Simulation Security in the Random Oracle Model

Jérémi Do Dinh

Master’s thesis supervised by Alessandro Chiesa and Giacomo Fenzi

Overview

- Motivation
- Preliminaries
- Results
- Construction:
  Encryption Scheme in the ROM

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Non-interactive ARGuments in the ROM

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- Simple setting.
- Heuristically instantiation with hash functions.
- Can have a transparent setup.

Non-interactive ARGuments in the ROM

Simulation security

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- Classical security: isolated adversary.

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- NARGs in <u>stronger adversarial</u> settings:
  - Soundness when protocols can be observed.

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- Classical security: isolated adversary.
- NARGs in stronger adversarial settings:
  - Soundness when protocols can be observed.
- *Concrete security* formalizations are required.

Concrete Security

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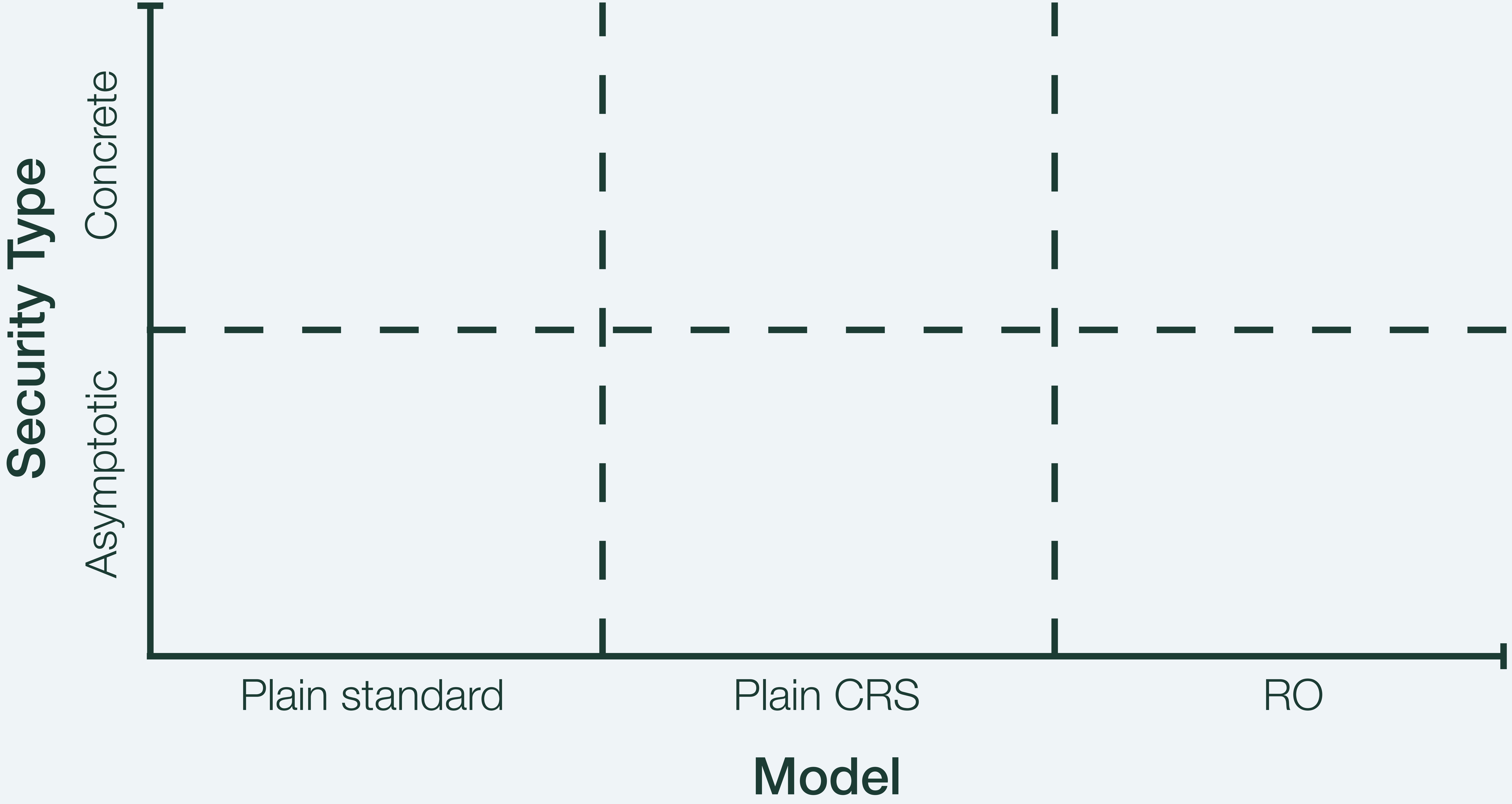
- Concrete security: parameterized error bounds.
- Security reductions and resource overhead.
- Practical protocol instantiation.

Simulation Security

Landscape



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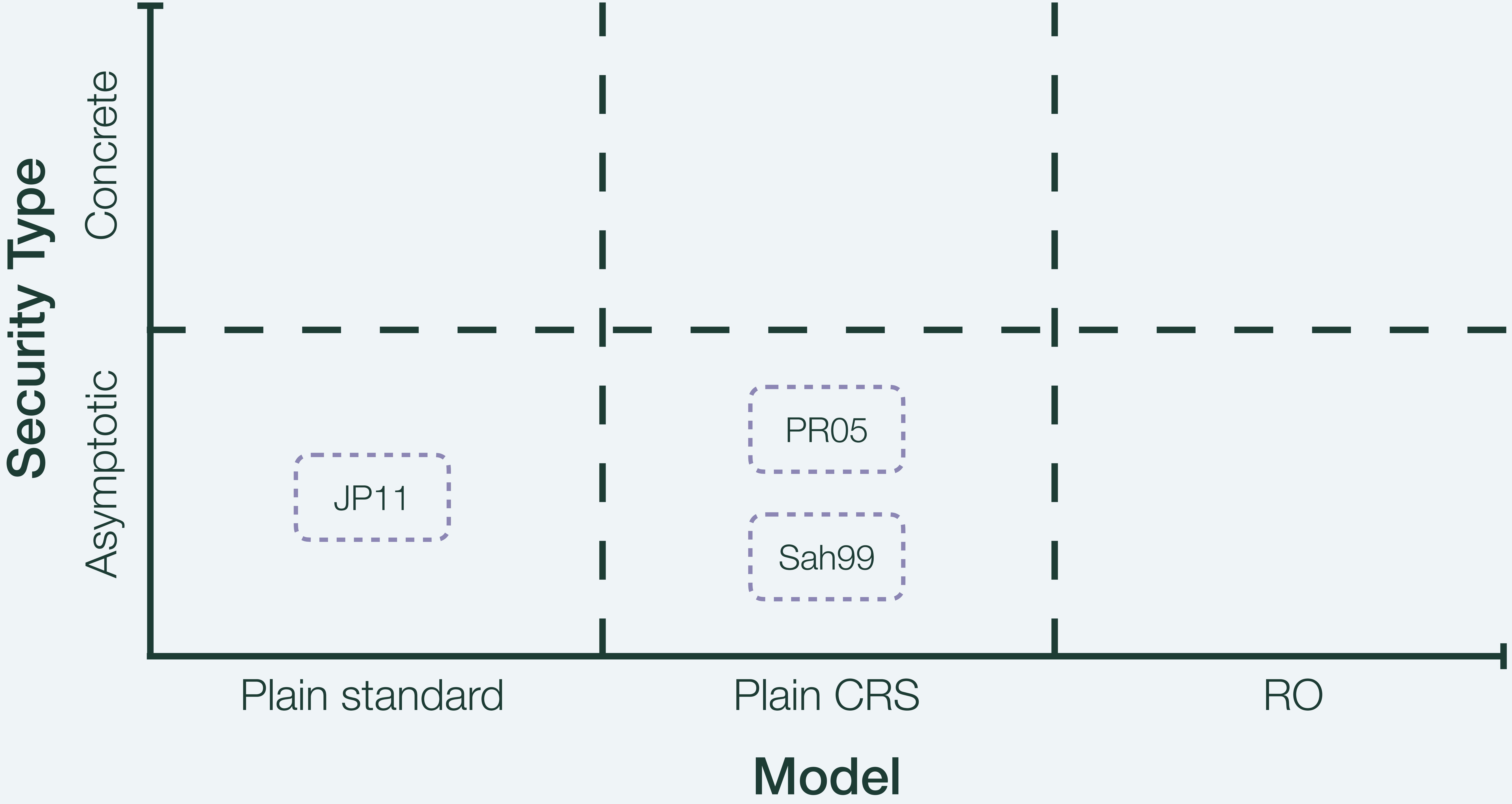

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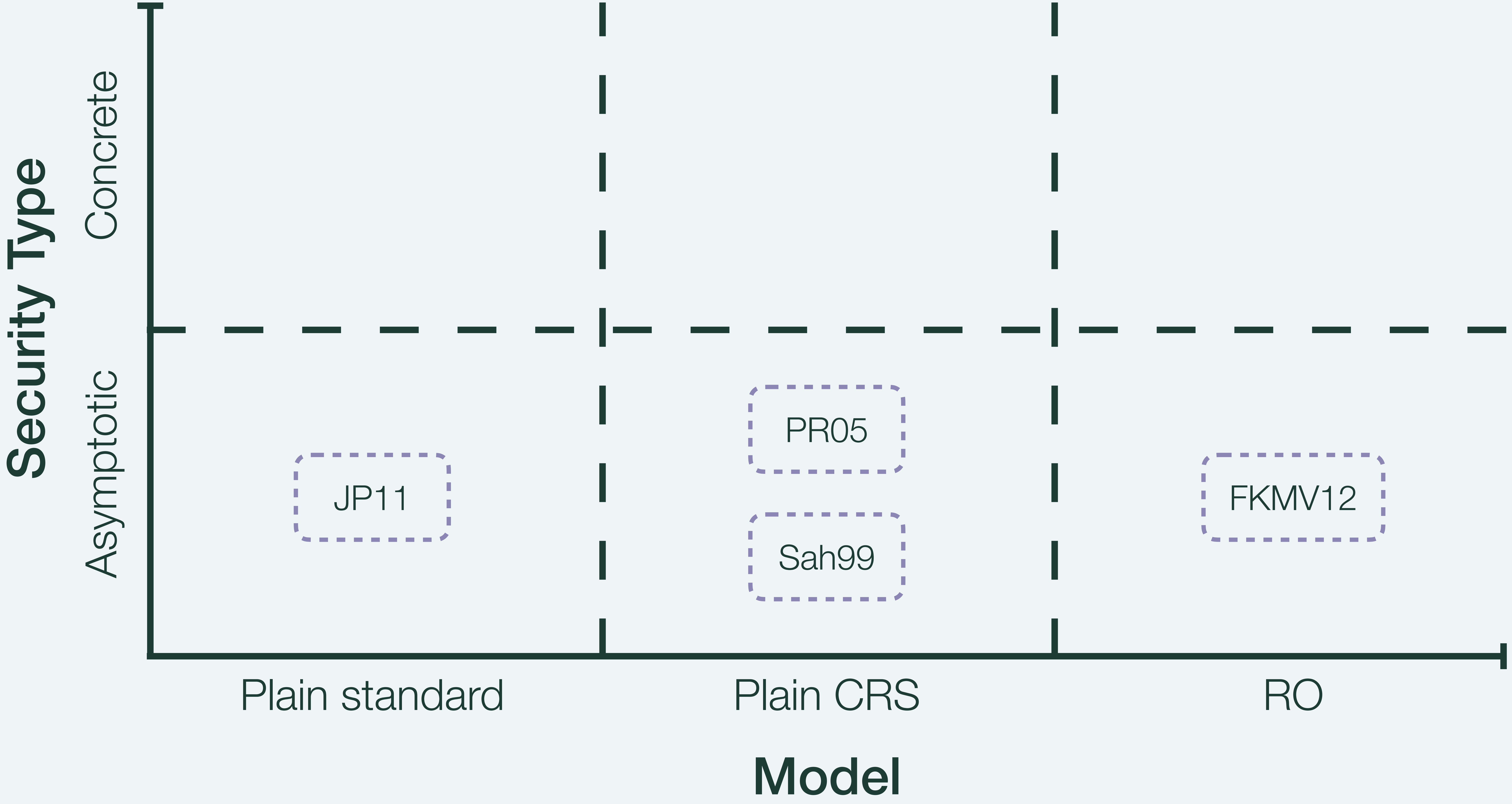

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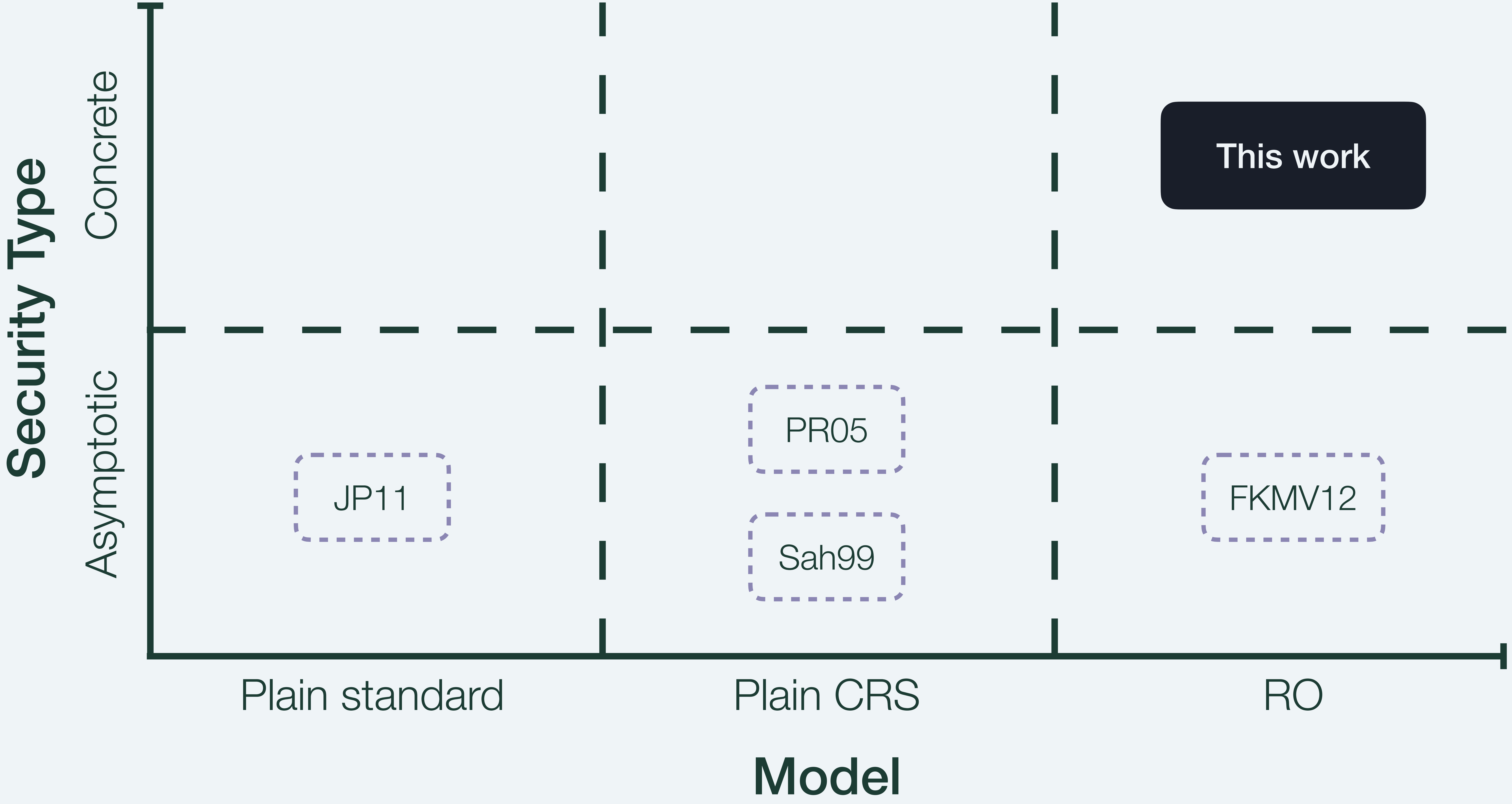

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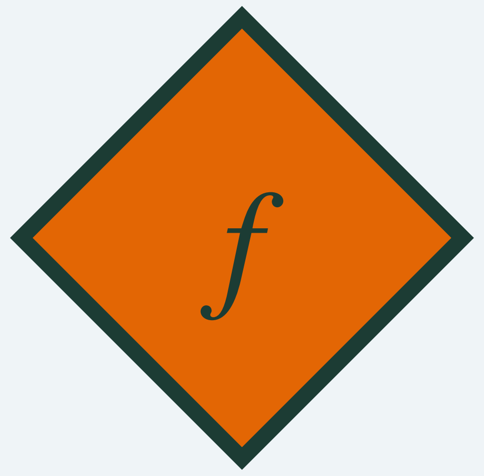

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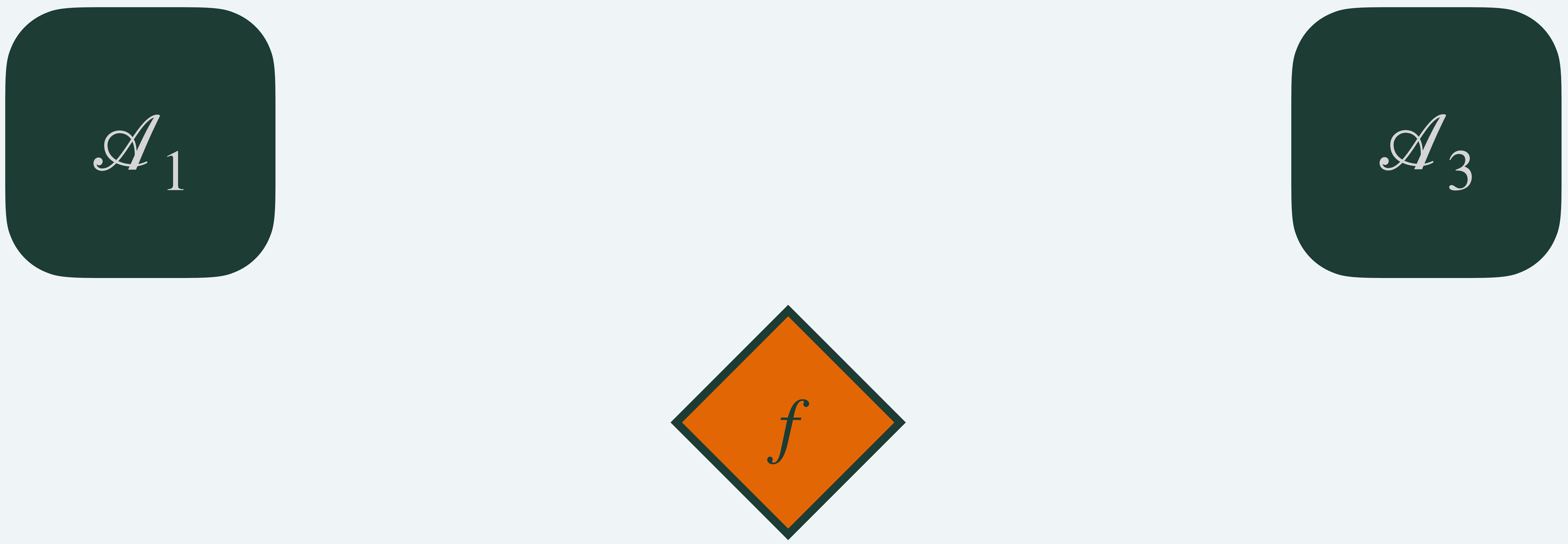

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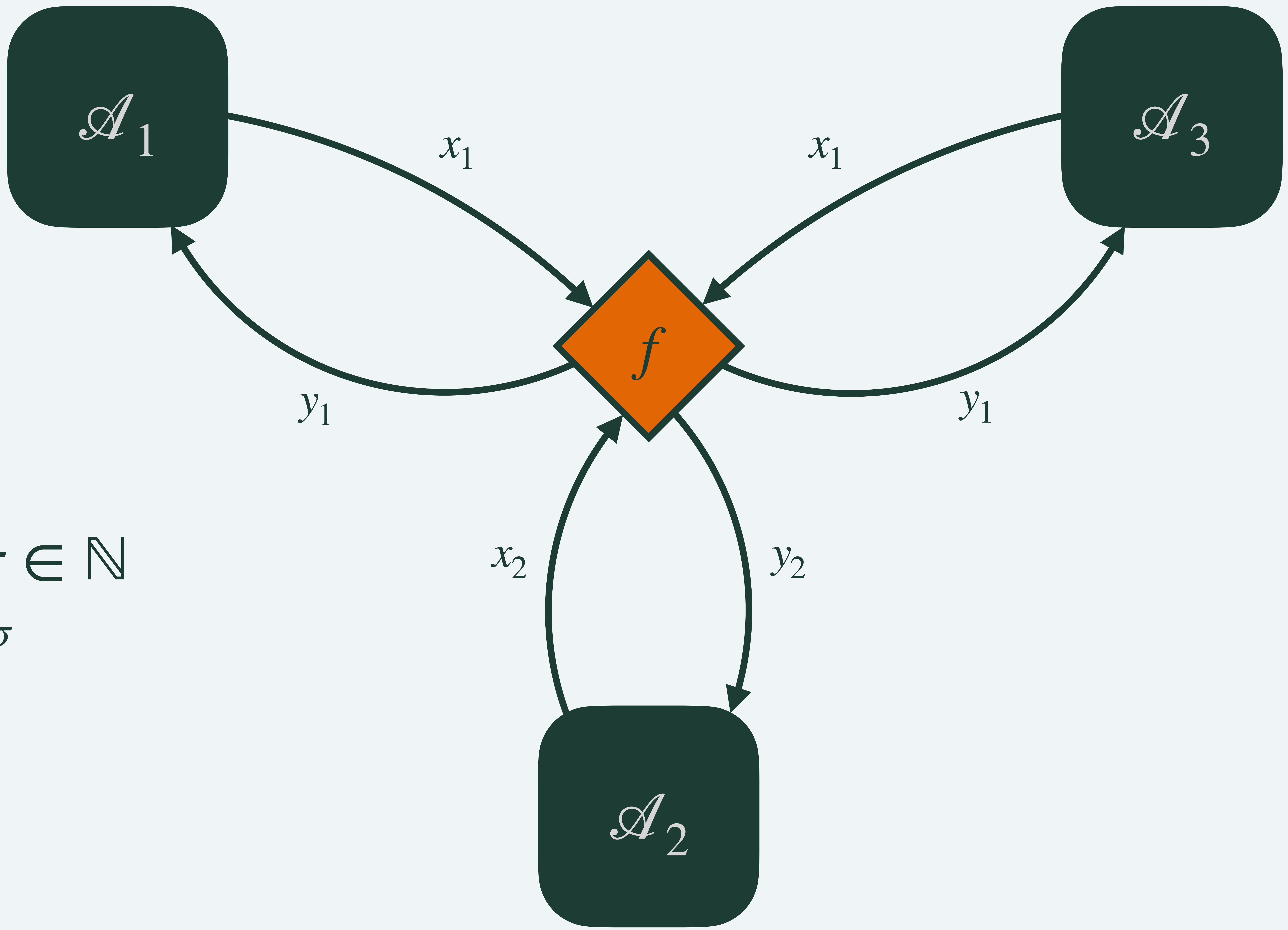

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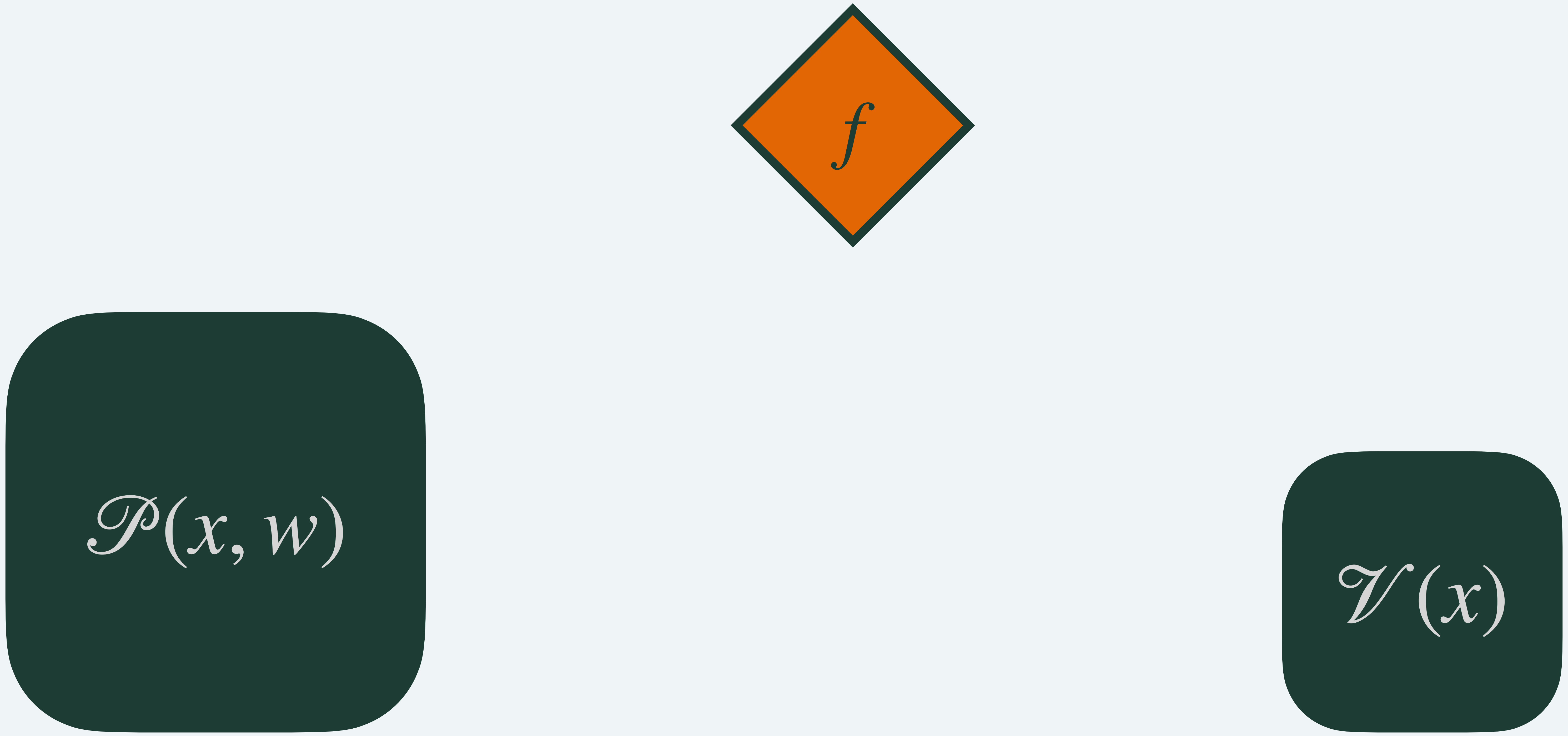

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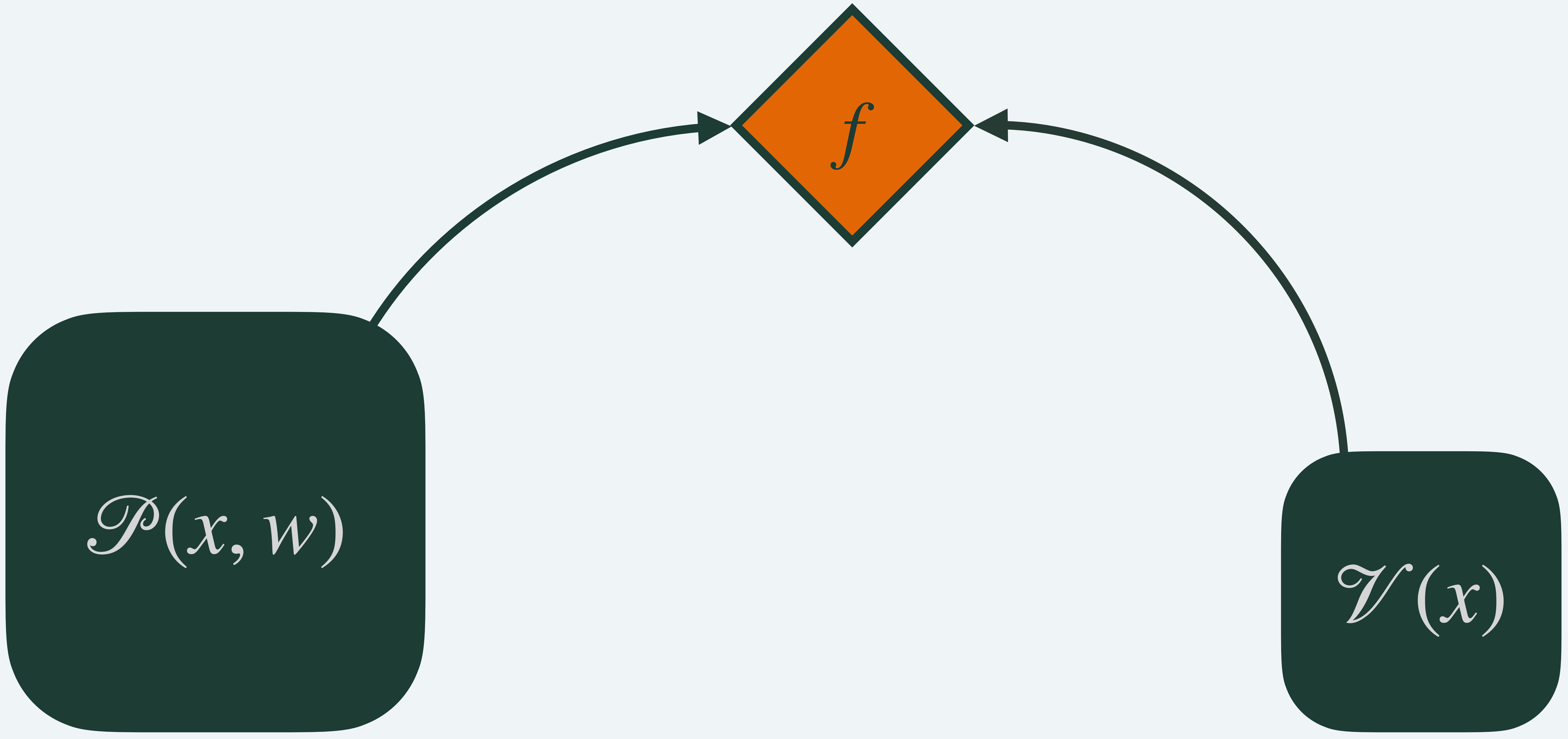

