Defining Privacy for Weighted Votes, Single and Multi-Voter Coercion

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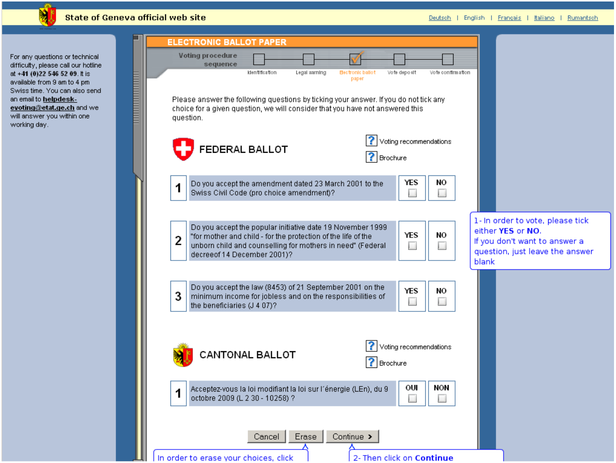
Internet voting

Available in

- Estonia
- France
- Switzerland
- ...



Security Requirements

Fairness

Verifiability

Eligibility

Correctness

Security Requirements

Privacy

Receipt-Freeness

Robustness

Coercion-Resistance

Security Requirements

Fairness

Verifiability

Eligibility

Correctness

Security Requirements

Privacy

Receipt-Freeness

Robustness

Coercion-Resistance

Defining Vote-Privacy [Swap-Privacy (SwP)]

Classical definition (e.g. [?, ?, ?]): Observational equivalence between two situations where two voters swap votes.

	Alice	Bob
Vote	A	B
	$\approx_l$	
Vote	B	A

Problem: Weighted Votes

What happens if votes are weighted (e.g. according to the number of shares in a company)?

	Alice	Bob	Result
	66%	34%	
Vote	A	B	
	$\approx_l$		
Vote	B	A	

Problem: Weighted Votes

What happens if votes are weighted (e.g. according to the number of shares in a company)?

	Alice	Bob	Result
	66%	34%	
Vote	A	B	66% A, 34% B

$$\approx_l$$

Vote	B	A	34% A, 66% B

Problem: Weighted Votes

What happens if votes are weighted (e.g. according to the number of shares in a company)?

	Alice	Bob	Result
	66%	34%	
Vote	A	B	66% A, 34% B
	$\approx_l$		$\neq$
Vote	B	A	34% A, 66% B

Problem: Weighted Votes

What happens if votes are weighted (e.g. according to the number of shares in a company)?

	Alice 66%	Bob 34%	Result
Vote	A	B	66% A, 34% B
	$\not\approx_l$		$\neq$
Vote	B	A	34% A, 66% B

Problem: Weighted Votes

Still: Some privacy is possible!

	Alice	Bob	Carol	Result
	50%	25%	25%	
Vote	A	B	B	
Vote	B	A	A	

Problem: Weighted Votes

Still: Some privacy is possible!

	Alice 50%	Bob 25%	Carol 25%	Result
Vote	A	B	B	50% A, 50% B
Vote	B	A	A	50% A, 50% B

Problem: Weighted Votes

Still: Some privacy is possible!

	Alice	Bob	Carol	Result
	50%	25%	25%	
Vote	A	B	B	50% A, 50% B
				=
Vote	B	A	A	50% A, 50% B

Problem: Weighted Votes

Still: Some privacy is possible!

	Alice	Bob	Carol	Result
	50%	25%	25%	
Vote	A	B	B	50% A, 50% B
		$\approx_l$		=
Vote	B	A	A	50% A, 50% B

Plan

Plan

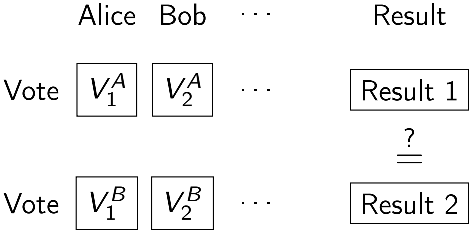
Solution: Defining Vote-Privacy (VP) for weighted votes

Idea: If two instances give the same result, they should be bisimilar.

	Alice	Bob	···	Result
Vote	V_1^A	V_2^A	···	Result 1
Vote	V_1^B	V_2^B	···	Result 2

Solution: Defining Vote-Privacy (VP) for weighted votes

Idea: If two instances give the same result, they should be bisimilar.



