EFFICIENT ADAPTIVELY SECURE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

Chaya Ganesh	Aarhus
Yashvanth Kondi	Northeastern
Arpita Patra	Indian Inst. of Science
Pratik Sarkar	

OUR RESULTS

- We start from [Jawurek-Kerschbaum-Orlandi13] ZK protocol: **improve rounds** and upgrade to **adaptive security** (without erasures) at essentially **zero overhead**
- This gives us the first **practical adaptively secure ZK protocol**

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

$x \quad f_x$

P ***V***

w

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x $f_x(w)=1$ if $x \in L$

P

w

V

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x $\quad f_x(w)=1$ if $x \in L$

P $\qquad\qquad\qquad\qquad$ ***V***

w

$\longrightarrow$

$\longleftarrow$

$\longrightarrow$

$\longleftarrow$

$\longrightarrow$ $\qquad$ accept/reject

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Sim$_P$ $\qquad\qquad$ V

accept/reject

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Sim$_{\boldsymbol{P}}$ $\boldsymbol{V}$

accept/reject

$\{\langle \boldsymbol{P}(w), \boldsymbol{V} \rangle(x)\}_{x \in L} \approx_c \{\langle \mathrm{Sim}_{\boldsymbol{P}} \rangle(x)\}_{x \in L}$

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P Sim_V

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$f_x(w)=1$

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FROM GARBLED CIRCUITS

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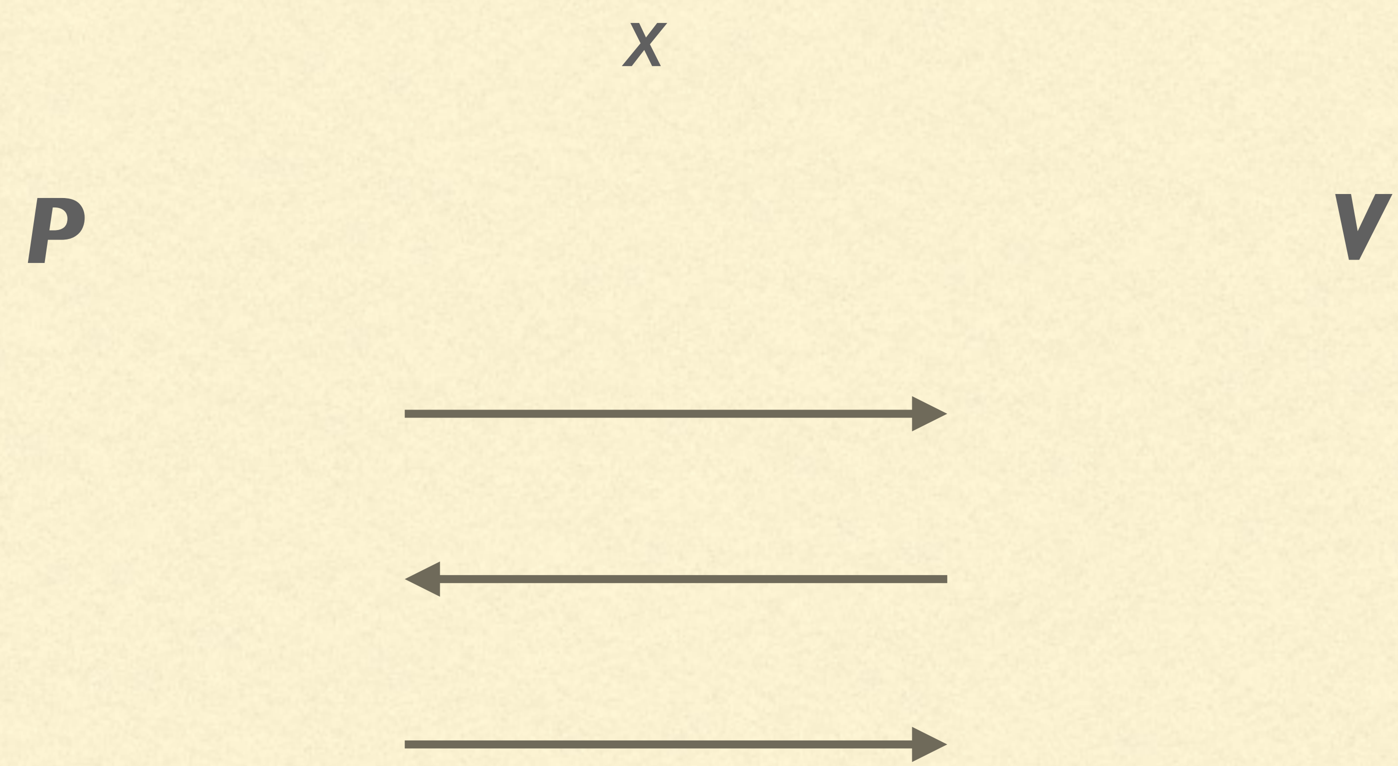
- Previous definition models static corruptions
- Adaptive corruptions closer to real world; systems ‘hacked’ dynamically
- Adaptive ZK composed to build larger protocols resilient to dynamic corruptions
- Adaptive security without erasures: Every simulated transcript has to be completely ‘explainable’ wrt any witness

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x

P V

ADAPTIVE ZERO-KNOWLEDGE
FROM GARBLED CIRCUITS



ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x

P $\qquad\qquad\qquad\qquad$ V

P corrupted here

ADAPTIVE ZERO-KNOWLEDGE
FROM GARBLED CIRCUITS

x

Sim_P

V

P corrupted here

ADAPTIVE ZERO-KNOWLEDGE
FROM GARBLED CIRCUITS

x

$\mathrm{Sim}_{\boldsymbol{P}}$ w $\qquad\qquad$ $\boldsymbol{V}$

$\longrightarrow$

$\longleftarrow$

$\longrightarrow$

P corrupted here

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x

$\mathrm{Sim}_{\boldsymbol{P}}(w)$: $r_{\boldsymbol{P}}$

$\boldsymbol{V}$

P corrupted here

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x

$\boldsymbol{P}\,(w\,;\,r_P)$ $\boldsymbol{V}$

$\longrightarrow$

$\longleftarrow$

$\longrightarrow$

P corrupted here

ADAPTIVE ZERO-KNOWLEDGE
FROM GARBLED CIRCUITS

x

$\boldsymbol{P}\ (w\ ;\ r_P)$ $\qquad\qquad\qquad\qquad$ $\boldsymbol{V}$

$\longrightarrow$

$\longleftarrow$

$\longrightarrow$

P corrupted here

r_P explains messages wrt w

ADAPTIVE ZERO-KNOWLEDGE
FROM GARBLED CIRCUITS

x

$\boldsymbol{P}$ (w ; r_P)

$\boldsymbol{V}$

$\boldsymbol{P}$ corrupted here

r_P explains messages wrt w

Execution finishes

accept/reject

ADAPTIVE ZERO-KNOWLEDGE
FROM GARBLED CIRCUITS

x

P (w ; r_P)

V

P corrupted here

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V corrupted now

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x

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Sim$_{\boldsymbol{V}}$

$\boldsymbol{P}$ corrupted here

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accept/reject

Execution finishes

$\boldsymbol{V}$ corrupted now

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x

$\boldsymbol{P}\,(w\,;\,r_P)$

Sim$_{\boldsymbol{V}}$ r_V

$\boldsymbol{P}$ corrupted here

r_P explains messages wrt w

accept/reject

Execution finishes

$\boldsymbol{V}$ corrupted now

ADAPTIVE ZERO-KNOWLEDGE FROM GARBLED CIRCUITS

x

$\boldsymbol{P}\,(w\,;\,r_P)$

$\boldsymbol{V}\,(\,r_V\,)$

P corrupted here

r_P explains messages wrt w

accept/reject

Execution finishes

V corrupted now

ADAPTIVE ZERO-KNOWLEDGE
FROM GARBLED CIRCUITS

x

P (w ; r_P)

V (r_V)

r_V explains messages and output

P corrupted here

r_P explains messages wrt w

Execution finishes

V corrupted now

accept/reject

ADAPTIVE ZERO-KNOWLEDGE: DESIDERATA

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- Most useful when **universally composable (UC)**

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- Most useful when **universally composable (UC)**
- Asymptotic: **constant rounds**, **linear communication**
- Towards **concrete efficiency**
- Assumptions: standard public-key (**DDH**, **LWE**, **LPN**, **QR**)

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- [Hazay-Venkitasubramaniam 16] Adaptive ZK from OWFs, Non-constant rounds, quasi-linear communication, standalone security
- [Jawurek-Kerschbaum-Orlandi 13] ZK from GCs: Static security, **upgraded** to adaptive with greater efficiency **in this work**

TECHNICAL CONTRIBUTIONS

Improving efficiency

Improving security

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OT+1 rounds, UC ZK, linear comm, GRO model

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Improving security	Adaptive UC ZK from Recv-Equiv-OT

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Improving efficiency	OT+1 rounds, UC ZK, linear comm, GRO model
Improving security	Adaptive UC ZK from Recv-Equiv-OT

- Any OT can be transformed to Recv-Equiv OT [Canetti-Lindell-Ostrovsky-Sahai 02]
- Two-round UC static ZK from garbled circuits with CRS

BUILDING BLOCK: GARBLED CIRCUITS

- Introduced by [Yao 86], formalization of [Bellare-Hoang-Rogaway 12]

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1^k

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1^k

f

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f

x

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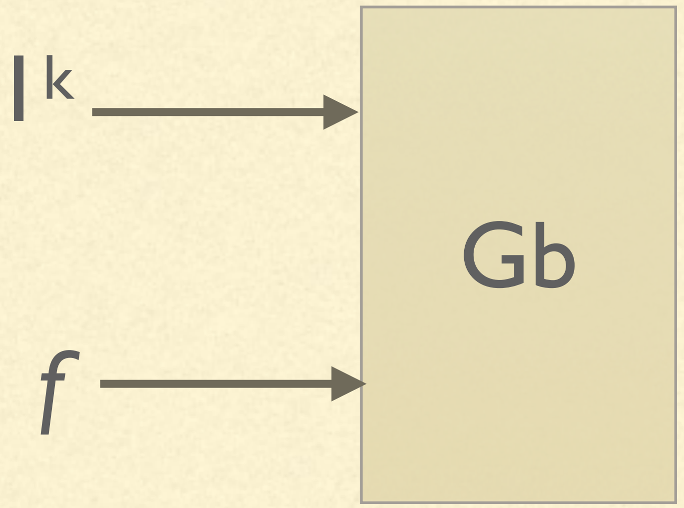

x

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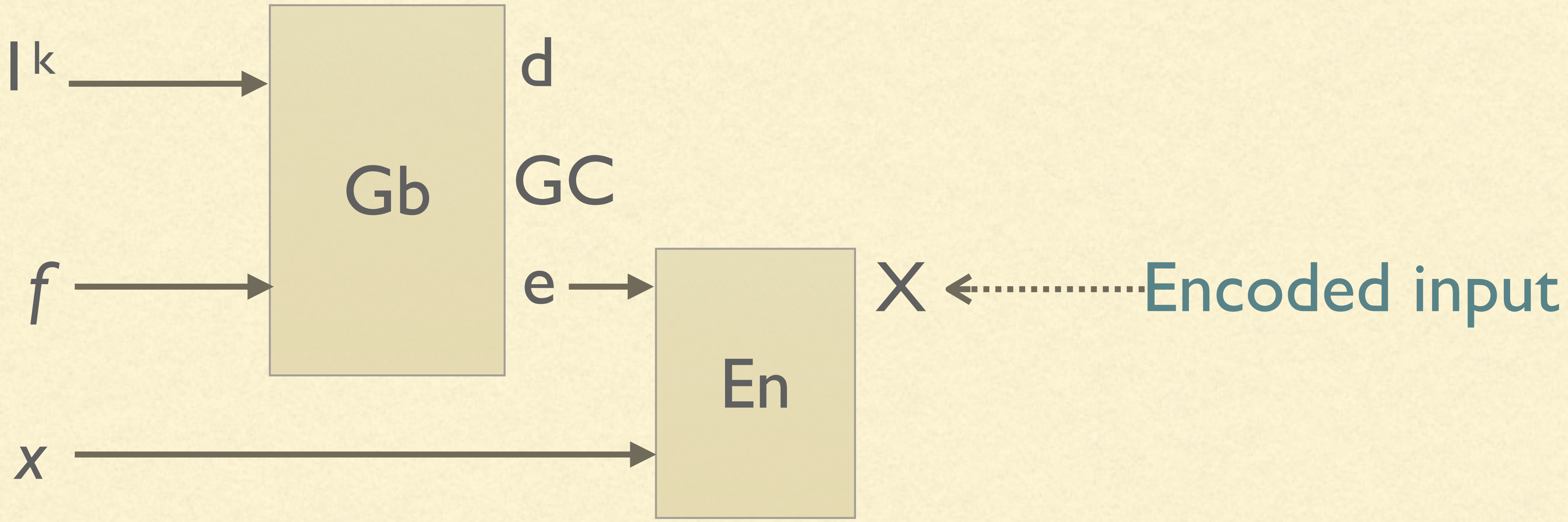

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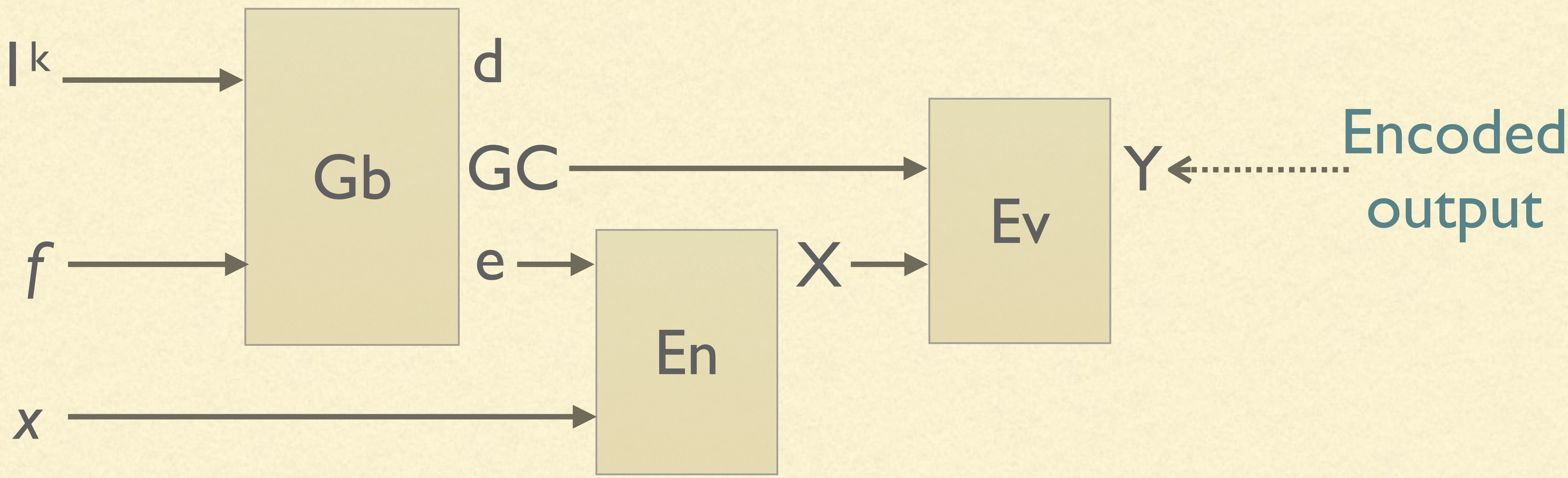

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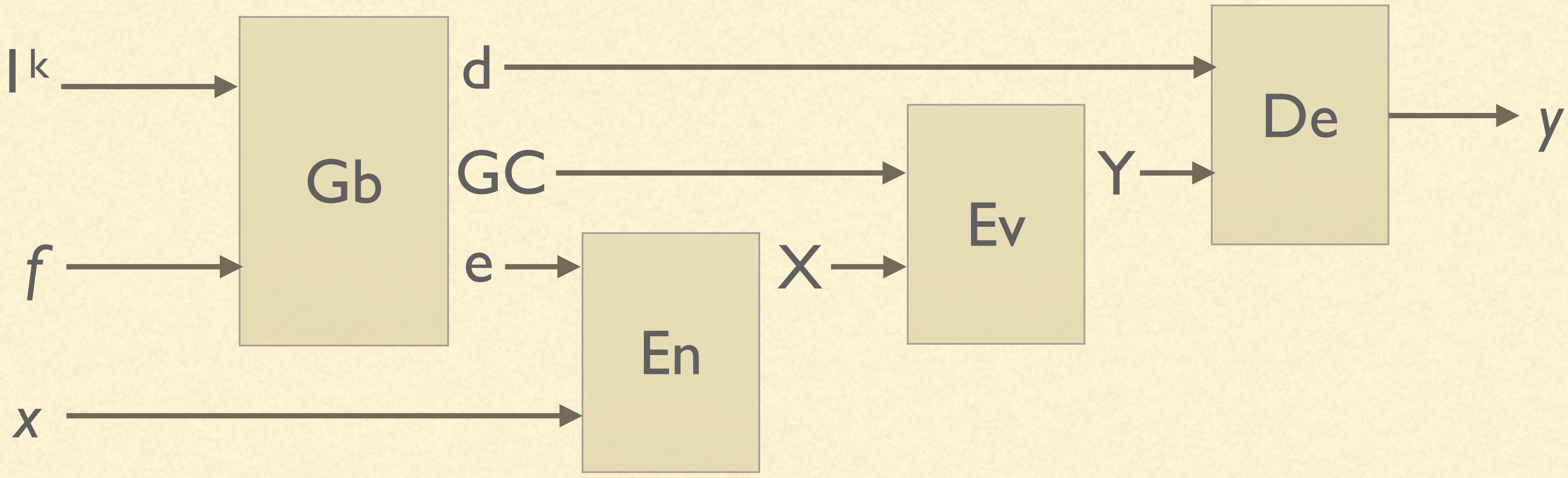