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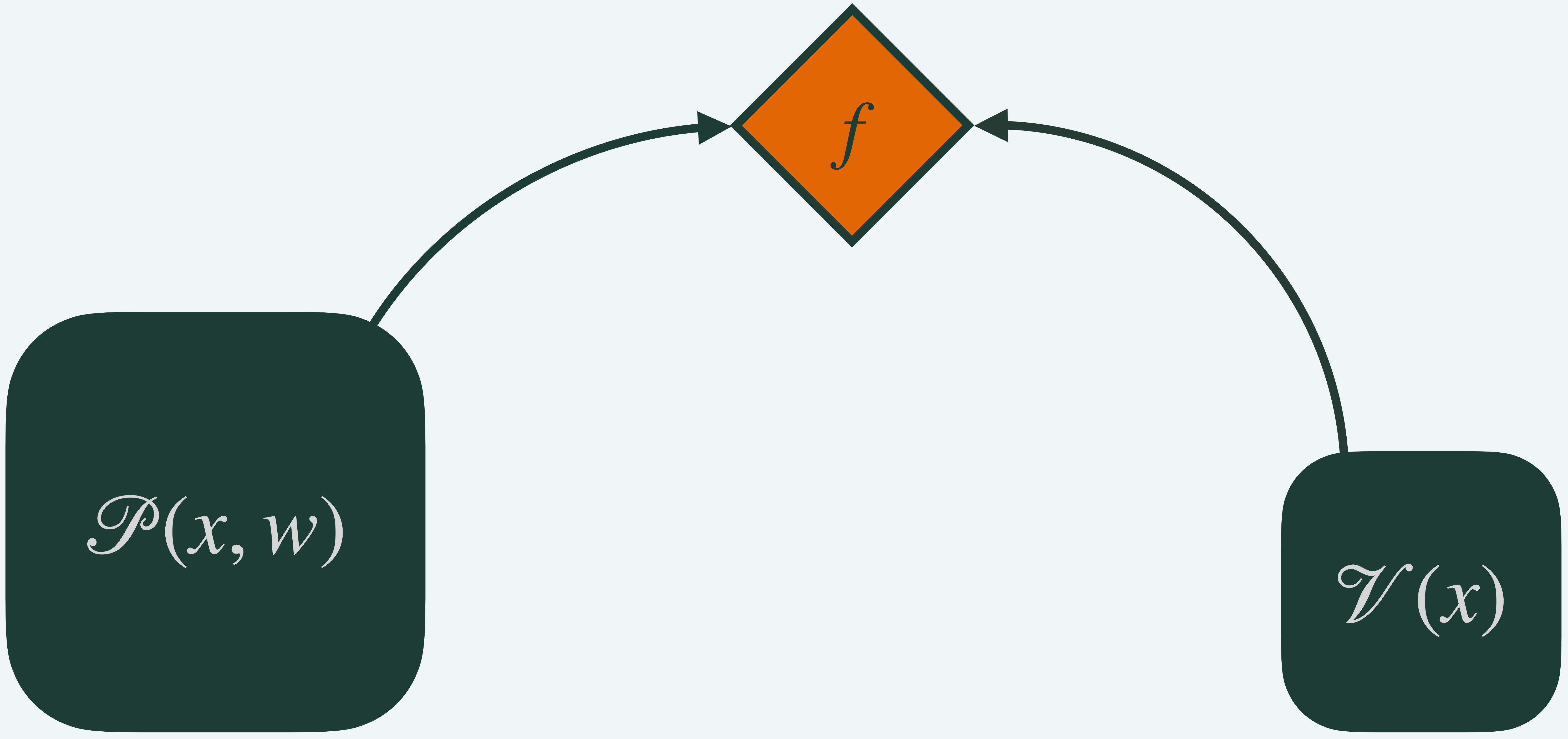

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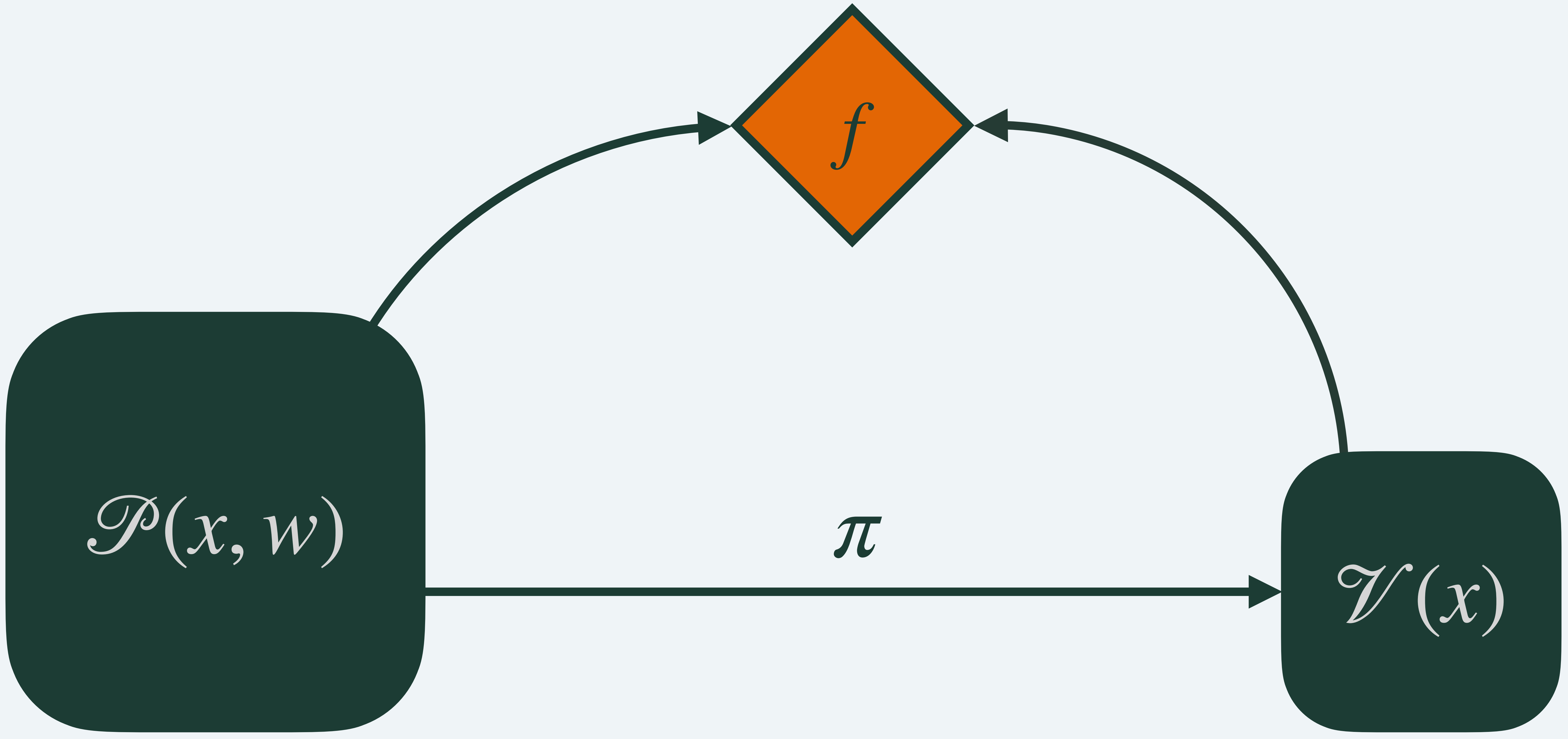

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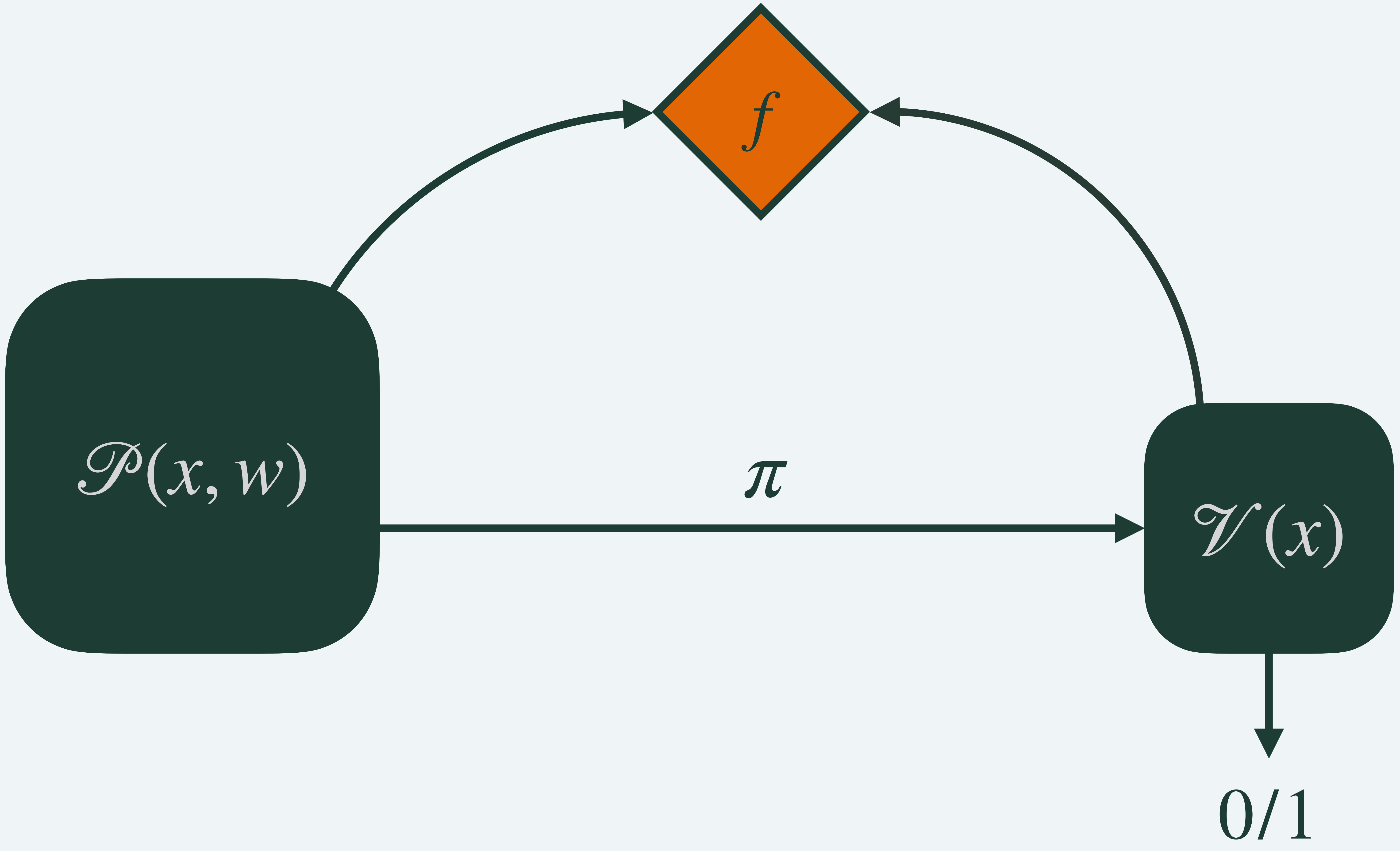

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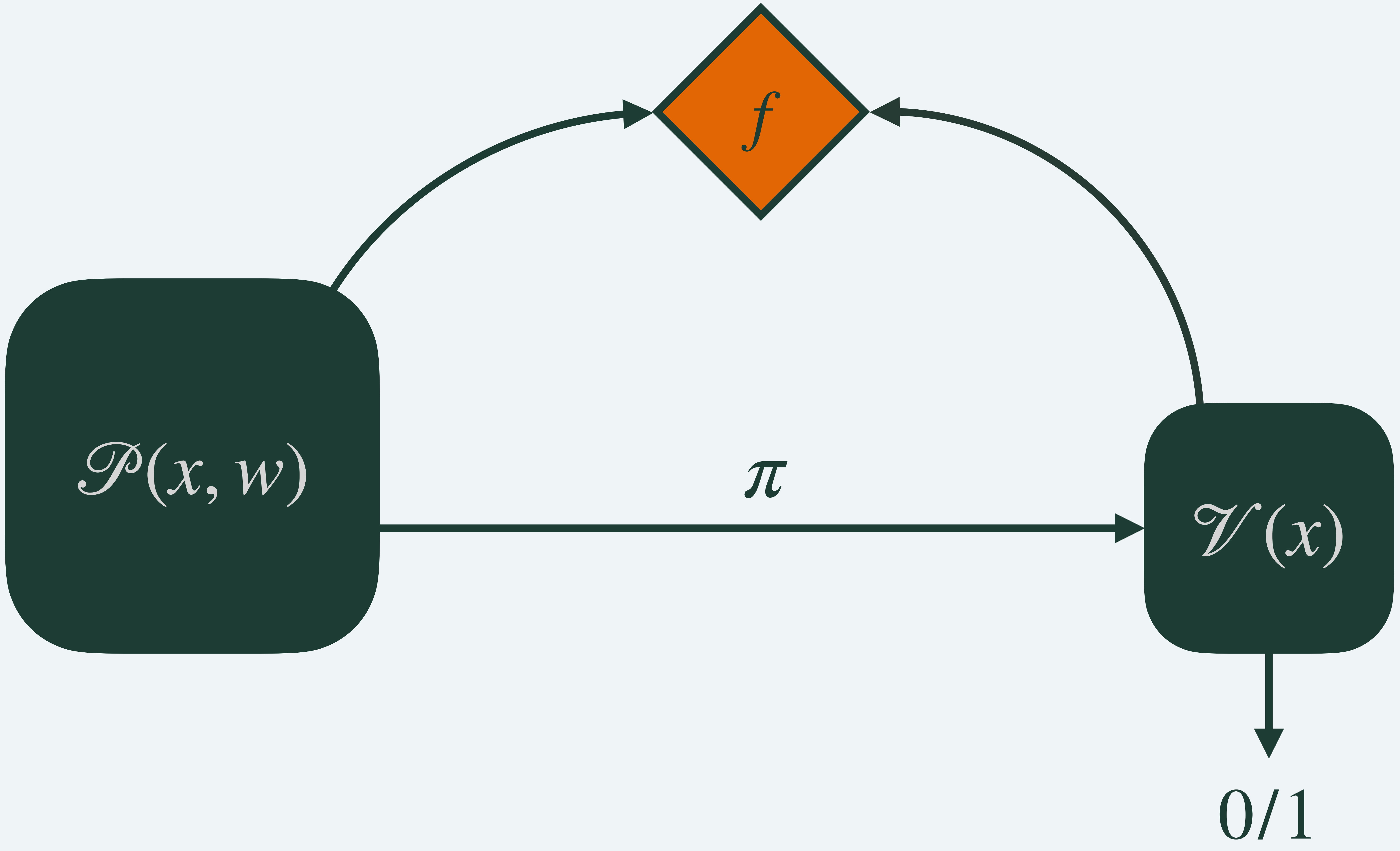
Complete:

If $(x, w) \in \mathscr{R}$, then $\mathscr{V}^f(x, \pi) = 1$.



Zero-knowledge

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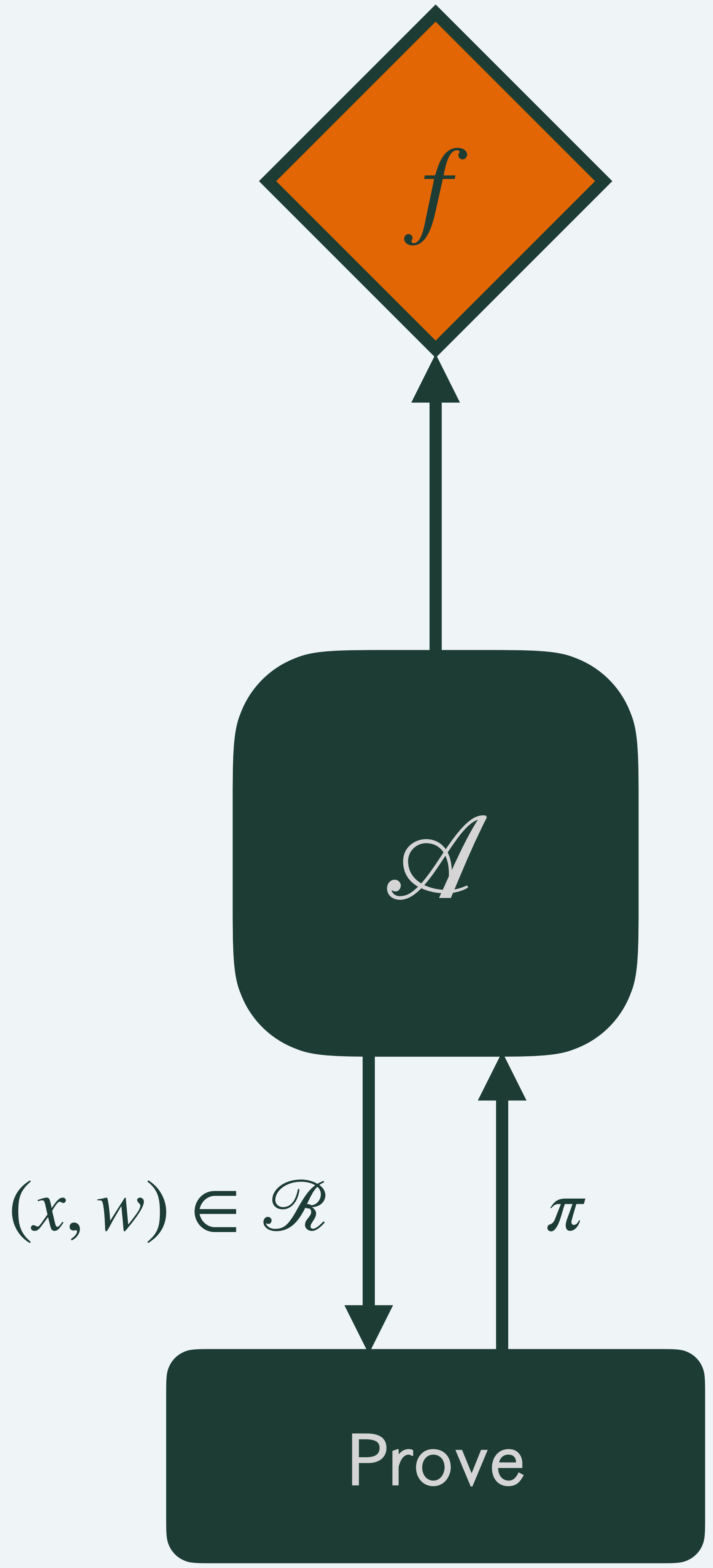

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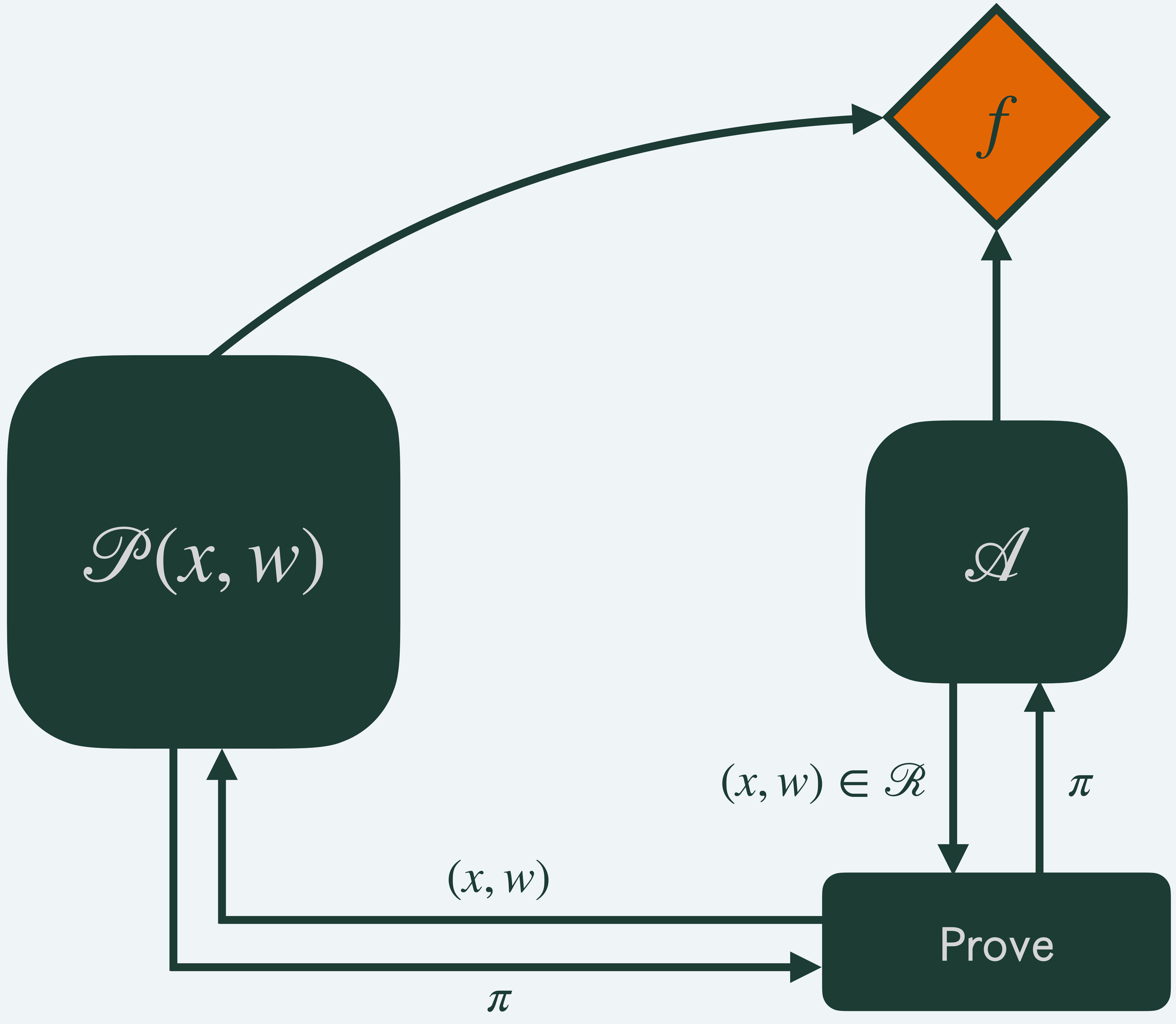

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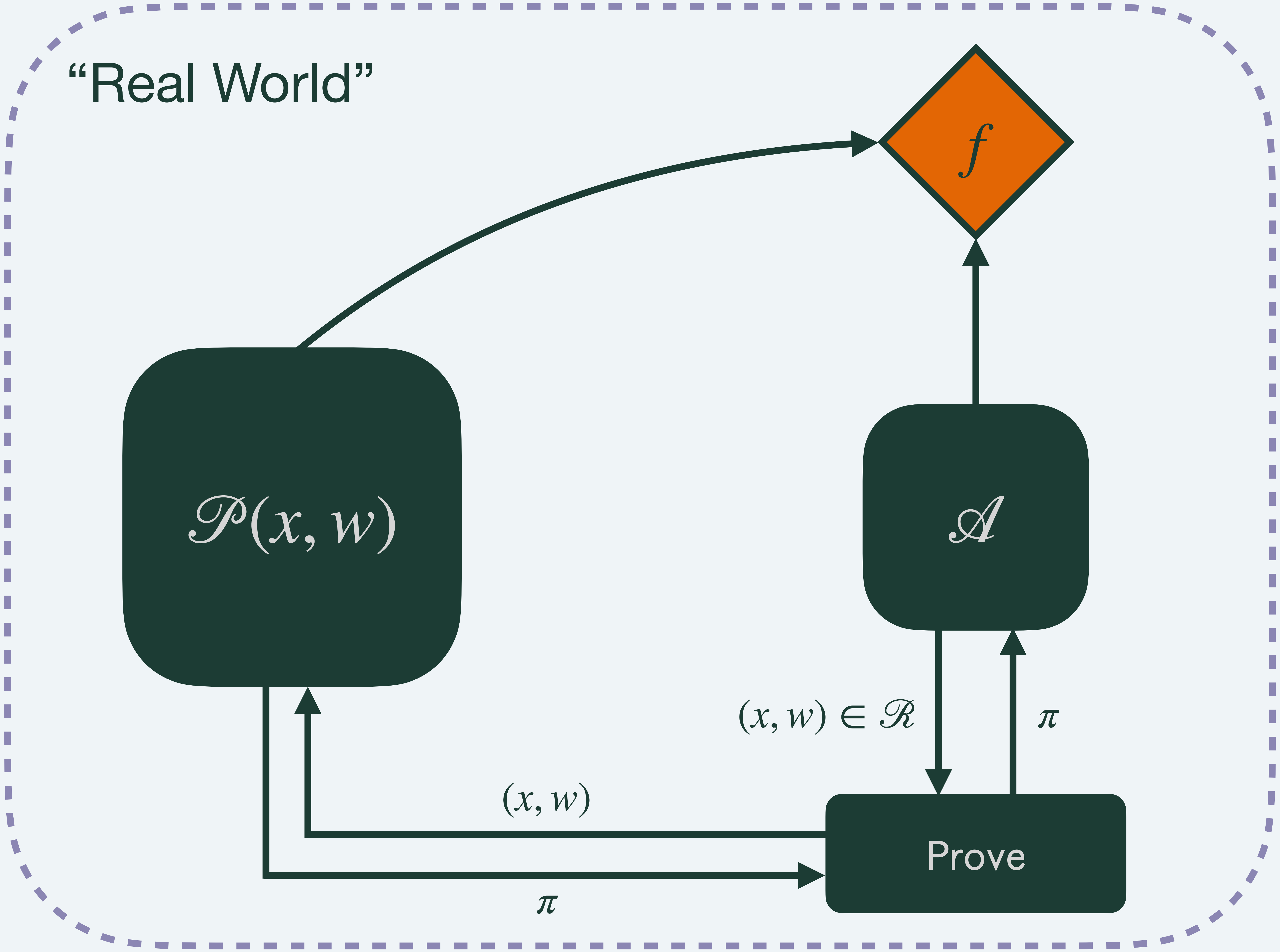

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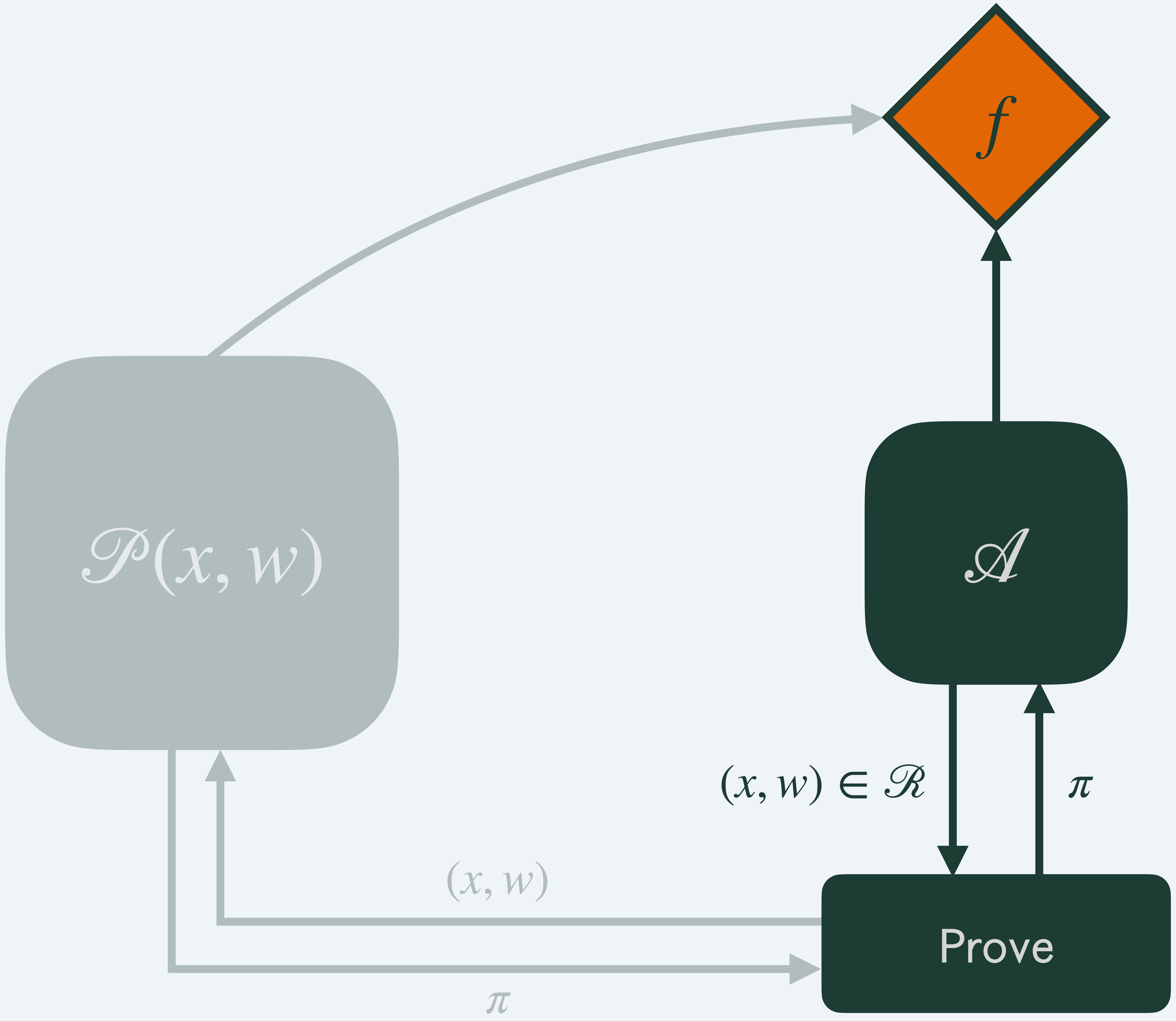

