Public Randomness Extraction with Ephemeral Roles and Worst-Case Corruptions

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Cryptography needs randomness!

How do we generate it?

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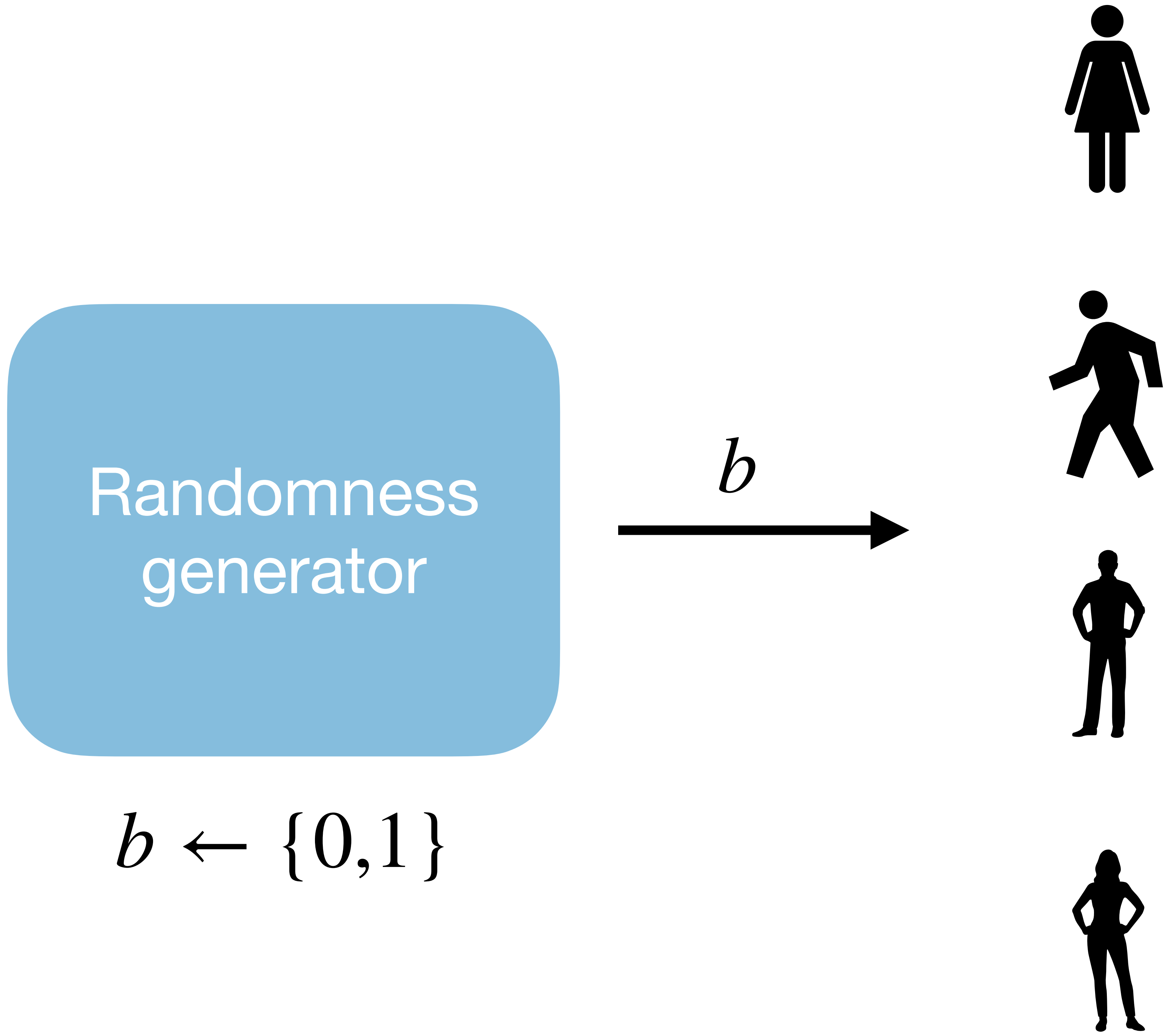

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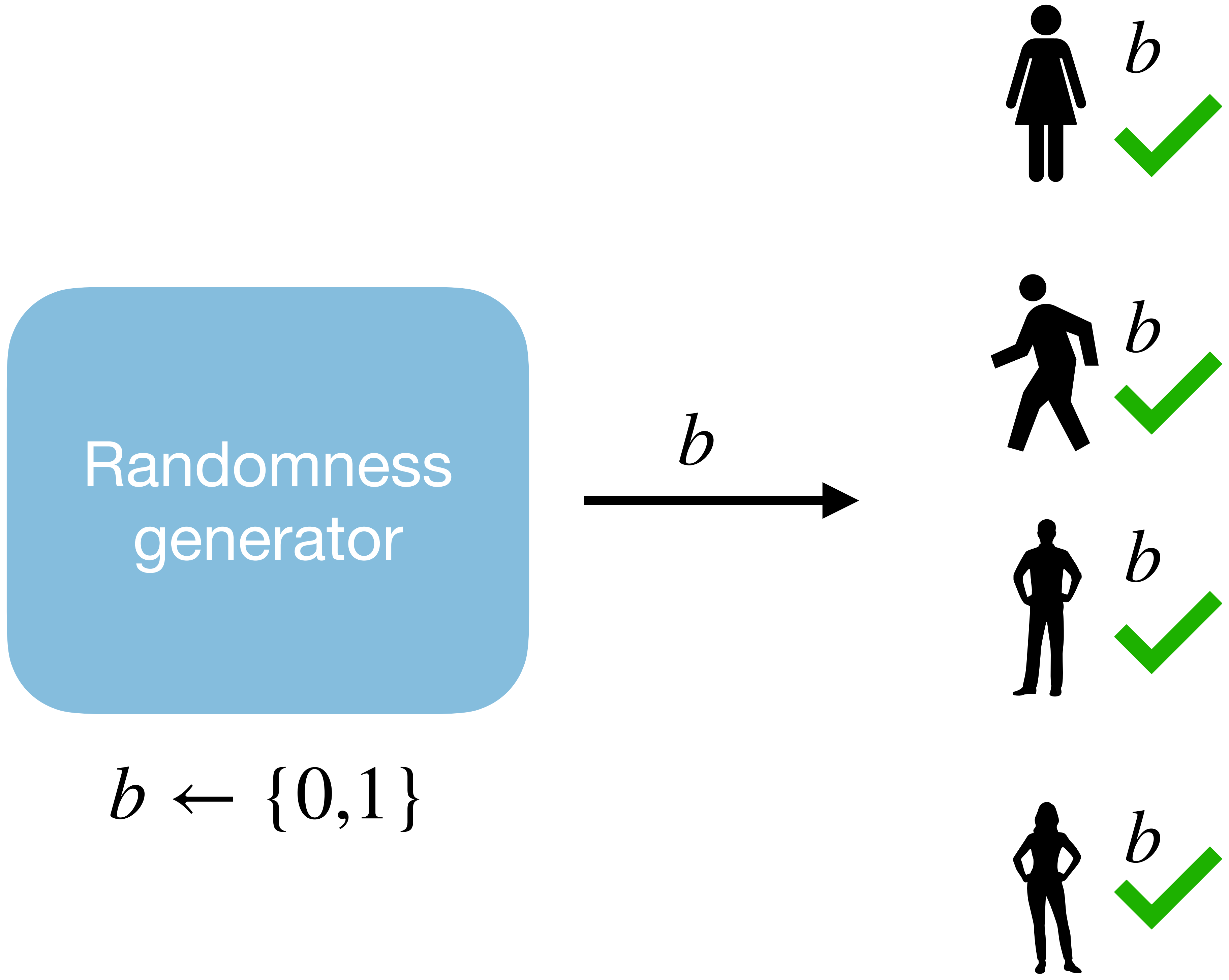

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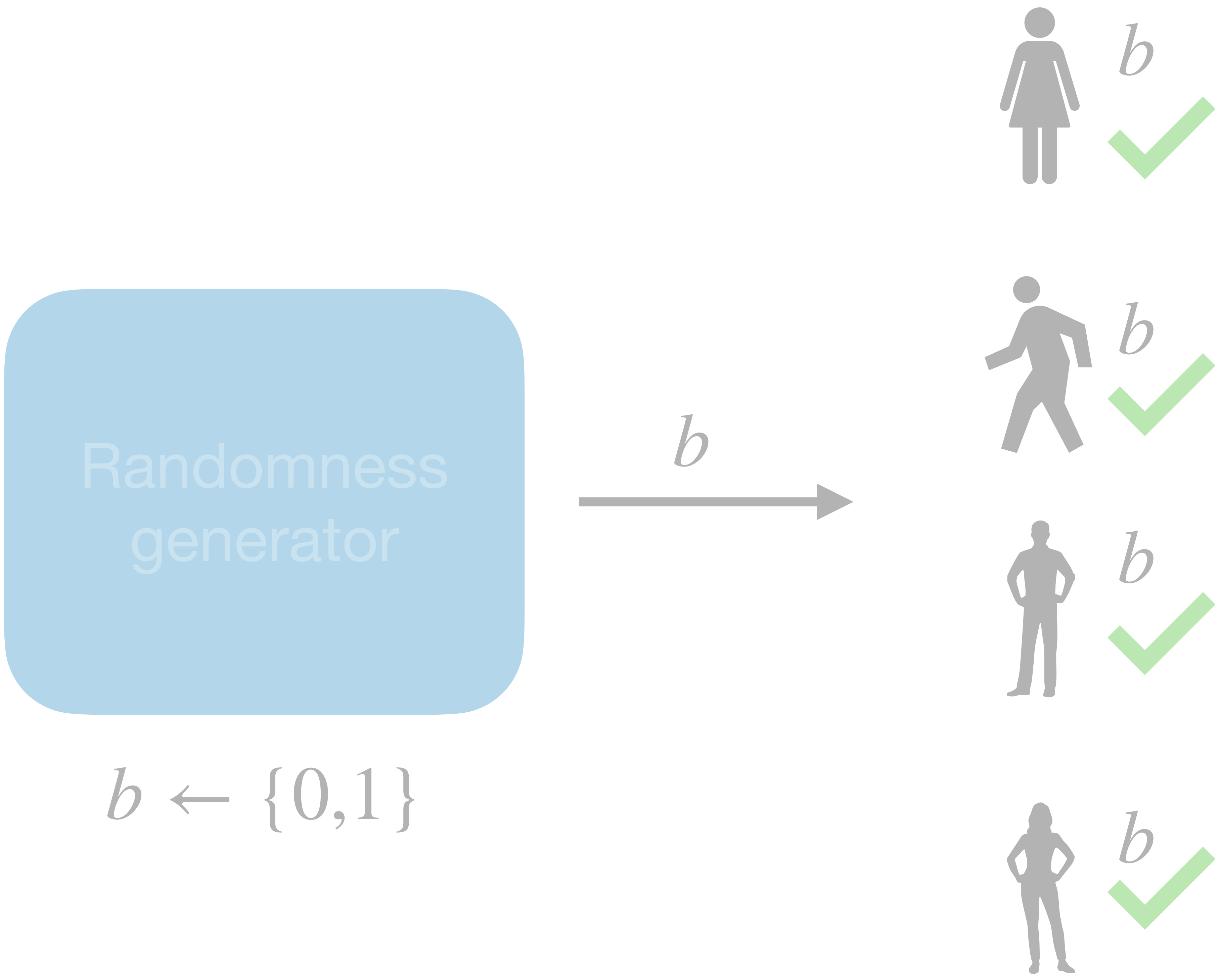

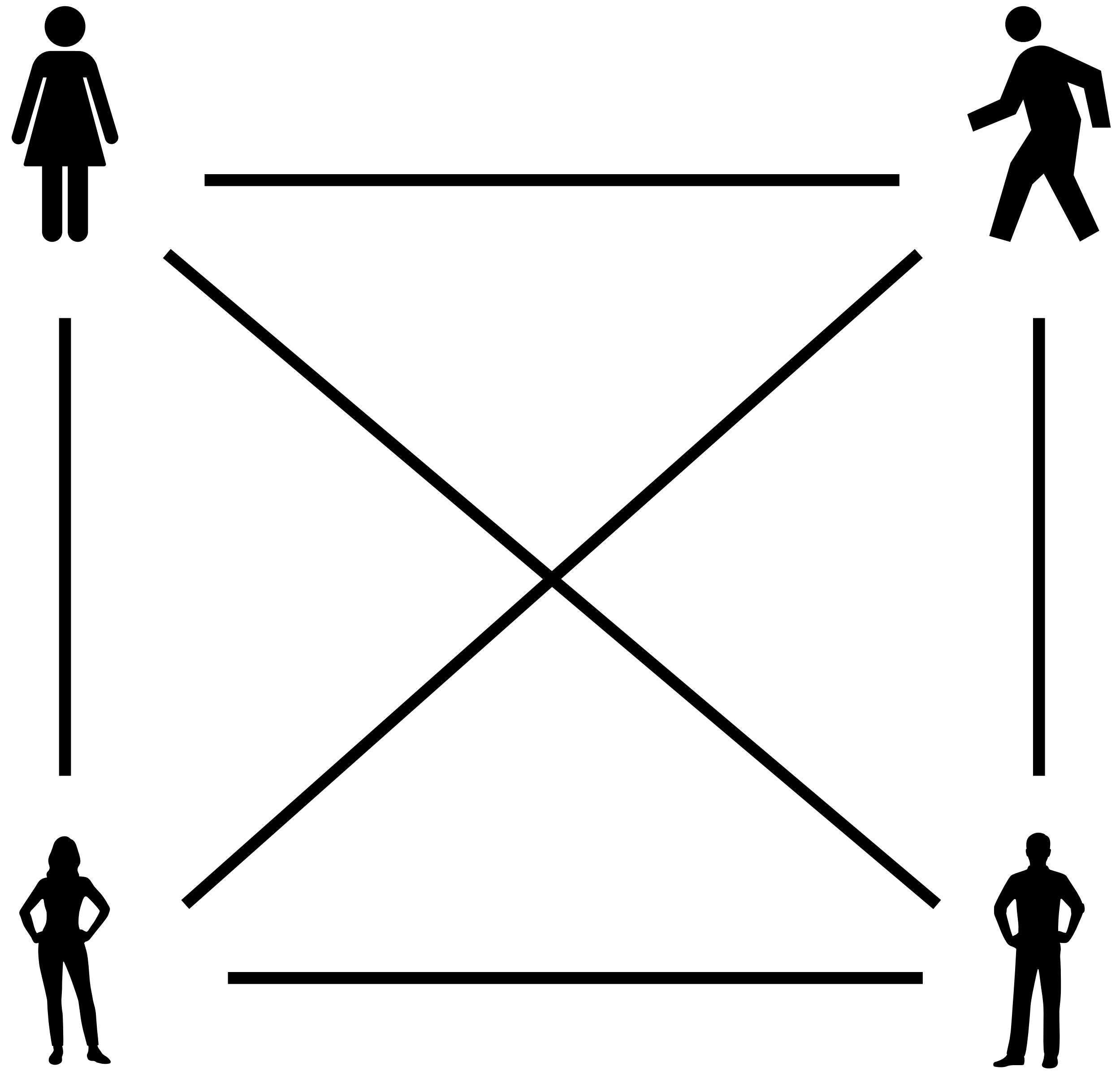

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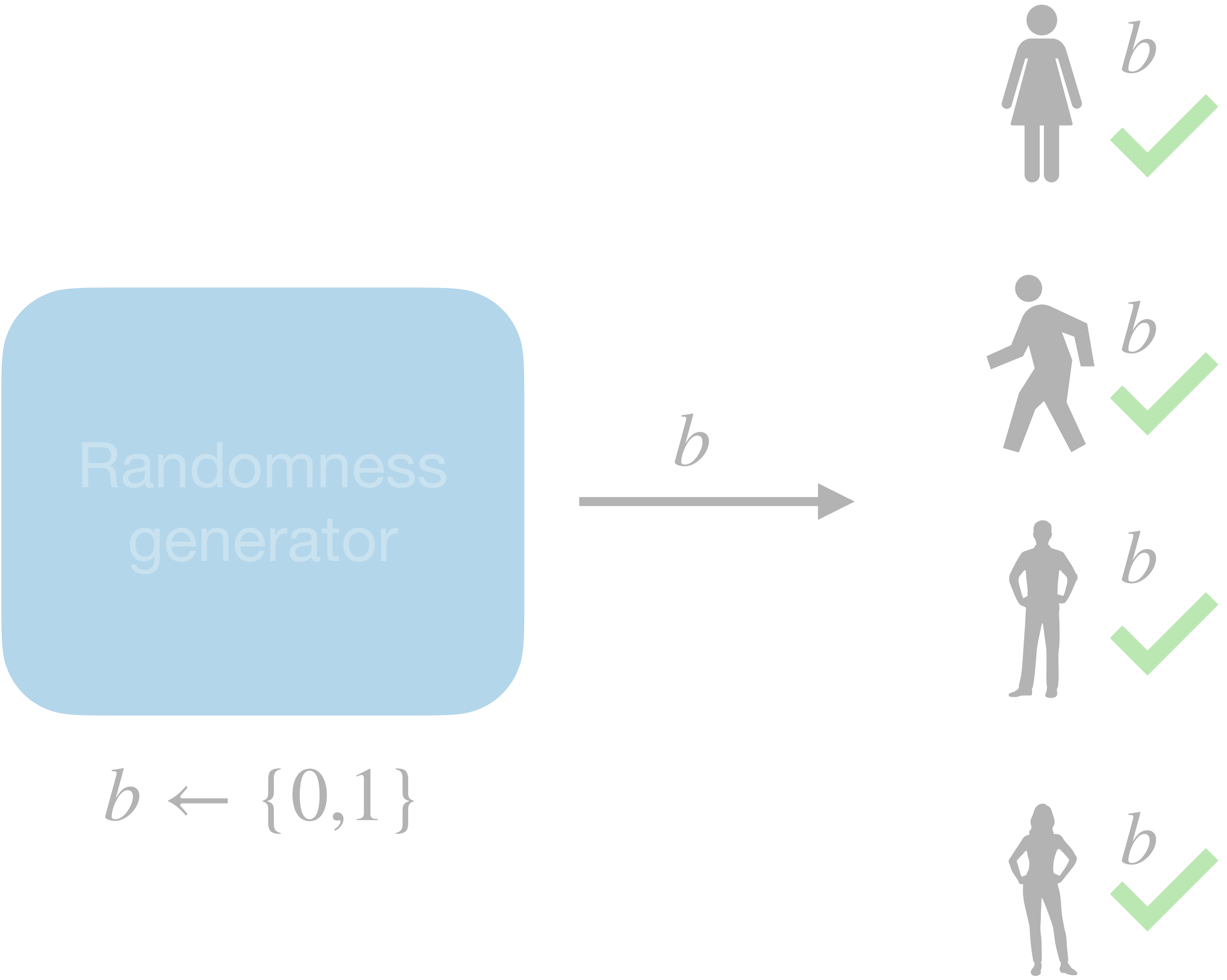

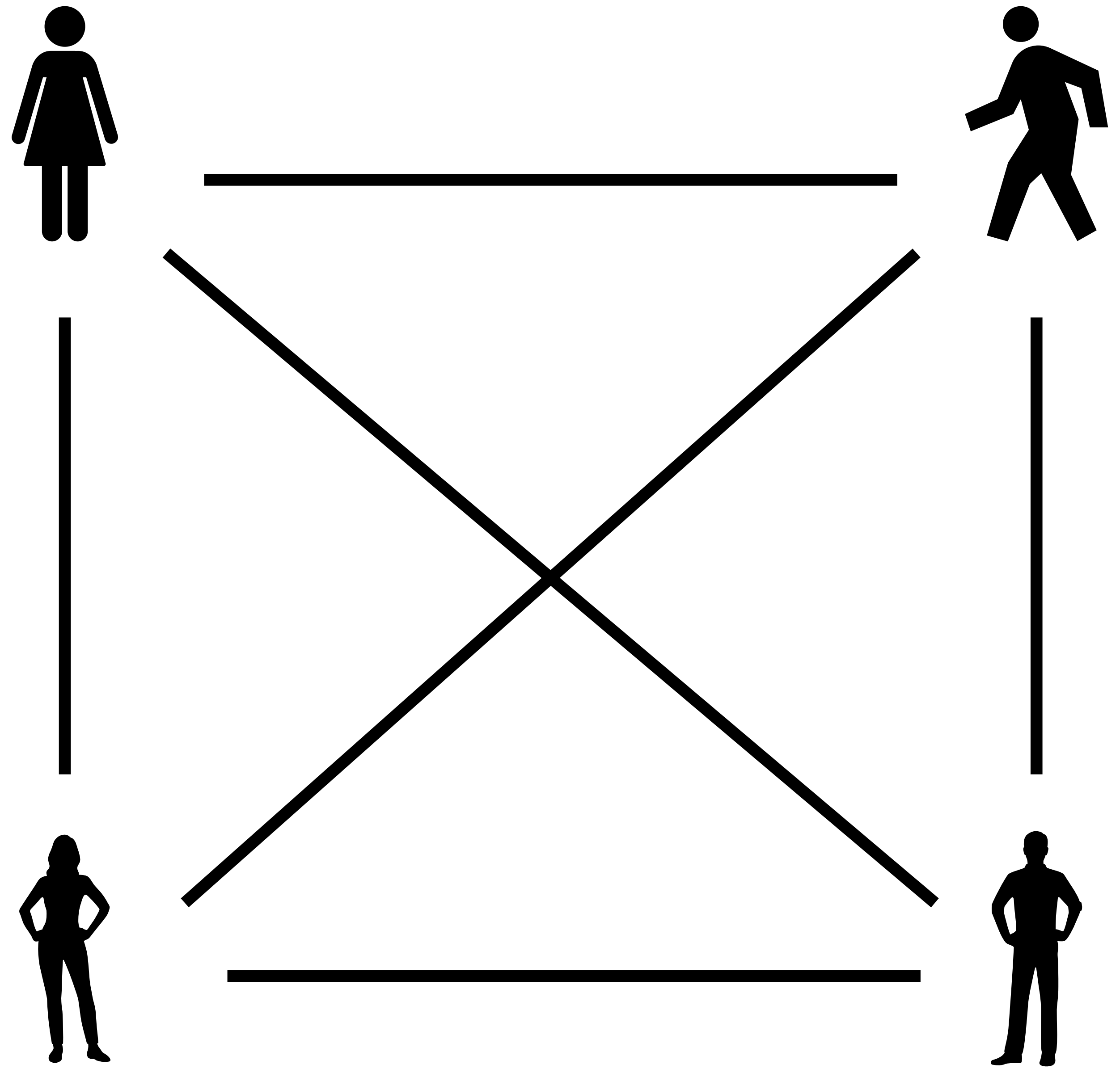

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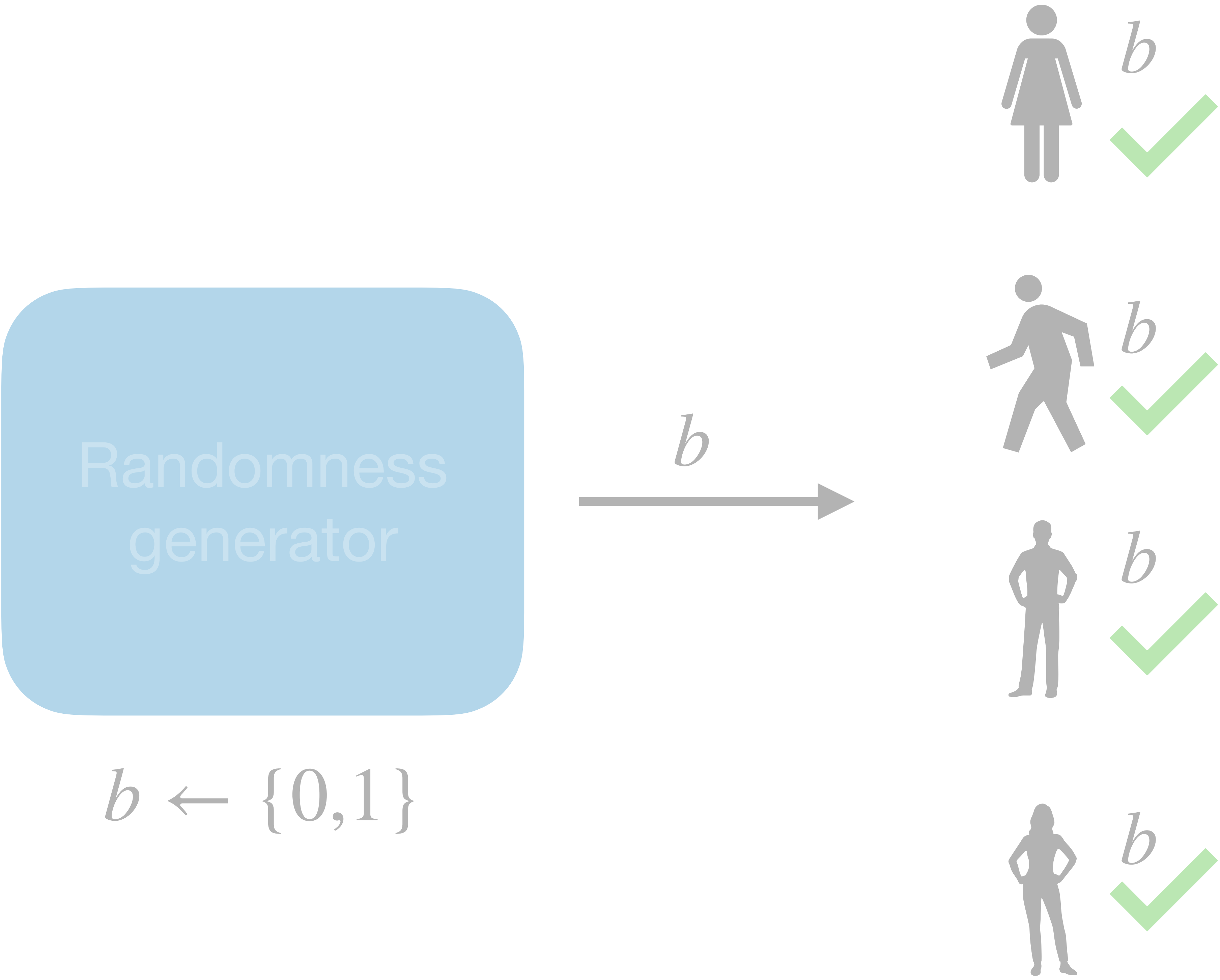

