Laconic Function Evaluation, Functional Encryption and Obfuscation for RAMs with Sublinear Computation

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&
NTT Research

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Laconic Function Evaluation (LFE)

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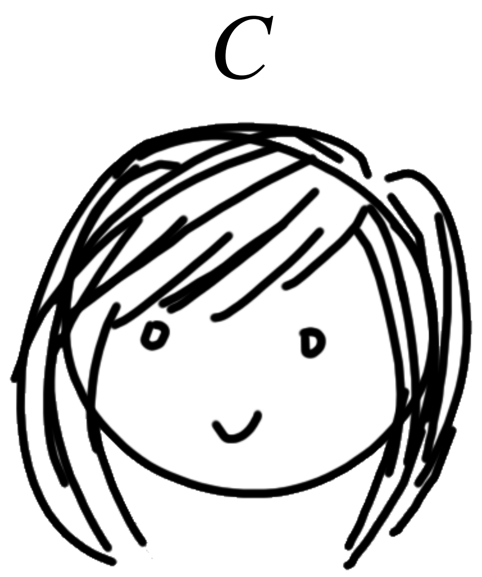
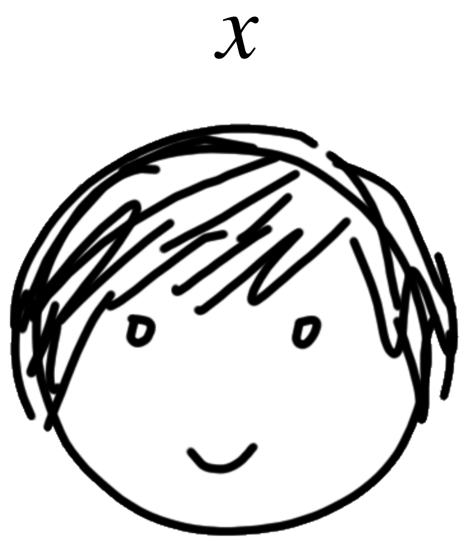
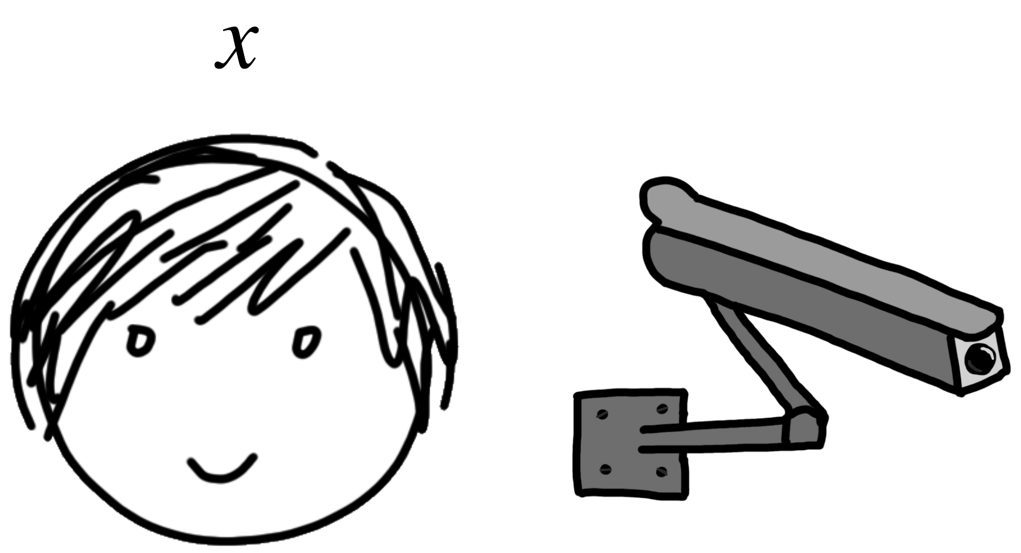


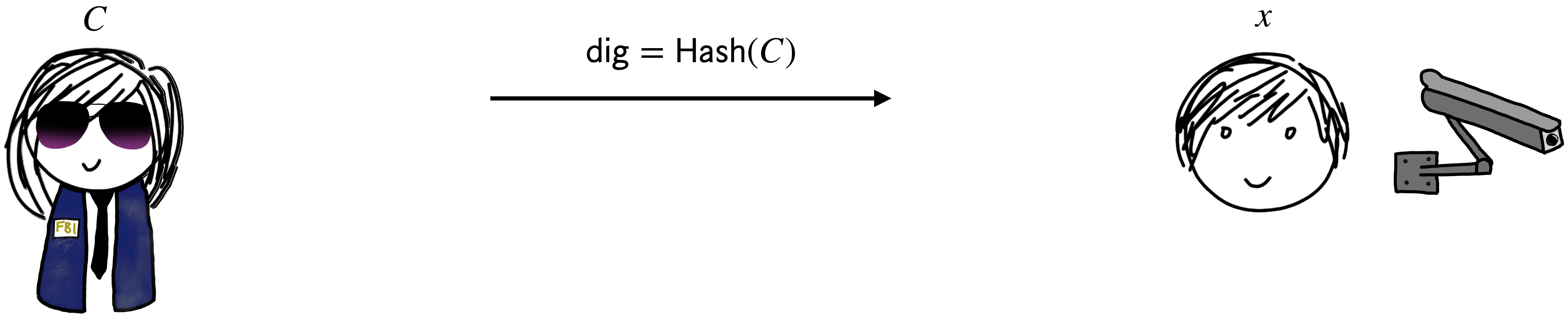


Laconic Function Evaluation (LFE)



Laconic Function Evaluation (LFE)

* in CRS model, CRS hidden



C

$\mathsf{dig} = \mathsf{Hash}(C)$

x

Laconic Function Evaluation (LFE)

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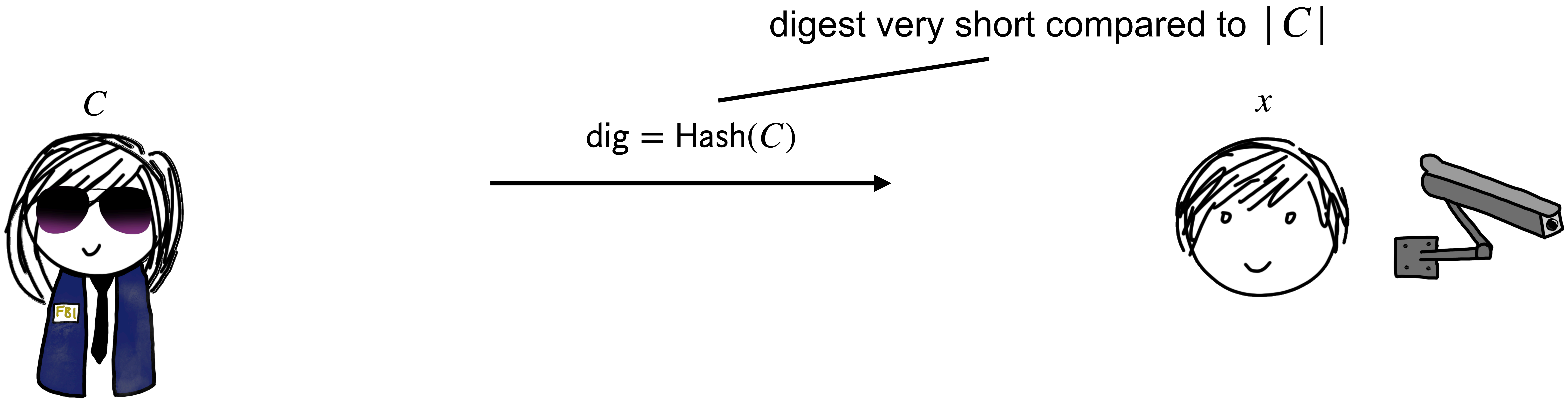

digest very short compared to $|C|$

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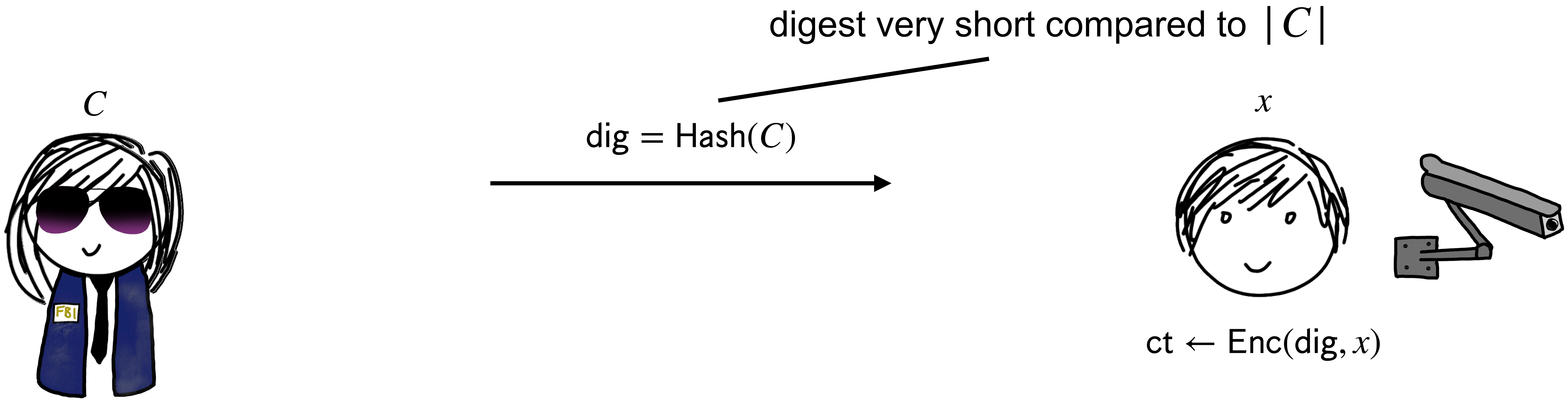

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$\text{ct} \leftarrow \text{Enc}(\text{dig}, x)$

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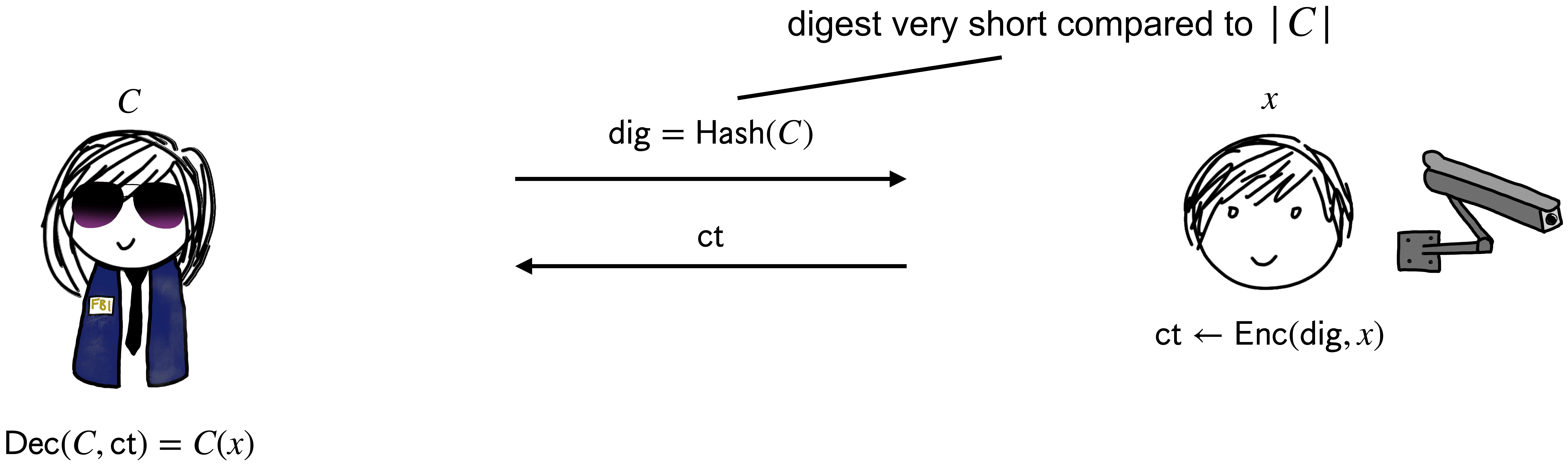

digest very short compared to $|C|$

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ct

x

$\mathsf{ct} \leftarrow \mathsf{Enc}(\mathsf{dig}, x)$

$\mathsf{Dec}(C, \mathsf{ct}) = C(x)$

Laconic Function Evaluation (LFE)

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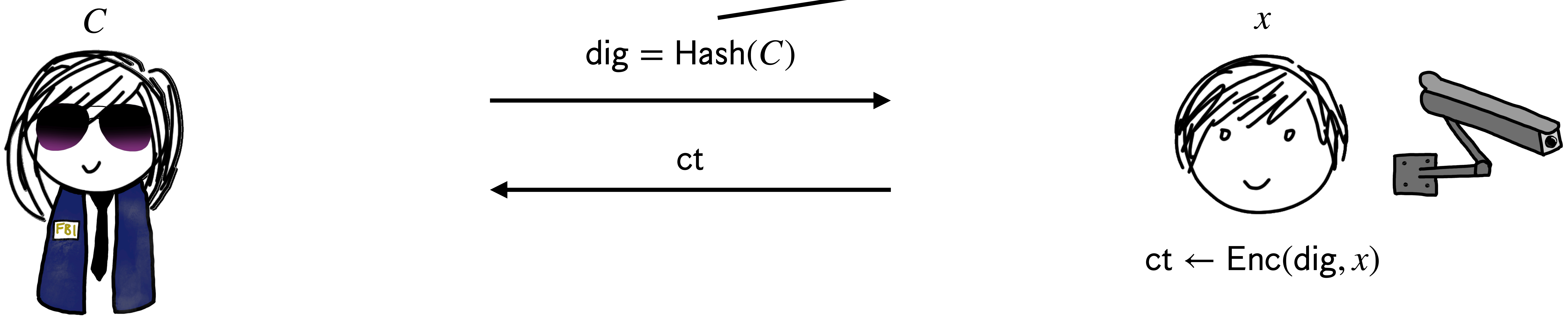
digest very short compared to $|C|$



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Security: Server learns nothing more than $C(x)$

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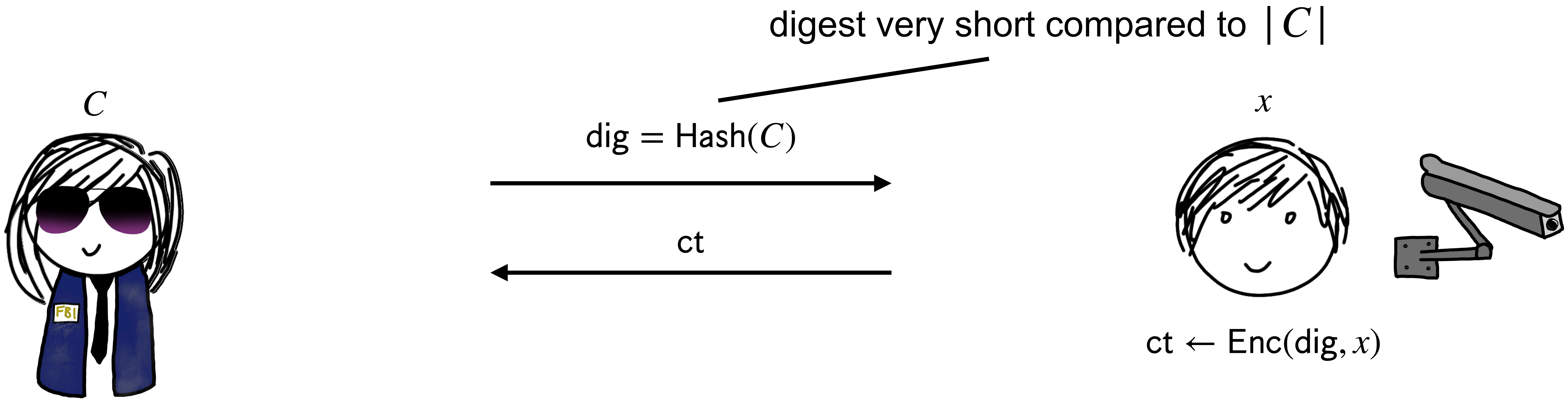

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Like FHE: 2-round 2PC where Server does the computational work

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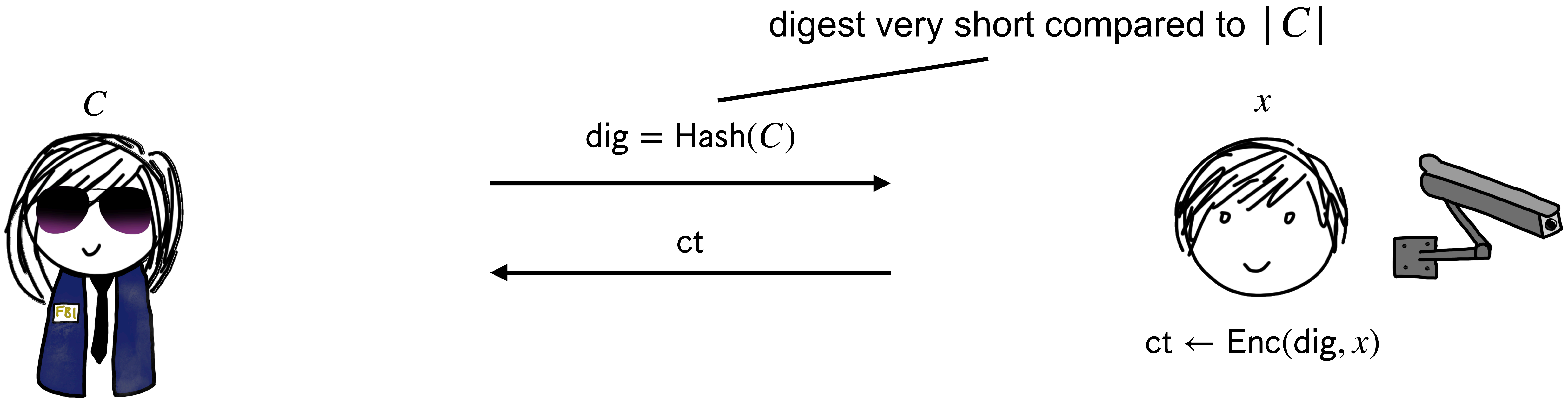

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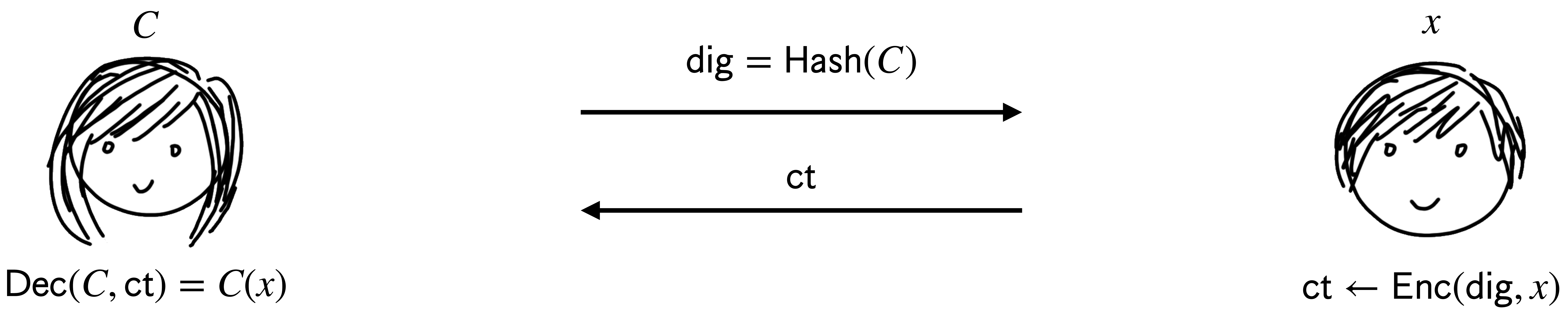
Security: Server learns nothing more than $C(x)$

Like FHE: 2-round 2PC where Server does the computational work
But "flipped": Server learns the output (instead of Client)

Laconic Function Evaluation (LFE)



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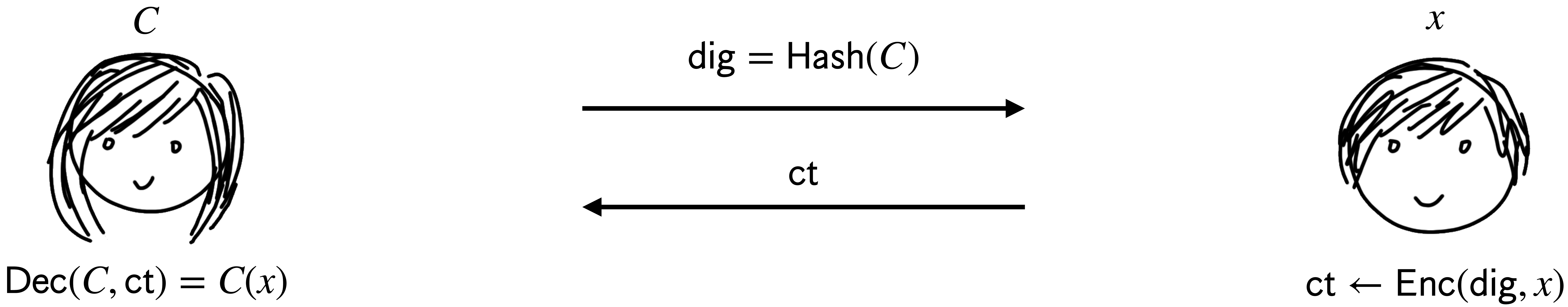

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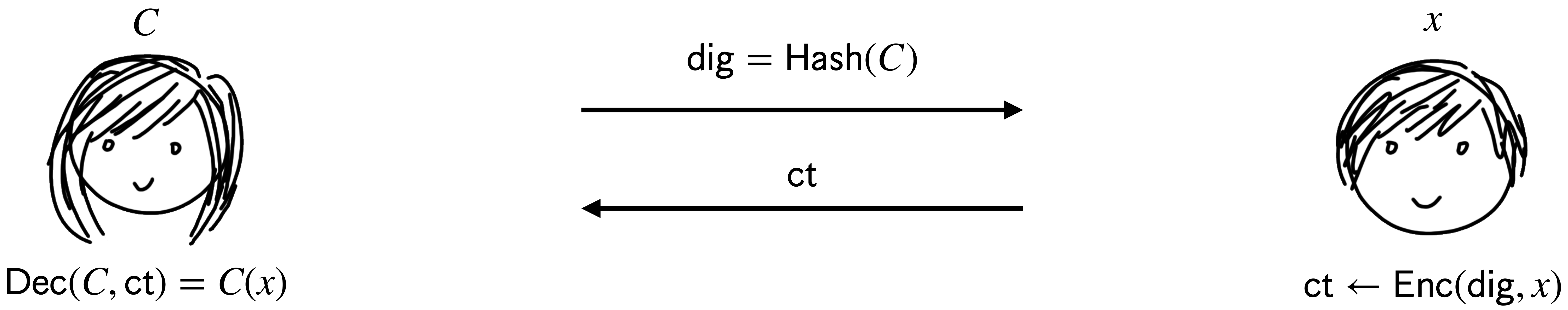
Prior work:

- [Quach-Wee-Wichs’17]: LFE for circuits from LWE

Laconic Function Evaluation (LFE)



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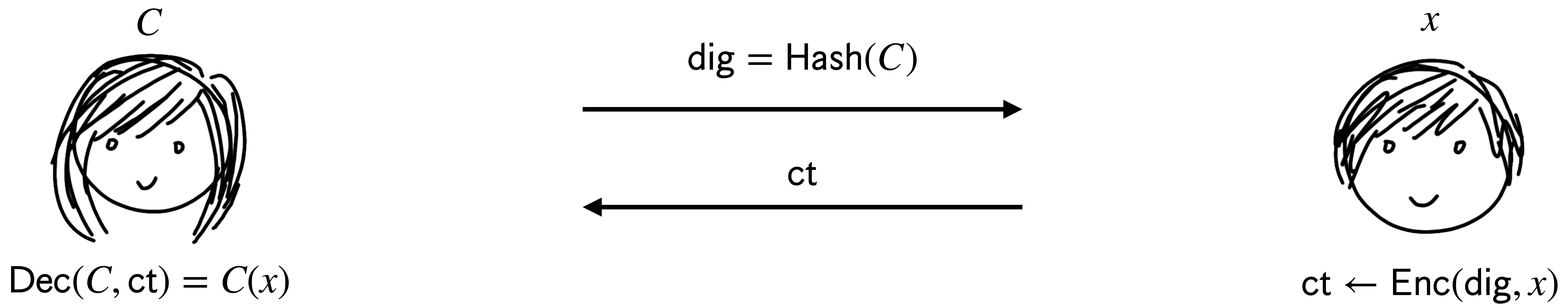

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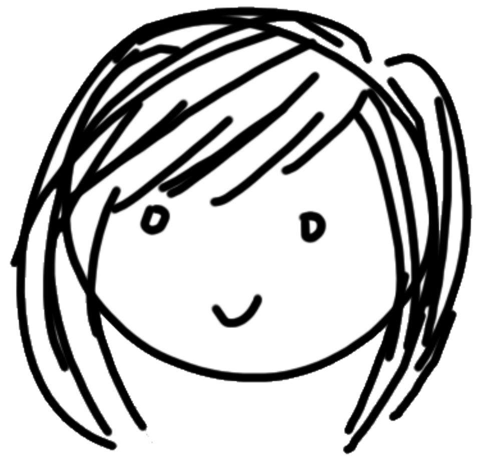
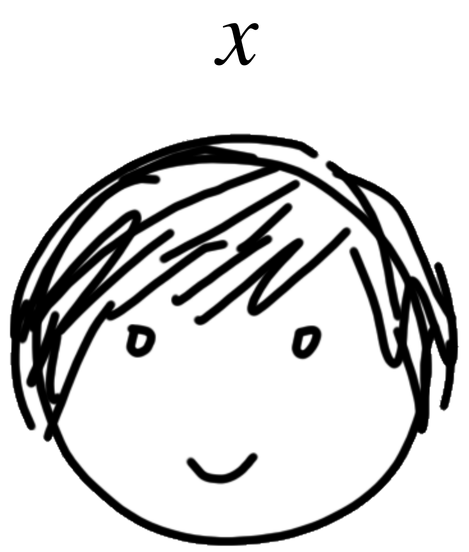
Problem: Server computation is at least linear in inputs!