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	Alice	Bob	···		Result
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				$\Leftarrow$	$\stackrel{?}{=}$
Vote	V_1^B	V_2^B	···		Result 2

Solution: Defining Vote-Privacy (VP) for weighted votes

Idea: If two instances give the same result, they should be bisimilar.

	Alice	Bob	⋯		Result
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		$\approx_l$		$\Leftarrow$	$\stackrel{?}{=}$
Vote	V_1^B	V_2^B	⋯		Result 2

Example revisited

Applying the definition:

	Alice	Bob	Carol	Result
	50%	25%	25%	
Vote	A	B	B	50% A, 50% B
Vote	B	A	A	50% A, 50% B

Example revisited

Applying the definition:

	Alice 50%	Bob 25%	Carol 25%	Result
Vote	A	B	B	50% A, 50% B
				$\stackrel{?}{=}$
Vote	B	A	A	50% A, 50% B

Example revisited

Applying the definition:

	Alice	Bob	Carol	Result
	50%	25%	25%	
Vote	A	B	B	50% A, 50% B
			$\Leftarrow$	$\stackrel{?}{=}$
Vote	B	A	A	50% A, 50% B

Example revisited

Applying the definition:

	Alice	Bob	Carol	Result
	50%	25%	25%	
Vote	A	B	B	50% A, 50% B
		$\approx_l$	$\Leftarrow$	$\stackrel{?}{=}$
Vote	B	A	A	50% A, 50% B

The Applied Pi Calculus [?]

Syntax

$P, Q, R :=$	processes
0	null process
$P \mid Q$	parallel composition
$!P$	replication
$\nu n.P$	name restriction ("new")
$\texttt{if } M = N \texttt{ then } P \texttt{ else } Q$	conditional
$\texttt{in}(u, x).P$	message input
$\texttt{out}(u, x).P$	message output
$\{^M/_x\}$	substitution

Modeling Voting Protocols

Definition (Voting Process)

A voting process is a closed process

$$\nu\tilde{n}.(V\sigma_{id_1}\sigma_{v_1}|\dots|V\sigma_{id_n}\sigma_{v_n}|A_1|\dots|A_l)$$

where

- $\tilde{n}$ is a set of restricted names,
- σ_{id_i} is a substitution assigning the identity to a voter process,
- σ_{v_i} specifies the vote and
- A_j are the election authorities which are required to be honest.

Vote-Privacy (VP) in the Applied Pi Calculus

Definition (Vote-Privacy (VP))

A voting protocol ensures *Vote-Privacy (VP)* if for any two instances $VP_A = \nu \tilde{n}.(V\sigma_{id_1}\sigma_{v_1^A} \mid \ldots \mid V\sigma_{id_n}\sigma_{v_n^A} \mid A_1 \mid \ldots \mid A_l)$ and $VP_B = \nu \tilde{n}.(V\sigma_{id_1}\sigma_{v_1^B} \mid \ldots \mid V\sigma_{id_n}\sigma_{v_n^B} \mid A_1 \mid \ldots \mid A_l)$ we have

$$VP_A|_{res} \approx_l VP_B|_{res} \Rightarrow VP_A \approx_l VP_B.$$

Link to existing definitions: Equality of Votes (EQ)

	Alice	Bob	$\cdots$		Result
Vote	V_1^A	V_2^A	$\cdots$		Result 1
		$\exists\ \pi$		$\Leftrightarrow$	$=$
Vote	$V^B_{\pi(1)}$	$V^B_{\pi(2)}$	$\cdots$		Result 2

Link to existing definitions, cont'd

Theorem (Equivalence of Privacy Definitions)

If a protocol respects Equality of Votes (EQ), then Vote-Privacy (VP) and Swap-Privacy (SwP) are equivalent:

$$SwP \xleftrightarrow{EQ} VP$$

Case Study

Eliasson and Zúquete [?]: different versions of Fujioka et al. [?] implementing weighted votes, for example using multiple ballots per voter. Manual proof to show that

$$VP_A|_{res} \approx_l VP_B|_{res} \Rightarrow \sum_{i=1}^{n} V_i^A * w_i = \sum_{i=1}^{n} V_i^B * w_i.$$

ProVerif [?] to establish the following, which gives (VP).

$$\sum_{i=1}^{n} V_i^A * w_i = \sum_{i=1}^{n} V_i^B * w_i \Rightarrow VP_A \approx_l VP_B$$

Plan

Existing Definition: Swap-Receipt-Freeness (SwRF) [?]

