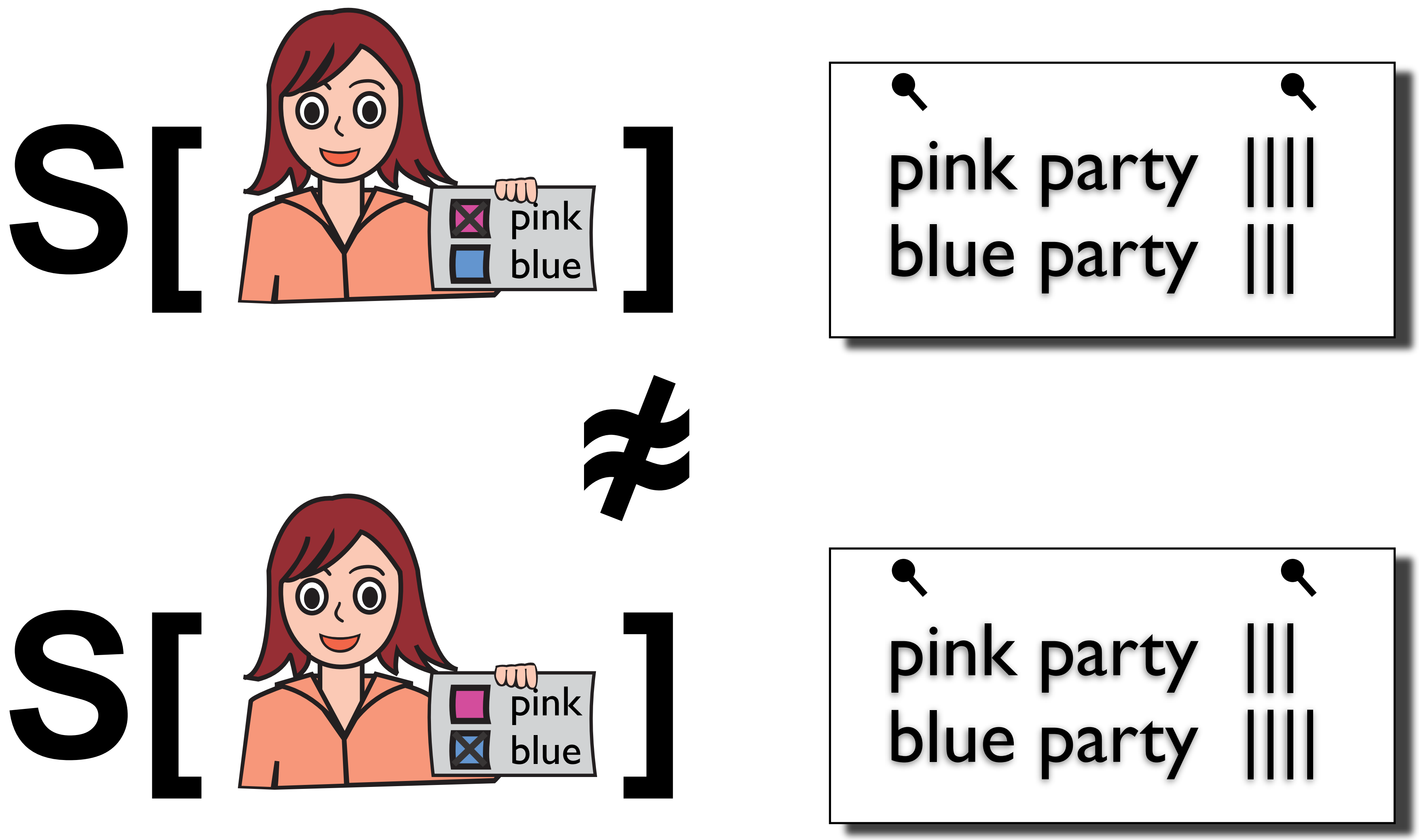

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