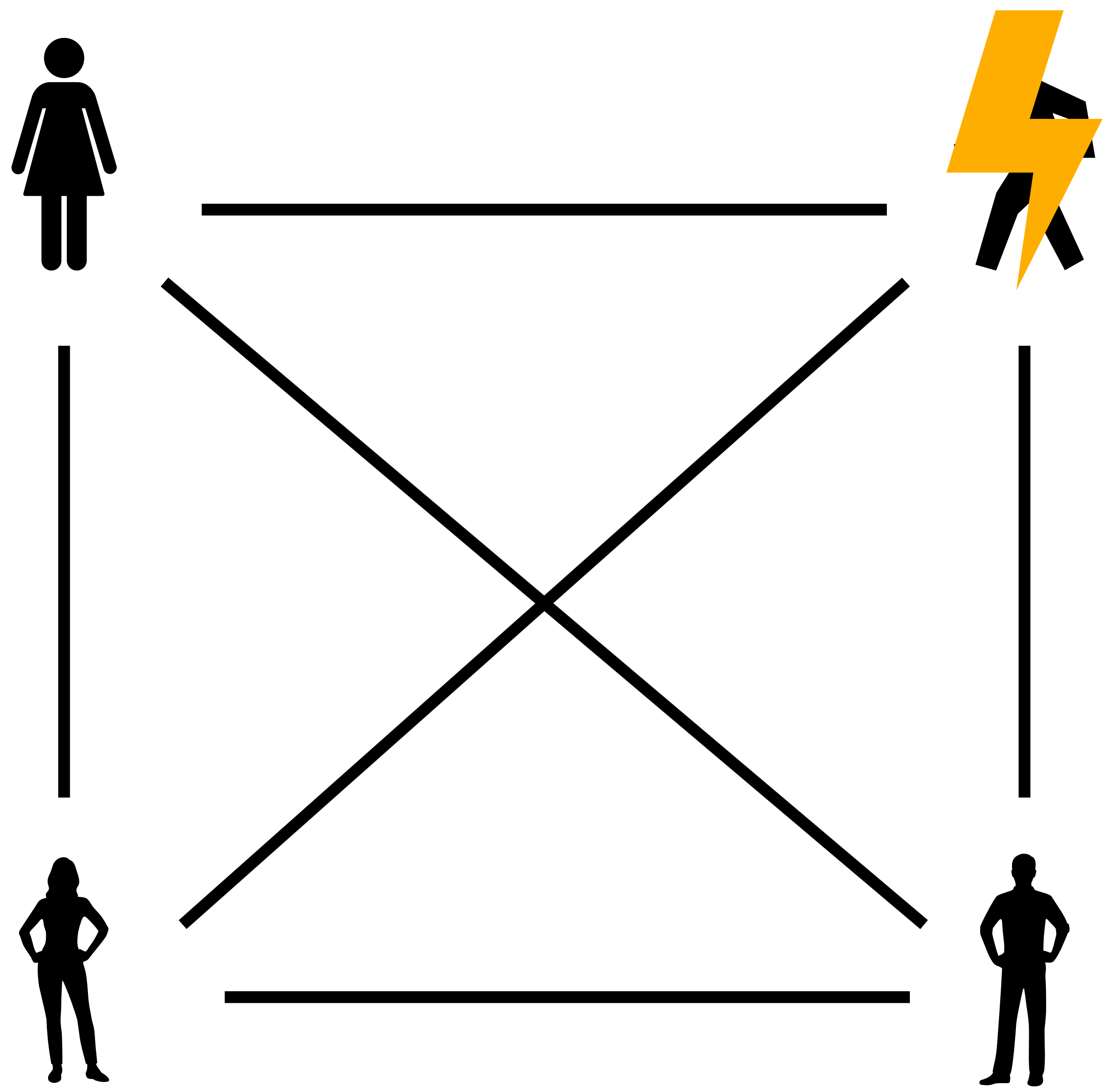

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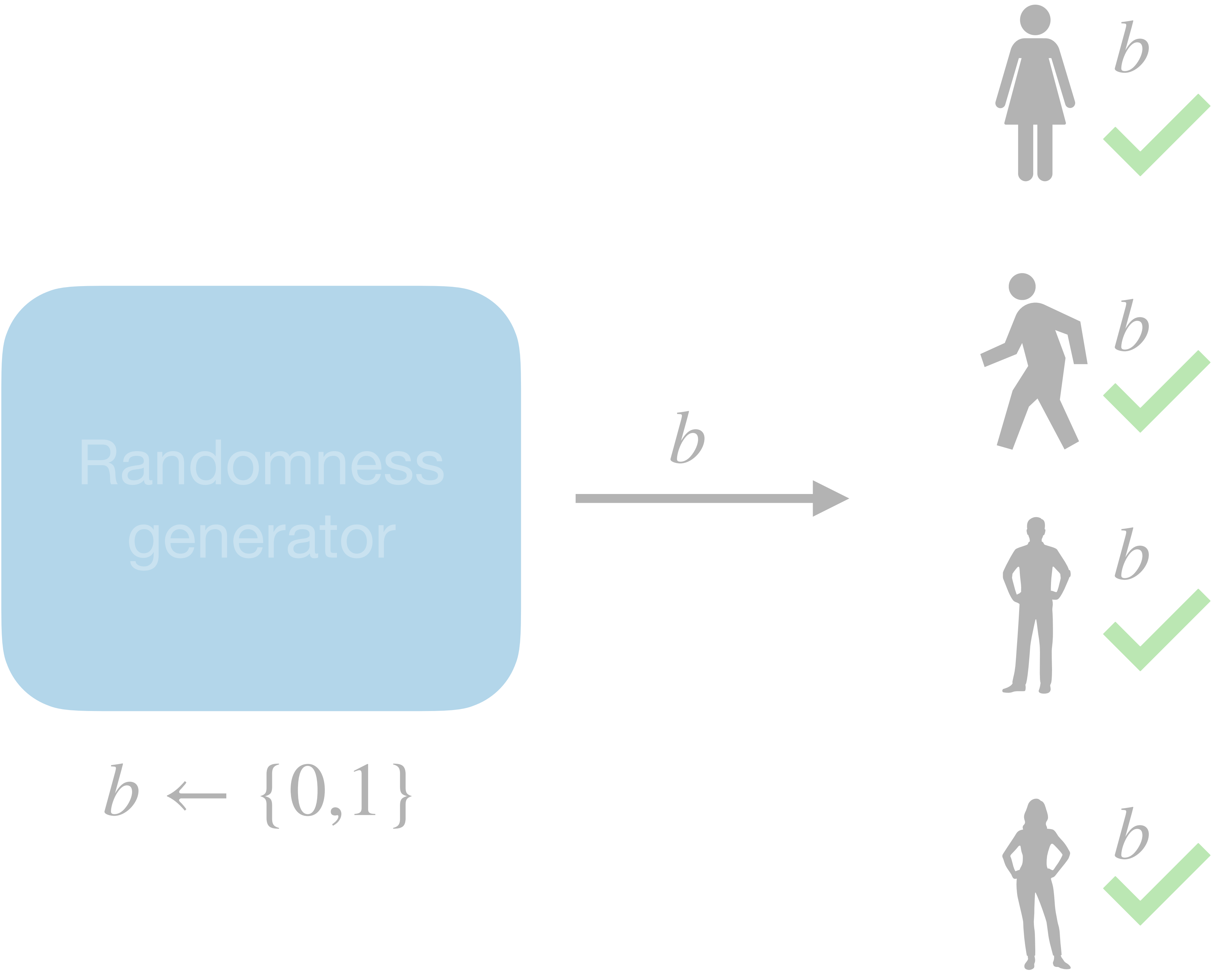

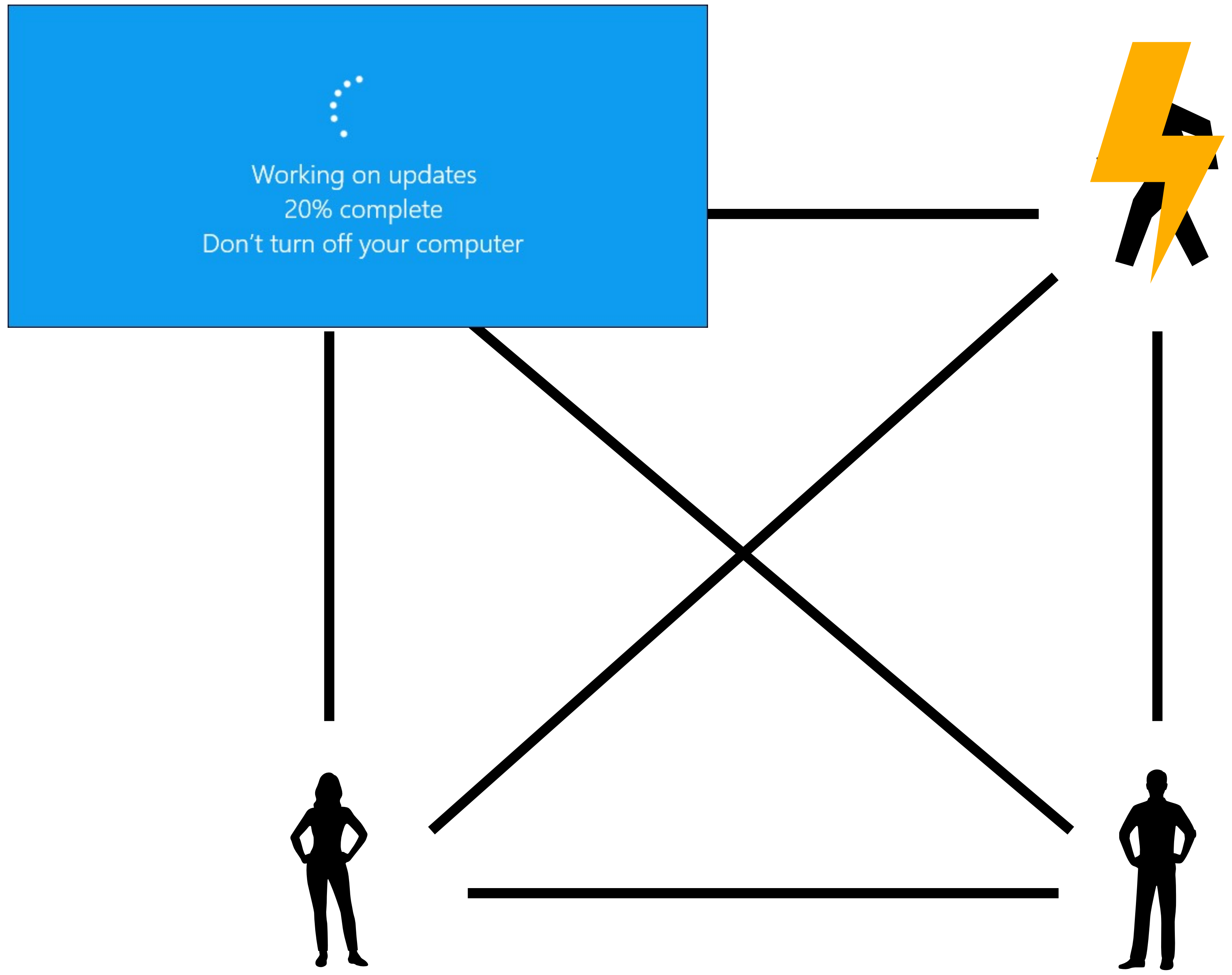

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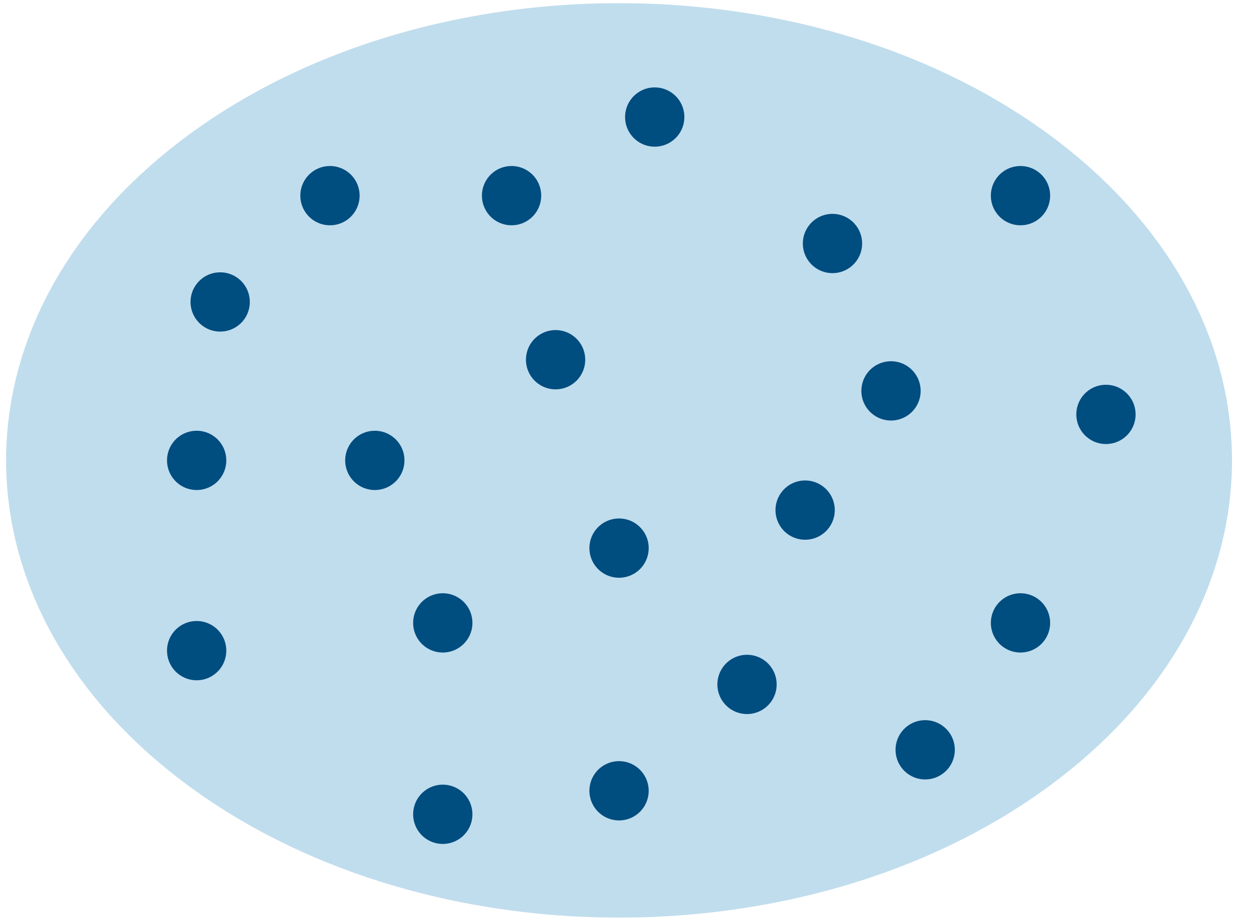
YOSO: You Only Speak Once

Secure MPC with Stateless Ephemeral Roles

Craig Gentry[1], Shai Halevi[1], Hugo Krawczyk[1], Bernardo Magri[2], Jesper Buus Nielsen[*2], Tal Rabin[1], and Sophia Yakoubov[†3]

Ground set of N parties



n ephemeral roles, $n \ll N$

R_1 R_2 R_3 $\ldots$

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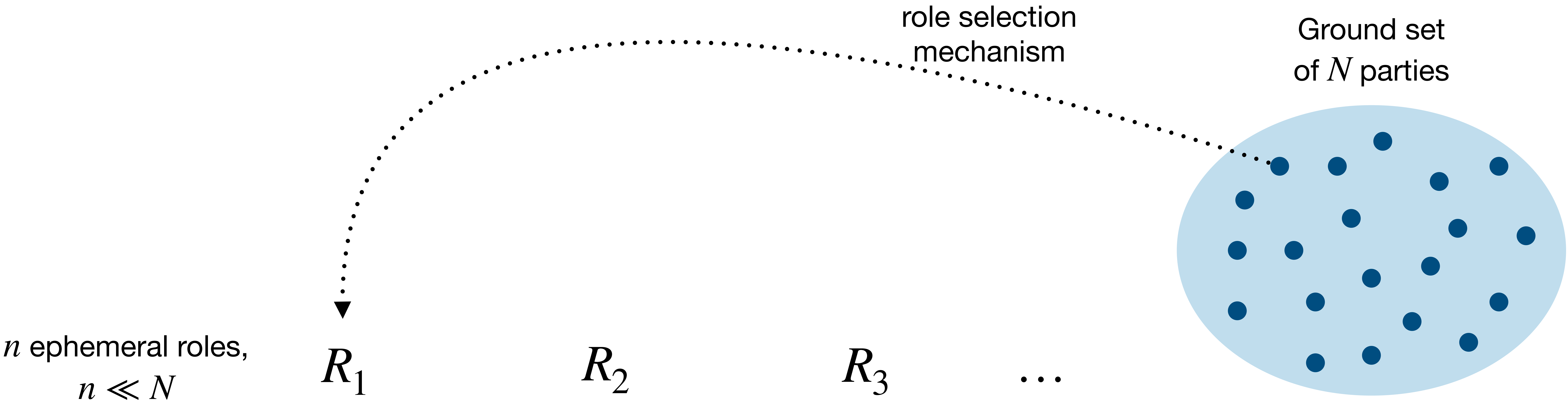

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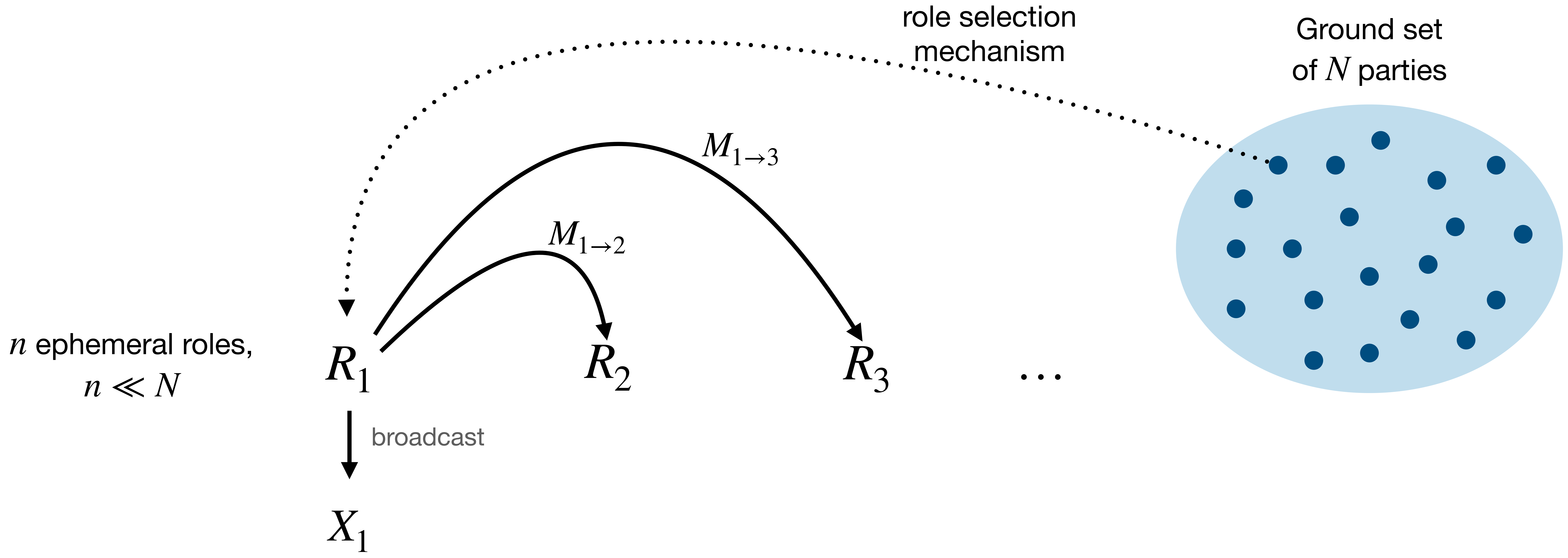

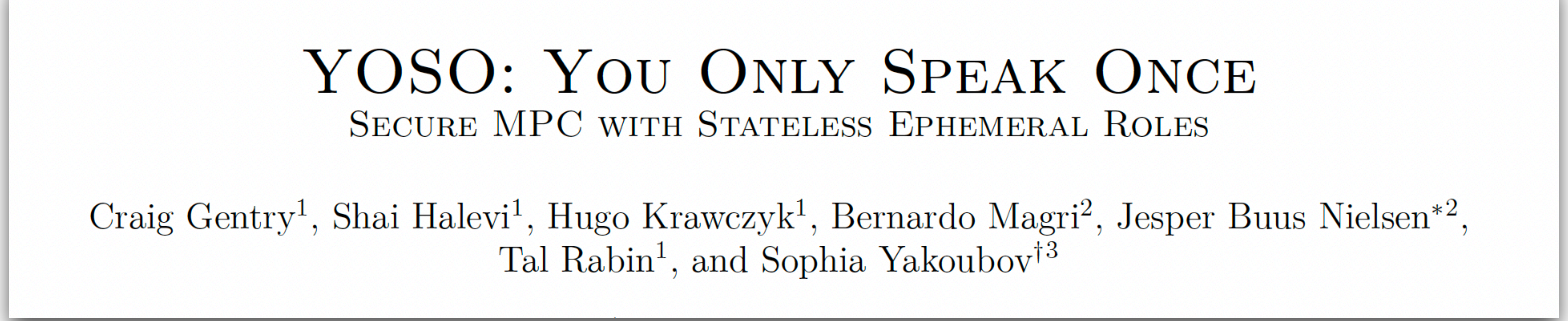

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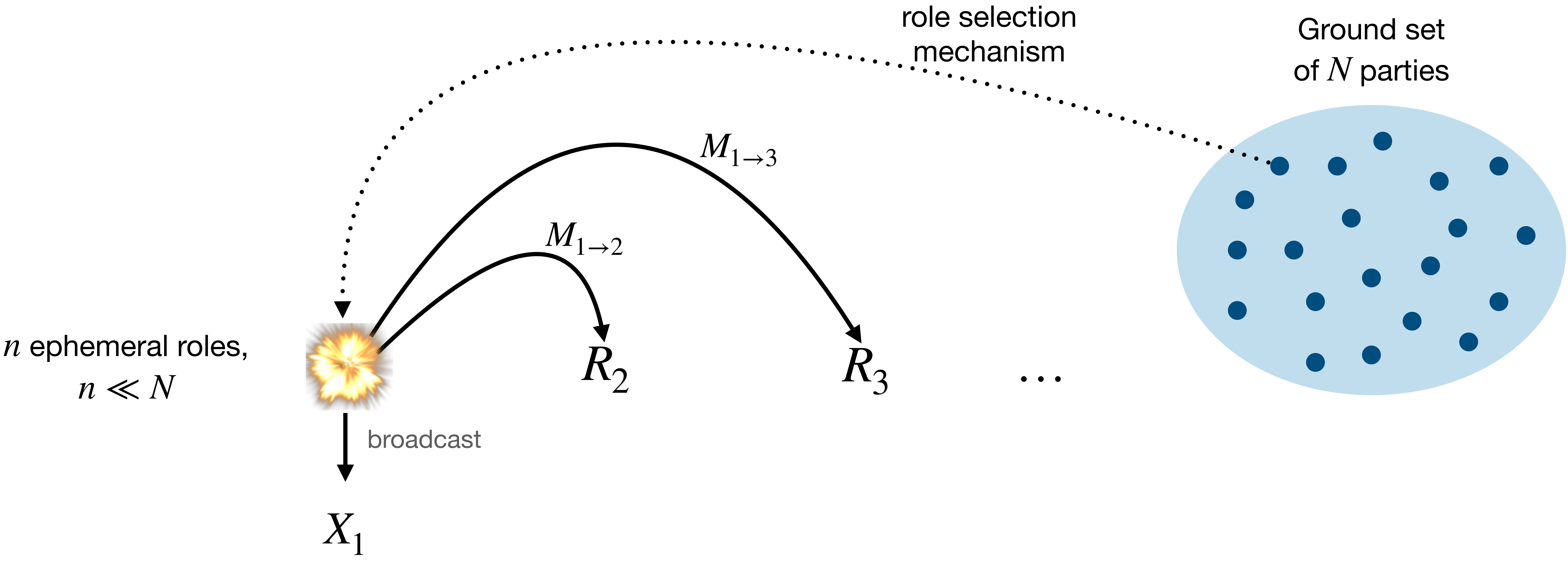

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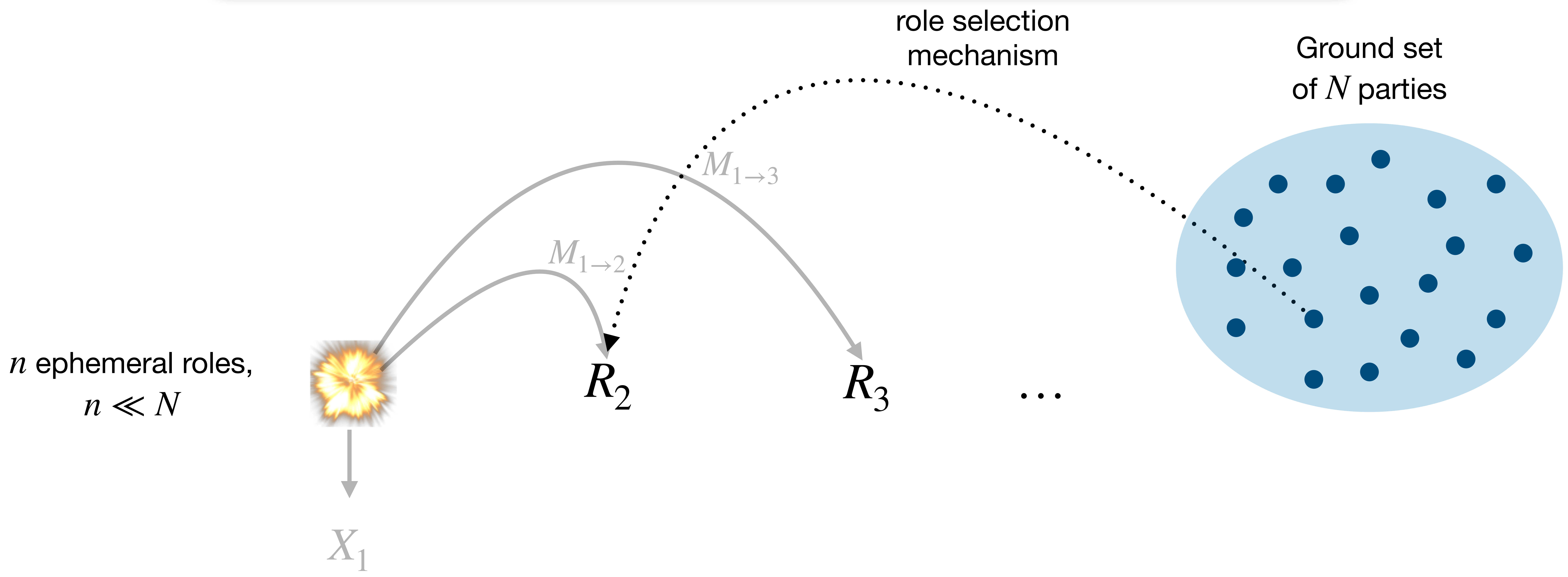