LFE for RAMs

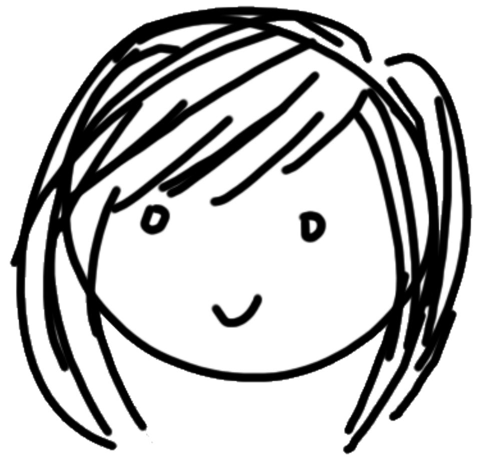


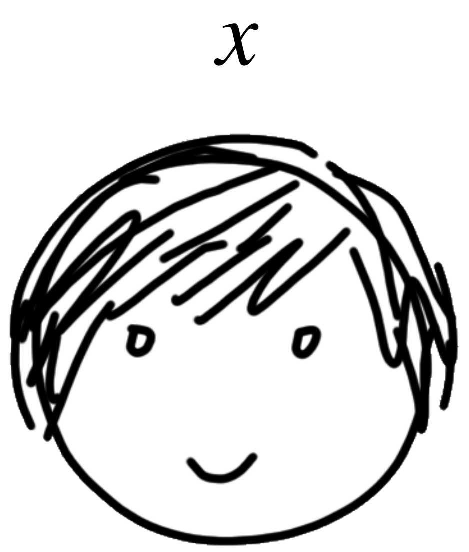


<u>Main Result</u>: We build LFE for RAMs assuming RingLWE

LFE for RAMs

Goal: output RAM computation $P(x, y)$





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Some fixed RAM program (e.g. universal)

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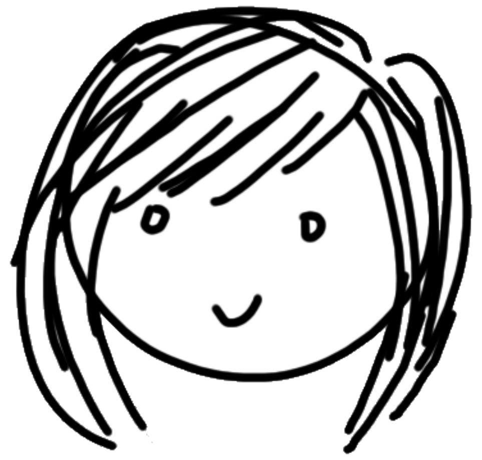

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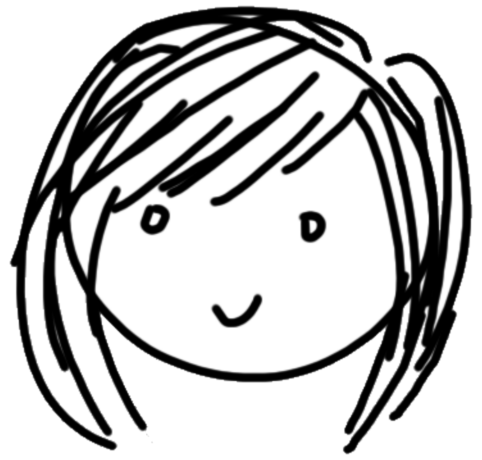
$P(x, y)$ has RAM runtime T



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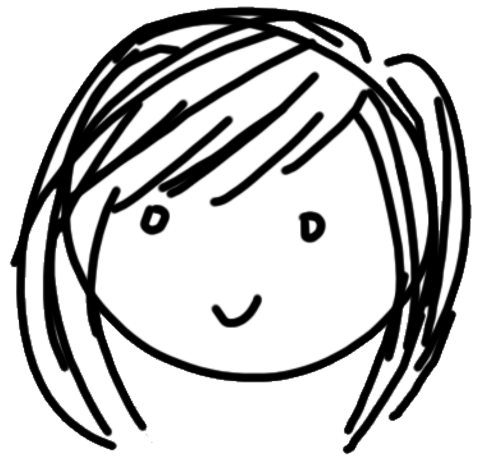

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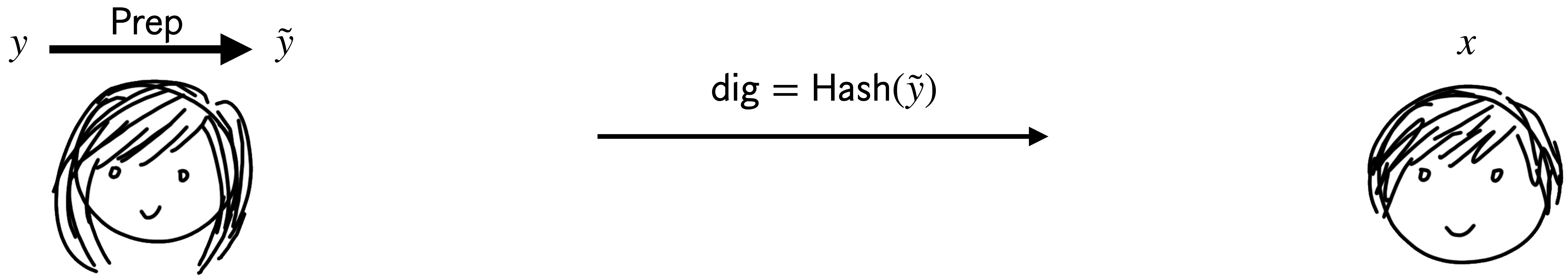

$y \xrightarrow{\text{Prep}} \tilde{y}$

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x

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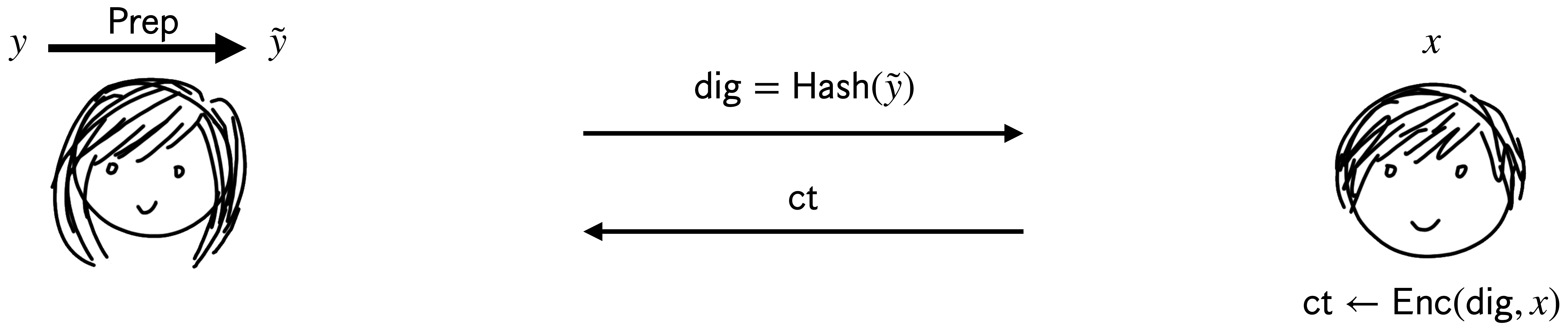

$y \xrightarrow{\text{Prep}} \tilde{y}$

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$\mathsf{ct} \leftarrow \mathsf{Enc}(\mathsf{dig}, x)$

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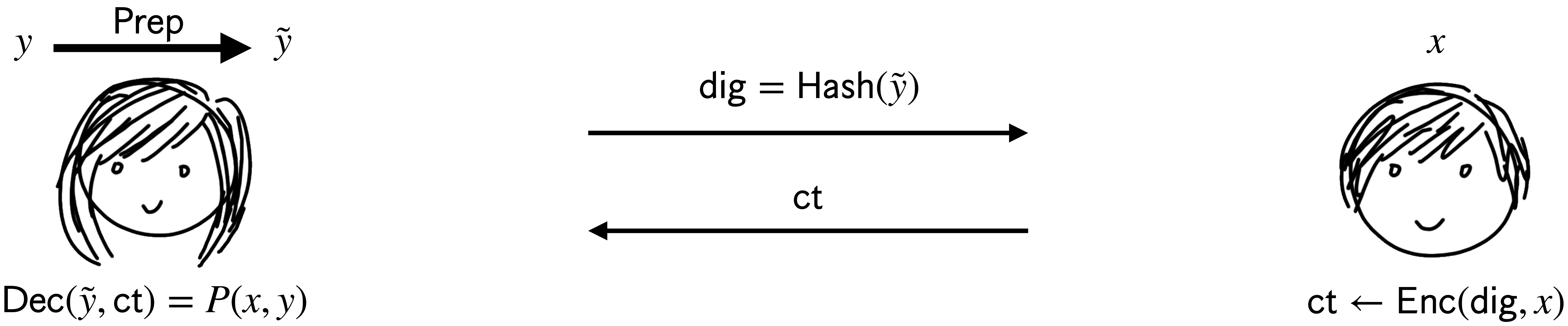
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$\text{Dec}(\tilde{y}, \text{ct}) = P(x, y)$
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*suppressing poly(λ) and polylog factors

LFE for RAMs

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Goal: output RAM computation $P(x, y)$

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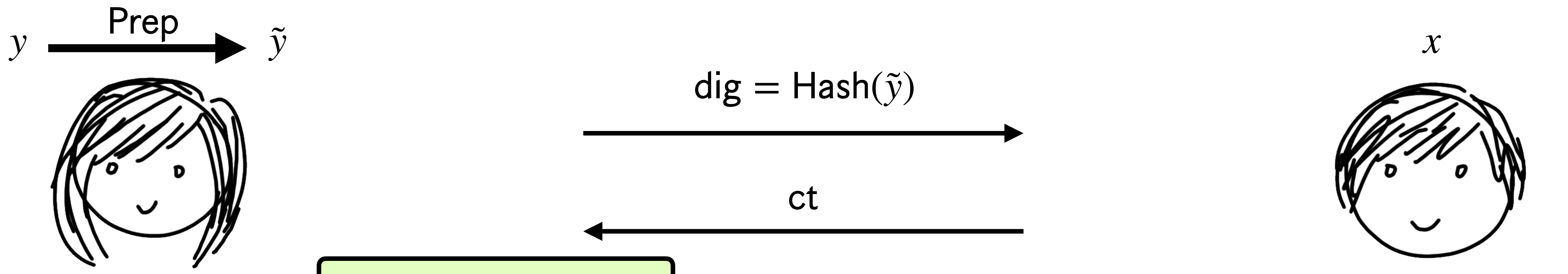


$y \xrightarrow{\text{Prep}} \tilde{y}$

x

$\text{dig} = \text{Hash}(\tilde{y})$

ct

$\text{Dec}(\tilde{y}, \text{ct}) = P(x, y)$

Dec run time: T

$\text{ct} \leftarrow \text{Enc}(\text{dig}, x)$

Main Result: We build LFE for RAMs assuming RingLWE

LFE for RAMs

*suppressing poly(λ) and polylog factors

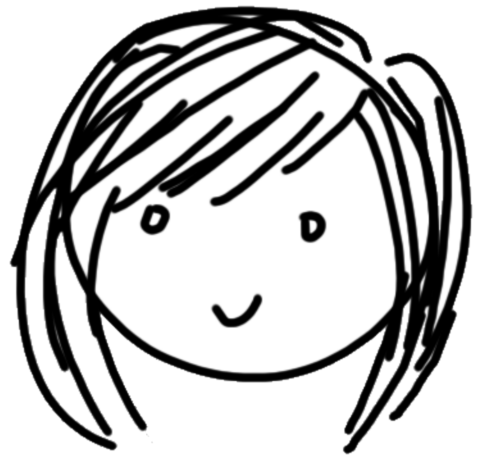
Some fixed RAM program (e.g. universal)

Goal: output RAM computation $P(x, y)$

$P(x, y)$ has RAM runtime T

Prep run time: $|y|^{1+\varepsilon}$

$y \xrightarrow{\text{Prep}} \tilde{y}$



x

$\mathsf{dig} = \mathsf{Hash}(\tilde{y})$ →

← ct

$\mathsf{Dec}(\tilde{y}, \mathsf{ct}) = P(x, y)$

Dec run time: T

$\mathsf{ct} \leftarrow \mathsf{Enc}(\mathsf{dig}, x)$

<u>Main Result</u>: We build LFE for RAMs assuming RingLWE

*suppressing poly(λ) and
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LFE for RAMs

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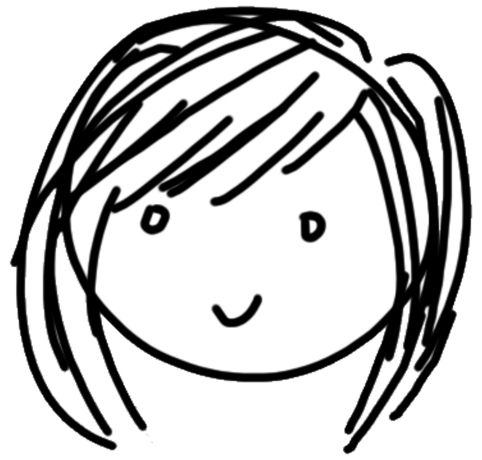
(e.g. universal)

Goal: output RAM computation $P(x, y)$

$P(x, y)$ has RAM runtime T

Prep run time: $|y|^{1+\varepsilon}$

$y \xrightarrow{\text{Prep}} \tilde{y}$



x

$\xrightarrow{\text{dig} = \text{Hash}(\tilde{y})}$

$\xleftarrow{\text{ct}}$

$\text{Dec}(\tilde{y}, \text{ct}) = P(x, y)$

Dec run time: T

Enc run time: $|x| + T$

$\text{ct} \leftarrow \text{Enc}(\text{dig}, x)$

<u>Main Result</u>: We build LFE for RAMs assuming RingLWE

LFE for RAMs

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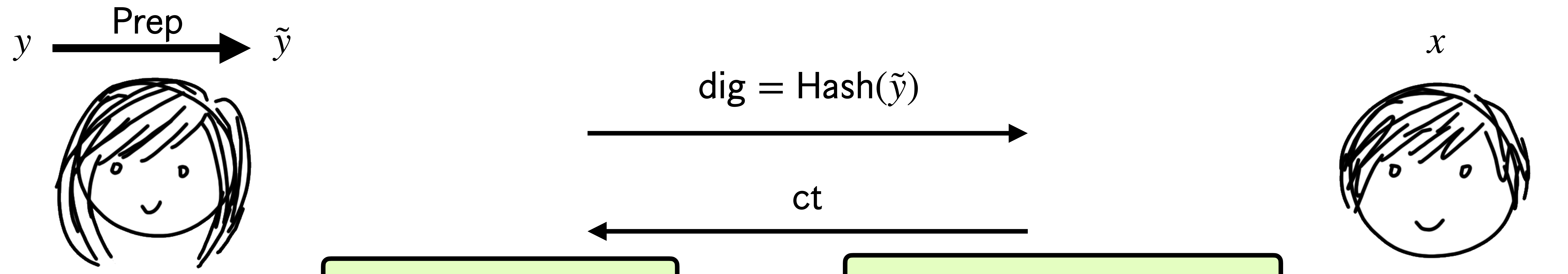

$y \xrightarrow{\text{Prep}} \tilde{y}$
x
dig $=$ Hash($\tilde{y}$)
ct

Dec($\tilde{y}$, ct) $= P(x, y)$

Dec run time: T

Enc run time: $|x| + \cancel{T}$

ct $\leftarrow$ Enc(dig, x)

<u>Main Result</u>: We build LFE for RAMs assuming RingLWE

Additionally assuming iO, get Enc run time just $|x|$

LFE for RAMs

*suppressing poly(λ) and polylog factors

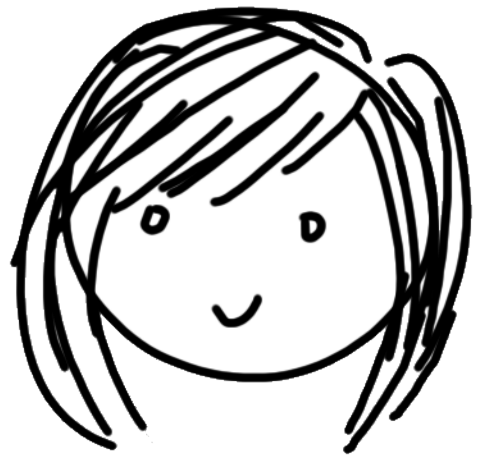
Goal: output RAM computation $P(x, y)$

Some fixed RAM program (e.g. universal)

$P(x, y)$ has RAM runtime T

Prep run time: $|y|^{1+\varepsilon}$

$y \xrightarrow{\text{Prep}} \tilde{y}$



x

dig $=$ Hash$(\tilde{y})$ →

← ct

Dec$(\tilde{y}, \text{ct}) = P(x, y)$

Dec run time: T

Enc run time: $|x| + \cancel{T}$

ct $\leftarrow$ Enc(dig, x)

<u>Main Result</u>: We build LFE for RAMs assuming RingLWE
Additionally assuming iO, get Enc run time just $|x|$

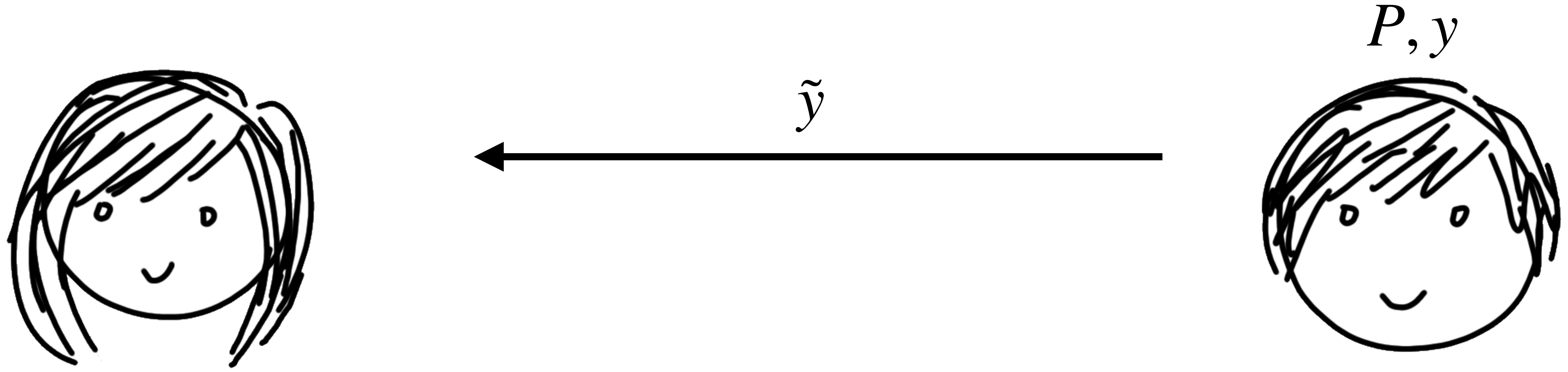
Main challenge: Privately accessing the public database y

RAM-LFE vs Garbled RAM

Garbled RAM

RAM-LFE

RAM-LFE vs Garbled RAM

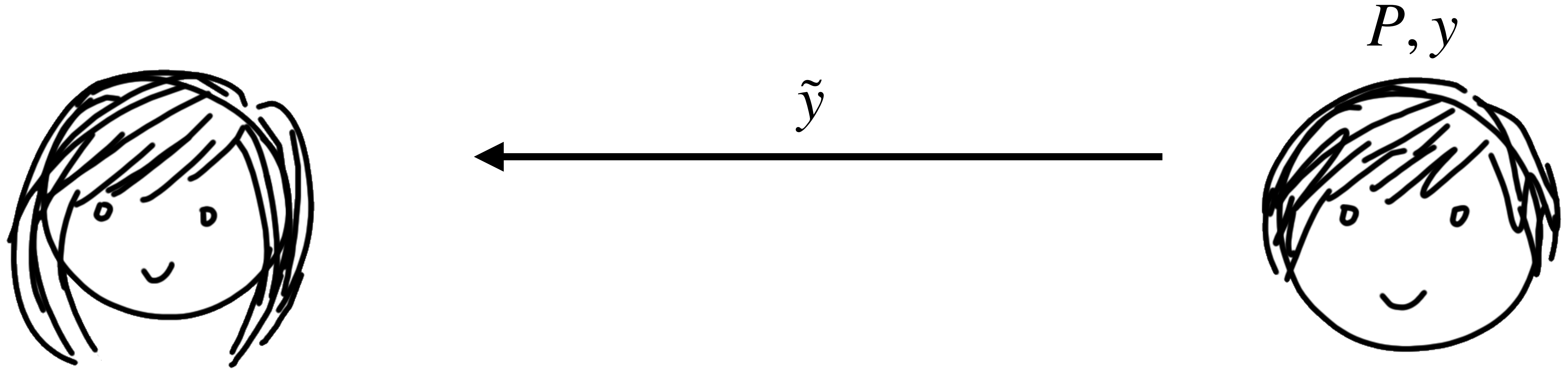


$\tilde{y}, \mathsf{sk} \leftarrow \mathsf{GarbleDB}(y)$

Garbled RAM

RAM-LFE

RAM-LFE vs Garbled RAM



P, y

$\tilde{y}$

$\tilde{y}, \mathsf{sk} \leftarrow \mathsf{GarbleDB}(y)$

y belongs to client and is garbled with respect to their secret key

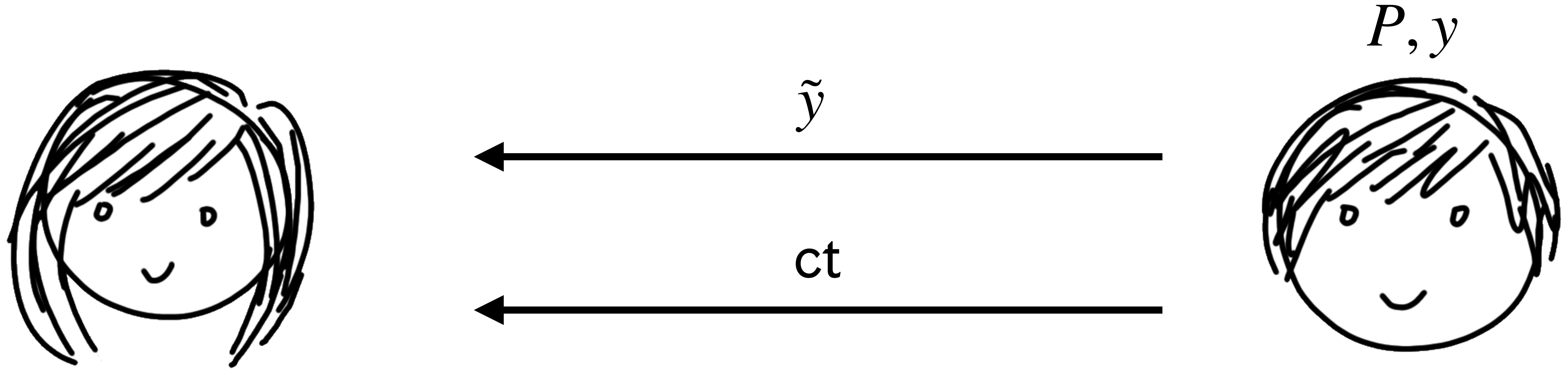
Garbled RAM

RAM-LFE

y

P, x

RAM-LFE vs Garbled RAM



$\tilde{y}, \mathsf{sk} \leftarrow \mathsf{GarbleDB}(y)$

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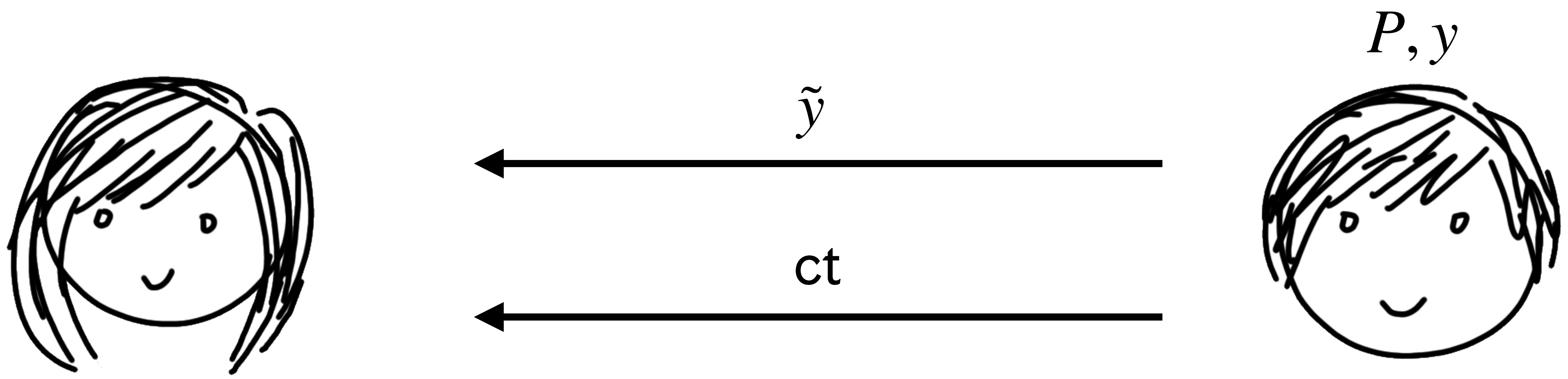