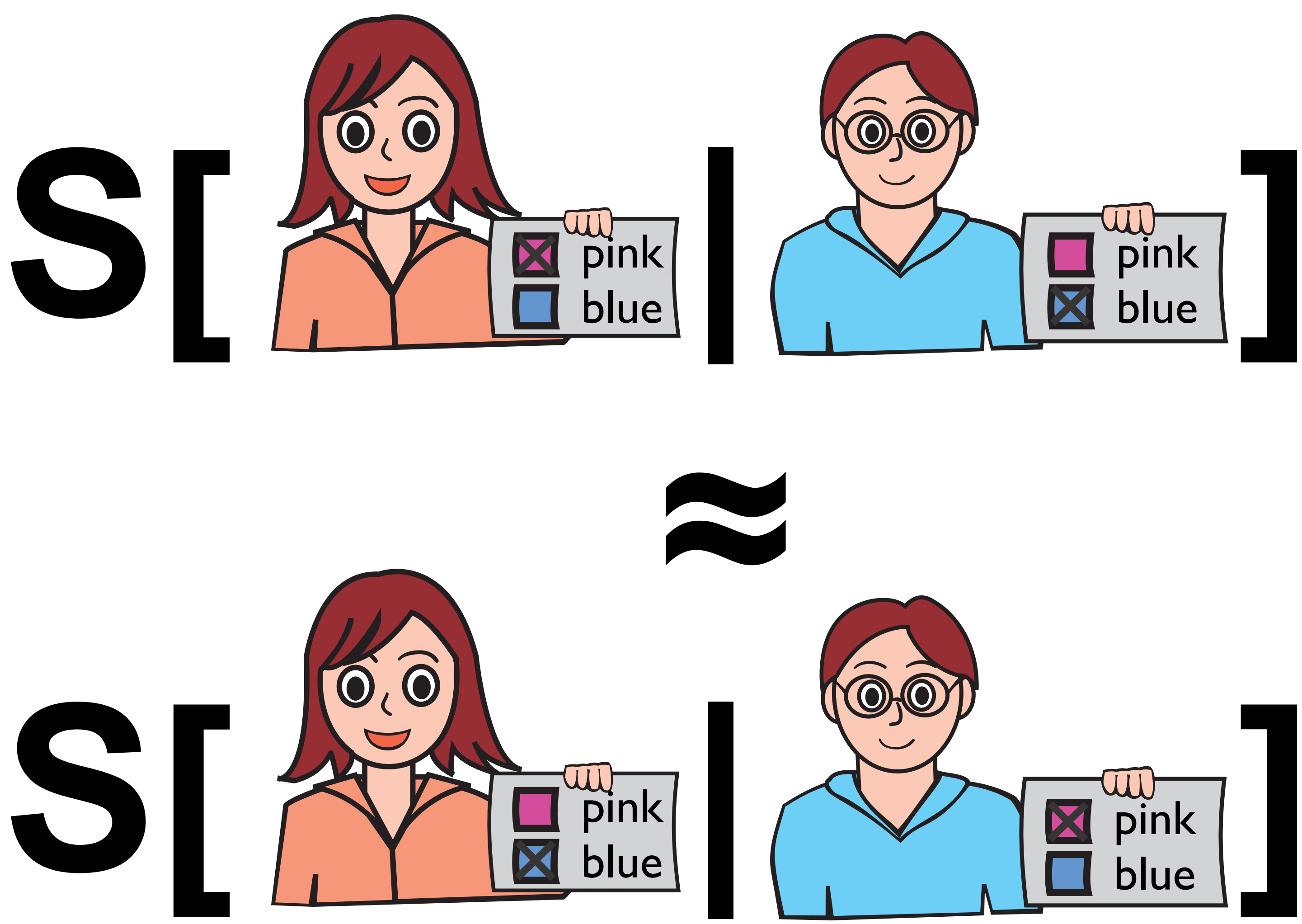
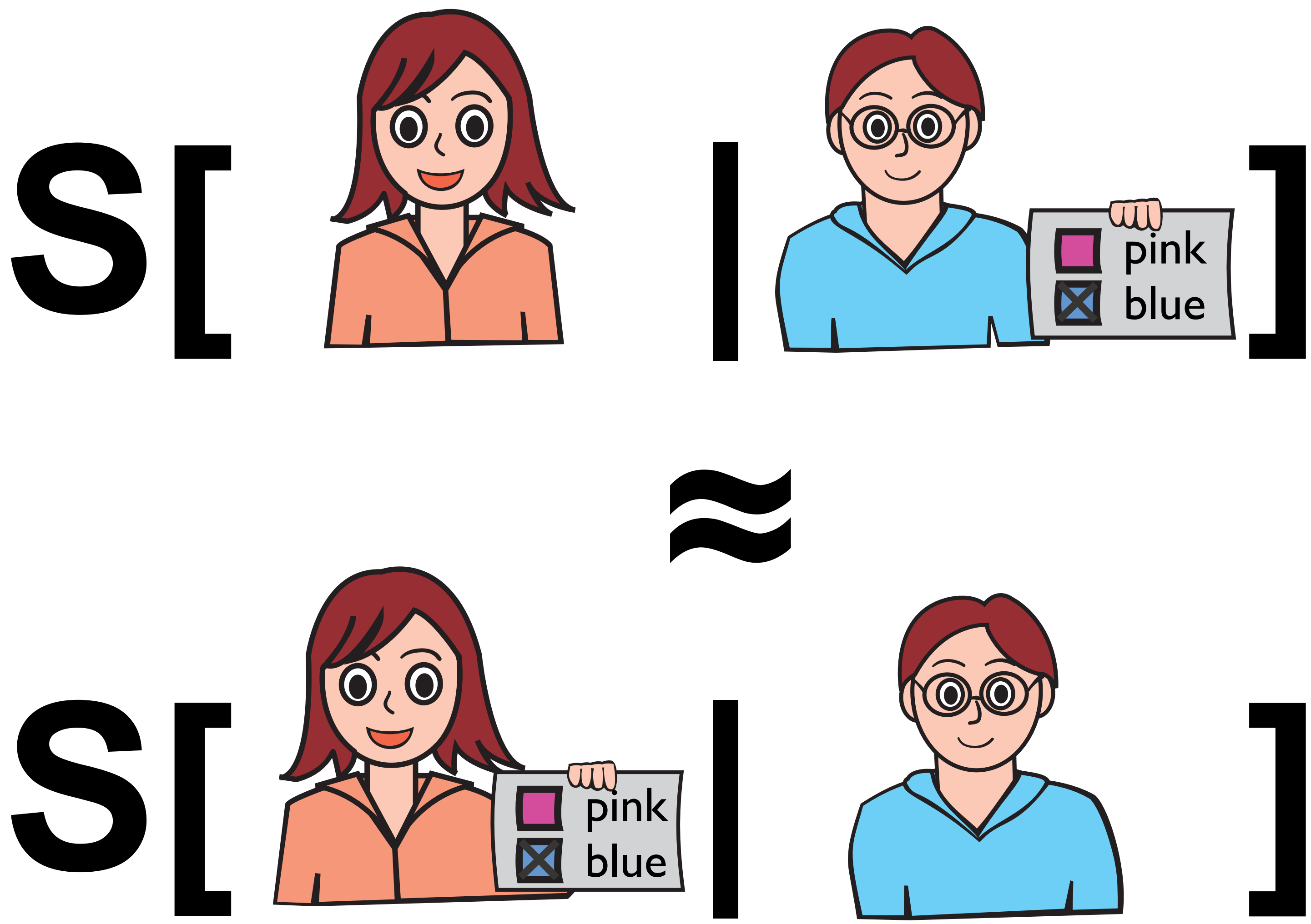
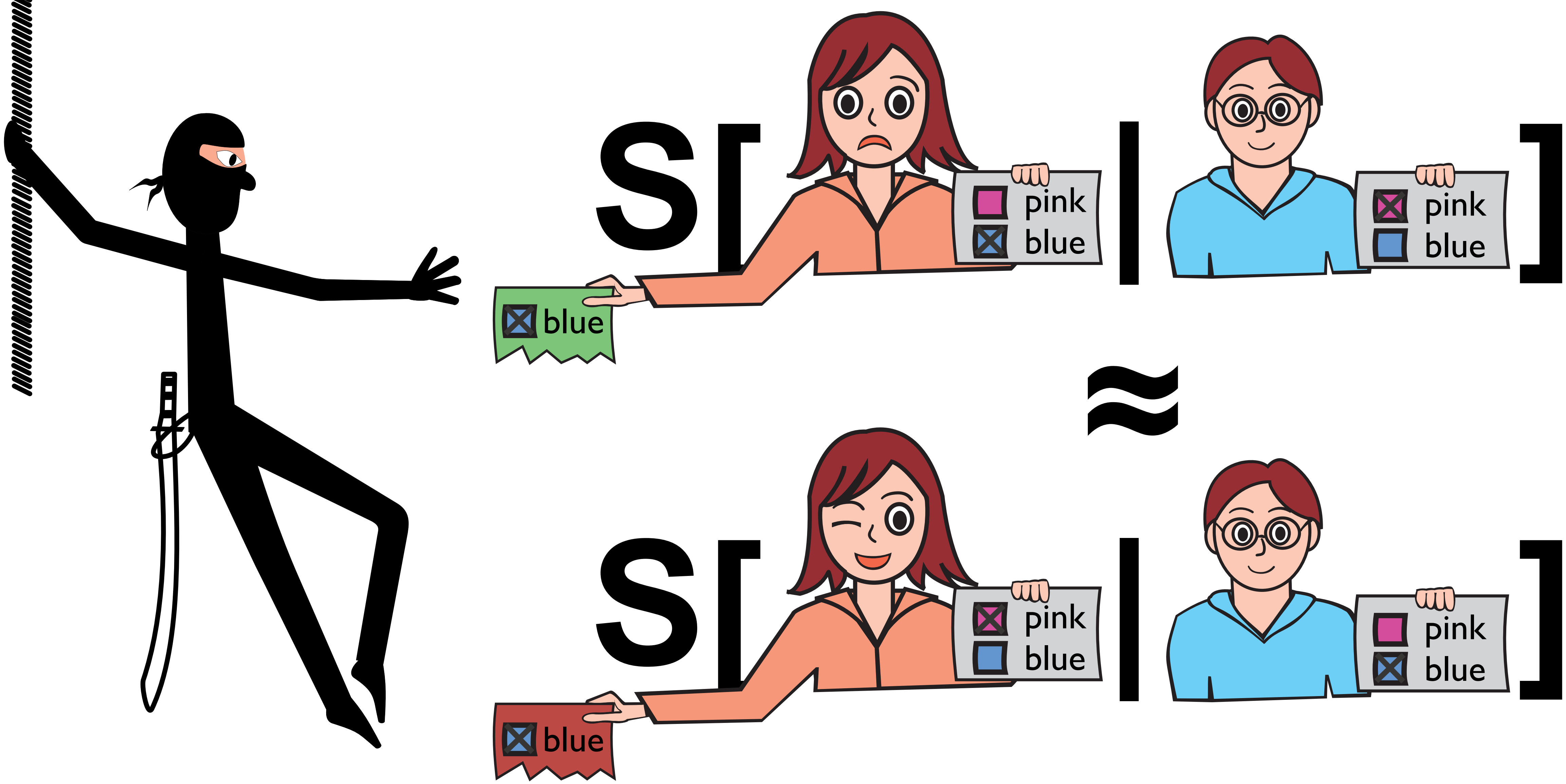