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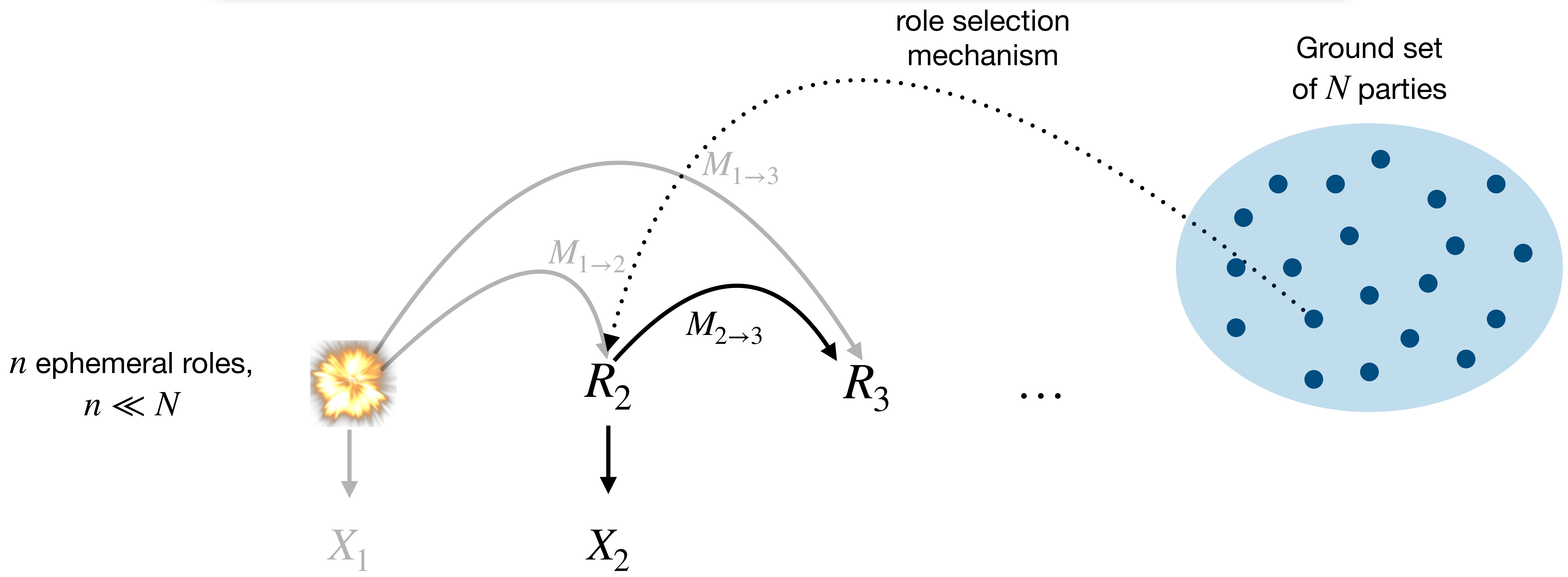

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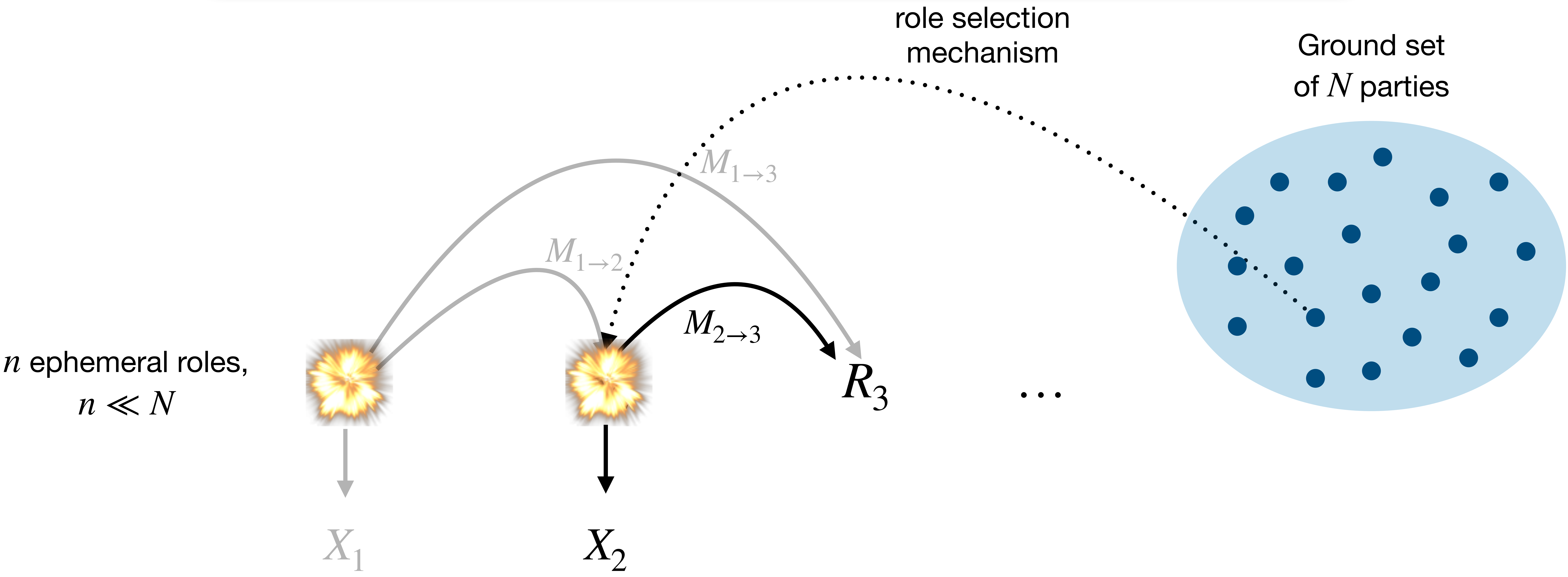

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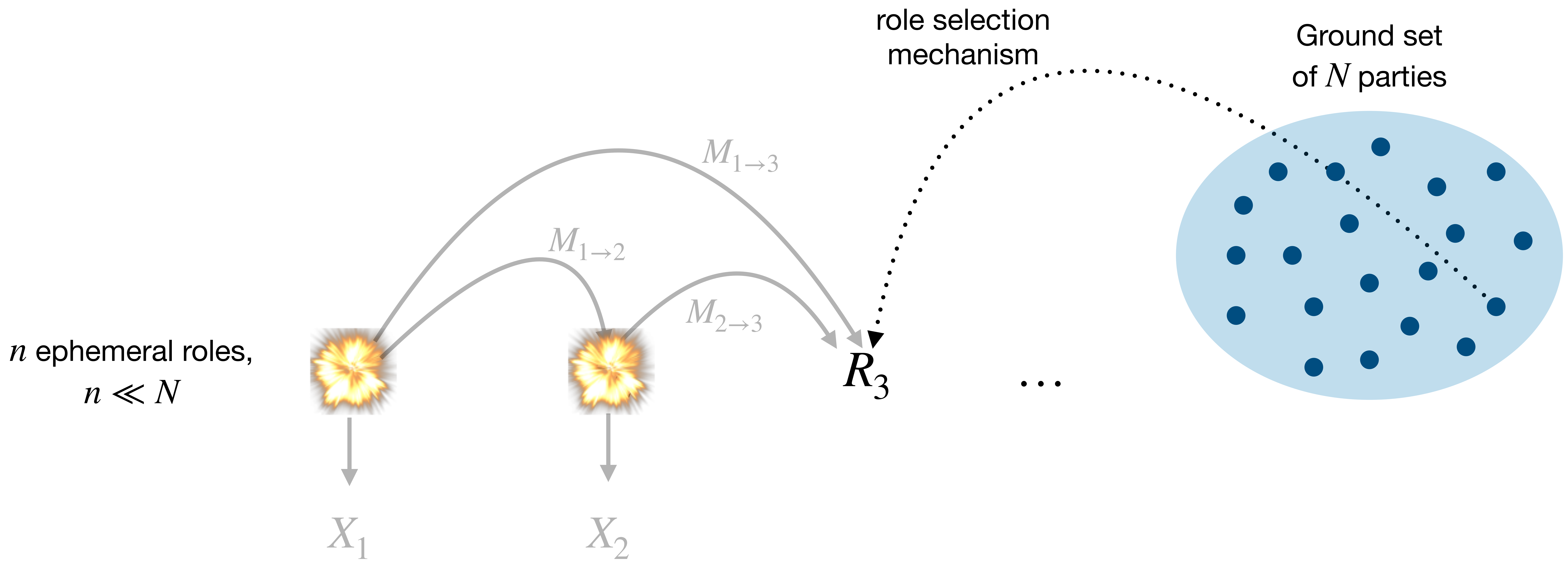

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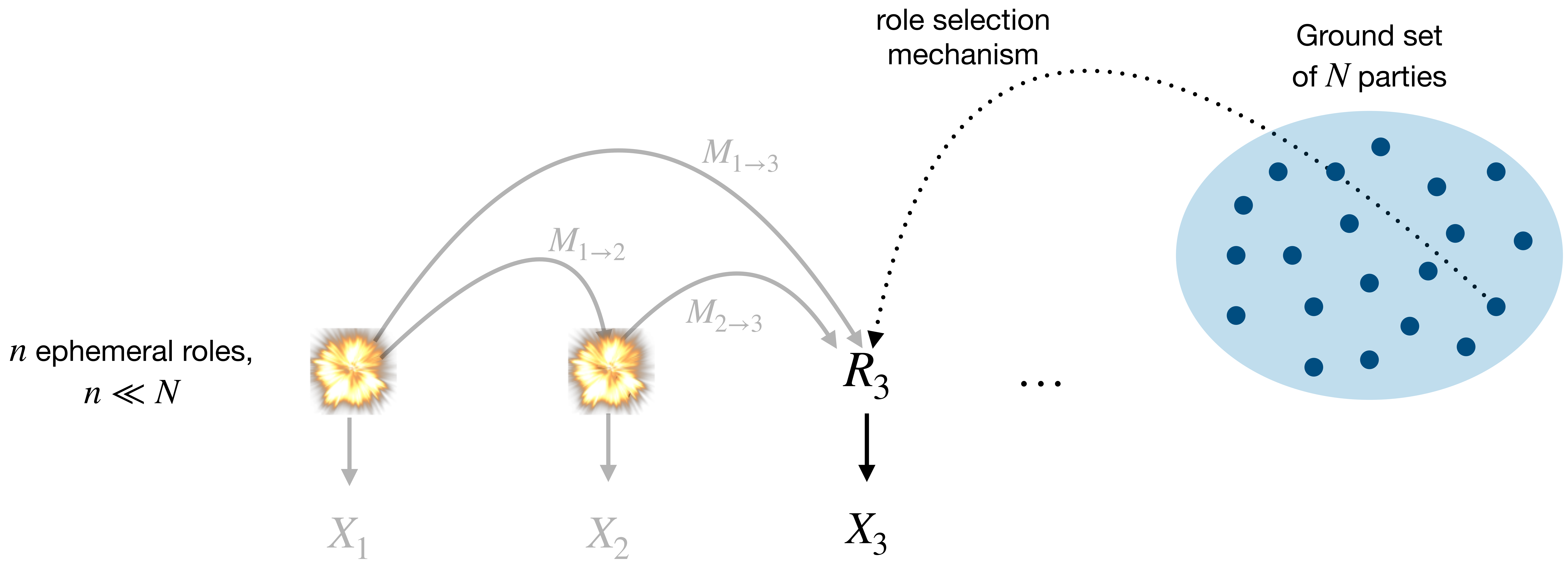

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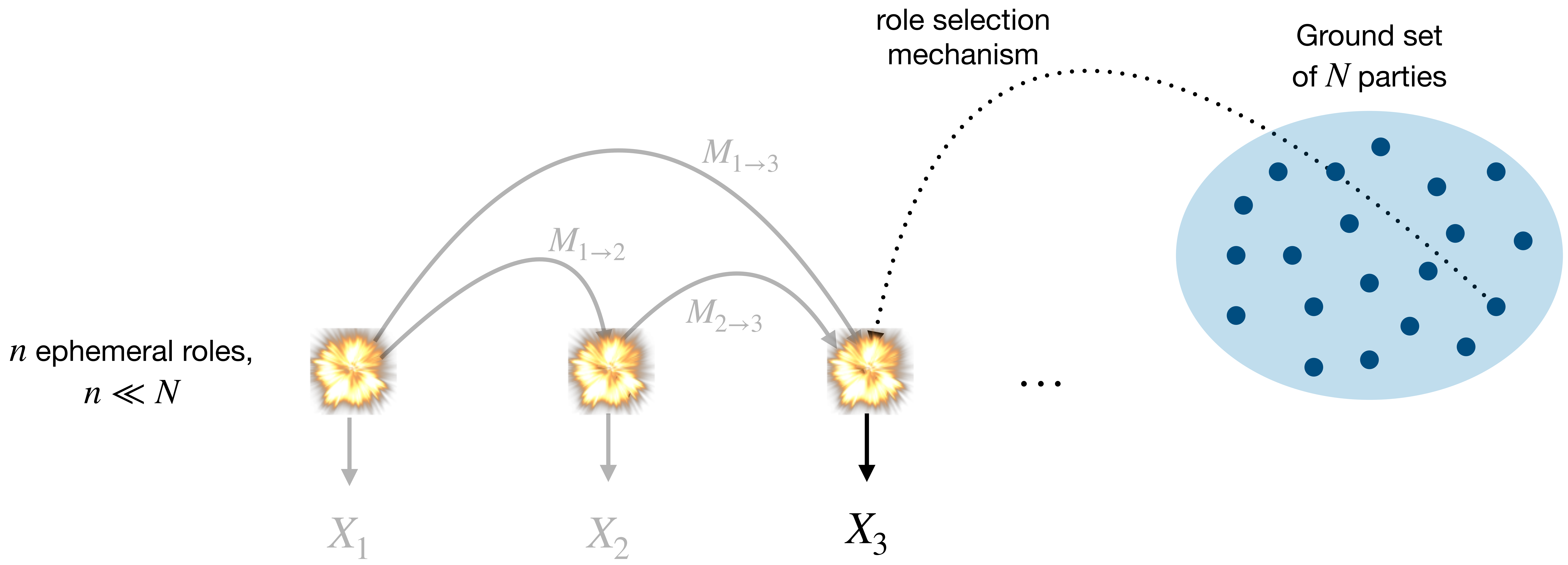

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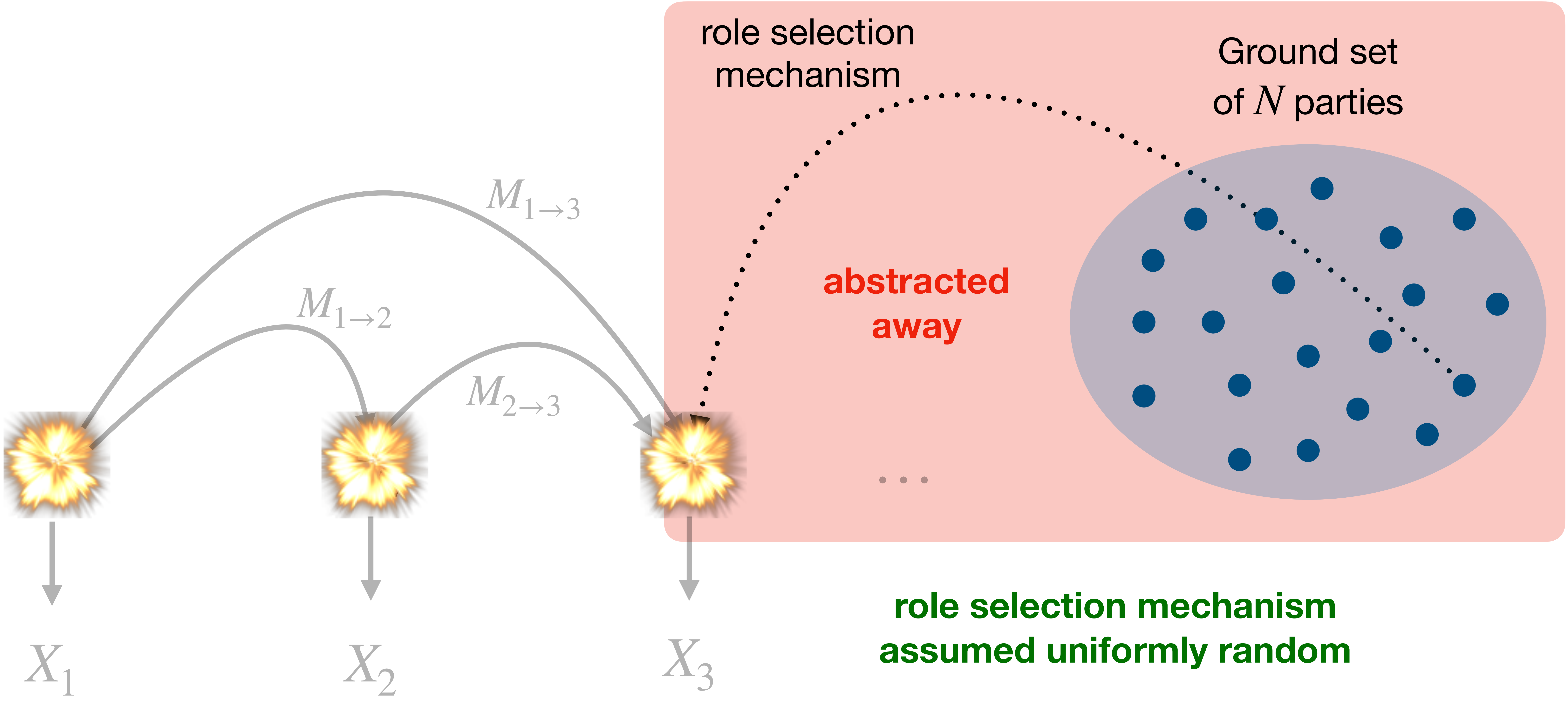

role selection mechanism assumed uniformly random

$\Longrightarrow$ **MPC with $t = (1/2 - \delta)N$ corruptions!**

YOSO *public* randomness extraction with worst-case corruptions

Replace i.i.d. random corruptions by **static chosen corruptions**

R_1 R_2 R_3 R_4

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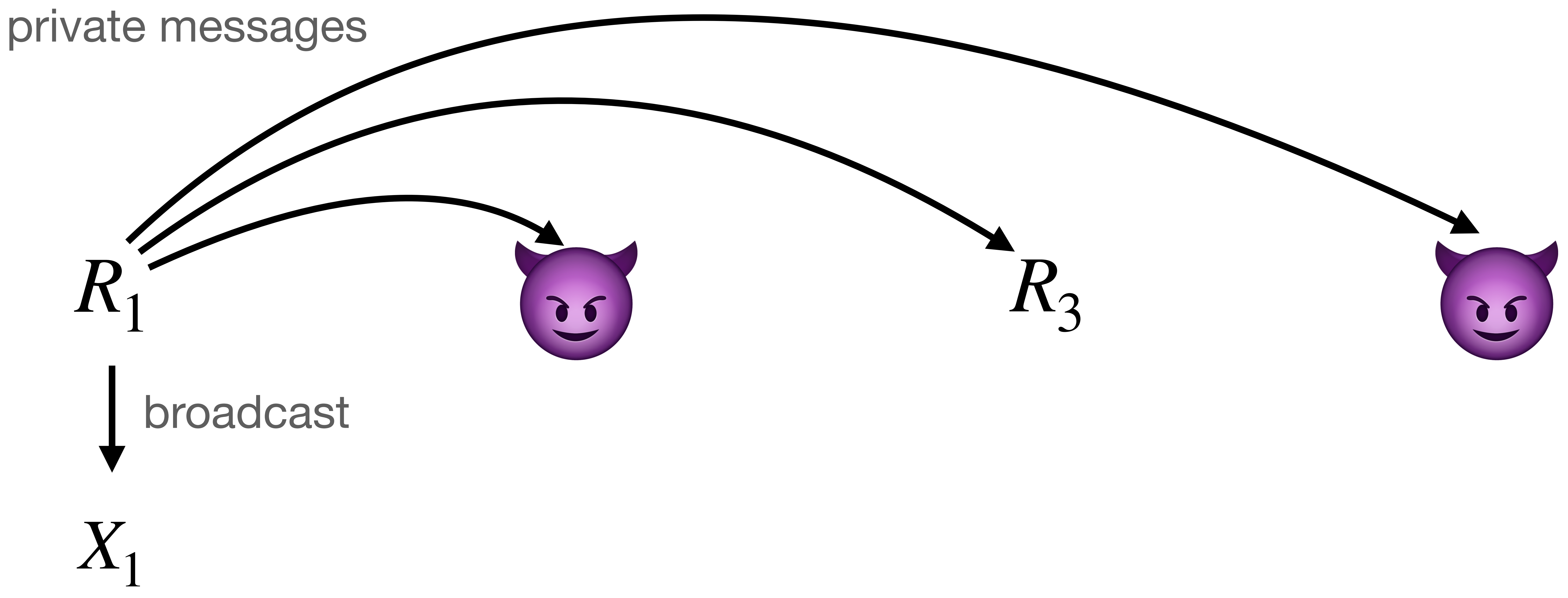

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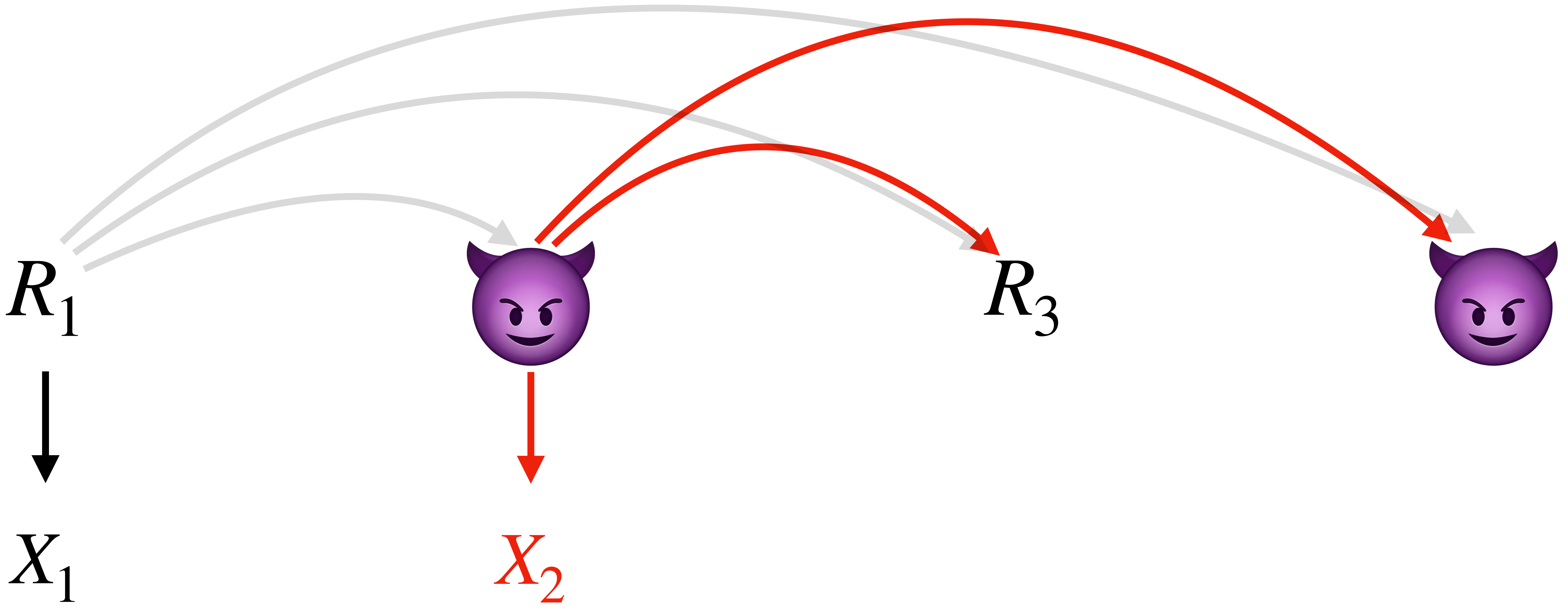

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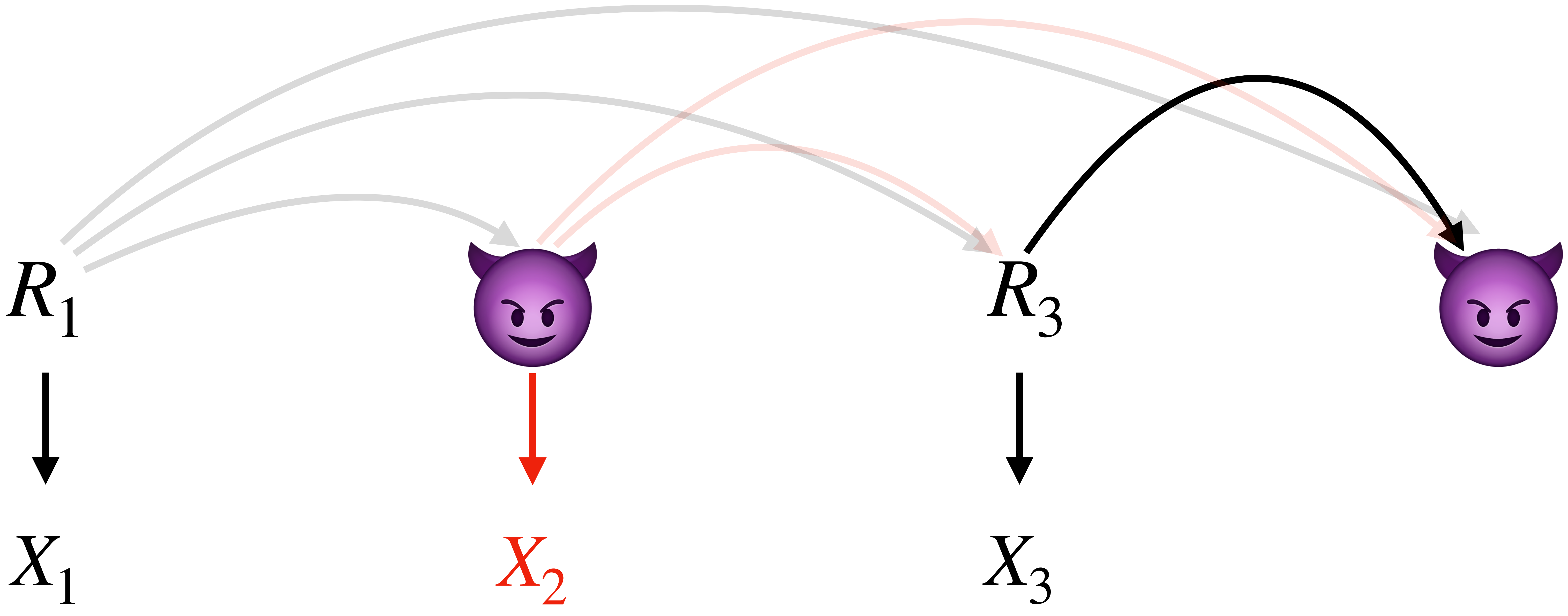

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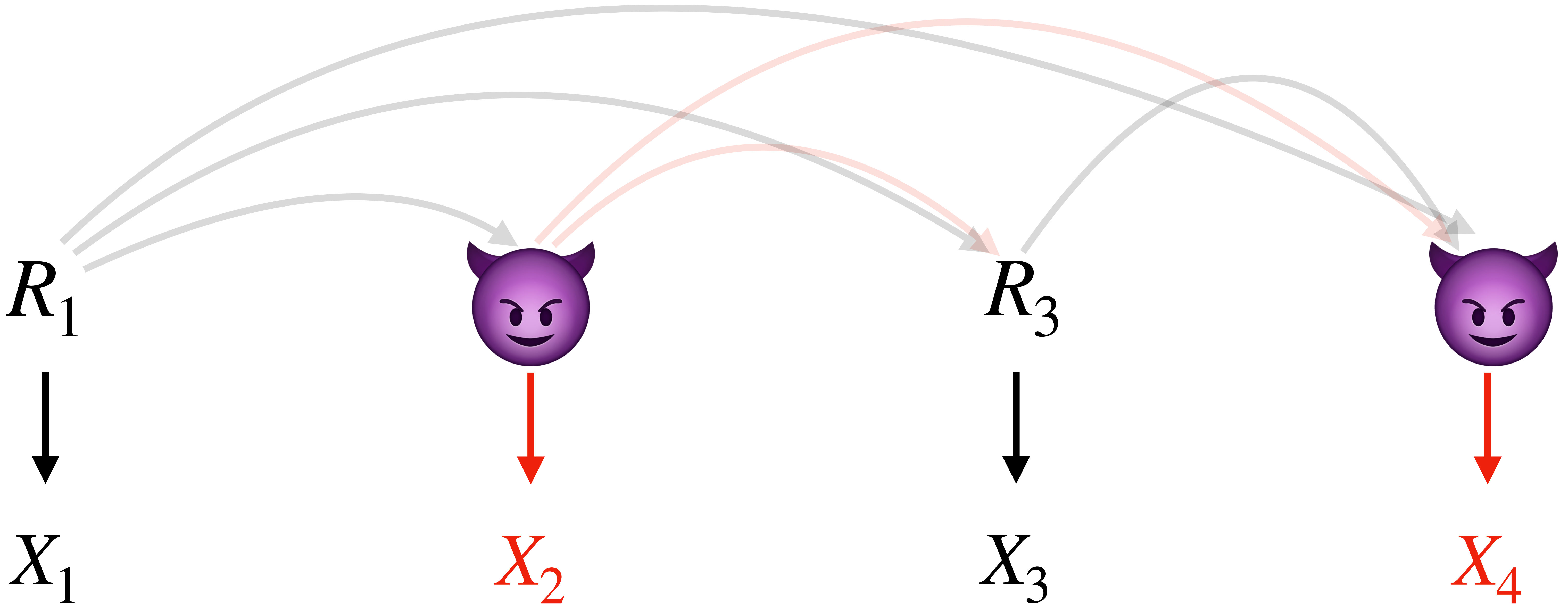