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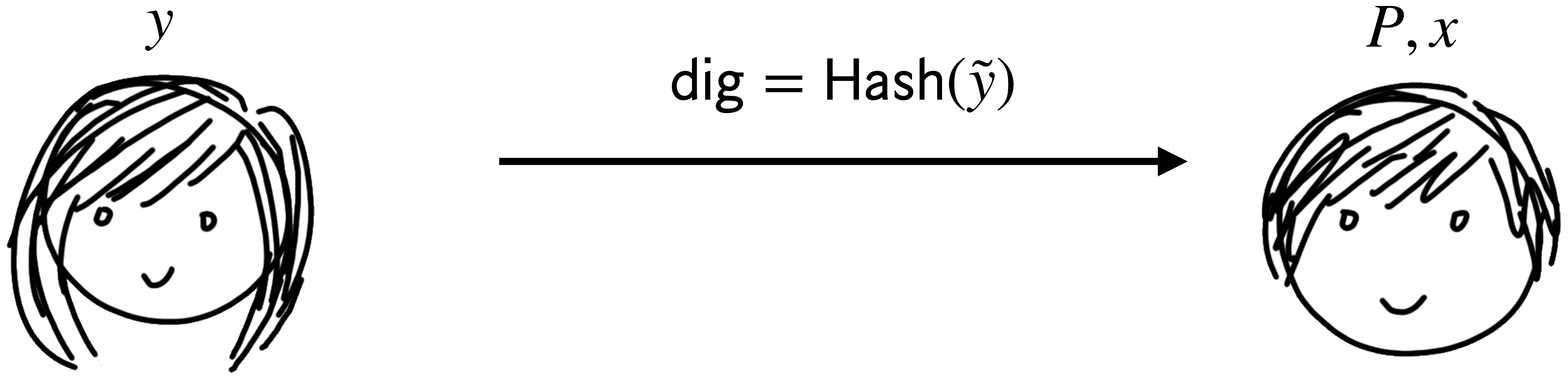

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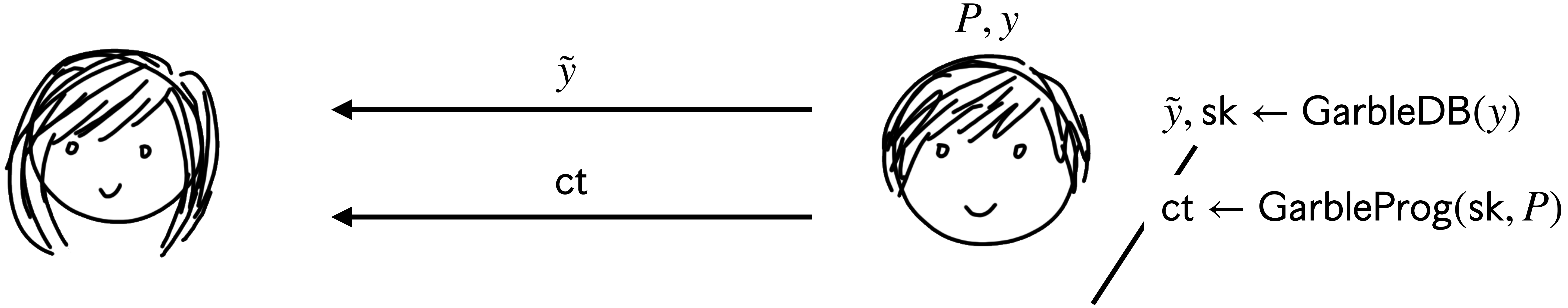

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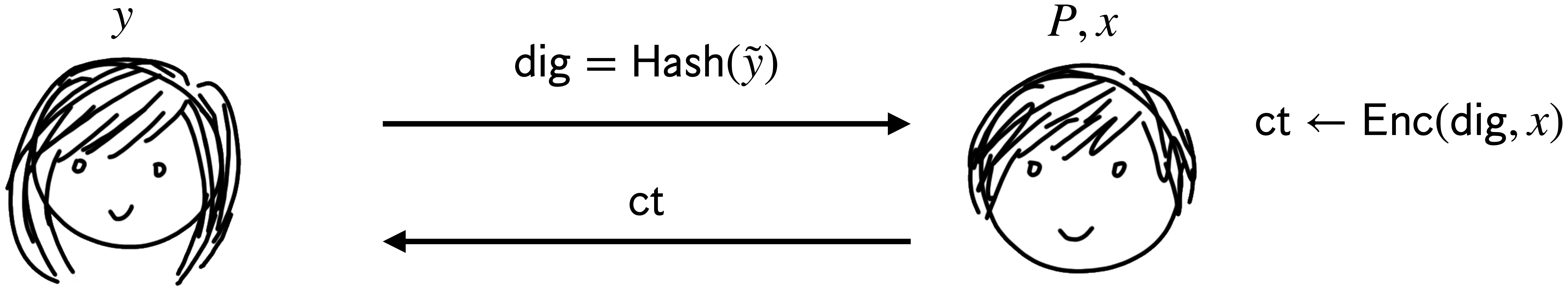

y

P, x

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ct

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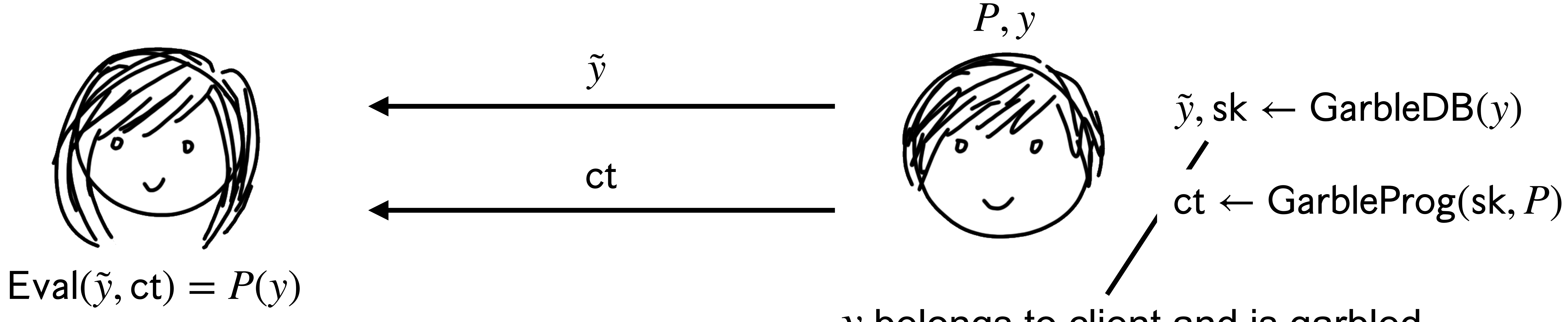
RAM-LFE vs Garbled RAM



P, y

$\tilde{y}$

ct

$\tilde{y}, \mathsf{sk} \leftarrow \mathsf{GarbleDB}(y)$

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$\mathsf{Eval}(\tilde{y}, \mathsf{ct}) = P(y)$

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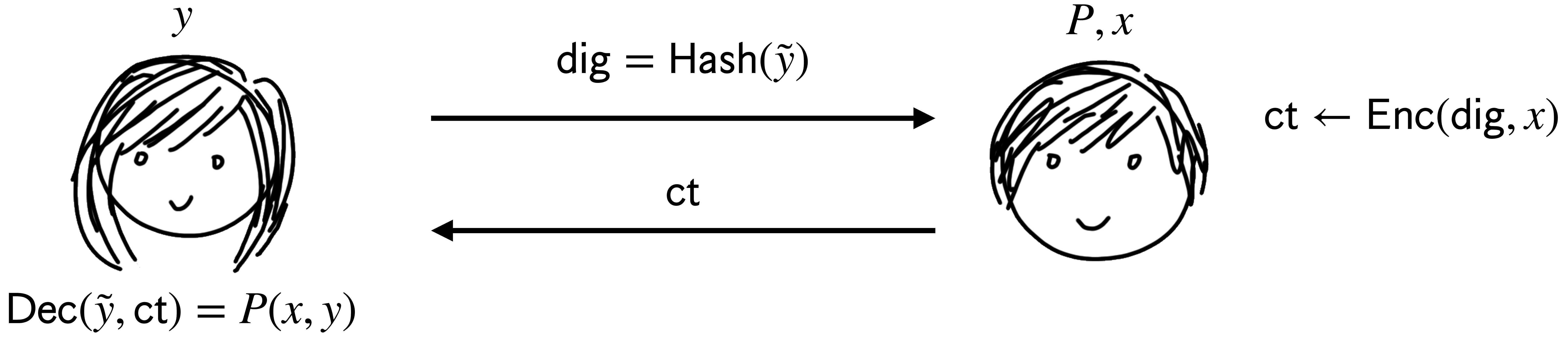
Garbled RAM

RAM-LFE



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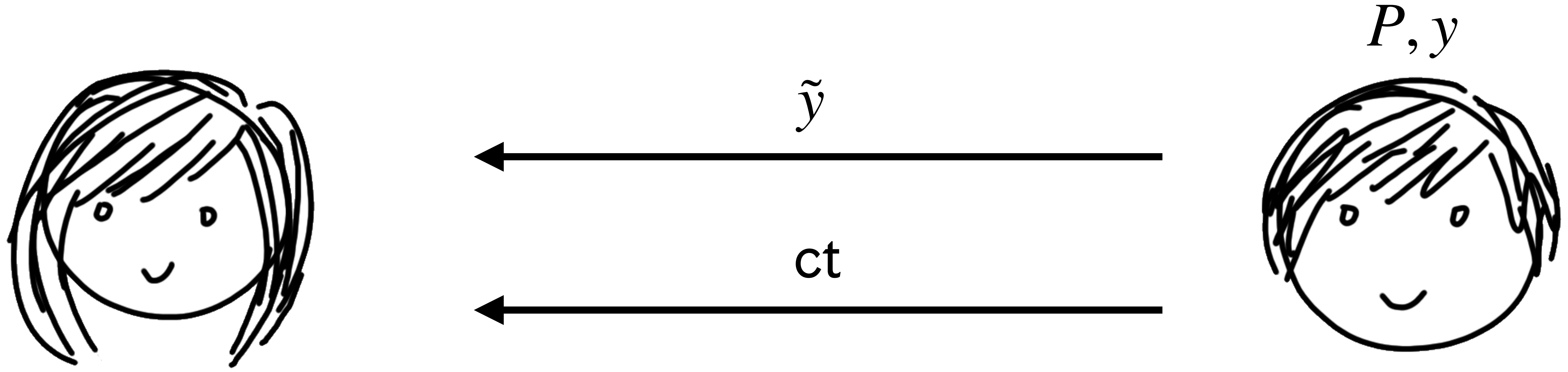
RAM-LFE vs Garbled RAM



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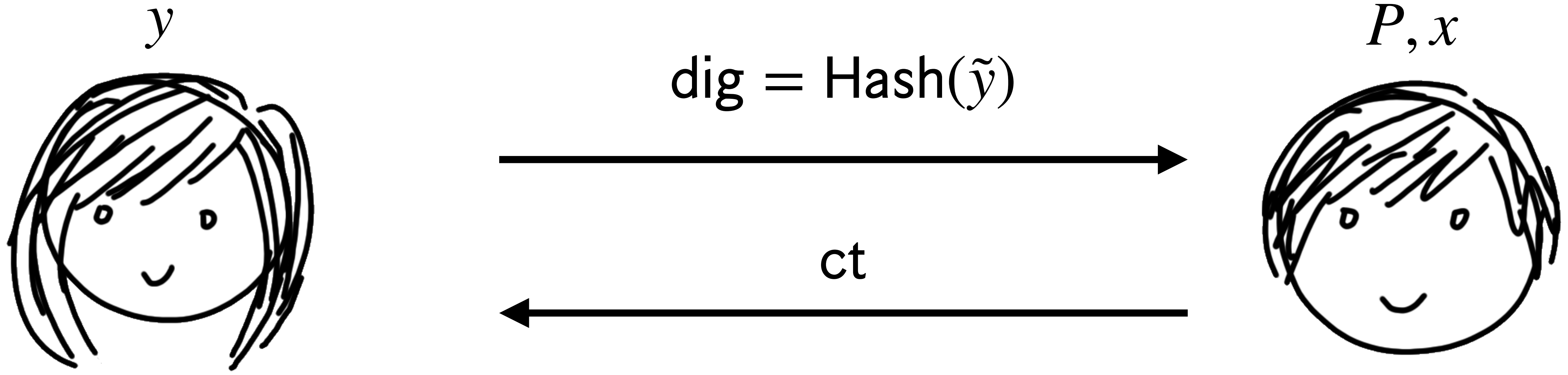

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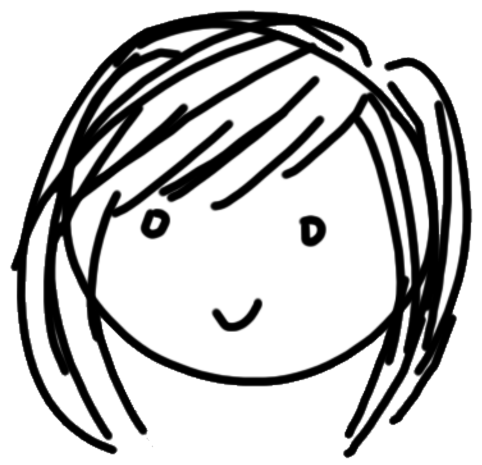
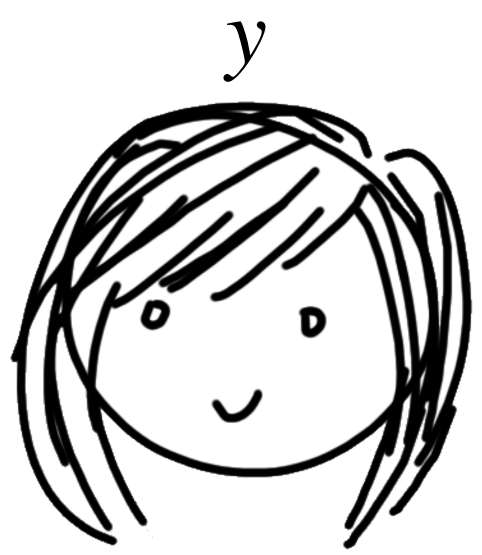
Need to evaluate over ***public*** database y

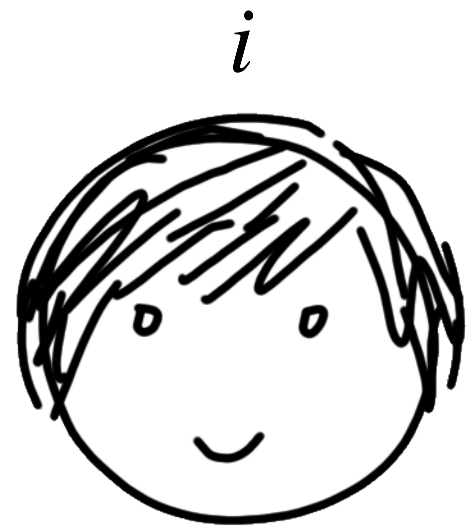
DEPIR vs ORAM



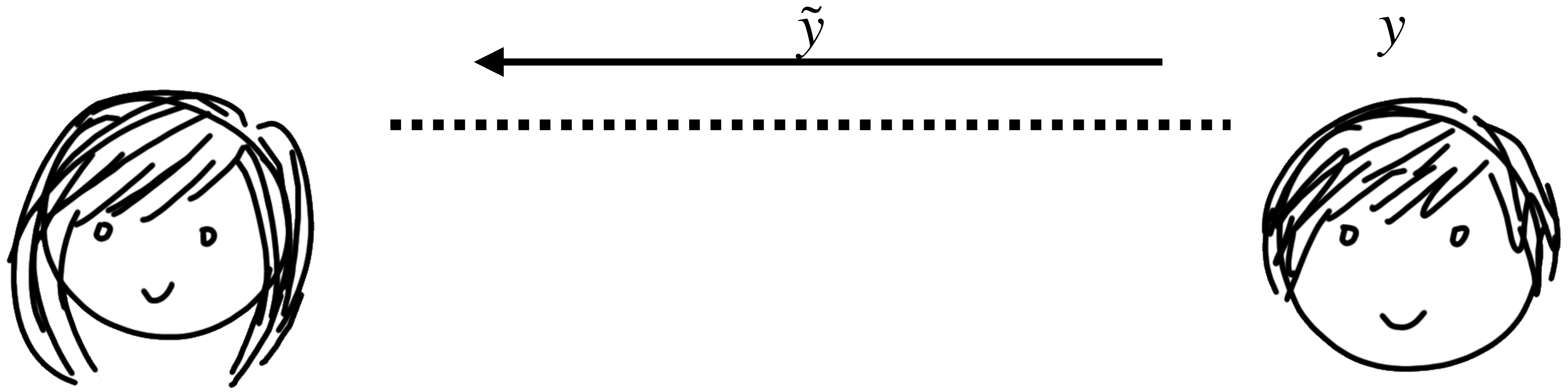
ORAM

DEPIR





DEPIR vs ORAM



$\tilde{y}, \mathsf{sk} \leftarrow \mathsf{ORAM}.\mathsf{Init}(y)$

ORAM

DEPIR

$I, r \leftarrow \mathsf{DEPIR}.\mathsf{Query}(i)$

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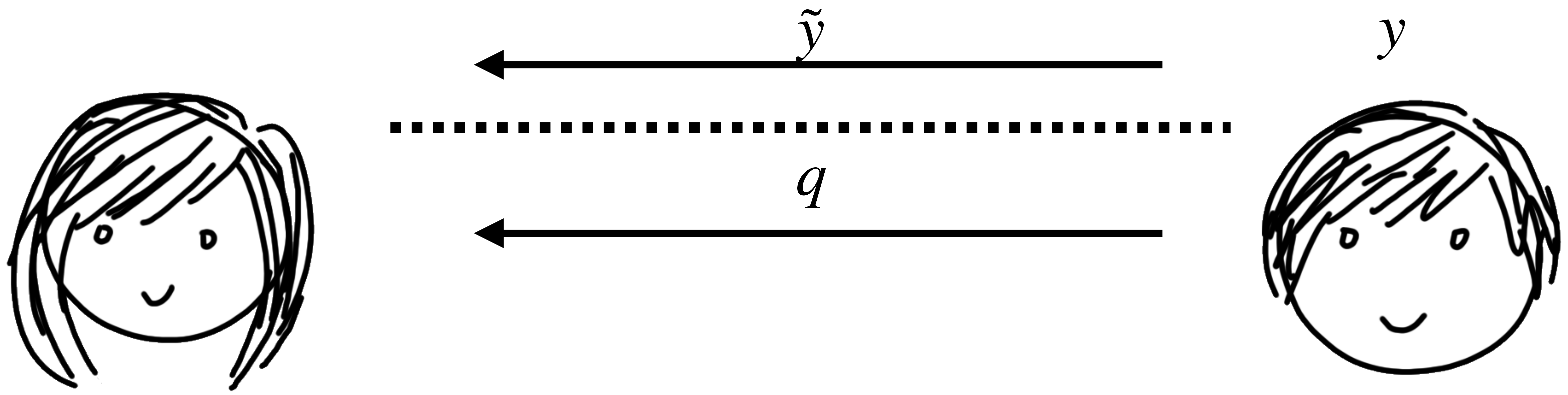

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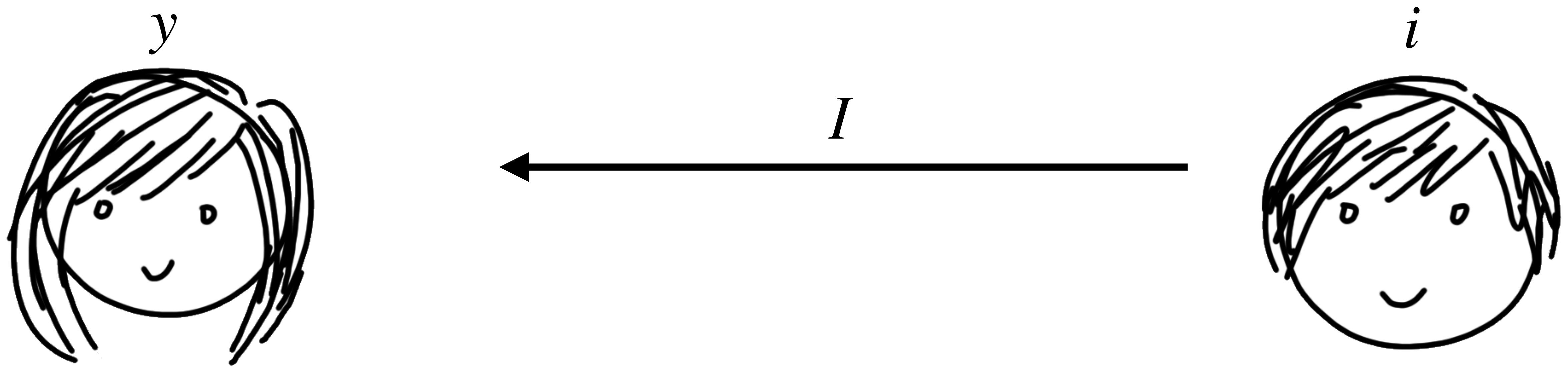