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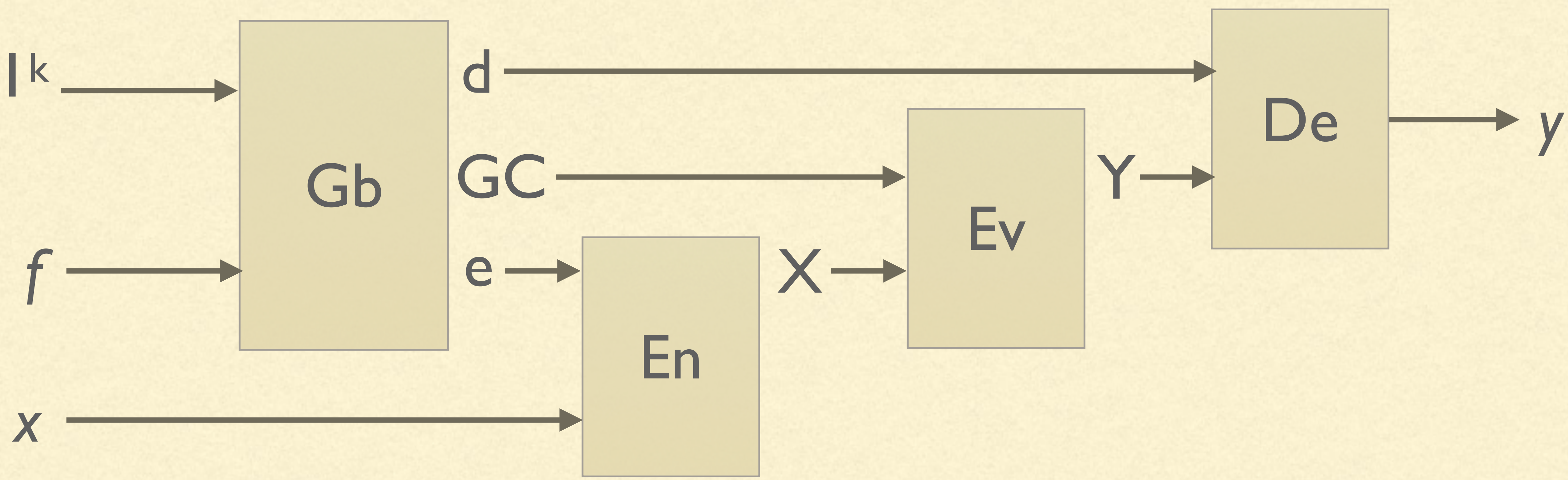

- Correctness: *f(x) = y*

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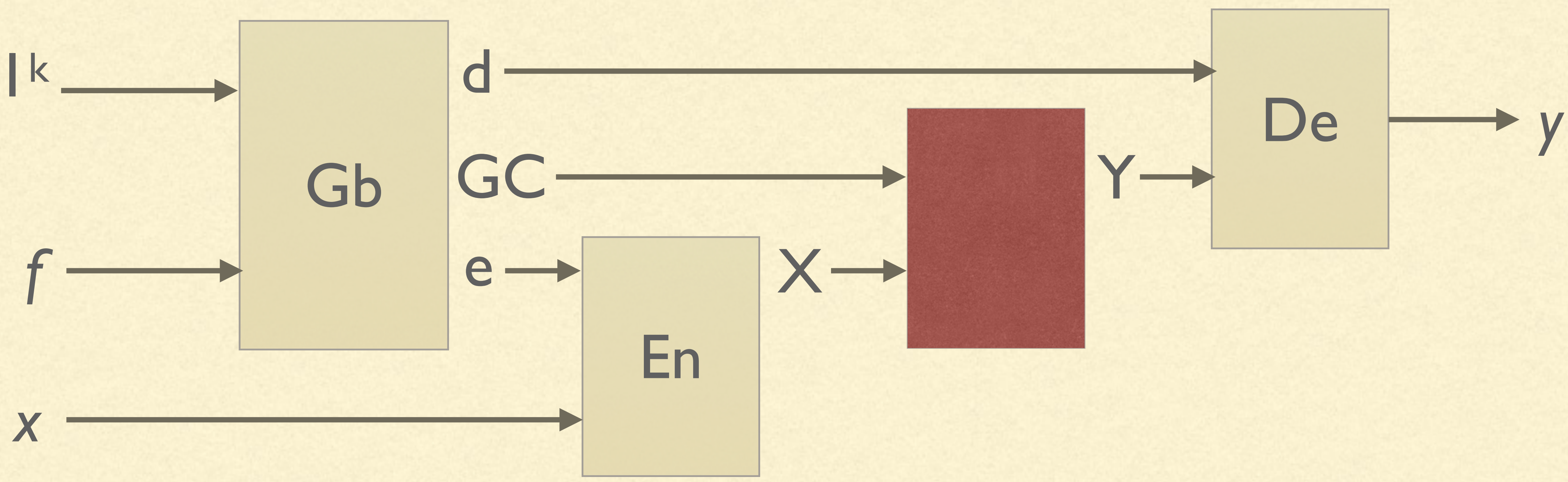

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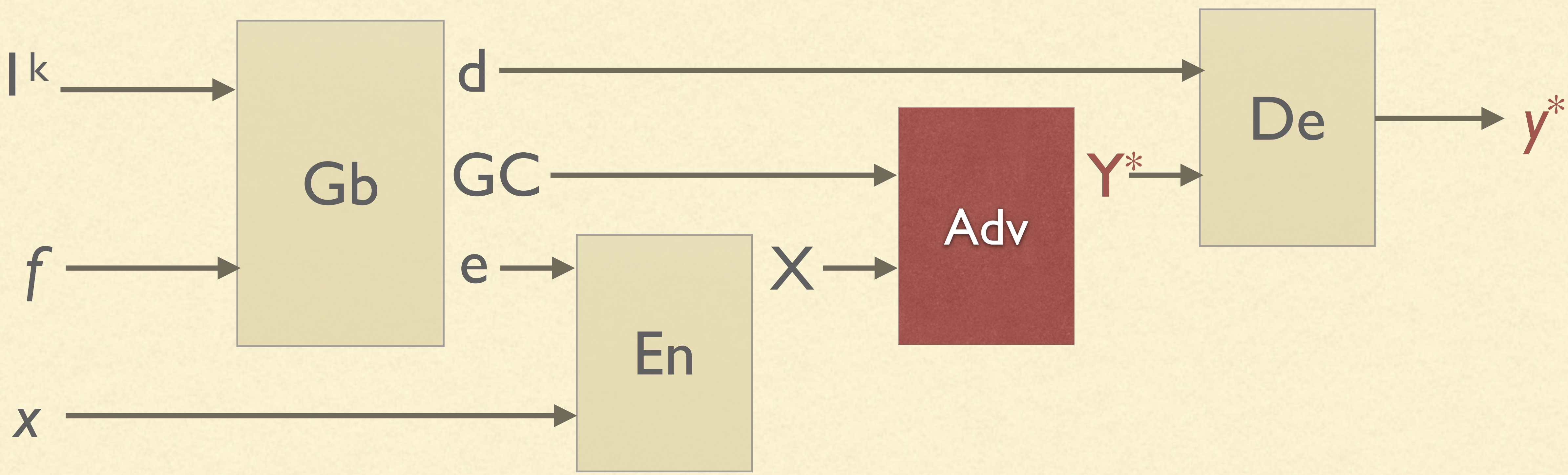

- Authenticity: $Y^* = \mathrm{Ev}(GC, X)$

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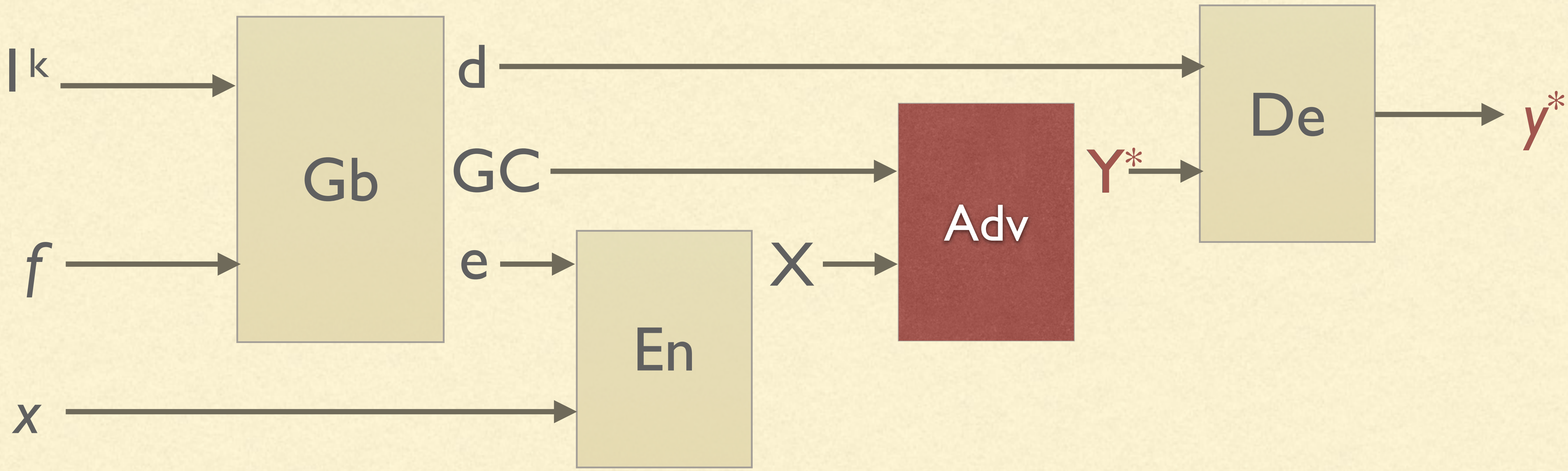

- Authenticity: Y* = Ev(GC, X) … or De fails

BUILDING BLOCK: 1-2 OBLIVIOUS TRANSFER

S

R

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S

m_0

m_1

R

BUILDING BLOCK: 1-2 OBLIVIOUS TRANSFER

S

m_0

m_1

R

b

BUILDING BLOCK: 1-2 OBLIVIOUS TRANSFER

S

m_0

m_1

OT

R

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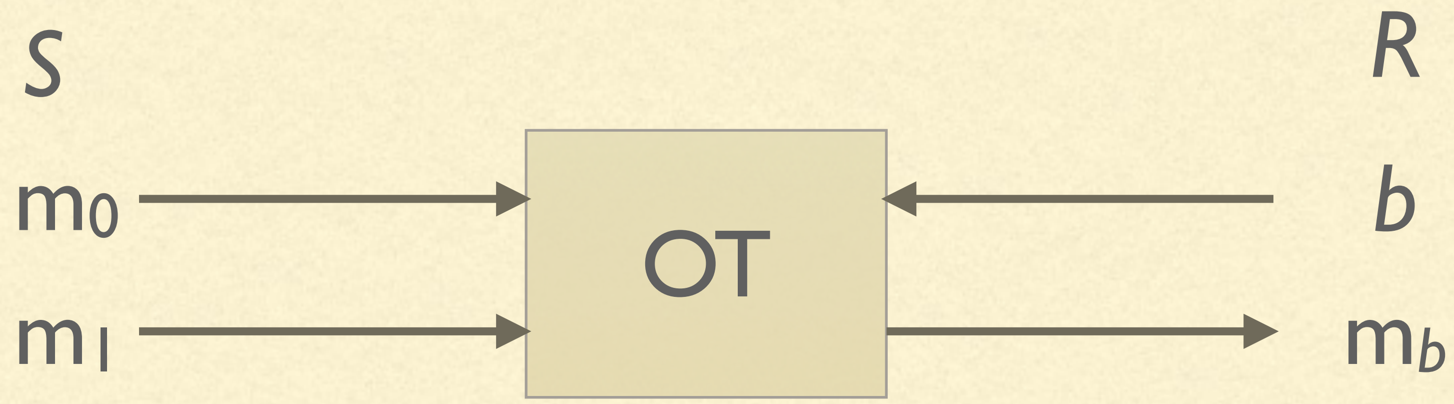
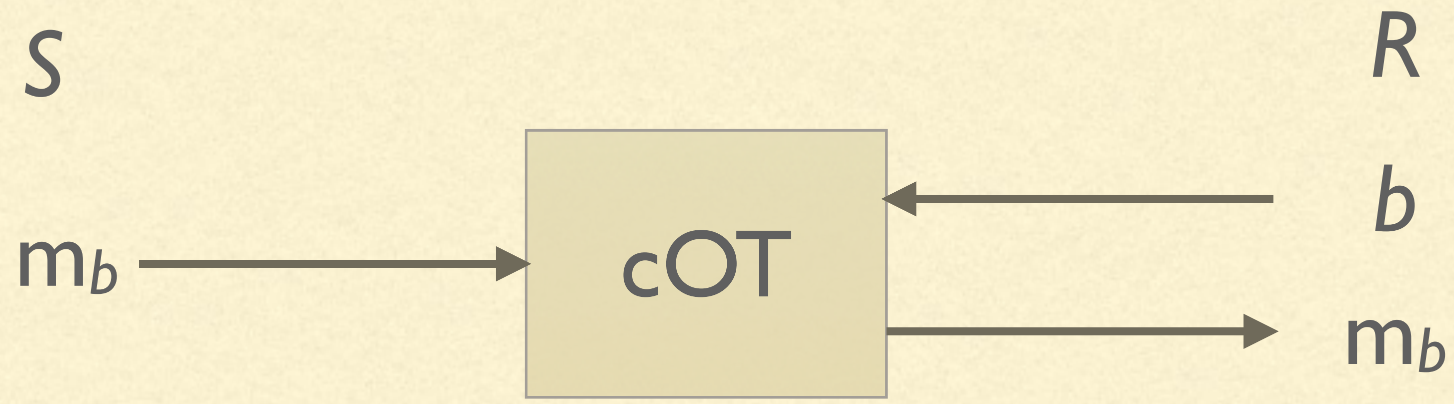


BUILDING BLOCK: COMMITTED OBLIVIOUS TRANSFER

- For this protocol: committed cOT

Receiver's view



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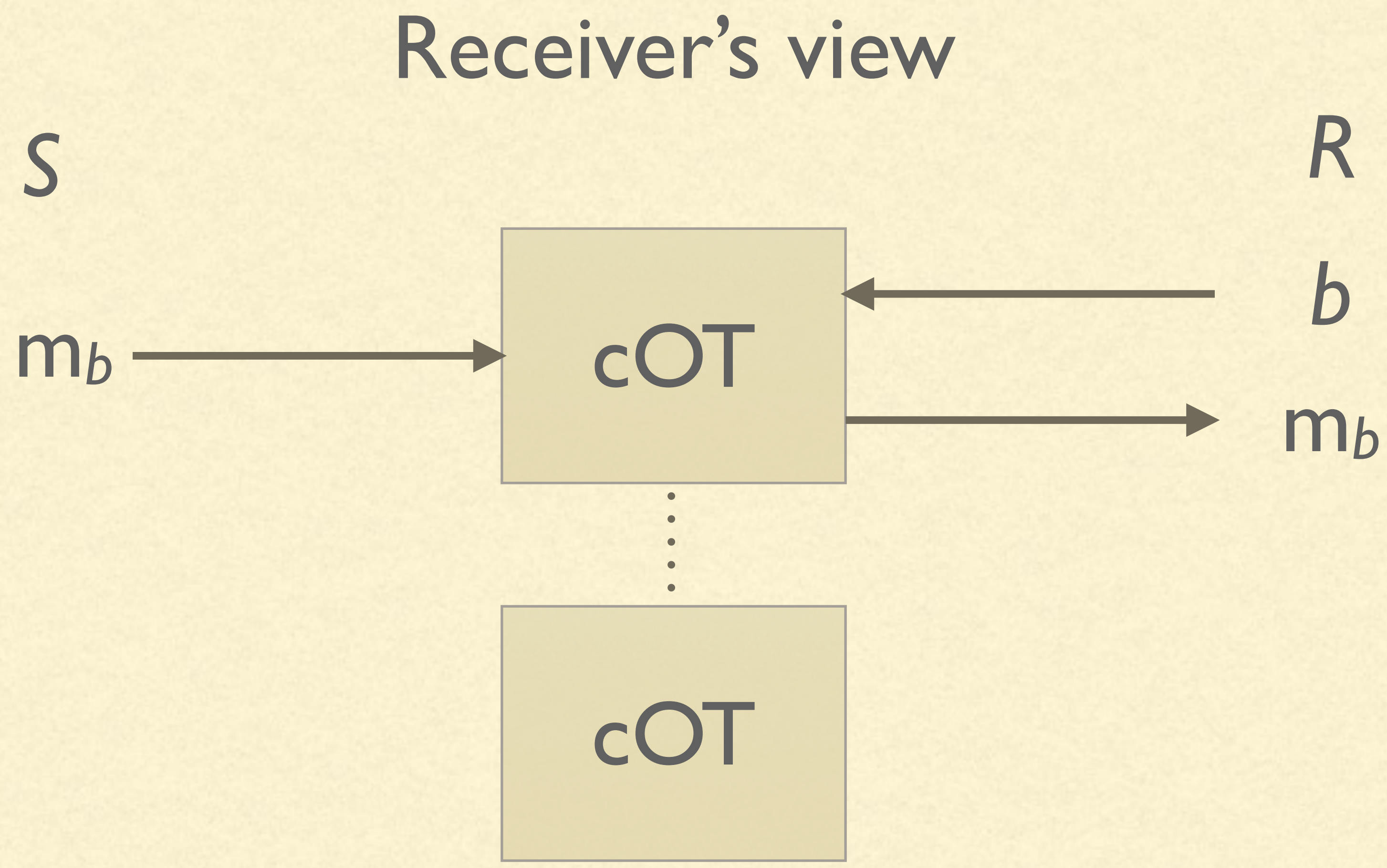