Immunity to forced-abstention



Receipt-freeness

- Cryptographic setting [Benaloh & Tuinstra; STOC '94]



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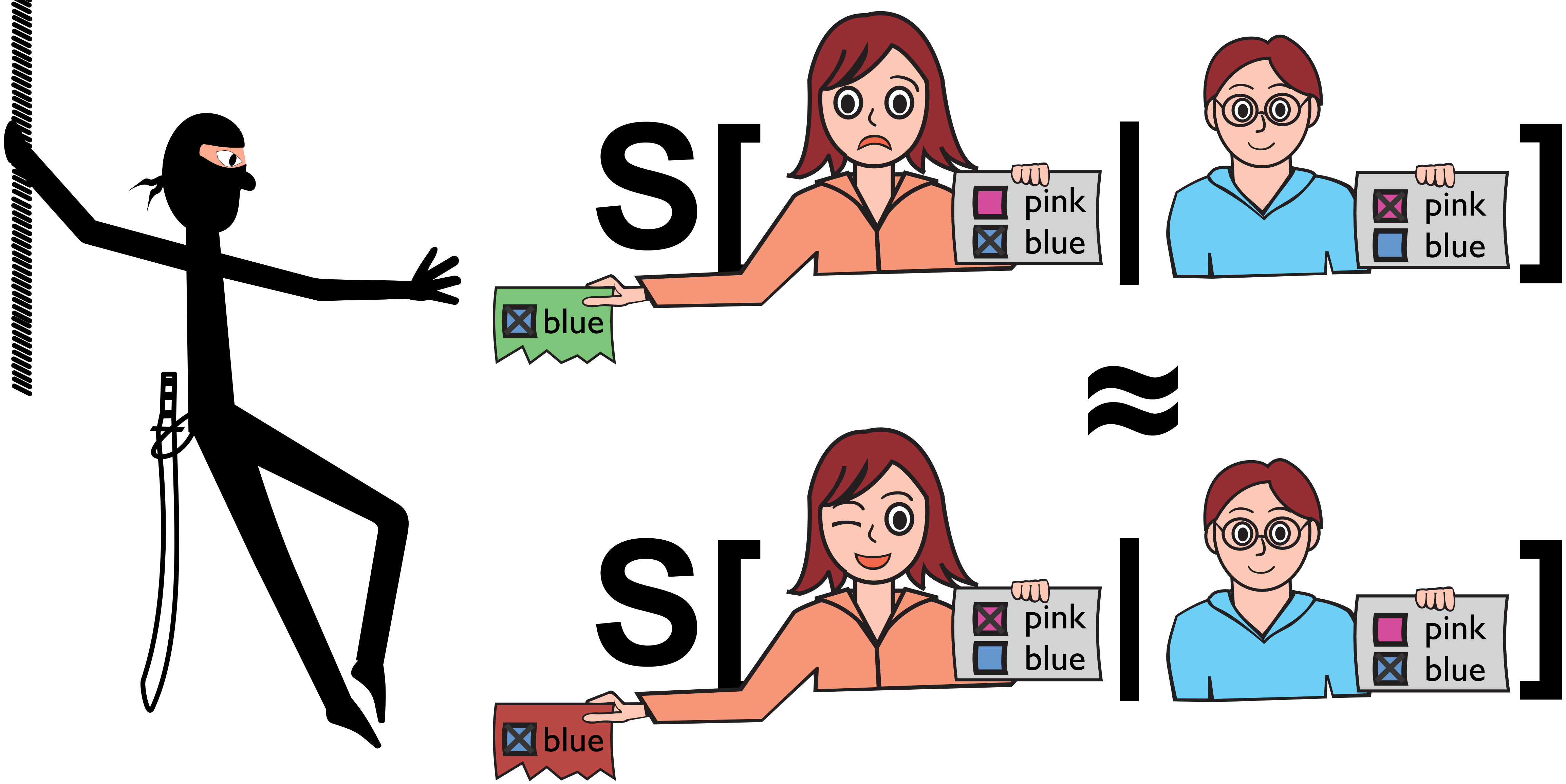
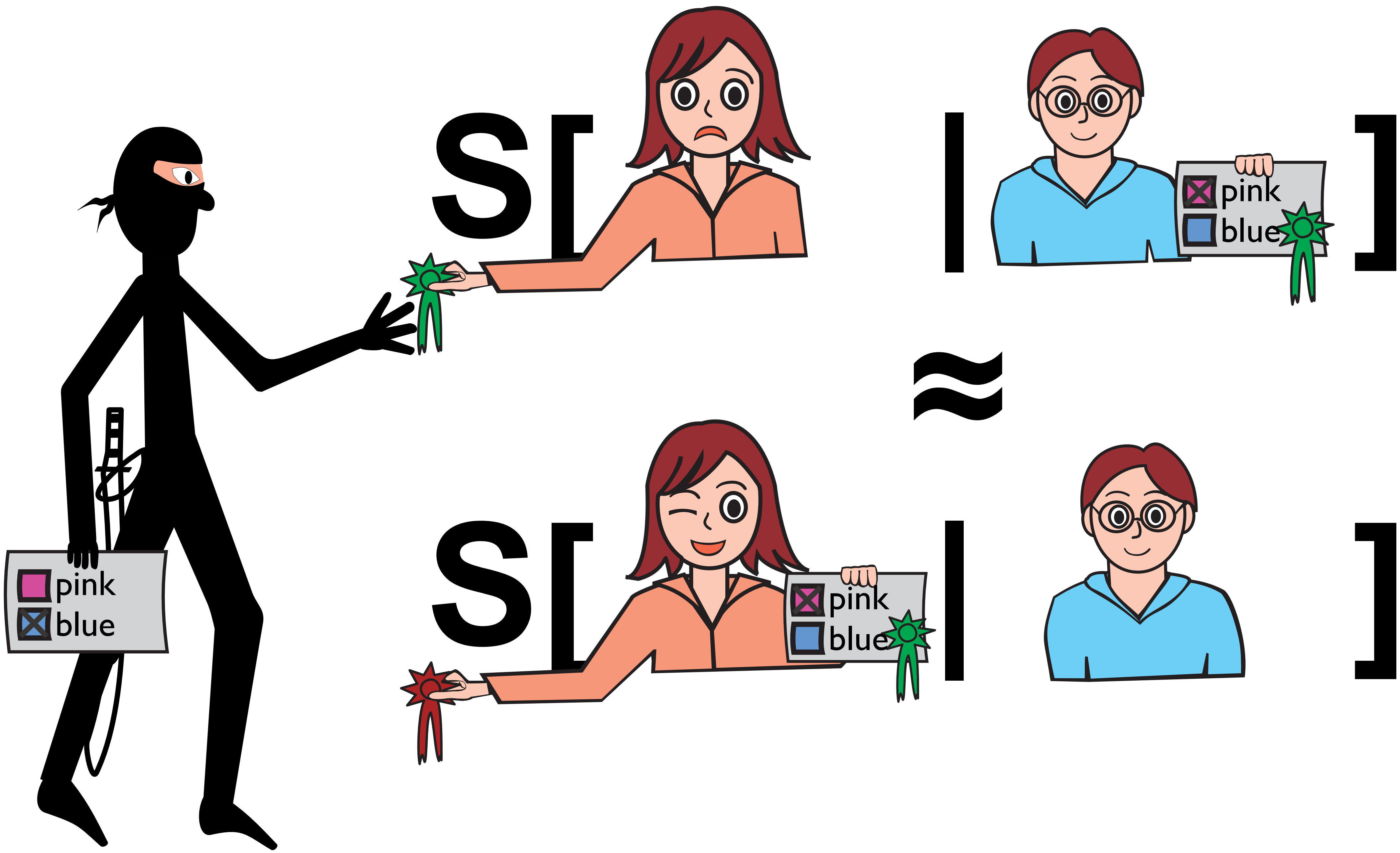