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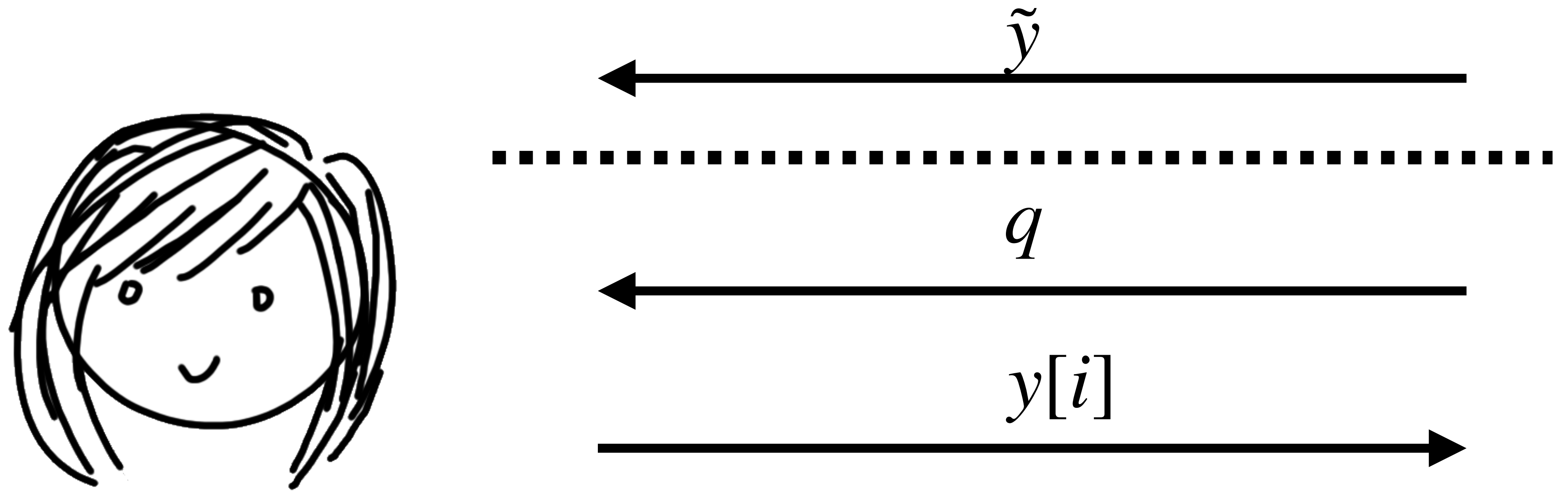

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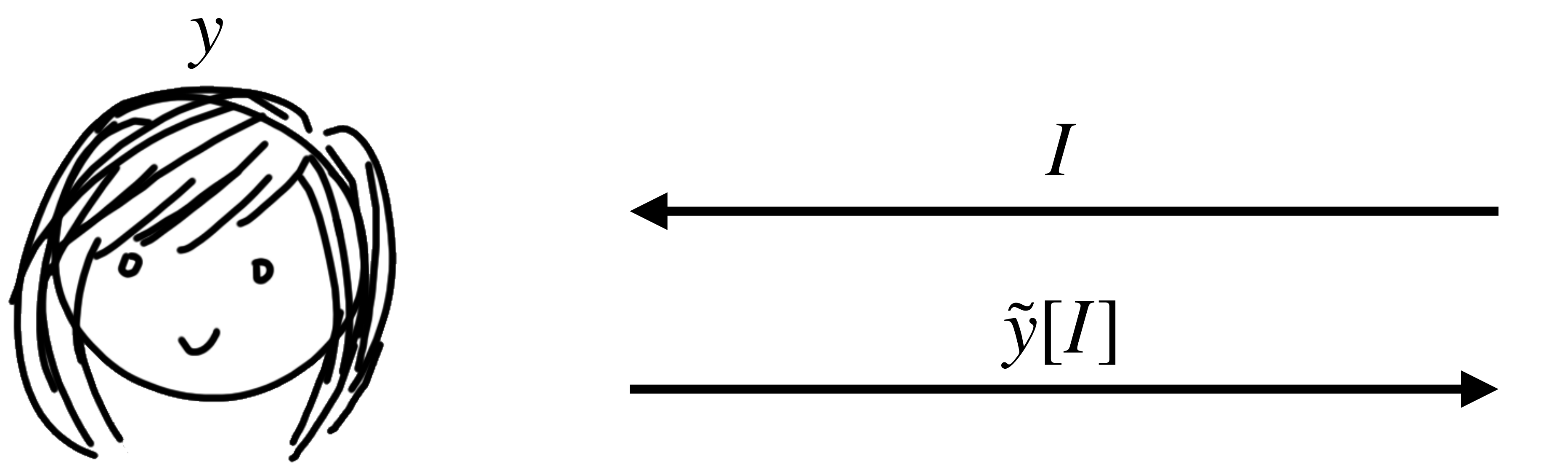

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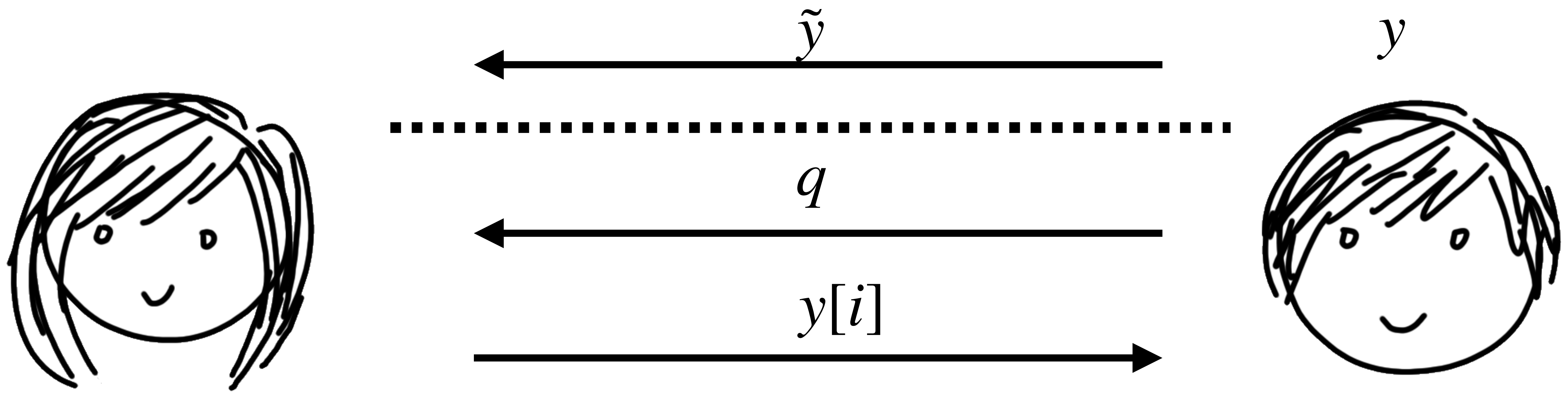

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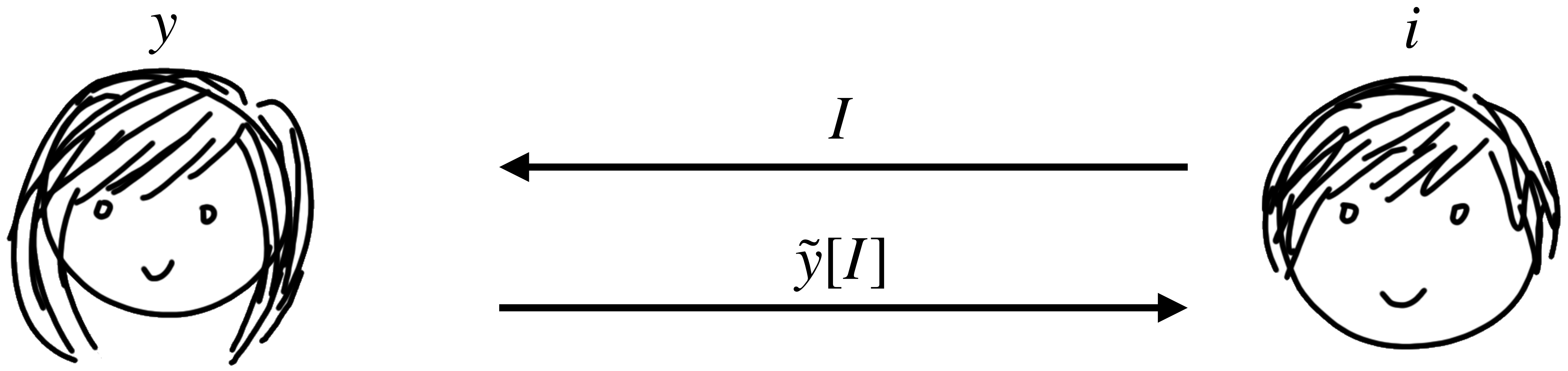

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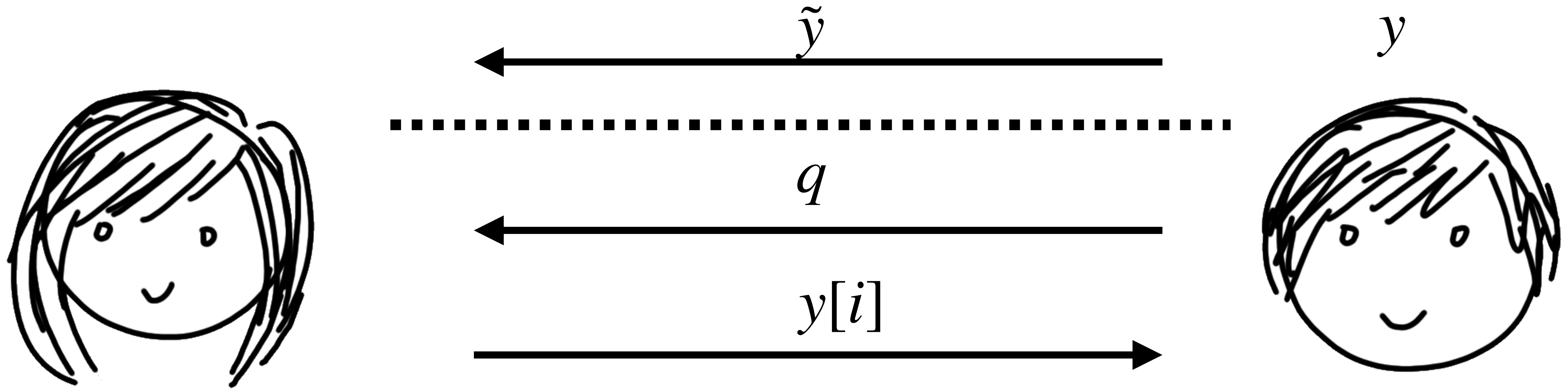

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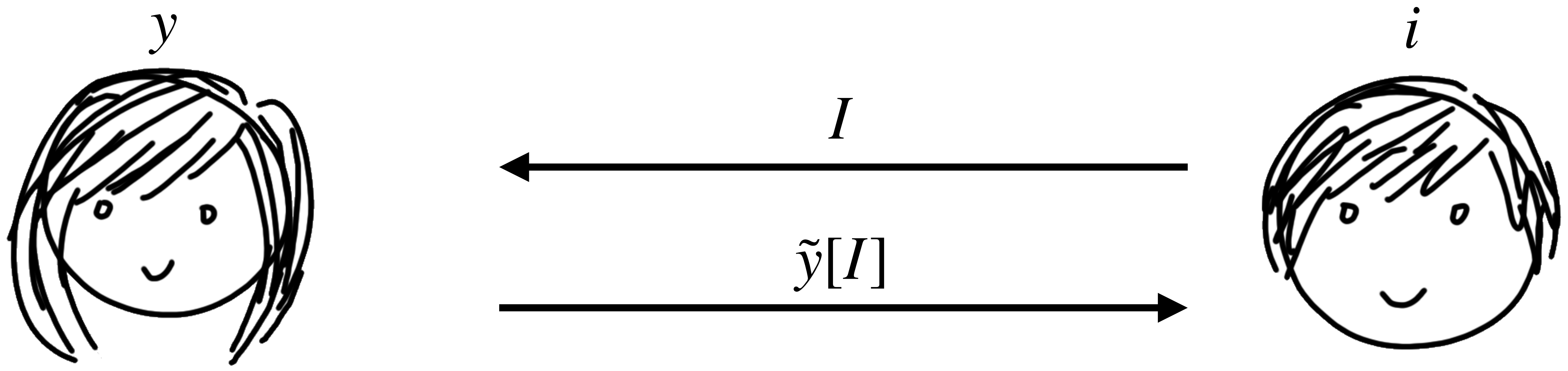

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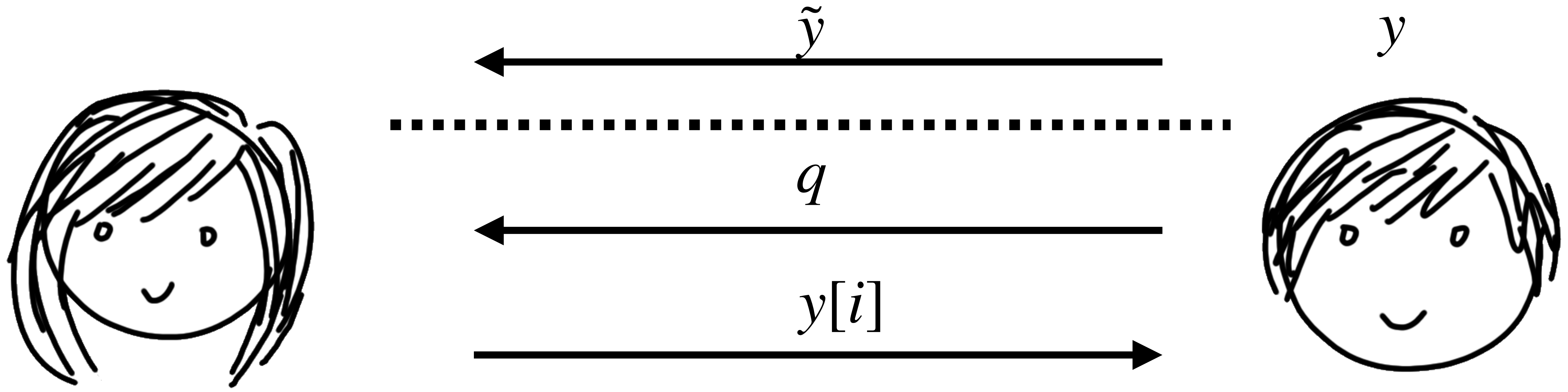

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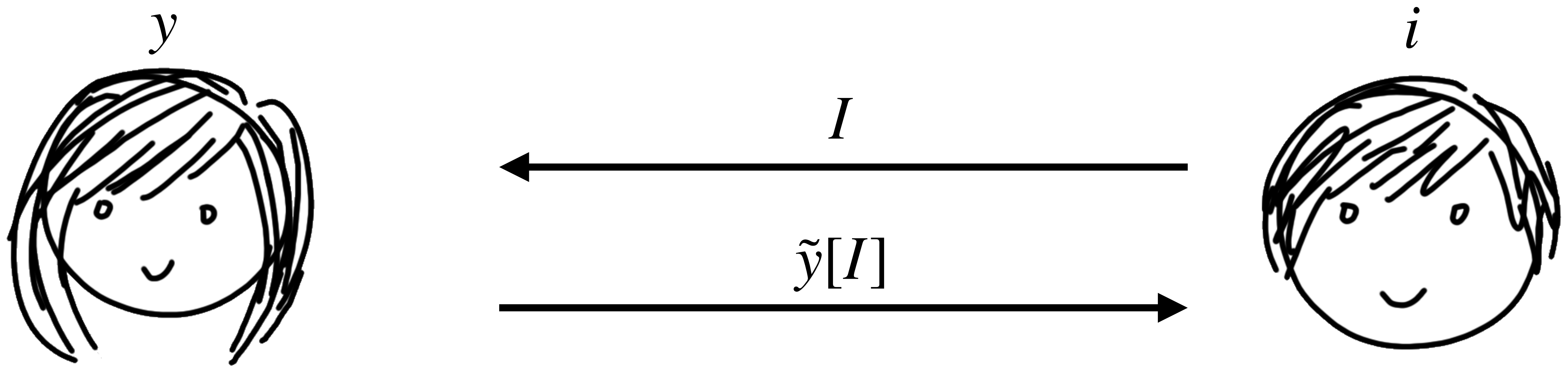

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Prior Work: [Lin-**M**-Wichs'23] build DEPIR from RingLWE

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Requires careful argument and special ORAM construction

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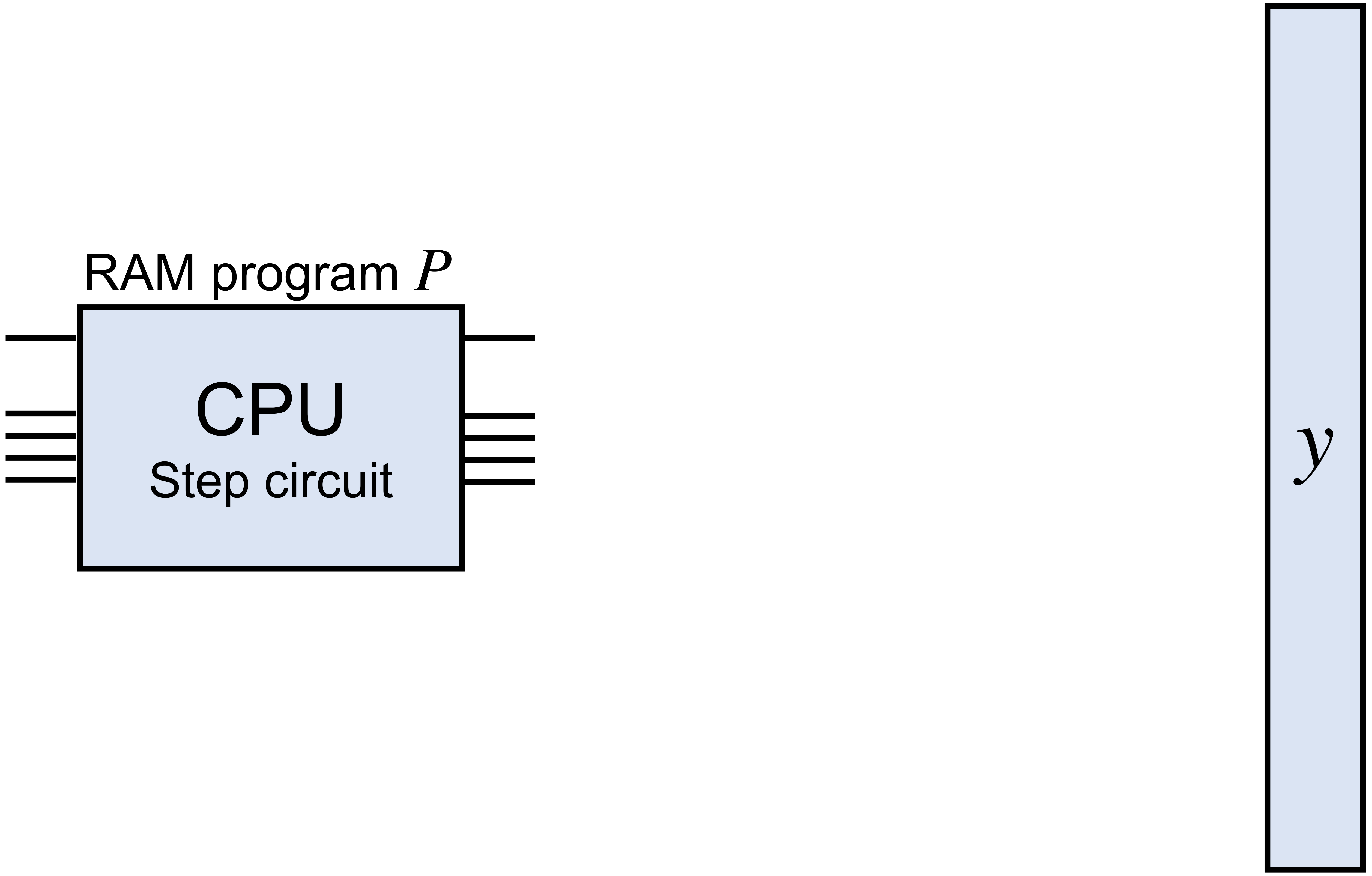
Building blocks: Laconic Oblivious Transfer + Garbled circuits



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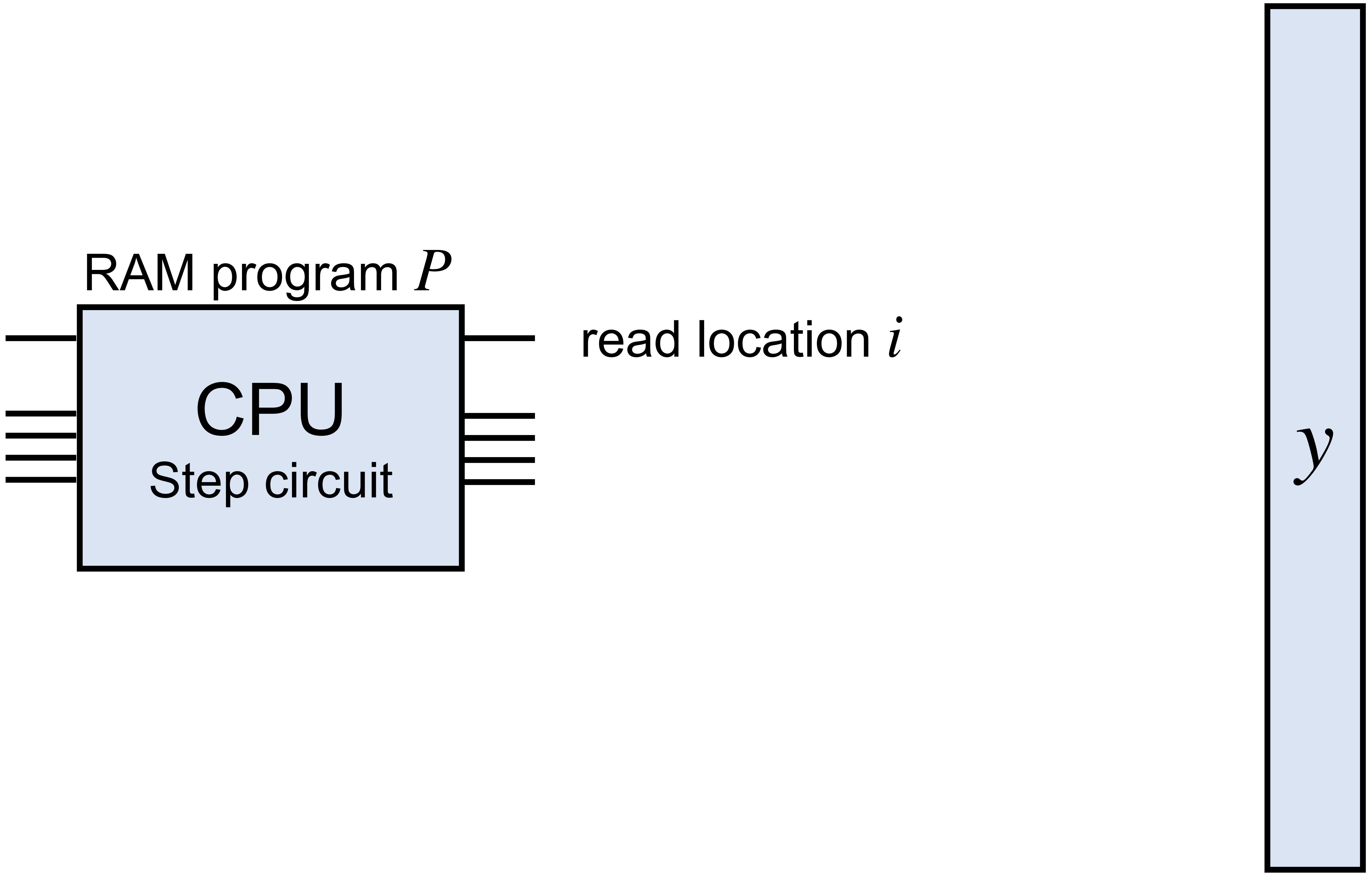