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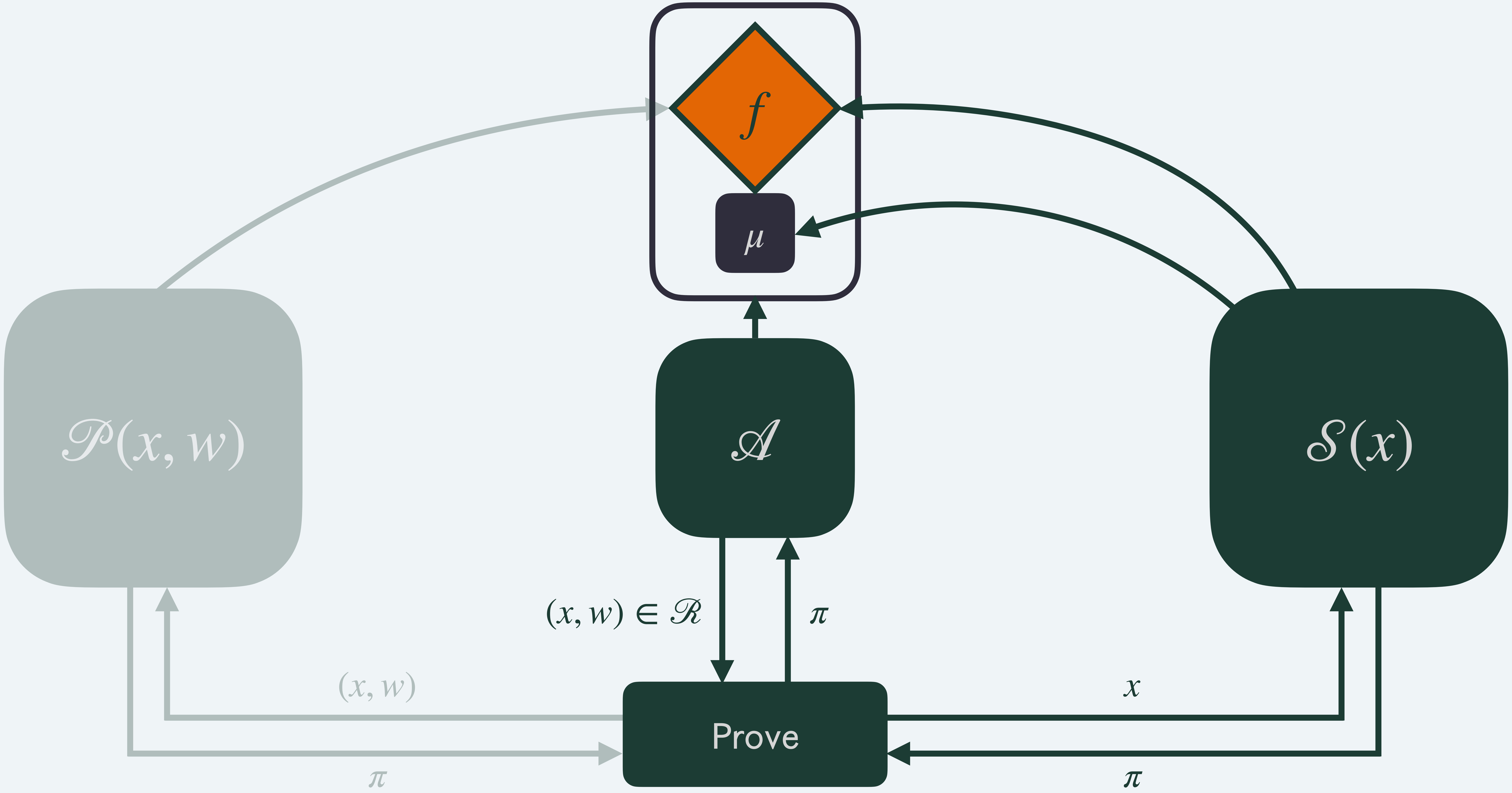

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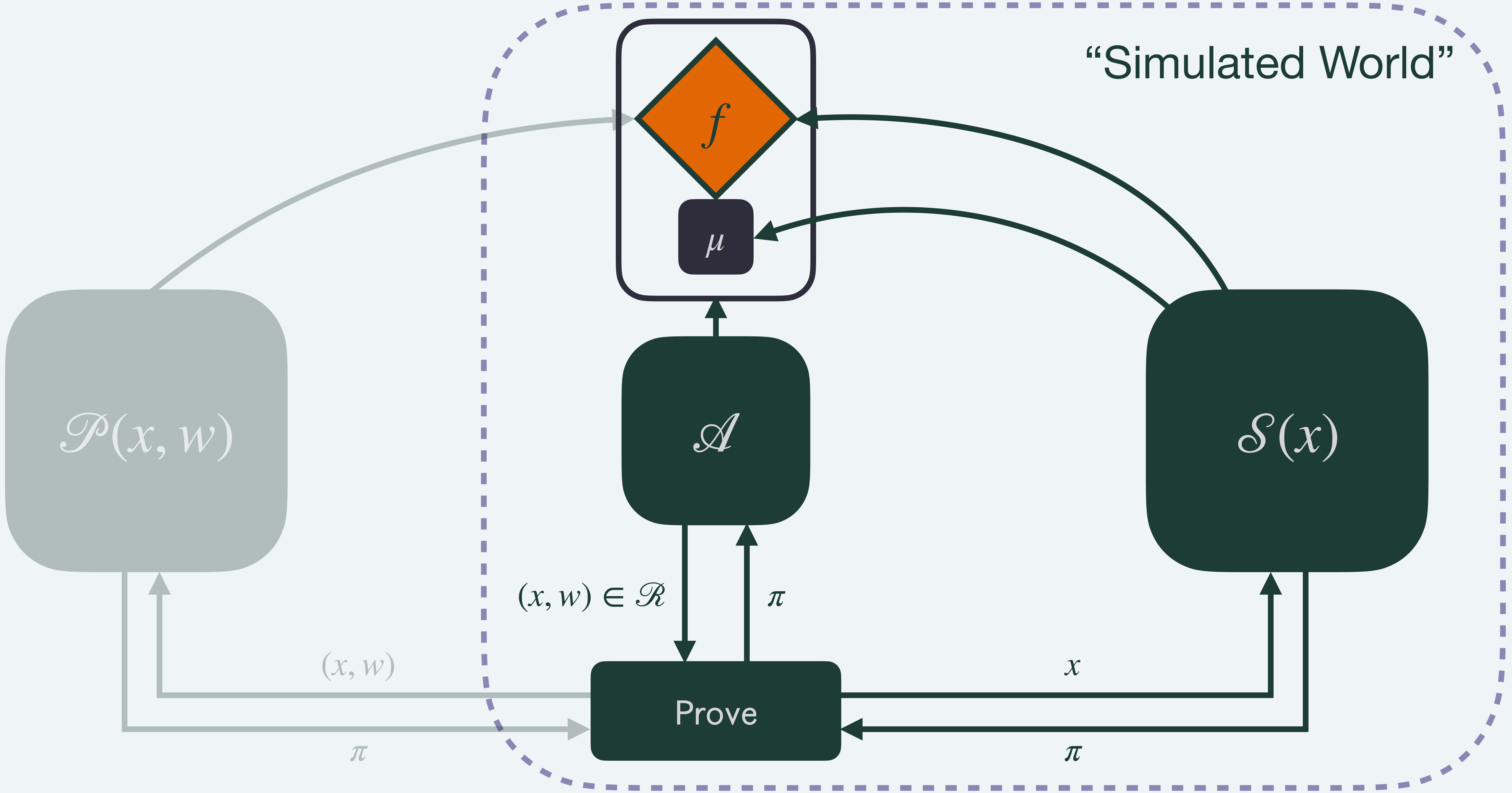

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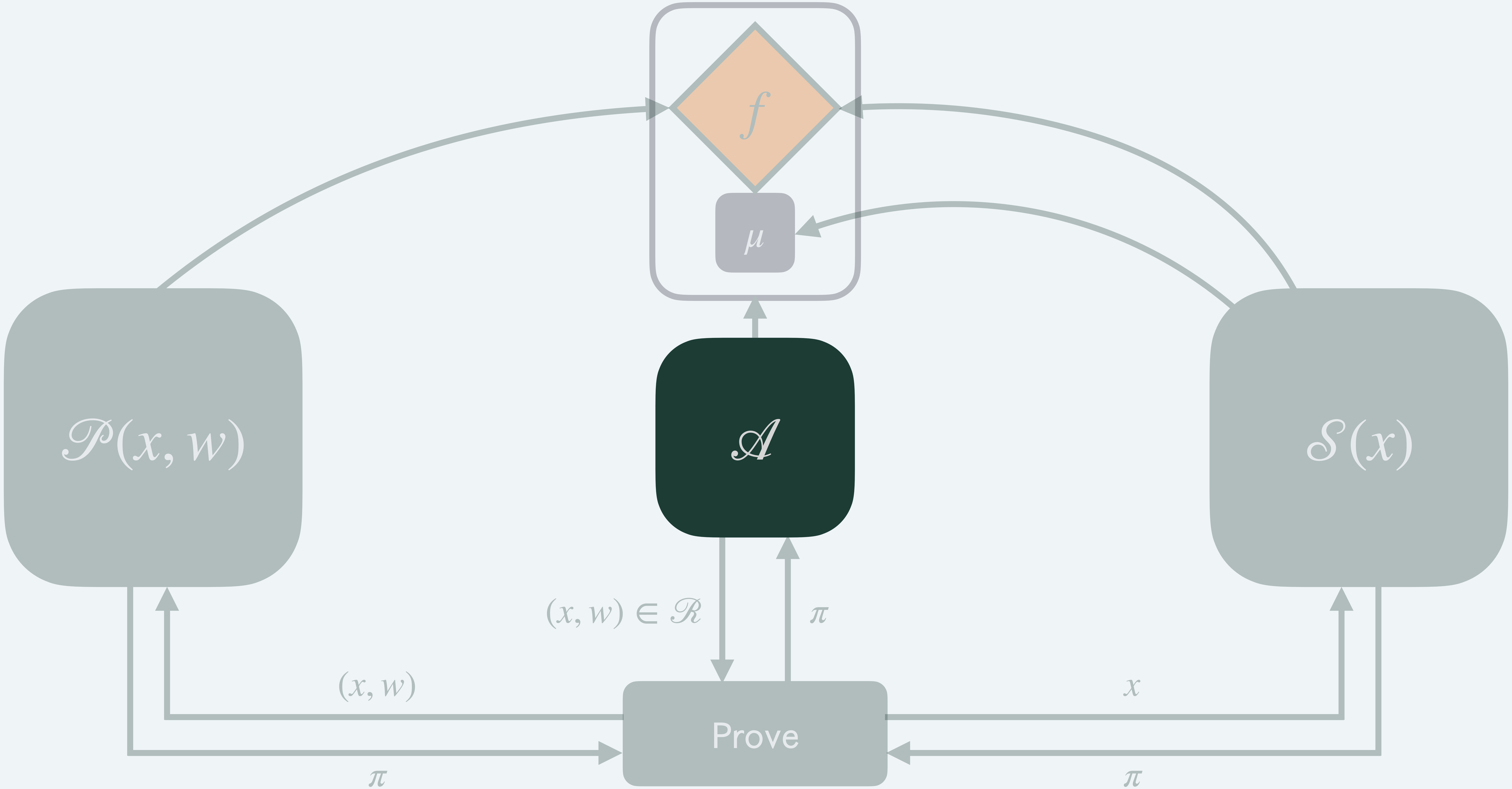

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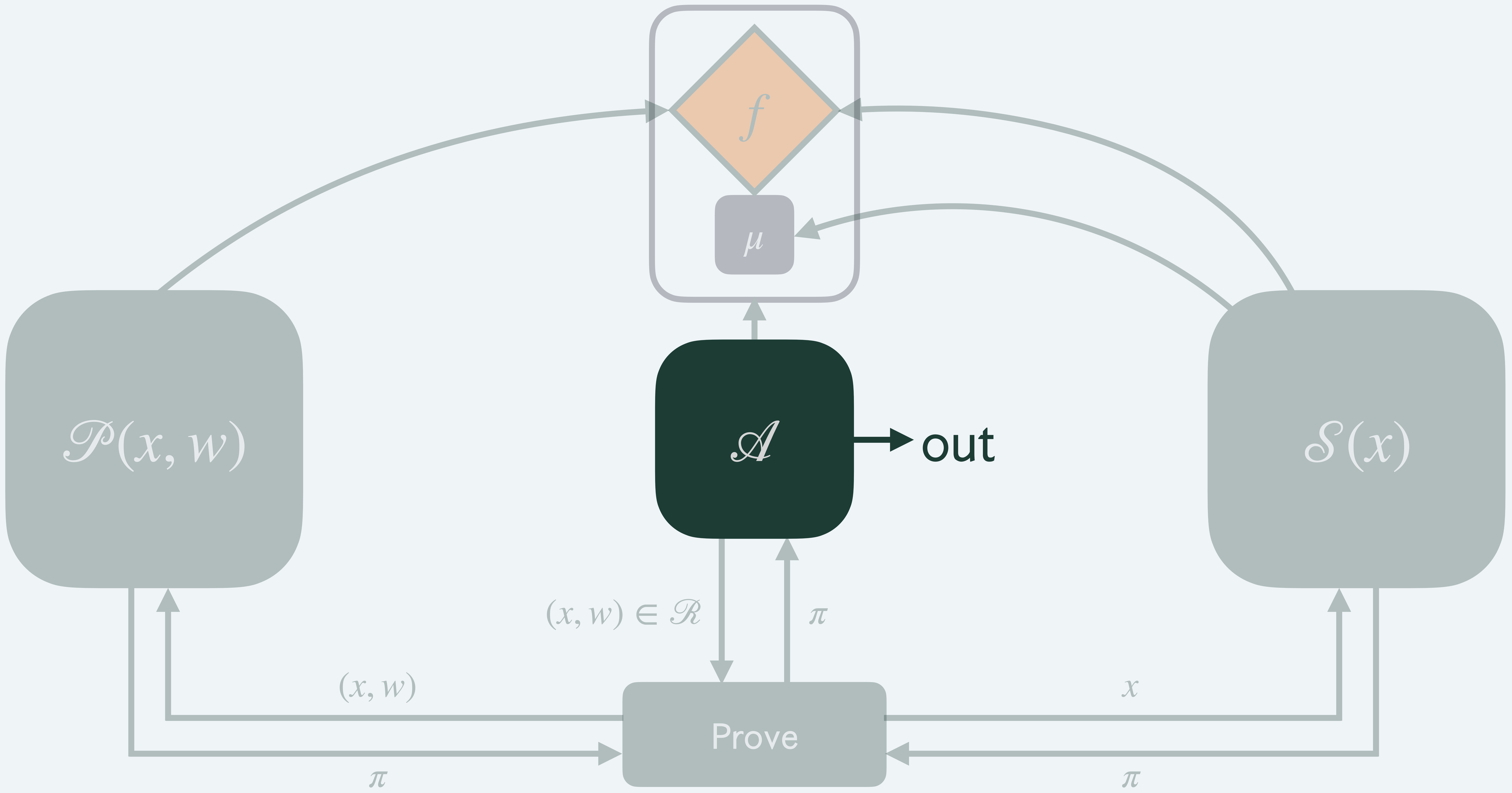

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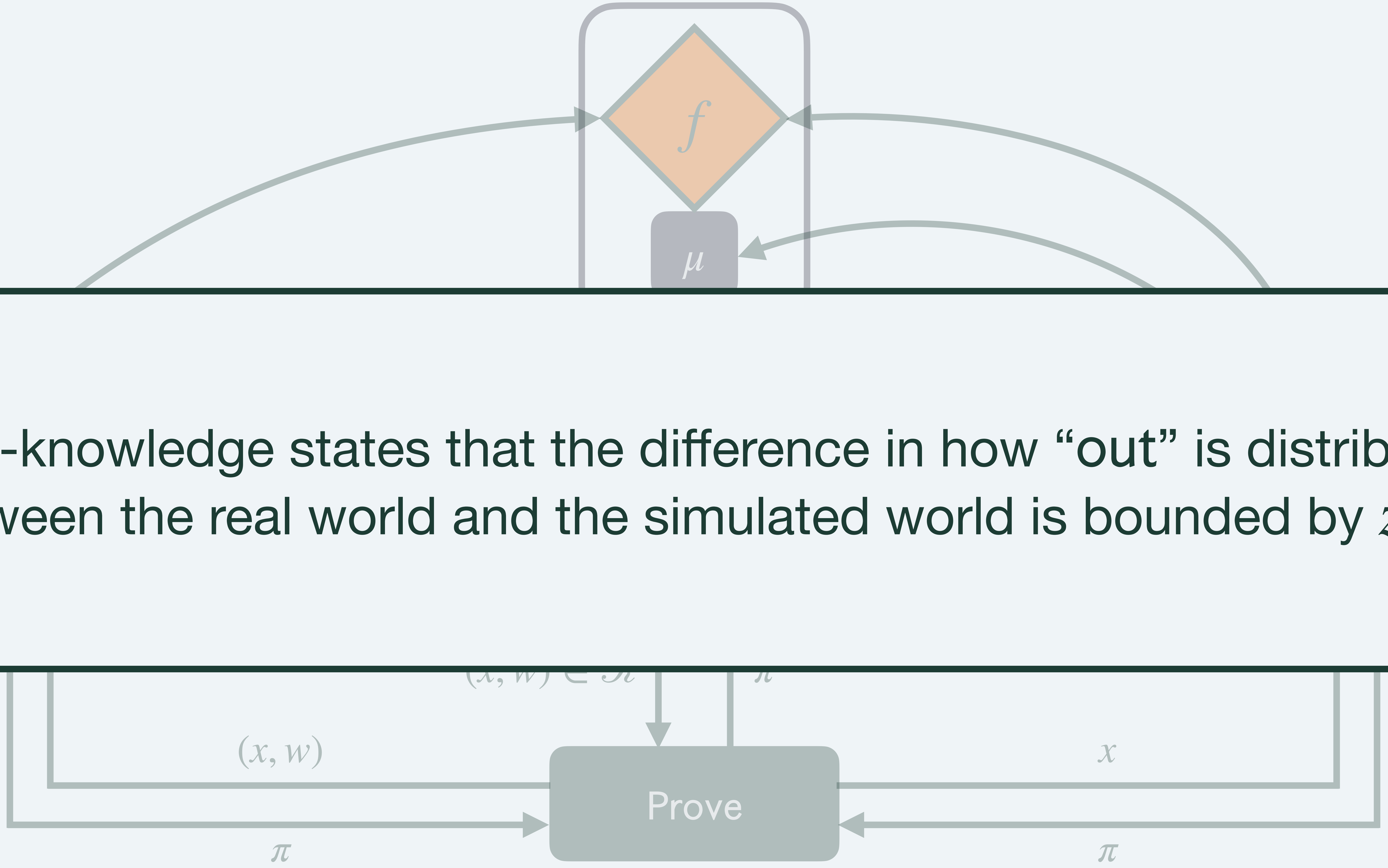

Zero-knowledge states that the difference in how "out" is distributed between the real world and the simulated world is bounded by z_{ARG}.

Soundness Notions

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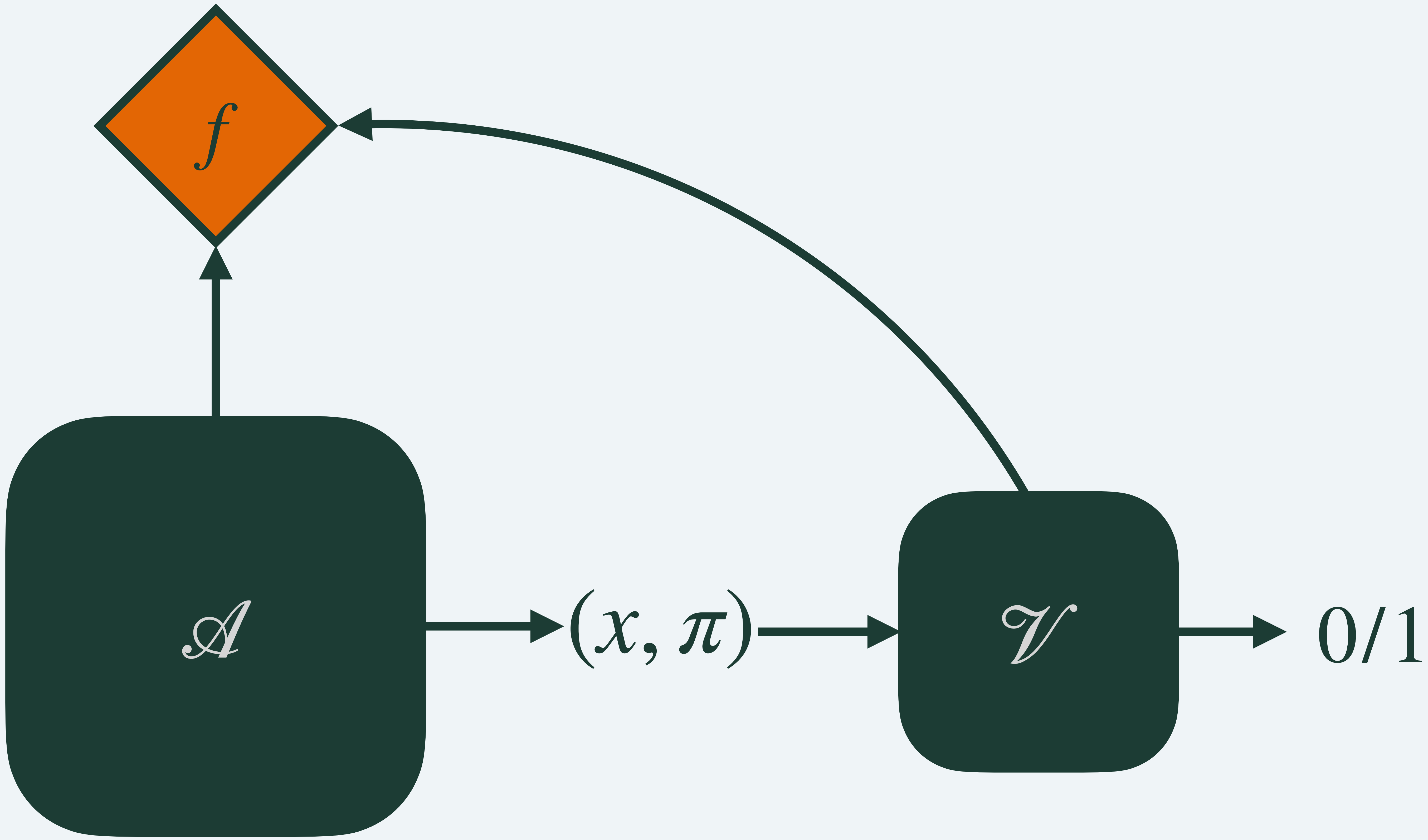
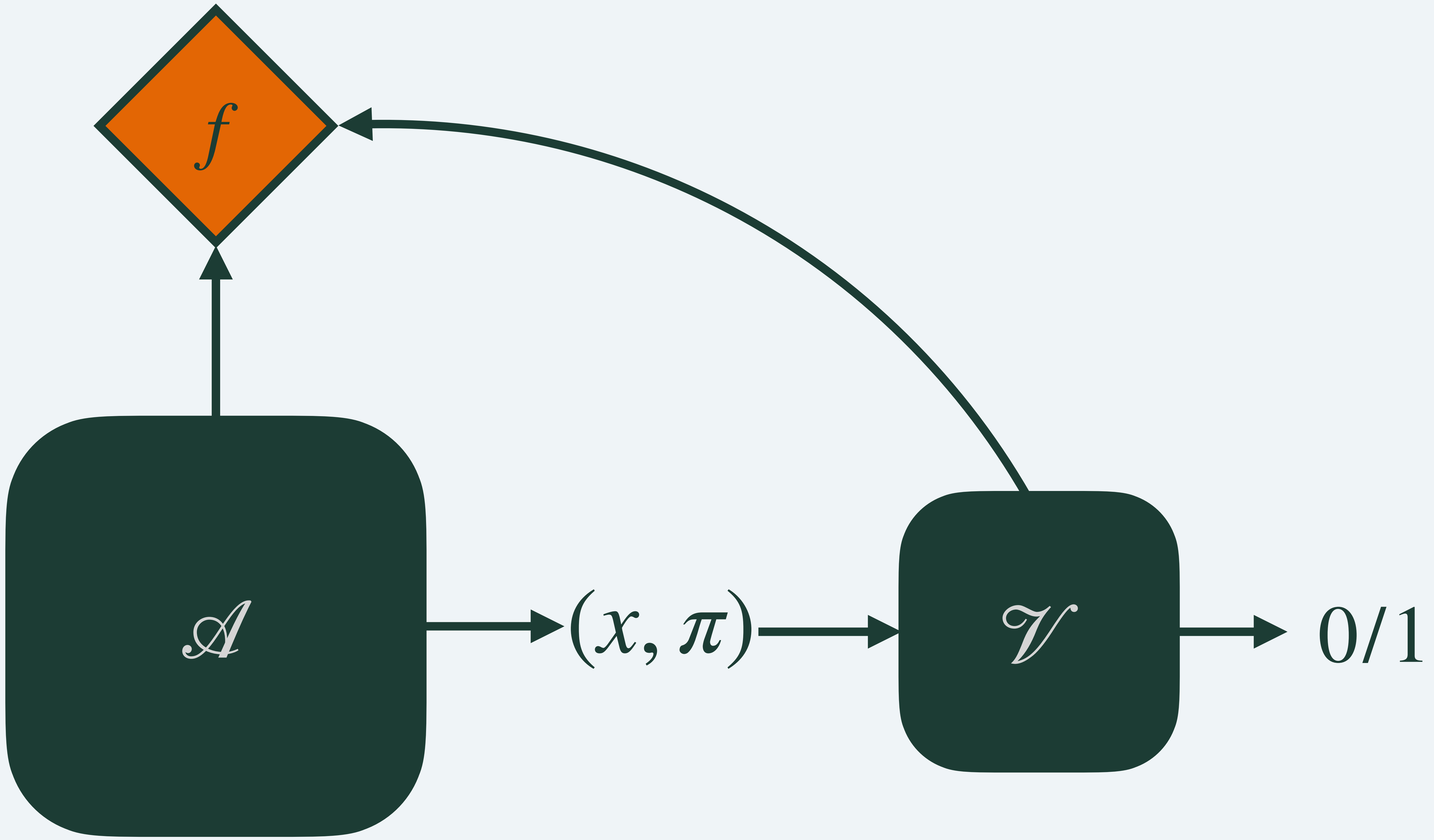


Soundness Notions

Knowledge Soundness:

The probability $\mathscr{V}^f(x, \pi) = 1$ **and** we cannot extract a witness w s.t. $(x, w) \in \mathscr{R}$ is "small".