- We adapted definition by [Delaune, Kremer & Ryan; CSF '06] to **remote voting**

Coercion-resistance

- Cryptographic setting [Juels, Catalano & Jakobsson; WPES 2005]



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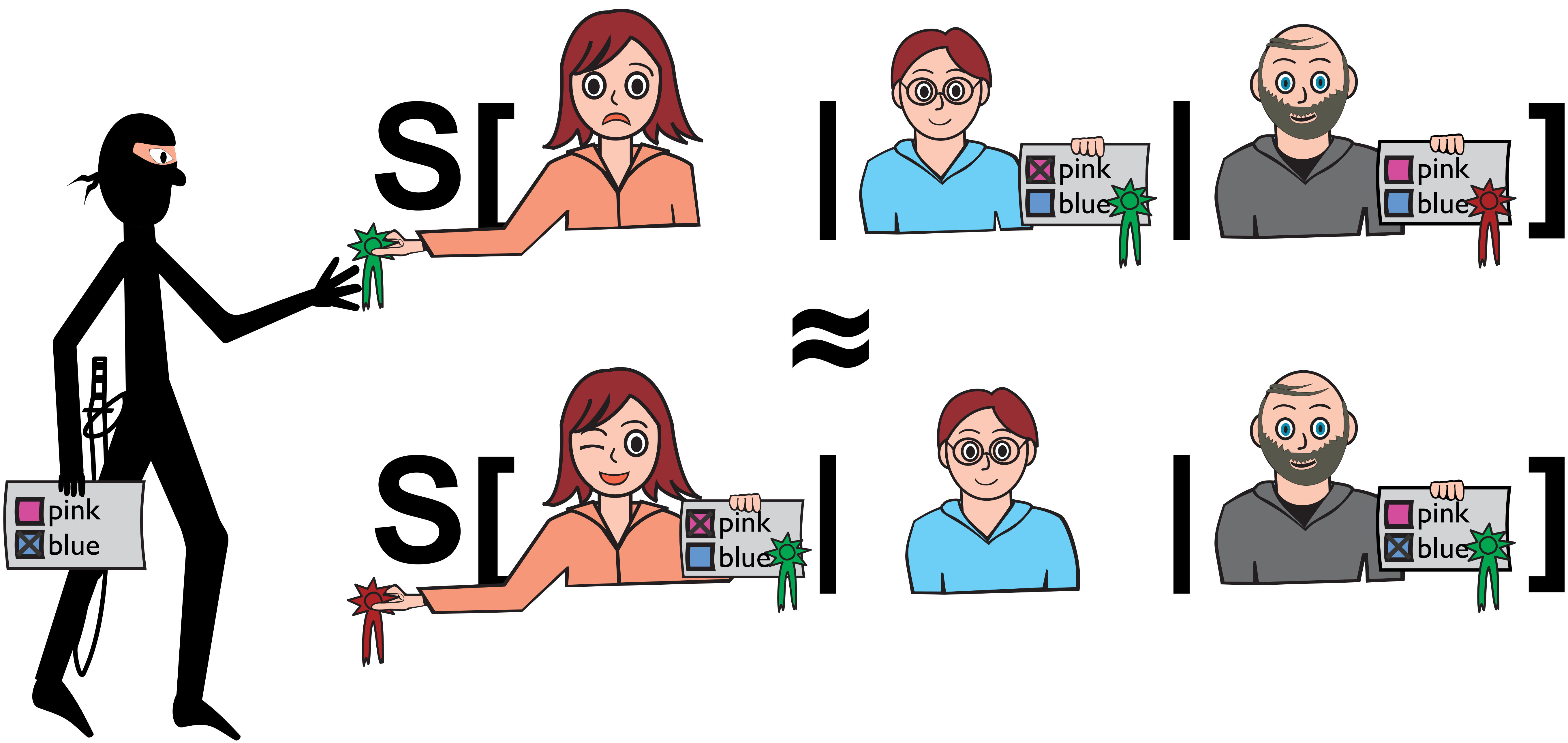

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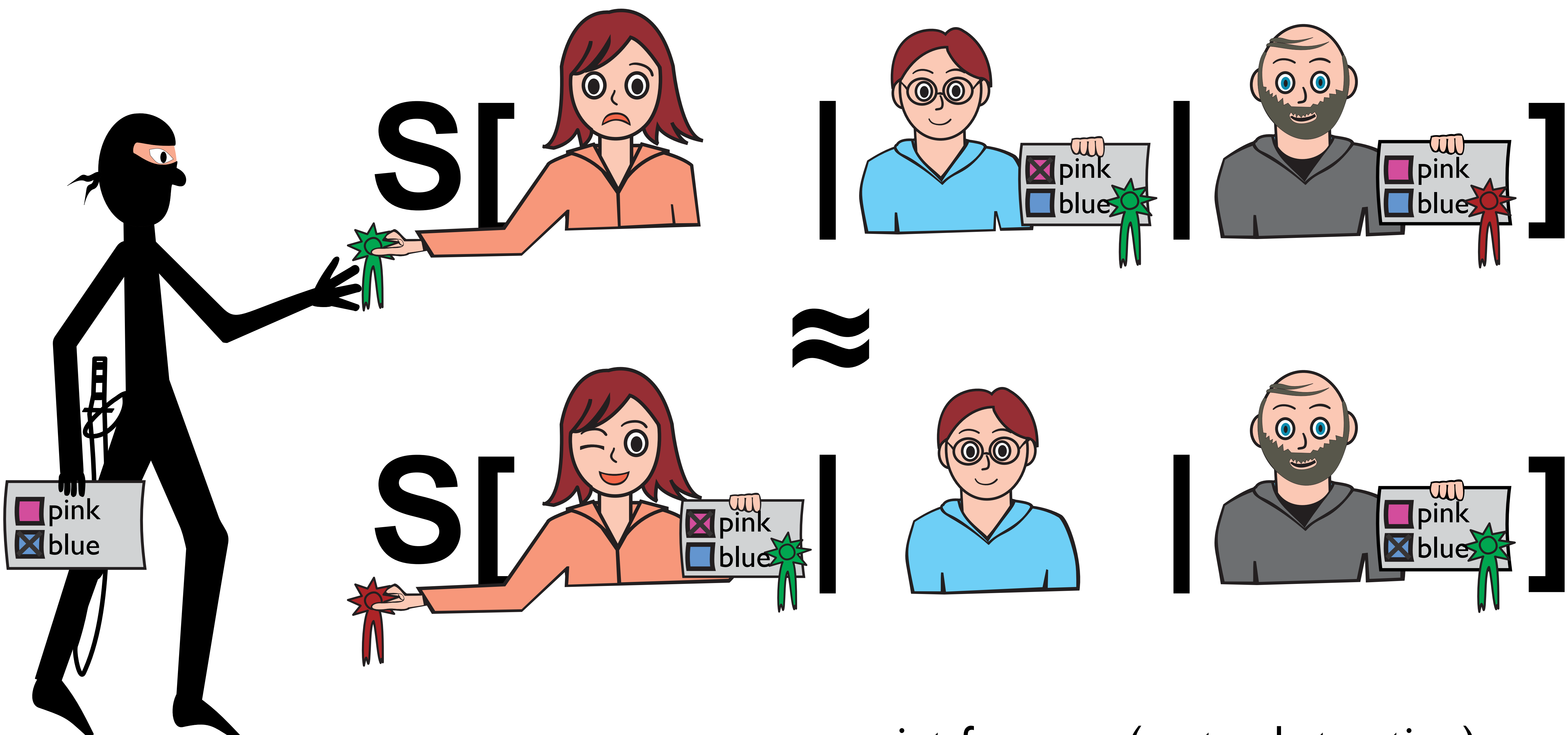