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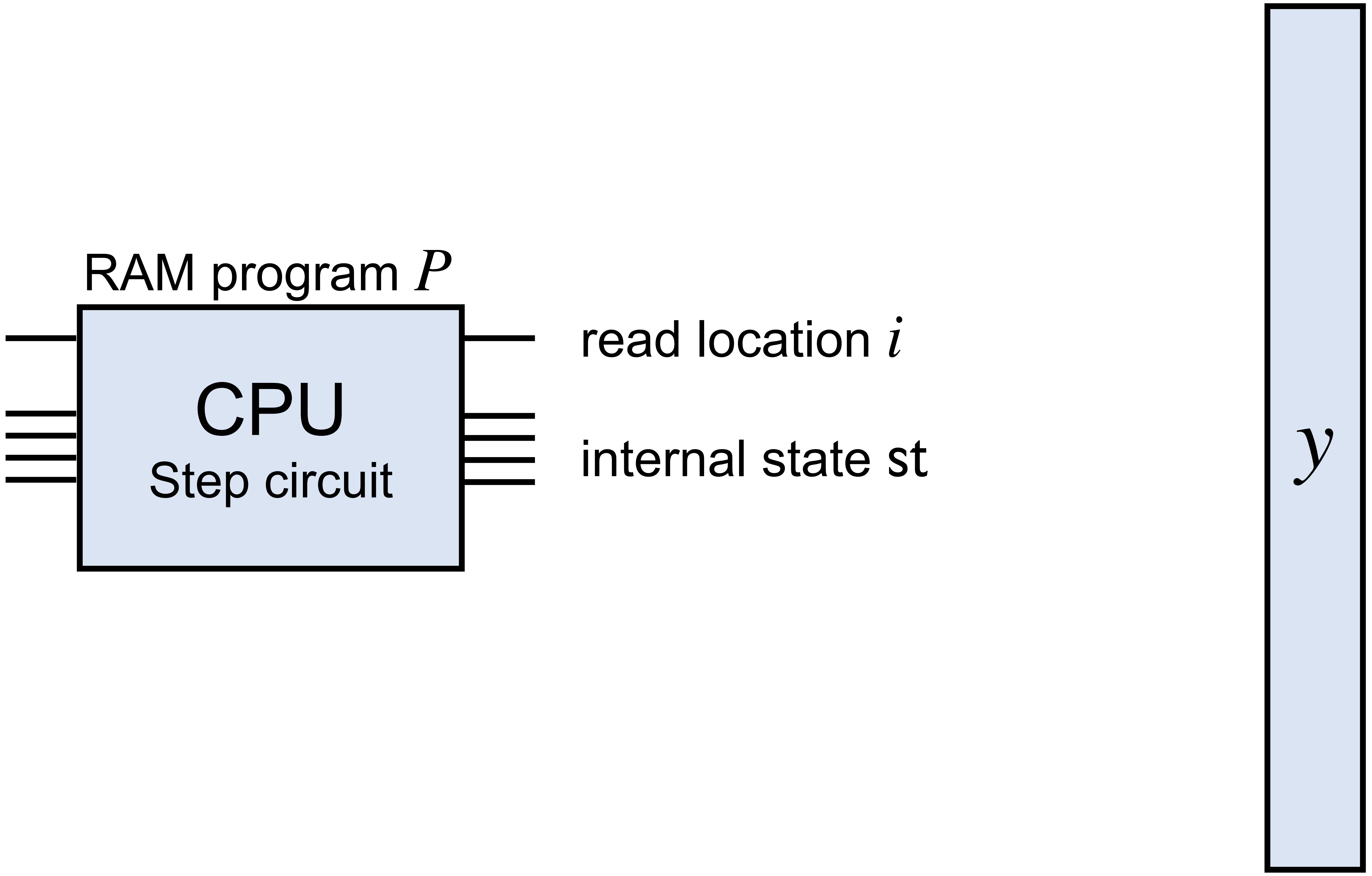

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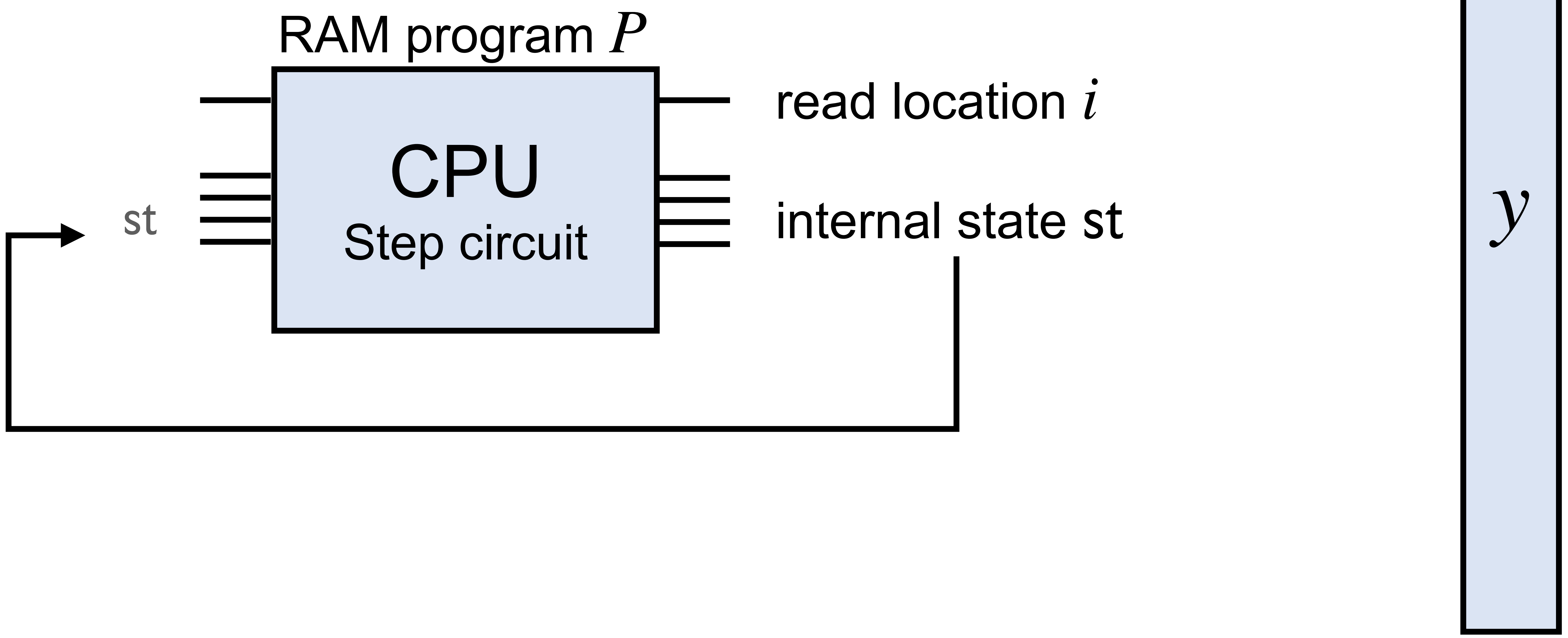

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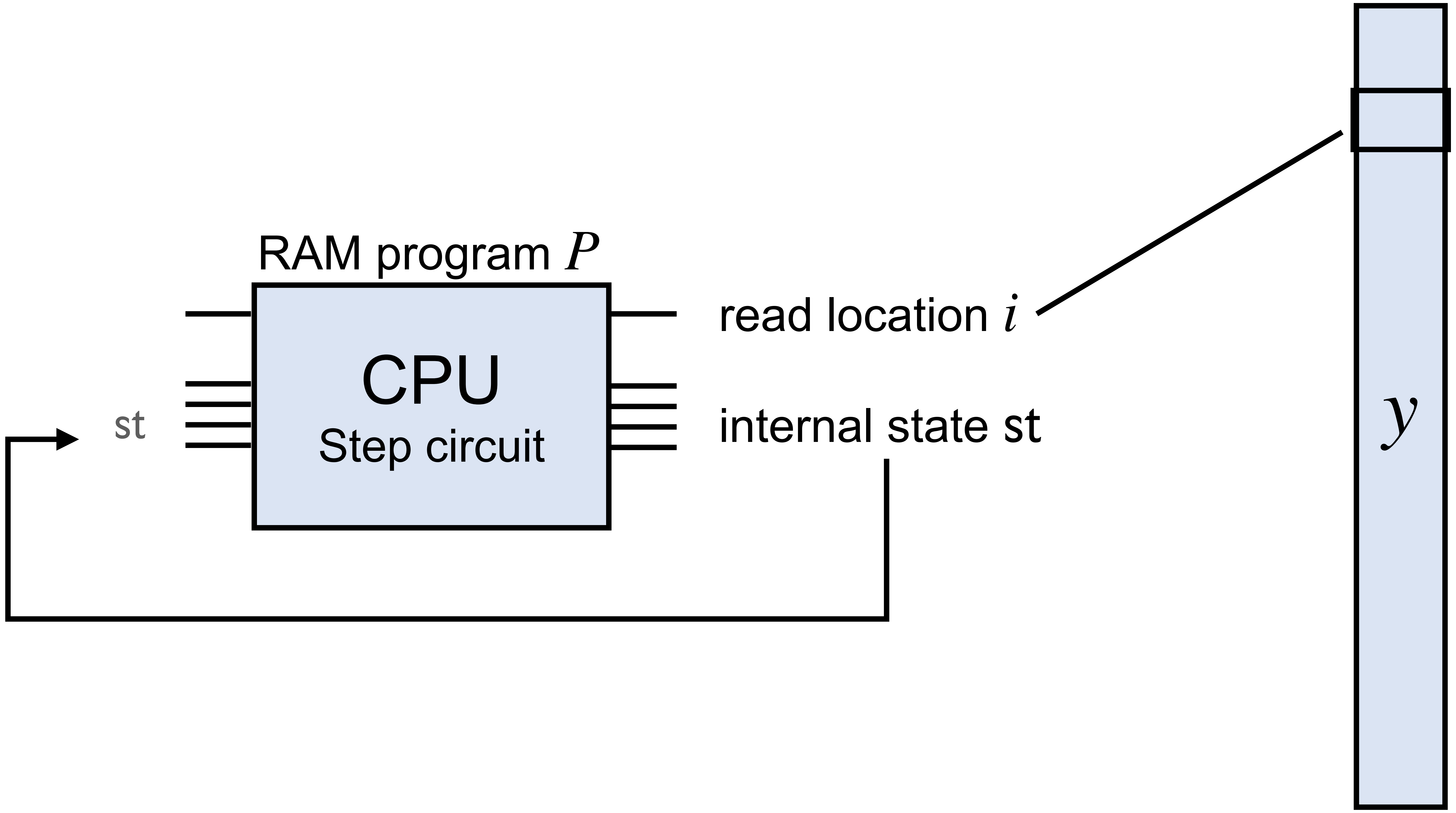

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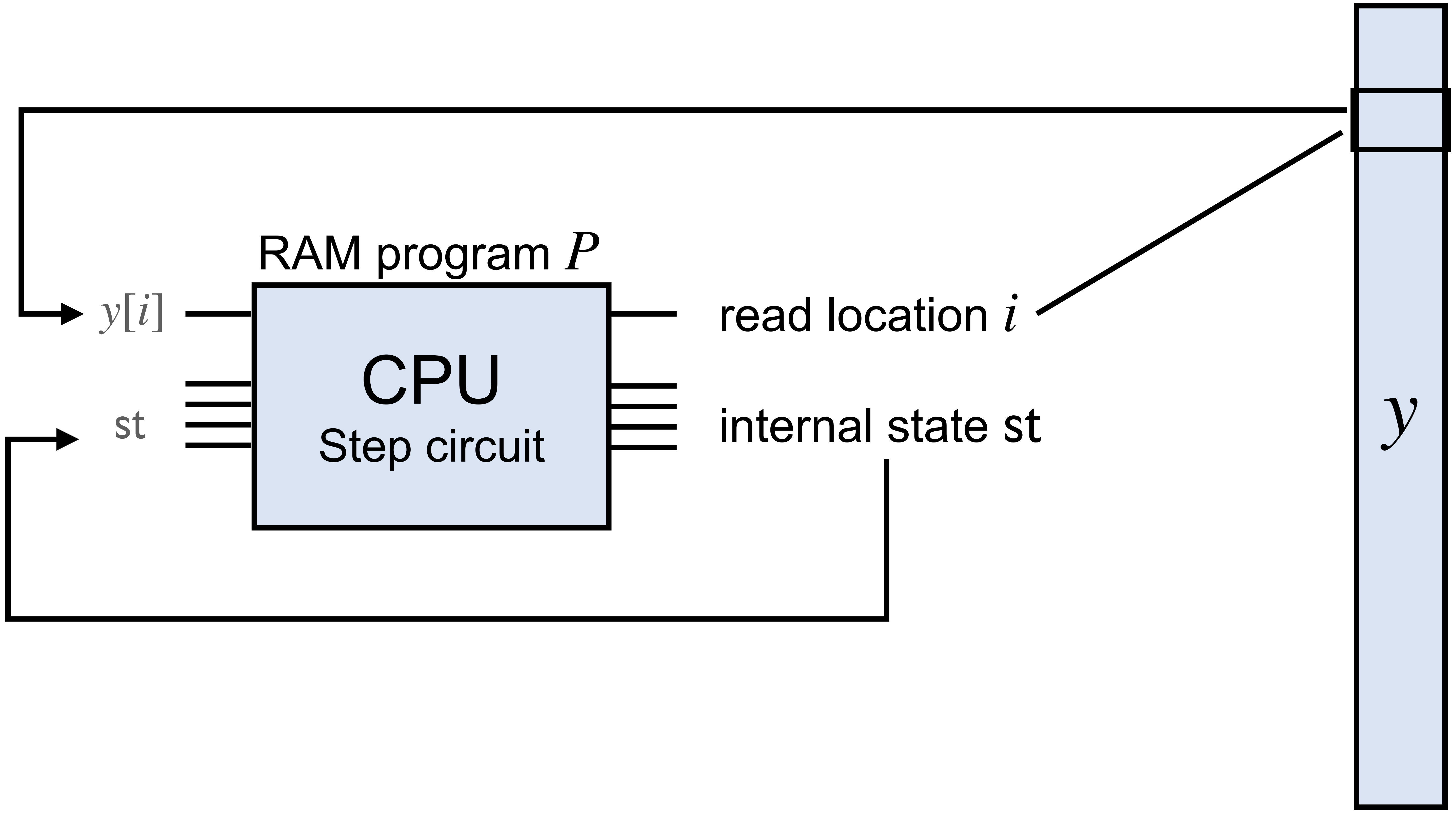

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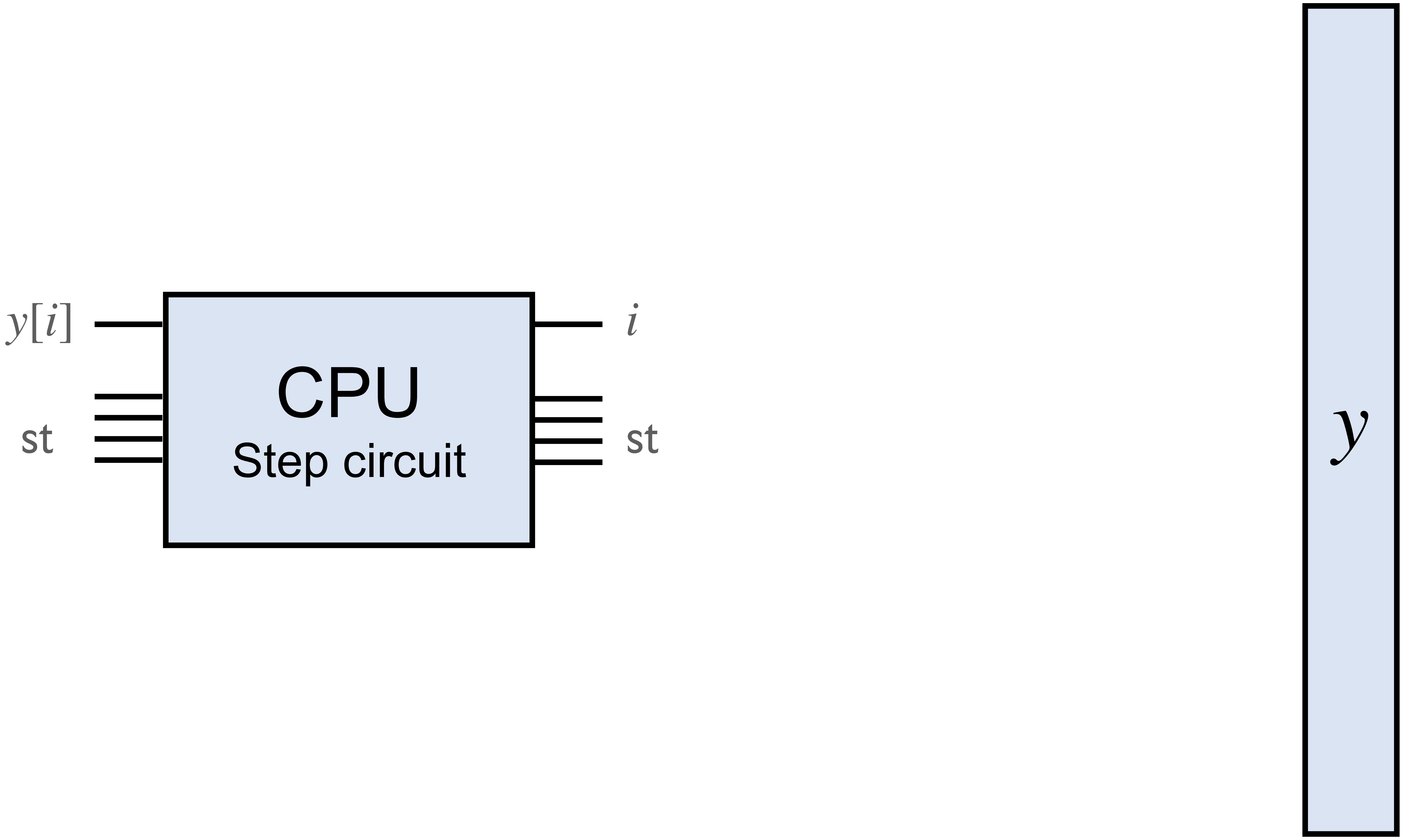

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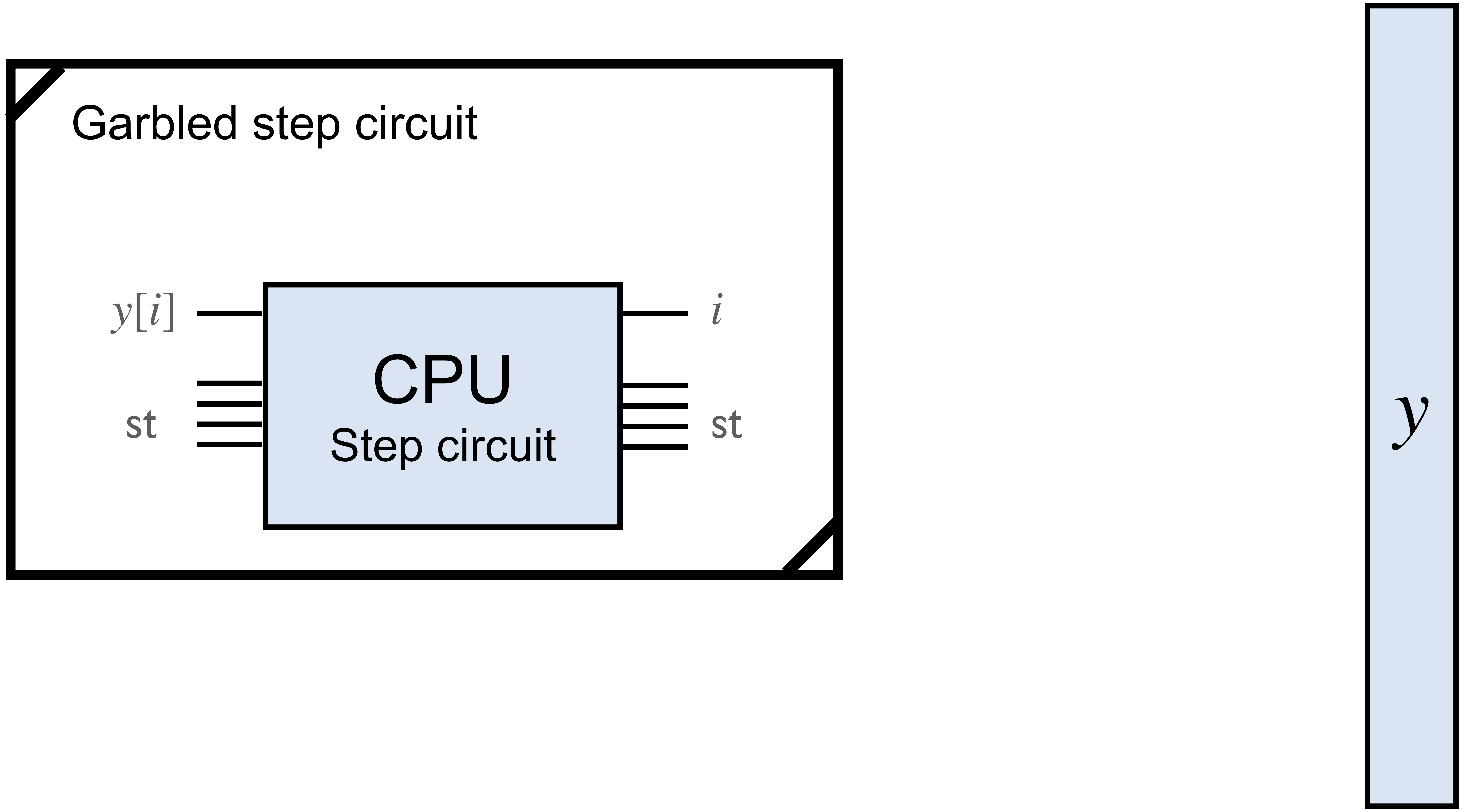

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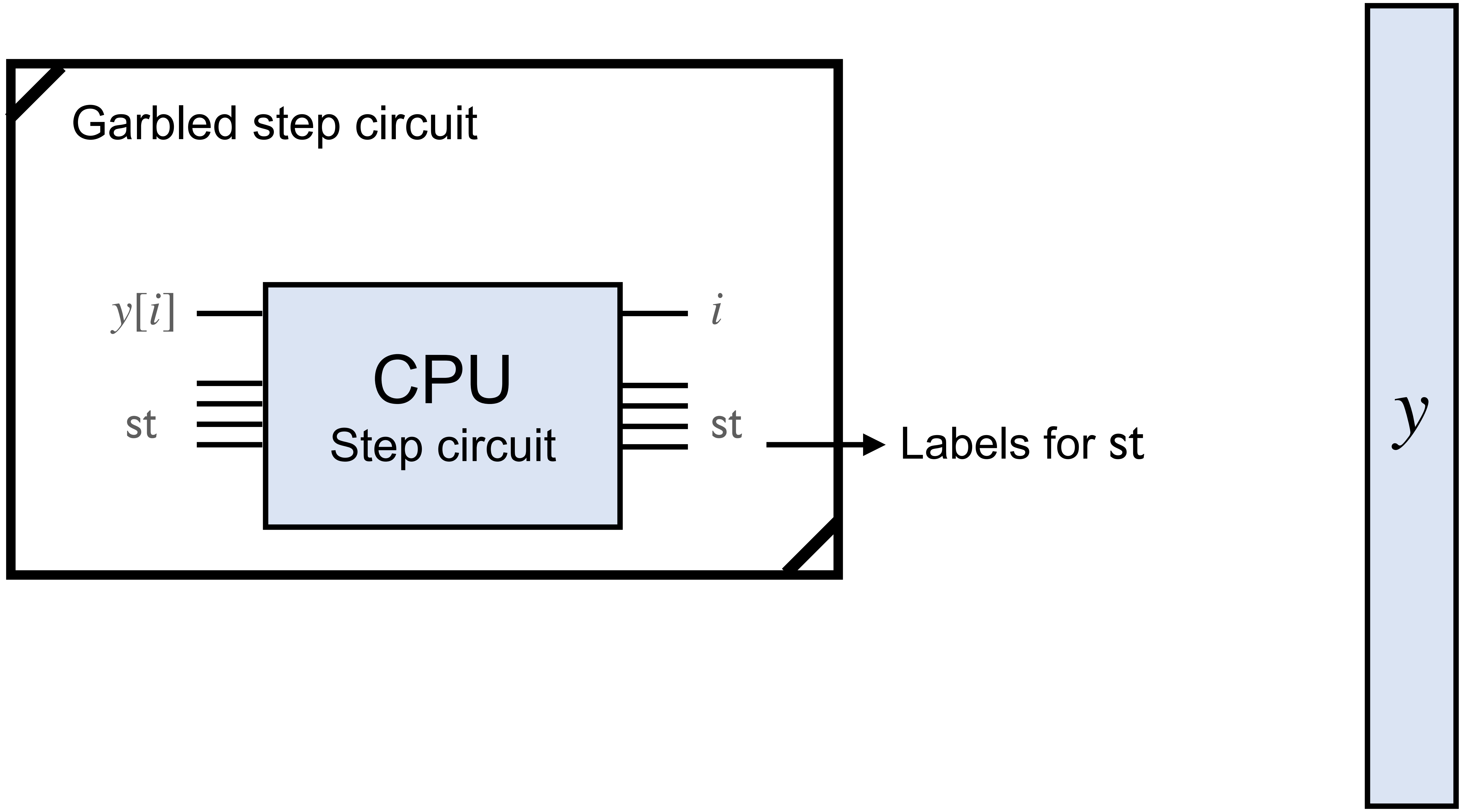