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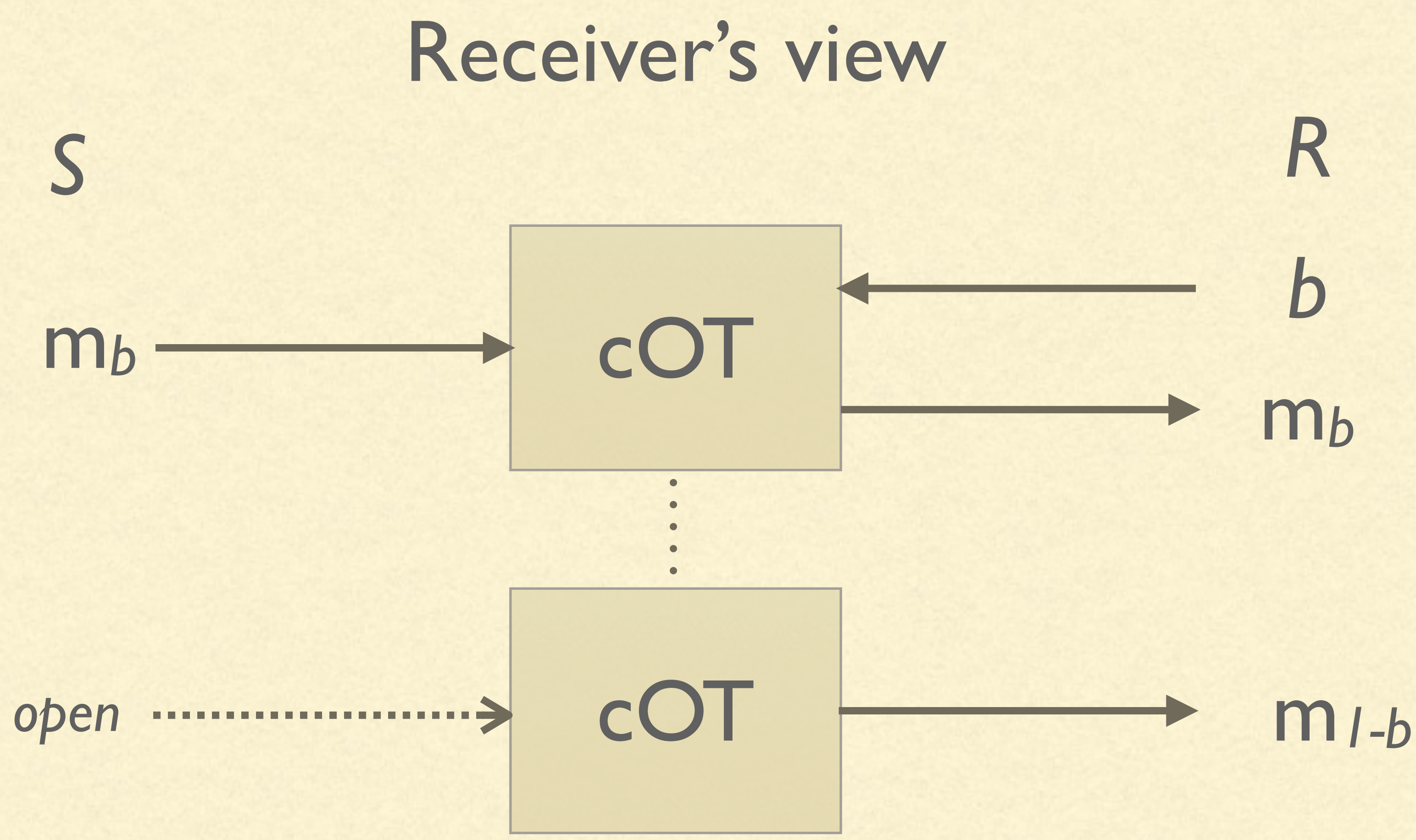

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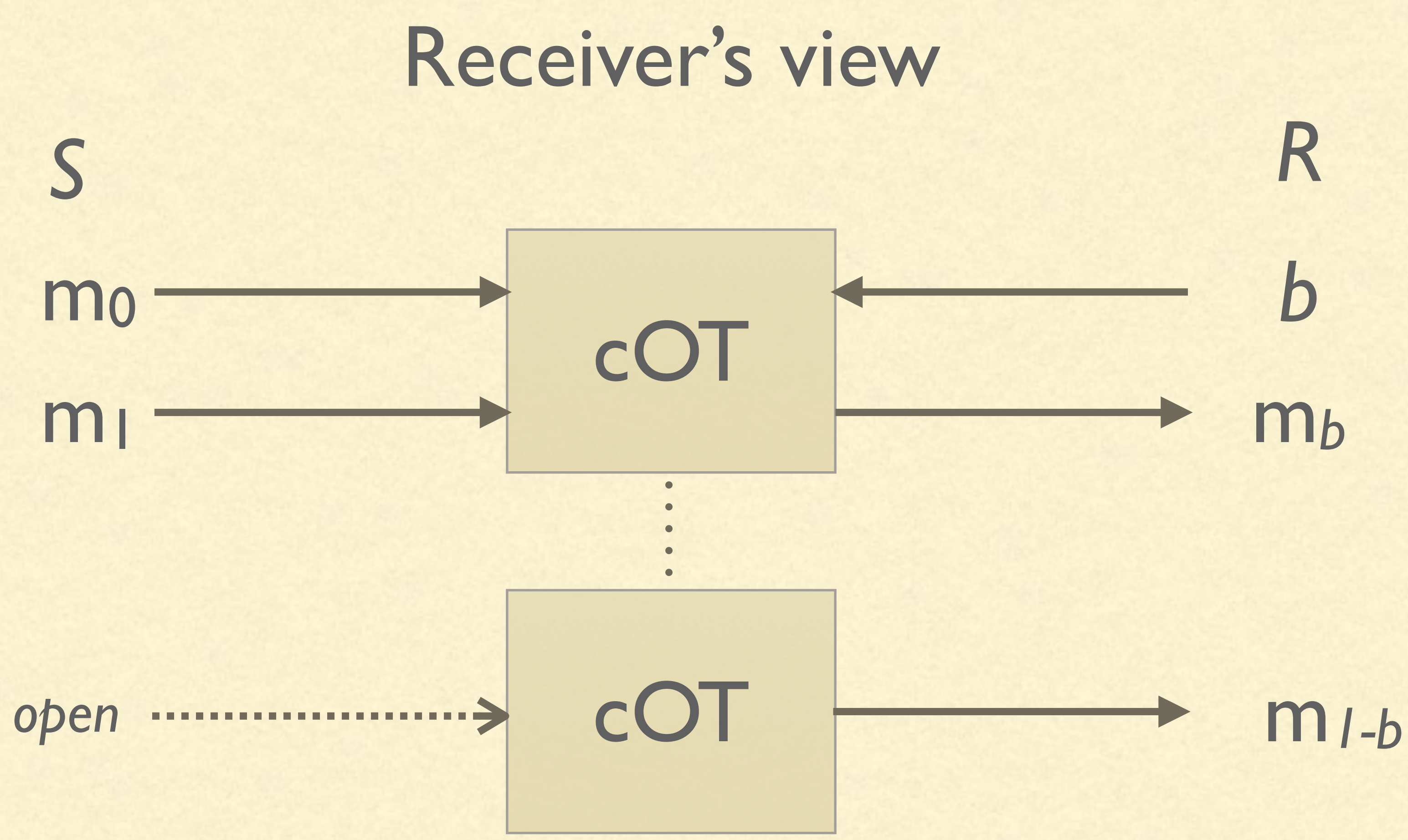

ZERO-KNOWLEDGE FROM GARBLED CIRCUITS [JKO13]

- ‘***P***’ wishes to prove knowledge of witness ‘w’ for NP statement ‘$x \in L$’ to ‘***V***’

P ***V***

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Gb(f_x, 1^k)

w

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- '***P***' wishes to prove knowledge of witness 'w' for NP statement '$x \in L$' to '***V***'

P	***V***
	GC $\longleftarrow \mathrm{Gb}(f_x, 1^k)$
w	

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P ***V***

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w

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w	

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P	***V***
	$GC, e, Z \longleftarrow Gb(f_x, 1^k)$
w	X^0
	e
	X^1

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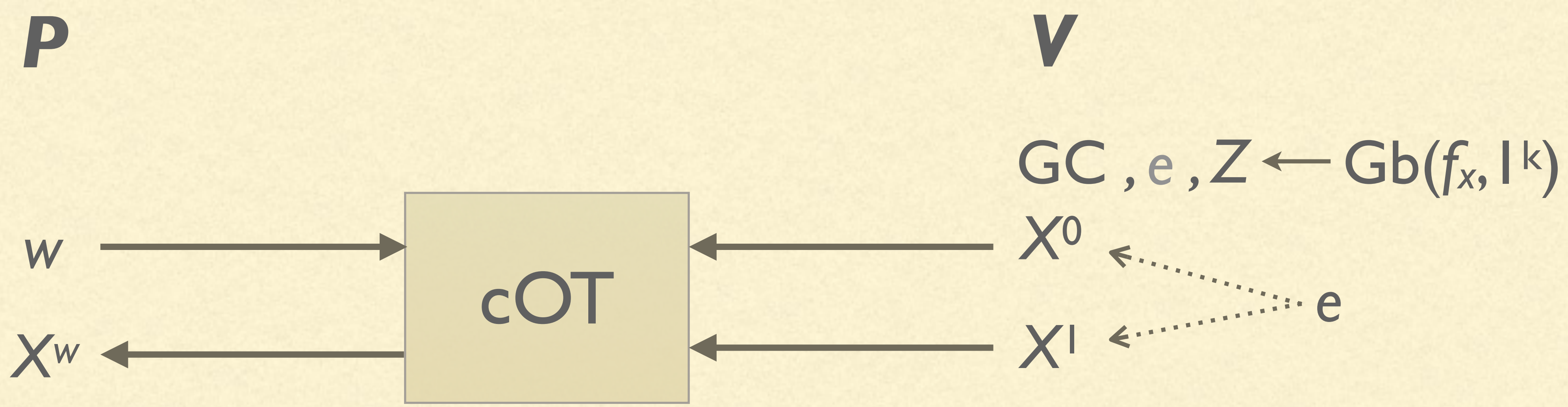

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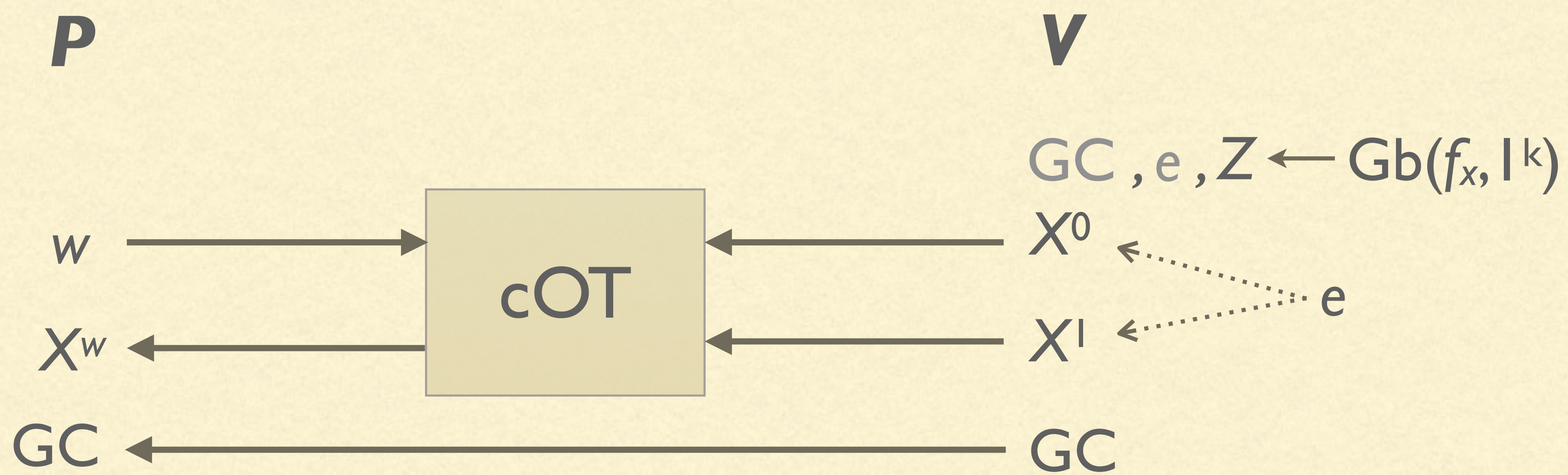

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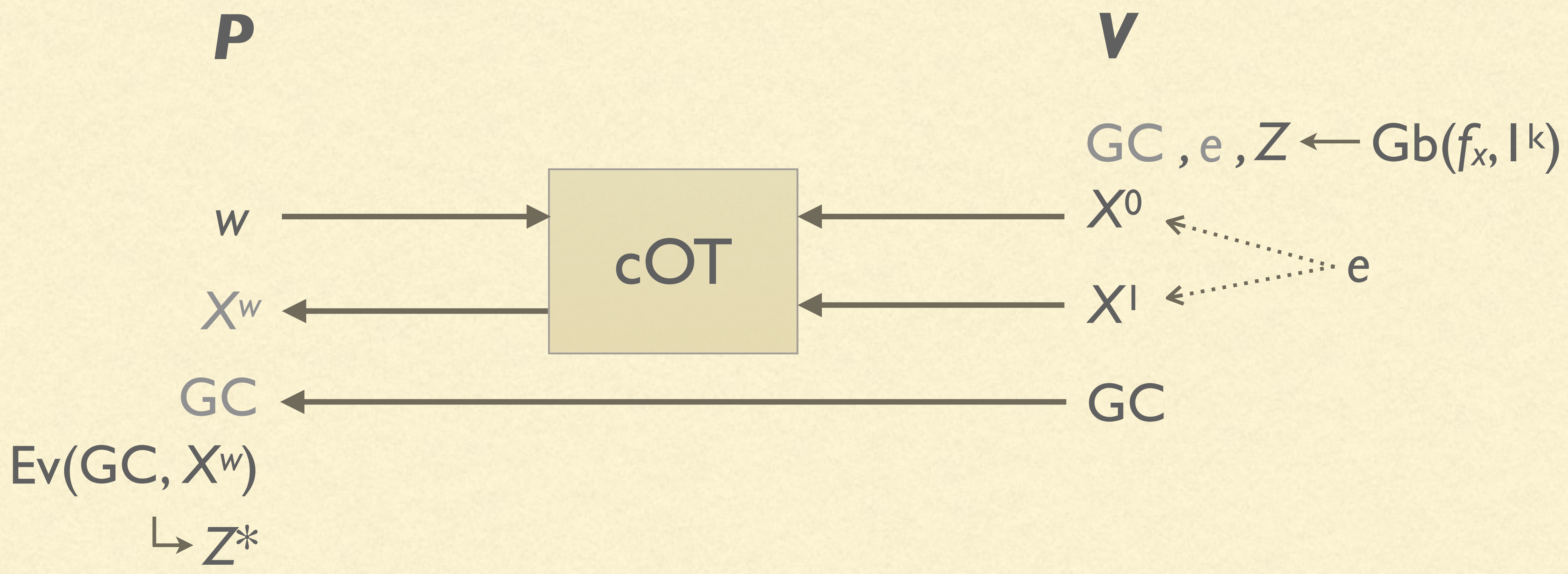

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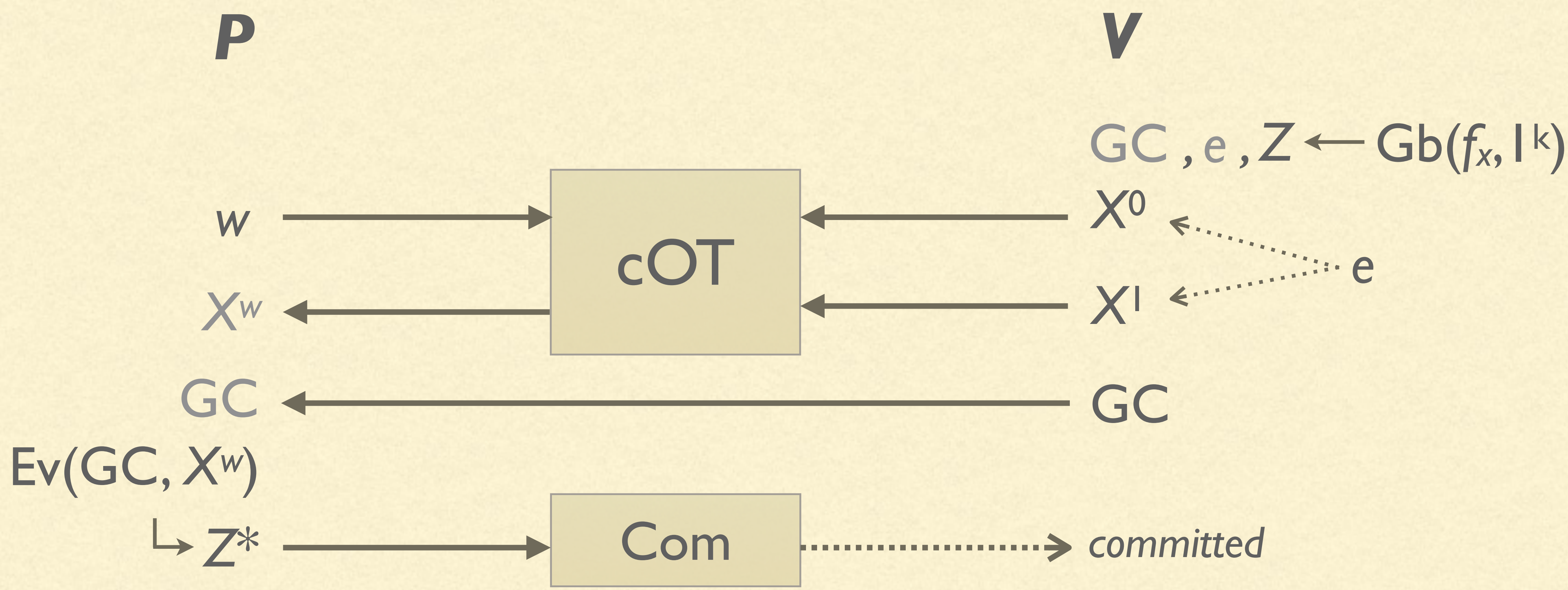