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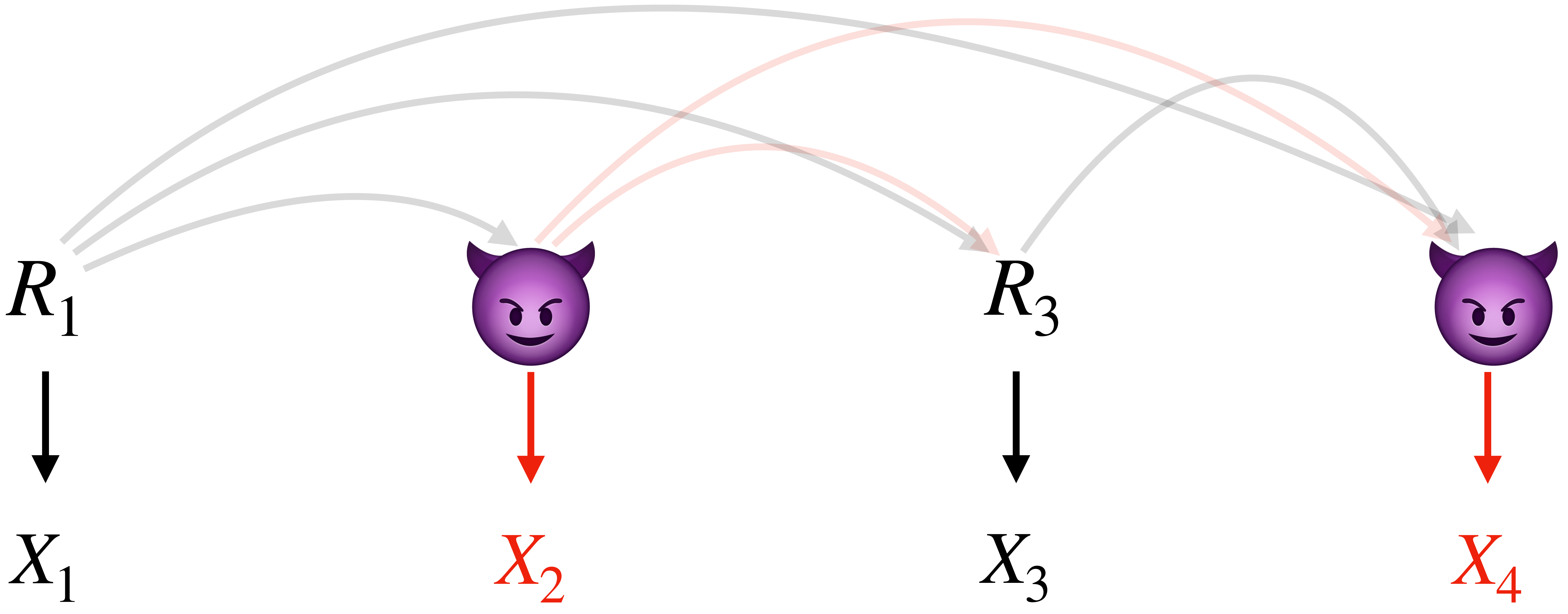

$$B = \mathrm{Ext}(X_1, X_2, X_3, X_4) \approx \mathrm{Unif}$$

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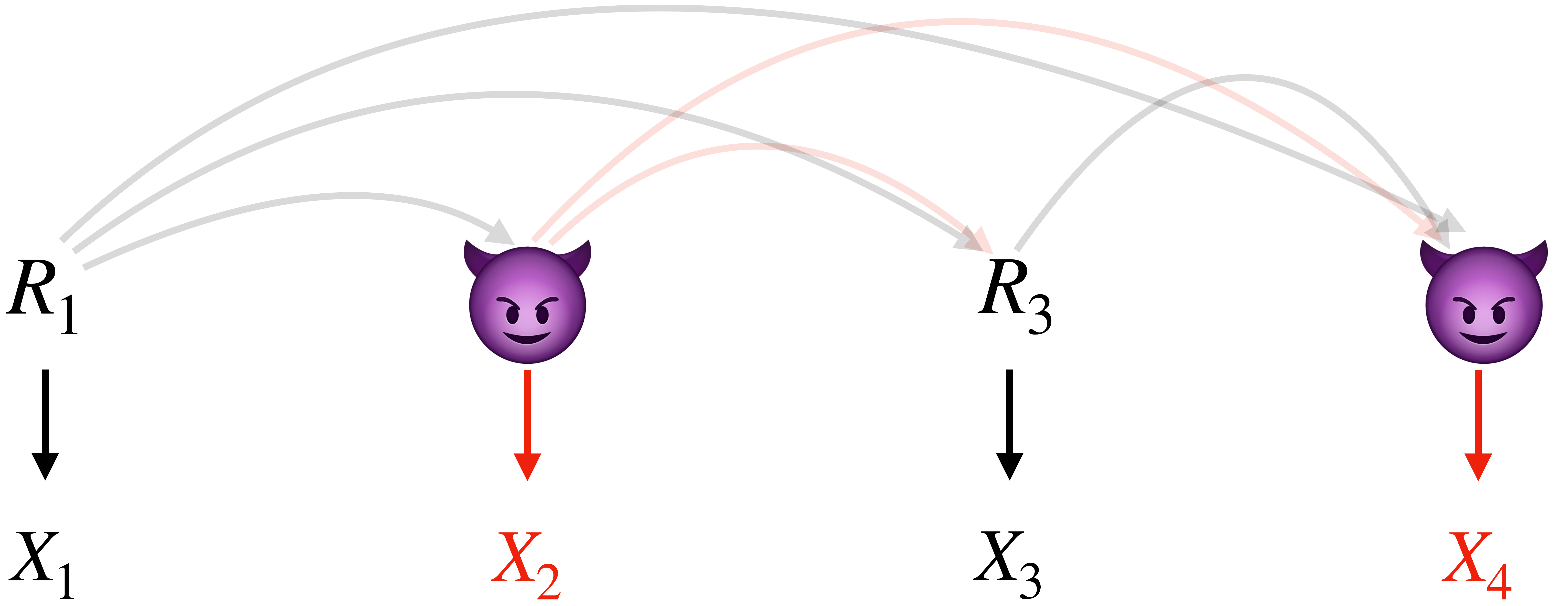

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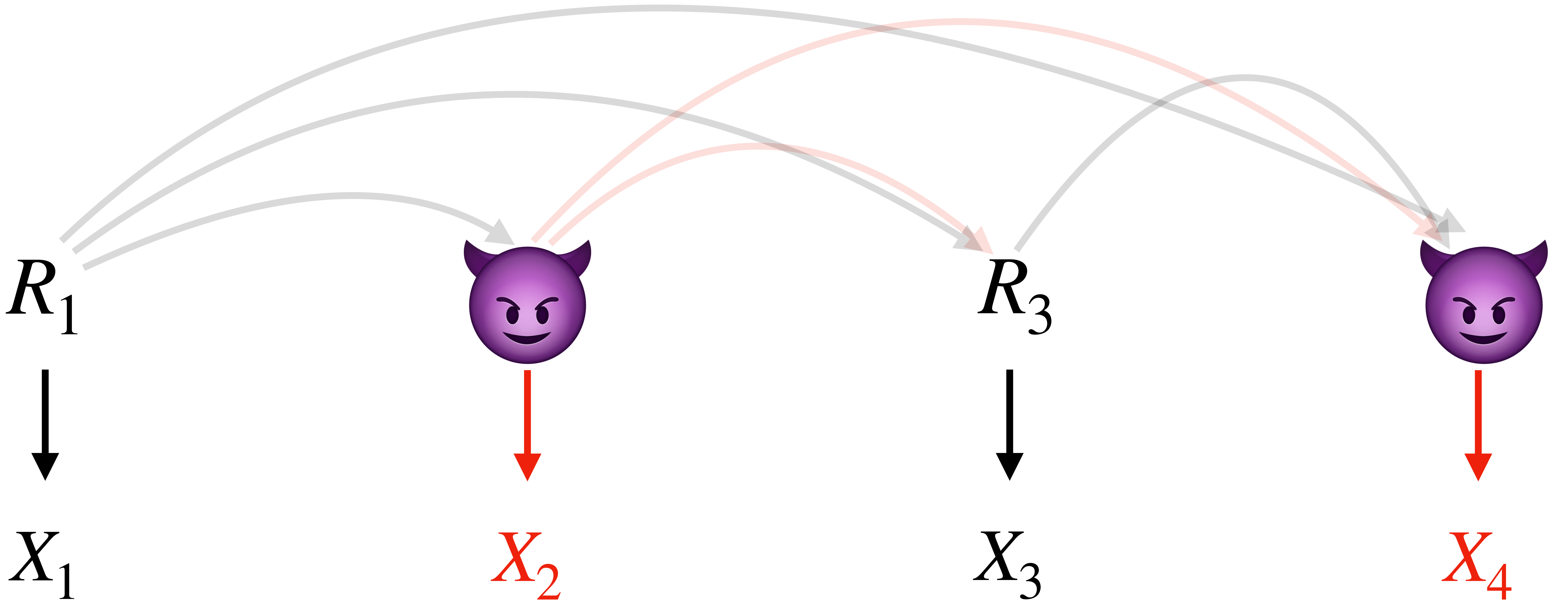

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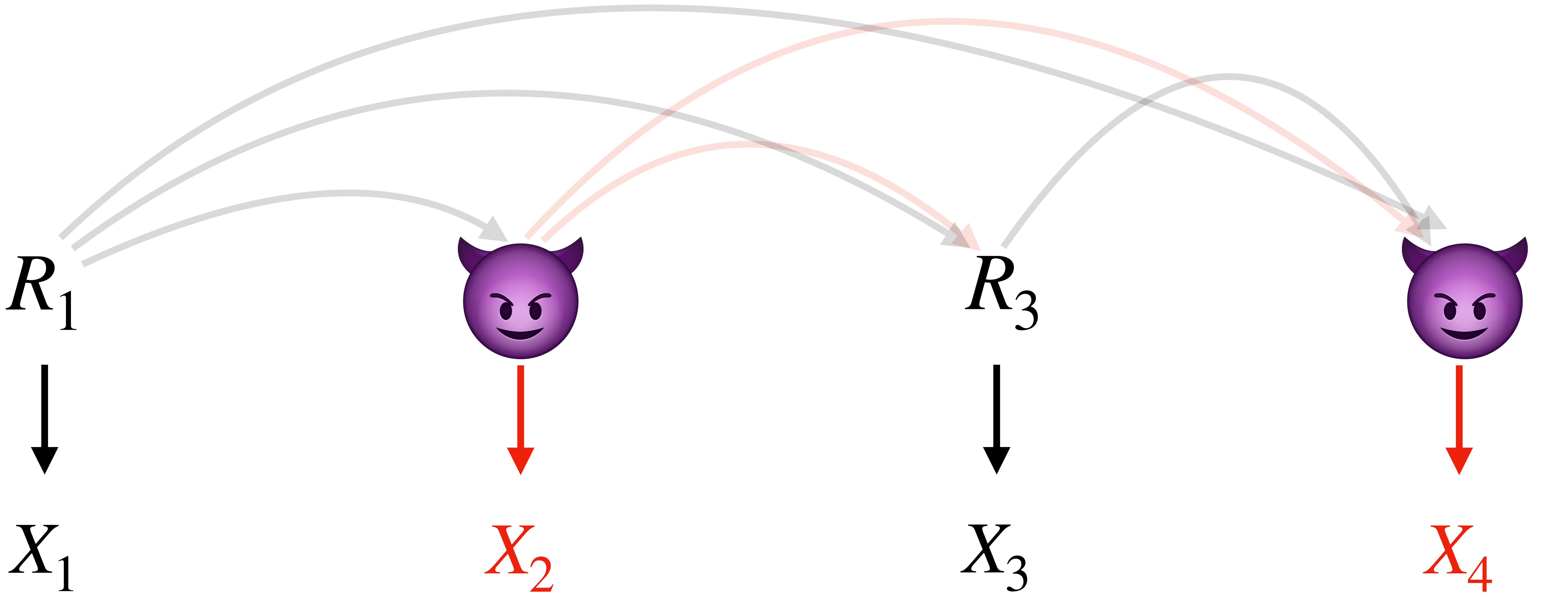

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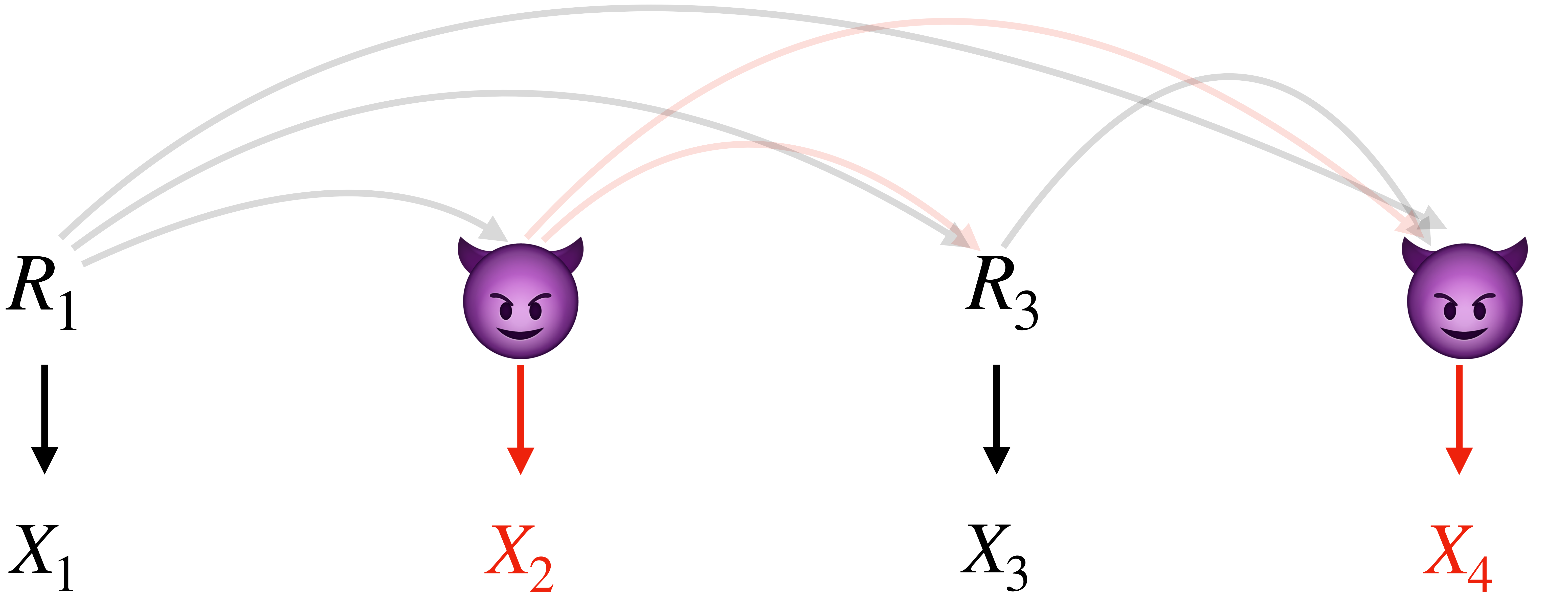

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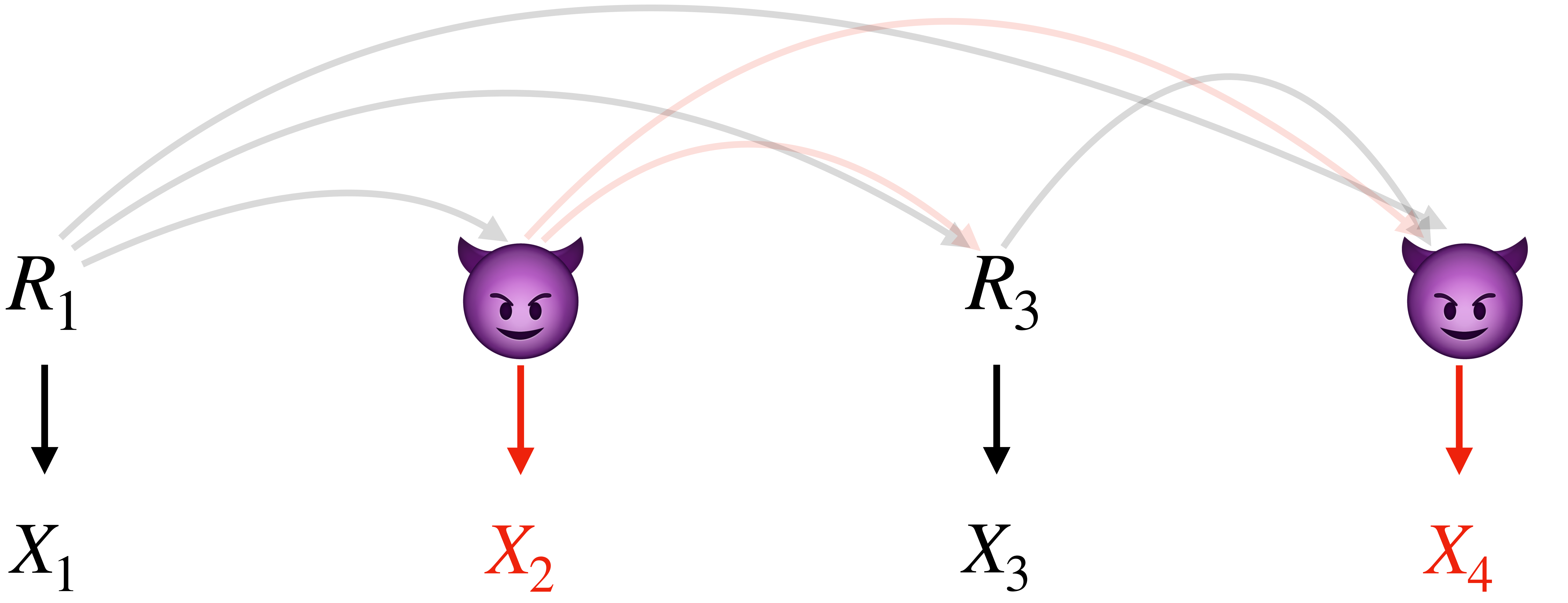

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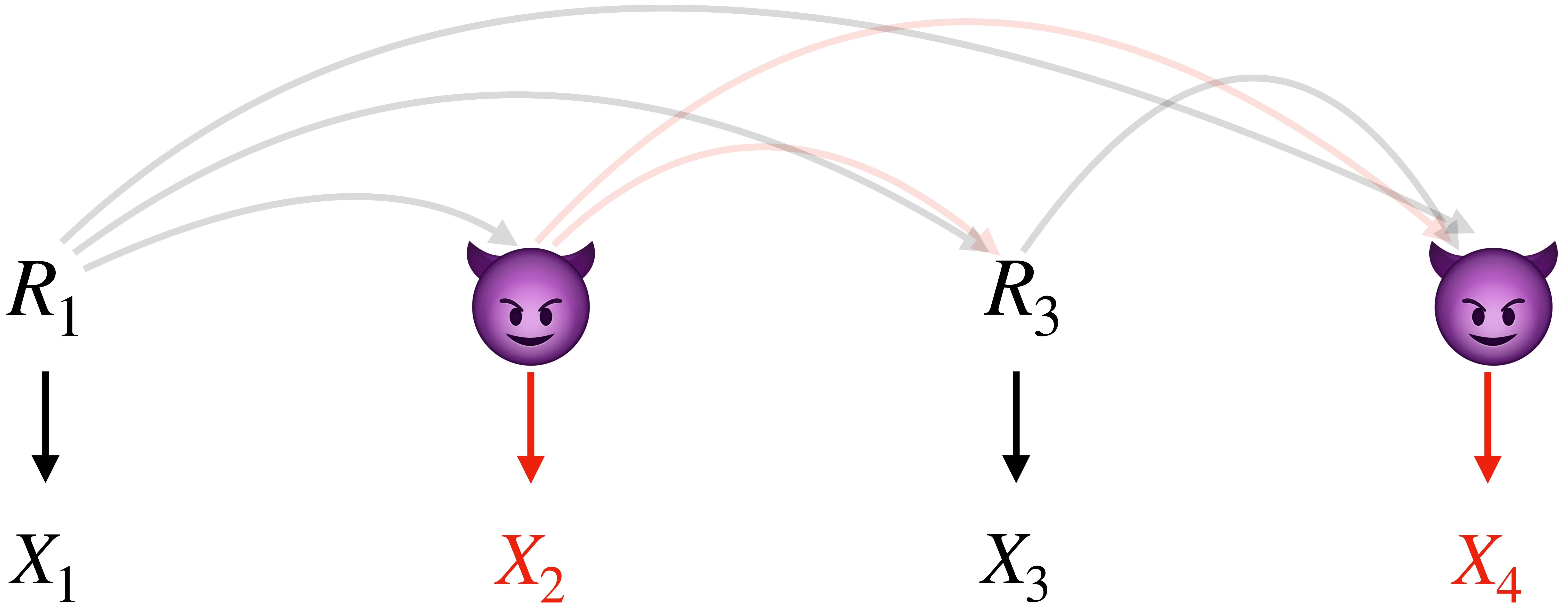

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- Clean model
- Relationship to other randomness extraction settings

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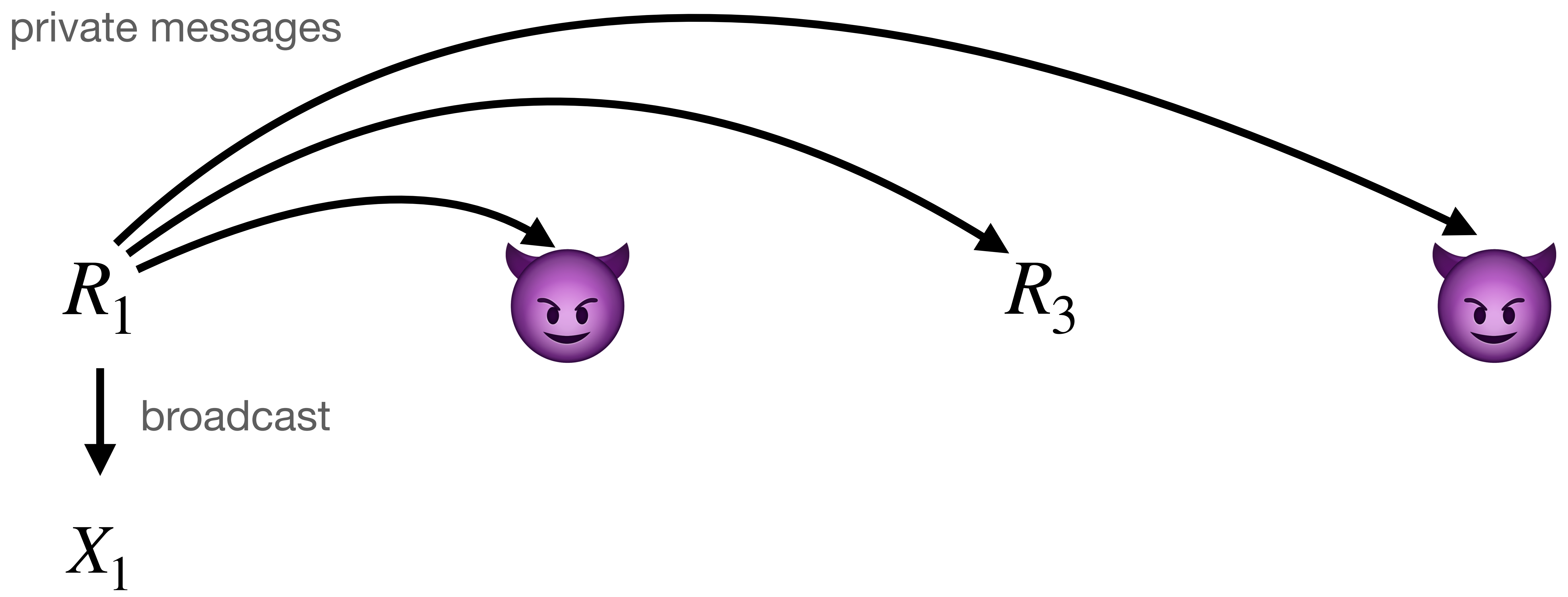
How are "messages to the future" implemented?



Simple models inspired by concrete implementations of such a mechanism.