Garbled step circuit

$y[i]$

st

CPU

Step circuit

i

st

Labels for st

y

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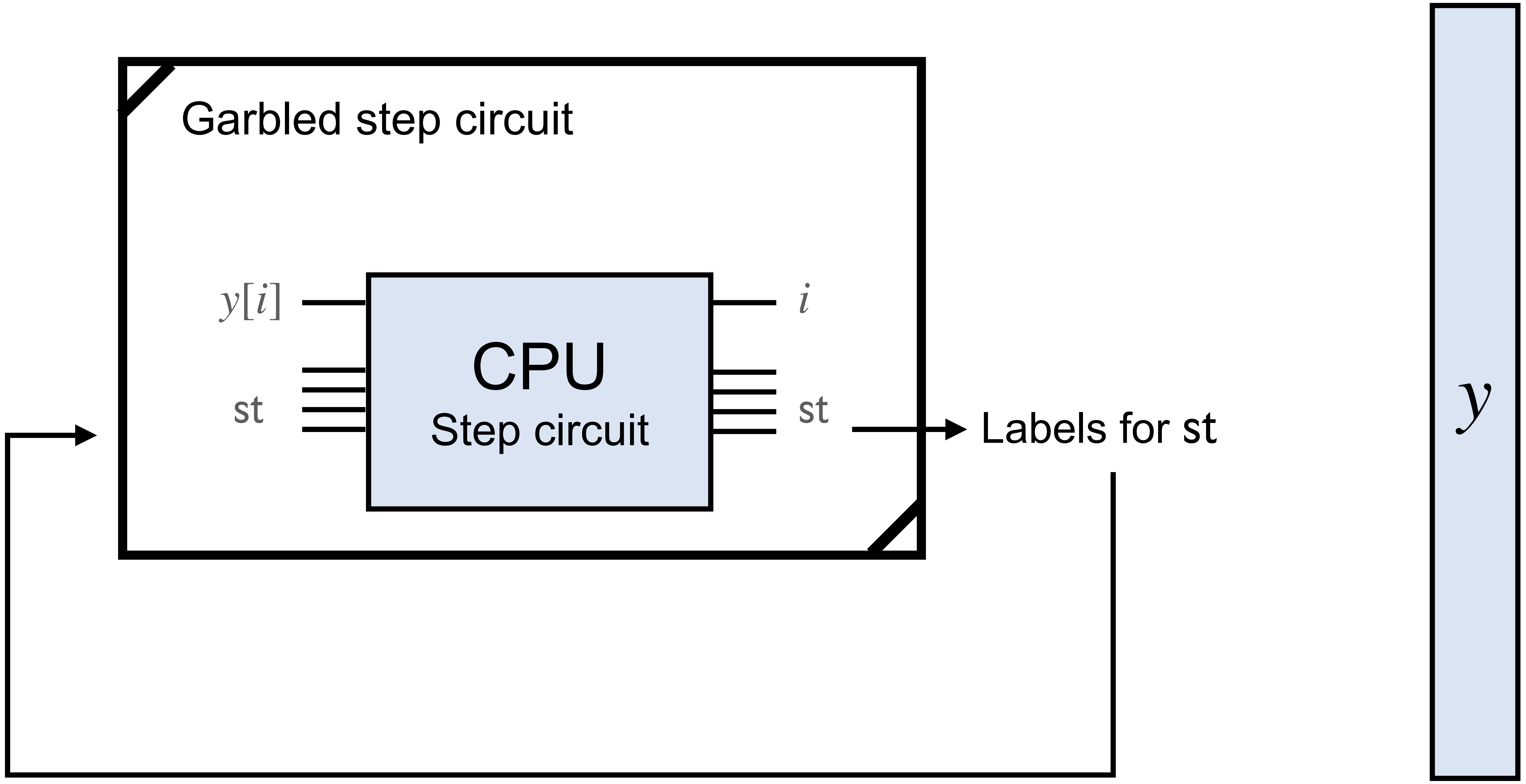

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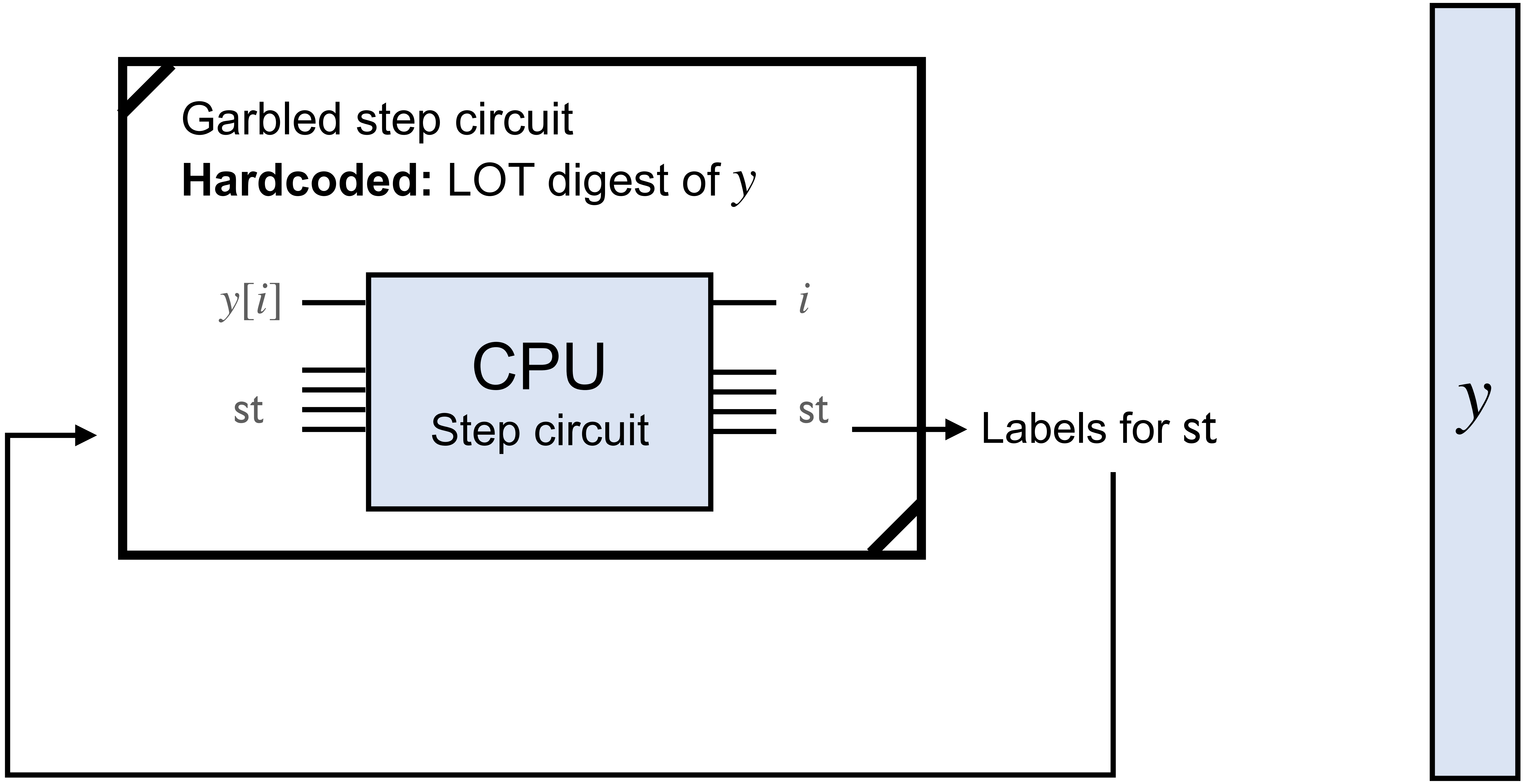

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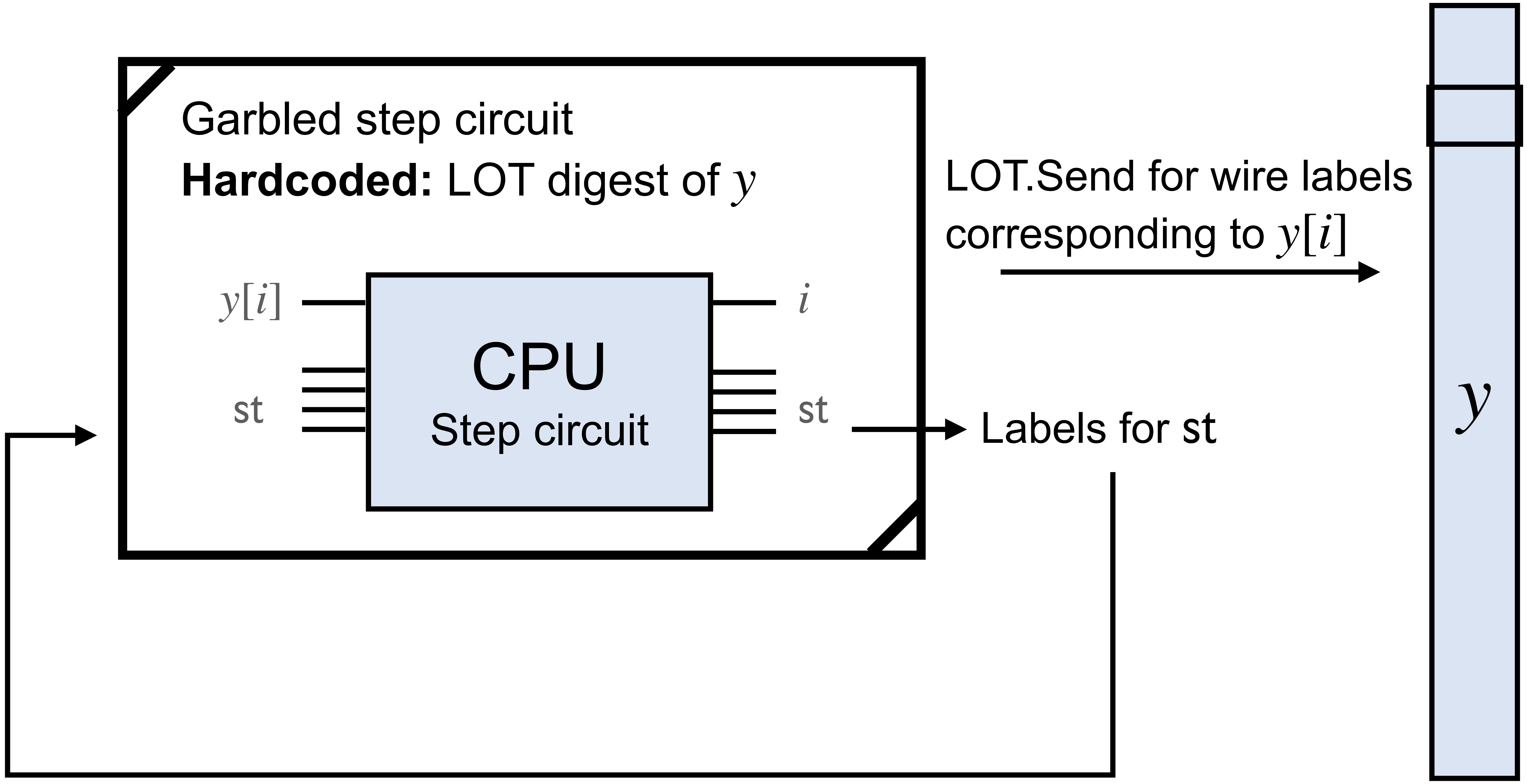

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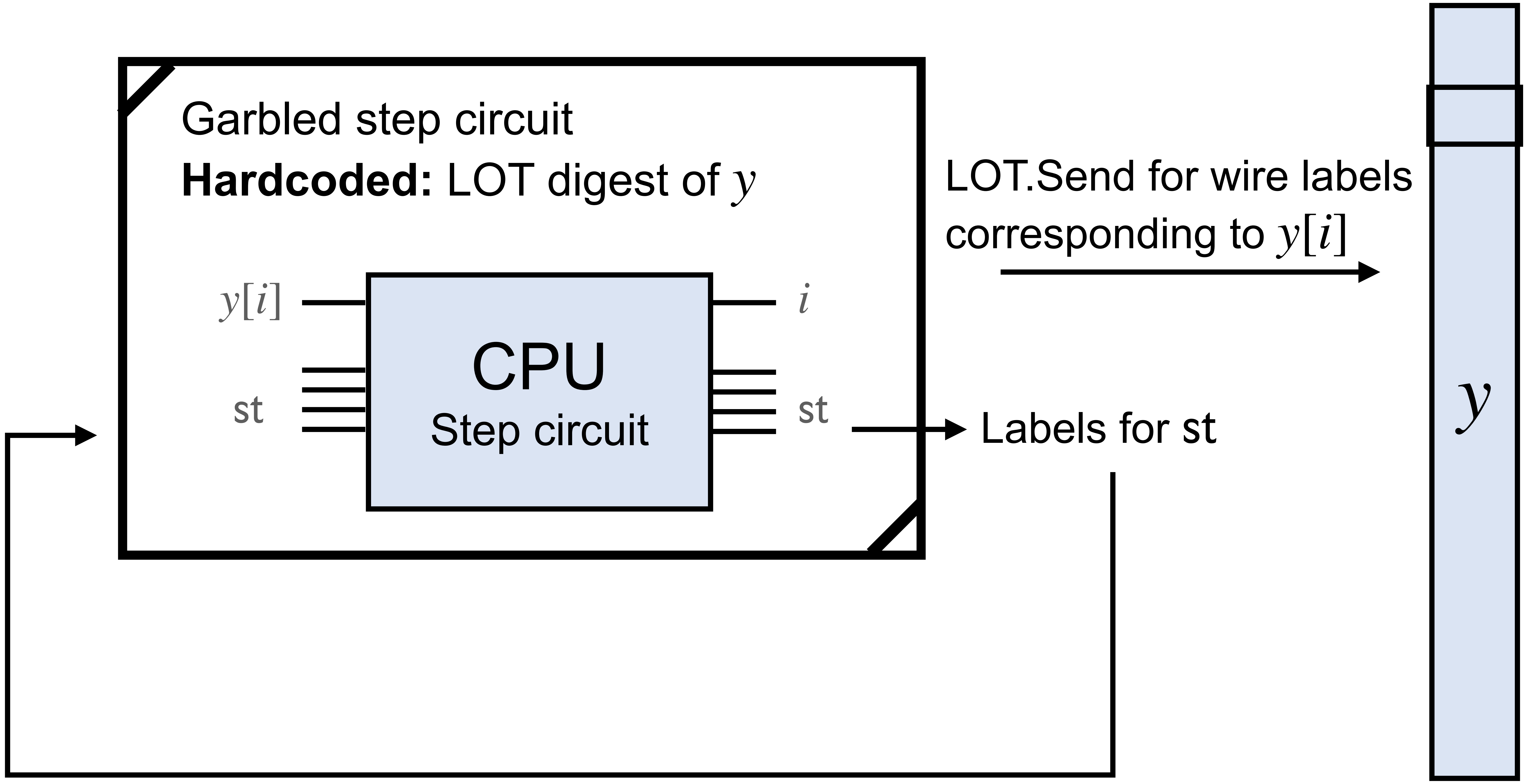

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LOT ensures that only the label for $y[i]$ is revealed (and not $1 - y[i]$)

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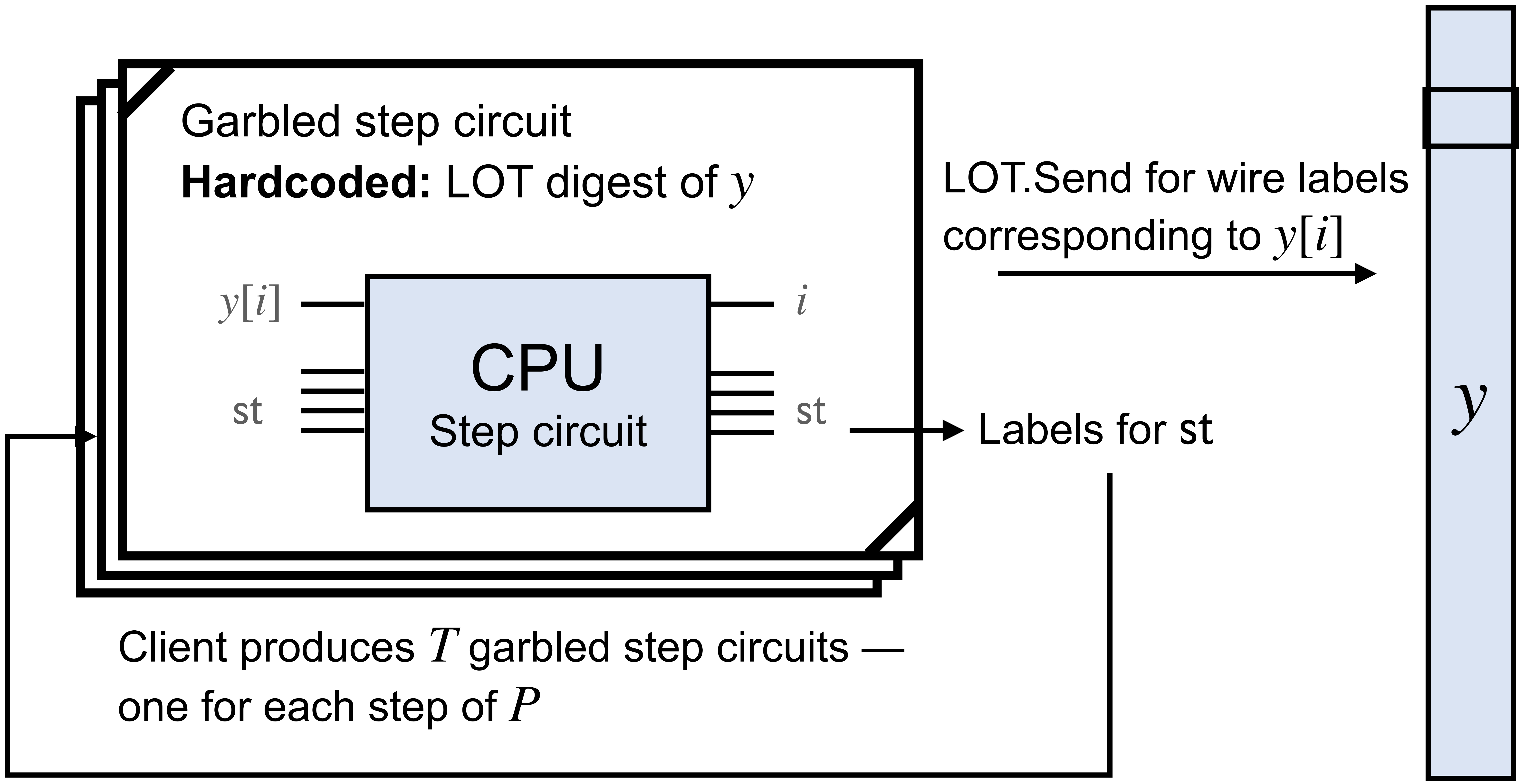

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Client produces T garbled step circuits — one for each step of P

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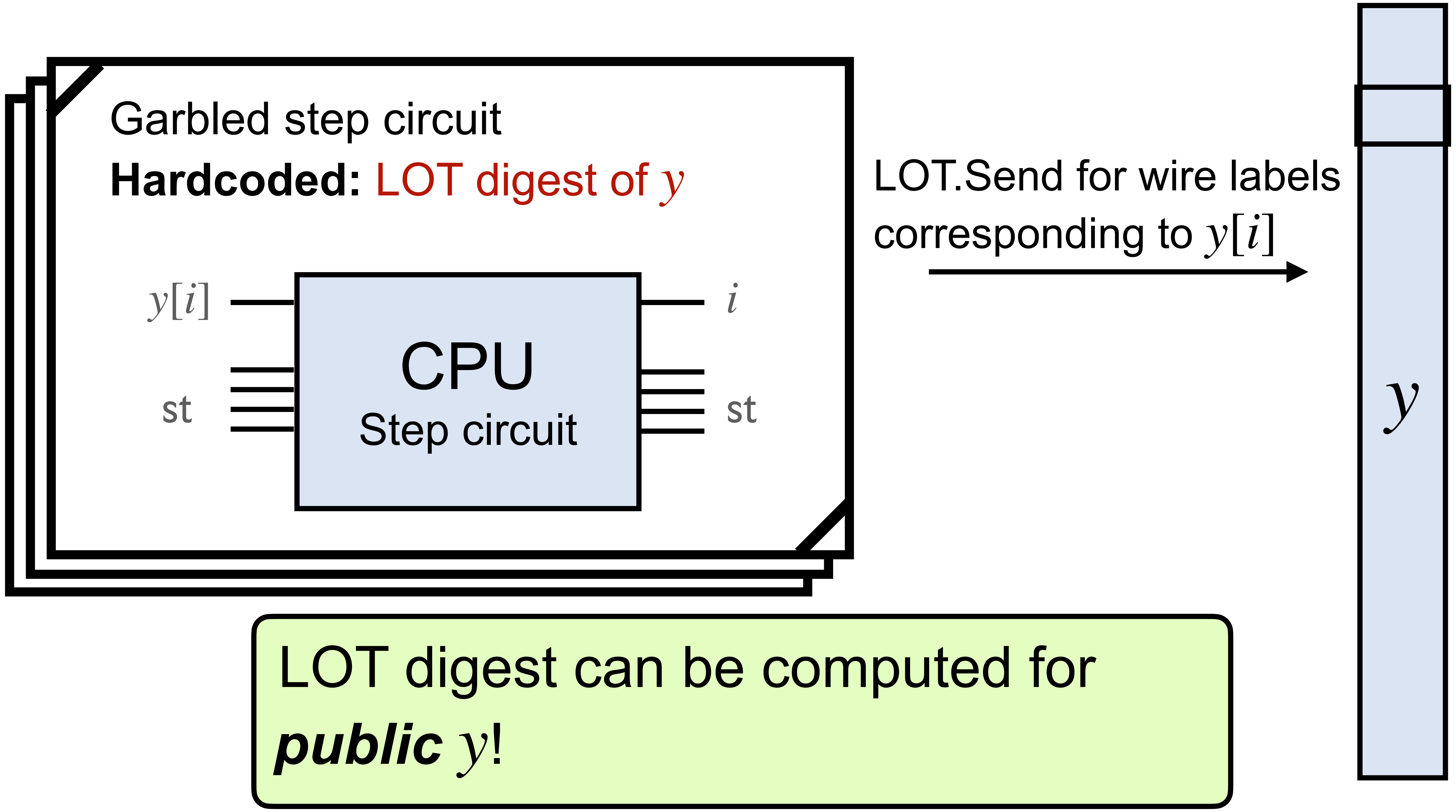

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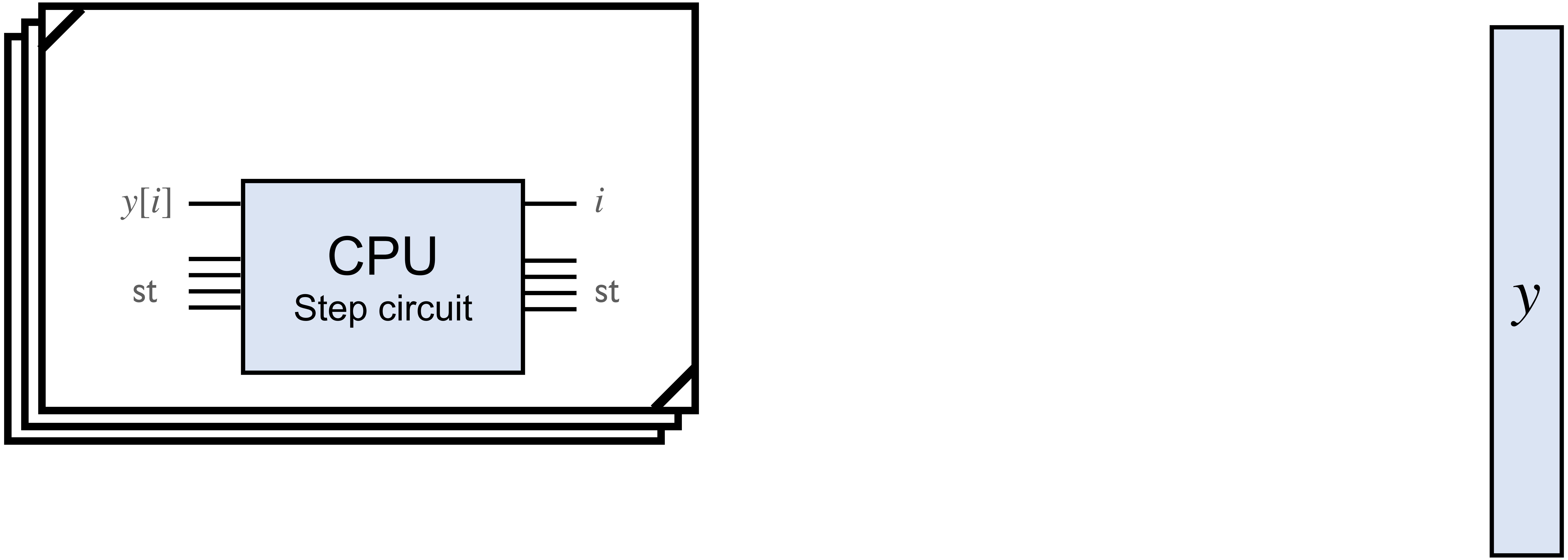
LOT digest can be computed for ***public*** y!