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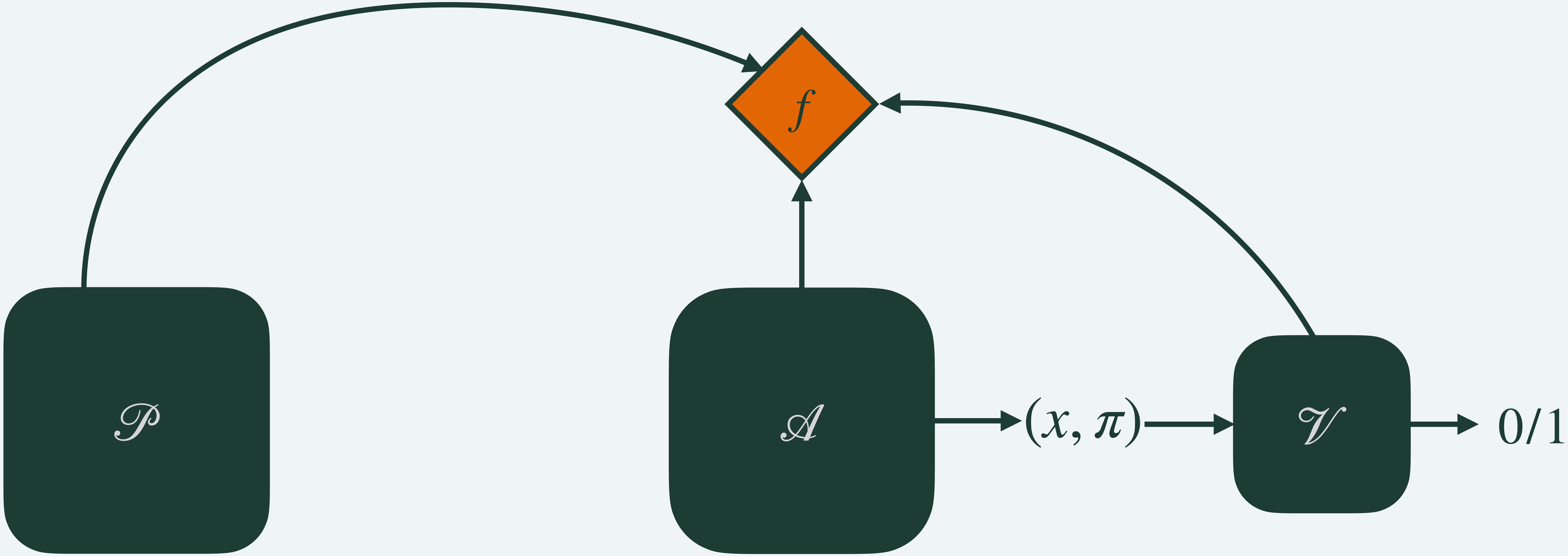

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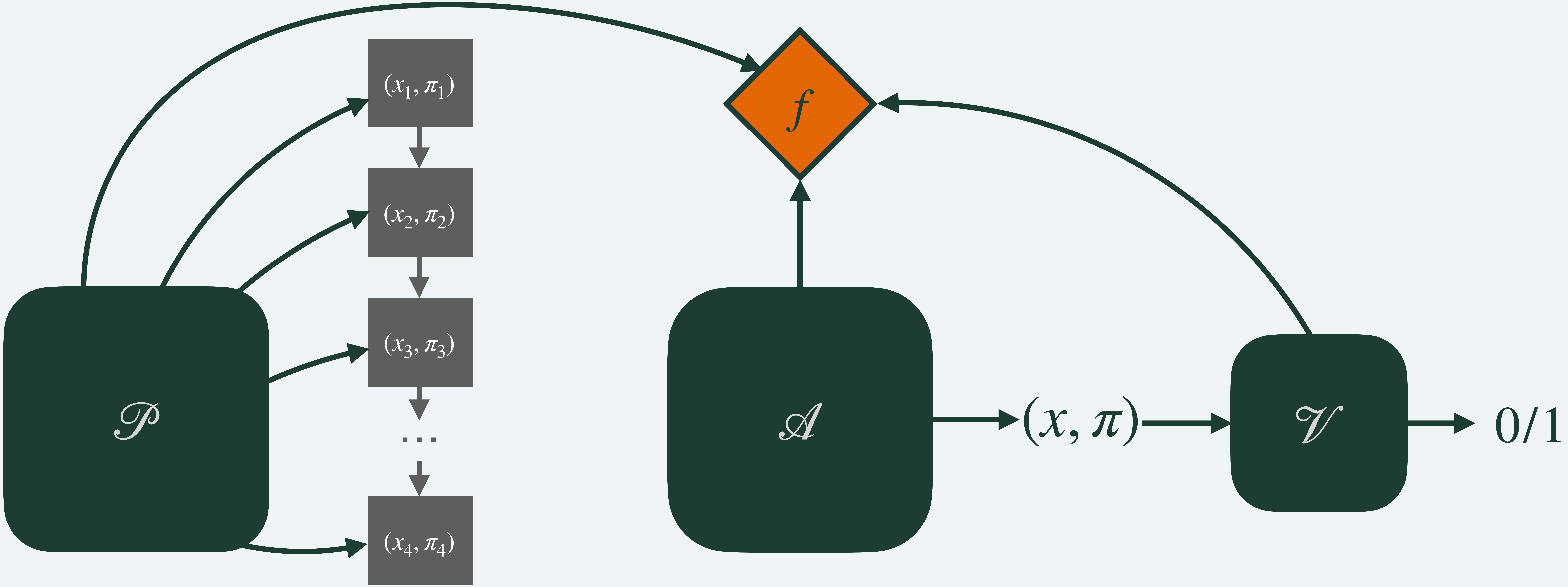

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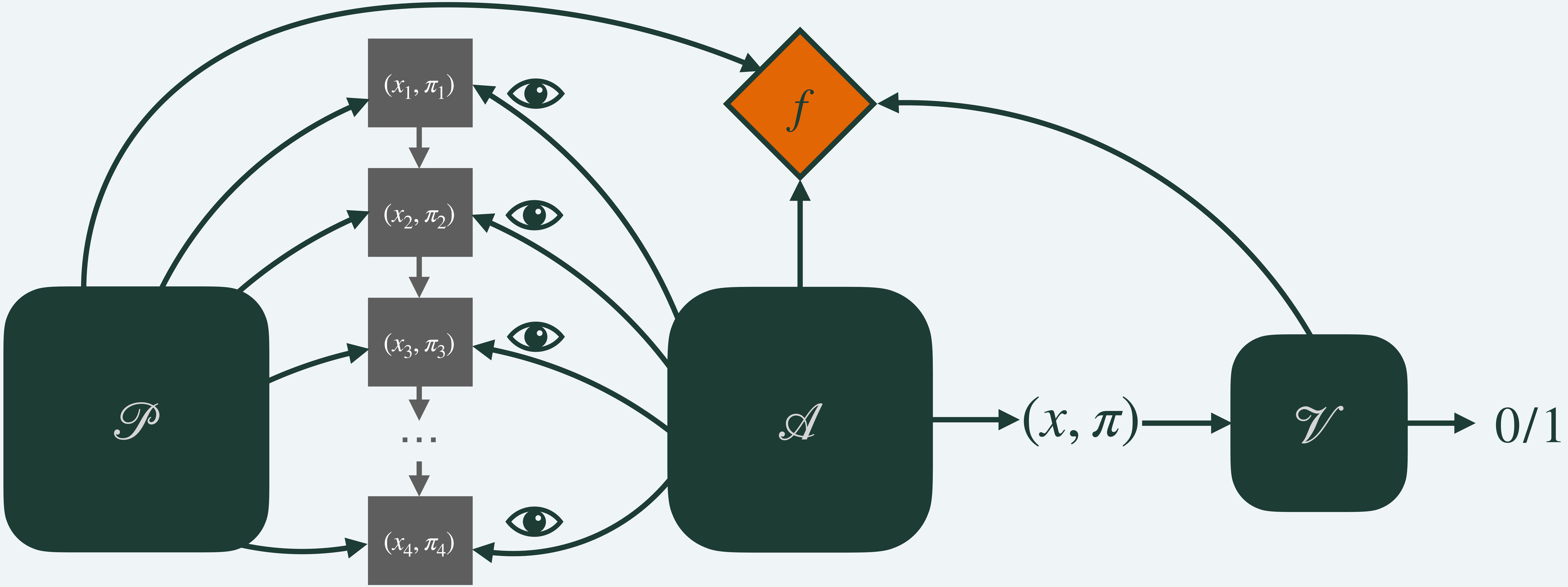
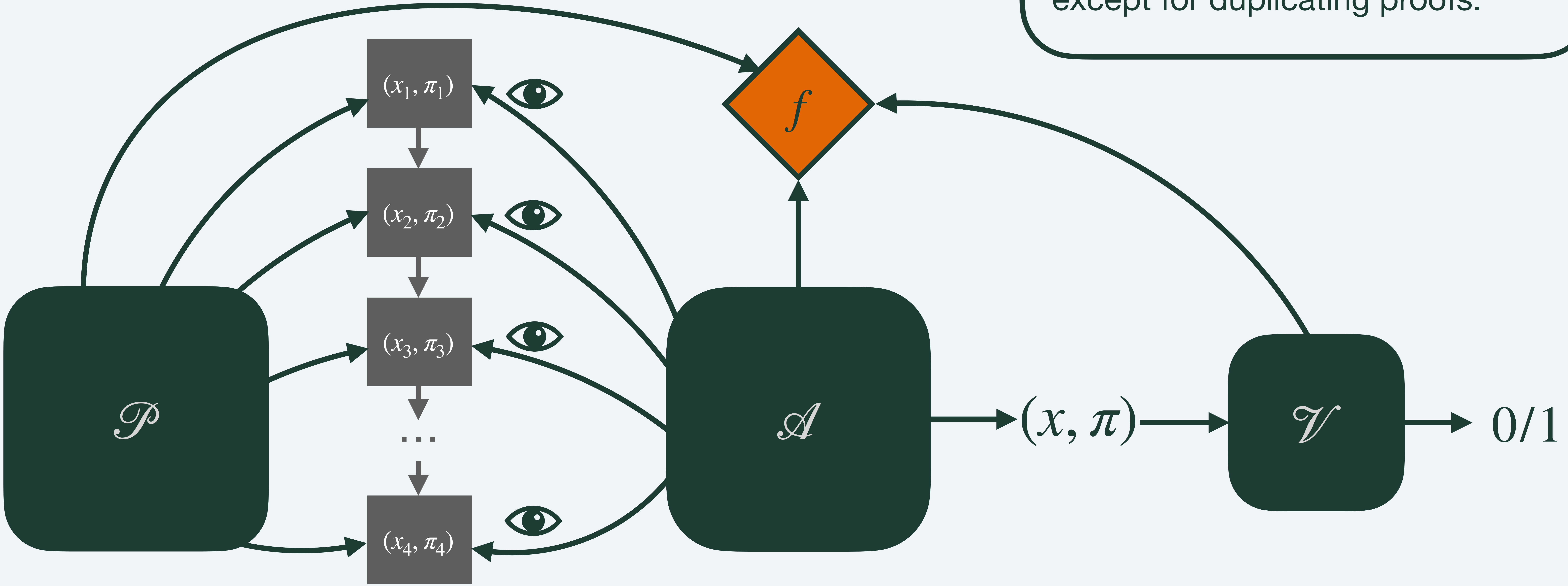


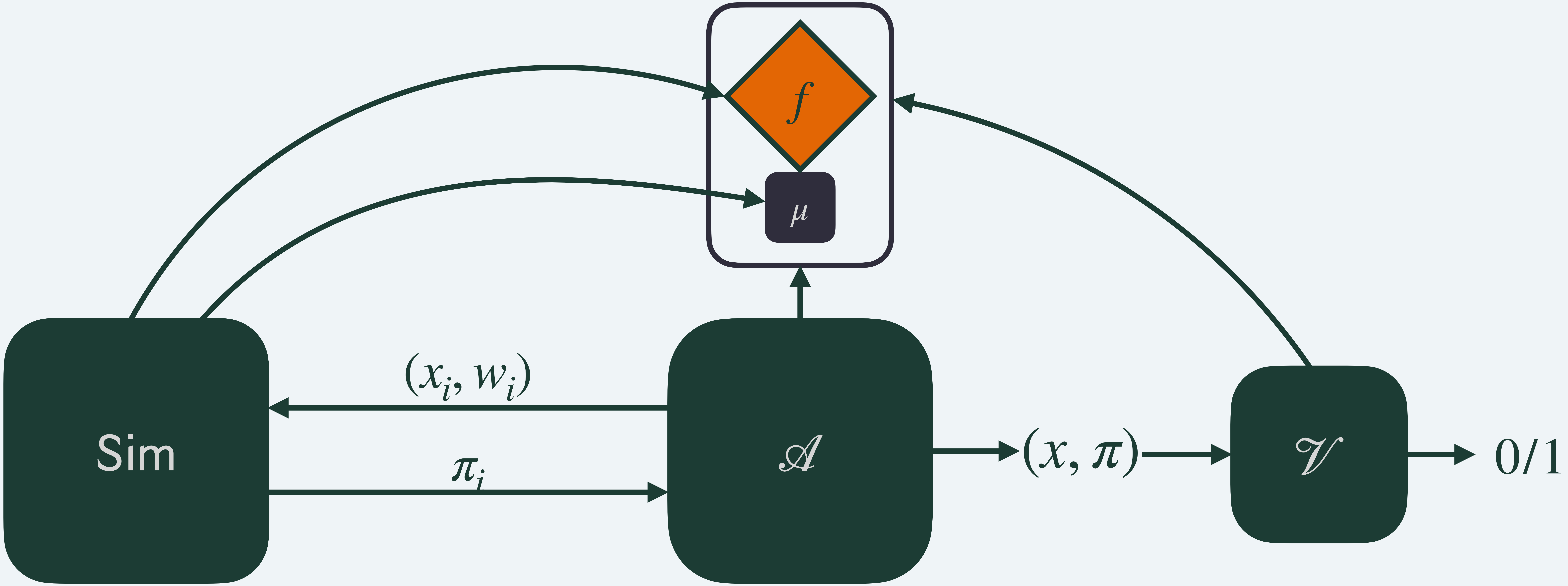
Soundness Notions

Non-malleability:

"Whatever one can compute after observing proofs, one could've computed before observing them, except for duplicating proofs."



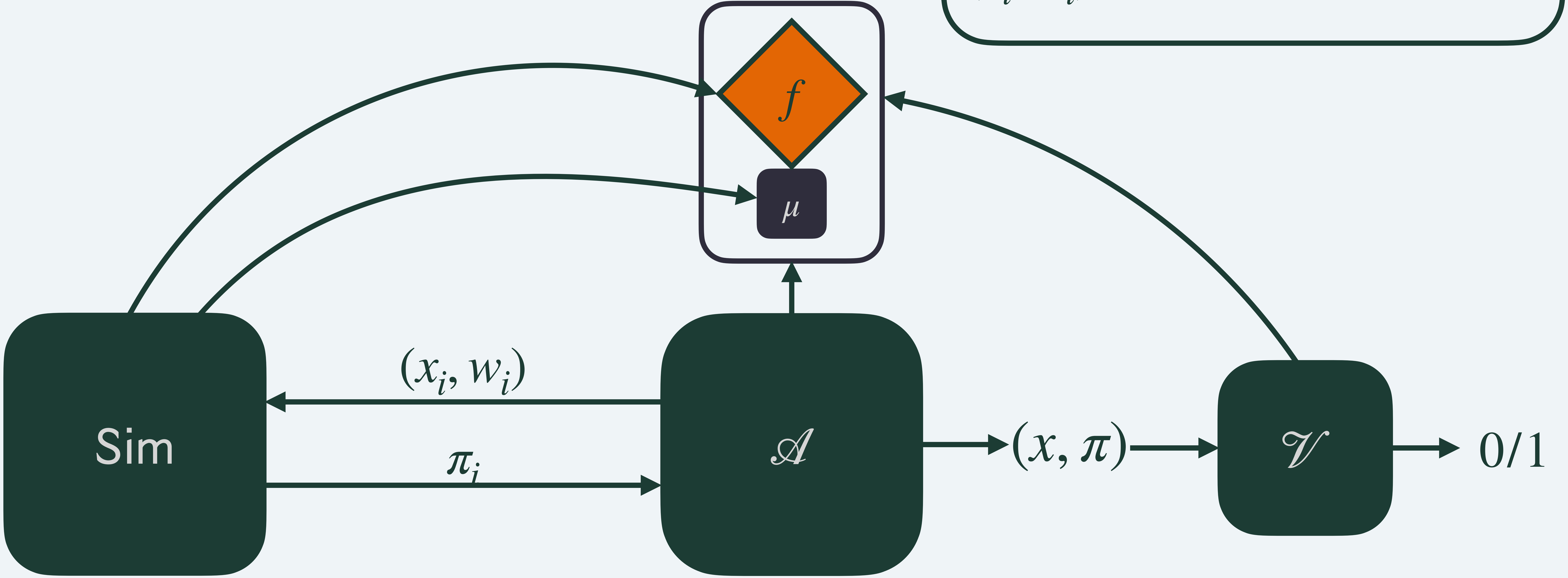
Simulation Security



Simulation Security

"True" Simulation Security:

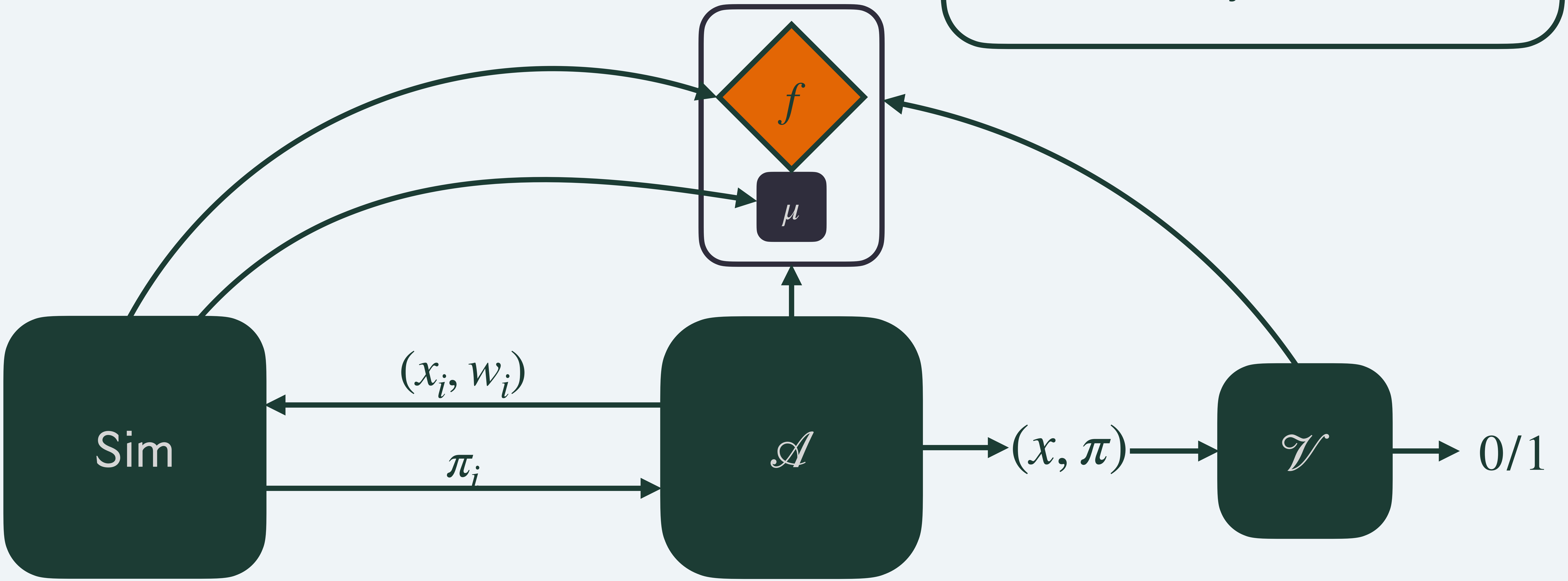
Sim answers with π_i only if $(x_i, w_i) \in \mathscr{R}$.



Simulation Security

“Any” Simulation Security:

Sim answers with π_i unconditionally



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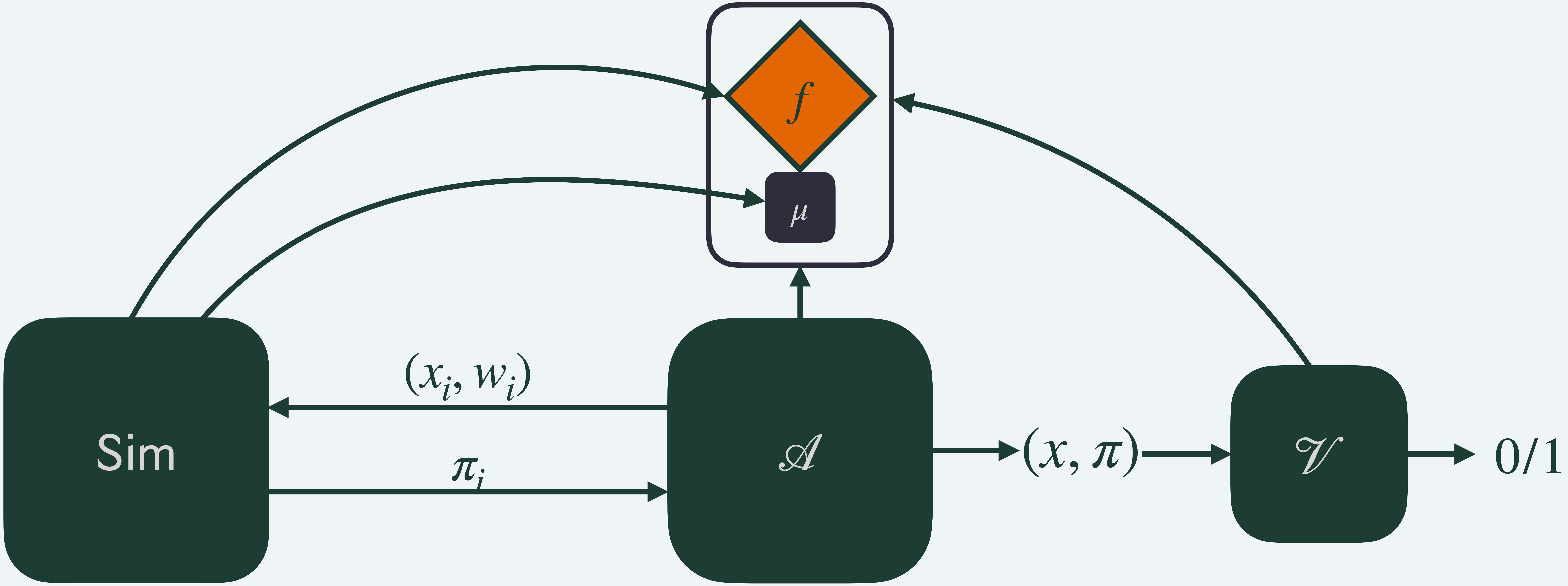
Simulation Security

Definitions



Simulation Security

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Simulation Soundness

The probability that $\mathscr{A}$ outputs (x, π) s.t. $\mathscr{V}$ accepts, but $x \notin \mathscr{L}(\mathscr{R})$ is at most $\epsilon_{\text{ARG}}^{\text{SIM}}$.

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Simulation Security

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Computational variants

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$\mathsf{ENC}[\lambda, \ell, \ell_c] = (\mathsf{Gen}, \mathsf{Enc}, \mathsf{Dec})$

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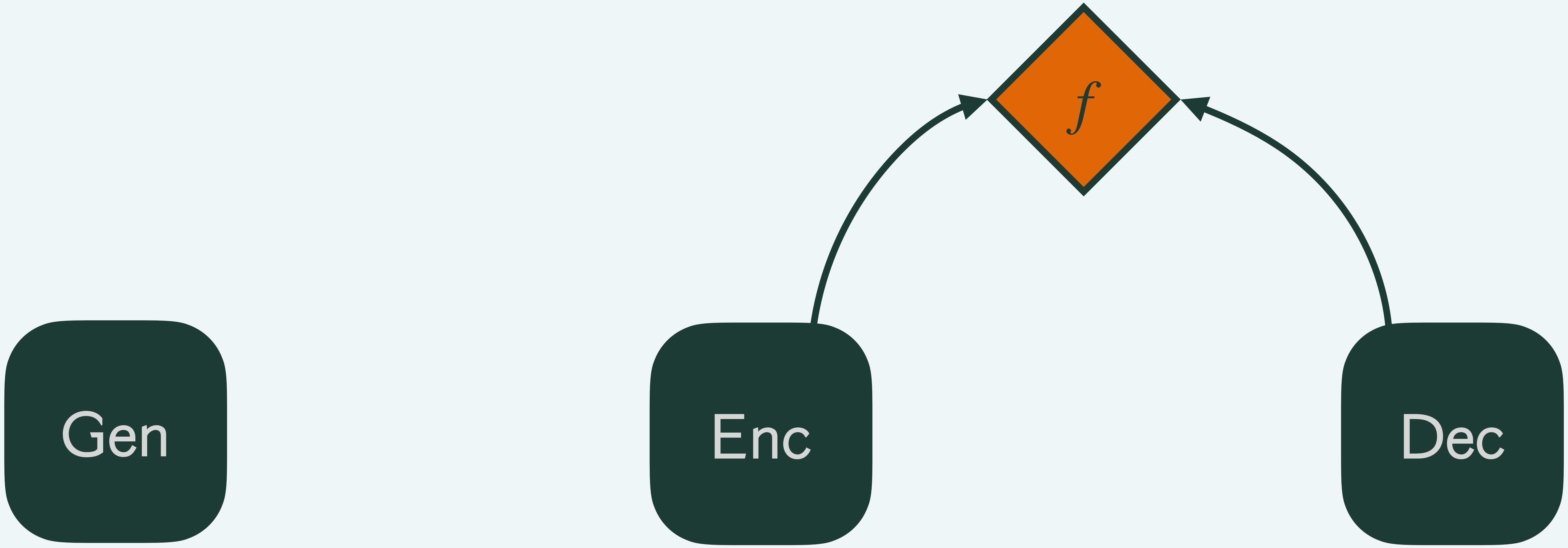

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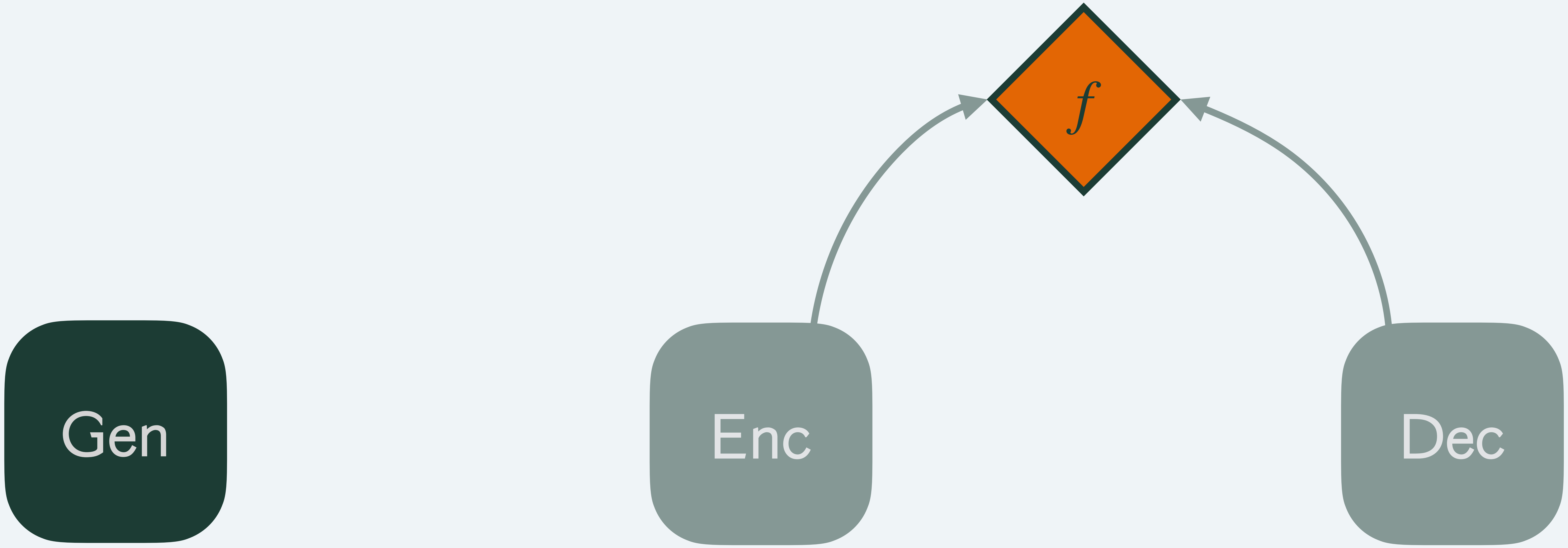

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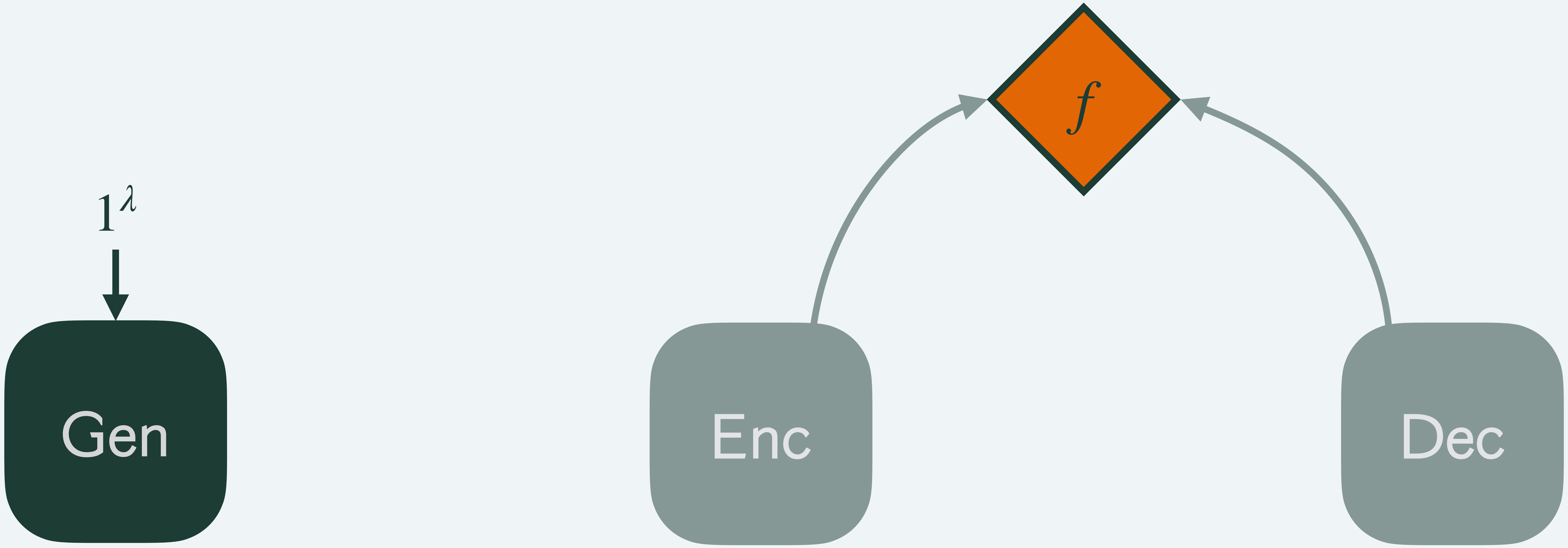

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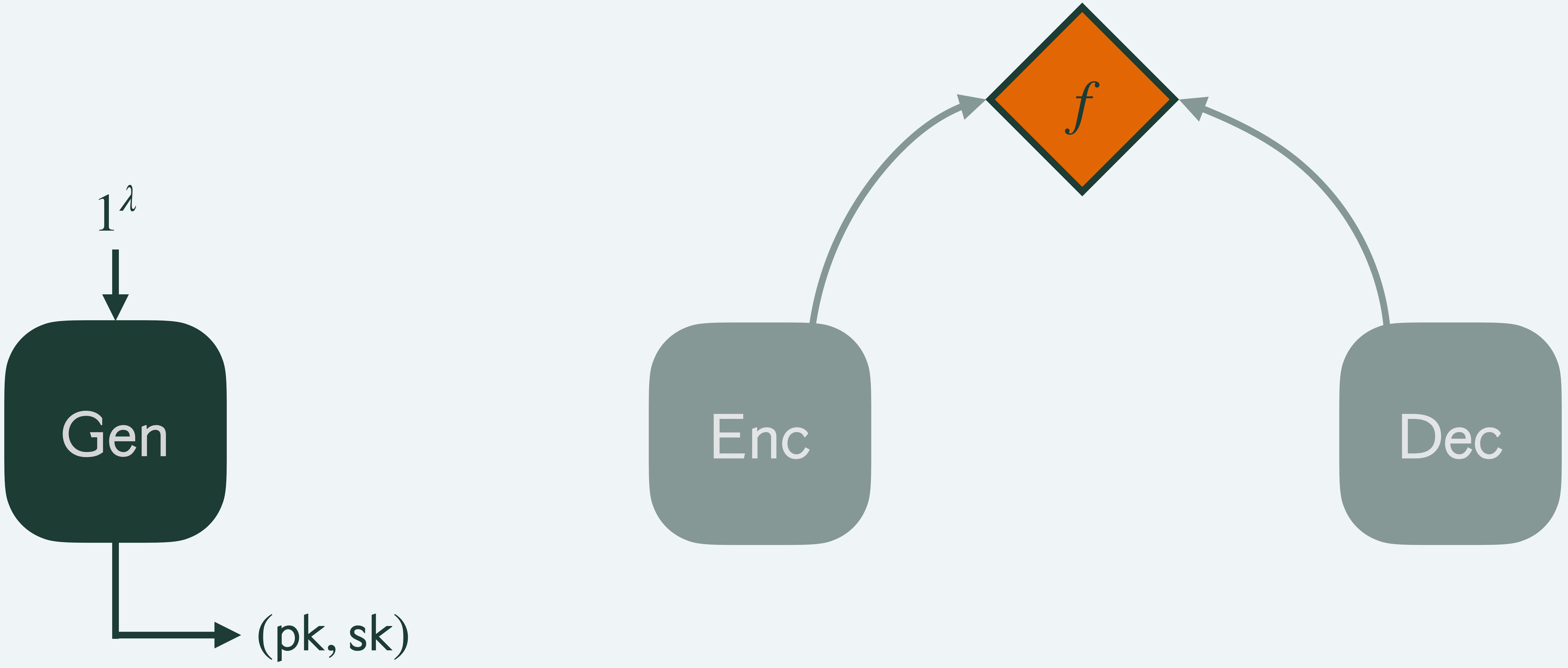