In this talk: Adversary learns incoming messages to corrupted role *only when role is executed*

[Campanelli-David-Khoshakhlagh-Kristensen-Nielsen '21]

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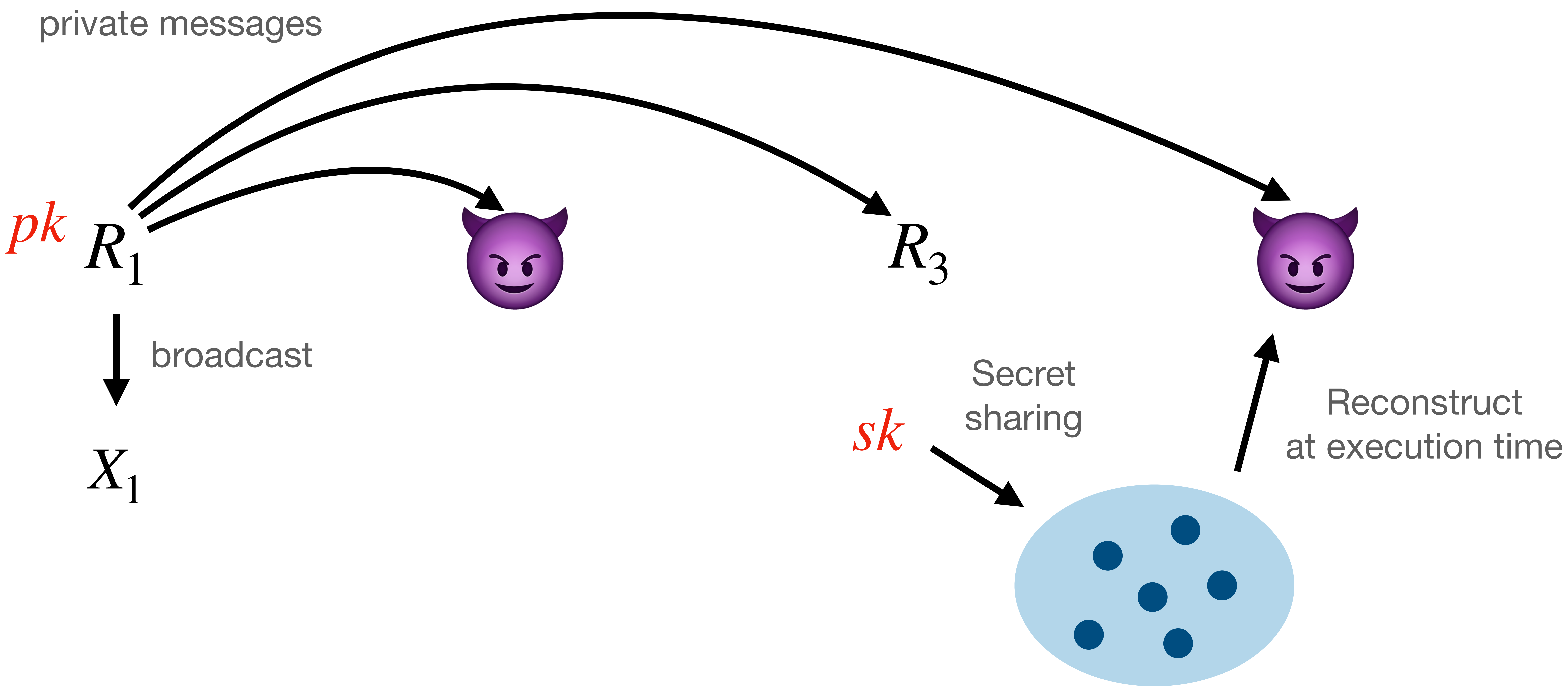

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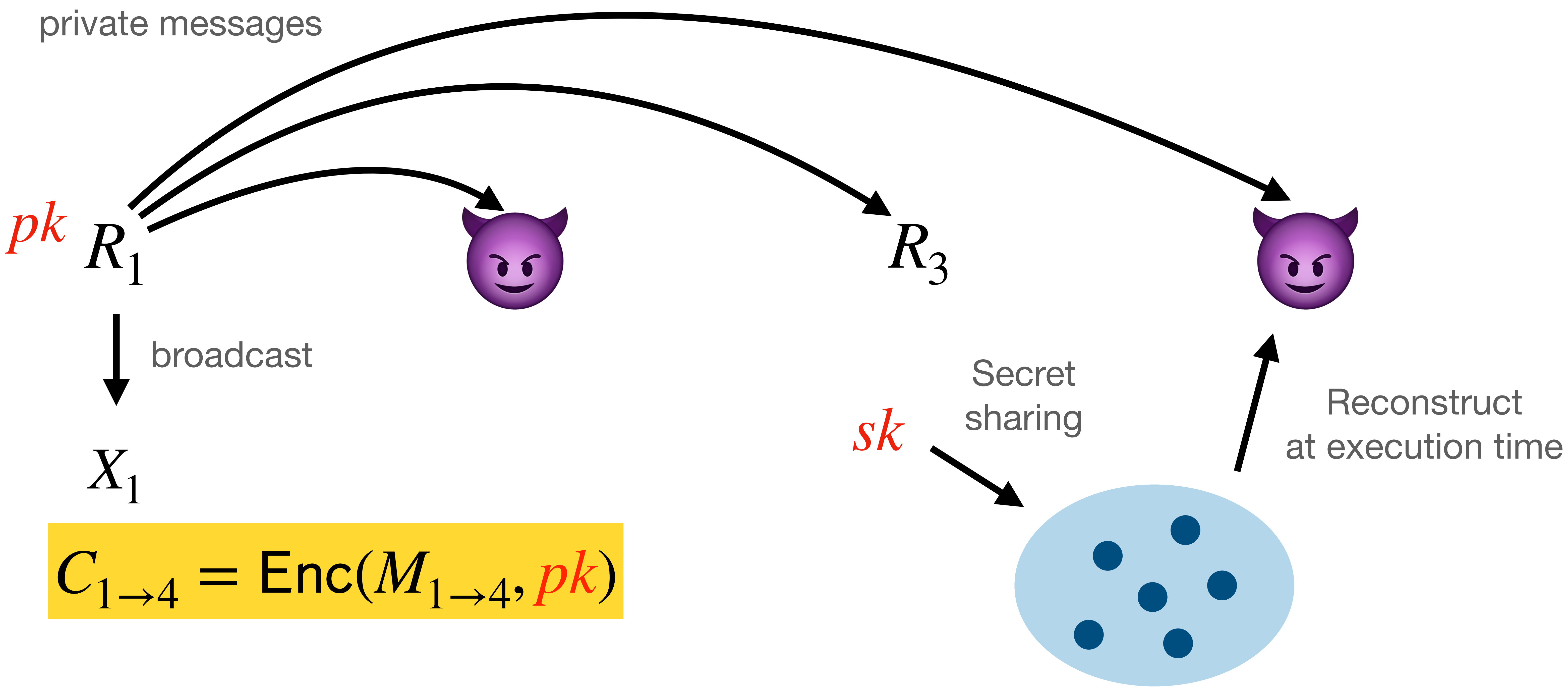

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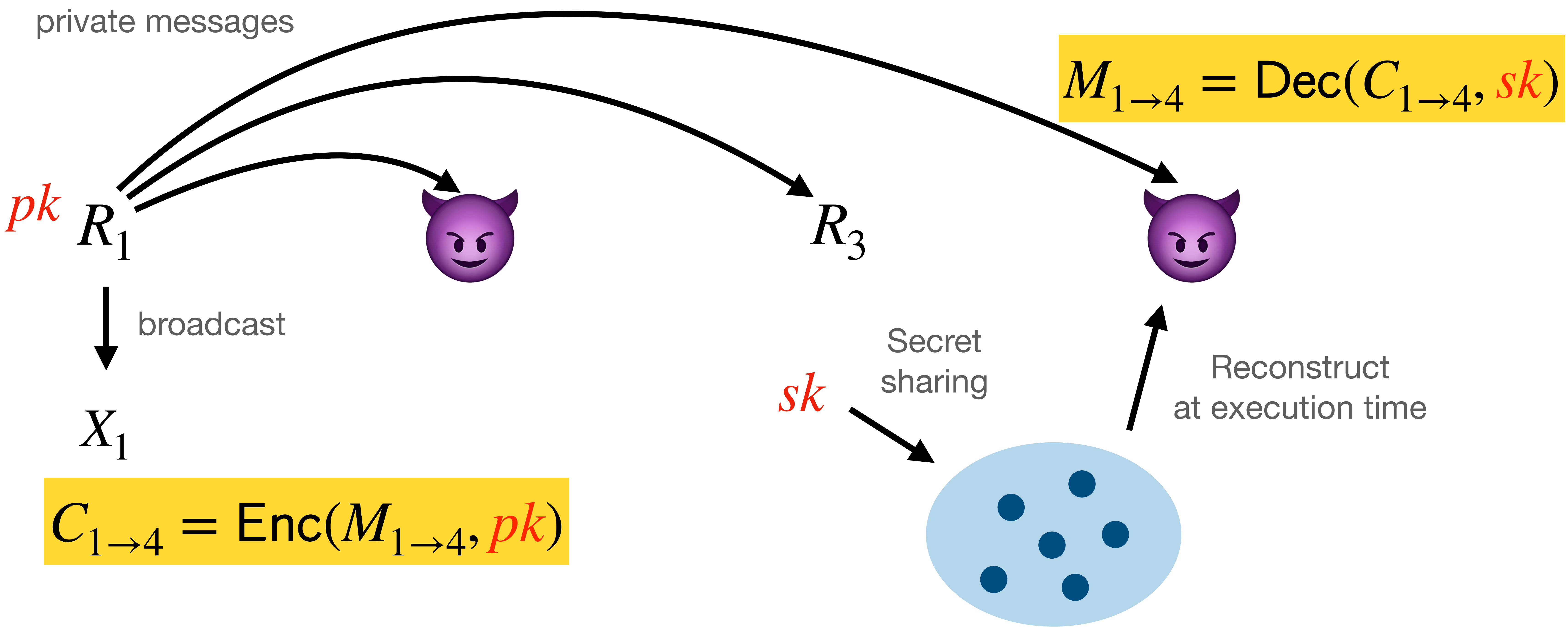

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Our central question

What is the maximum corruption rate that allows for low-bias randomness extraction?

A naive approach to YOSO protocols

Starting point: Round-based n-party r-round protocol secure against $t = \delta n$ corruptions.

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Emulate rounds in YOSO:

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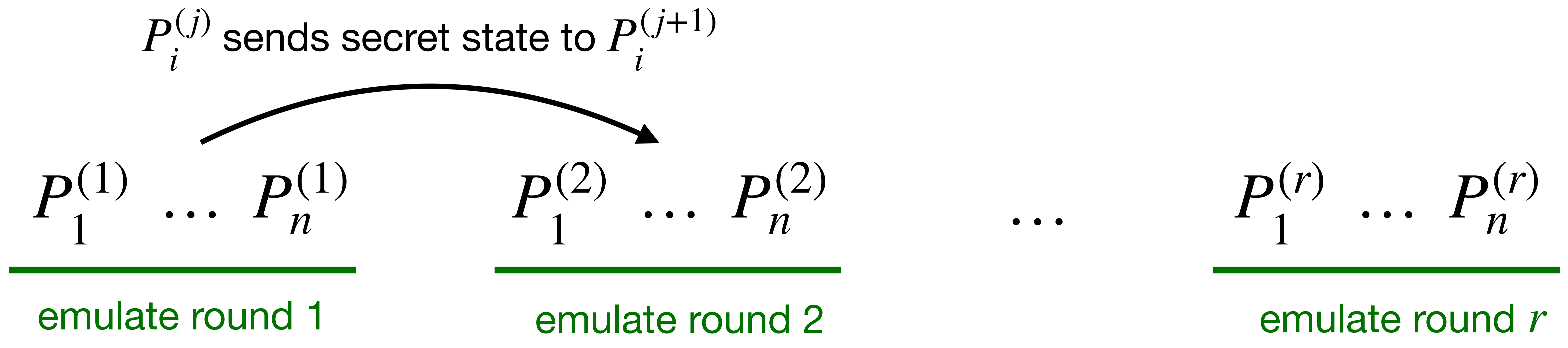

Tolerated corruption rate decreased from δ to δ/r

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emulate round 1   emulate round 2   emulate round r

Tolerated corruption rate decreased from δ to δ / r

3 rounds, $\delta \approx 1/3$ corruption rate $\Longrightarrow$ YOSO protocol secure against $\approx 1/9$ corruption rate

Our results

Feasibility

Impossibility

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Zero-error randomness extraction against t corruptions
with $n = 5t$ roles
(or $n = 6t + 1$ roles against stronger adversary)

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Impossibility

Randomness extraction with bias < 0.01
against t corruptions requires $n \geq 4t + 1$ roles

Protocol

There is a zero-error randomness extraction protocol secure against t chosen corruptions in the with $n = 5t + 2$ roles.

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samplers

R'_1 R'_2 $\cdots$ R'_{2t+1}

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High-level idea:

1. Several subsets of samplers commit to values and send them to publishers;
2. Publishers broadcast whatever they receive;
3. Extract random bit by taking majorities and XOR.

Protocol

$S = \{i_1 < i_2 < \cdots < i_{2t+1}\} \subseteq [3t+1]$

publishers

R_{i_1} R_{i_2} $\cdots$ R_{i_j} $\cdots$ $R_{i_{2t+1}}$ R'_1 $\cdots$ R'_{2t+1}

samplers

Protocol

$S = \{i_1 < i_2 < \cdots < i_{2t+1}\} \subseteq [3t+1]$

publishers

$x_1 \leftarrow \{0,1\}$

R_{i_1} R_{i_2} $\cdots$ R_{i_j} $\cdots$ $R_{i_{2t+1}}$ R'_1 $\cdots$ R'_{2t+1}

samplers

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$S = \{i_1 < i_2 < \cdots < i_{2t+1}\} \subseteq [3t+1]$

x_1

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Protocol

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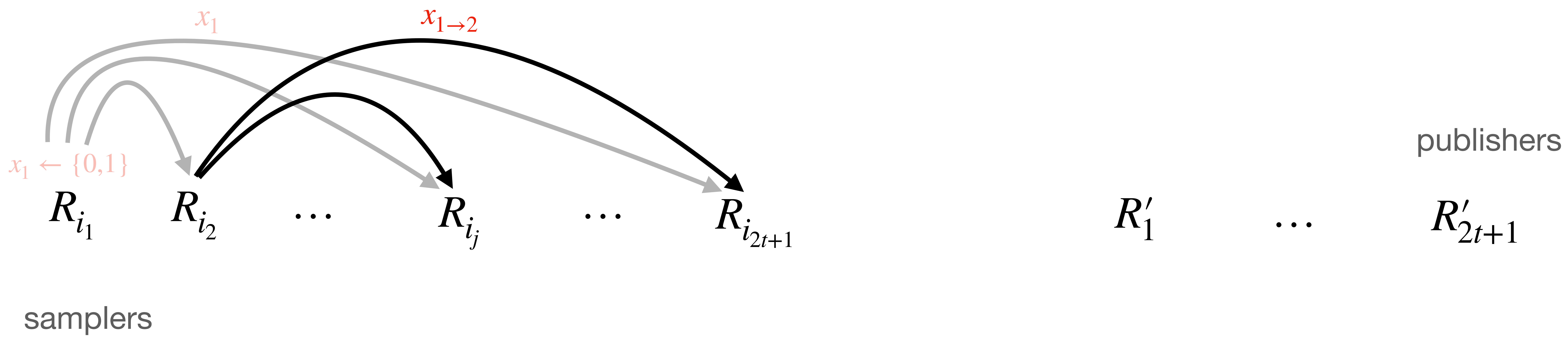

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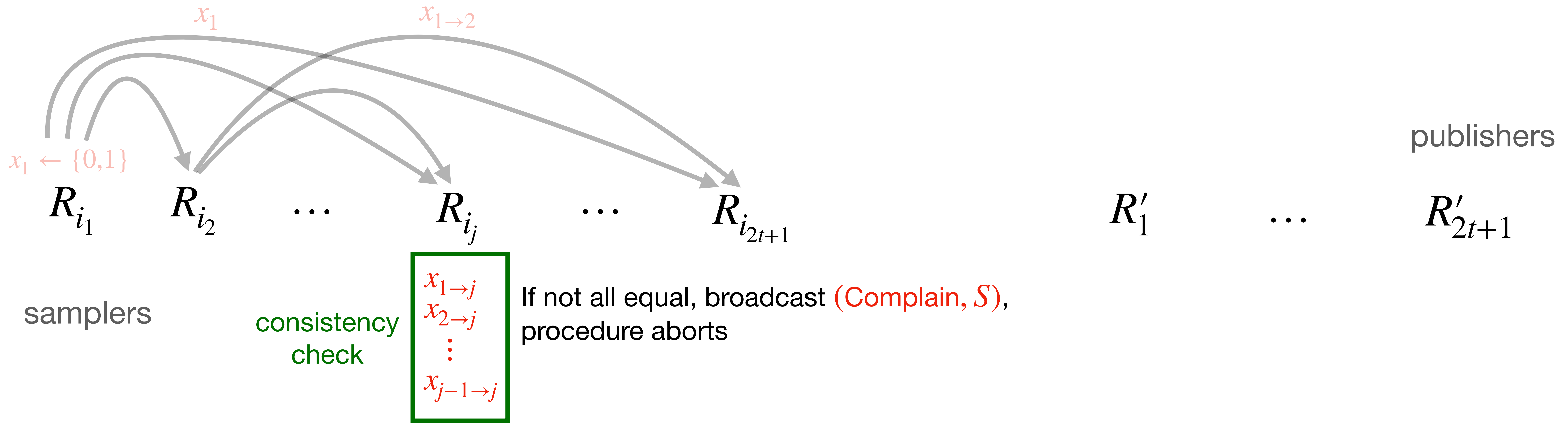

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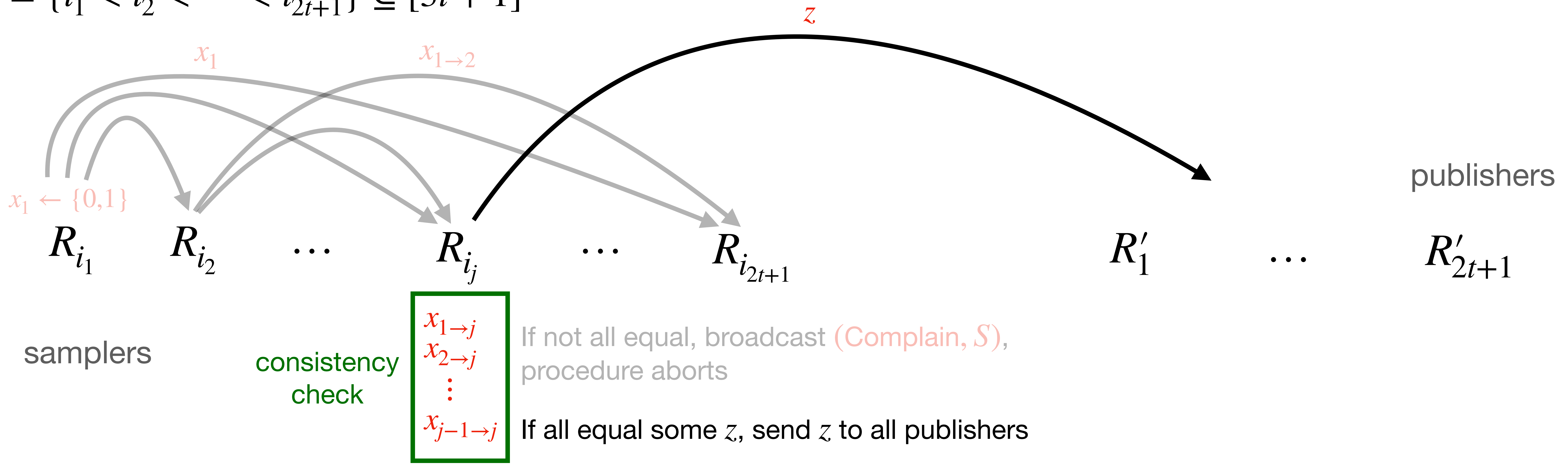

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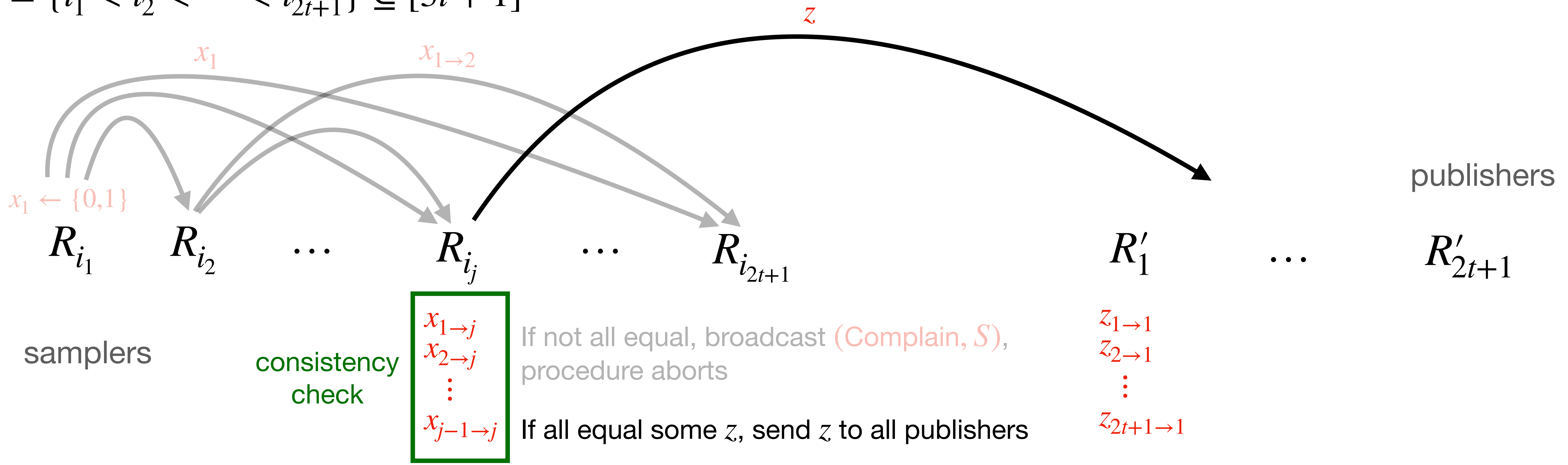
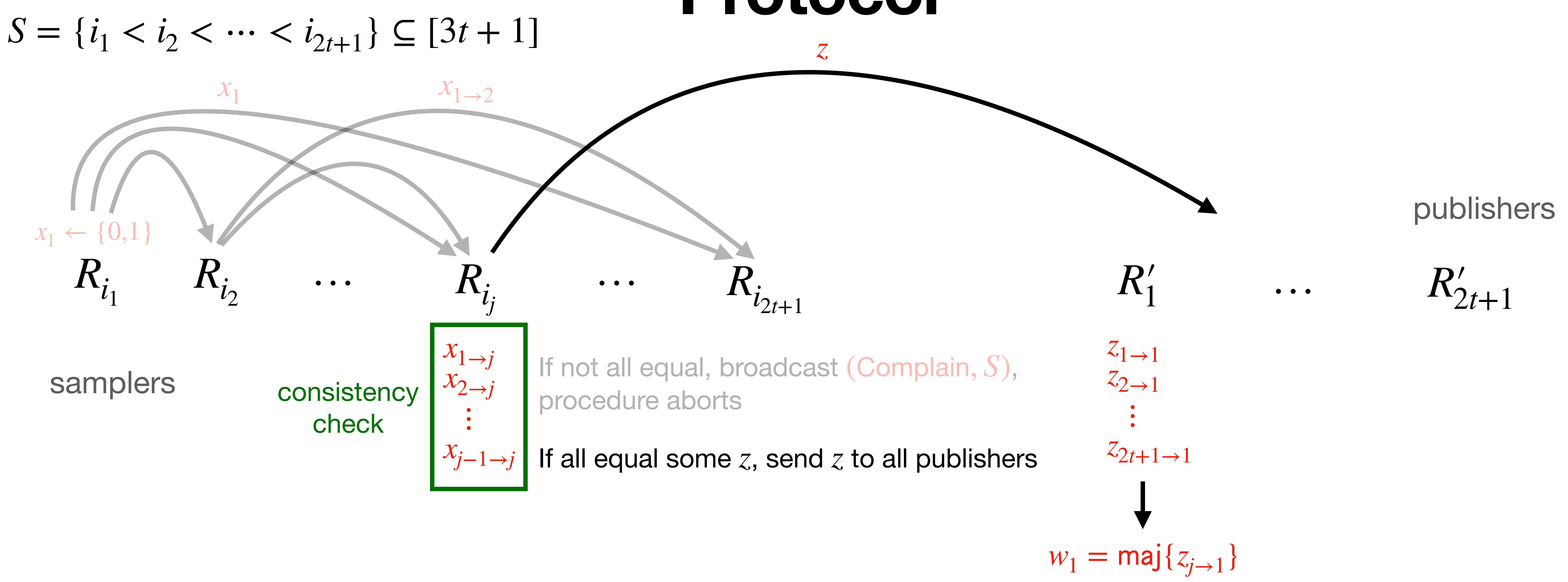


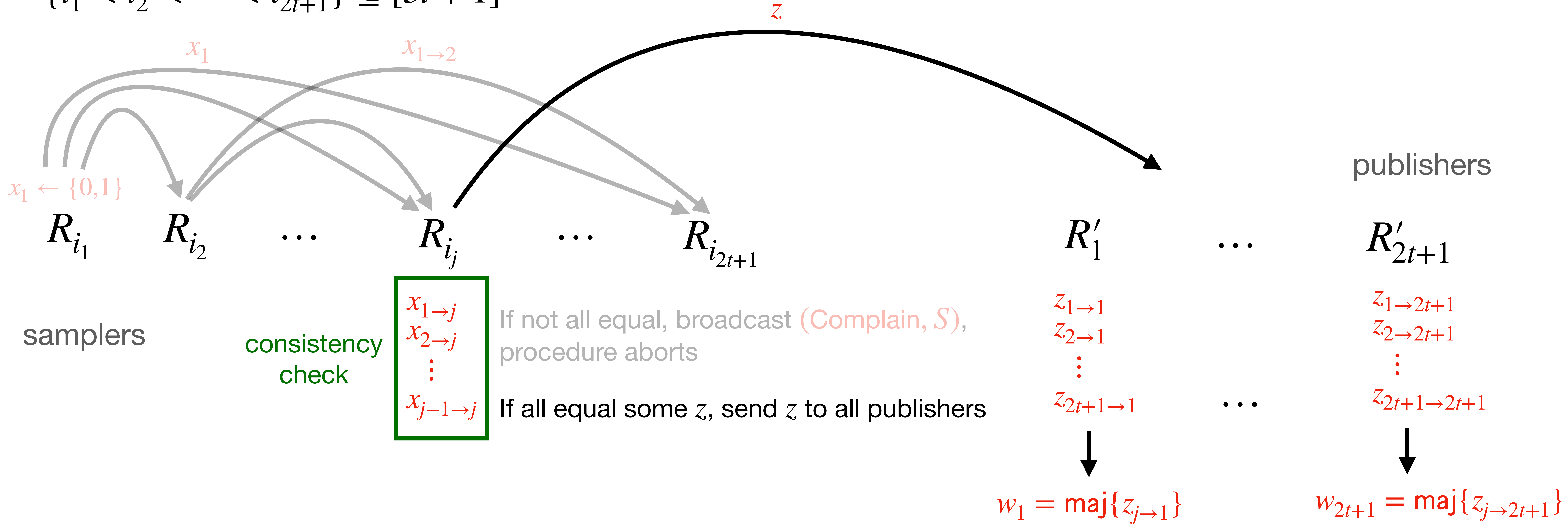
Protocol



$S = \{i_1 < i_2 < \cdots < i_{2t+1}\} \subseteq [3t+1]$
z
x_1
$x_{1\to 2}$
$x_1 \leftarrow \{0,1\}$
publishers
R_{i_1} R_{i_2} $\cdots$ R_{i_j} $\cdots$ $R_{i_{2t+1}}$
R'_1 $\cdots$ R'_{2t+1}
samplers
consistency check
$x_{1\to j}$
$x_{2\to j}$
$\vdots$
$x_{j-1\to j}$
If not all equal, broadcast (Complain, S), procedure aborts
If all equal some z, send z to all publishers
$z_{1\to 1}$
$z_{2\to 1}$
$\vdots$
$z_{2t+1\to 1}$
$w_1 =$ maj$\{z_{j\to 1}\}$