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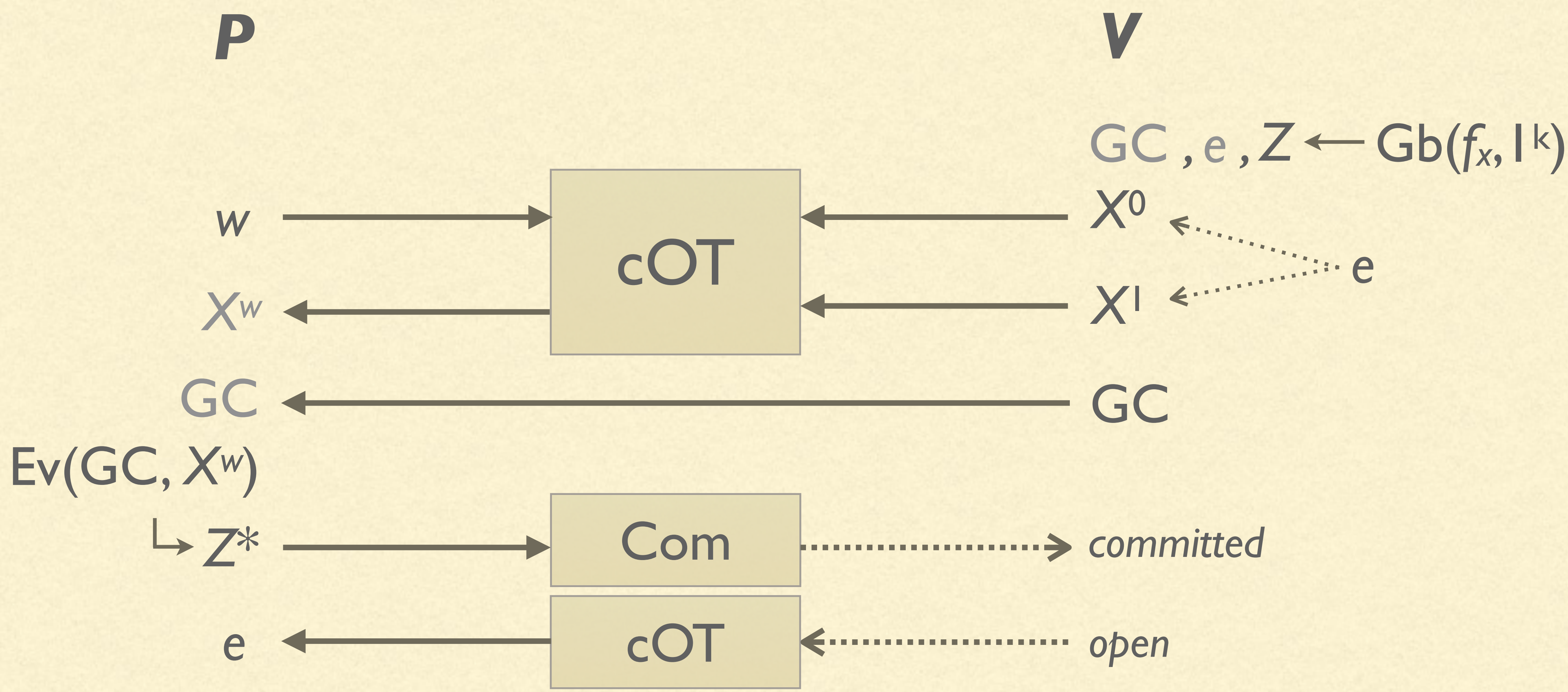

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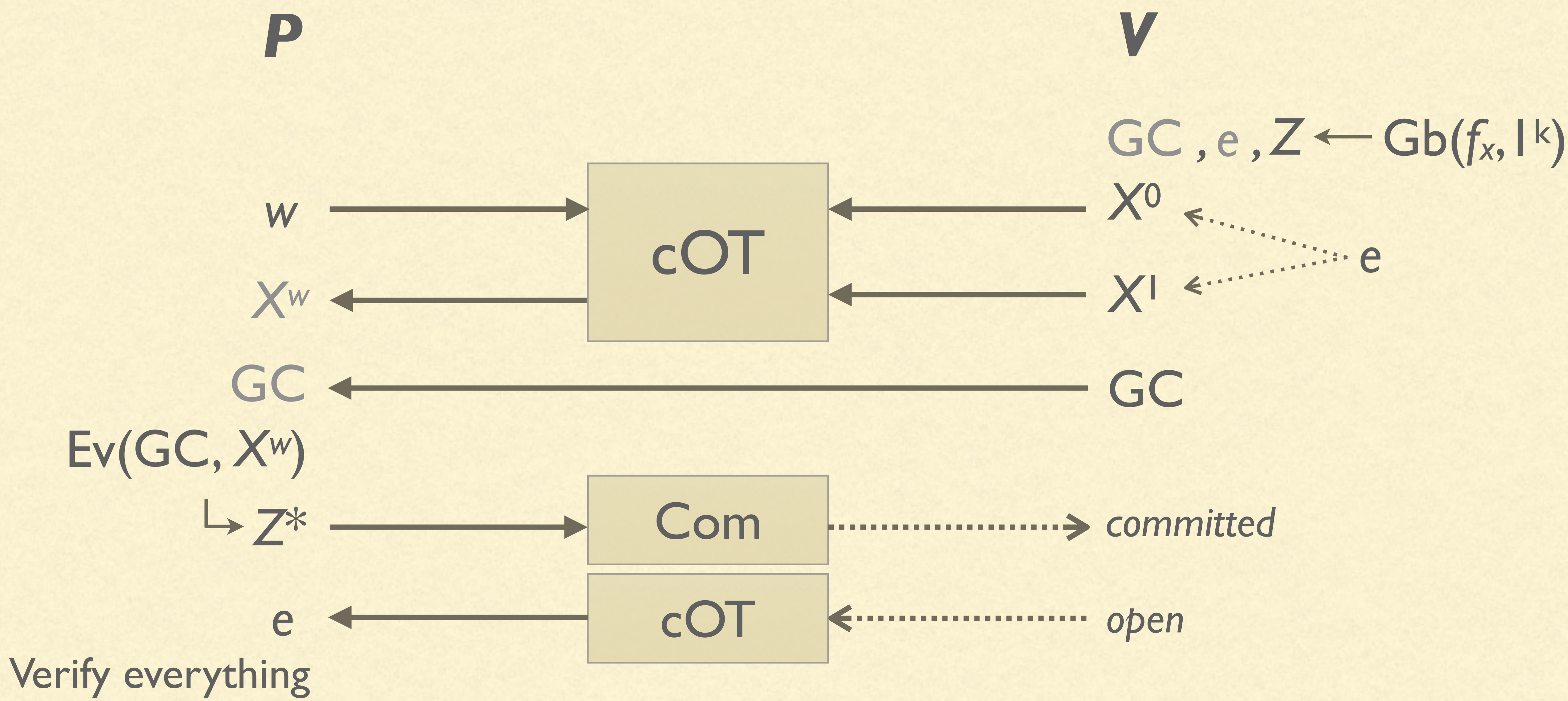

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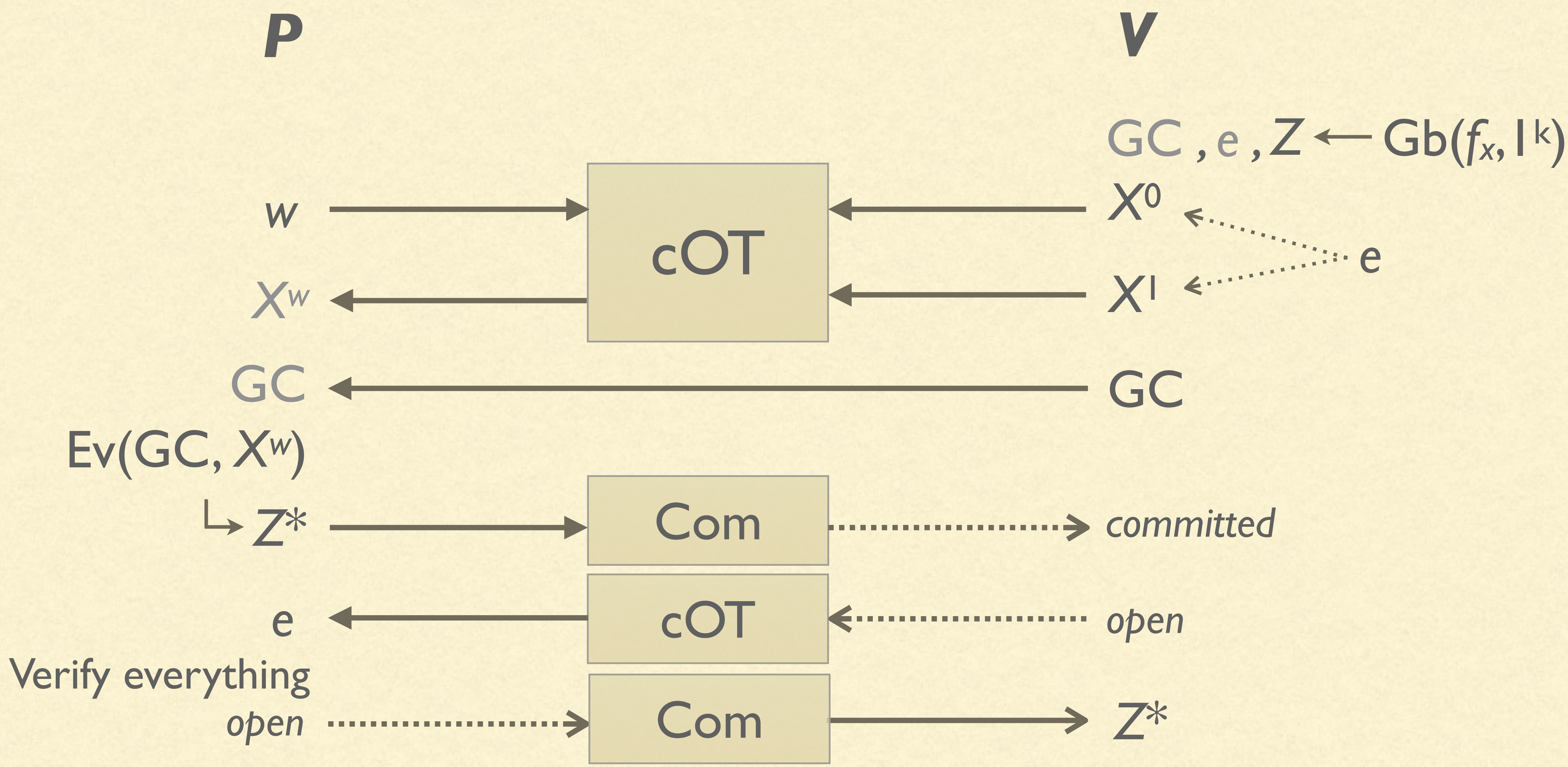

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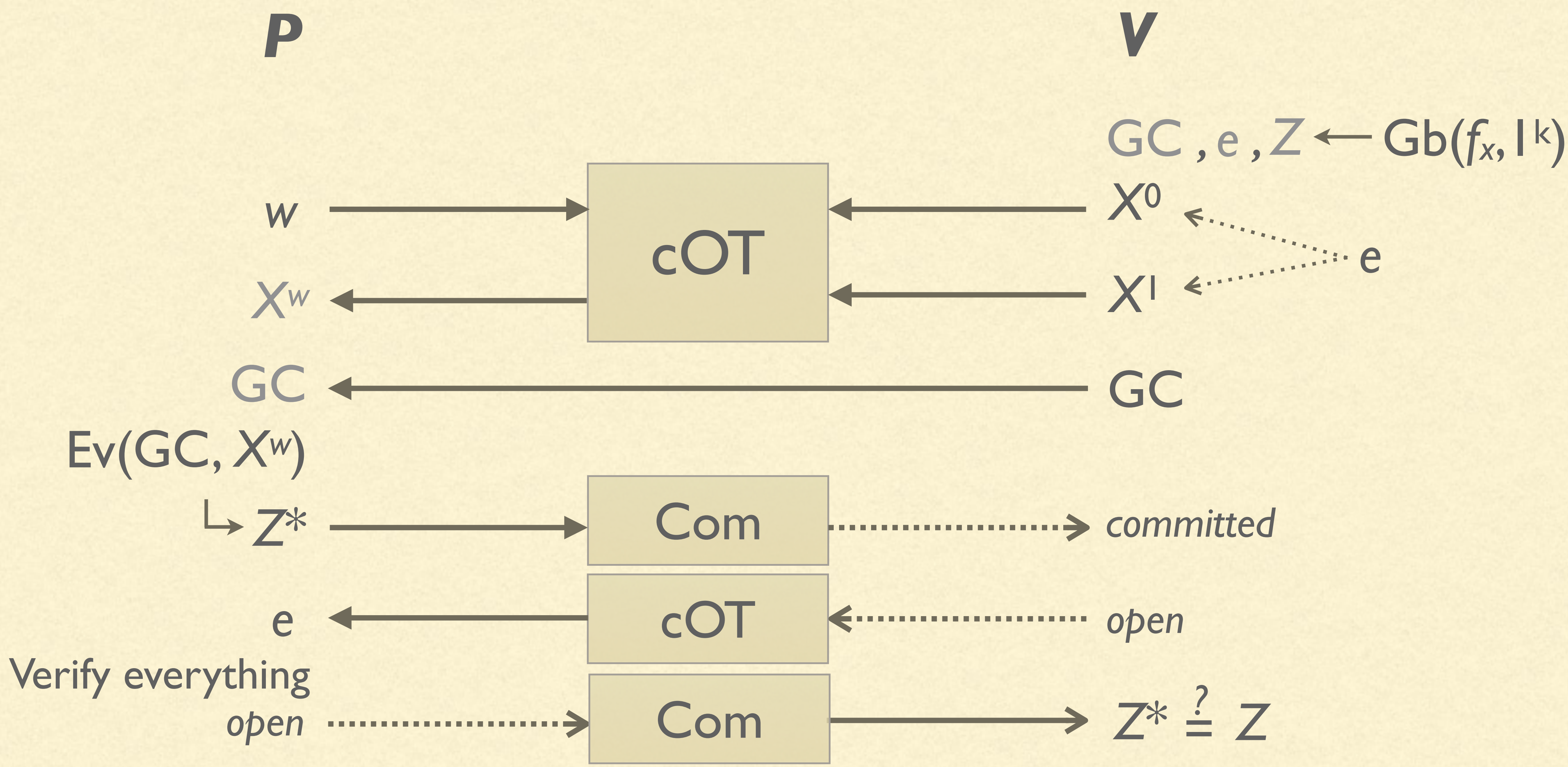
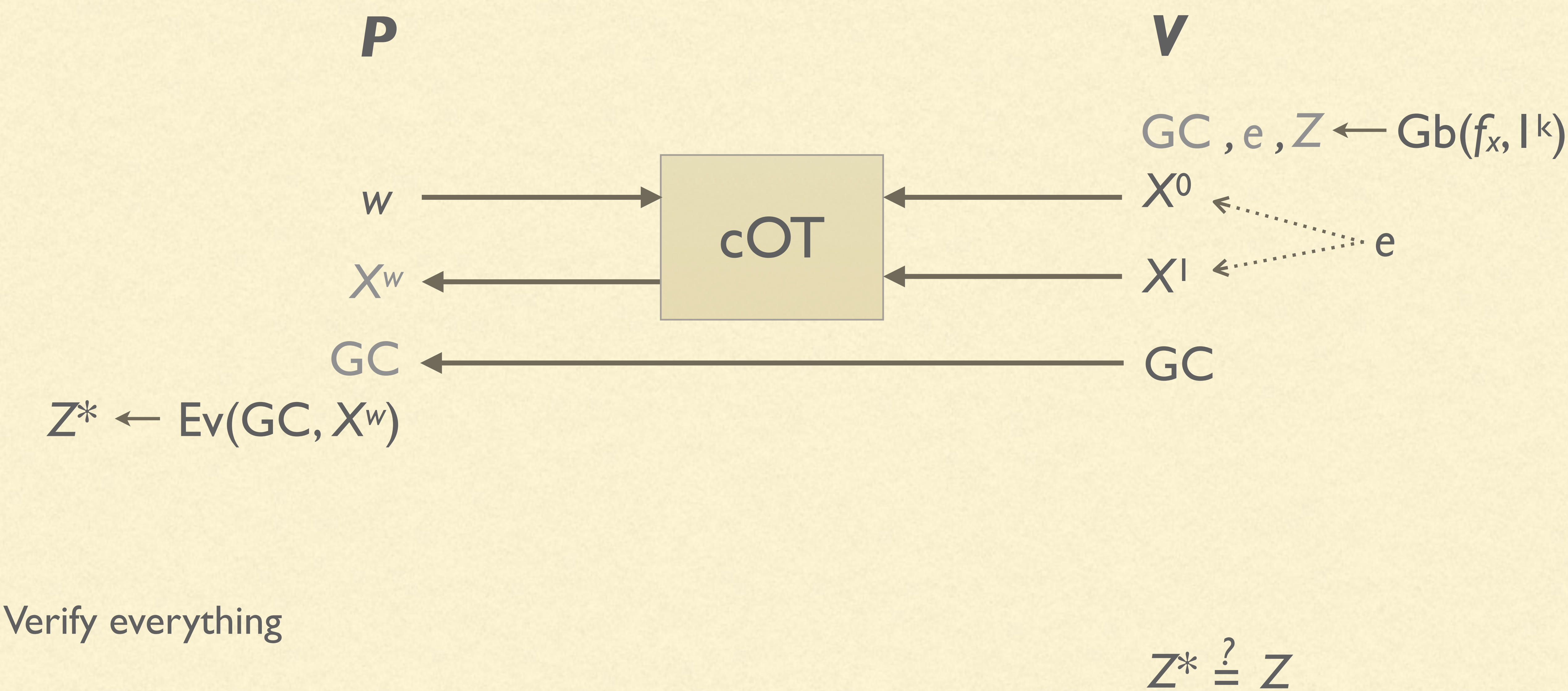