Again: Observational equivalence between two situations, but Alice tries to create a receipt or a fake.

Mallory

Alice Bob

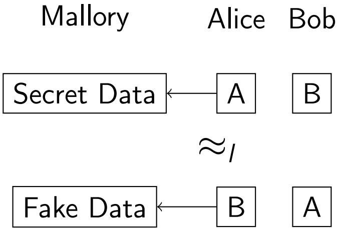
A B

$\approx_l$

B A

Existing Definition: Swap-Receipt-Freeness (SwRF) [?]

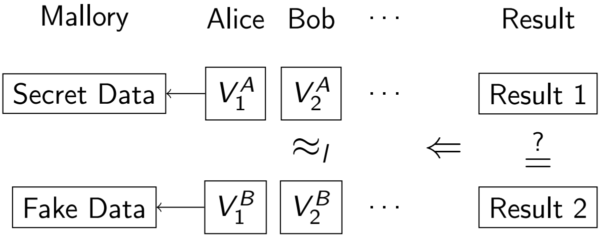
Again: Observational equivalence between two situations, but Alice tries to create a receipt or a fake.



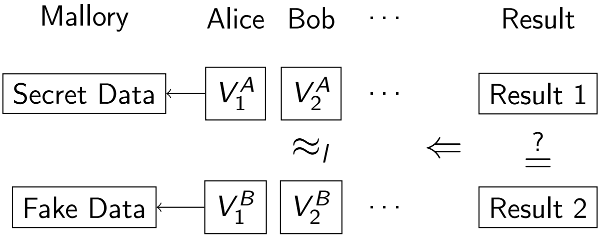
Single-Voter Receipt Freeness (SRF)

Mallory	Alice	Bob	$\cdots$		Result
	V_1^A	V_2^A	$\cdots$		Result 1
		$\approx_l$		$\Leftarrow$	$\stackrel{?}{=}$
	V_1^B	V_2^B	$\cdots$		Result 2

Single-Voter Receipt Freeness (SRF)

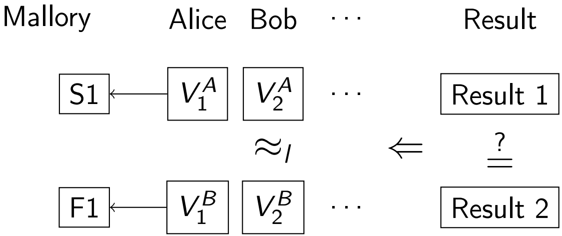


Single-Voter Receipt Freeness (SRF)

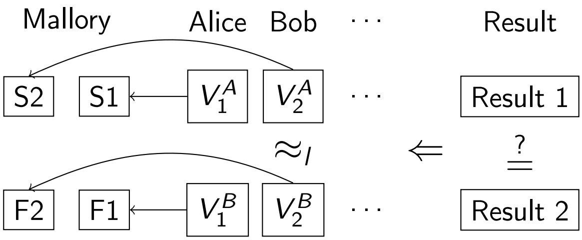


If a protocol respects (EQ), then (SRF) and (SwRF) are equivalent.

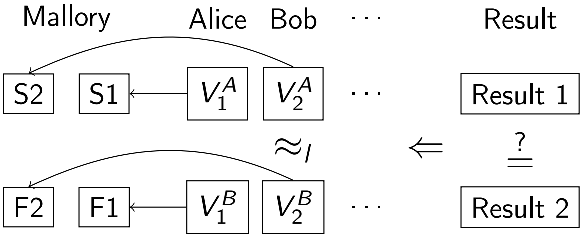
Multi-Voter Receipt Freeness (MRF)



Multi-Voter Receipt Freeness (MRF)

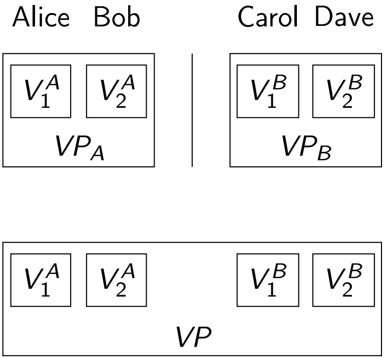


Multi-Voter Receipt Freeness (MRF)