- Proved: coercion-resistance ⇒ no forced-abstention ⇒ vote-privacy

  ⇗ receipt-freeness (up to abstraction)

Definitions of coercion-resistance

	JCJ-WPES'05	DKR-CSF'06	DKR-TR'08	current
setting	remote voting	supervised voting	supervised voting	remote voting
automation	no (crypto)	no (adaptive simulation)	no ($\forall C.\ P \approx Q$)	yes ($\approx$)
vote-privacy	yes	yes	yes	yes
no simulation attacks	yes	n/a	n/a	yes
no forced-abstention	yes	no	no	yes
no randomization attacks (?)	yes (claimed not proved)	no	no	no
receipt-freeness	yes	yes	yes	yes (up to abstraction)

Analysis of JCJ

- first coercion-resistant protocol for remote voting [Juels, Catalano & Jakobsson; WPES '05]
- forms the basis of many recent protocols (e.g. Civitas [Clarkson, Chong & Myers; S&P '08])
- Analysis performed with ProVerif [Blanchet et. al.]
  - automatic protocol analyzer using Horn-clause resolution
  - we use our symbolic abstraction of zero-knowledge [Backes, Maffei & Unruh; S&P '08]
  - analyzing observational equivalence required (re)writing the specification in the shape of a biprocess
  - verification of JCJ succeeds, which yields security guarantees for unbounded number of voters, sessions, etc.

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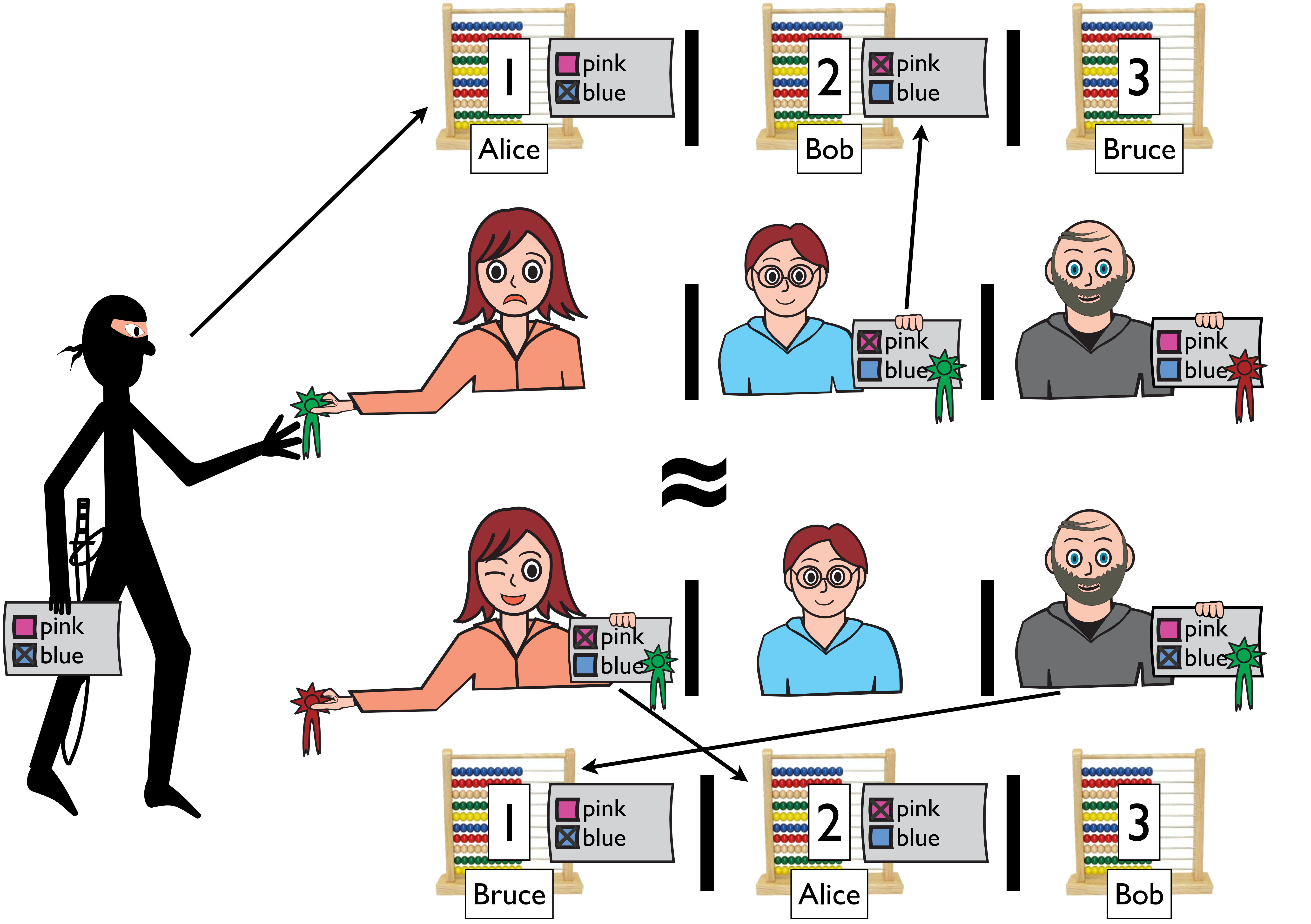
- More accurate protocol models
  - The ultimate goal is to analyze implementations