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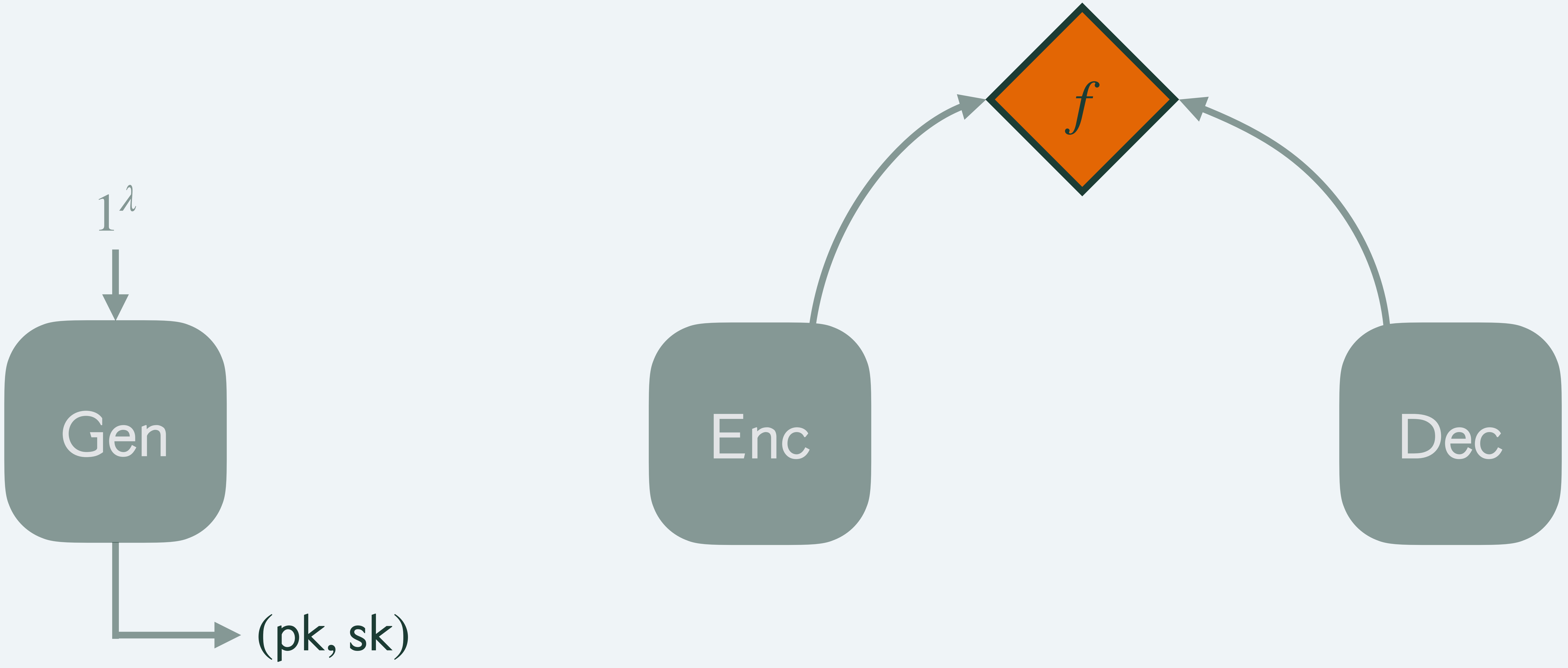

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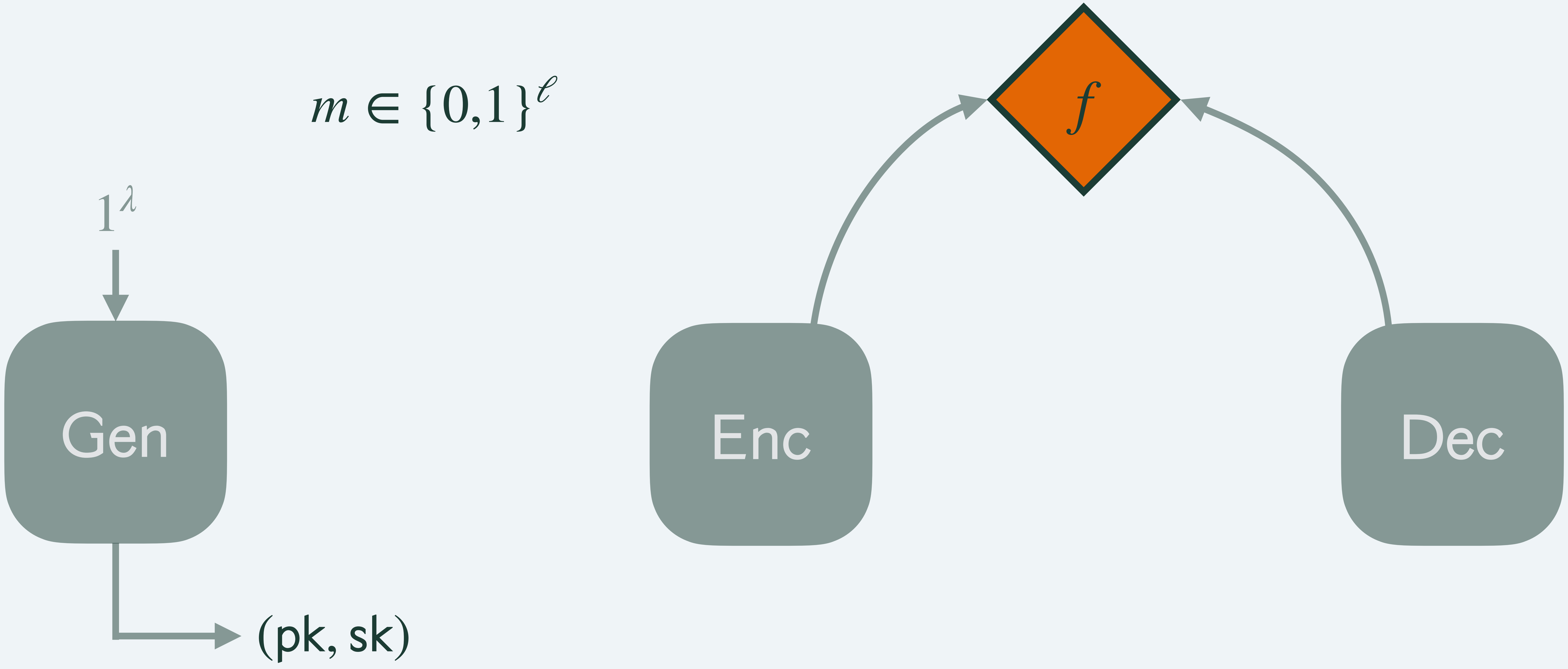

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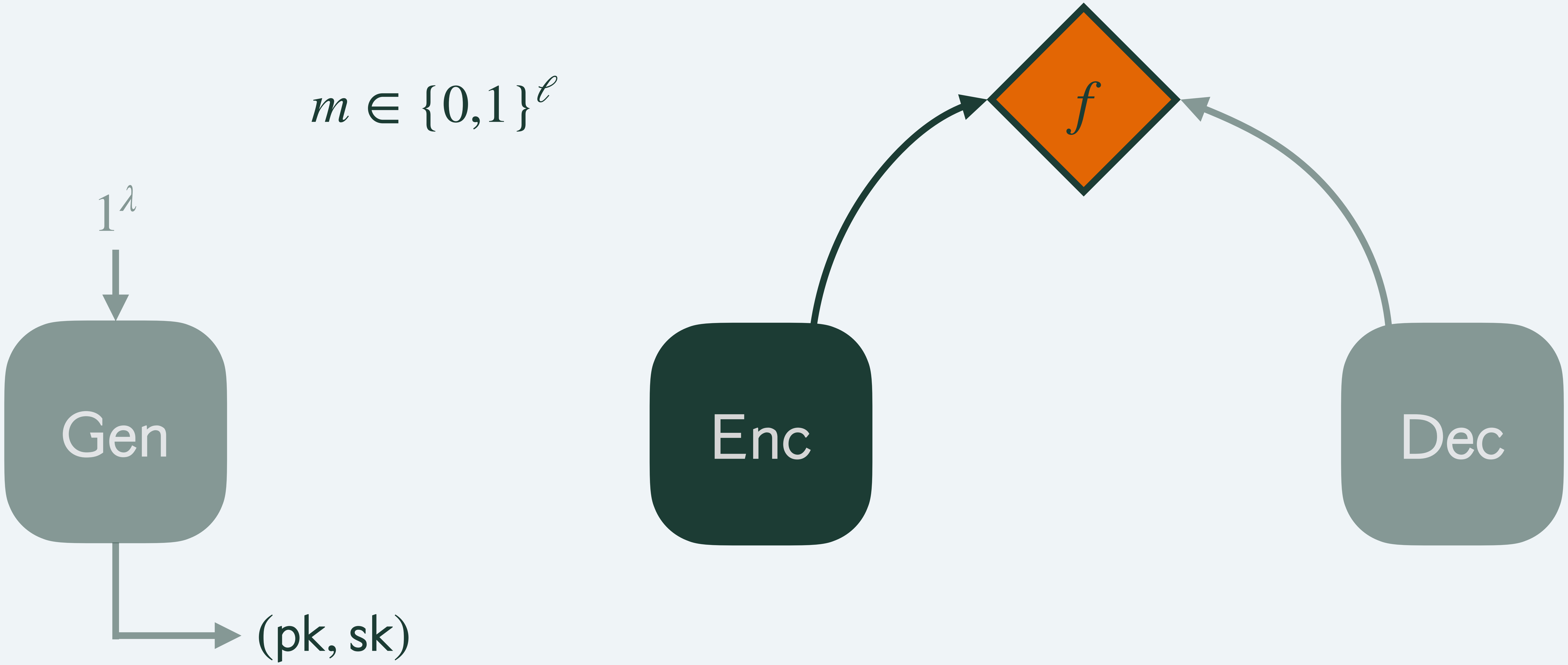

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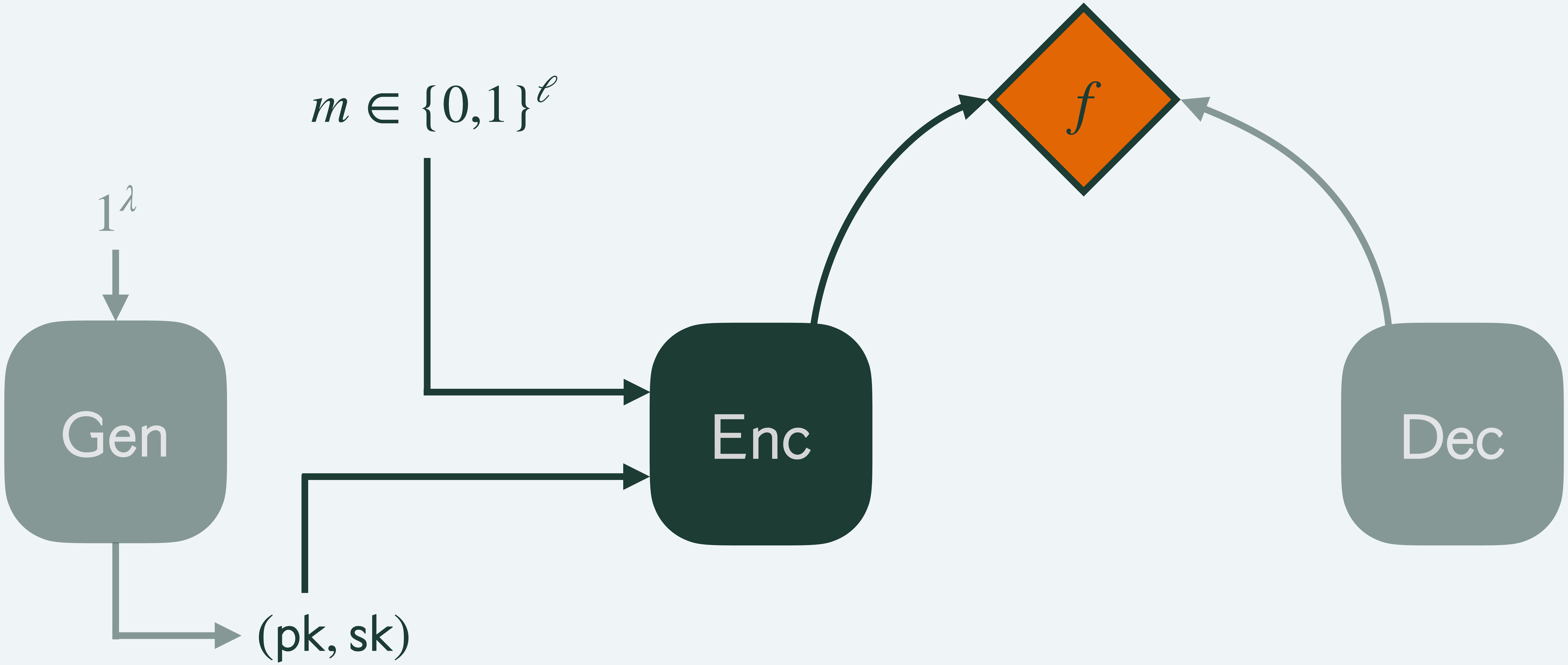

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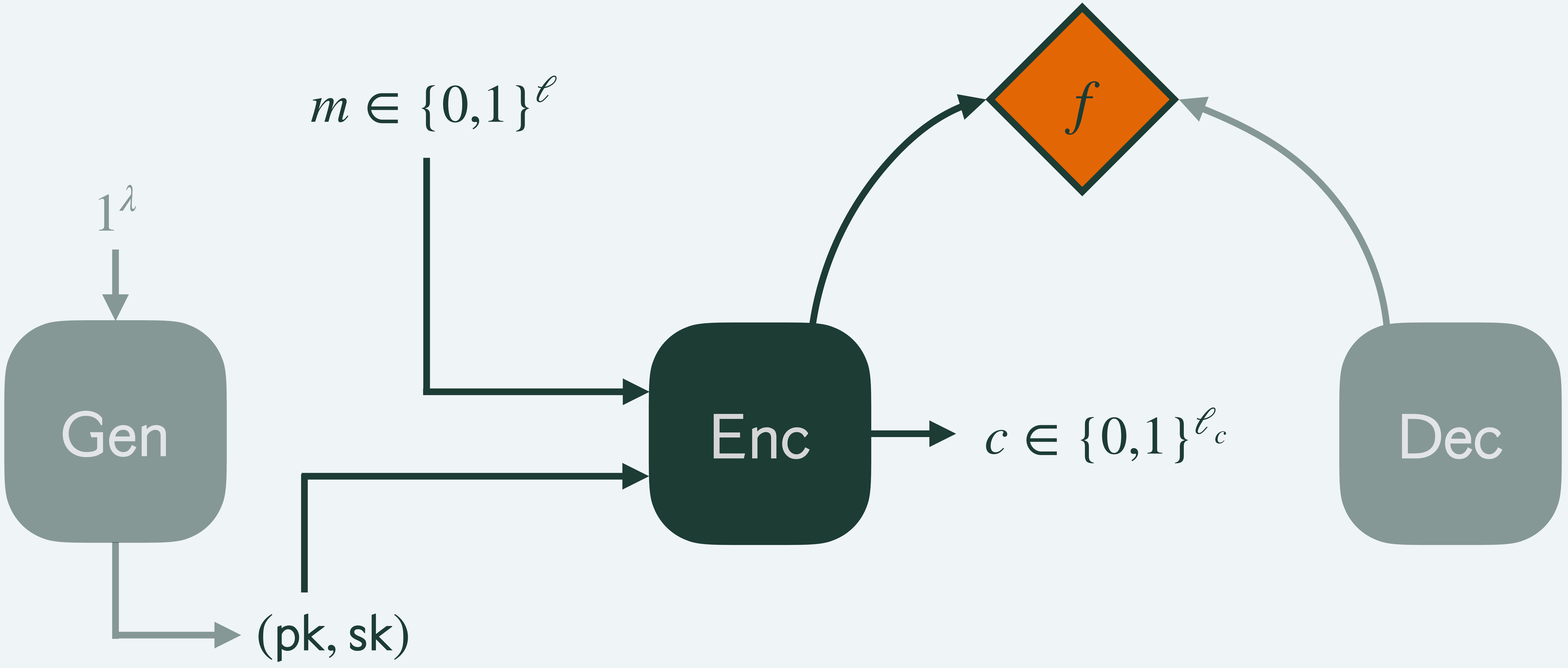

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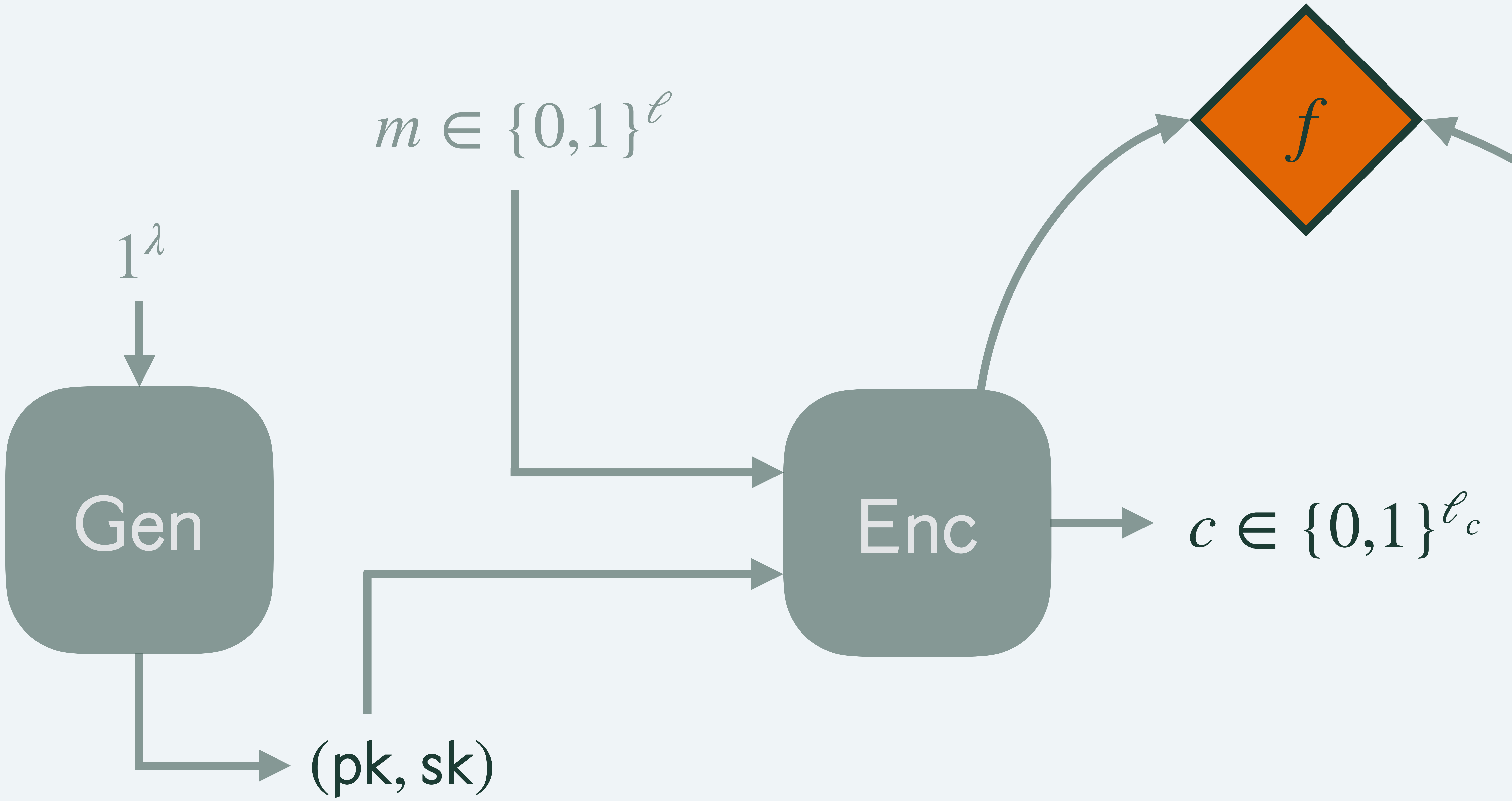

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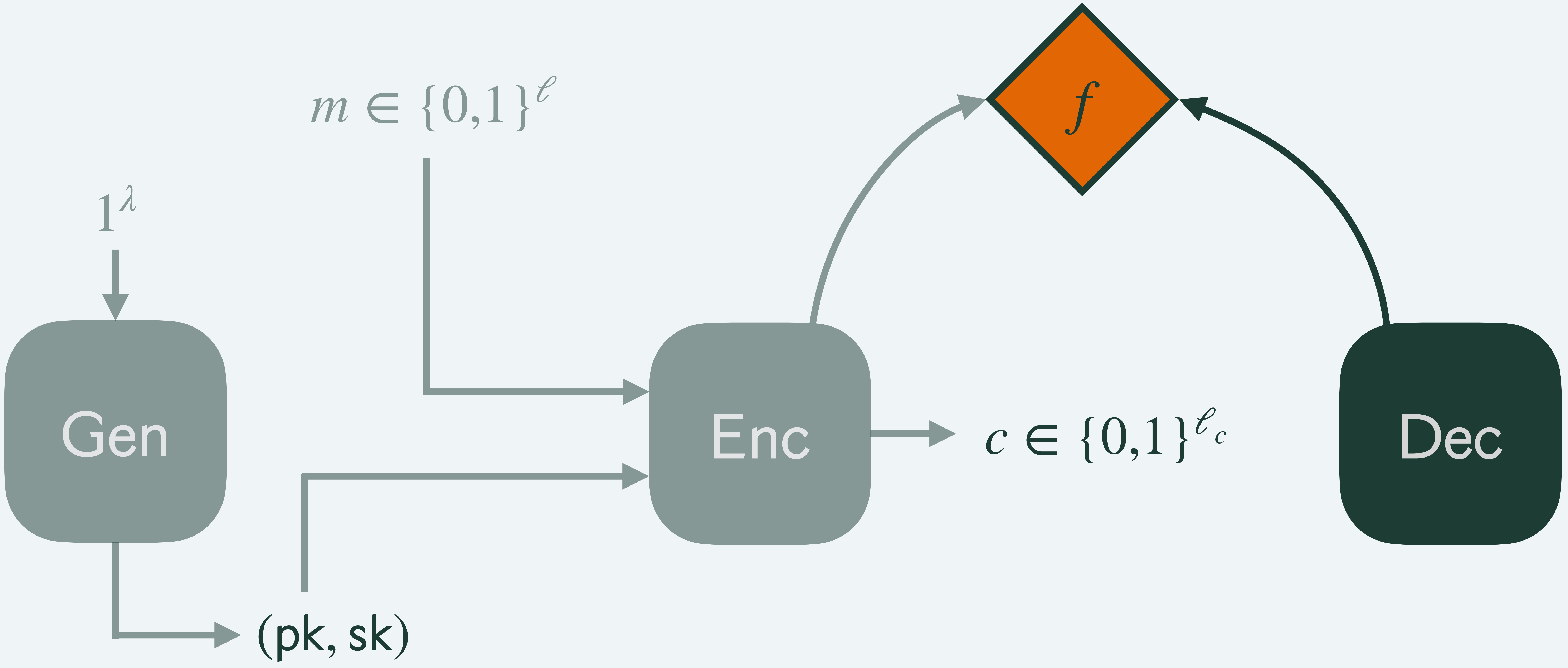

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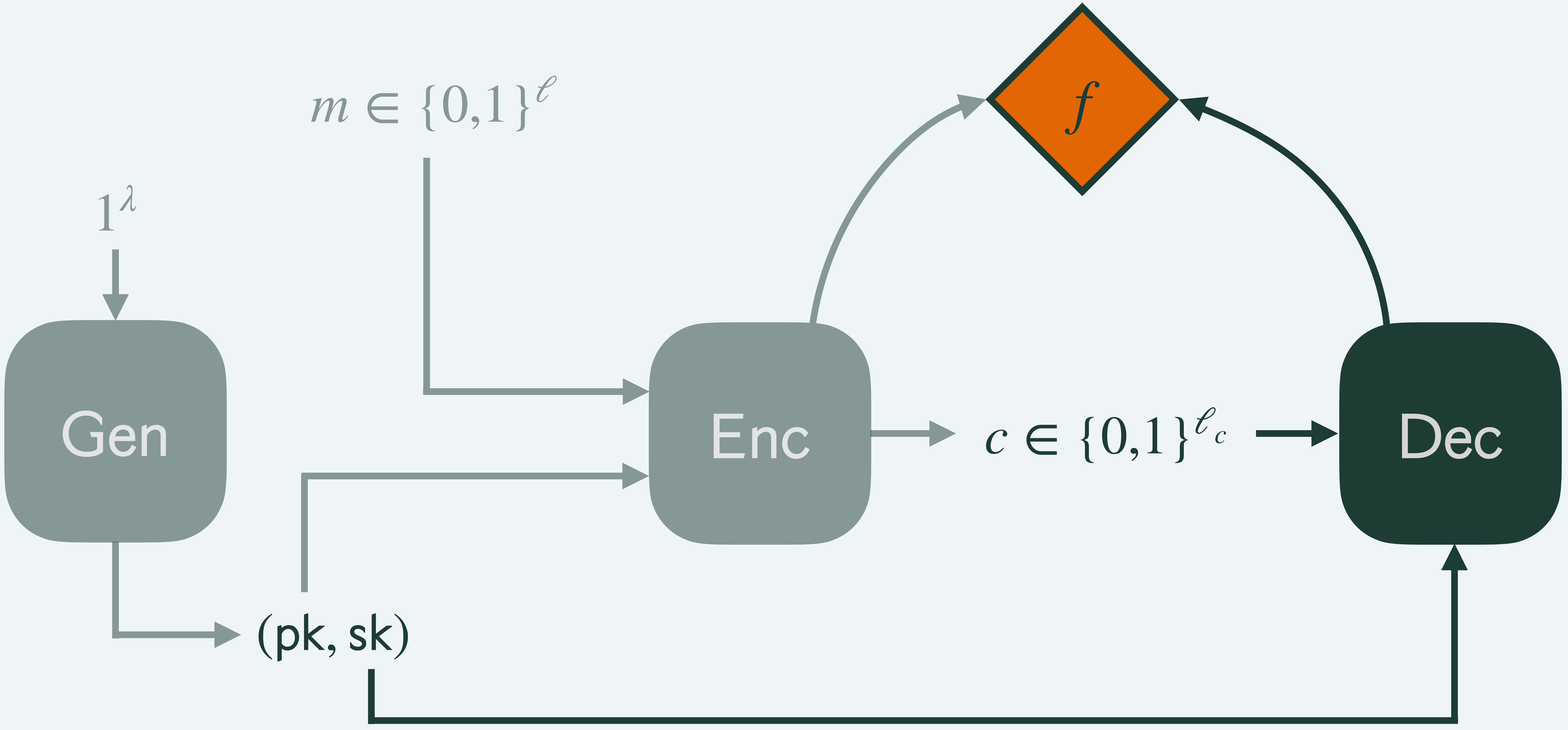

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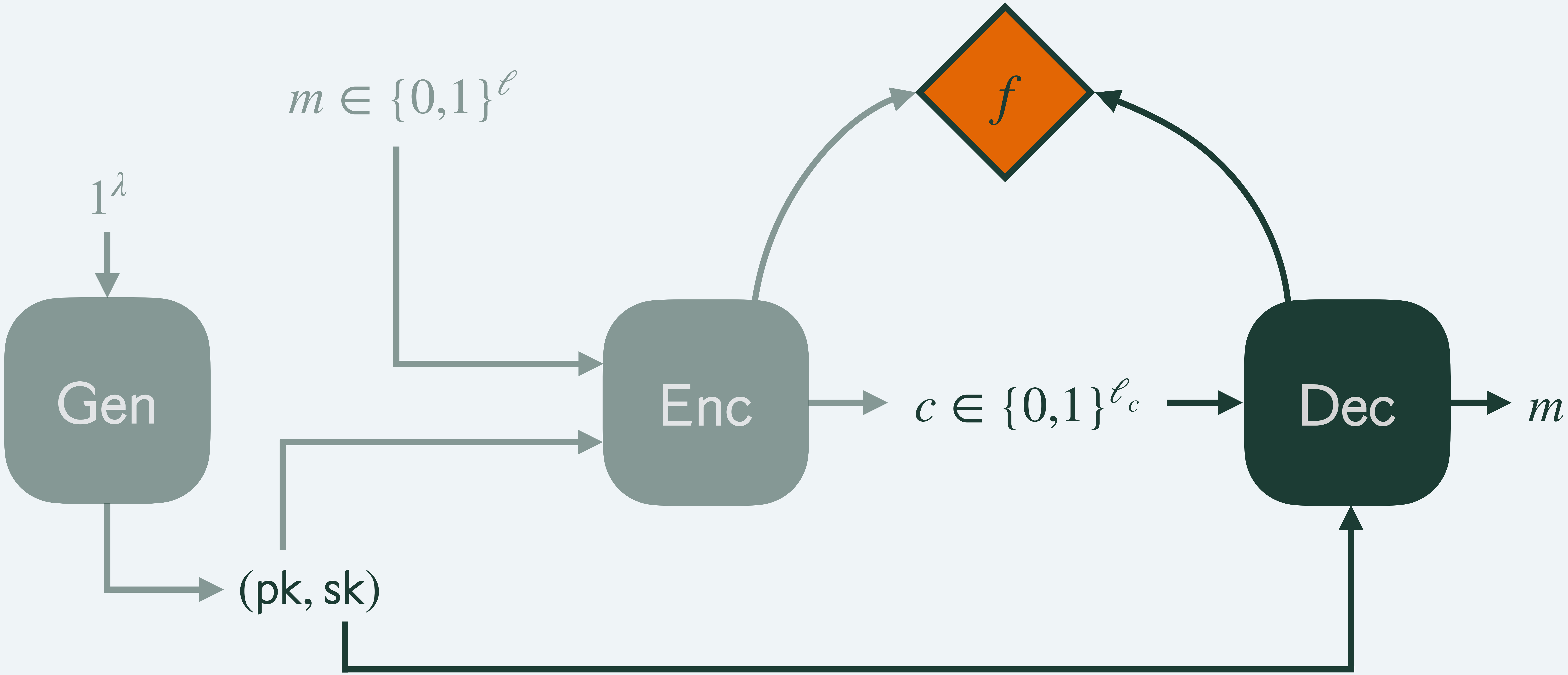