REDUCING TO (OT+1) ROUNDS

- ***P***'s verification phase made non-interactive (still not adaptive)



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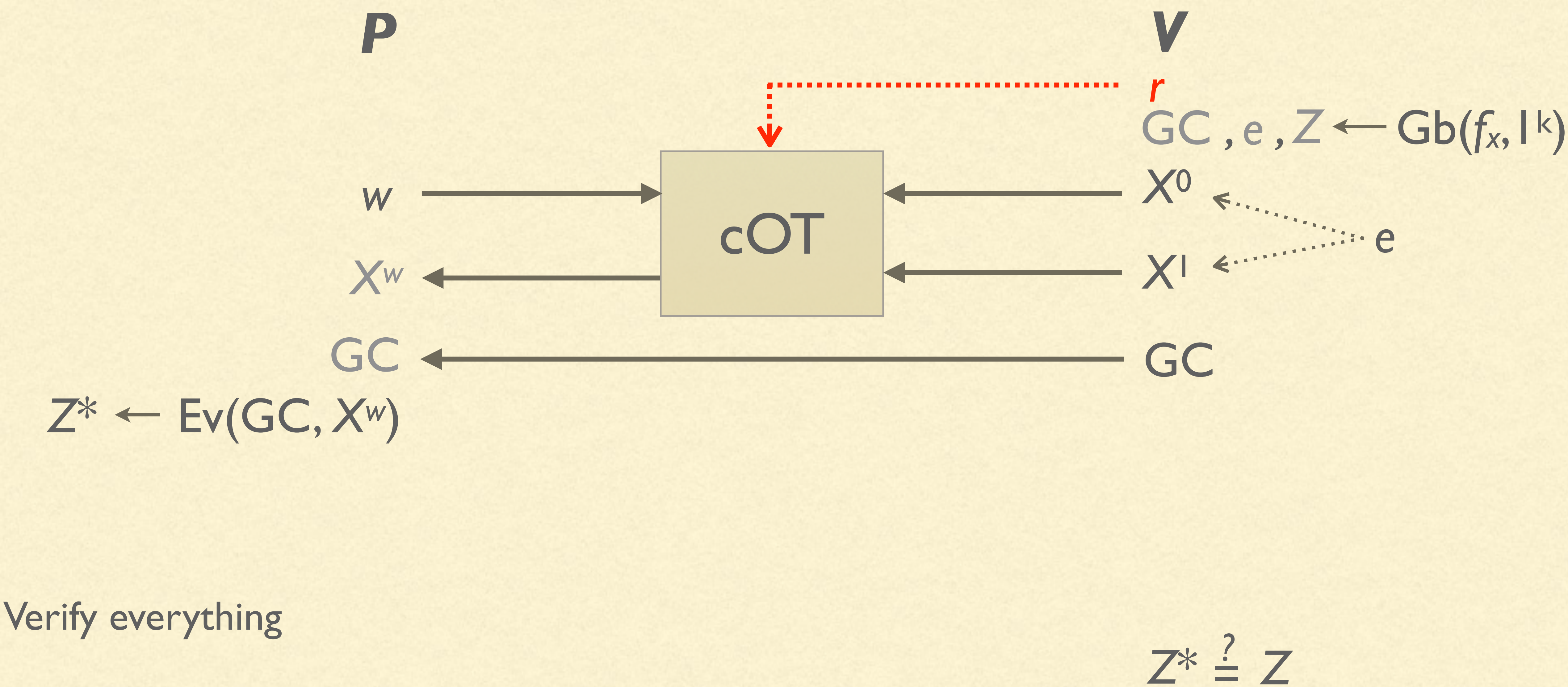

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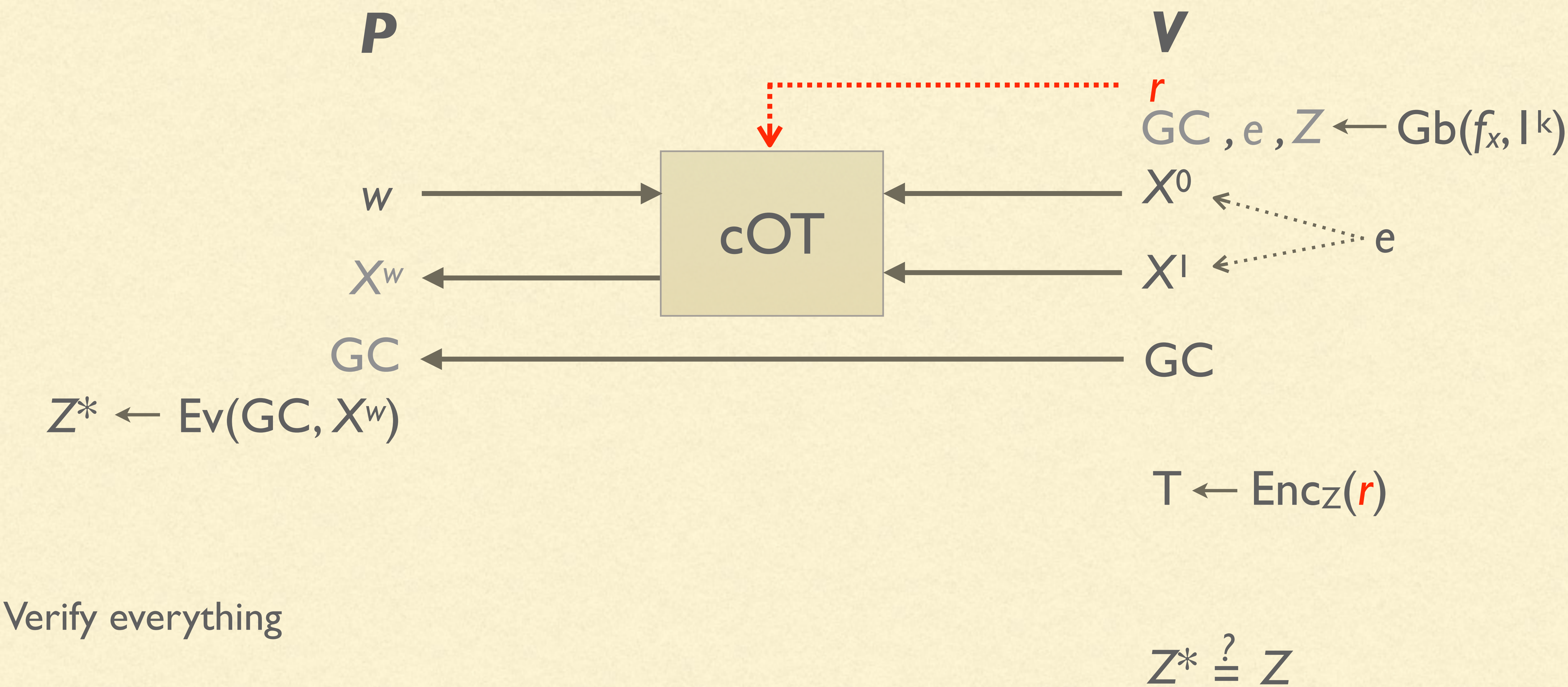

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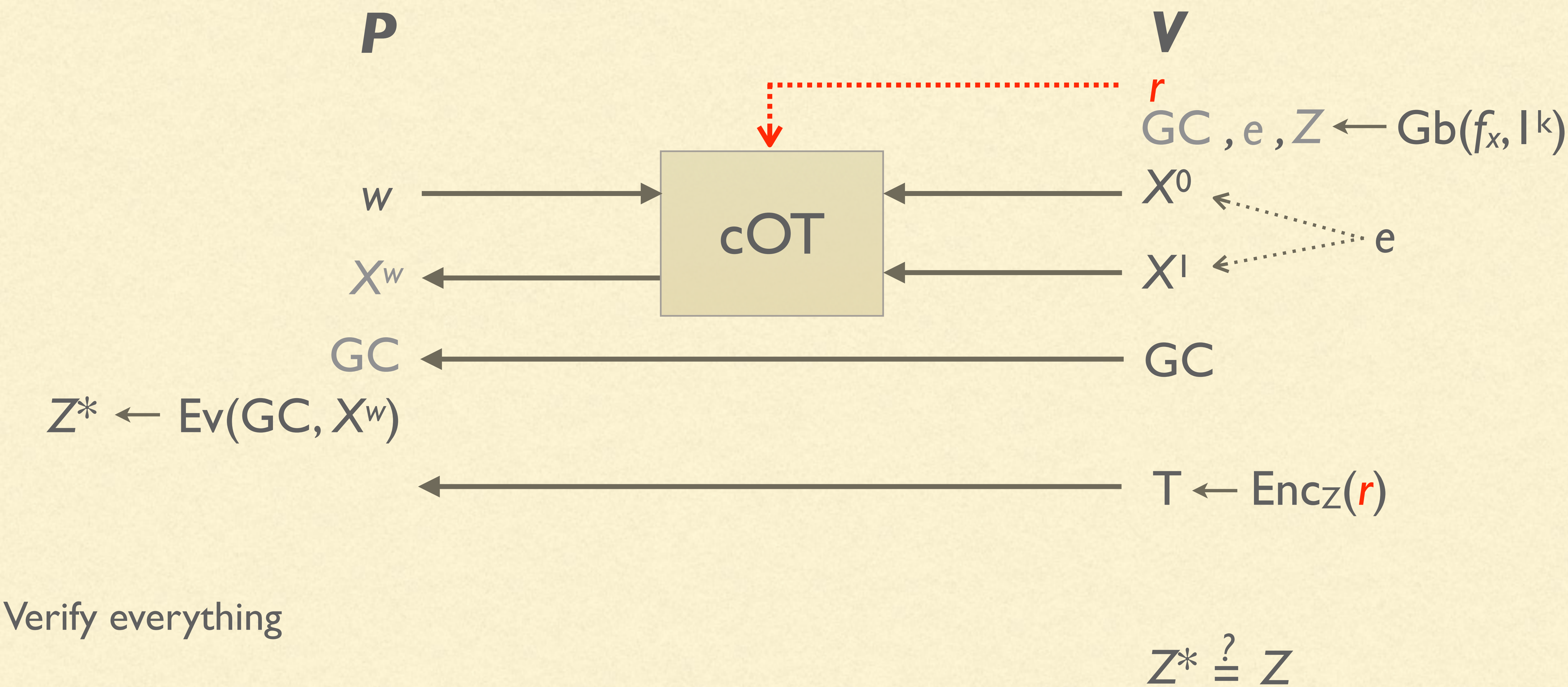

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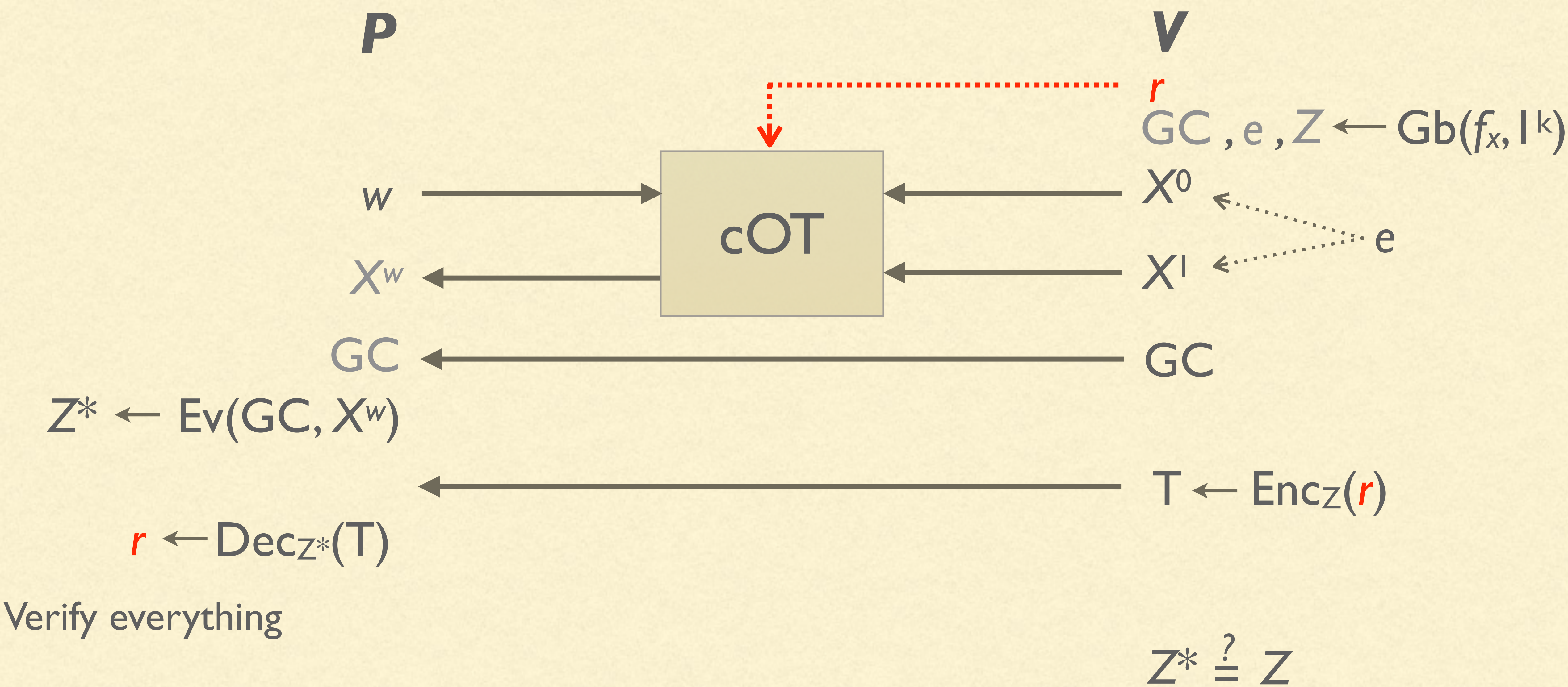

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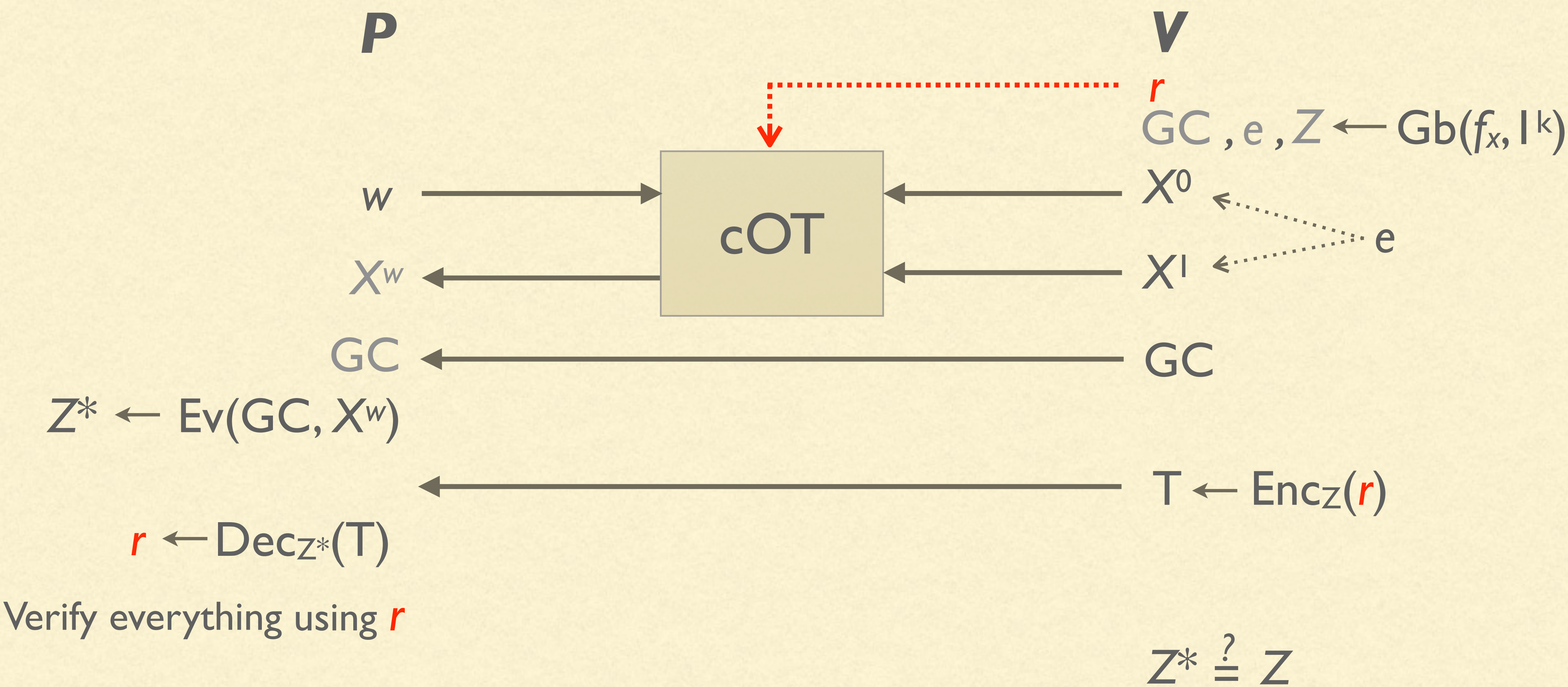