Full security with DEPIR

+ ORAM for the client’s database x



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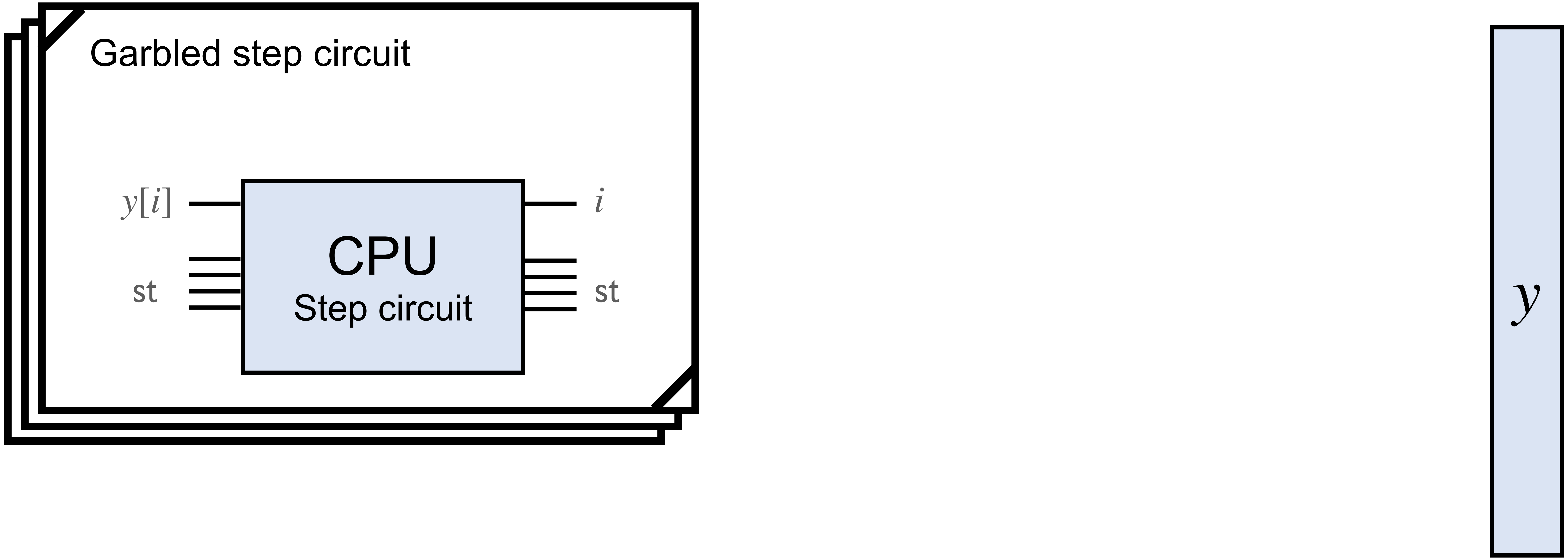

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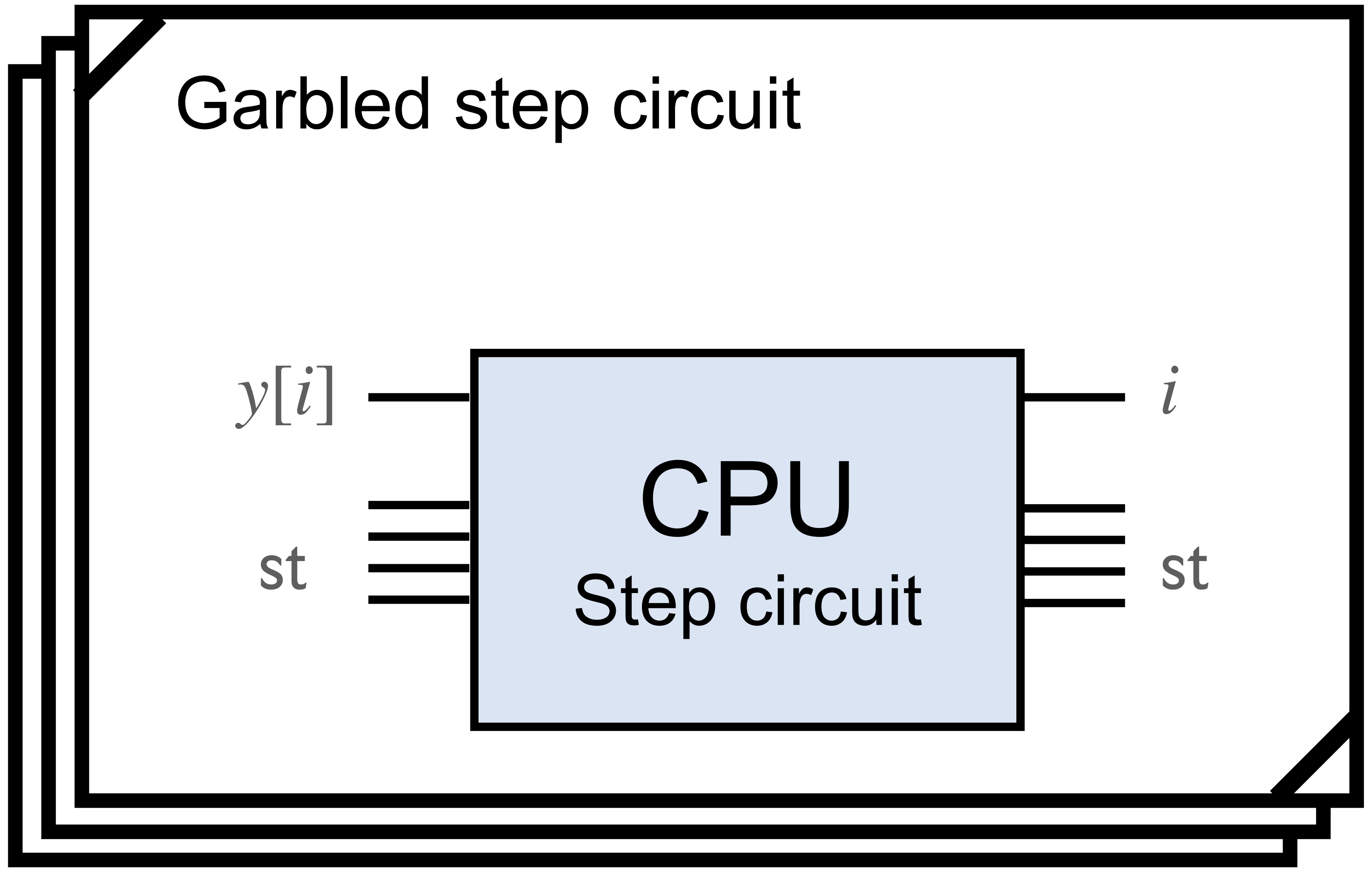

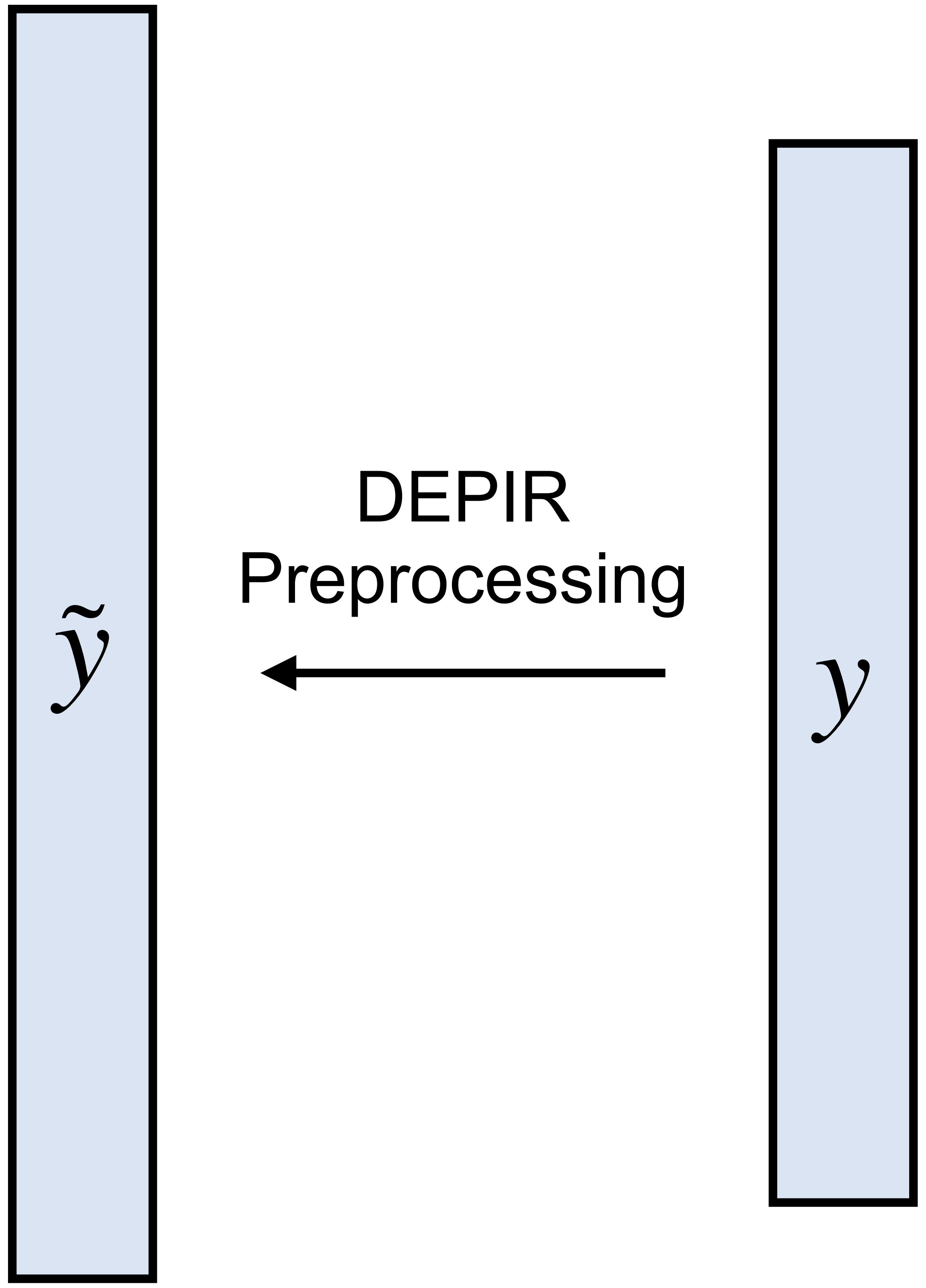

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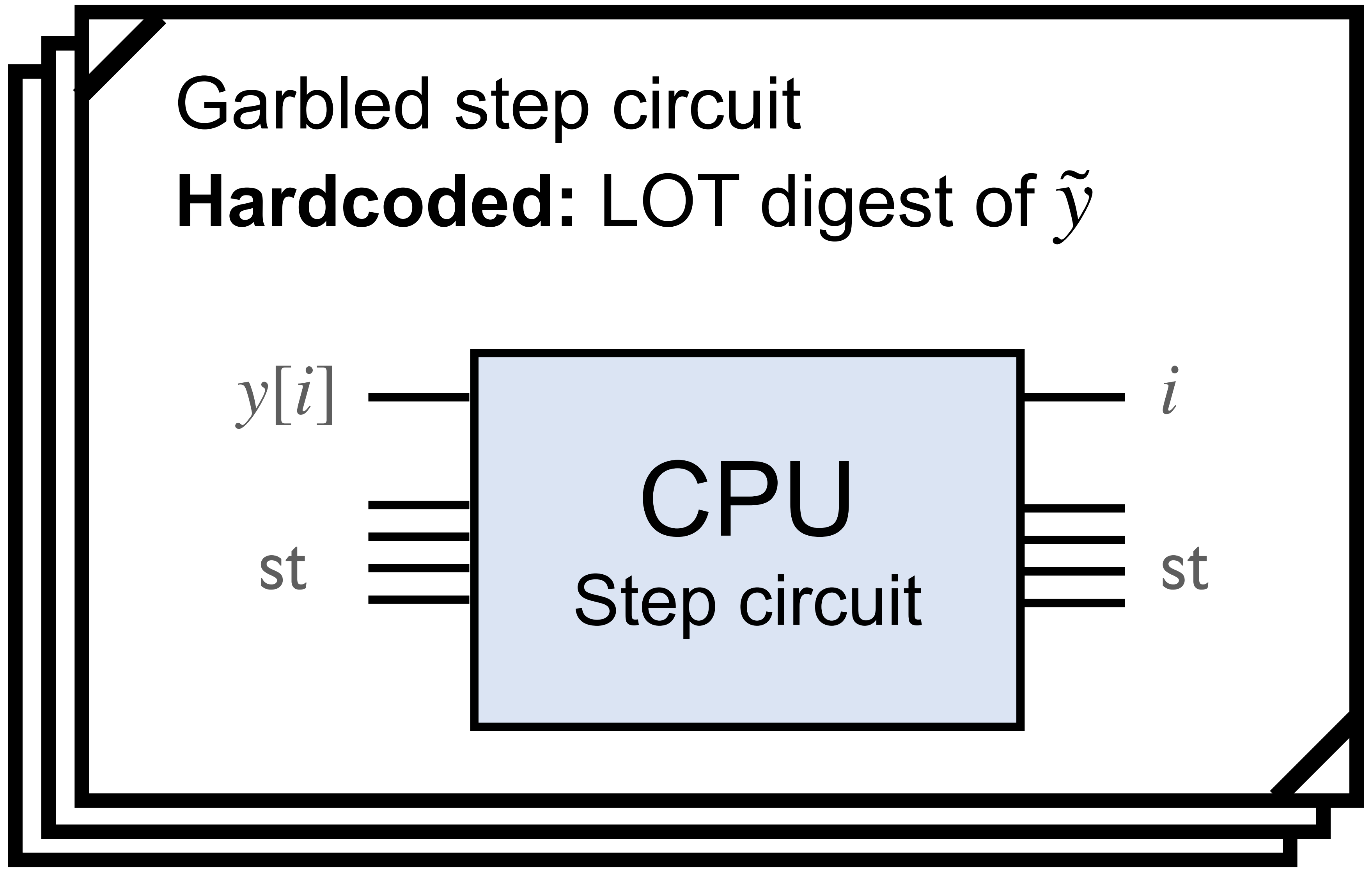

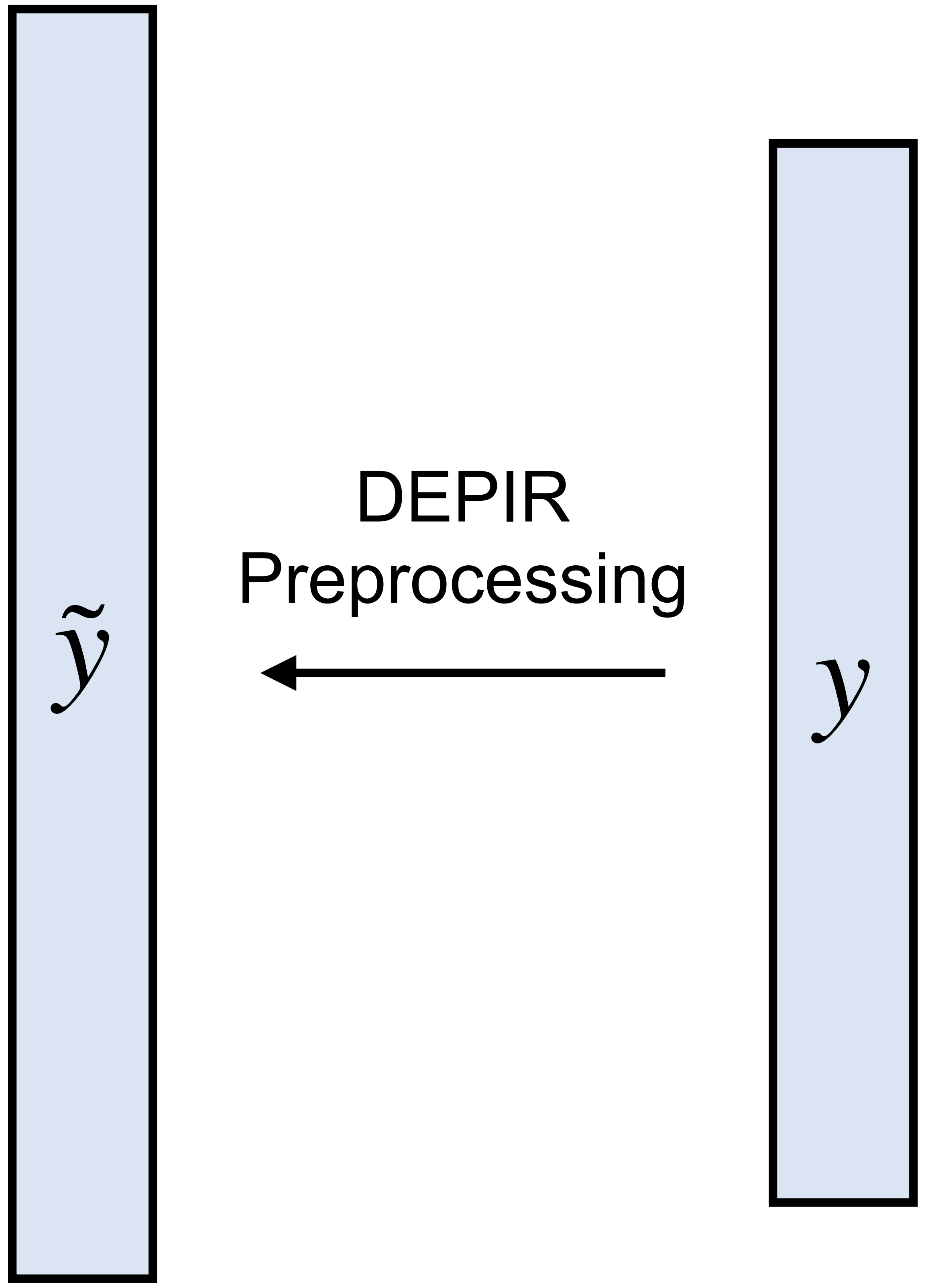

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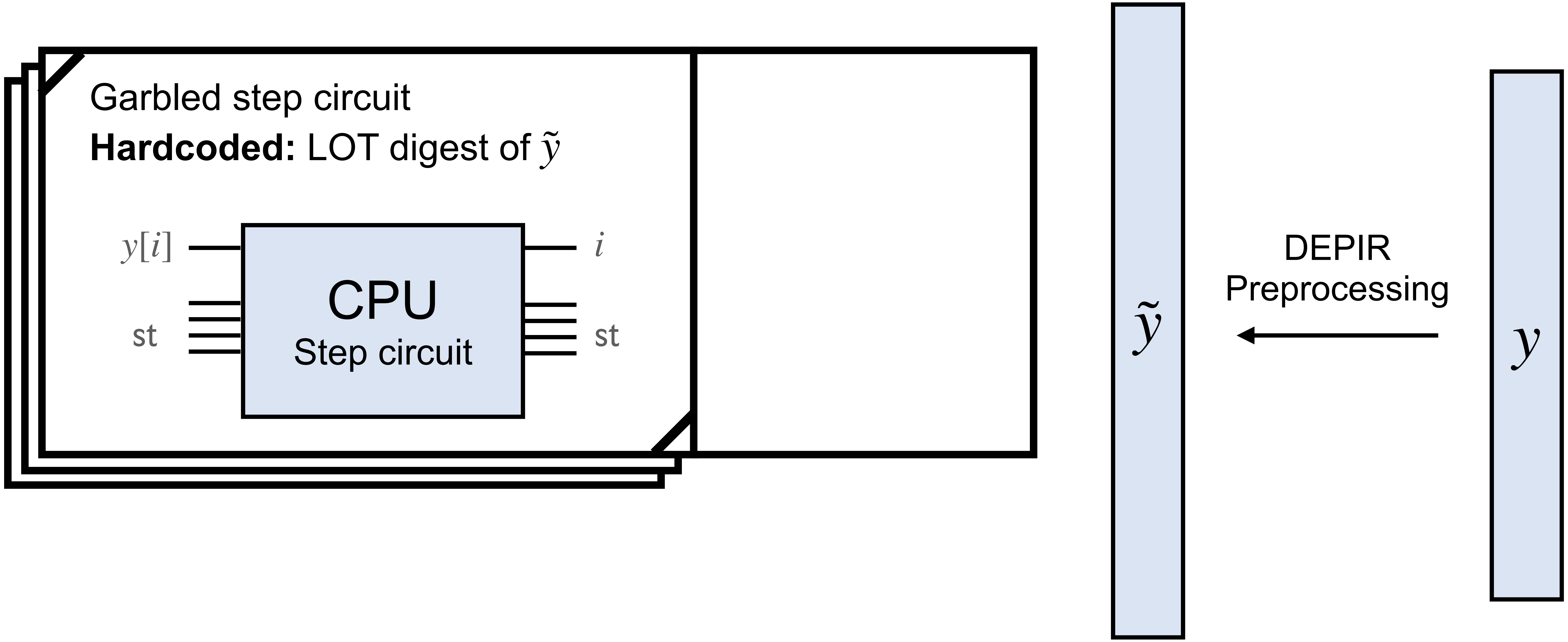

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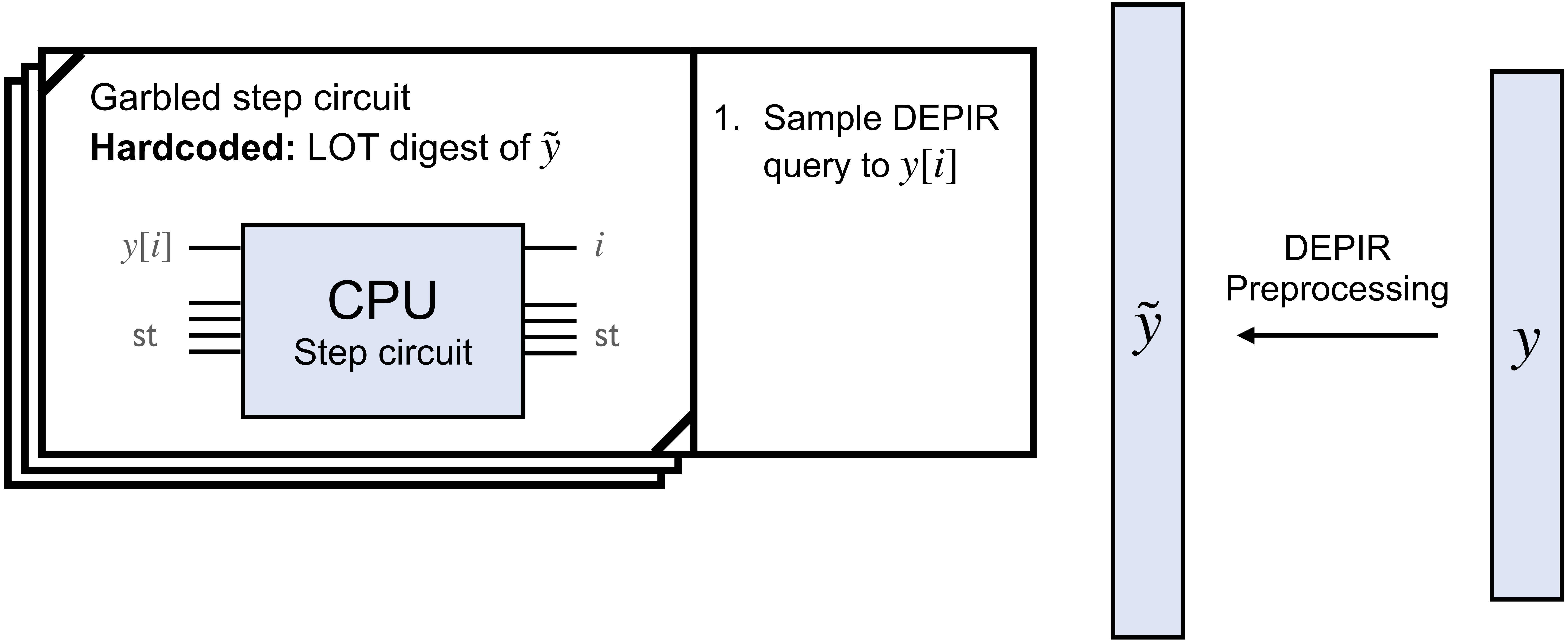