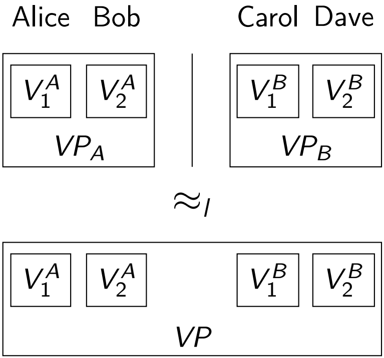


Multi-Voter Receipt Freeness (MRF) implies Single-Voter Receipt Freeness (SRF).

Link between (SRF) and (MRF): Modularity (Mod)



Link between (SRF) and (MRF): Modularity (Mod)



Link between (SRF) and (MRF) cont'd: Correctness (Cor)

	Alice	Bob	⋯	Result
Vote	V_1^A	V_2^A	⋯	Result 1
Vote	V_1^B	V_2^B	⋯	Result 2

Link between (SRF) and (MRF) cont'd: Correctness (Cor)

	Alice	Bob	$\cdots$	Result
Vote	V_1^A	V_2^A	$\cdots$	Result 1
	$\forall i\ V_i^A = V_i^B$			
Vote	V_1^B	V_2^B	$\cdots$	Result 2

Link between (SRF) and (MRF) cont'd: Correctness (Cor)

	Alice	Bob	$\cdots$		Result
Vote	V_1^A	V_2^A	$\cdots$		Result 1
	$\forall i \; V_i^A = V_i^B$			$\Rightarrow$	
Vote	V_1^B	V_2^B	$\cdots$		Result 2

Link between (SRF) and (MRF) cont'd: Correctness (Cor)

	Alice	Bob	$\cdots$		Result
Vote	V_1^A	V_2^A	$\cdots$		Result 1
	$\forall i\ V_i^A = V_i^B$			$\Rightarrow$	$=$
Vote	V_1^B	V_2^B	$\cdots$		Result 2

Link between (SRF) and (MRF) cont'd: Correctness (Cor)

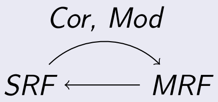
	Alice	Bob	$\cdots$		Result
Vote	V_1^A	V_2^A	$\cdots$		Result 1
	$\forall i\ V_i^A = V_i^B$			$\Rightarrow$	$=$
Vote	V_1^B	V_2^B	$\cdots$		Result 2

Equality of Votes (EQ) implies Correctness (Cor).

Link between (SRF) and (MRF) cont'd

Theorem (Equivalence of Single- and Multi-Voter Coercion)

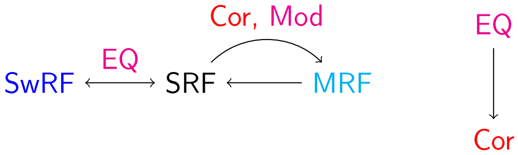
If a protocol is modular and correct, Single-Voter Receipt Freeness and Multi-Voter Receipt Freeness are equivalent.



Case Study

Protocol by Okamoto [?]:

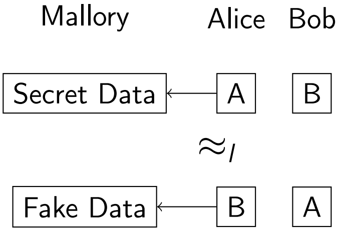
- (SwRF) shown before [?].
- We prove (EQ) and (Mod)
- and obtain Multi-Voter Receipt Freeness (MRF):



Plan

Existing Definition: Swap-Coercion-Resistance (SwCR) [?]

Observational equivalence between two situations, but Alice is under control by Mallory or only pretends to be so.