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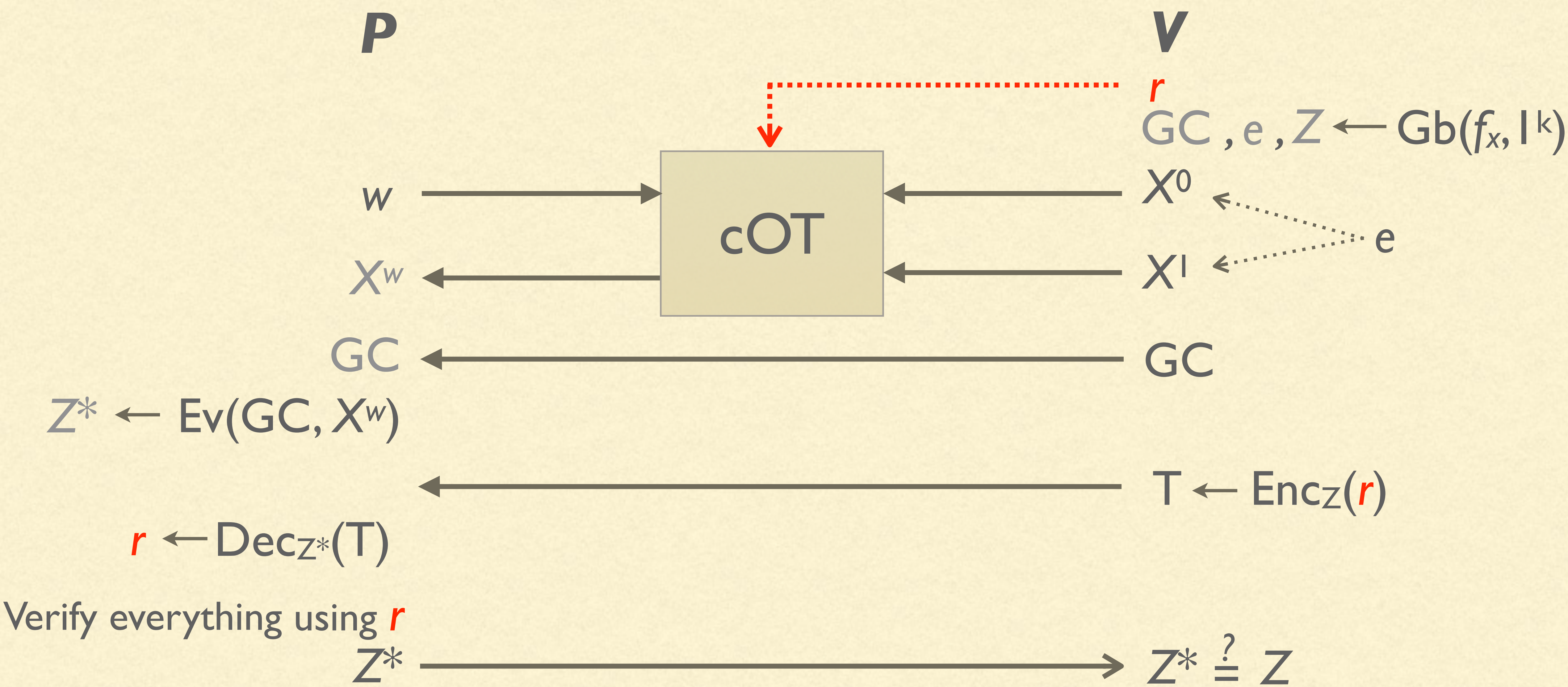

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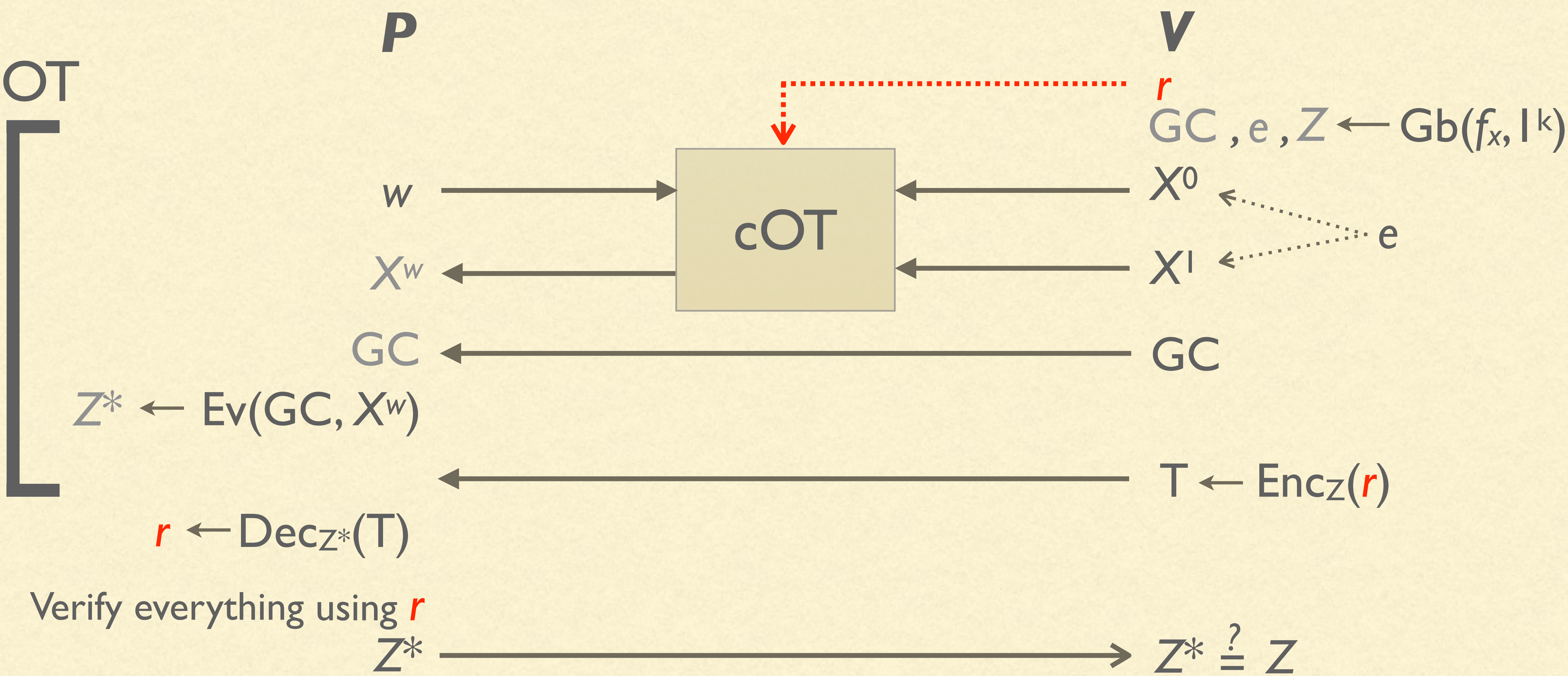

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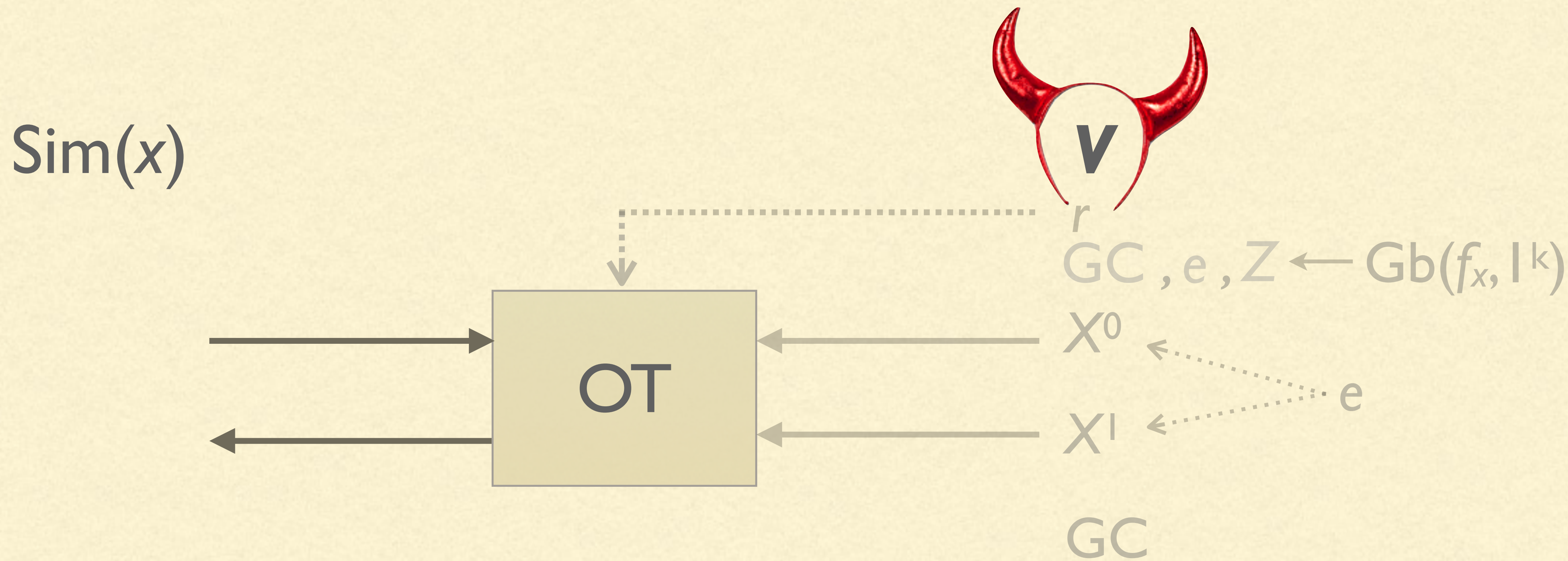
REDUCING TO (OT+1) ROUNDS

- Encryption scheme has to be "committing"
- Circular security and observability of decryption key: solved by random oracle (non-programmable)
- Still simulatable; less work for prover, verifier is the same

ADAPTIVE SECURITY

- Many cases of corruption order to consider
- Hardest case is when Verifier is initially corrupted, and Prover is corrupted post-execution. We focus on this case.
- For simplicity, we focus on adaptivity of OT+1 version

HARDEST CASE: ***V*** , ***P***



As with [JKO13], simulator extracts X^0, X^1 from OT.

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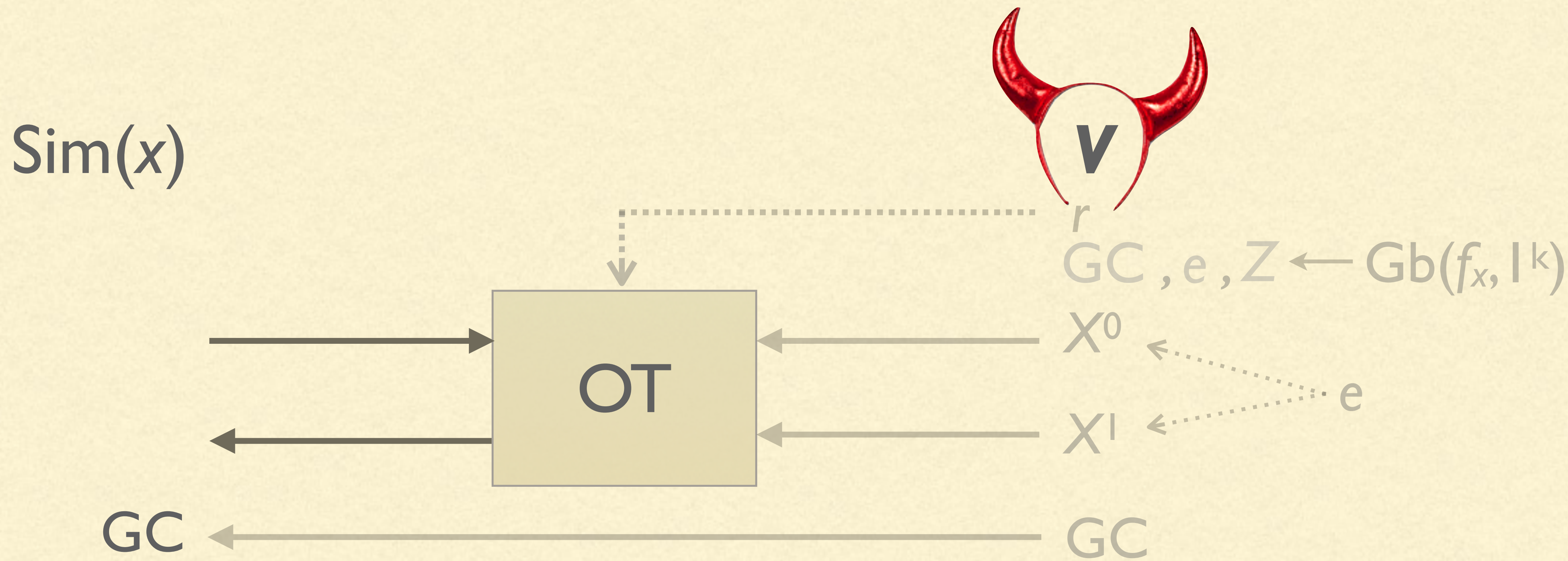

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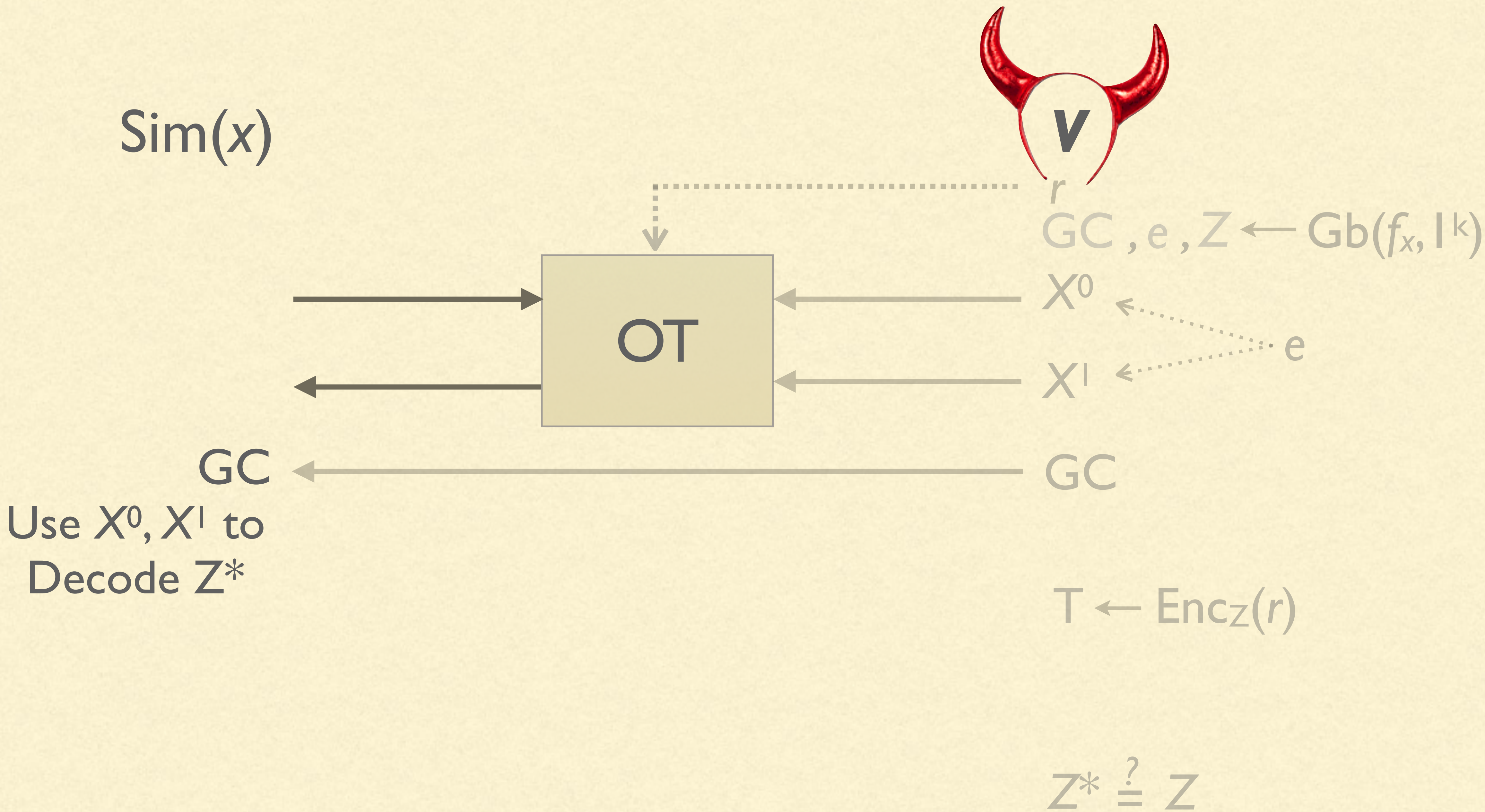