Encryption scheme in the ROM

Security Properties: Completeness

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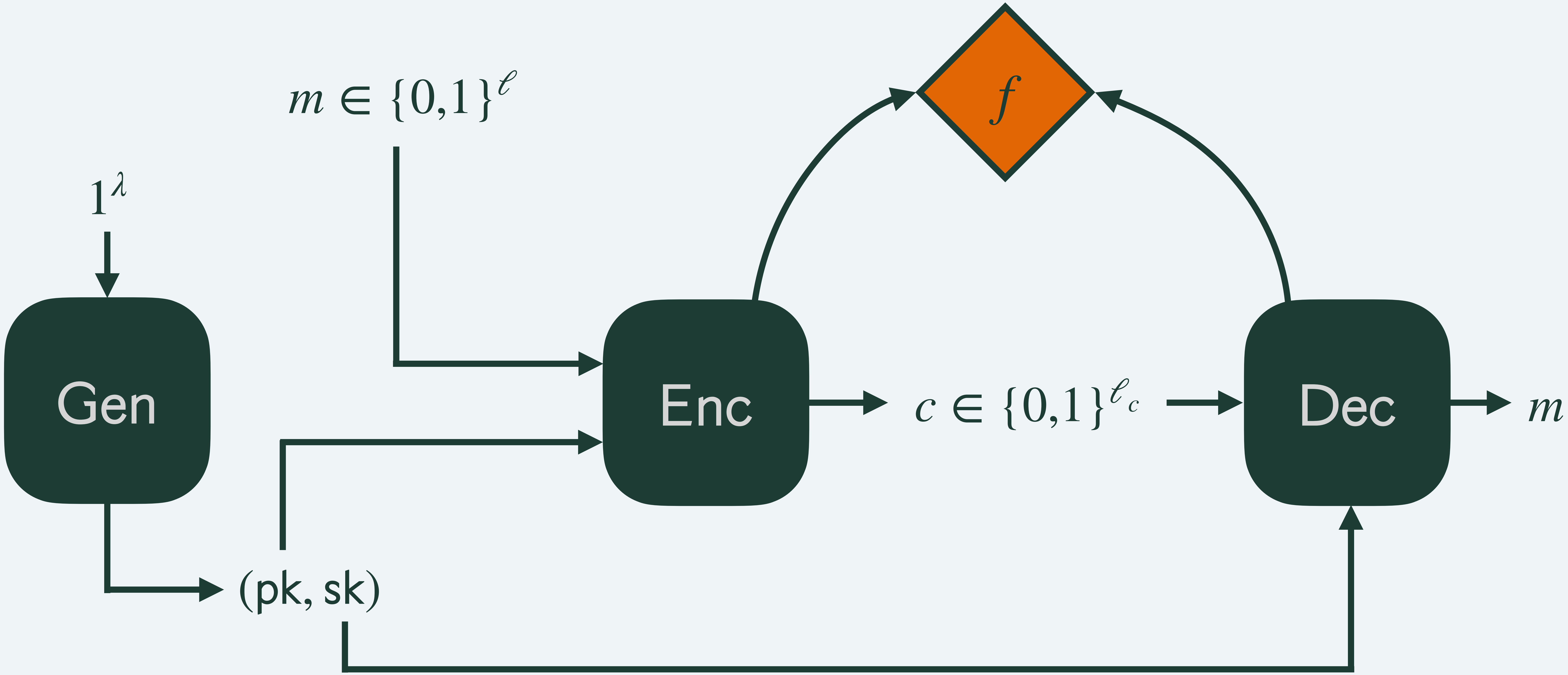

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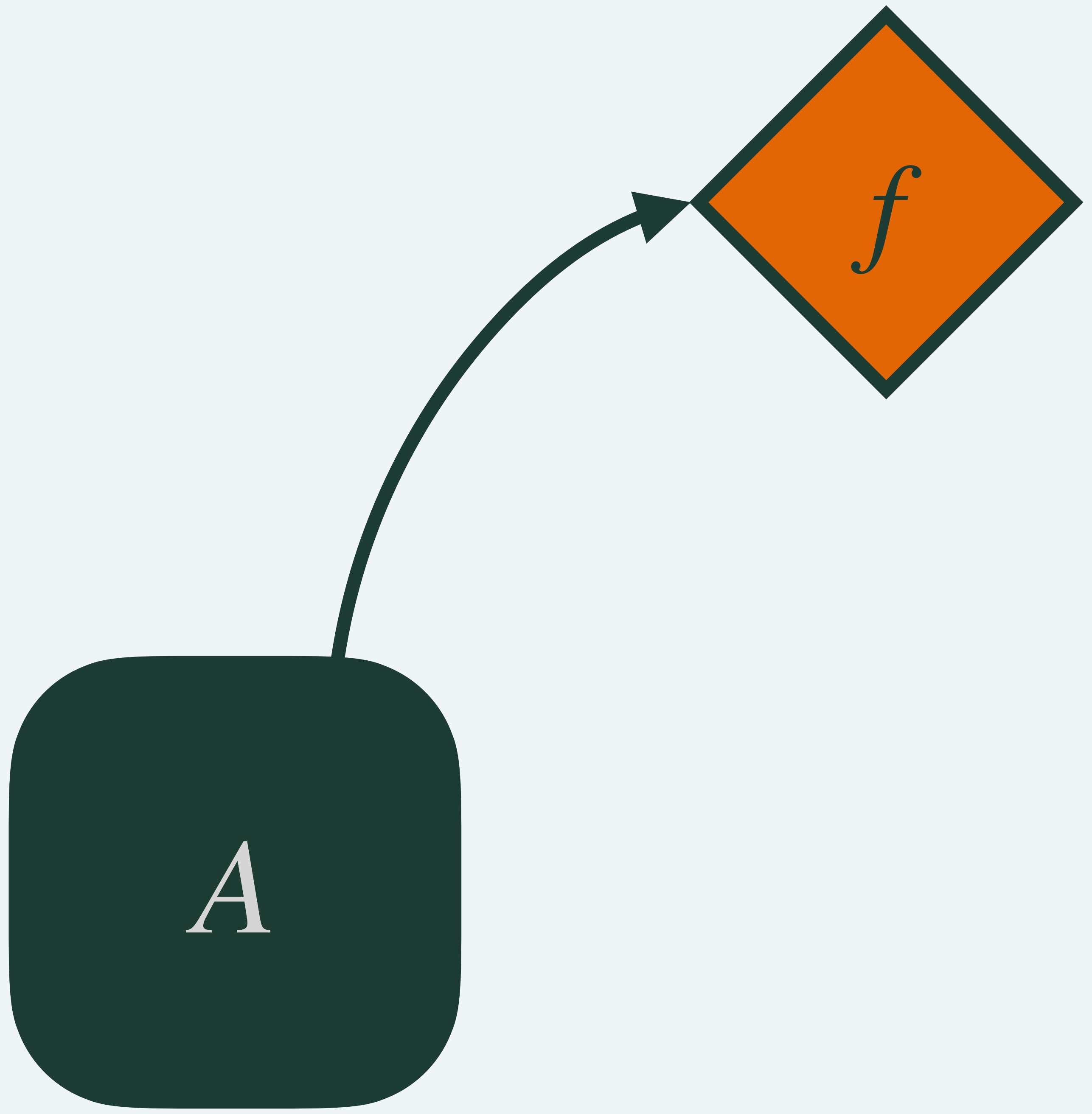
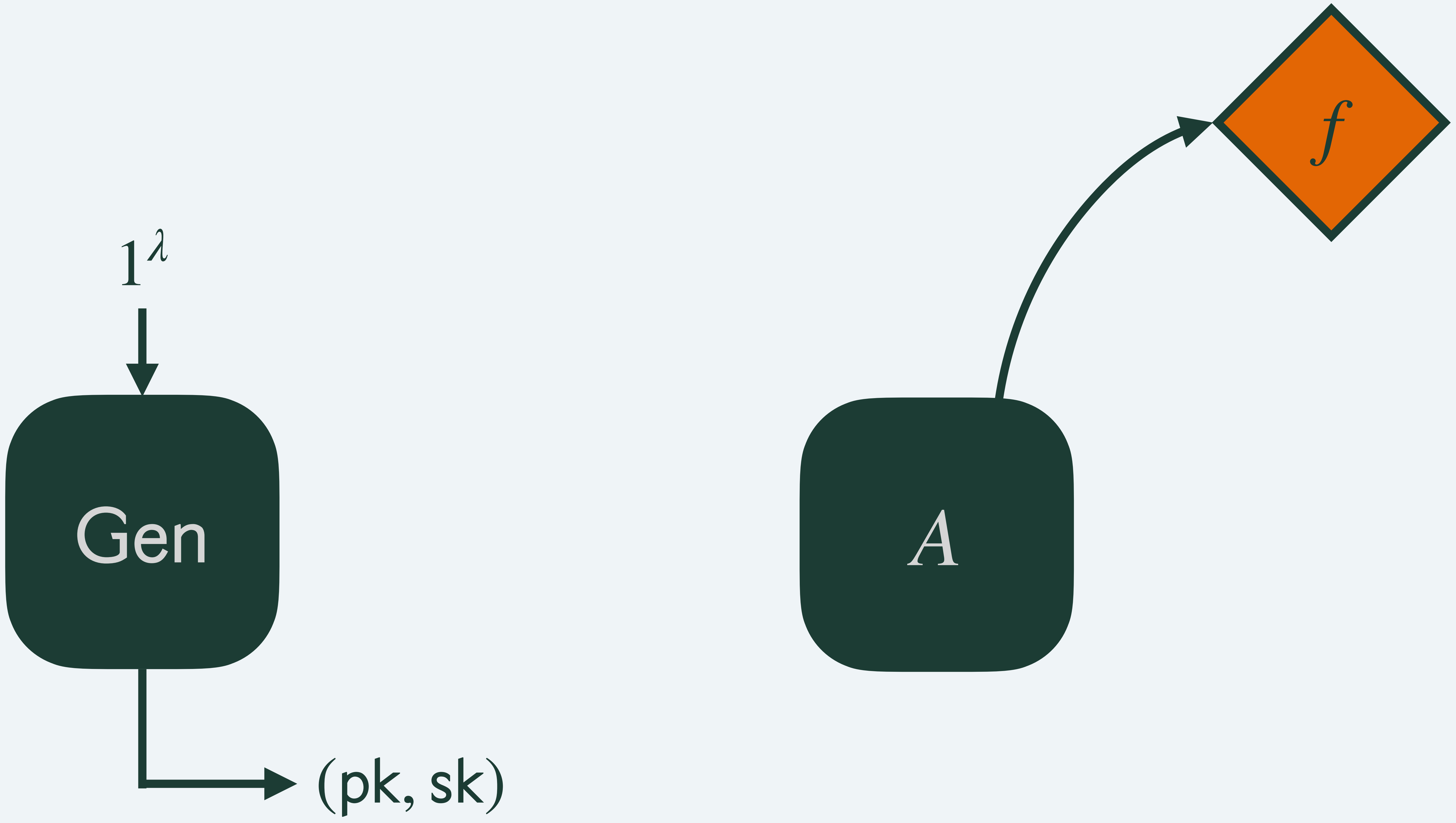


Encryption scheme in the ROM

Security Properties: CPA Security



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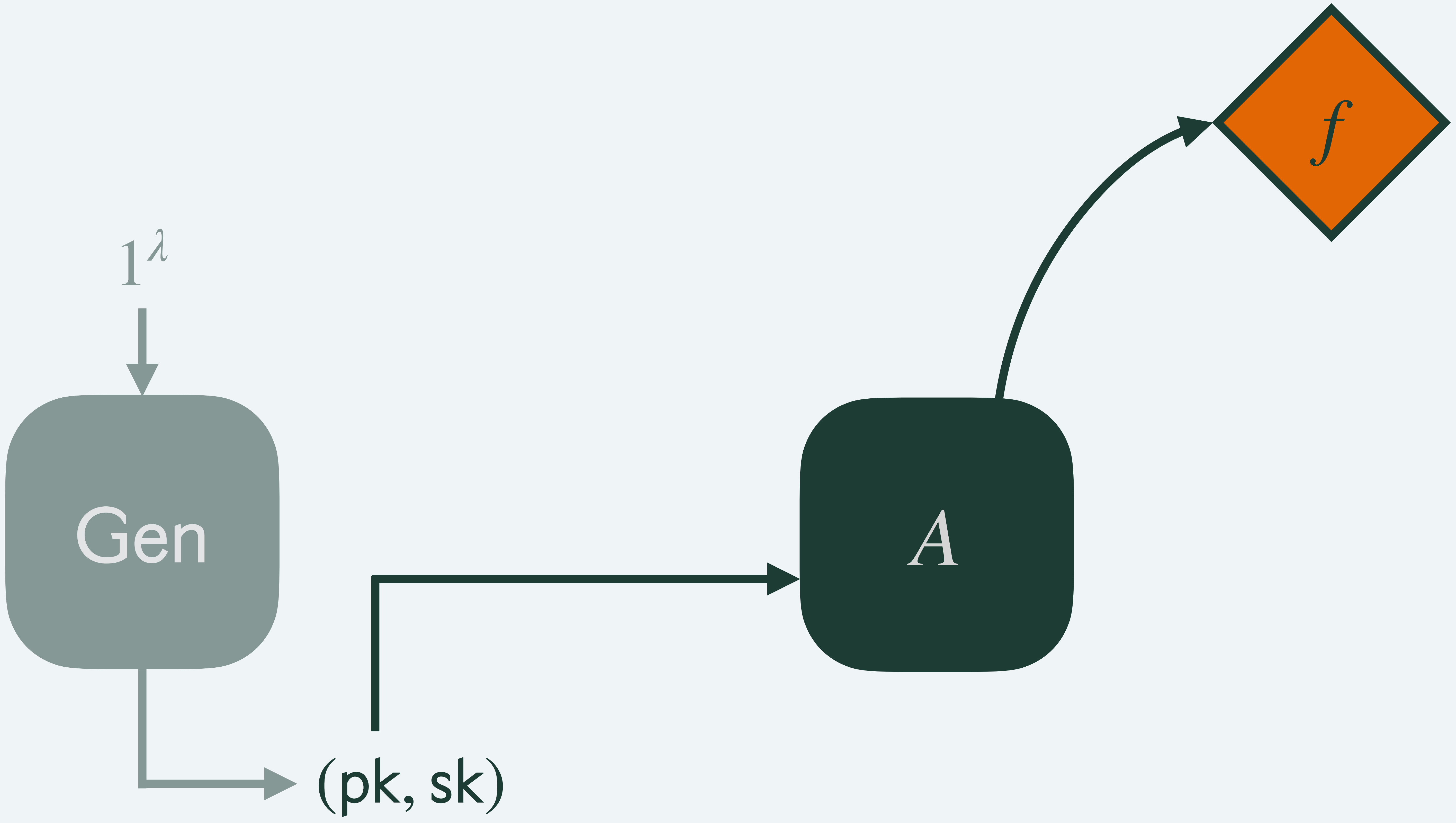

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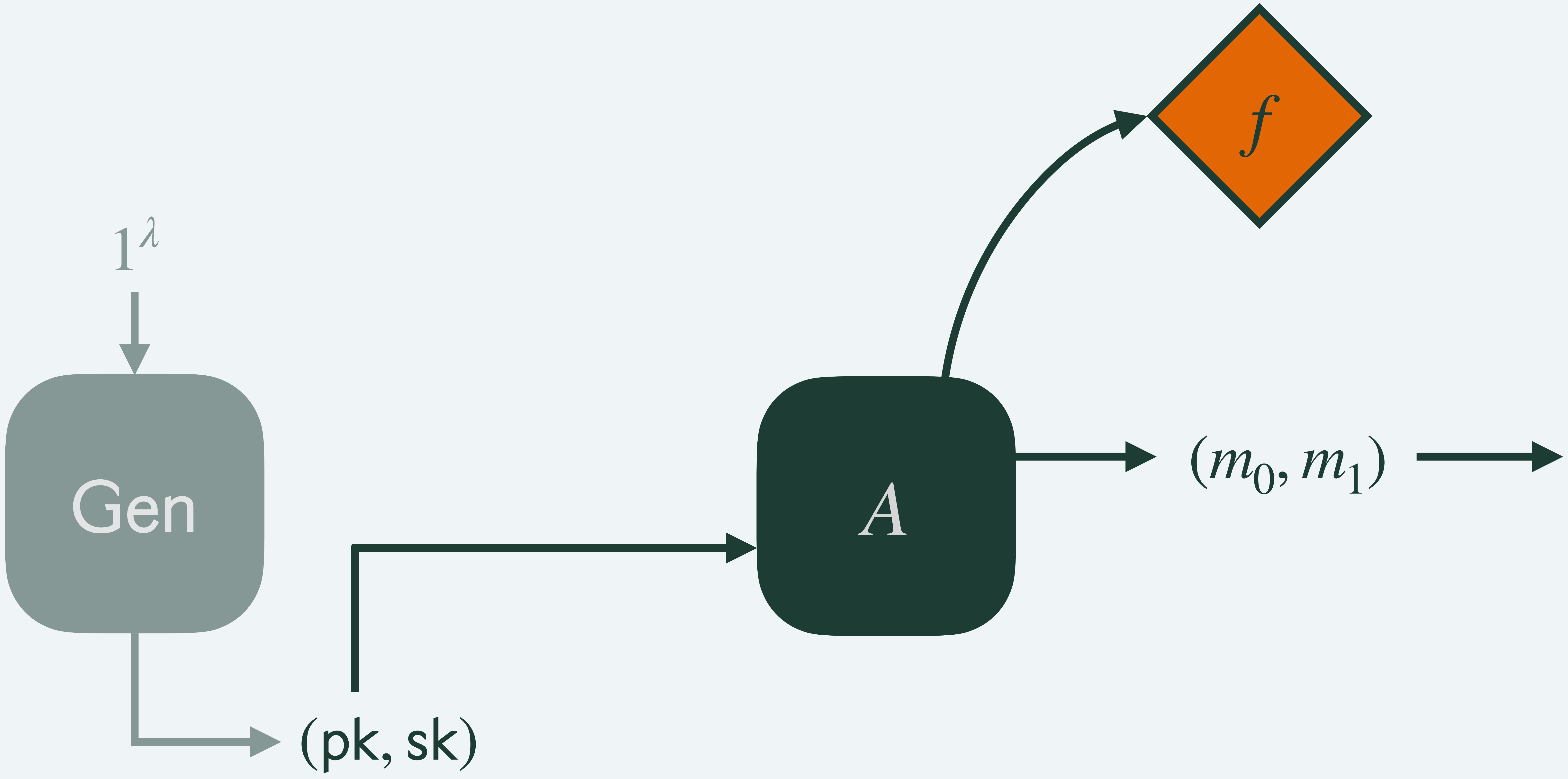

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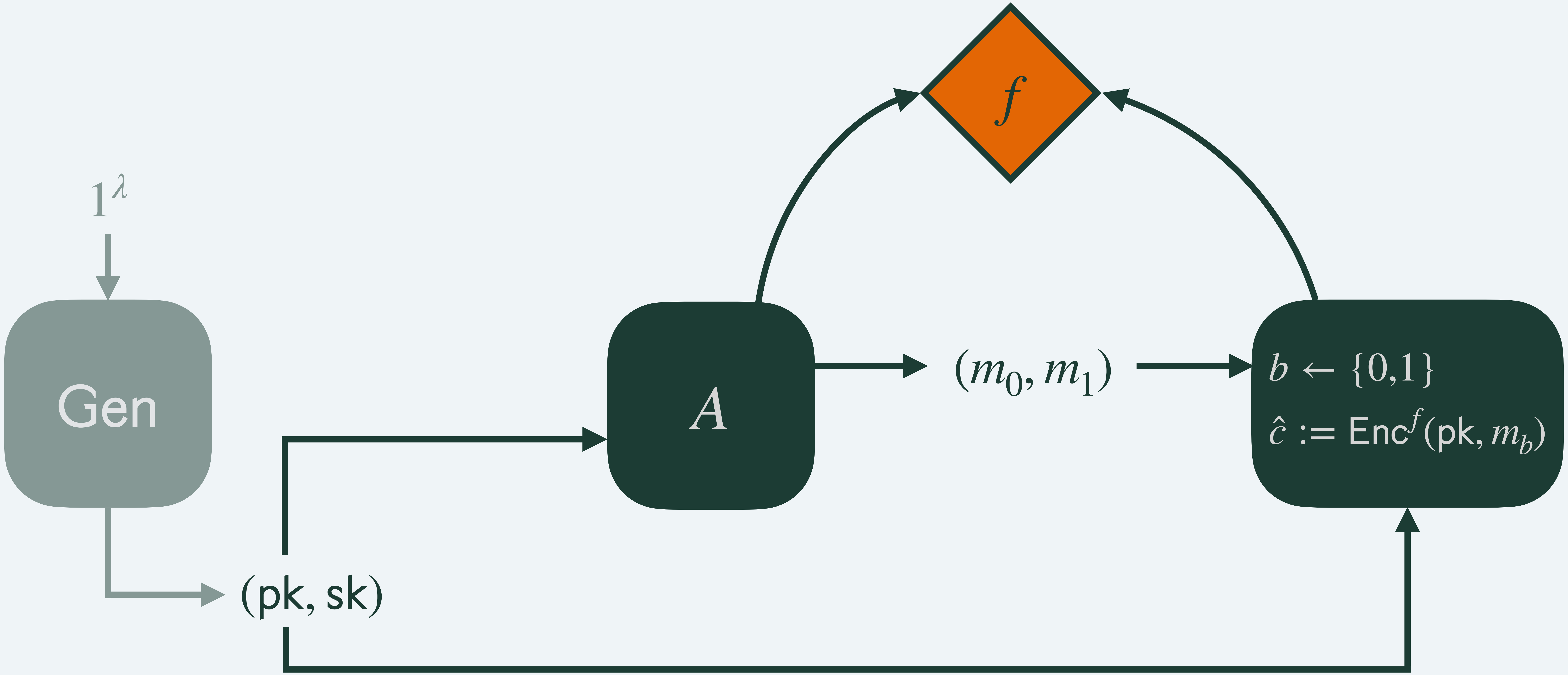

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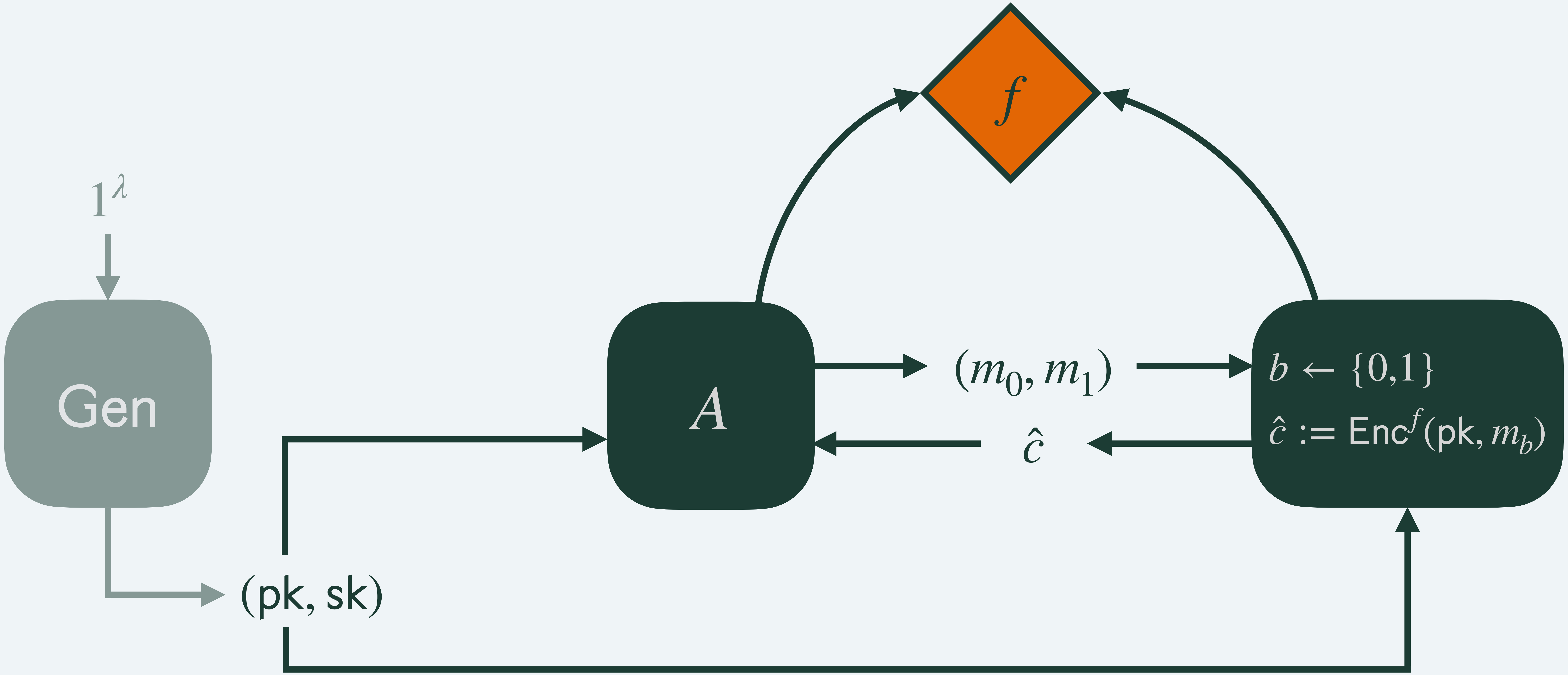

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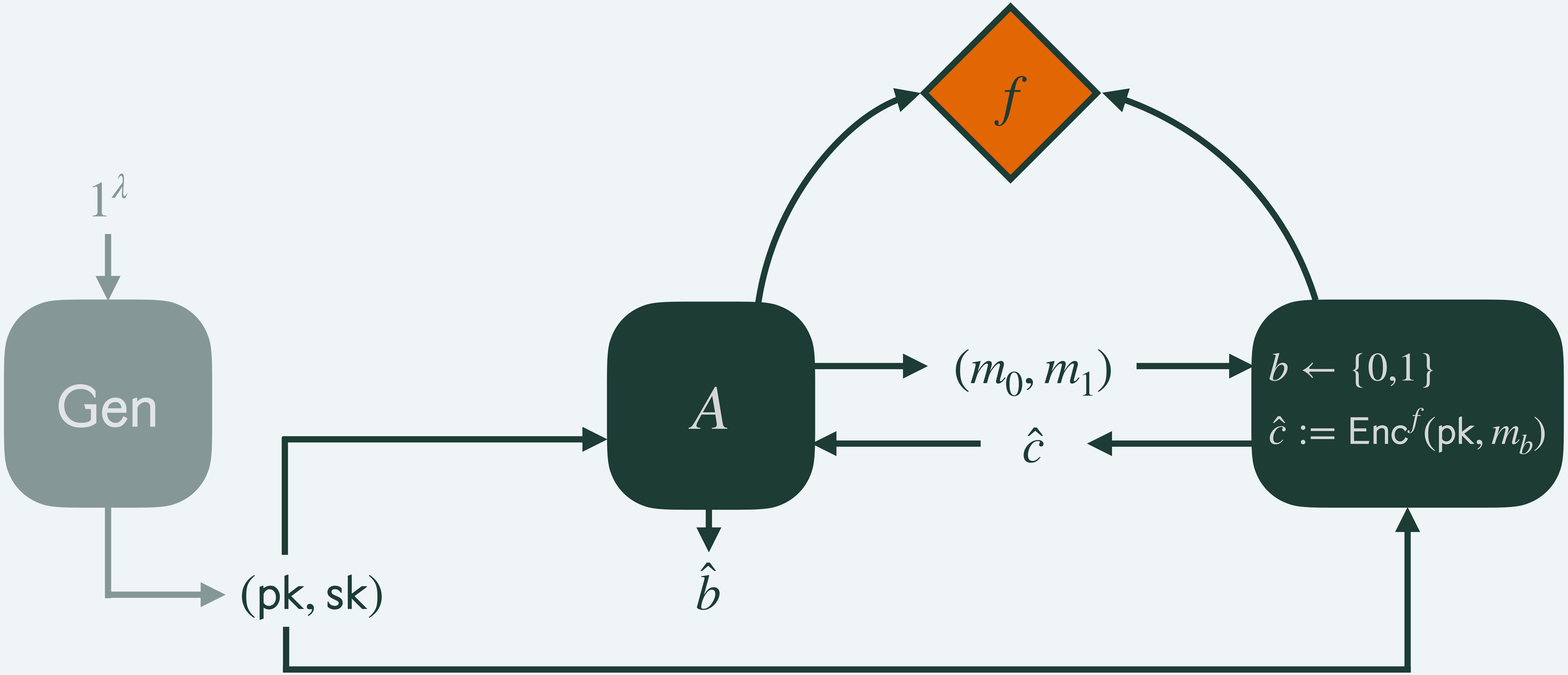