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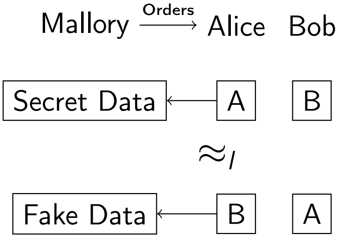
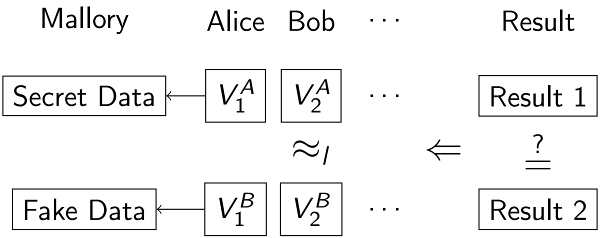
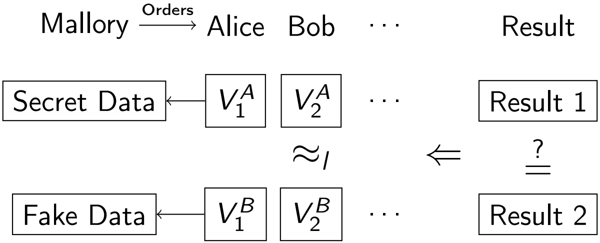


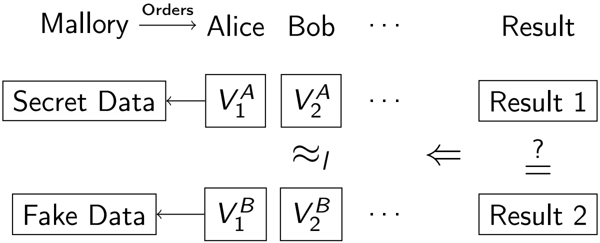
Single-Voter Coercion-Resistance (SCR)



Single-Voter Coercion-Resistance (SCR)

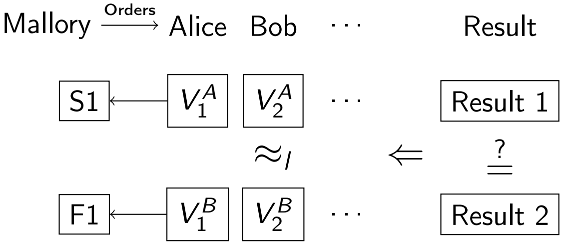


Single-Voter Coercion-Resistance (SCR)

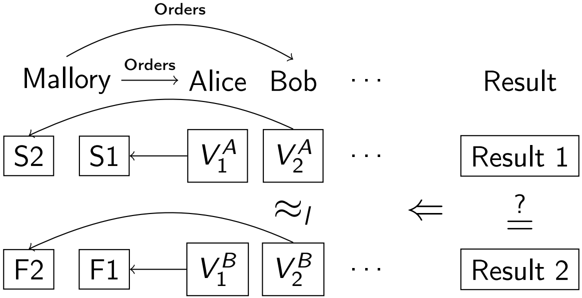


If a protocol respects (EQ), then (SCR) and (SwCR) are equivalent.

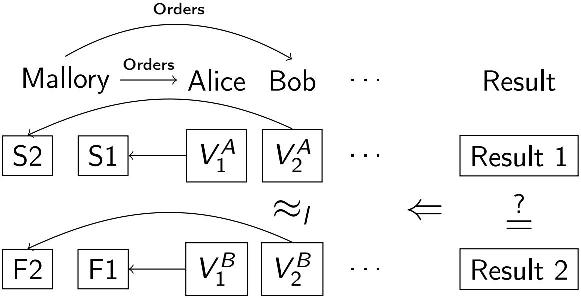
Multi-Voter Coercion-Resistance (MCR)



Multi-Voter Coercion-Resistance (MCR)



Multi-Voter Coercion-Resistance (MCR)

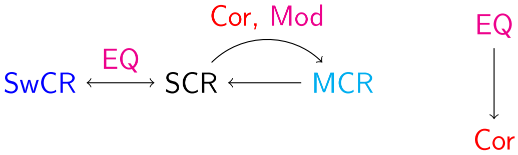


If a protocol is modular and correct, Single-Voter Coercion-Resistance and Multi-Voter Coercion-Resistance are equivalent.

Case Study

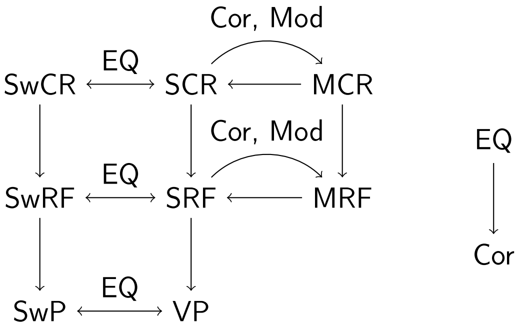
Bingo Voting [?]:

- (SwCR) shown before [?].
- We prove (EQ) and (Mod)
- and obtain Multi-Voter Coercion-Resistance (MCR):



Plan

Relations among the notions



Conclusion

- Generalized definition for weighted votes
- Definition of Single- and Multi-Voter Receipt-Freeness and Coercion
- Proofs of Equivalence
- Case studies:
  - Variant of Fujioka et al. [?]: Vote-Privacy (VP)
  - Okamoto [?]: Multi-Voter Receipt Freeness (MRF)
  - Bingo Voting [?]: Multi-Voter Coercion-Resistance (MCR)

Thank you for your attention!