Backup slides


1
pink
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Alice
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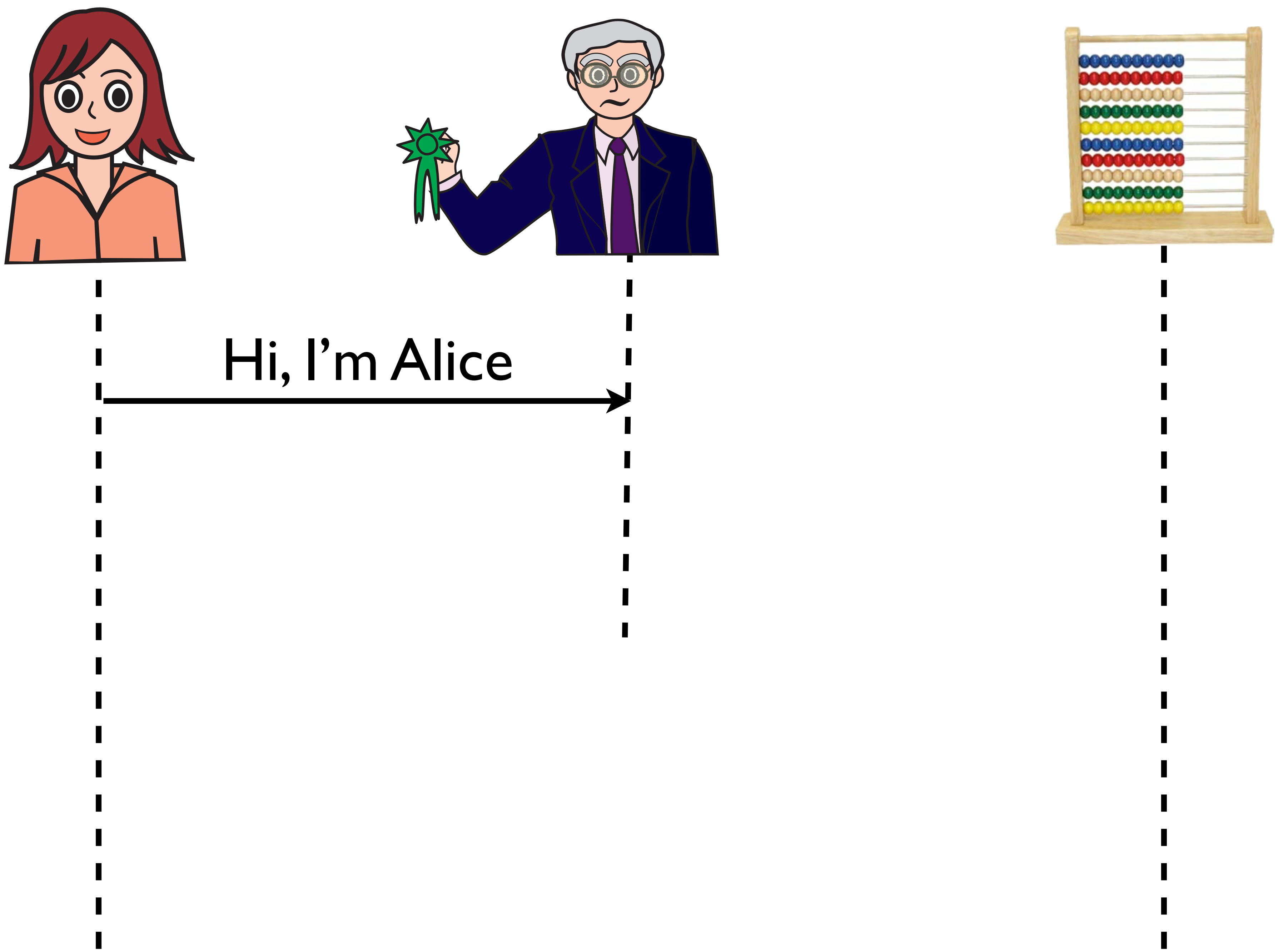
Bob

Simplified JCJ protocol



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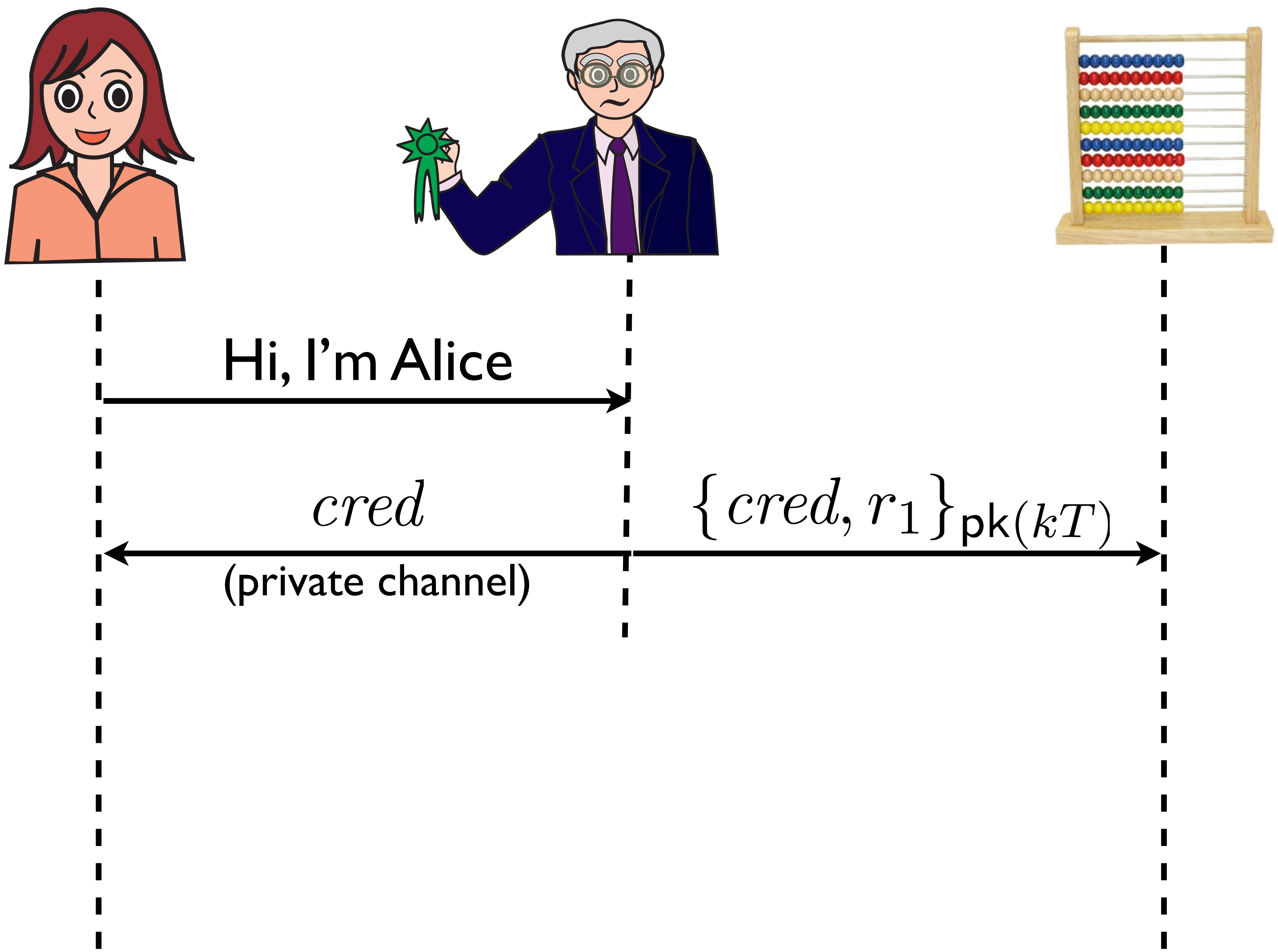