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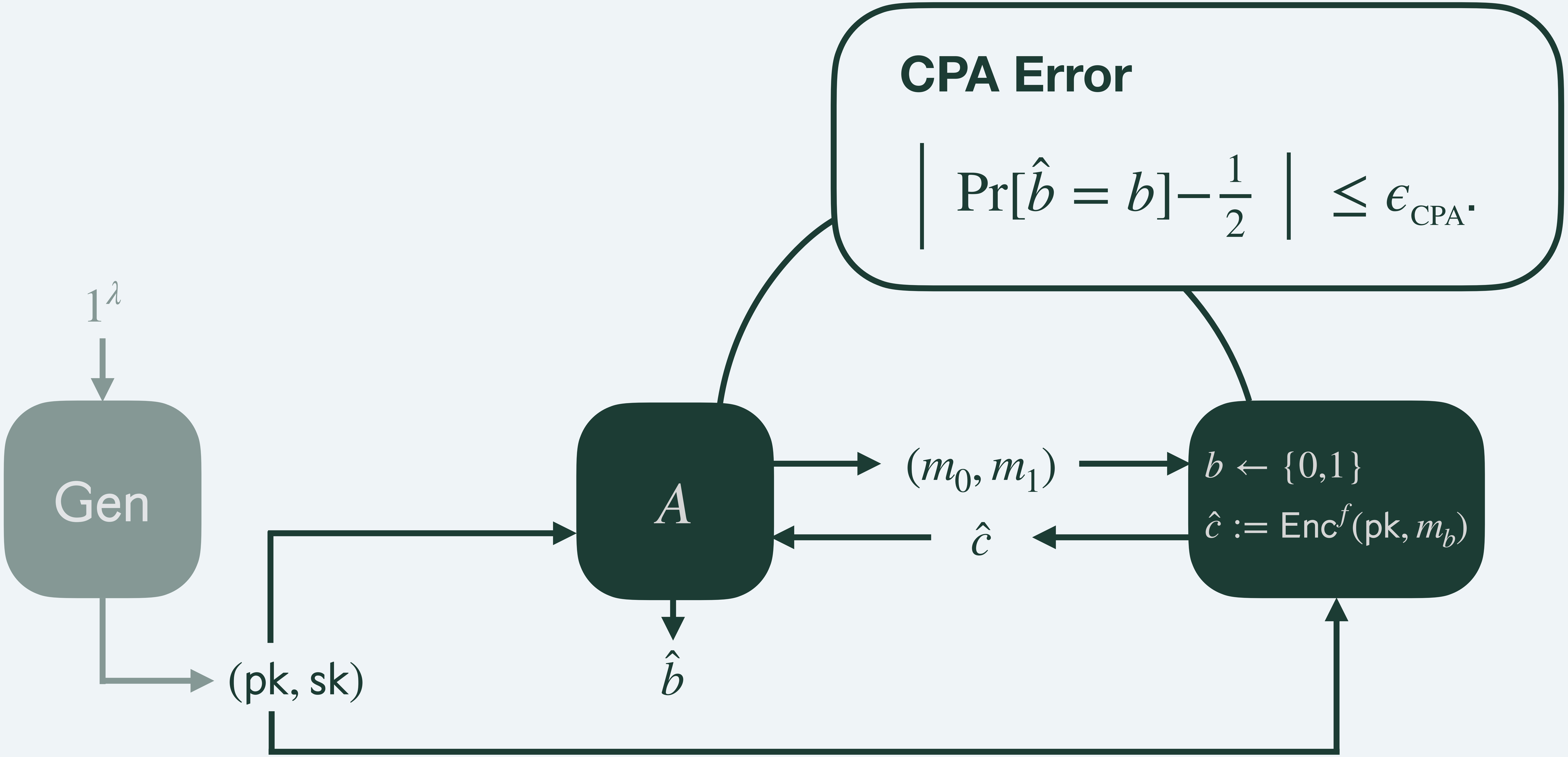
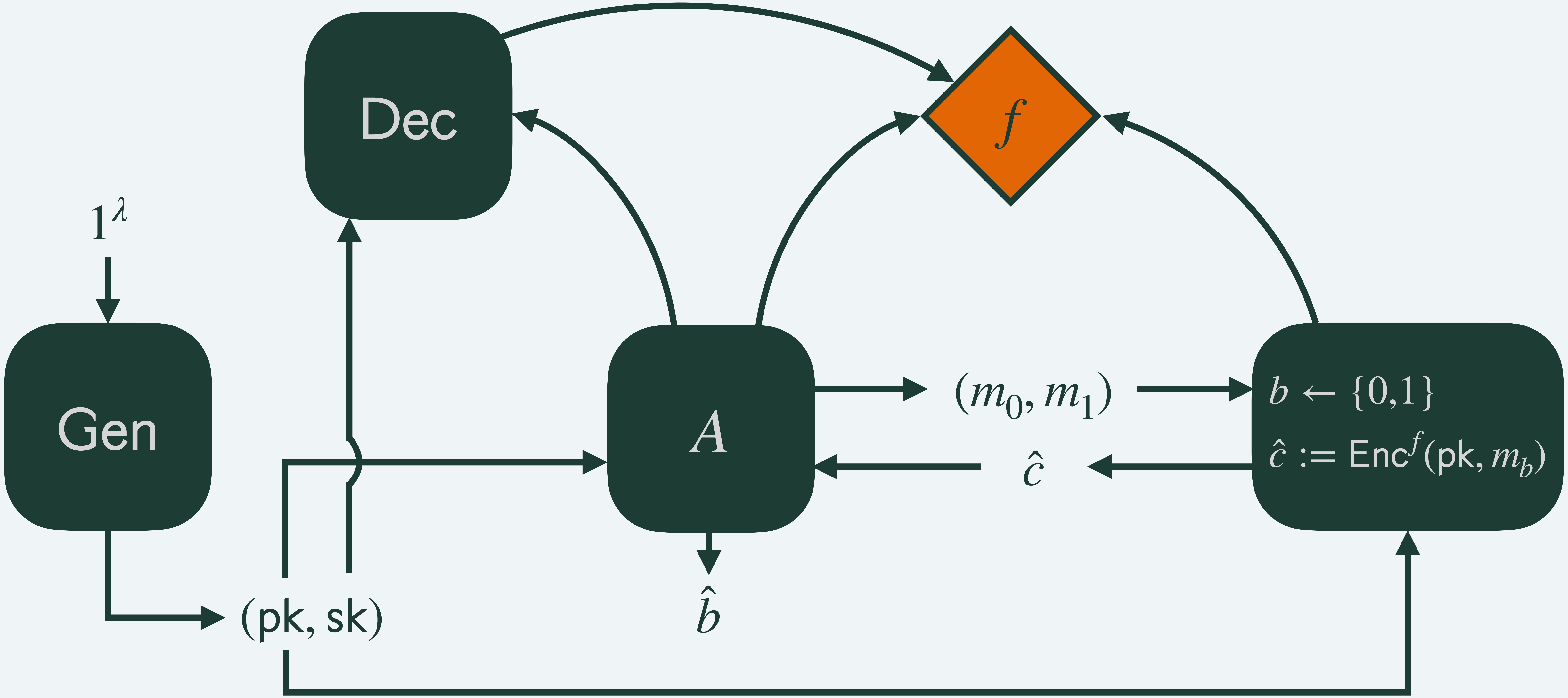


Encryption scheme in the ROM

Security Properties: CCA Security



Encryption scheme in the ROM

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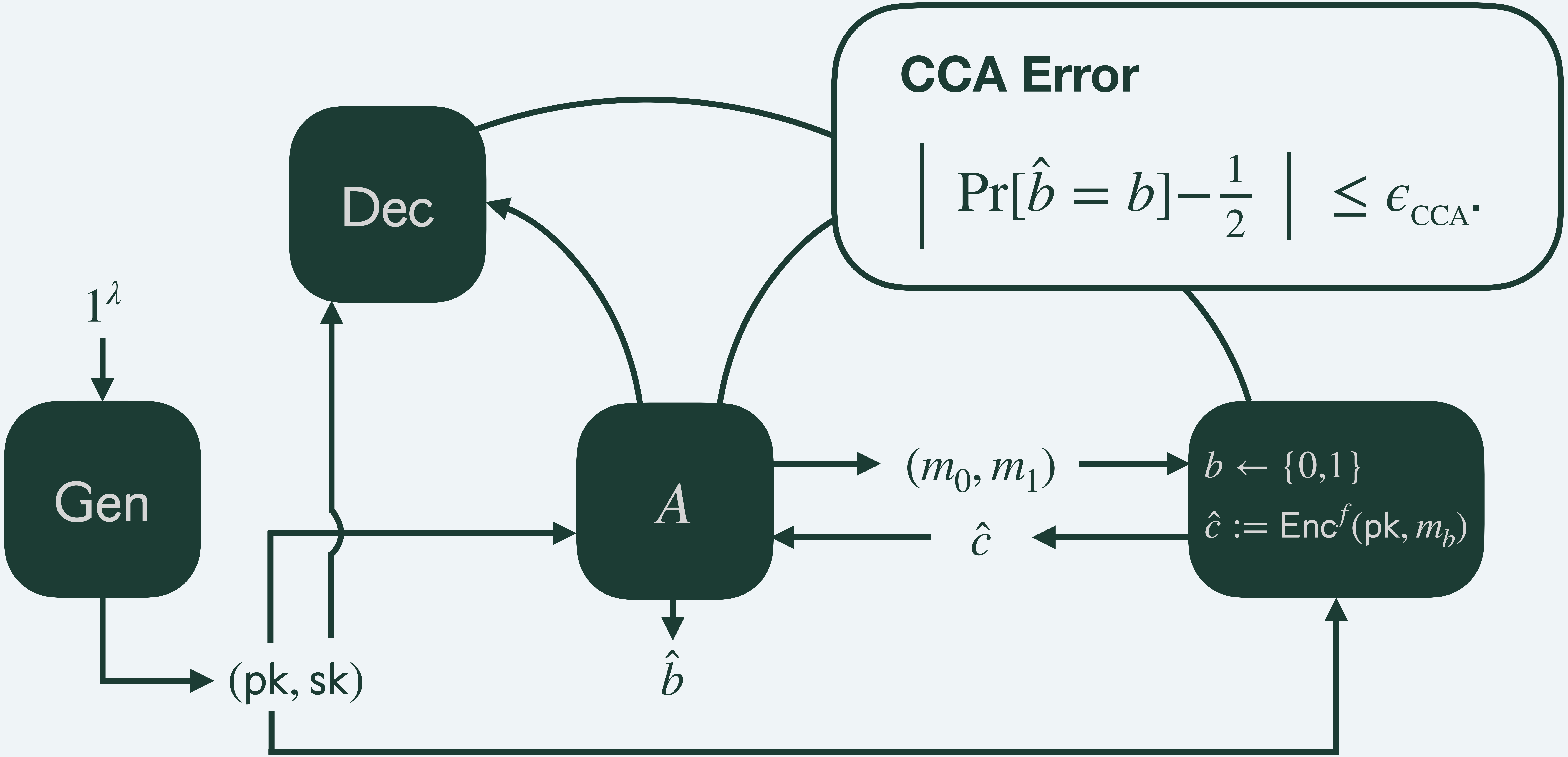

Encryption scheme in the ROM

Construction

Encryption scheme in the ROM

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Ingredients:

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- A CPA Secure Encryption Scheme; and

Encryption scheme in the ROM

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$$\mathcal{R}_\ell := \left\{ \big((\mathsf{pk}_0, c_0, \mathsf{pk}_1, c_1), (\rho_0, m_0, \rho_1, m_1)\big) \;\middle|\; \begin{array}{l} m_0, m_1 \in \{0,1\}^\ell \\ \wedge\, m_0 = m_1 \\ \wedge\, c_0 = \mathsf{ENC}.\mathsf{Enc}^f_{\mathrm{CPA}}(\mathsf{pk}_0, m_0; \rho_0) \\ \wedge\, c_1 = \mathsf{ENC}.\mathsf{Enc}^f_{\mathrm{CPA}}(\mathsf{pk}_1, m_1; \rho_1) \end{array} \right\}.$$

Encryption scheme in the ROM

Construction

NARG **needs to satisfy:**

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Encryption scheme in the ROM

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NARG **needs to satisfy**:

- Computational zero-knowledge; and

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Encryption scheme in the ROM

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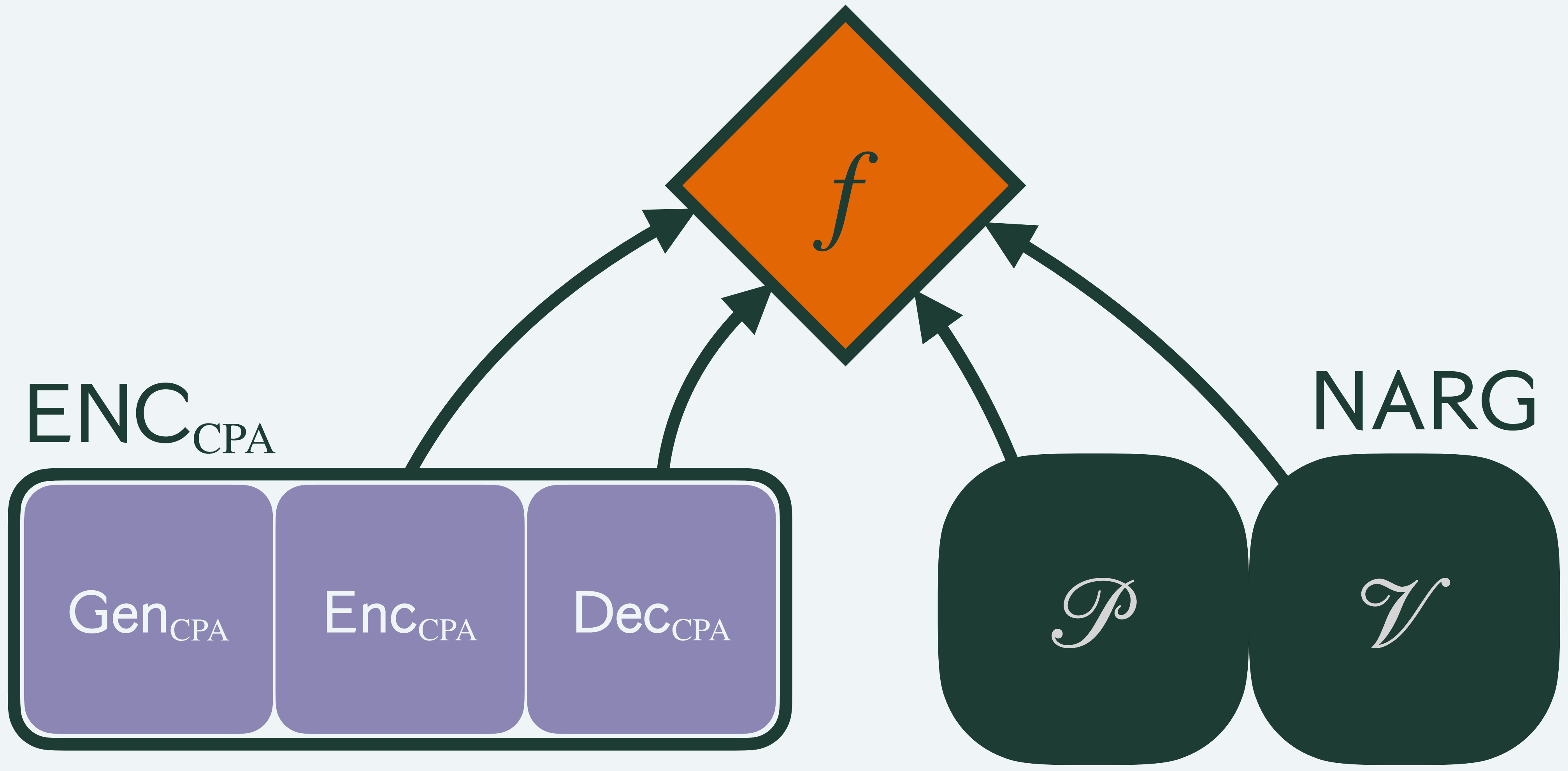

Encryption scheme in the ROM

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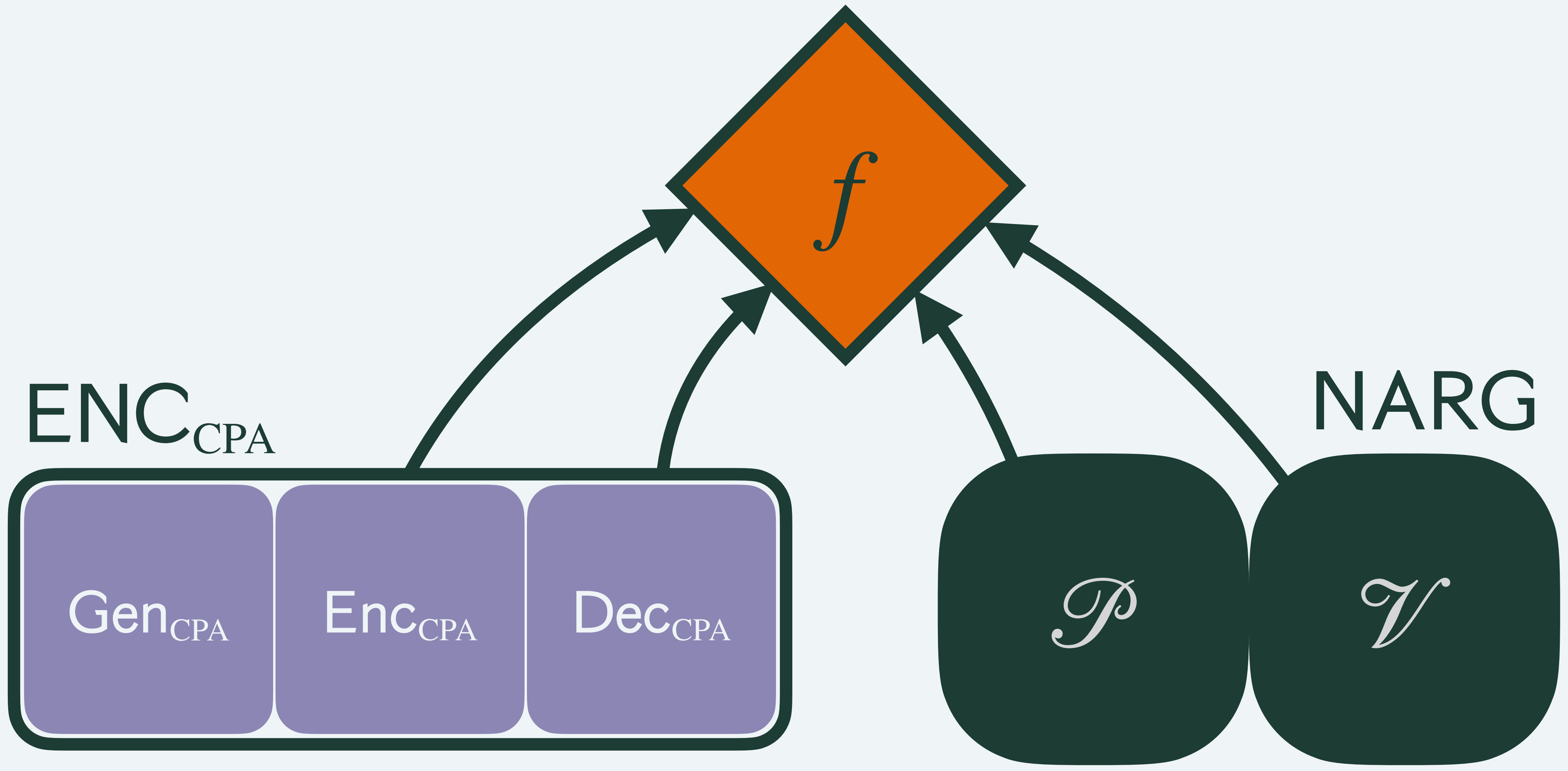

$\underline{\mathsf{Gen}(1^\lambda)}$

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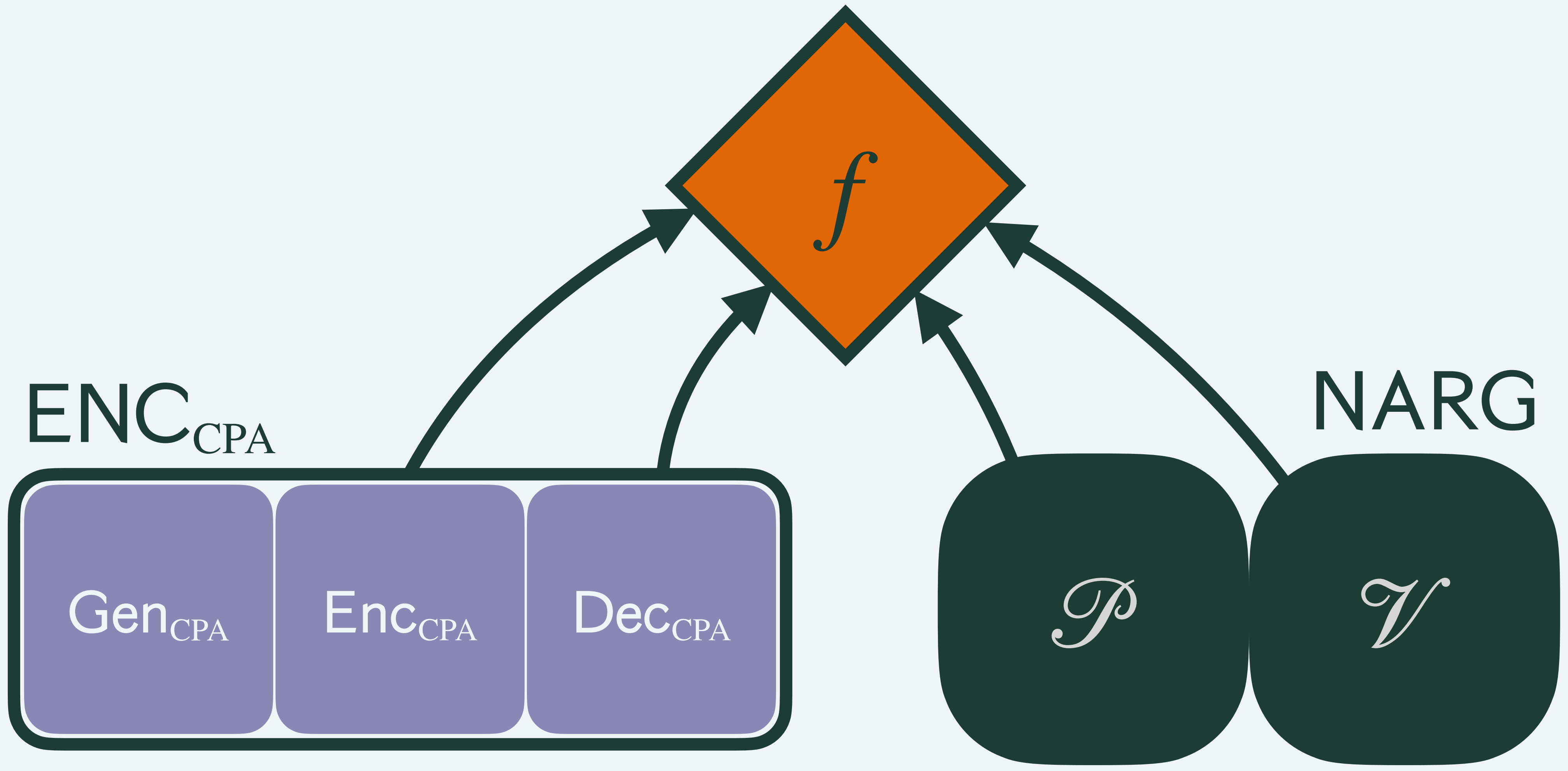

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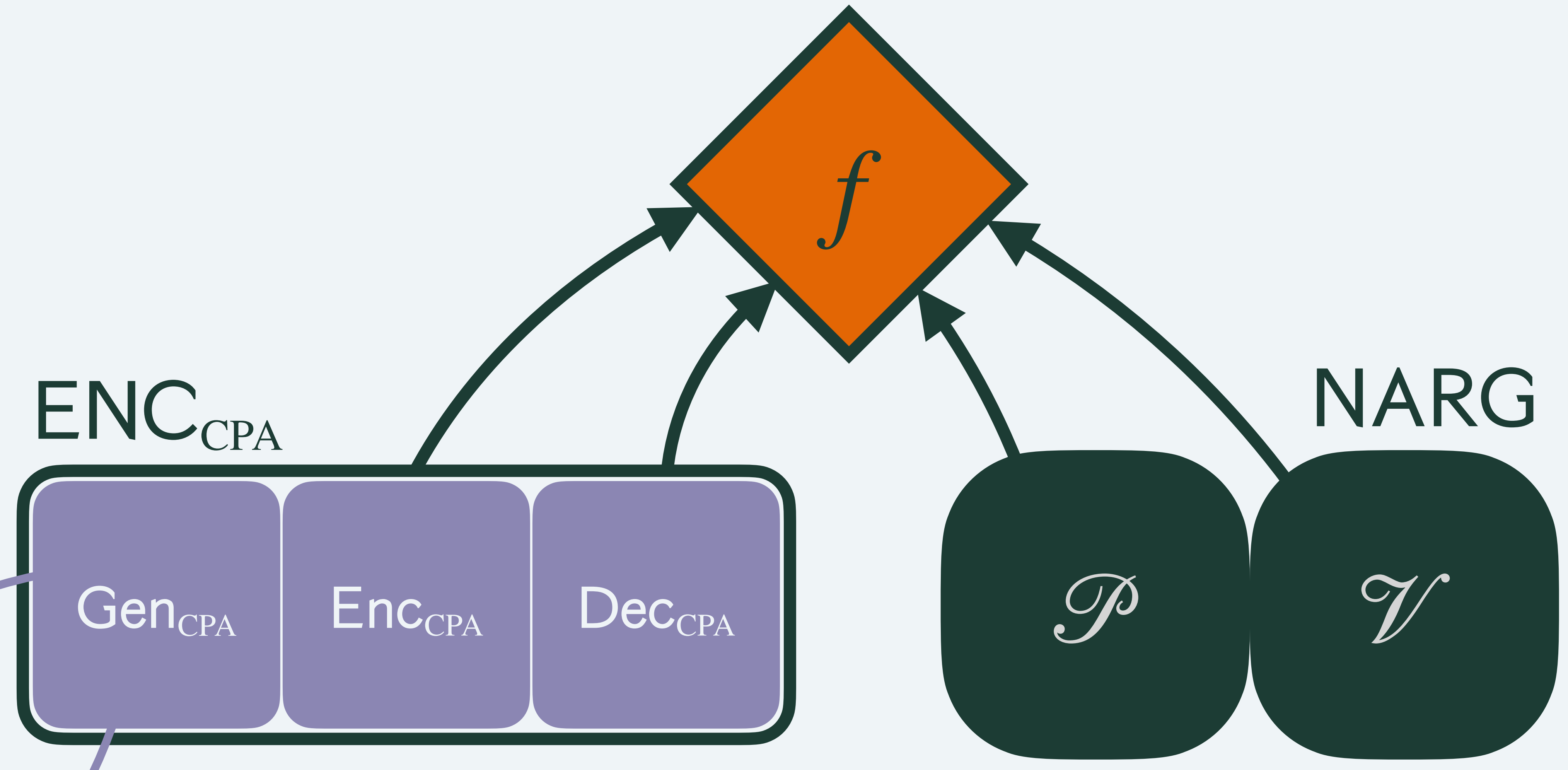
$\downarrow$

(pk, sk)

Encryption scheme in the ROM

Construction



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Encryption scheme in the ROM

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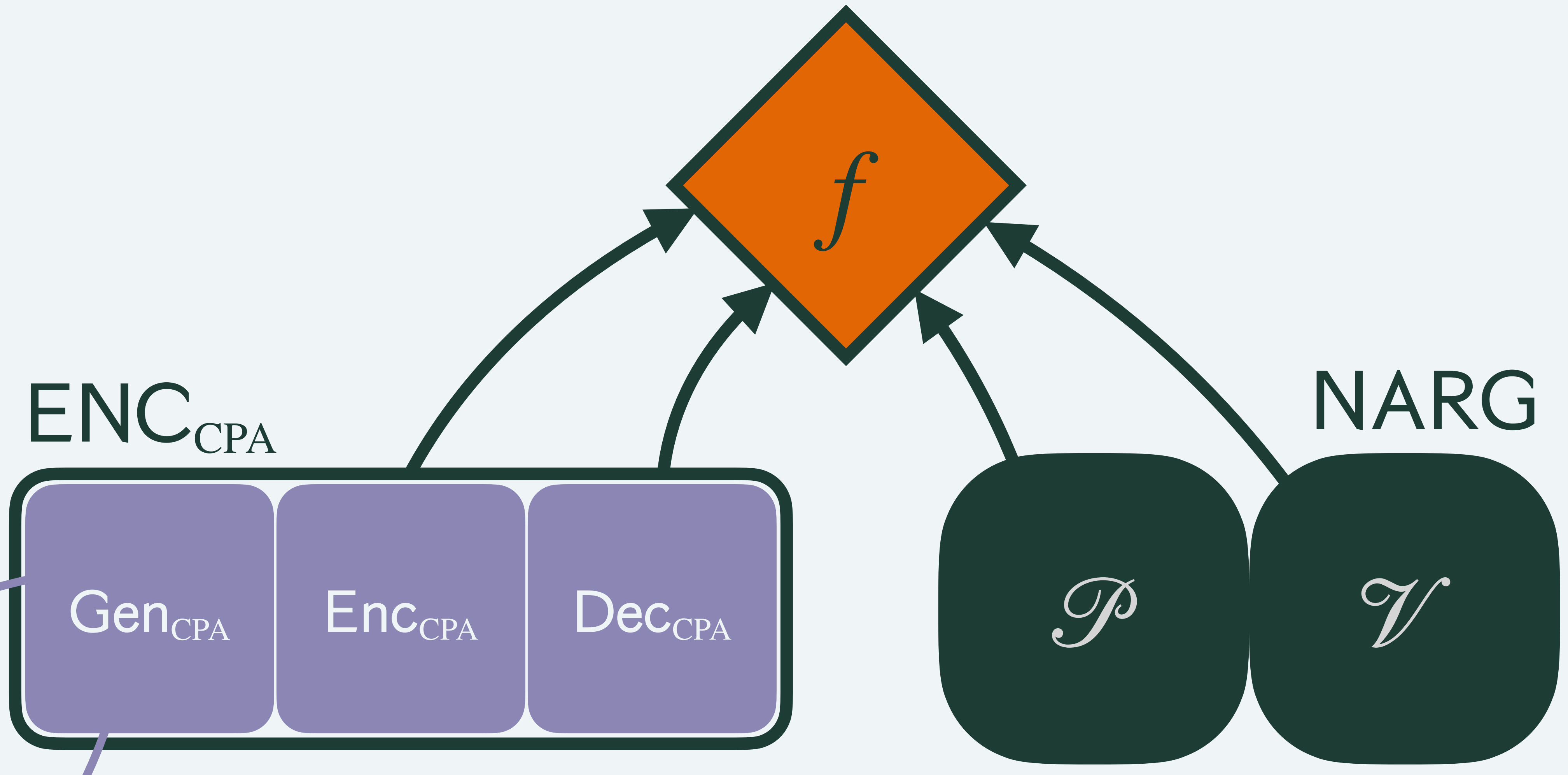