Protocol

$S = \{i_1 < i_2 < \cdots < i_{2t+1}\} \subseteq [3t+1]$



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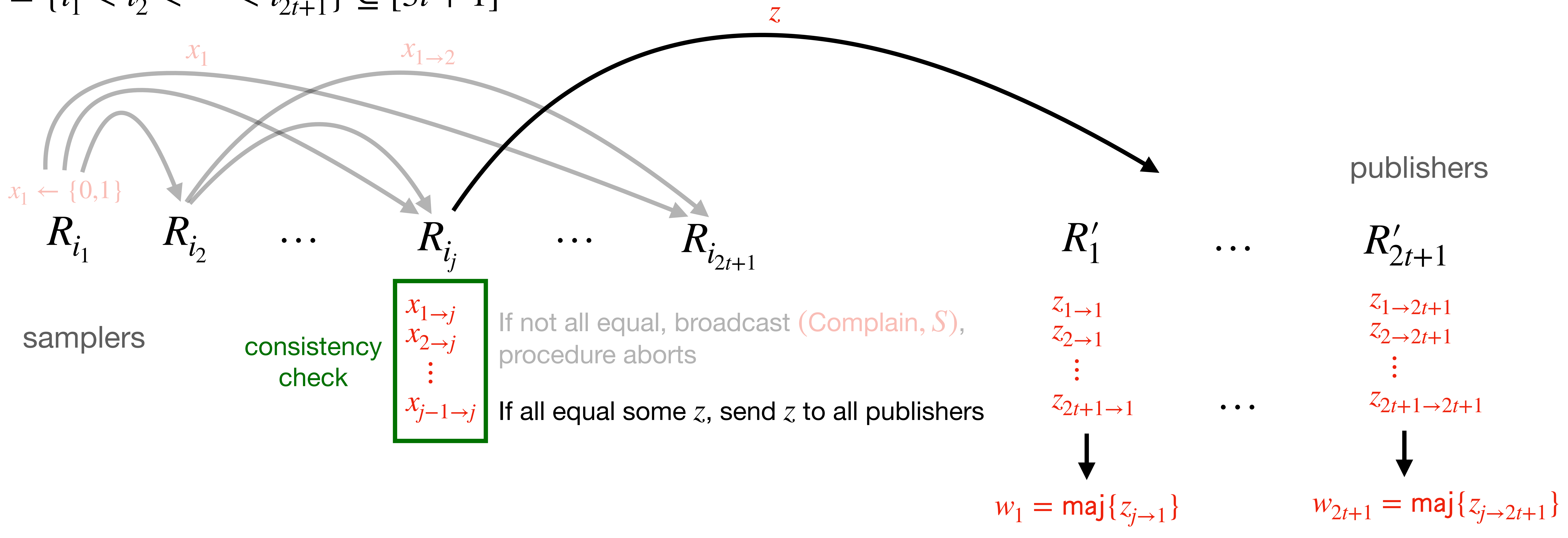

$$w_S = \begin{cases} 0, & \text{if } S \text{ received a complaint,} \\ \text{maj}(w_j), & \text{else.} \end{cases}$$

Protocol

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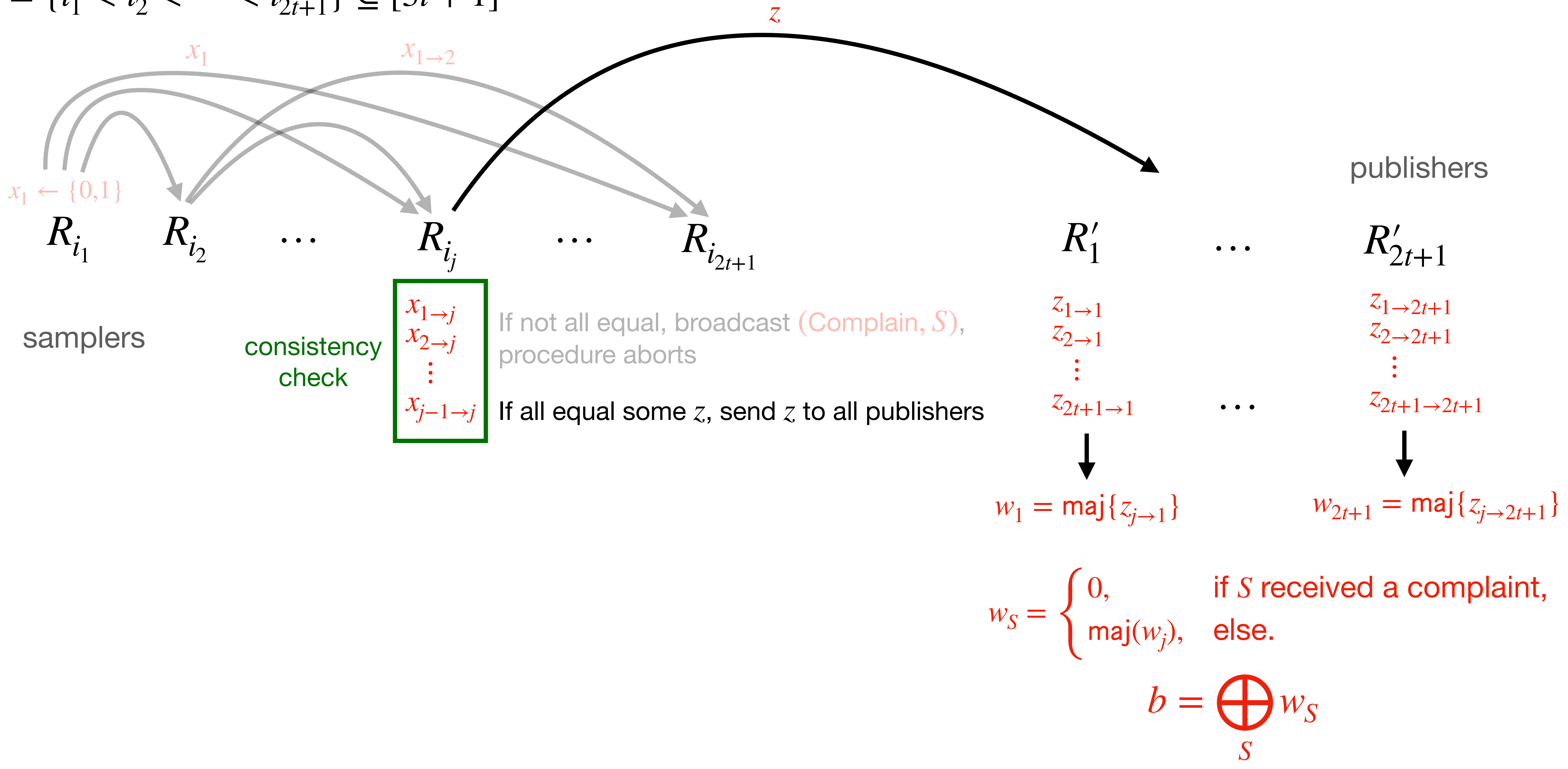

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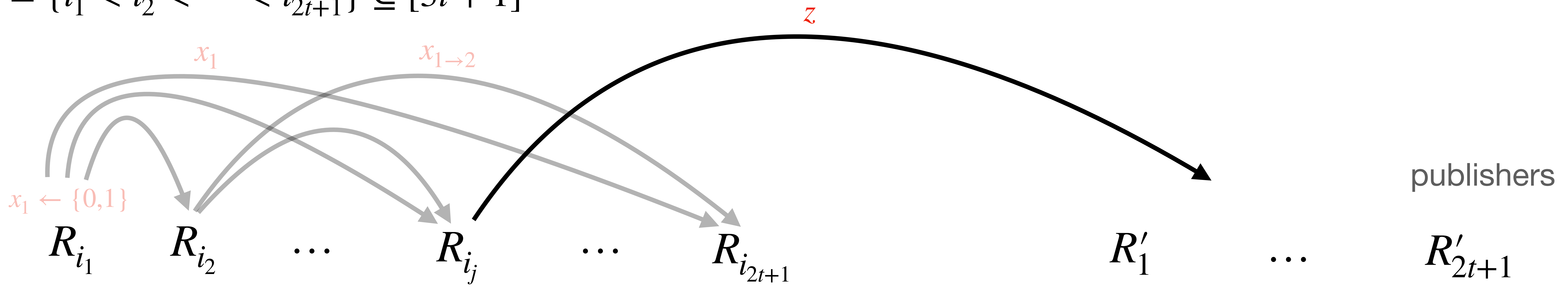

samplers

consistency check

$$\boxed{\begin{matrix} x_{1\to j} \\ x_{2\to j} \\ \vdots \\ x_{j-1\to j} \end{matrix}}$$

If not all equal, broadcast (Complain, S), procedure aborts

If all equal some z, send z to all publishers

$$\begin{matrix} z_{1\to 1} \\ z_{2\to 1} \\ \vdots \\ z_{2t+1\to 1} \end{matrix} \quad \cdots \quad \begin{matrix} z_{1\to 2t+1} \\ z_{2\to 2t+1} \\ \vdots \\ z_{2t+1\to 2t+1} \end{matrix}$$

$$w_1 = \text{maj}\{z_{j\to 1}\} \qquad w_{2t+1} = \text{maj}\{z_{j\to 2t+1}\}$$

$$w_S = \begin{cases} 0, & \text{if } S \text{ received a complaint,} \\ \text{maj}(w_j), & \text{else.} \end{cases}$$

$$b = \bigoplus_S w_S$$

Key properties:

Protocol

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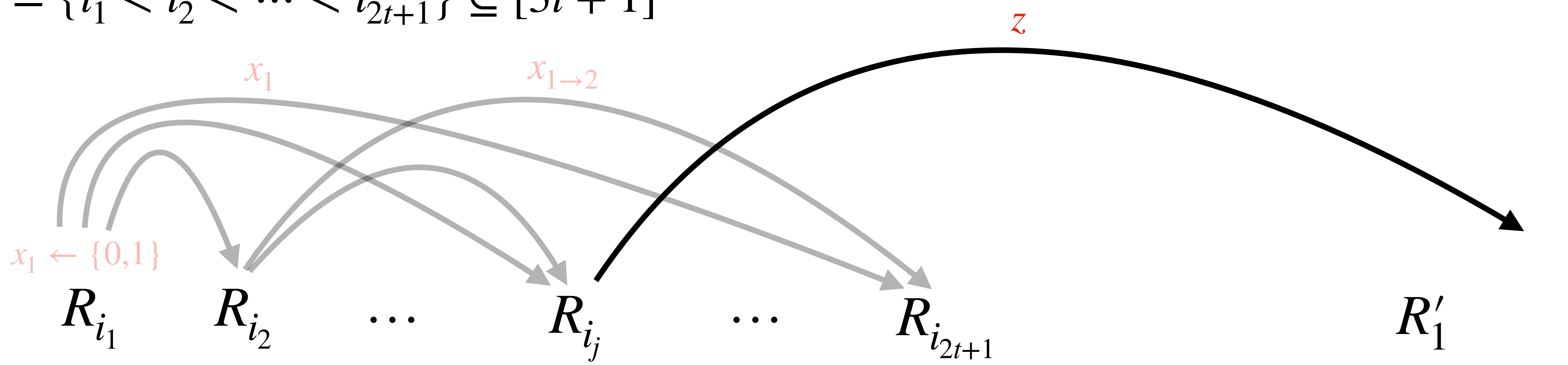

samplers

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$$\begin{matrix} z_{1\to 1} & & z_{1\to 2t+1} \\ z_{2\to 1} & & z_{2\to 2t+1} \\ \vdots & \cdots & \vdots \\ z_{2t+1\to 1} & \cdots & z_{2t+1\to 2t+1} \\ \downarrow & & \downarrow \\ w_1 = \mathrm{maj}\{z_{j\to 1}\} & & w_{2t+1} = \mathrm{maj}\{z_{j\to 2t+1}\} \end{matrix}$$

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- Every set S has a strict honest majority;

Protocol

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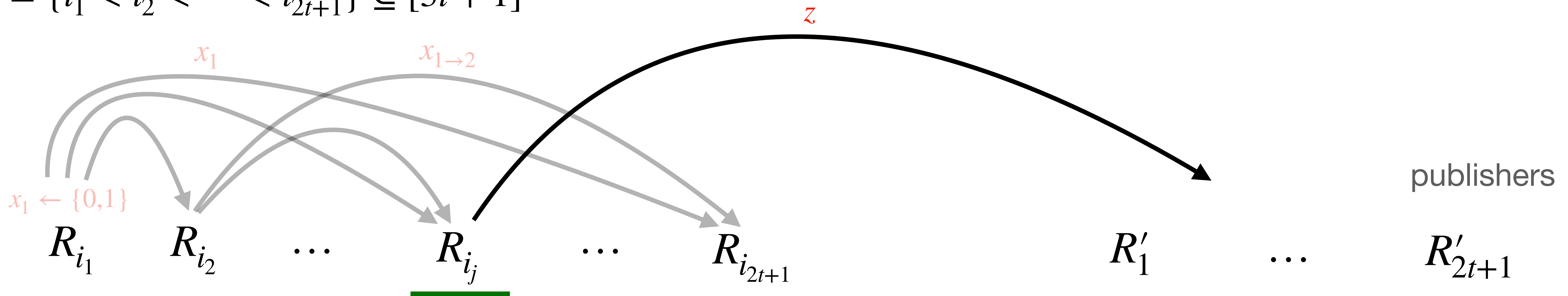

samplers

consistency check

$\boxed{\begin{matrix} x_{1\to j} \\ x_{2\to j} \\ \vdots \\ x_{j-1\to j} \end{matrix}}$

If not all equal, broadcast (Complain, S), procedure aborts

If all equal some z, send z to all publishers

$z_{1\to 1}$, $z_{2\to 1}$, $\vdots$, $z_{2t+1\to 1}$ $\cdots$ $z_{1\to 2t+1}$, $z_{2\to 2t+1}$, $\vdots$, $z_{2t+1\to 2t+1}$

$w_1 = \text{maj}\{z_{j\to 1}\}$ $\qquad$ $w_{2t+1} = \text{maj}\{z_{j\to 2t+1}\}$

$$w_S = \begin{cases} 0, & \text{if } S \text{ received a complaint,} \\ \text{maj}(w_j), & \text{else.} \end{cases}$$

$$b = \bigoplus_S w_S$$

Key properties:

- Every set S has a strict honest majority;
- If S did not receive a complaint, then all honest roles in S agree on the same value;

Protocol

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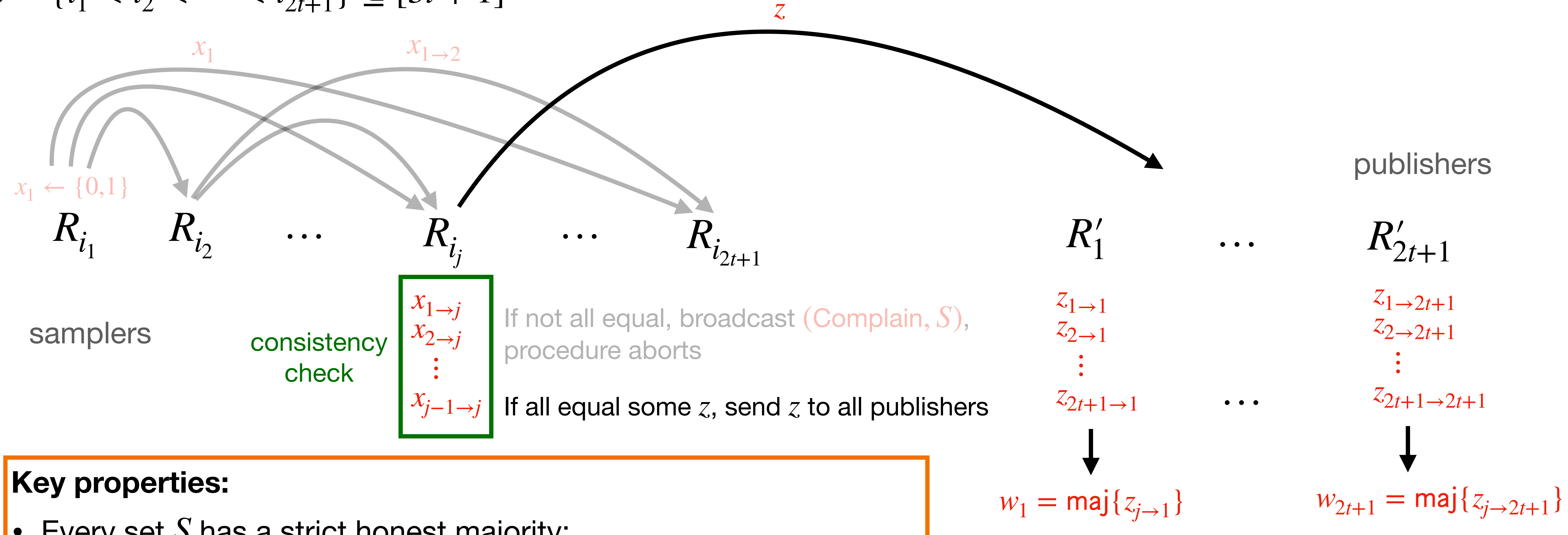

Key properties:

- Every set S has a strict honest majority;
- If S did not receive a complaint, then all honest roles in S agree on the same value;
- There is a set $S^\star$ such that all roles $(P_i)_{i\in S^\star}$ are honest.

$$w_S = \begin{cases} 0, & \text{if } S \text{ received a complaint,} \\ \mathrm{maj}(w_j), & \text{else.} \end{cases}$$

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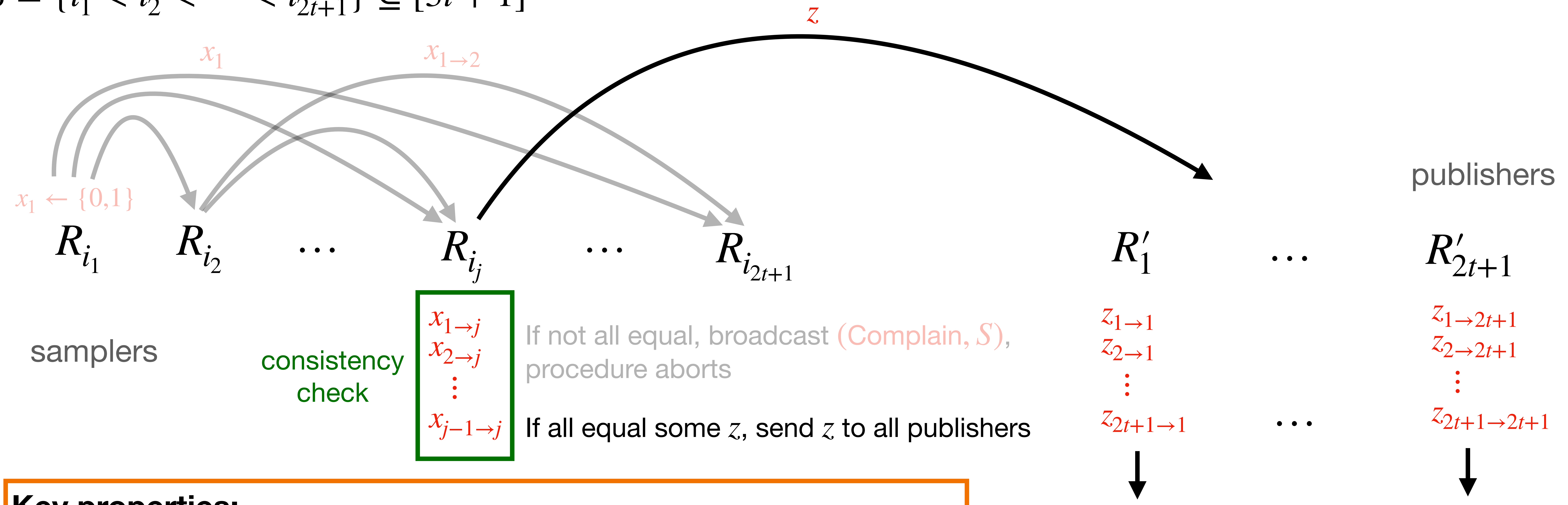
Protocol

$$S = \{i_1 < i_2 < \cdots < i_{2t+1}\} \subseteq [3t+1]$$



$w_1 = \text{maj}\{z_{j\to 1}\}$ $\quad$ $w_{2t+1} = \text{maj}\{z_{j\to 2t+1}\}$

Key properties:

- Every set S has a strict honest majority;
- If S did not receive a complaint, then all honest roles in S agree on the same value;
- There is a set $S^\star$ such that all roles $(P_i)_{i\in S^\star}$ are honest.

$\Longrightarrow$ $w_{S^\star}$ is uniform and independent of $(w_S)_{S\neq S^\star}$.

$$w_S = \begin{cases} 0, & \text{if } S \text{ received a complaint,} \\ \text{maj}(w_j), & \text{else.} \end{cases}$$

$$b = \bigoplus_S w_S$$

A simple improved protocol for one corruption

samplers

publishers

R_1 R_2 R'_1 R'_2 R'_3

A simple improved protocol for one corruption

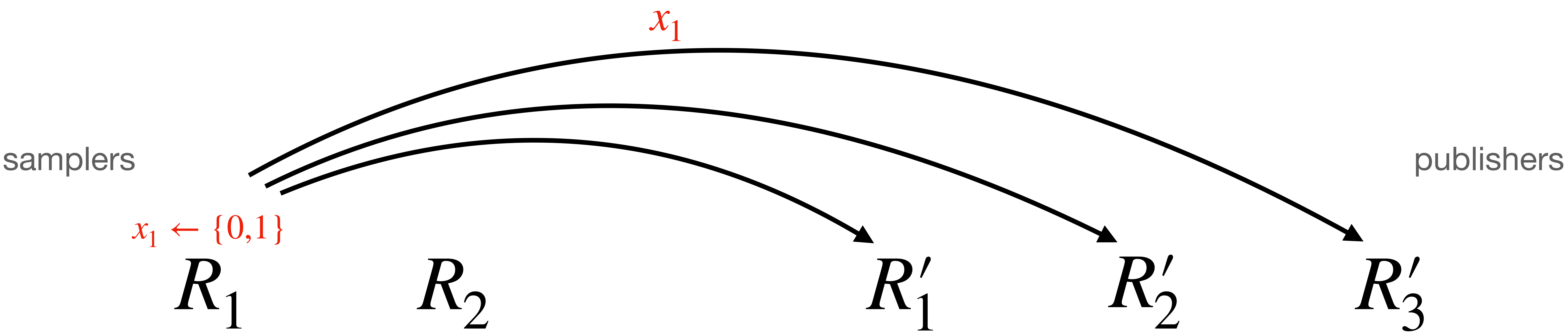
samplers

publishers

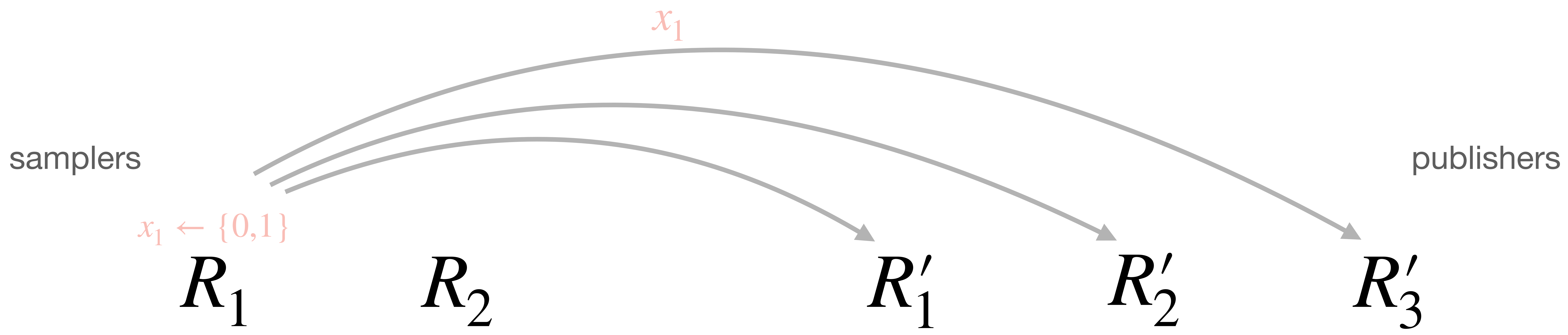
$x_1 \leftarrow \{0,1\}$

R_1 R_2 R'_1 R'_2 R'_3

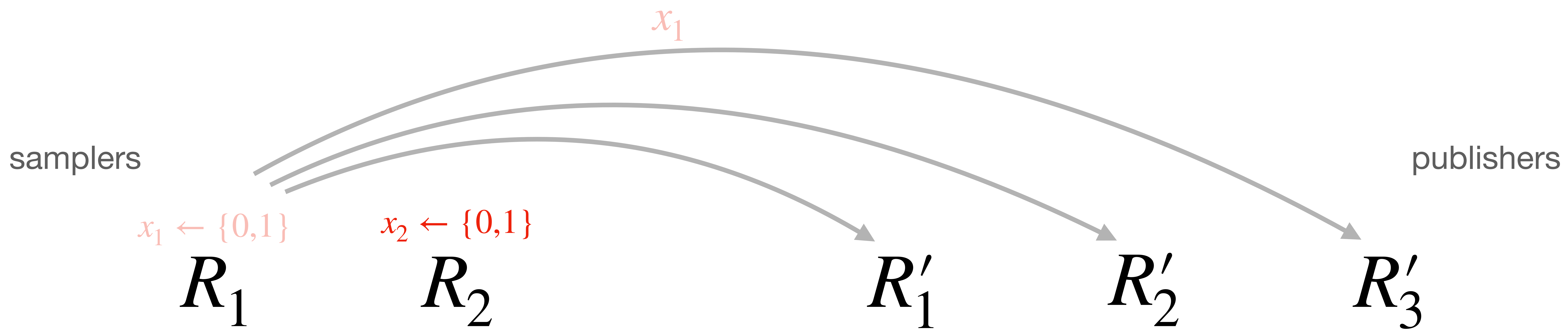
A simple improved protocol for one corruption



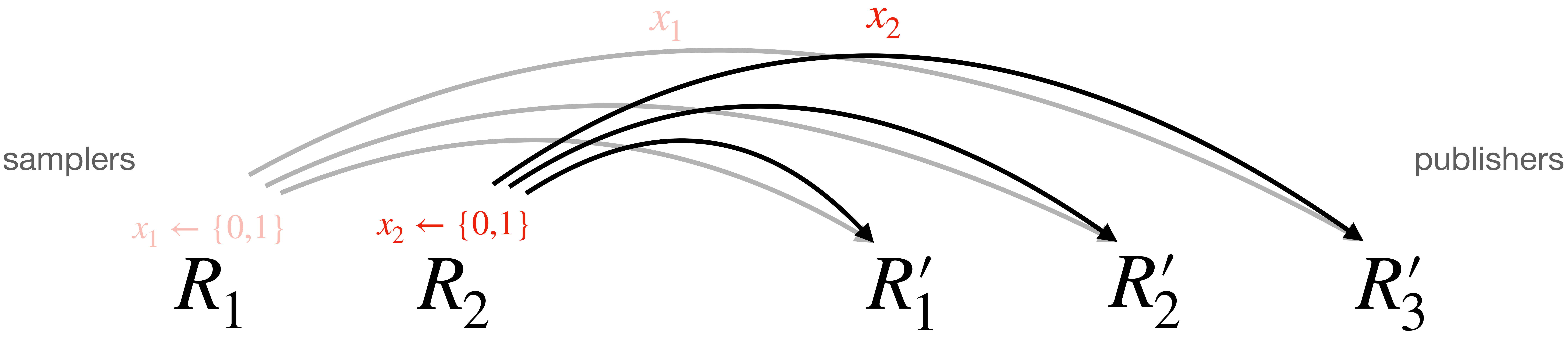
A simple improved protocol for one corruption