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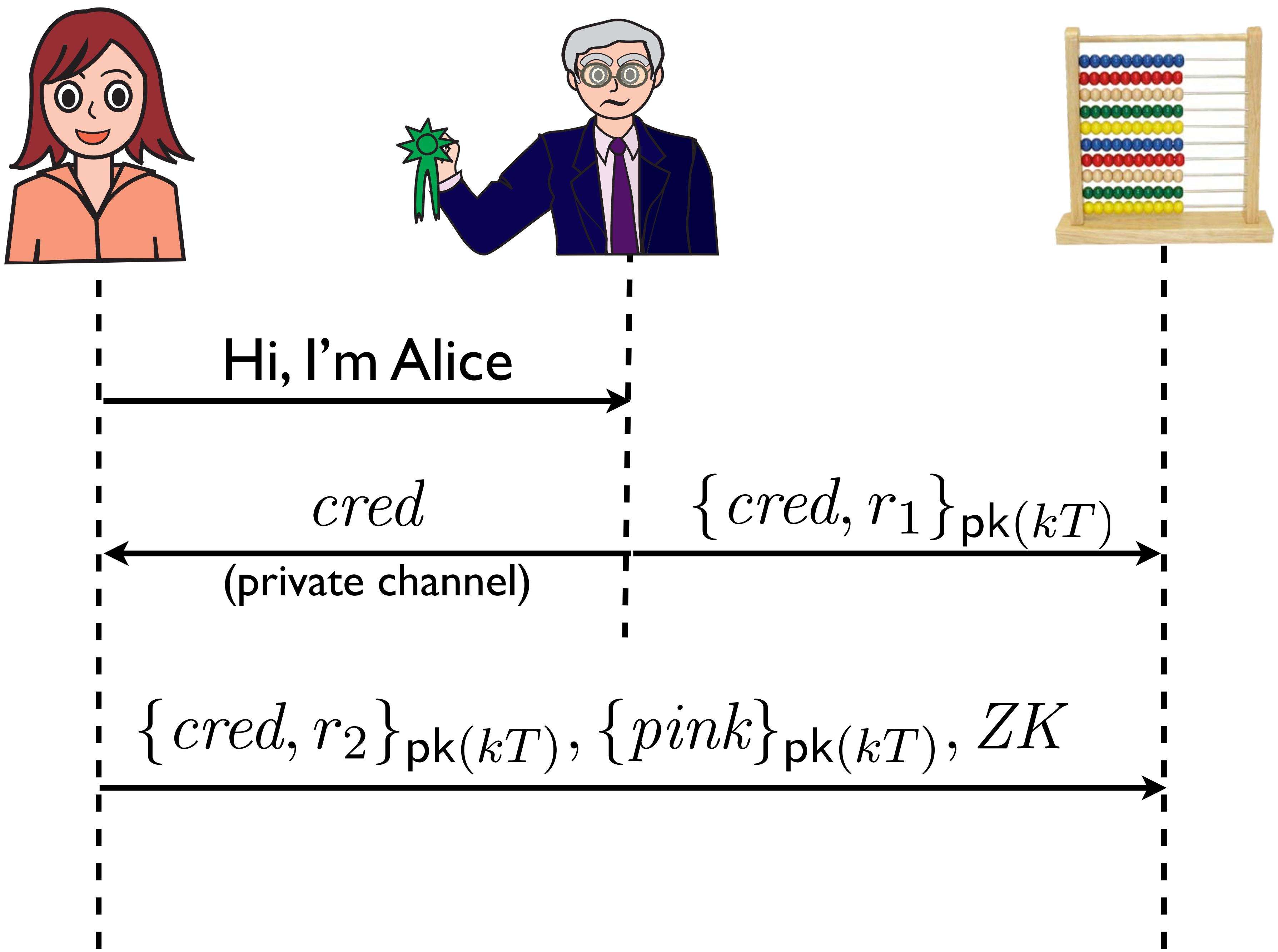

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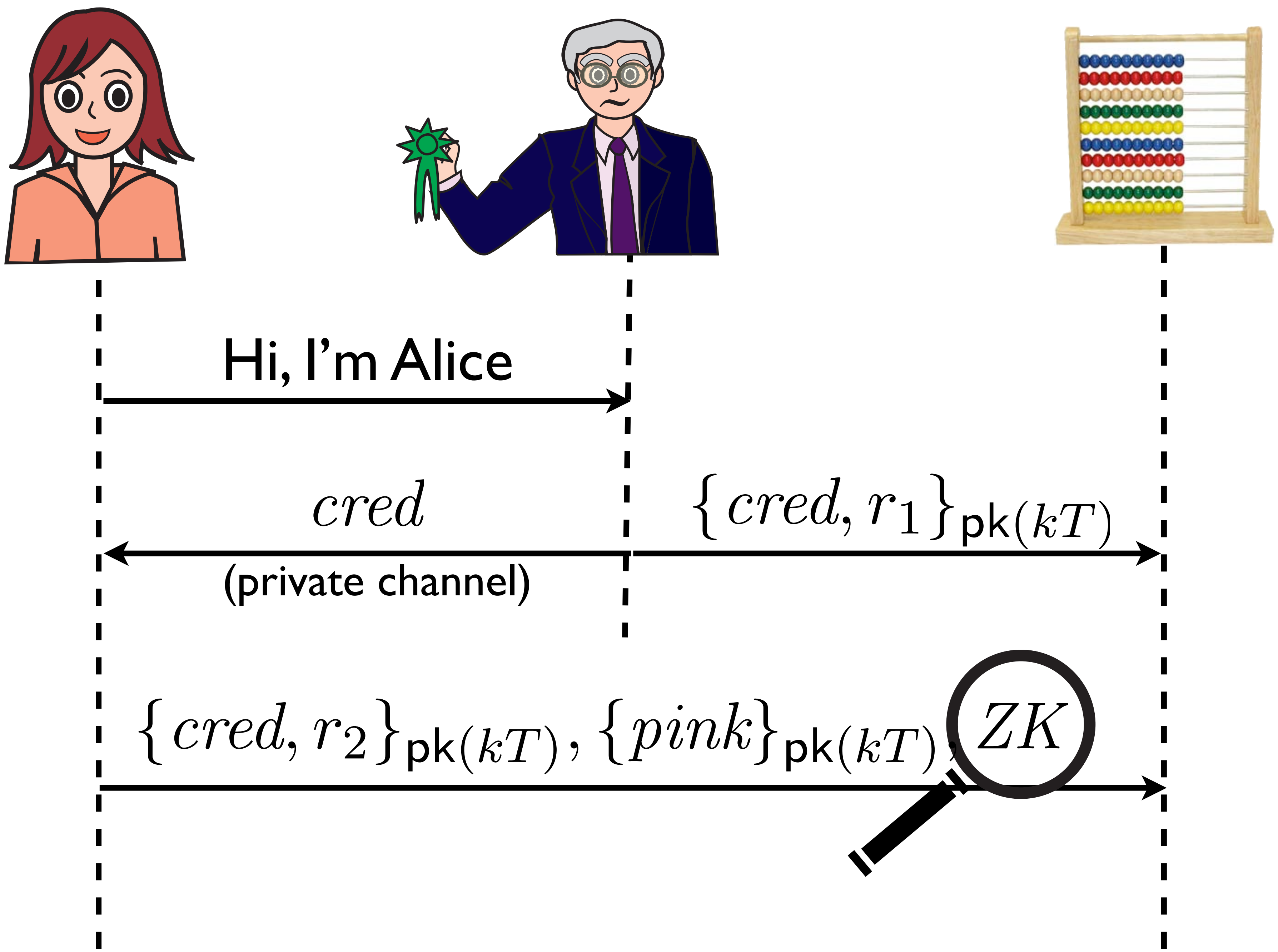