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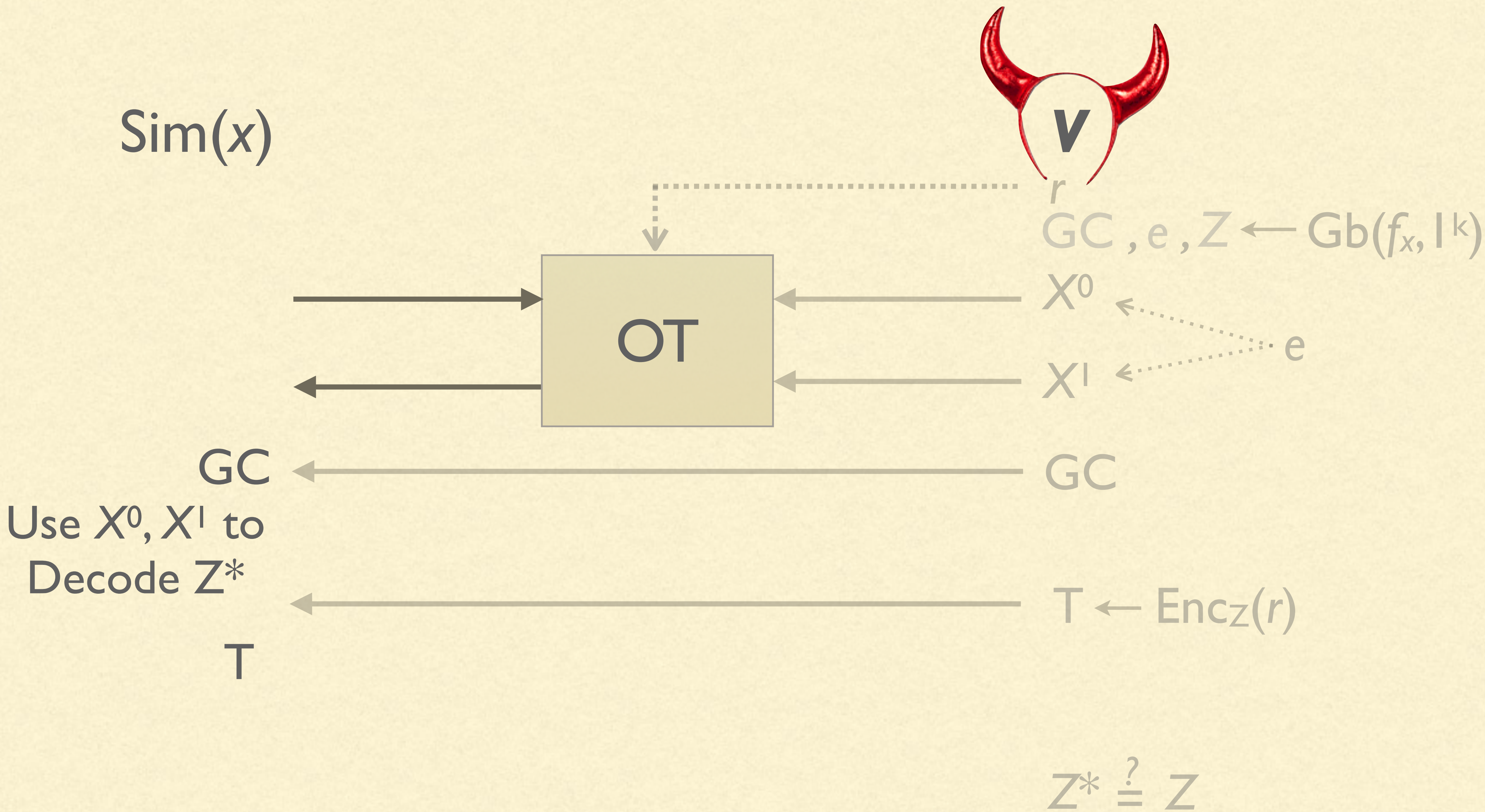

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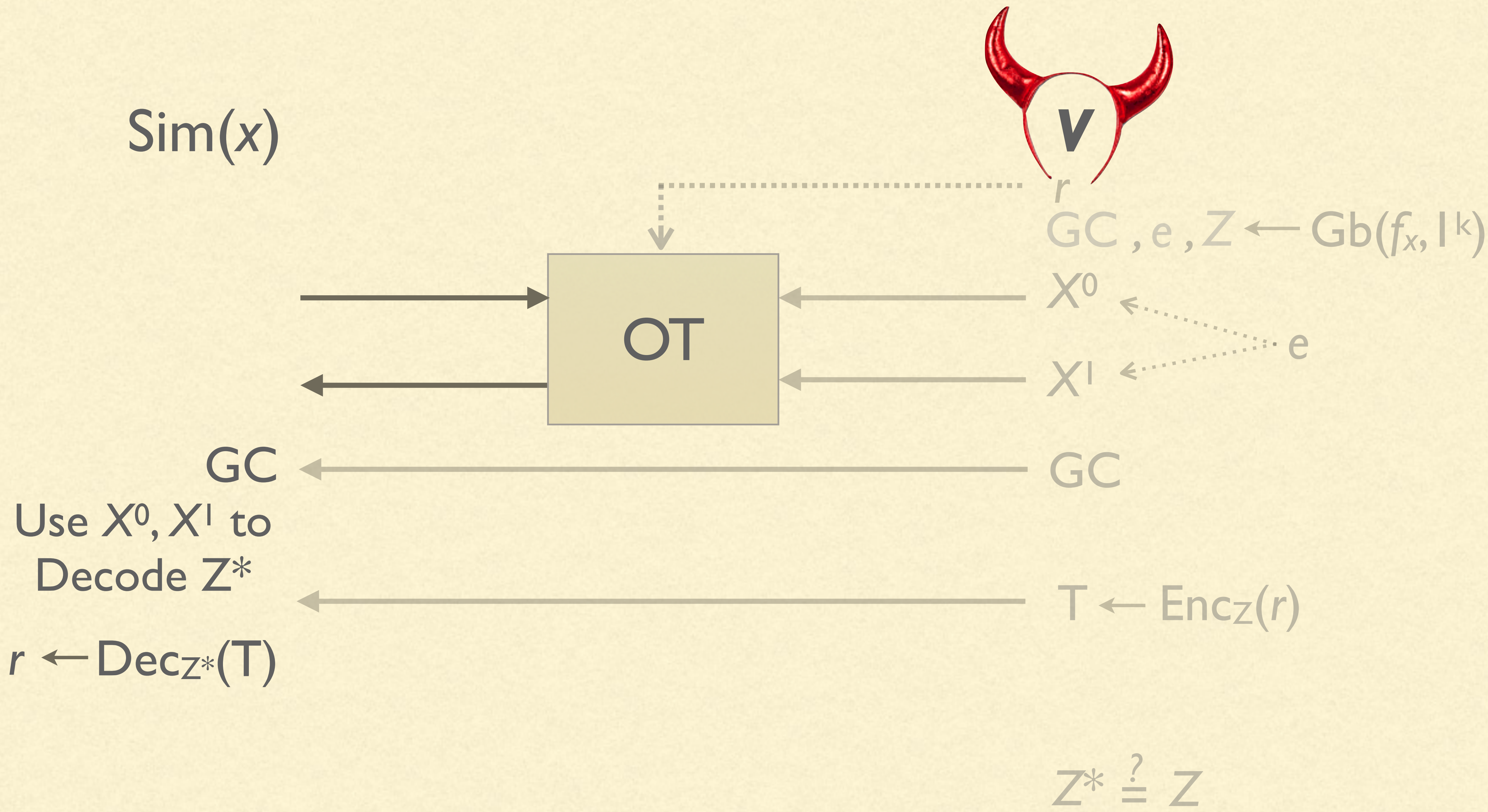

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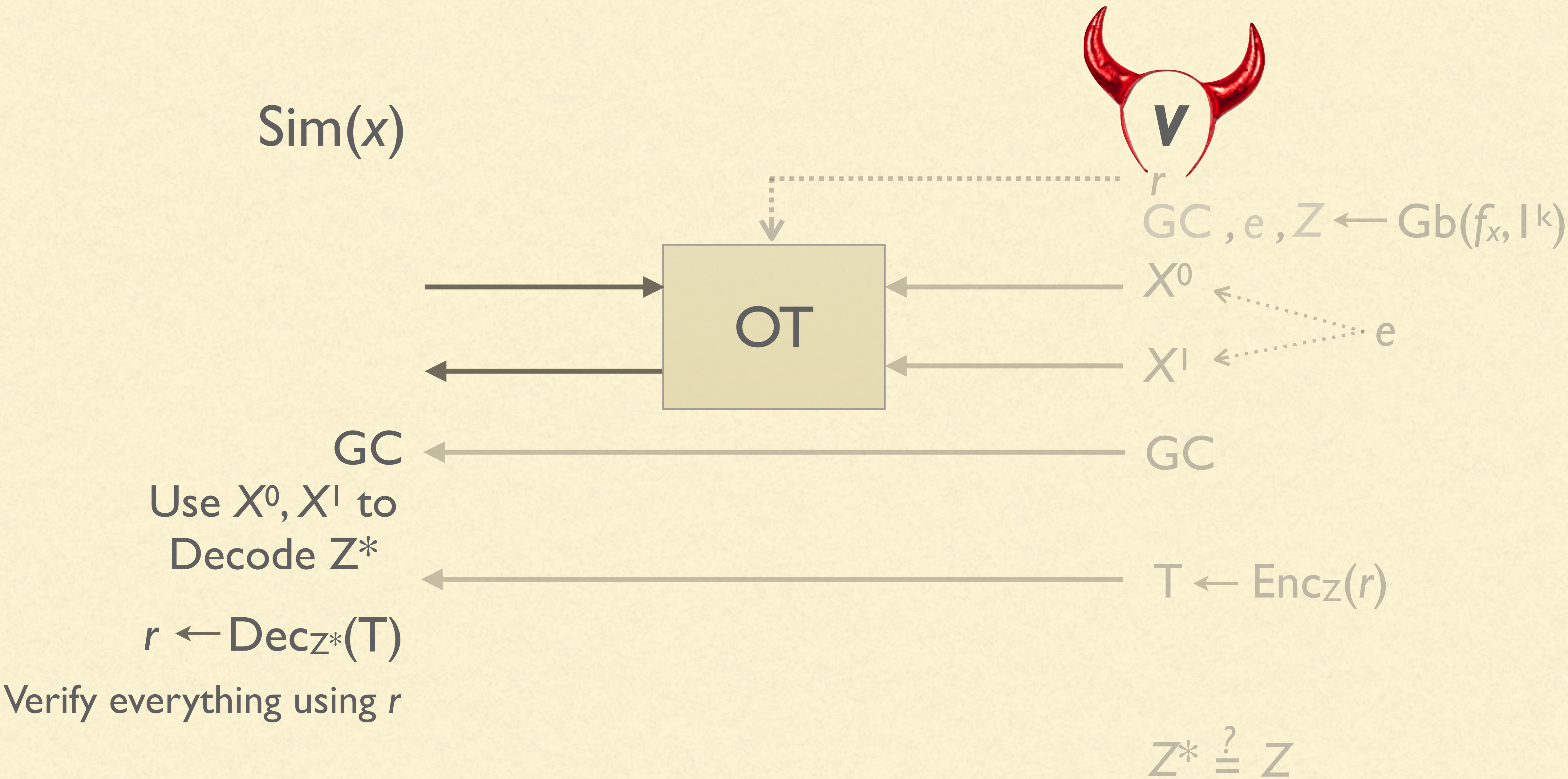

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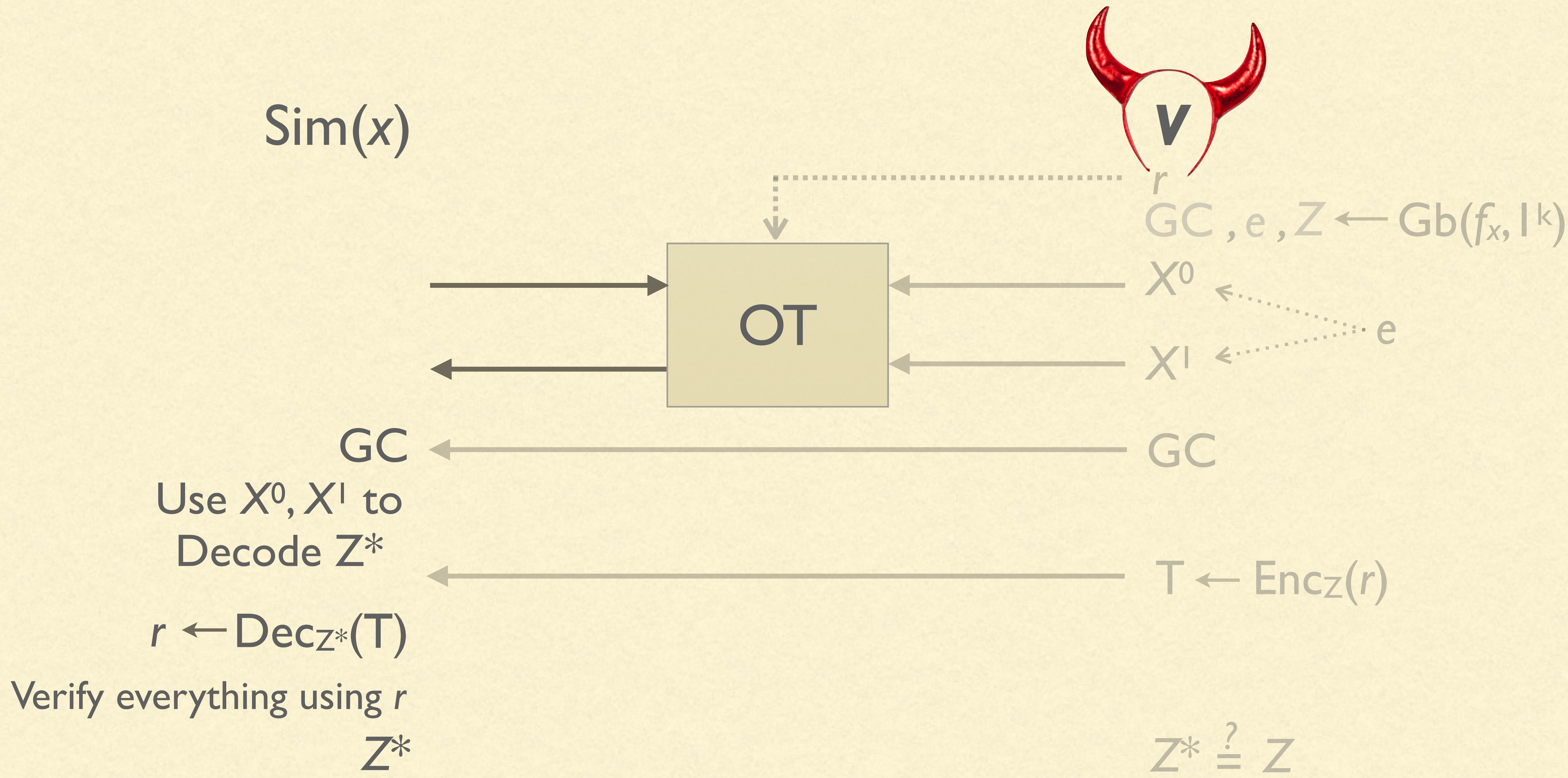


HARDEST CASE: *V*, *P*

Sim(x)