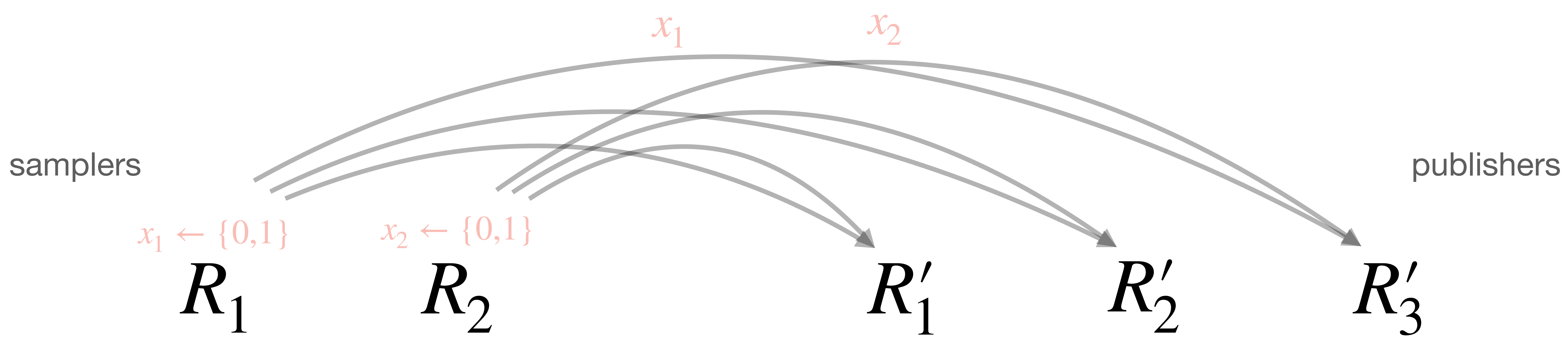
A simple improved protocol for one corruption



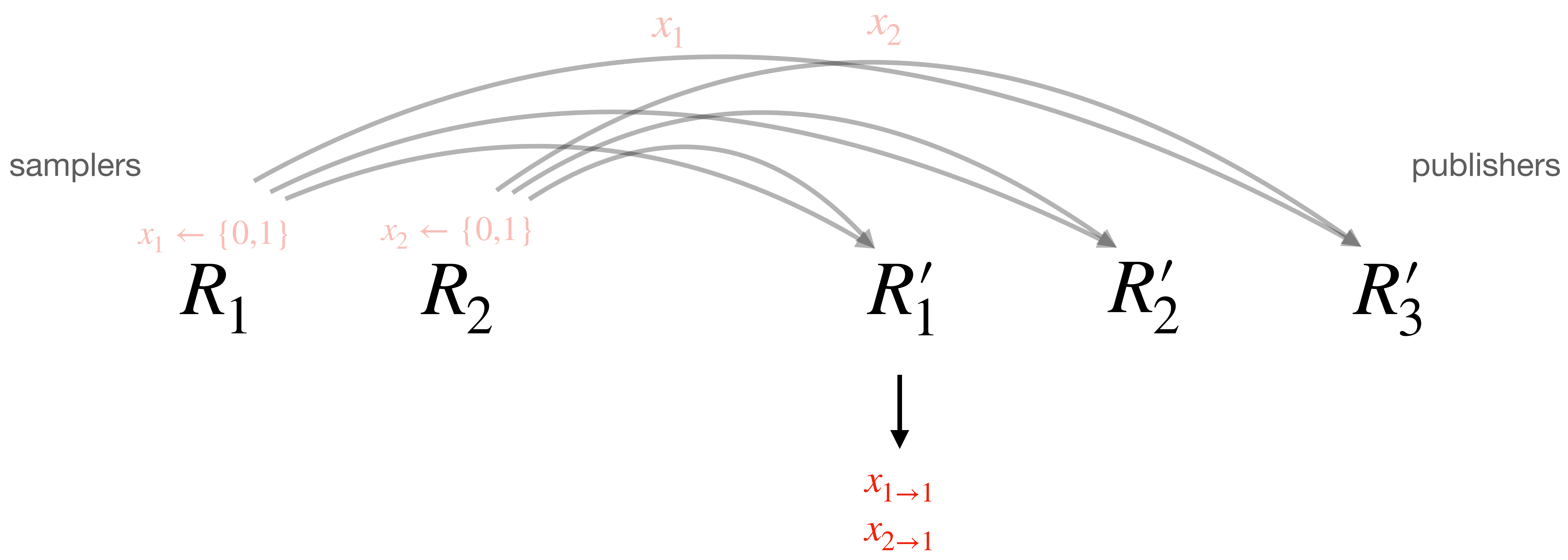
A simple improved protocol for one corruption



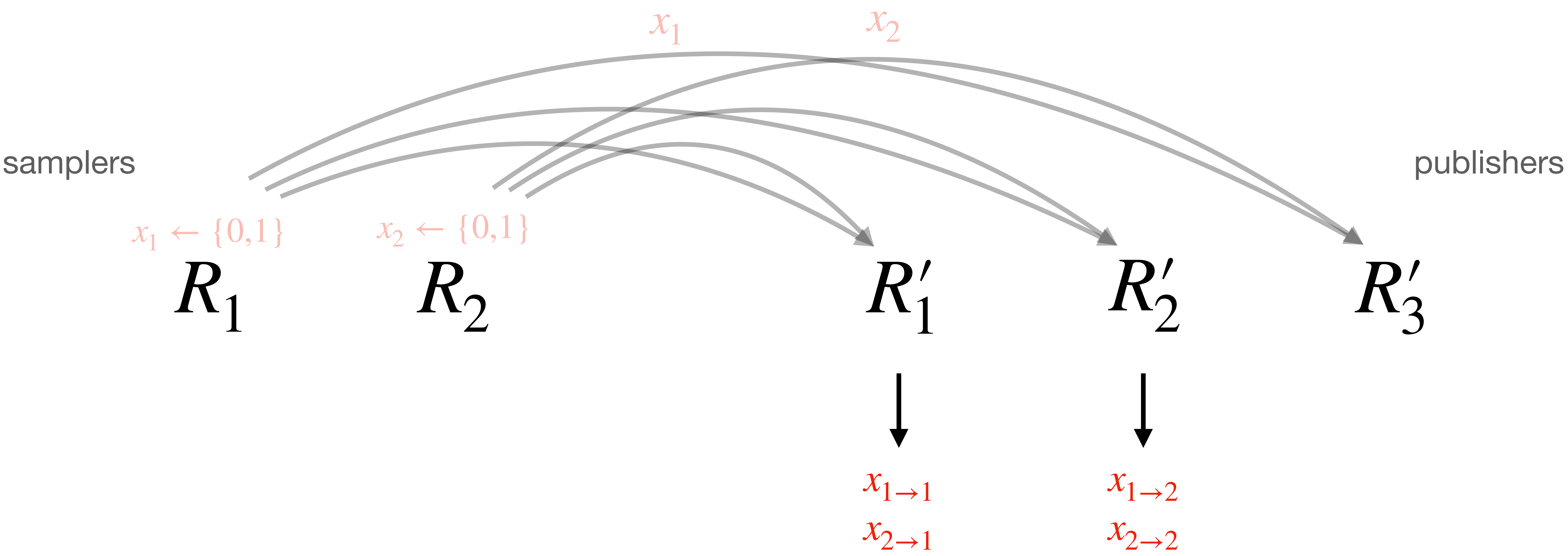
A simple improved protocol for one corruption



A simple improved protocol for one corruption



A simple improved protocol for one corruption



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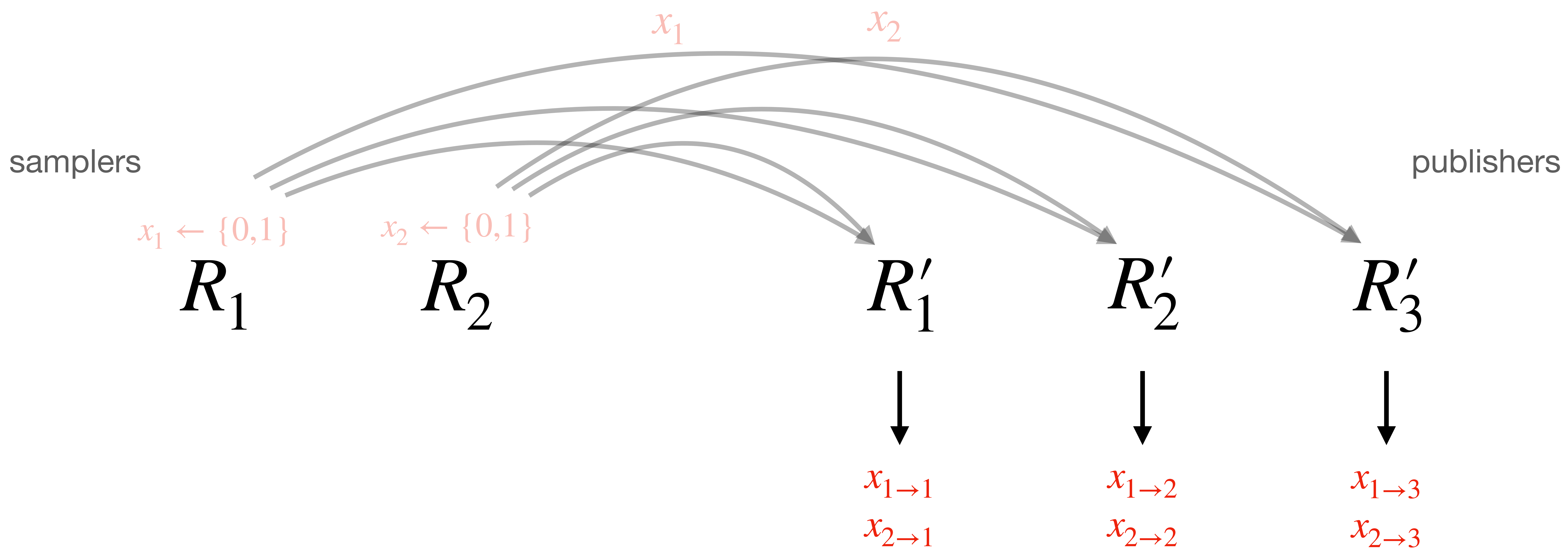

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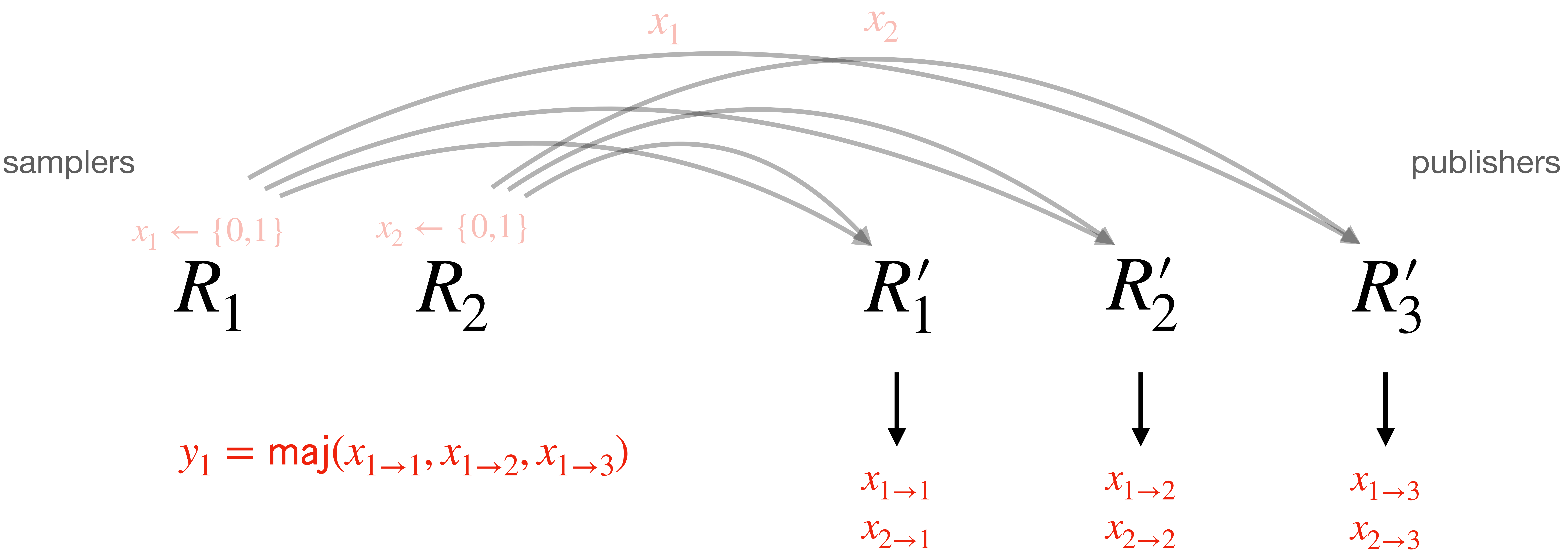

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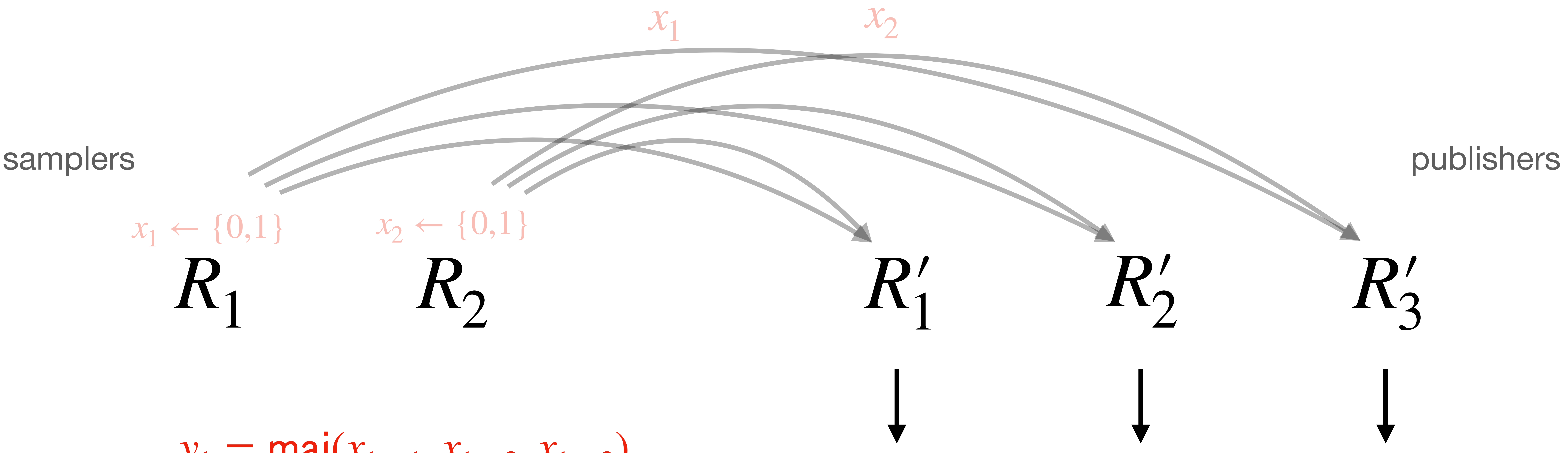
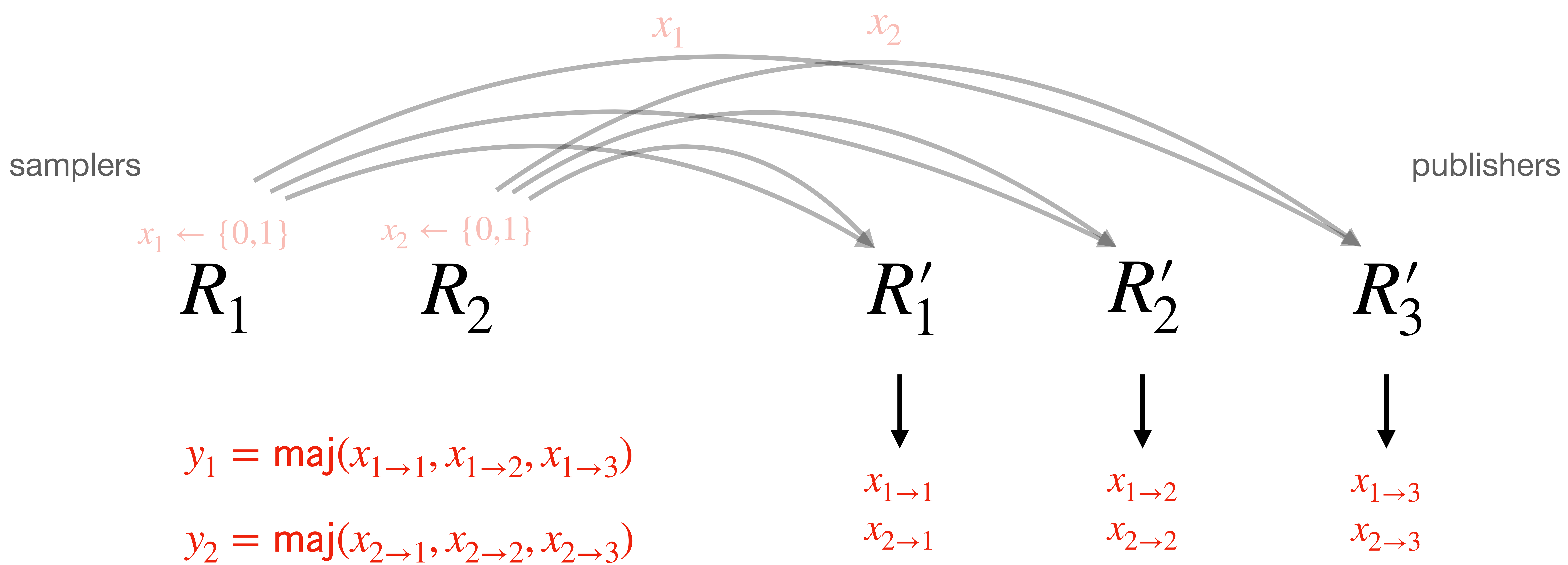


$x_{1\to 1}$	$x_{1\to 2}$	$x_{1\to 3}$
$x_{2\to 1}$	$x_{2\to 2}$	$x_{2\to 3}$

$y_1 = \text{maj}(x_{1\to 1}, x_{1\to 2}, x_{1\to 3})$

$y_2 = \text{maj}(x_{2\to 1}, x_{2\to 2}, x_{2\to 3})$

A simple improved protocol for one corruption

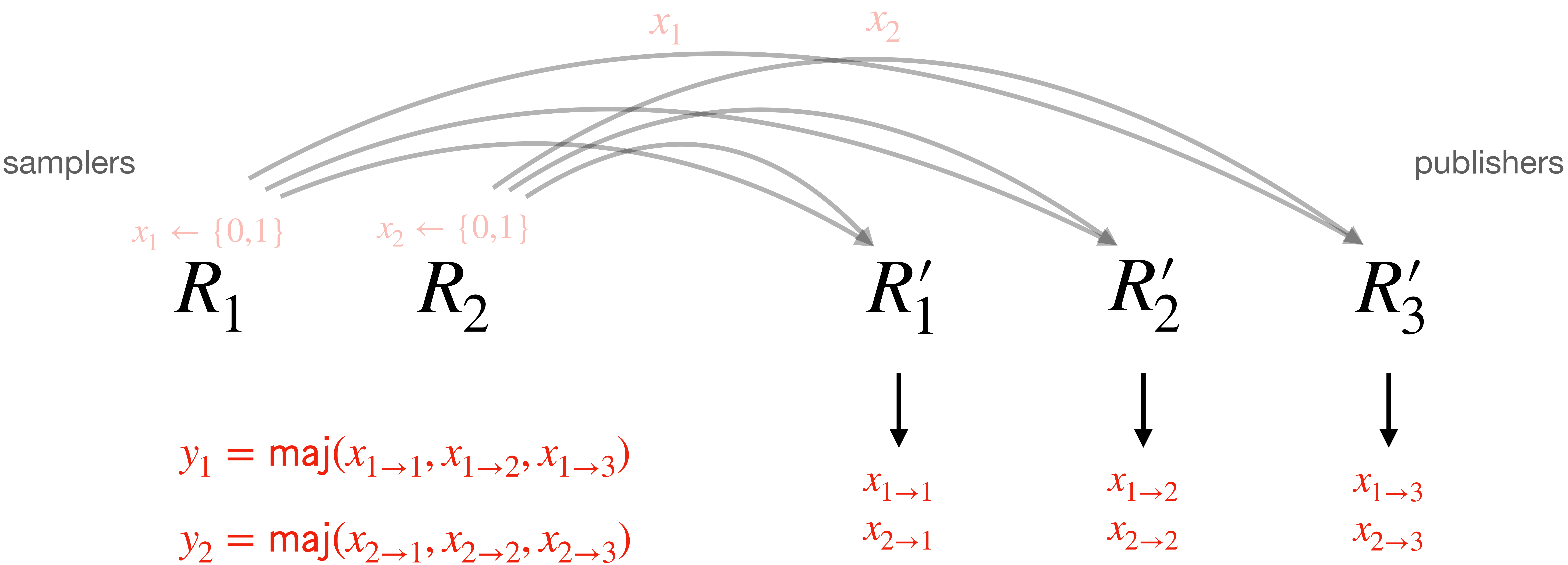


$y_1 = \mathsf{maj}(x_{1\to1}, x_{1\to2}, x_{1\to3})$

$y_2 = \mathsf{maj}(x_{2\to1}, x_{2\to2}, x_{2\to3})$

$b = y_1 \oplus y_2$

A simple improved protocol for one corruption



$y_1 = \text{maj}(x_{1\to1}, x_{1\to2}, x_{1\to3})$

$y_2 = \text{maj}(x_{2\to1}, x_{2\to2}, x_{2\to3})$

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Can be generalized using $n = 5t$ roles.

Impossibility result

Every randomness extraction protocol with bias < 0.01 against t corruptions requires $n \geq 4t + 1$ roles.

Impossibility result

Every randomness extraction protocol with bias < 0.01 against t corruptions requires $n \geq 4t + 1$ roles.

$n^\star = n^\star(t) =$ Smallest number of roles for which we can handle t corruptions

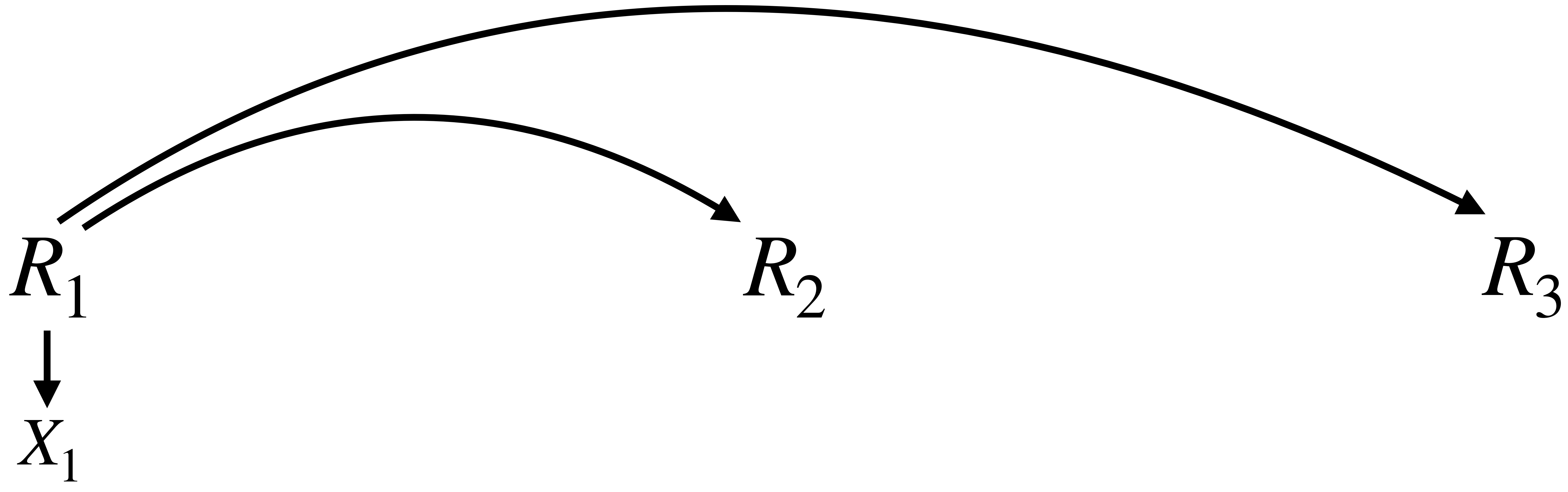
Stronger adversary: $4t + 1 \leq n^\star \leq 6t + 1$