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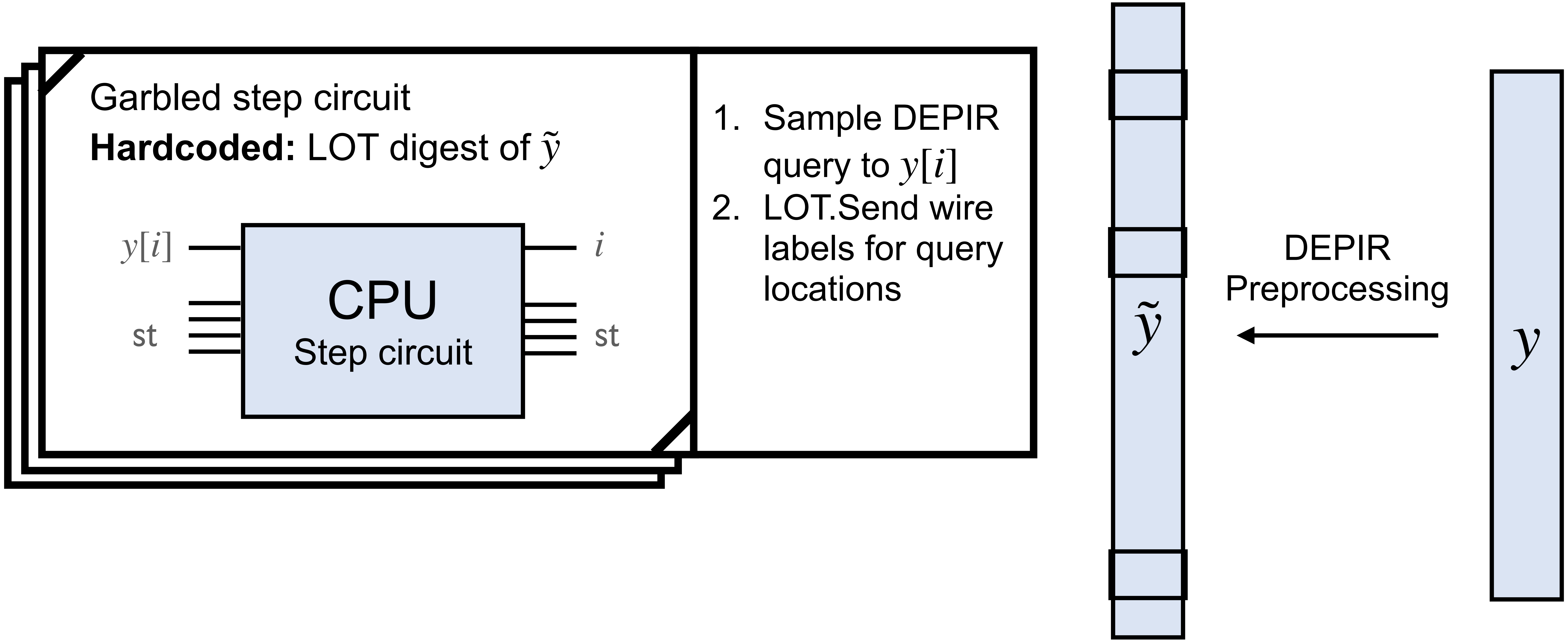

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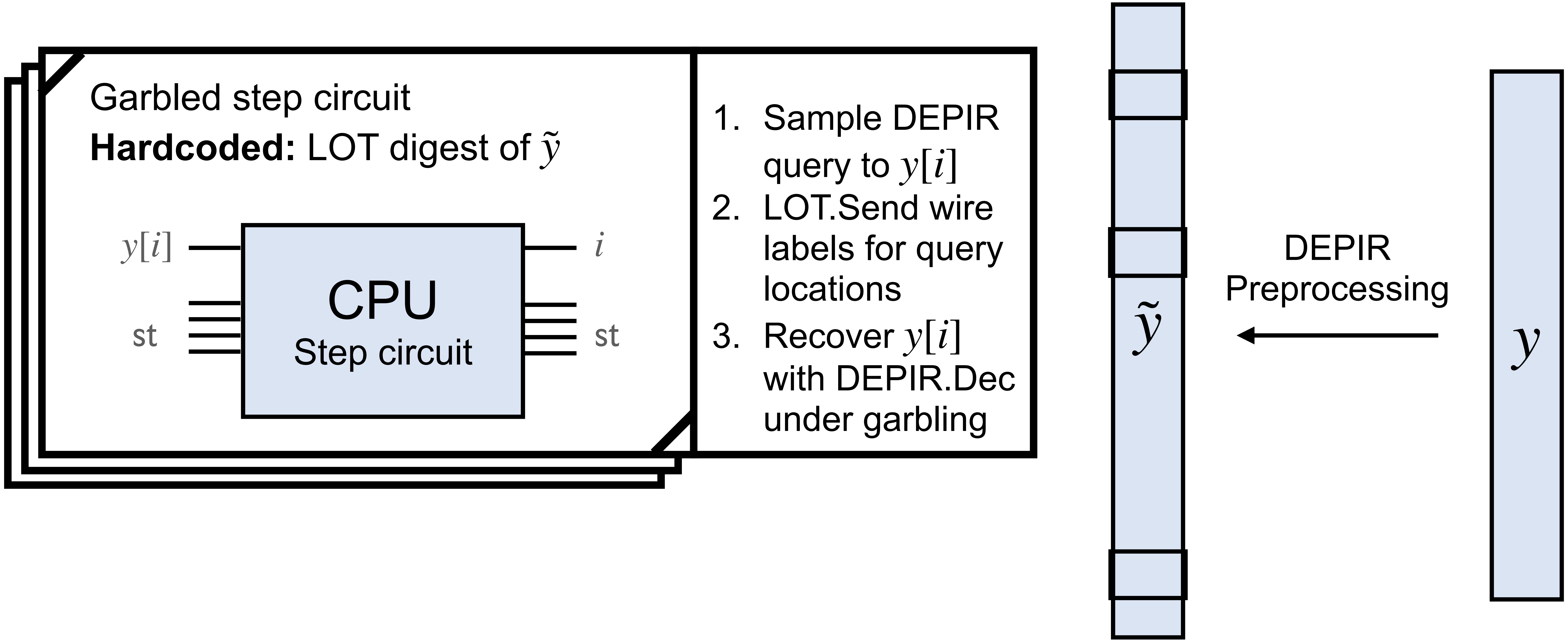

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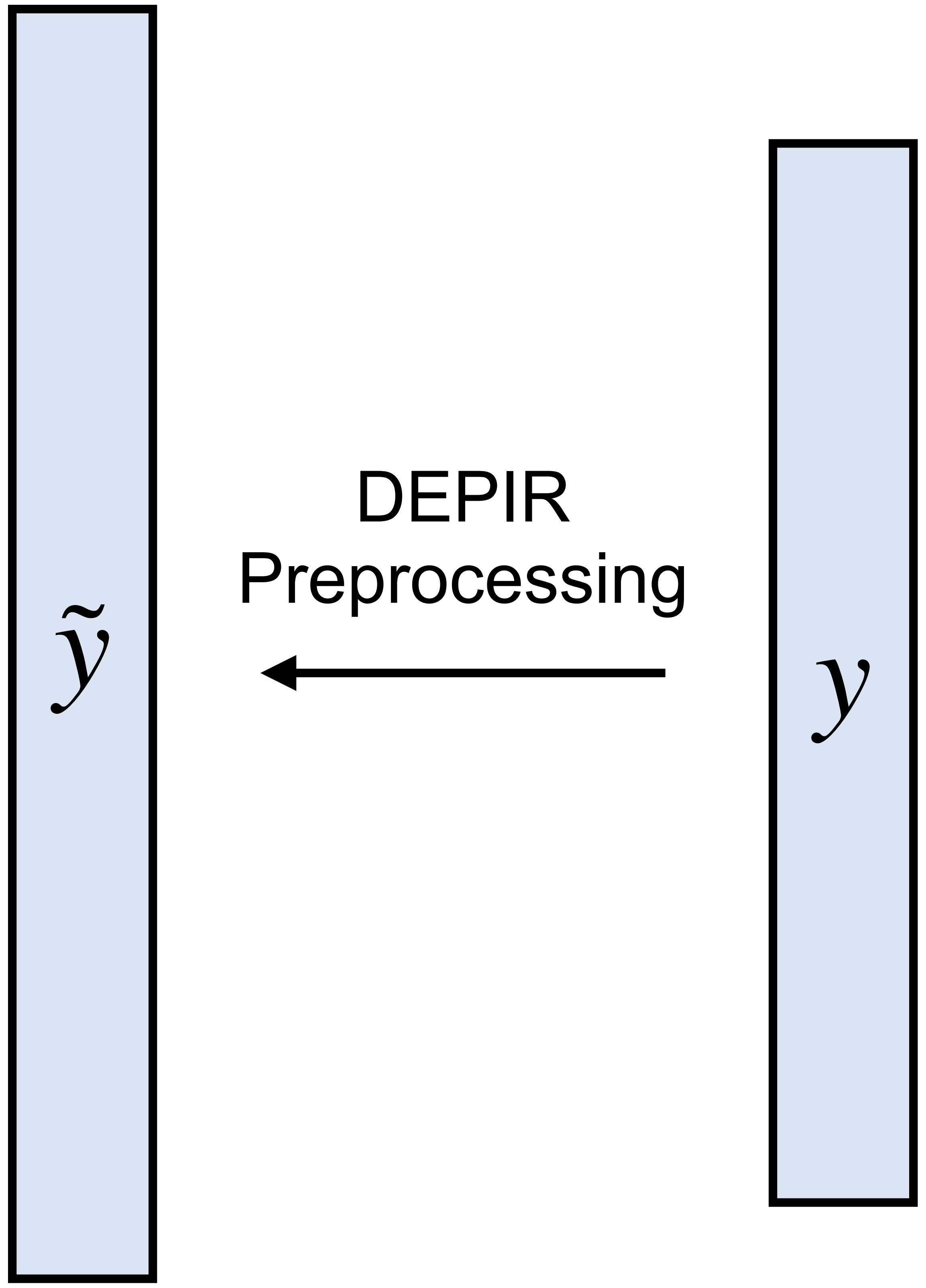

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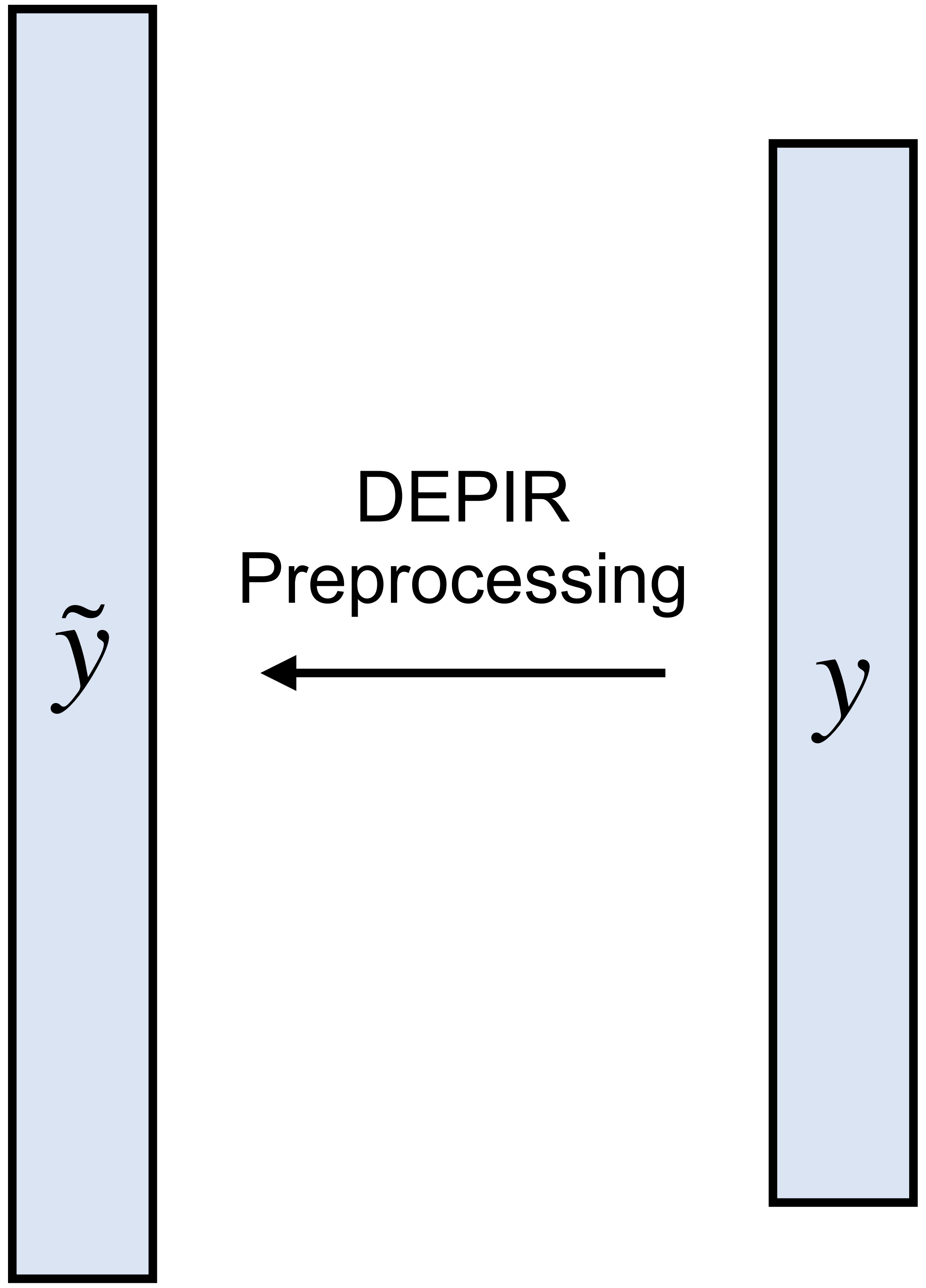

$\tilde{y}$

DEPIR
Preprocessing

y

$\mathsf{GCGen}_{\mathsf{dig}_{\tilde{y}}}(t)$

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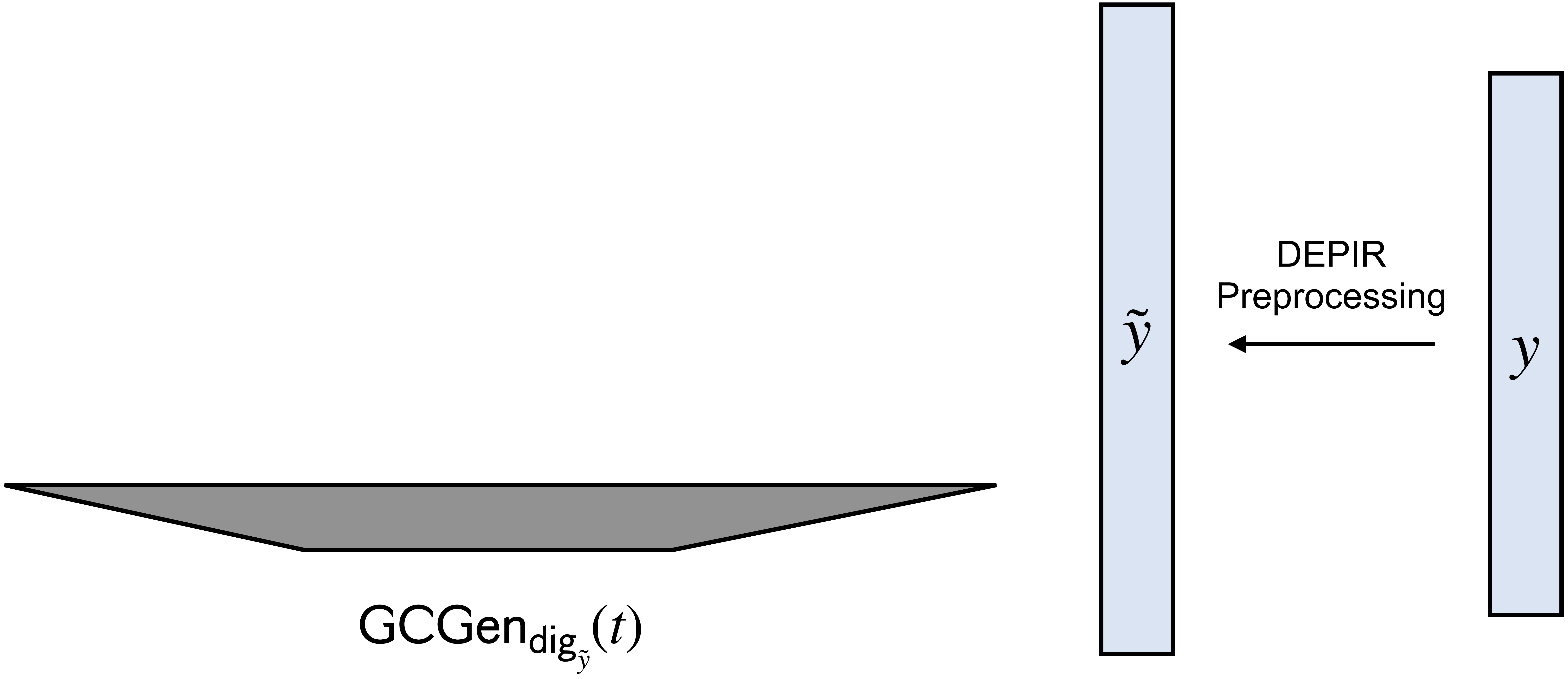

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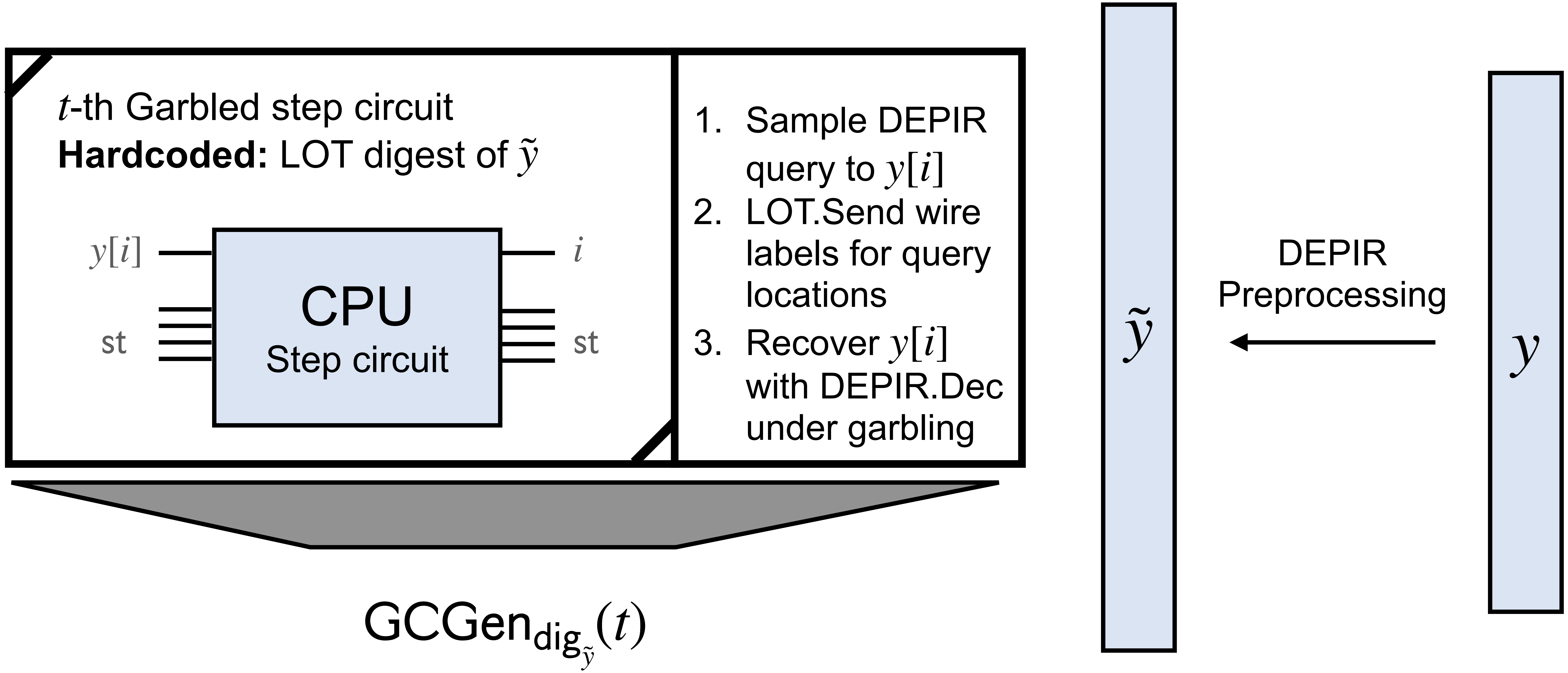

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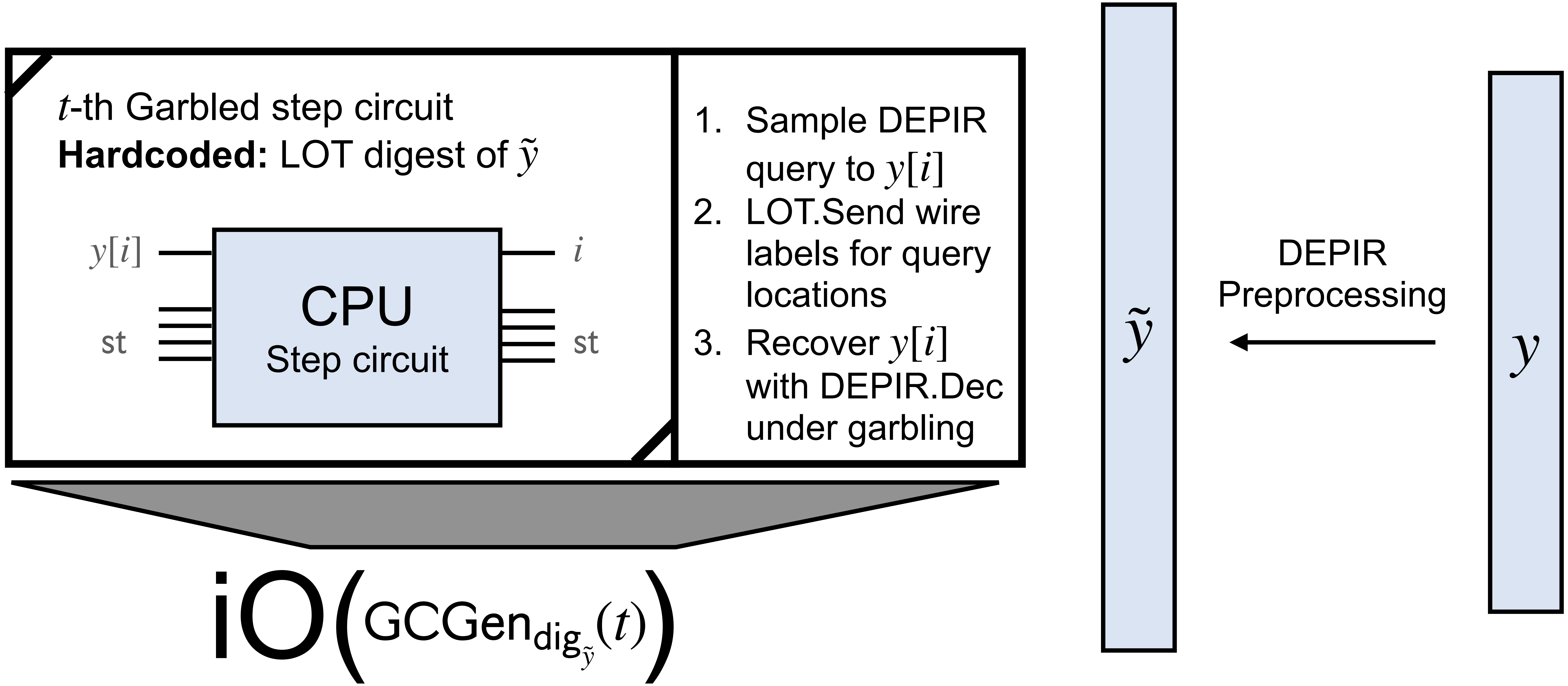

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Additional Results

Result: We build (multi-key) functional encryption for RAMs

- Each secret key associated to large database y
- Decryption recovers $P(x, y)$ in sublinear time in $|x|, |y|$

Assumptions: FE for circuits + RingLWE

Prior work: [ACFQ’22] only allows short secret keys

Result: We build iO for RAMs

- Given (P, y), obfuscate the program $P(\cdot, y)$
- Evaluation can be sublinear in $|y|$

Assumptions: iO for circuits + RingLWE

Prior work: [BCGHJLPTV’18] doesn’t allow sublinear runtime

Thank you!

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