Questions?

Cryptographic Primitives

- *Commitments:* open(commit(v, r), r) = v
- *Signatures:* checksign(sign(x, sk(Y)), pk(Y)) = ok
- *Blind signatures:* unblind(sign(blind(x, r), key), r) = sign(x, r)

Protocol Description [?]

The protocol is split into three phases:

- Eligibility Check
- Voting
- Counting

Authorities:

- Administrator
- Collector

Assumptions:

- Anonymous channel to the collector

Eligibility Check

Bob

Administrator

Eligibility Check

Bob Administrator

sign(blind(commit(B, r_1^B), r_2^B), sk(B)), Identity(B)

$\longrightarrow$

Eligibility Check

Bob Administrator

$\text{sign}(\text{blind}(\text{commit}(B, r_1^B), r_2^B), \text{sk}(B)), \text{Identity}(B)$

$\longrightarrow$

$\text{sign}(\text{blind}(\text{commit}(B, r_1^B), r_2^B), \text{sk}(Ad))$

$\longleftarrow$

Eligibility Check

Bob — Administrator

Bob → Administrator: sign(blind(commit(B, r_1^B), r_2^B), sk(B)), Identity(B)

Administrator → Bob: sign(blind(commit(B, r_1^B), r_2^B), sk(Ad))

sign(commit(V, r_1^B), sk(Ad))

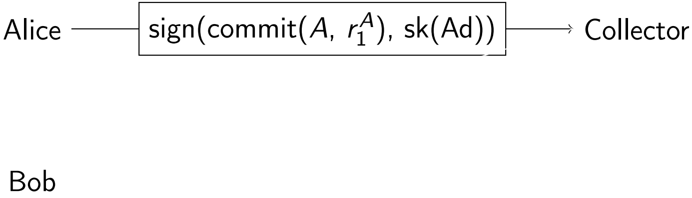
Voting Phase

Alice

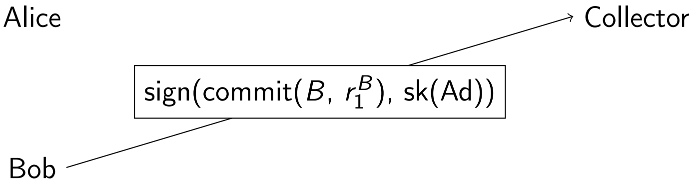
Collector

Bob

Voting Phase



Voting Phase



Couting Phase

Alice

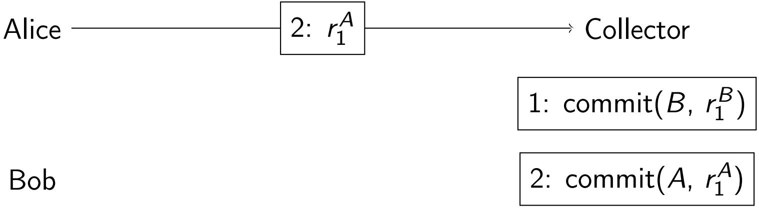
Bob

Collector

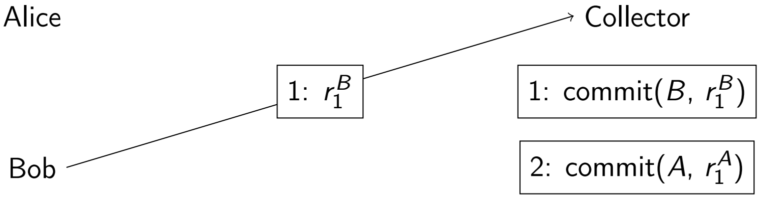
1: $\text{commit}(B,\ r_1^B)$

2: $\text{commit}(A,\ r_1^A)$

Couting Phase



Couting Phase



Couting Phase

Alice

Bob