Weaker adversary (this talk): $4t + 1 \leq n^\star \leq 5t$

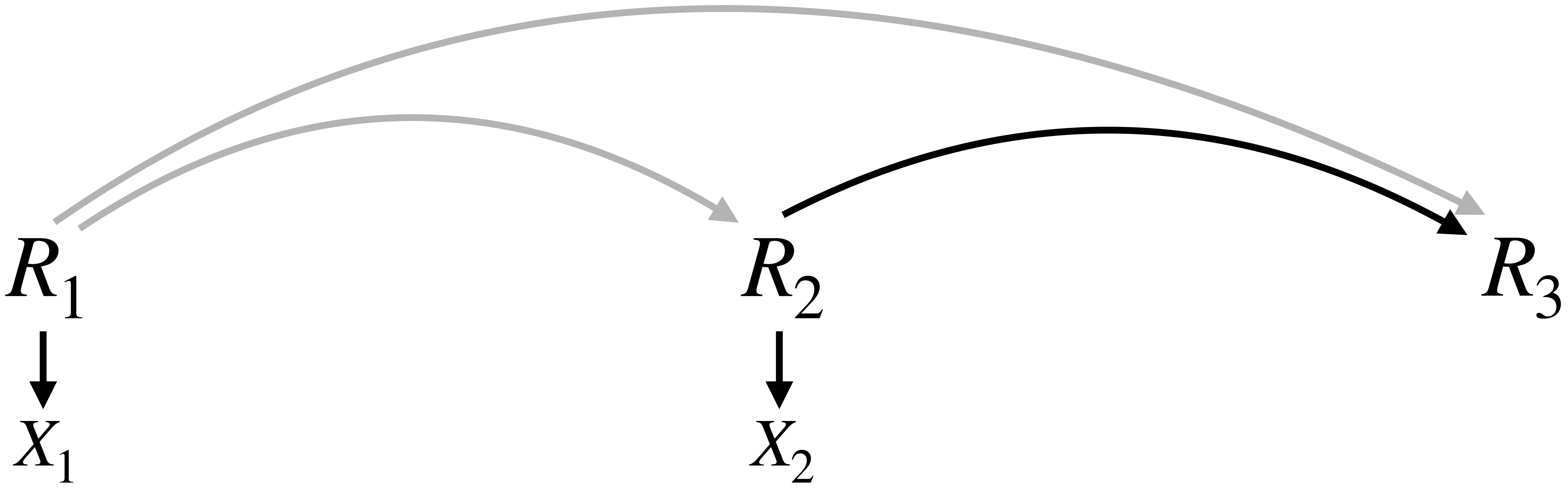
Impossibility for 3 roles, 1 corruption

R_1 R_2 R_3

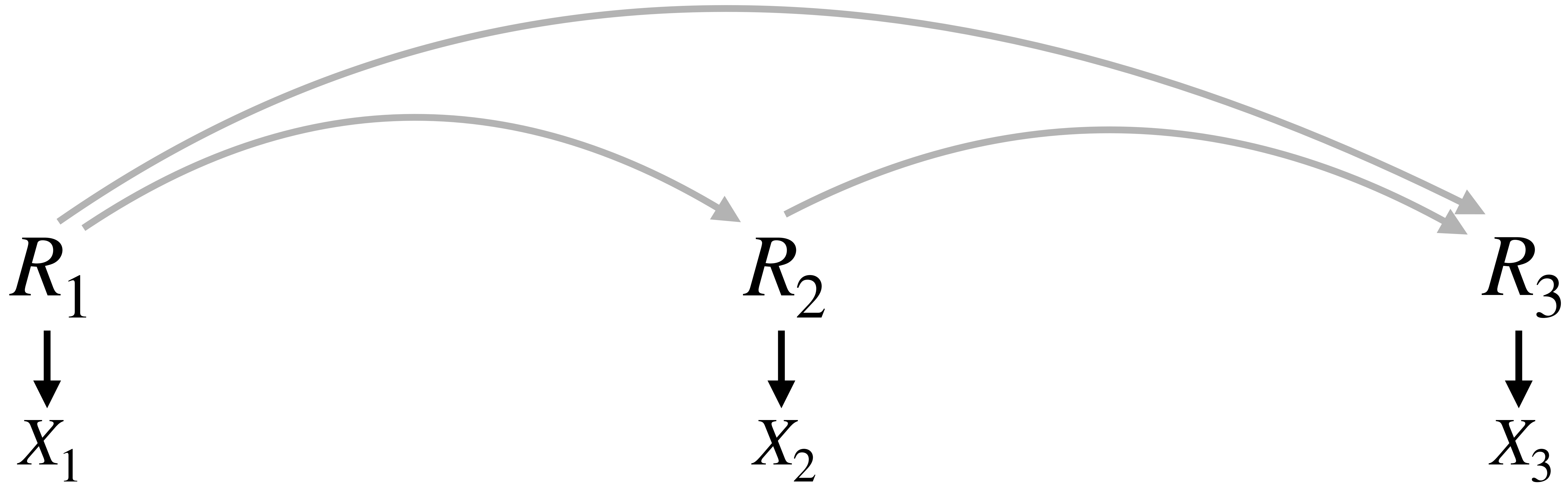
Impossibility for 3 roles, 1 corruption



Impossibility for 3 roles, 1 corruption



Impossibility for 3 roles, 1 corruption

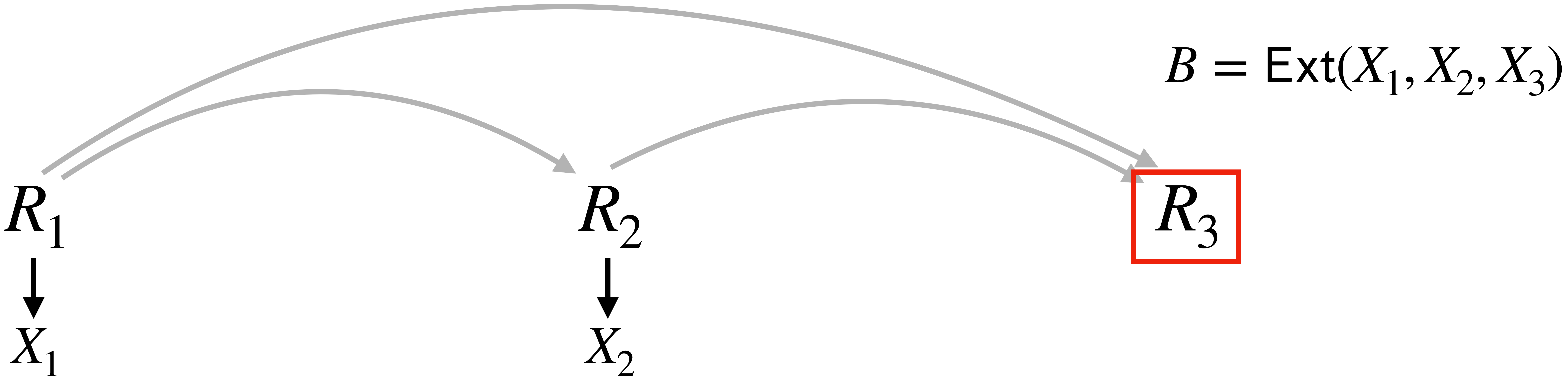


Impossibility for 3 roles, 1 corruption

$$B = \mathsf{Ext}(X_1, X_2, X_3)$$

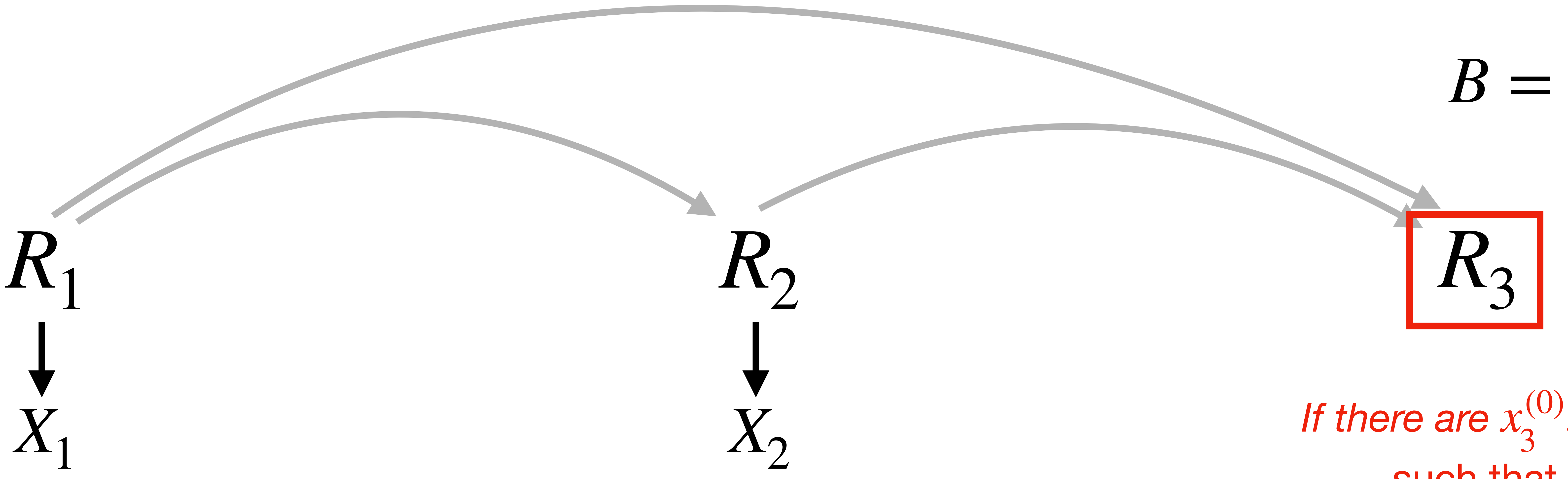
$$\begin{tikzcd}
R_1 \arrow[r, bend left] \arrow[rr, bend left] \arrow[d] & R_2 \arrow[r, bend left] \arrow[d] & R_3 \arrow[d] \\
X_1 & X_2 & X_3
\end{tikzcd}$$

Impossibility for 3 roles, 1 corruption



Impossibility for 3 roles, 1 corruption

$B = \mathsf{Ext}(X_1, X_2, X_3)$



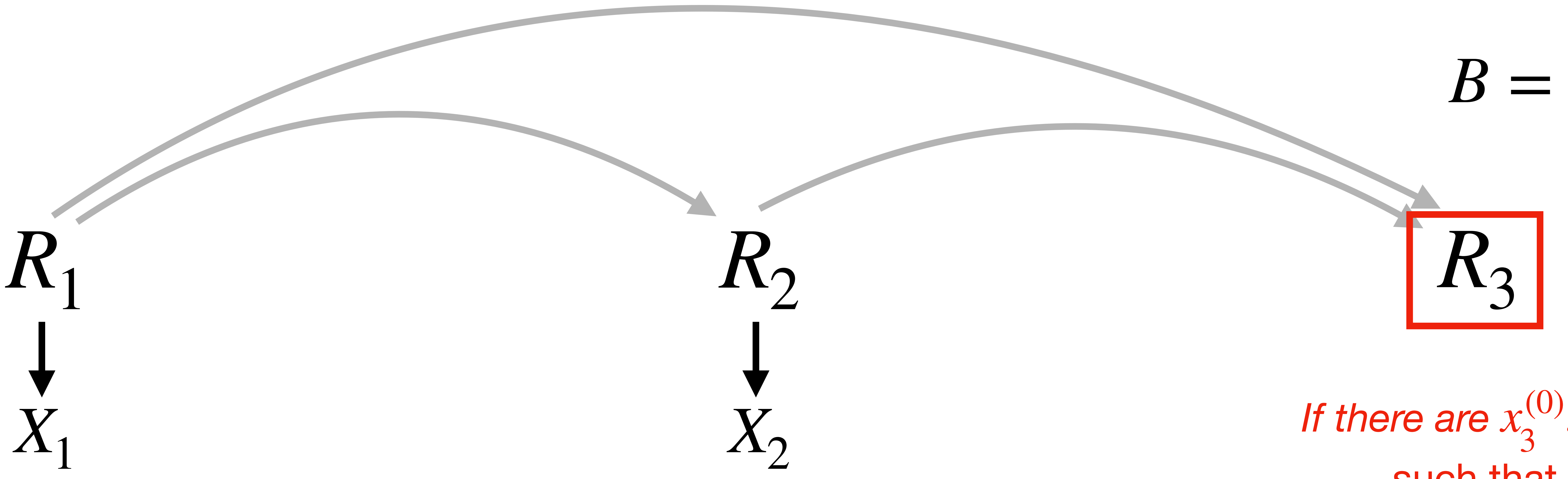
If there are $x_3^{(0)}, x_3^{(1)}$

such that

$\mathsf{Ext}(X_1, X_2, x_3^{(b)}) = b$

Impossibility for 3 roles, 1 corruption

$B = \mathsf{Ext}(X_1, X_2, X_3)$



If there are $x_3^{(0)}, x_3^{(1)}$
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Bias!

Impossibility for 3 roles, 1 corruption

$B = \text{Ext}(X_1, X_2, X_3)$

R_1 $\quad$ R_2 $\quad$ $\boxed{R_3}$

$\downarrow$ $\quad$ $\downarrow$

X_1 $\quad$ X_2

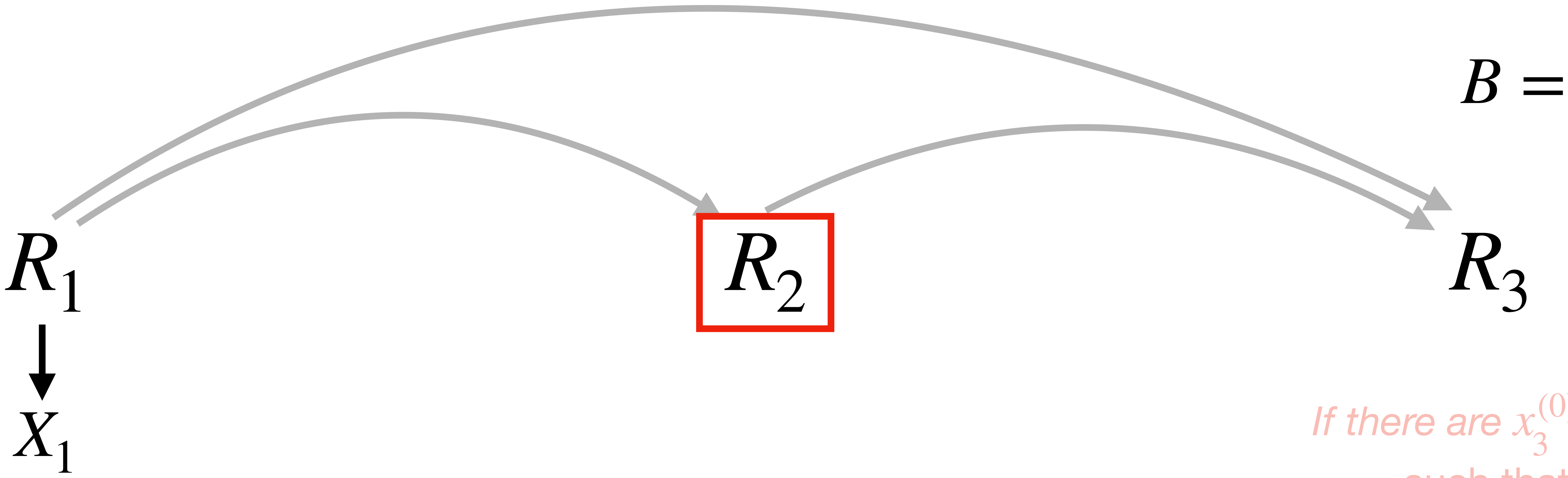
If there are $x_3^{(0)}, x_3^{(1)}$
such that
$\text{Ext}(X_1, X_2, x_3^{(b)}) = b$

Bias!

X_1, X_2 must fully determine output w/ high prob

Impossibility for 3 roles, 1 corruption

$B = \mathsf{Ext}(X_1, X_2, X_3)$



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Bias!

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Impossibility for 3 roles, 1 corruption

$B = \text{Ext}(X_1, X_2, X_3)$

R_1 $\qquad$ $\boxed{R_2}$ $\qquad$ R_3

$R_1 \to X_1$

Sample $X_2^{(0)}, X_2^{(1)} \overset{i.i.d.}{\sim} (X_2 \mid X_1, M_{1\to 2})$

If $\text{Ext}(X_1, X_2^{(0)}, \cdot\,) \not\equiv \text{Ext}(X_1, X_2^{(1)}, \cdot\,)$
and both are constant

If there are $x_3^{(0)}, x_3^{(1)}$
such that
$\text{Ext}(X_1, X_2, x_3^{(b)}) = b$

Bias!

X_1, X_2 must fully determine output w/ high prob

Impossibility for 3 roles, 1 corruption

$B = \text{Ext}(X_1, X_2, X_3)$

R_1 $\qquad$ $\boxed{R_2}$ $\qquad$ R_3

$R_1 \downarrow X_1$

Sample $X_2^{(0)}, X_2^{(1)} \overset{i.i.d.}{\sim} (X_2 \mid X_1, M_{1\to 2})$

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Bias!

If there are $x_3^{(0)}, x_3^{(1)}$
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$\text{Ext}(X_1, X_2, x_3^{(b)}) = b$

Bias!

X_1, X_2 must fully determine output w/ high prob

Impossibility for 3 roles, 1 corruption

$B = \text{Ext}(X_1, X_2, X_3)$

R_1 $\boxed{R_2}$ R_3

$R_1 \downarrow X_1$

Sample $X_2^{(0)}, X_2^{(1)} \overset{i.i.d.}{\sim} (X_2 \mid X_1, M_{1\to 2})$

If $\text{Ext}(X_1, X_2^{(0)}, \cdot\,) \not\equiv \text{Ext}(X_1, X_2^{(1)}, \cdot\,)$
and both are constant

Bias!

If there are $x_3^{(0)}, x_3^{(1)}$
such that
$\text{Ext}(X_1, X_2, x_3^{(b)}) = b$

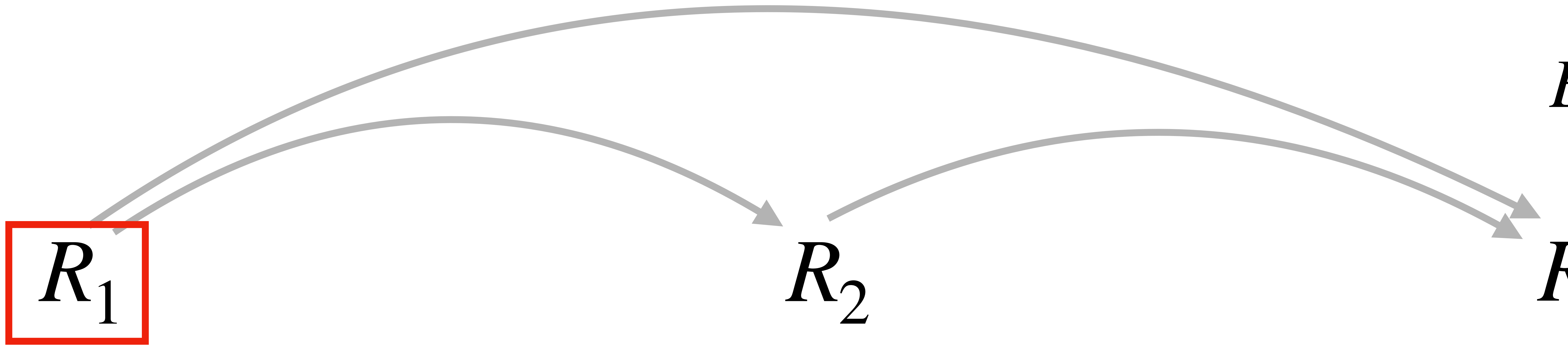
Bias!

W/ high prob over sampling
$X_2^{(0)}, X_2^{(1)} \overset{i.i.d.}{\sim} (X_2 \mid X_1, M_{1\to 2})$
must have
$\text{Ext}(X_1, X_2^{(0)}, \cdot\,) \equiv \text{Ext}(X_1, X_2^{(1)}, \cdot\,)$

X_1, X_2 ***must fully determine output w/ high prob***

Impossibility for 3 roles, 1 corruption

$B = \mathsf{Ext}(X_1, X_2, X_3)$



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If $\mathsf{Ext}(X_1, X_2^{(0)}, \cdot\,) \not\equiv \mathsf{Ext}(X_1, X_2^{(1)}, \cdot\,)$
and both are constant

Bias!

If there are $x_3^{(0)}, x_3^{(1)}$
such that
$\mathsf{Ext}(X_1, X_2, x_3^{(b)}) = b$

Bias!

W/ high prob over sampling
$X_2^{(0)}, X_2^{(1)} \overset{i.i.d.}{\sim} (X_2 \mid X_1, M_{1\to 2})$
must have
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X_1, X_2 ***must fully determine output w/ high prob***

Impossibility for 3 roles, 1 corruption

$B = \mathsf{Ext}(X_1, X_2, X_3)$

$\boxed{R_1}$ R_2 R_3

Sample $X_1^{(0)}, X_1^{(1)} \overset{i.i.d.}{\sim} X_1$
With prob $\approx 1/2$ *lead to different coin values and* R_1 *can predict values w/ high prob*

Sample $X_2^{(0)}, X_2^{(1)} \overset{i.i.d.}{\sim} (X_2 \mid X_1, M_{1\to 2})$

If $\mathsf{Ext}(X_1, X_2^{(0)}, \cdot\,) \not\equiv \mathsf{Ext}(X_1, X_2^{(1)}, \cdot\,)$ and both are constant

Bias!

If there are $x_3^{(0)}, x_3^{(1)}$ such that $\mathsf{Ext}(X_1, X_2, x_3^{(b)}) = b$

Bias!

W/ high prob over sampling $X_2^{(0)}, X_2^{(1)} \overset{i.i.d.}{\sim} (X_2 \mid X_1, M_{1\to 2})$ ***must have*** $\mathsf{Ext}(X_1, X_2^{(0)}, \cdot\,) \equiv \mathsf{Ext}(X_1, X_2^{(1)}, \cdot\,)$

X_1, X_2 ***must fully determine output w/ high prob***

Impossibility for 3 roles, 1 corruption

$B = \text{Ext}(X_1, X_2, X_3)$

R_1 $\quad$ R_2 $\quad$ R_3

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Impossibility for 4 roles, 1 corruption

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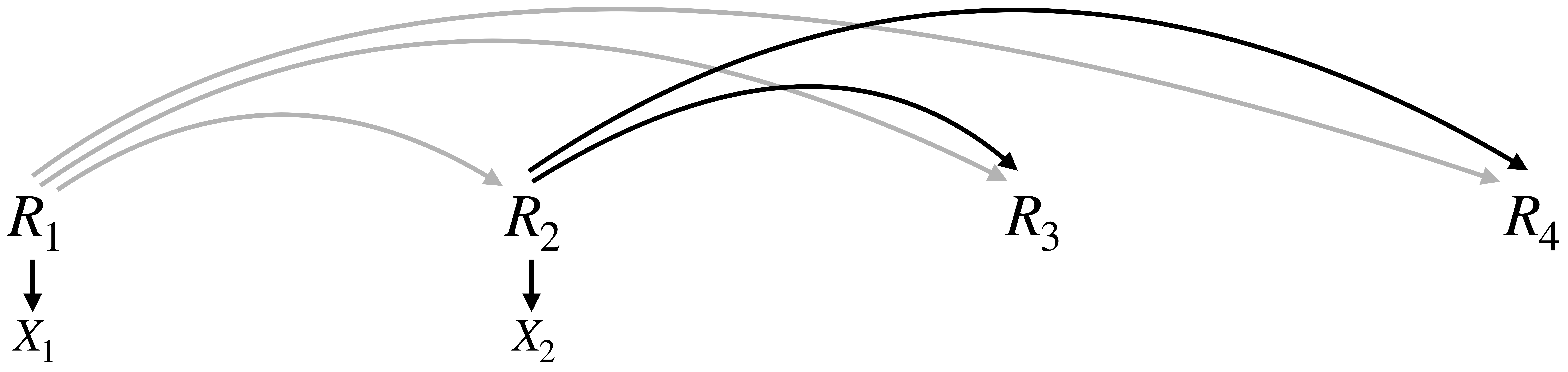

Impossibility for 4 roles, 1 corruption

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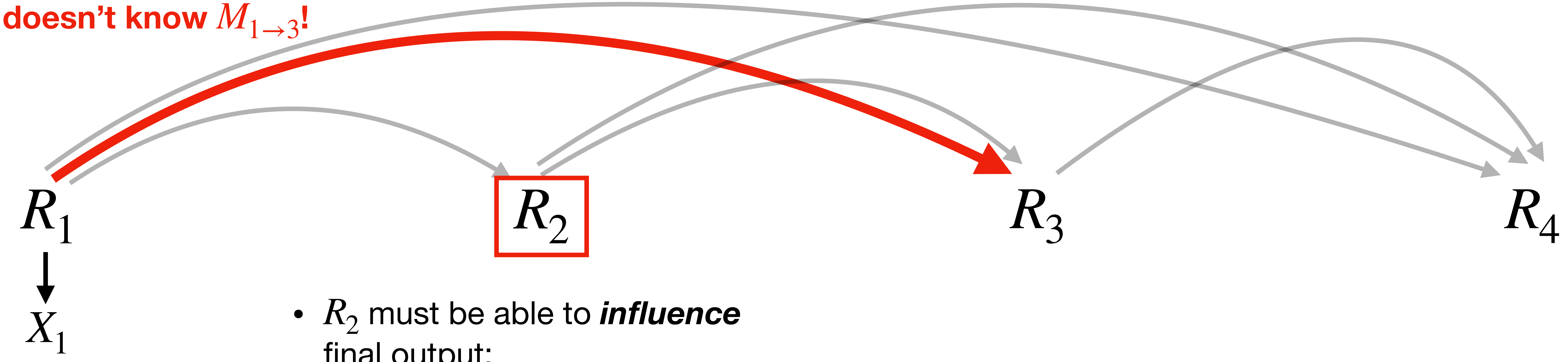
Impossibility for 4 roles, 1 corruption

- R_2 must be able to ***influence*** final output;
- R_2 must be able to ***predict*** which path leads to each value.

Impossibility for 4 roles, 1 corruption

R_2 **doesn't know** $M_{1\to 3}$**!**



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Concluding

- YOSO: Stateless MPC, avoids denial-of-service attacks
- Public randomness extraction in YOSO with **worst-case corruptions**:
  - Still secure if role selection mechanism is biased
  - Go beyond round-based MPC techniques
  - Related to prior work on multi-source randomness extraction

Stronger adversary: $4t + 1 \leq n^{\star} \leq 6t + 1$

Weaker adversary: $4t + 1 \leq n^{\star} \leq 5t$

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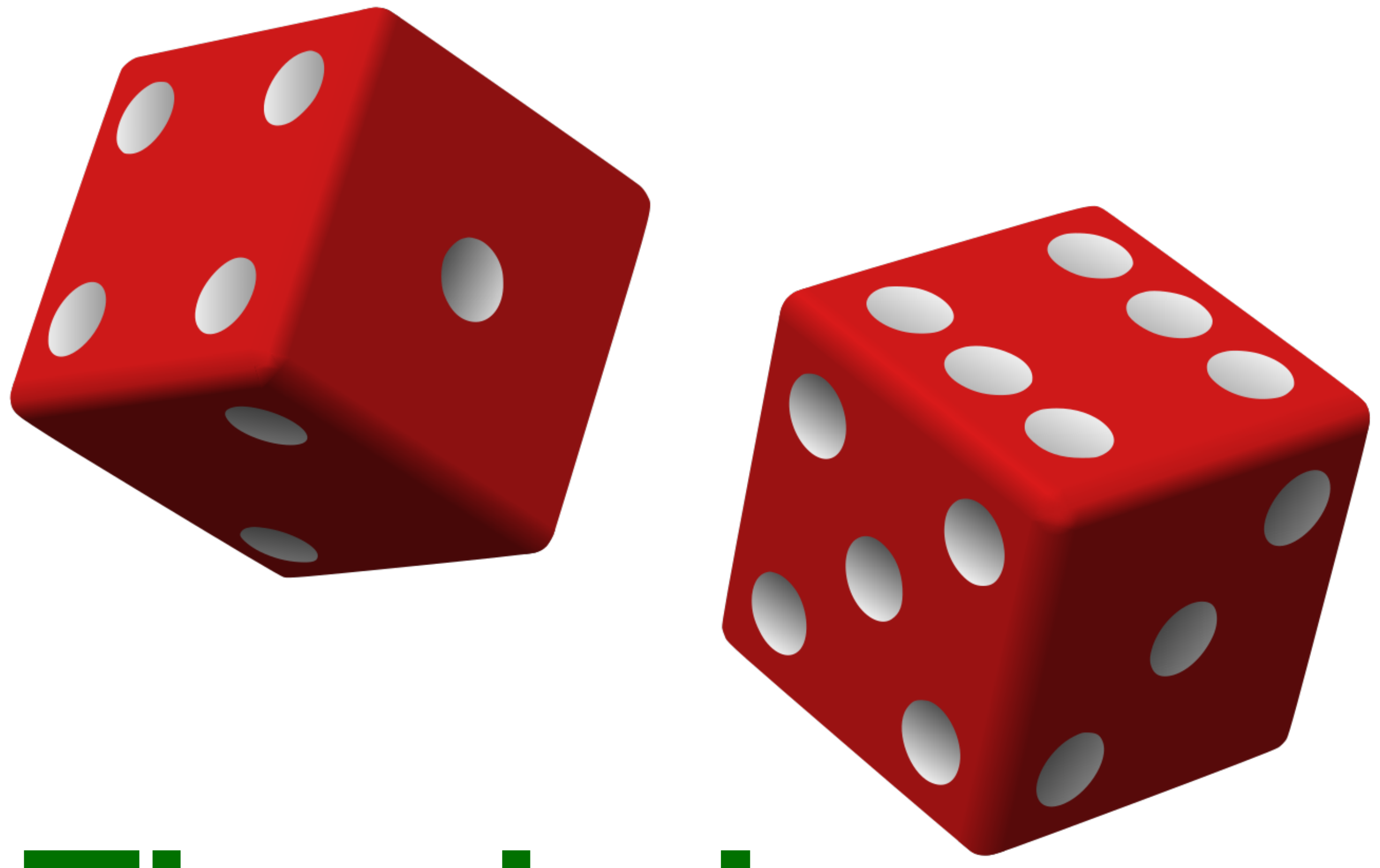

Thanks!