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<u>$\mathsf{Enc}^f(\mathsf{pk}, m)$</u>

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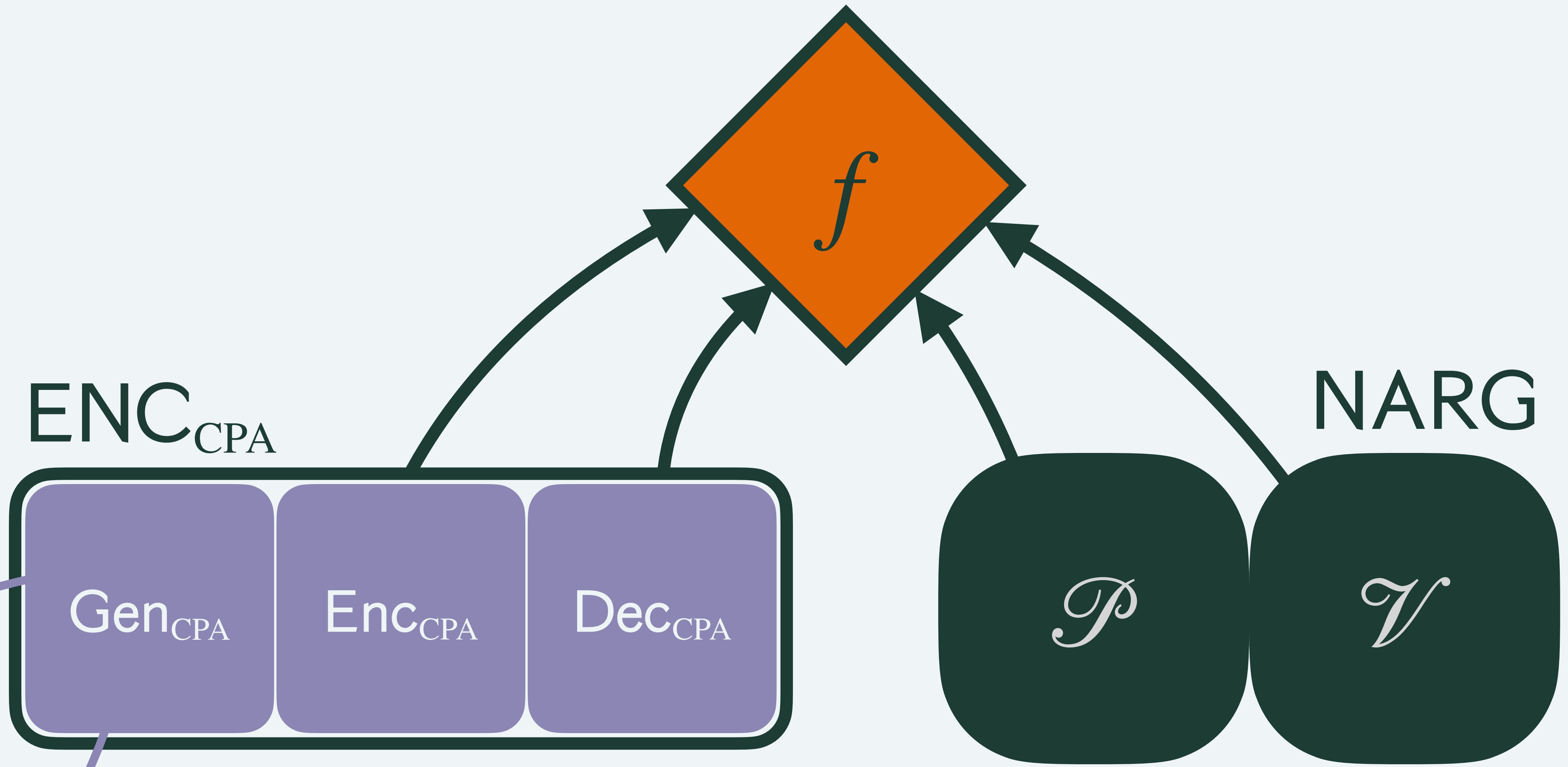
Encryption scheme in the ROM

Construction



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Encryption scheme in the ROM

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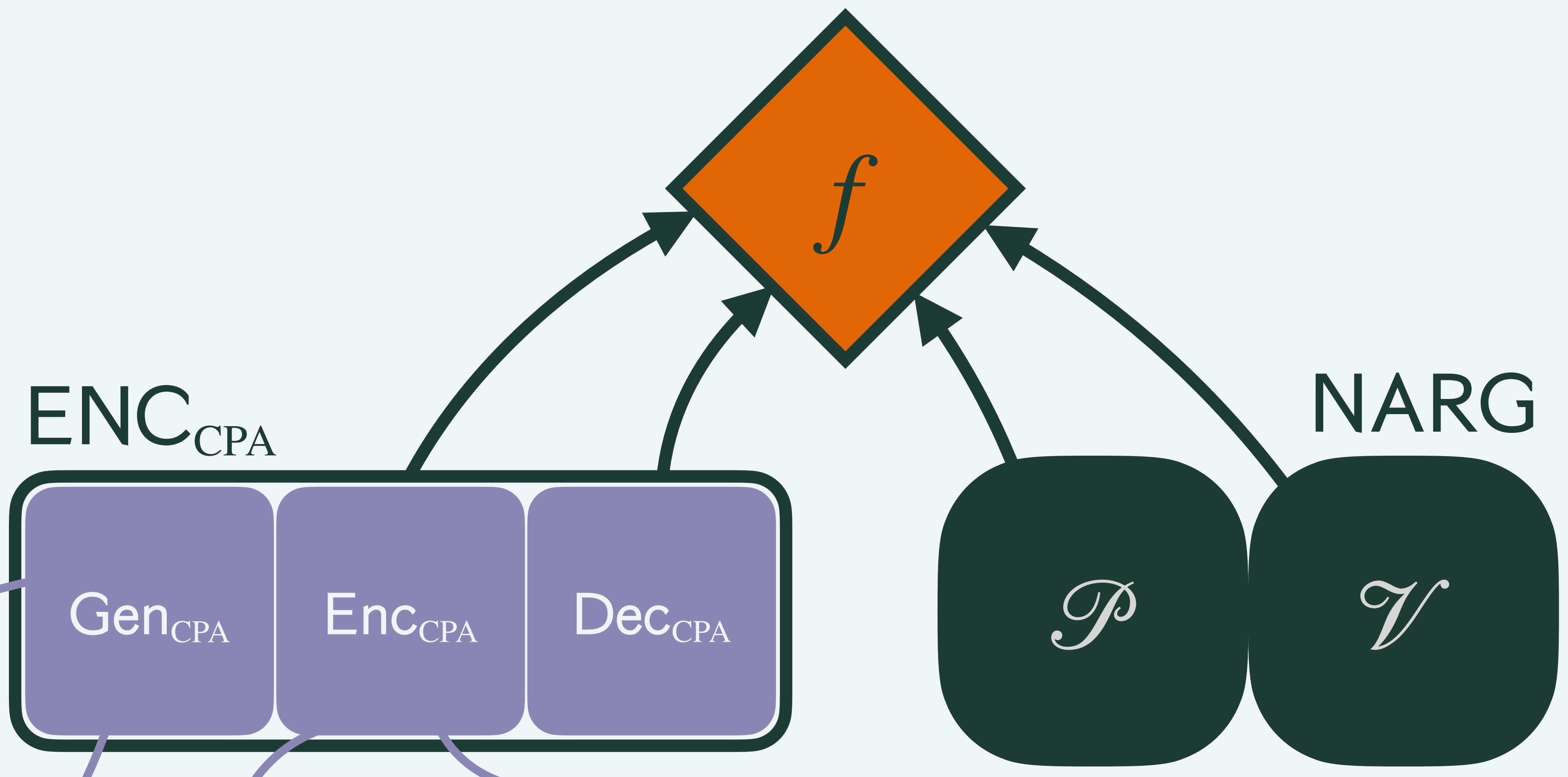

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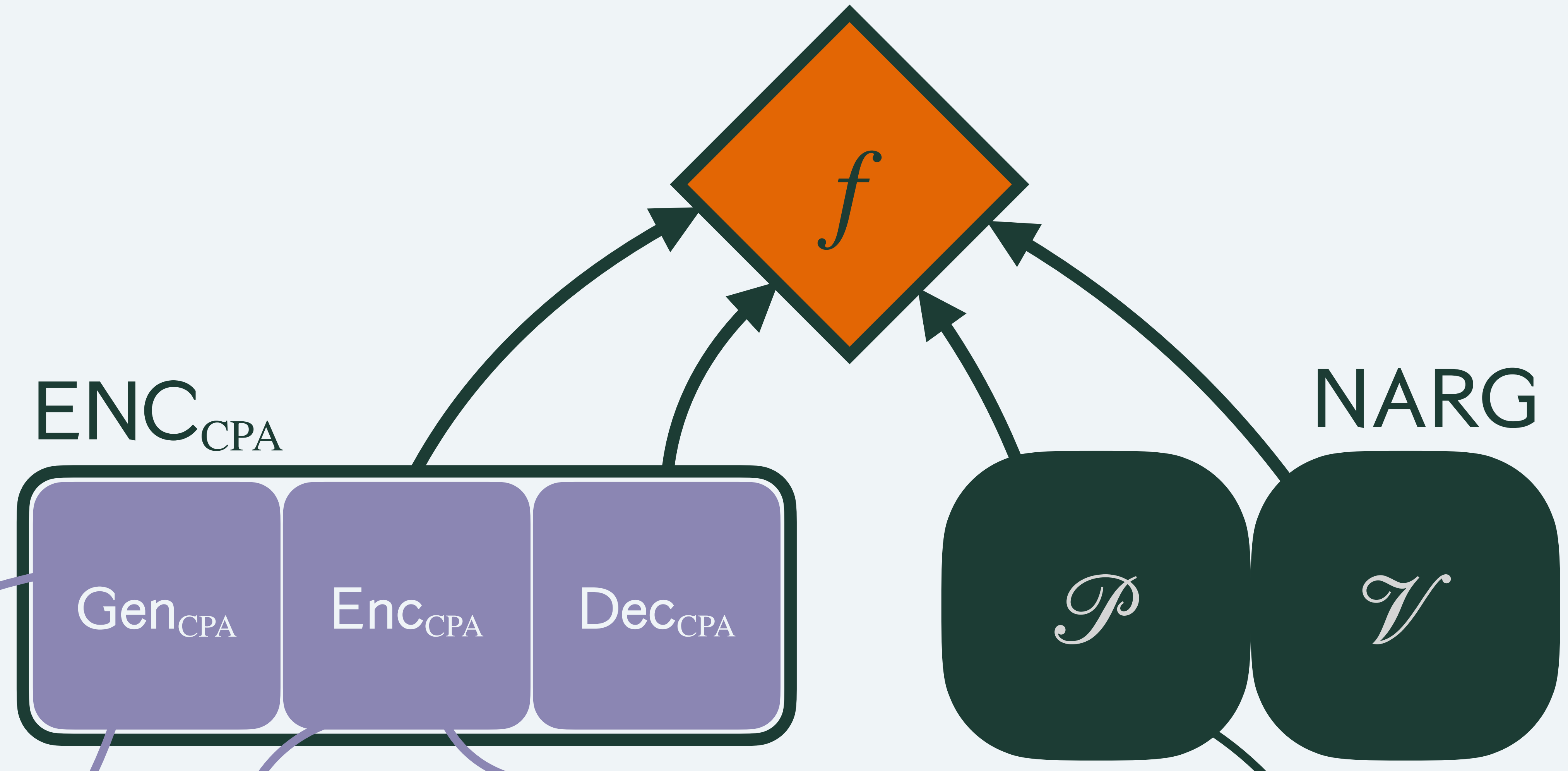

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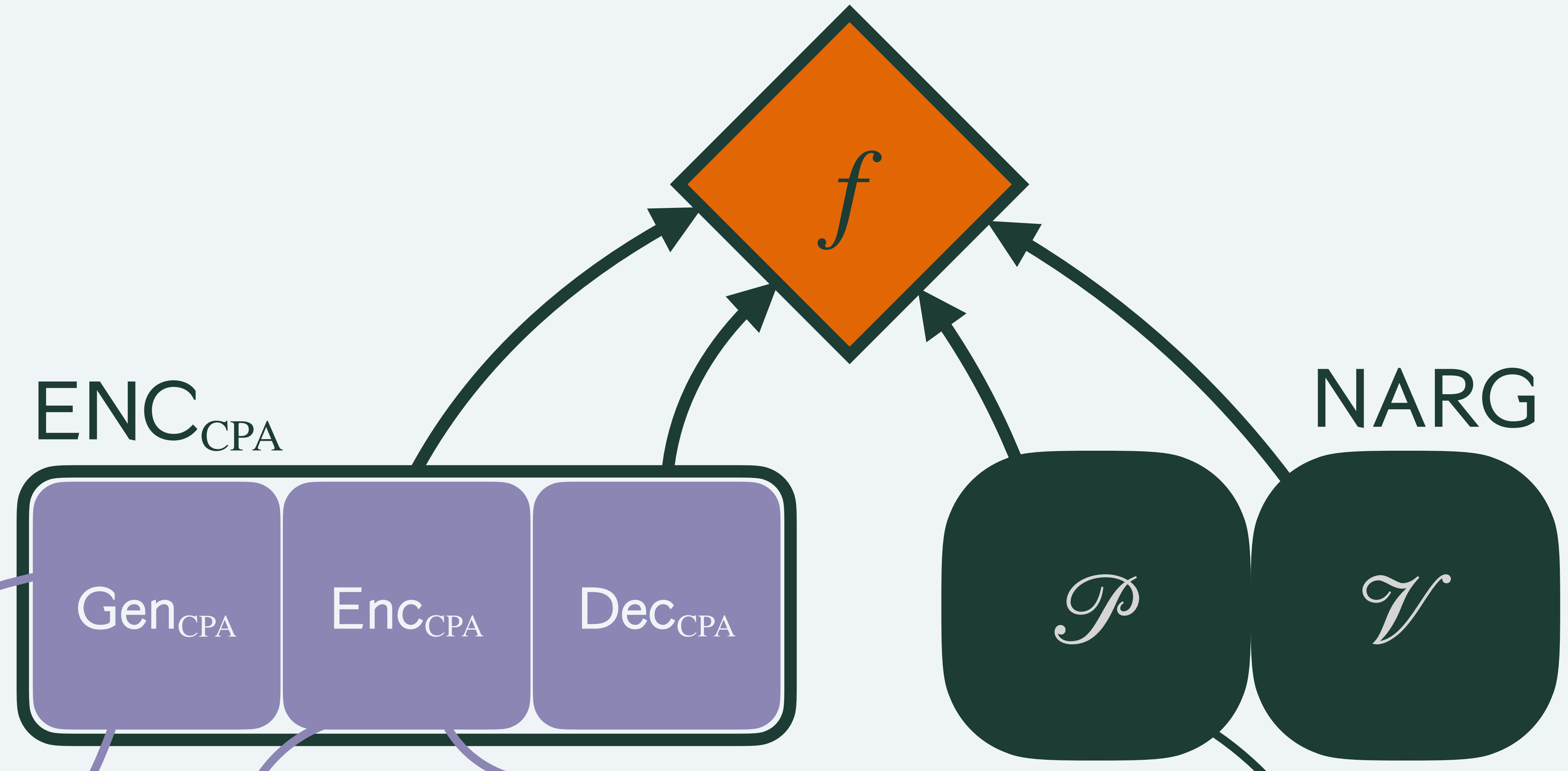

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(c_0, c_1, π)

<u>$\mathsf{Dec}^f(\mathsf{sk}, c)$</u>

$x := (\mathsf{pk}_0, c_0, \mathsf{pk}_1, c_1)$

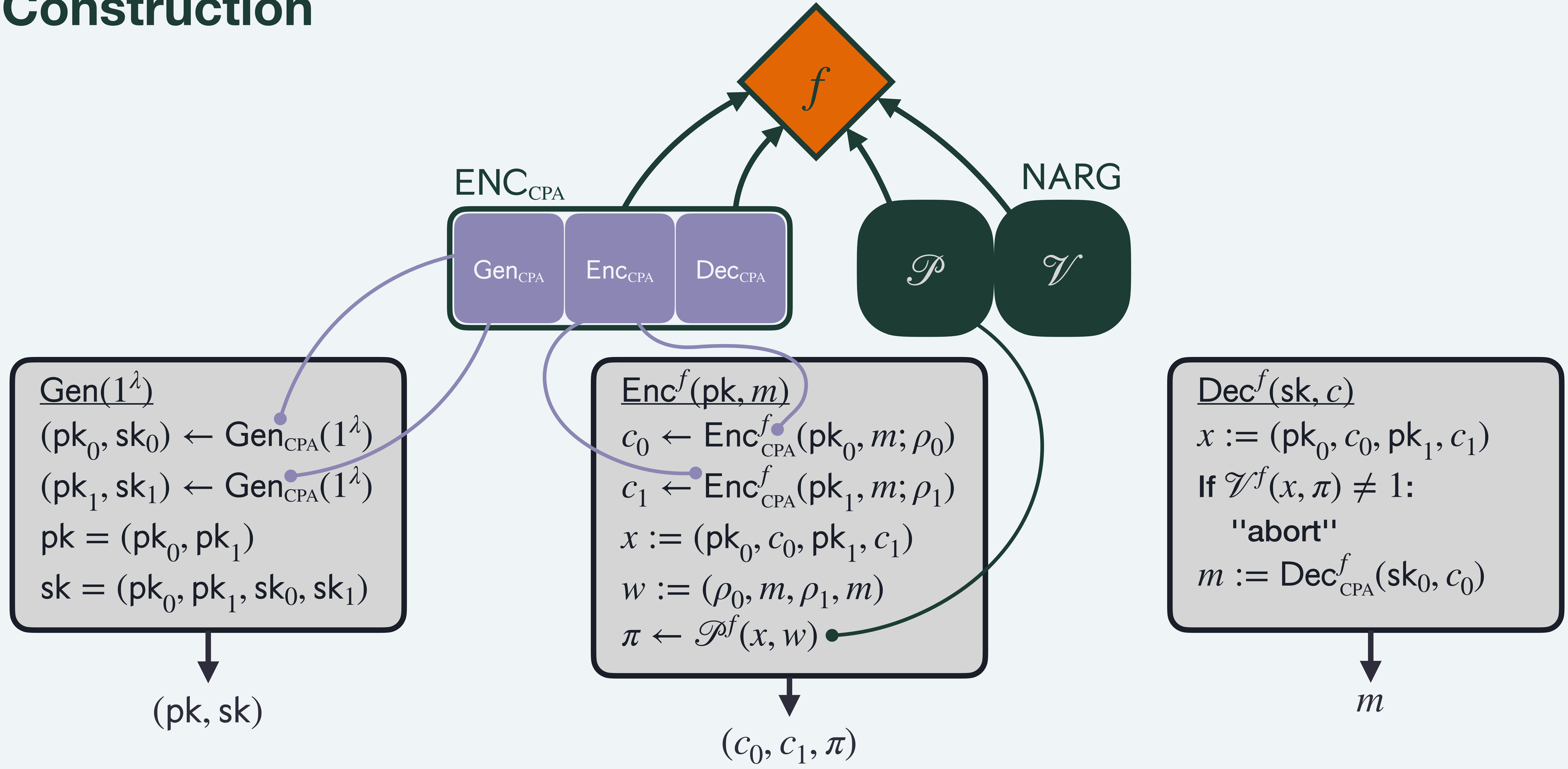
If $\mathscr{V}^f(x, \pi) \neq 1$:

"abort"

$m := \mathsf{Dec}^f_{\text{CPA}}(\mathsf{sk}_0, c_0)$

Encryption scheme in the ROM

Construction



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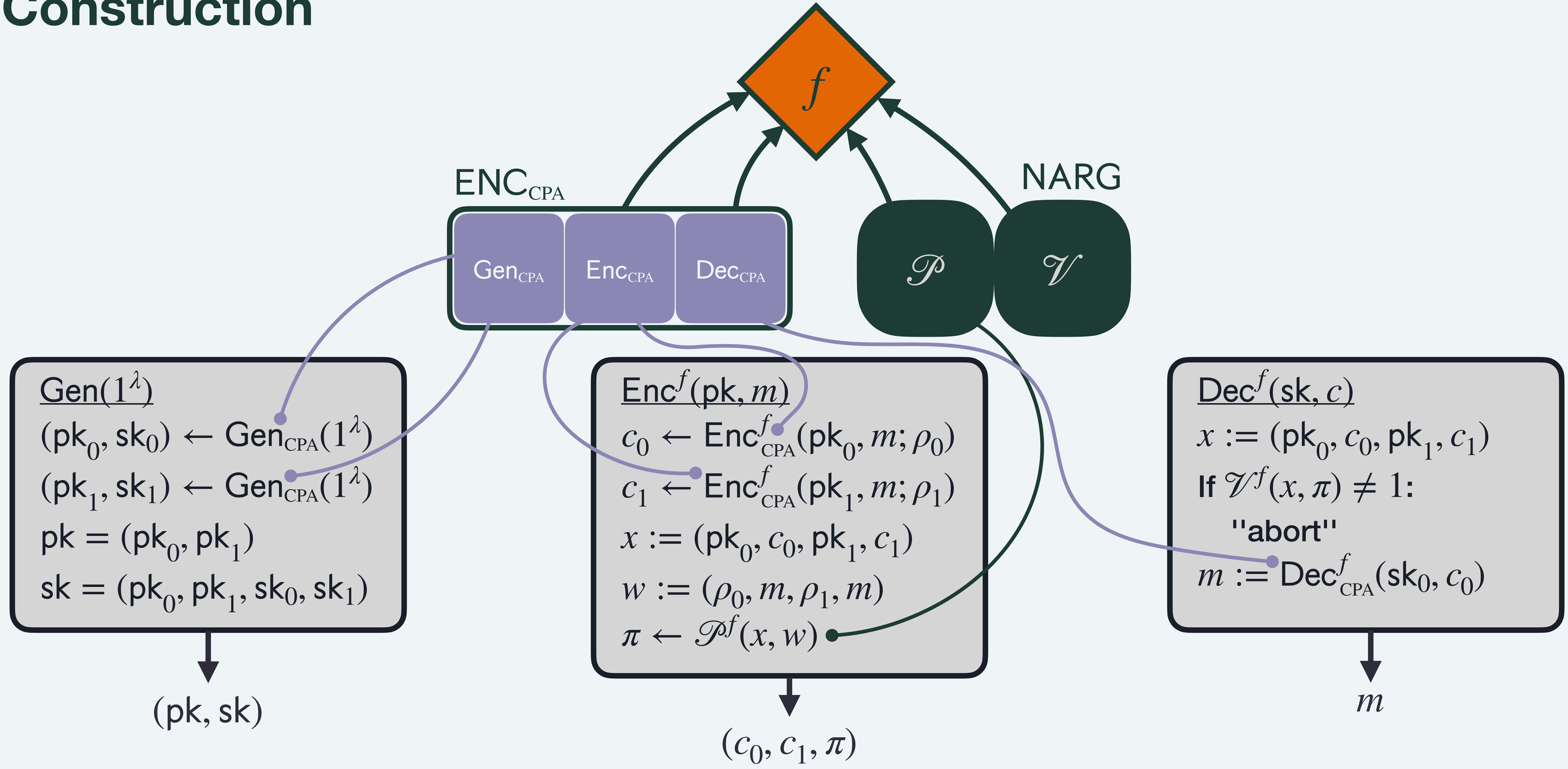

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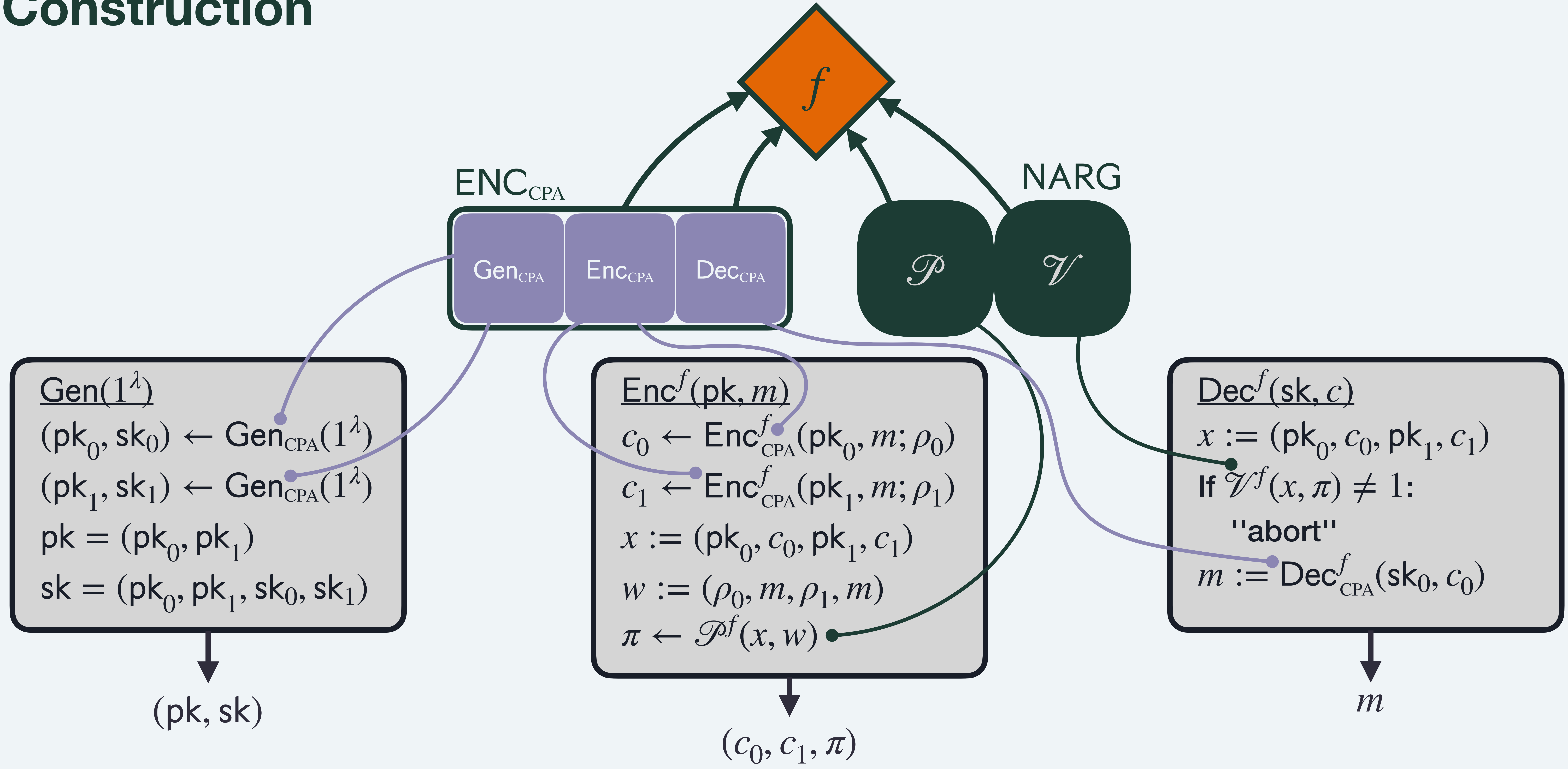

Encryption scheme in the ROM

Theorem 5.4

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Encryption scheme in the ROM

Theorem 5.4

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$$
\begin{aligned}
&\epsilon_{\mathrm{CCA}}(\lambda, \ell, t, t_{\mathrm{DEC}}, s) \leqslant \\
&\qquad z_{\mathrm{ARG}}(\lambda, t + t_{\mathrm{DEC}} \cdot (t_{\mathrm{RO},\mathcal{V}} + t^{\mathrm{CPA}}_{\mathrm{RO},\mathsf{Dec}}) + 2t^{\mathrm{CPA}}_{\mathrm{RO},\mathsf{Enc}}, 1, 2\ell_{\mathsf{key},\mathrm{CPA}} + 2\ell_{c,\mathrm{CPA}}, s + \mathsf{poly}(\lambda, \ell, t, t_{\mathrm{DEC}})) \\
&\qquad + \epsilon^{\mathrm{SIM}}_{\mathrm{ARG}}(\lambda, t + t_{\mathrm{DEC}} \cdot (t_{\mathrm{RO},\mathcal{V}} + 2t^{\mathrm{CPA}}_{\mathrm{RO},\mathsf{Dec}}) + 2t^{\mathrm{CPA}}_{\mathrm{RO},\mathsf{Enc}}, 1, 2\ell_{\mathsf{key},\mathrm{CPA}} + 2\ell_{c,\mathrm{CPA}}, s + \mathsf{poly}(\lambda, \ell, t, t_{\mathrm{DEC}})) \\
&\qquad + \epsilon_{\mathrm{CPA}}(\lambda, \ell, t + t_{\mathrm{DEC}} \cdot (t_{\mathrm{RO},\mathcal{V}} + t^{\mathrm{CPA}}_{\mathrm{RO},\mathsf{Dec}}) + 2t^{\mathrm{CPA}}_{\mathrm{RO},\mathsf{Enc}} + t_{\mathrm{RO},\mathcal{S}}, s + \mathsf{poly}(\lambda, \ell, t, t_{\mathrm{DEC}})) \quad .
\end{aligned}
$$

Thank you

Questions