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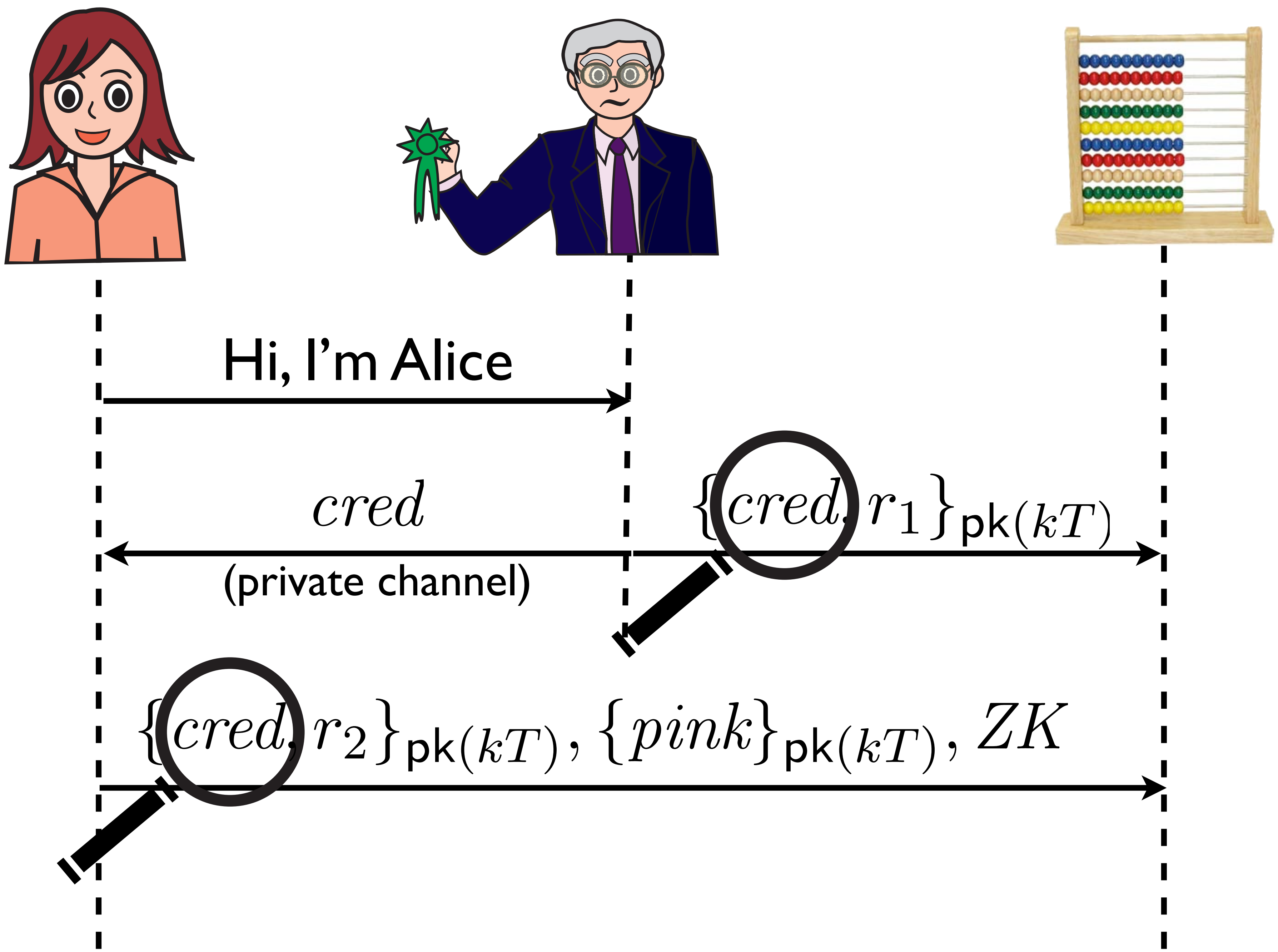

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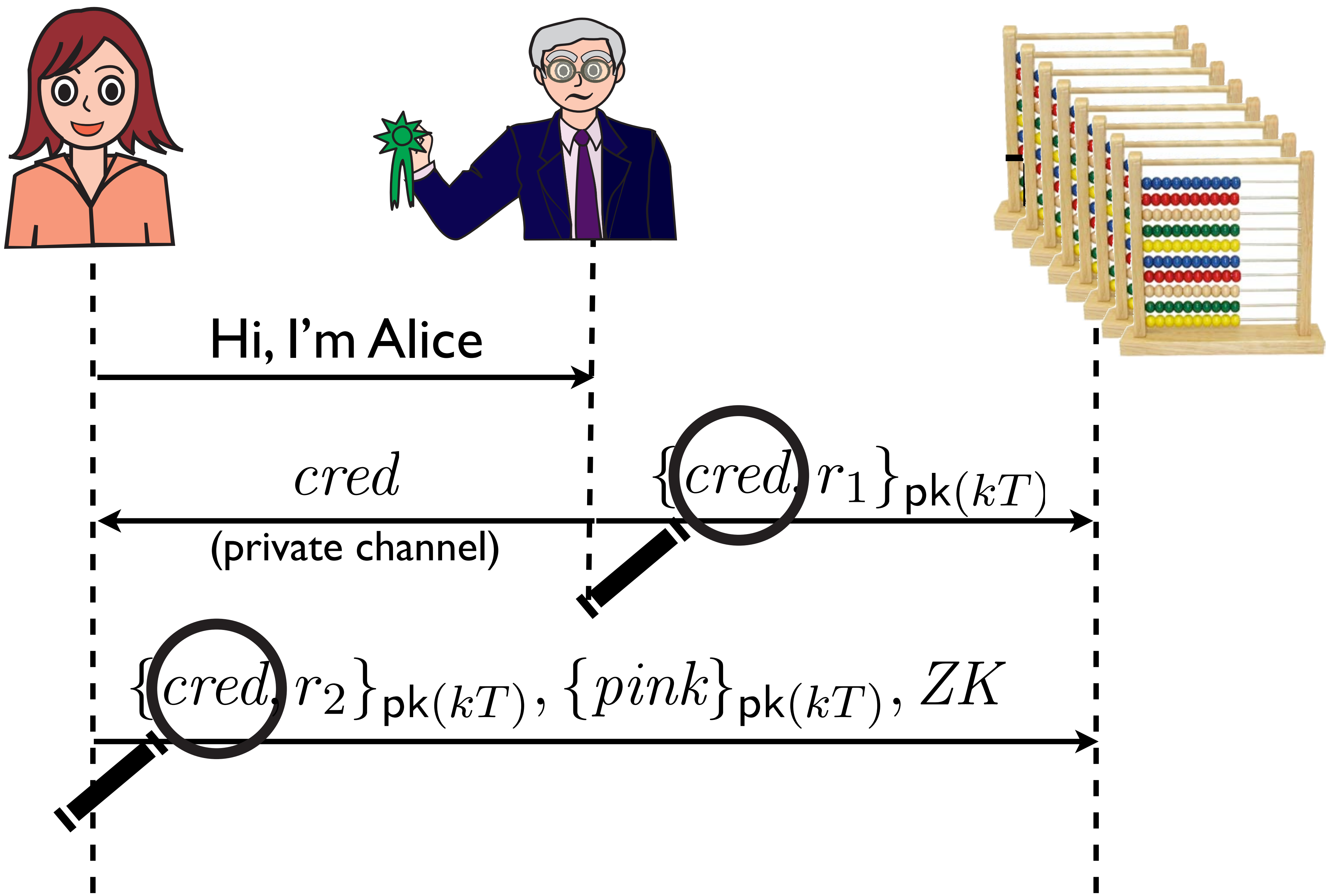

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