V

r

GC, e, $Z \leftarrow \mathrm{Gb}(f_x, 1^k)$

OT

X^0

e

X^1

GC

GC

Use X^0, X^1 to Decode Z*

$T \leftarrow \mathrm{Enc}_Z(r)$

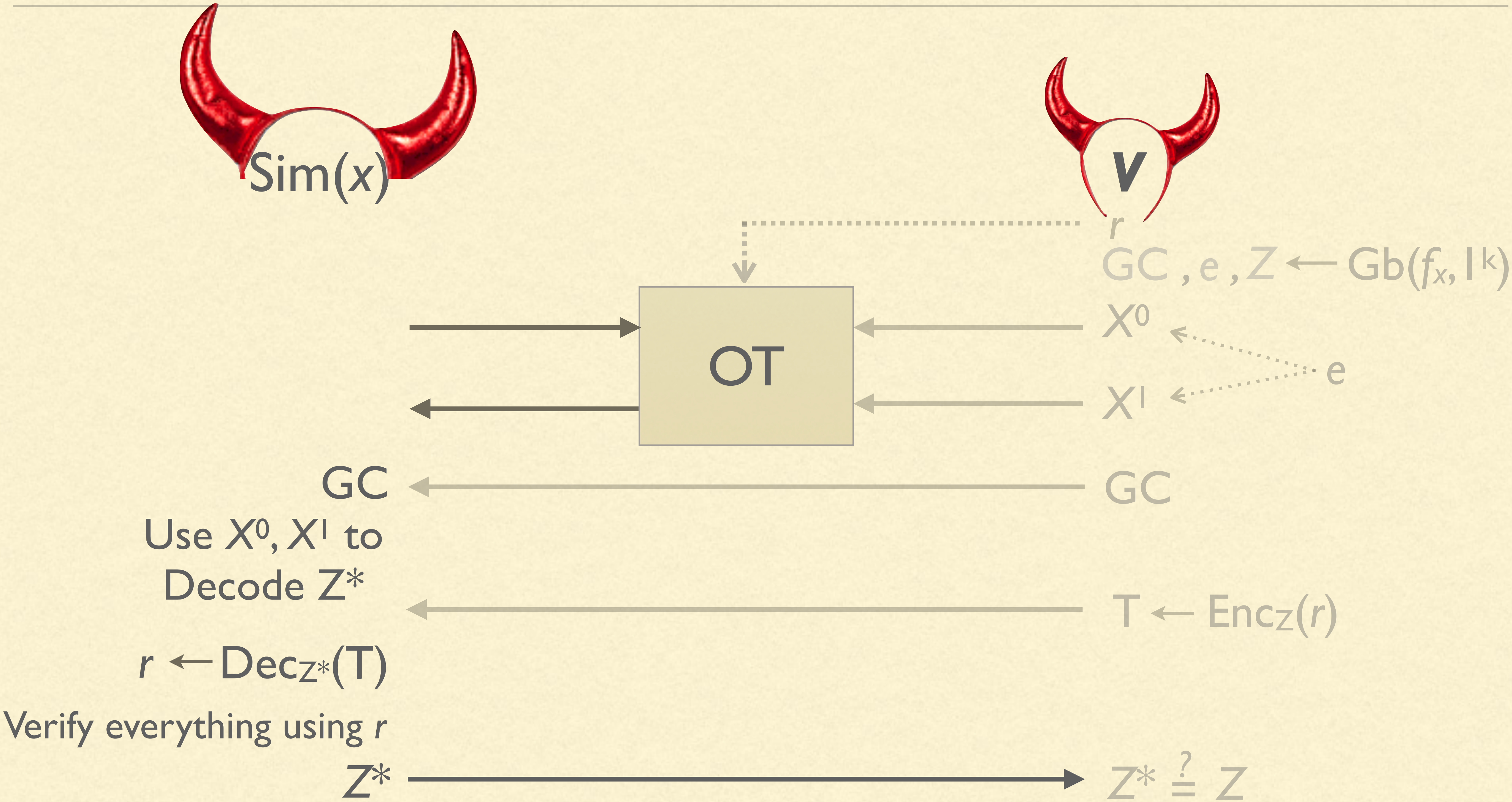
$r \leftarrow \mathrm{Dec}_{Z*}(T)$

Verify everything using r

Z^*

$Z^* \stackrel{?}{=} Z$

HARDEST CASE: ***V***, ***P***



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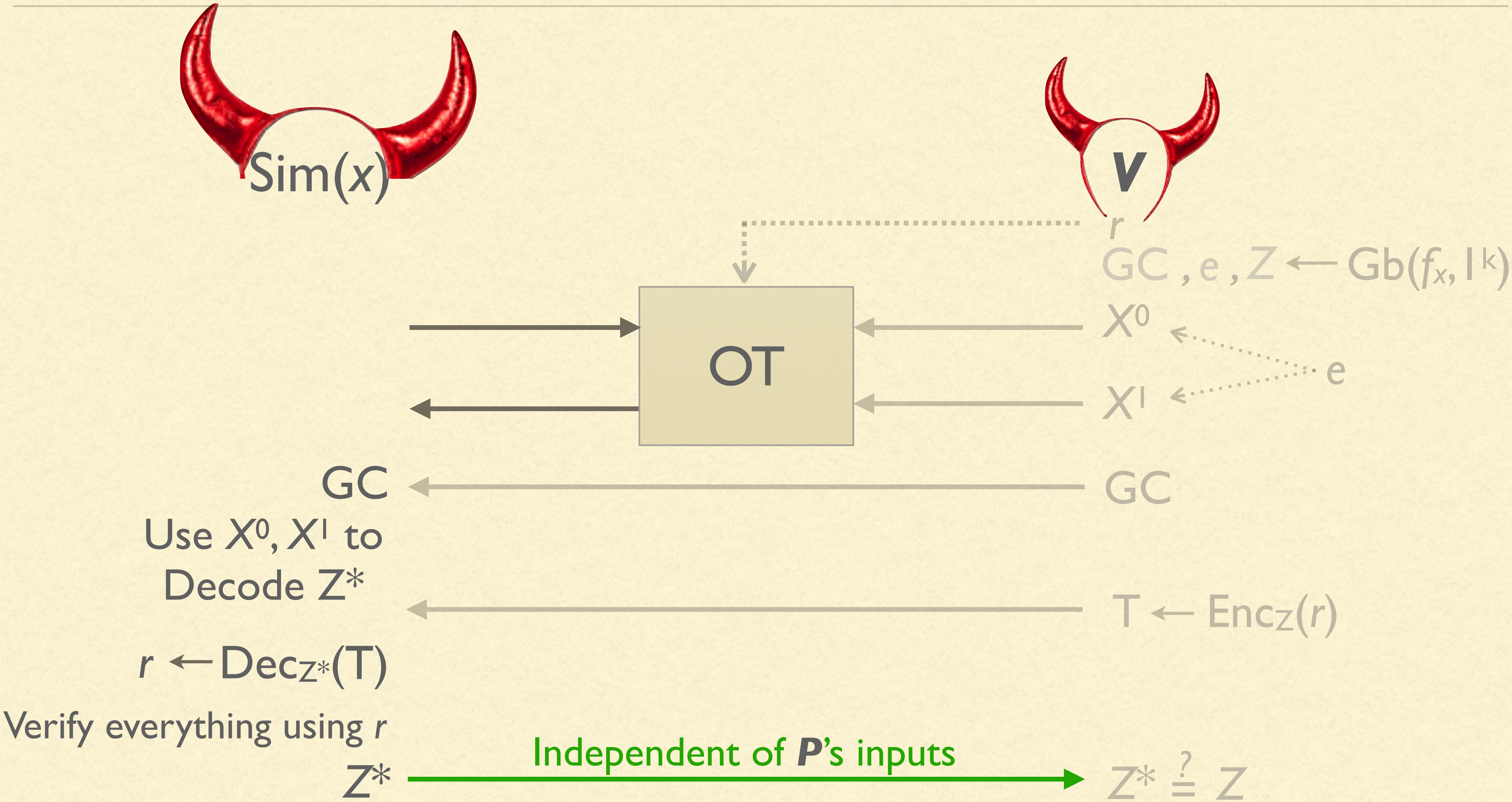

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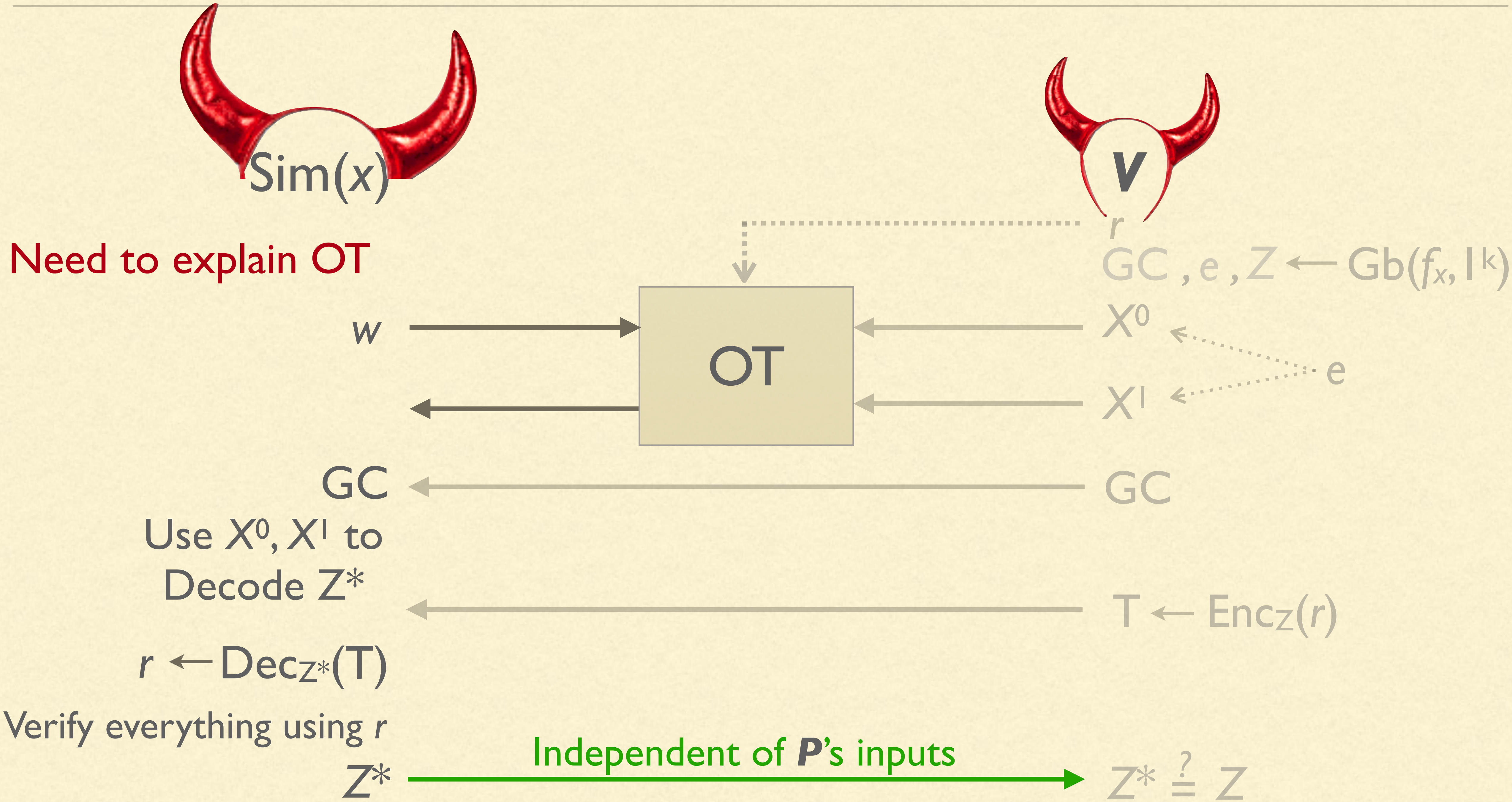
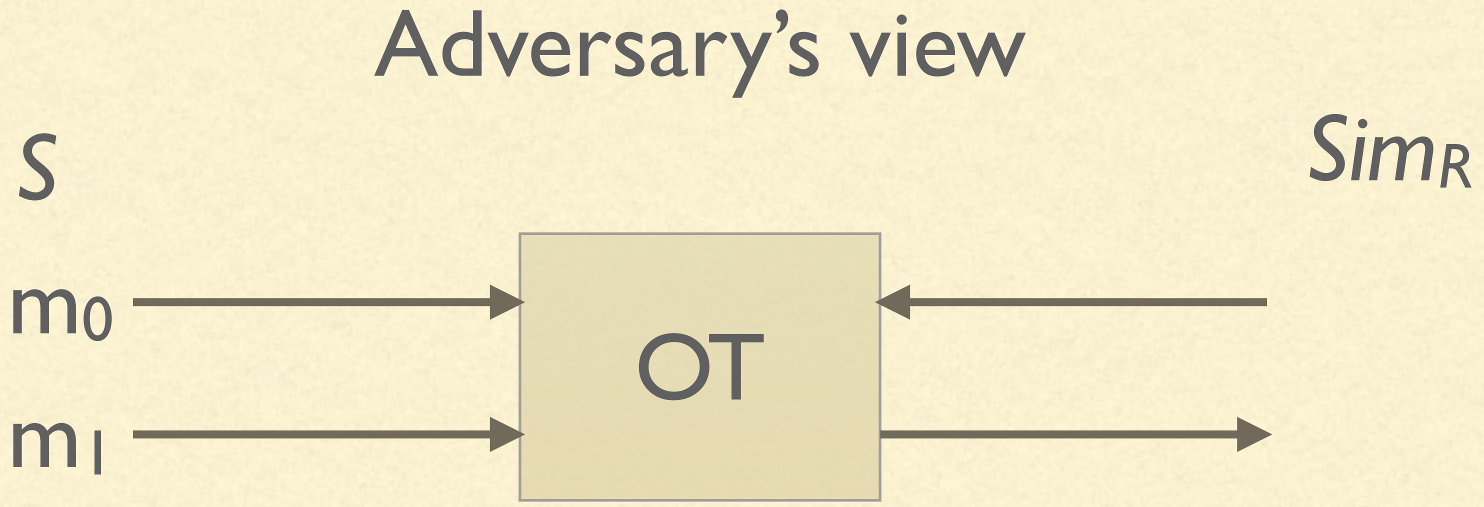


RECEIVER EQUIVOCAL OT

- Notion introduced in [Beaver 96]



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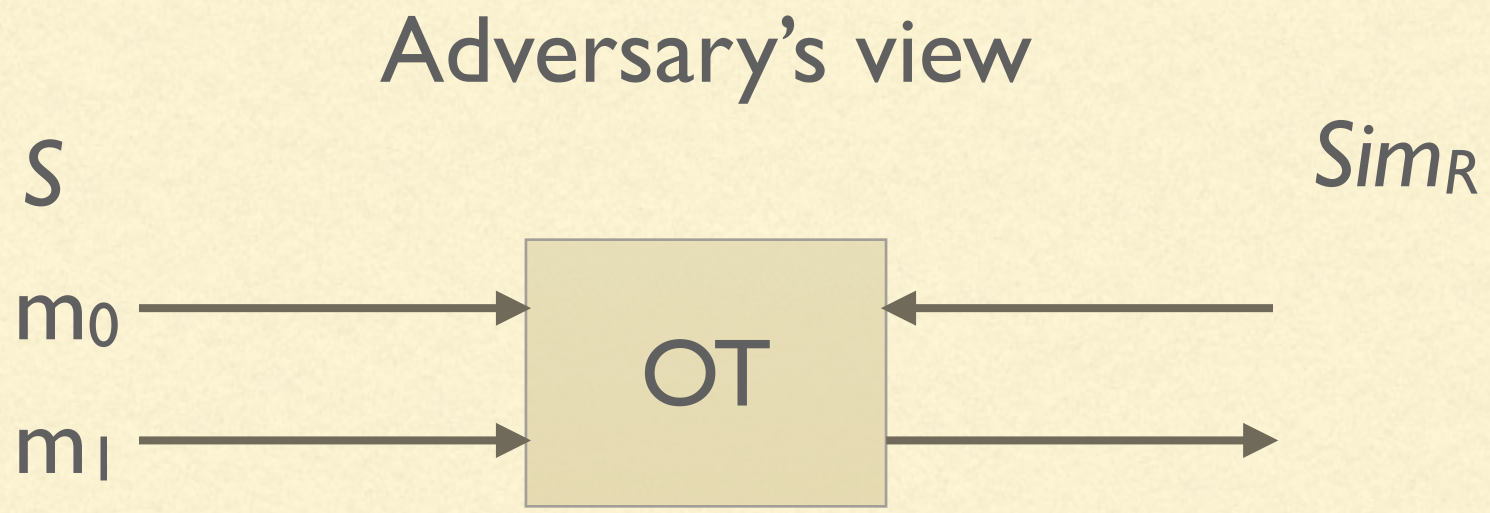
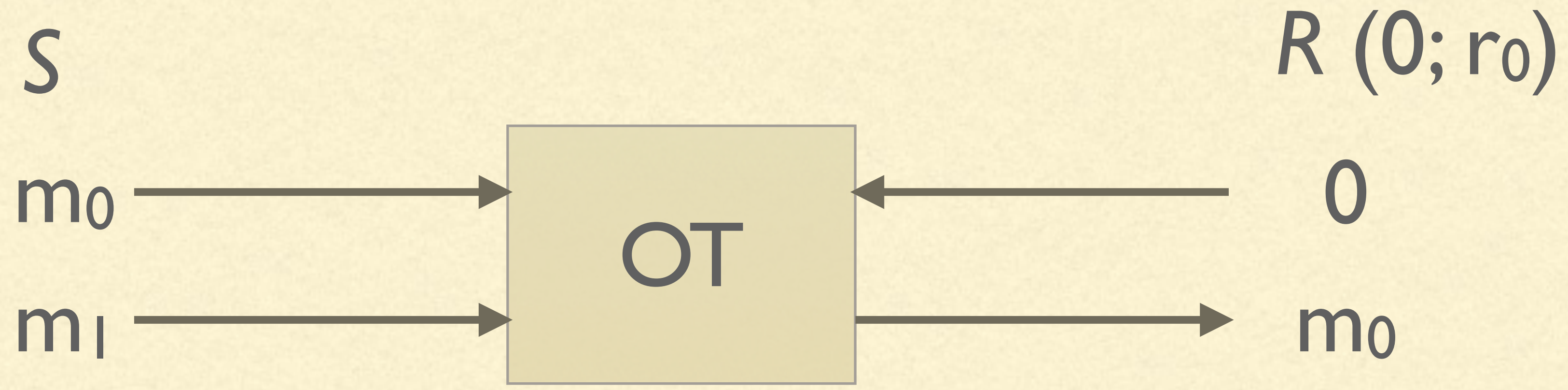


- Sim_R is able to produce r_0 and r_1

RECEIVER EQUIVOCAL OT

- Notion introduced in [Beaver 96]

Adversary's view



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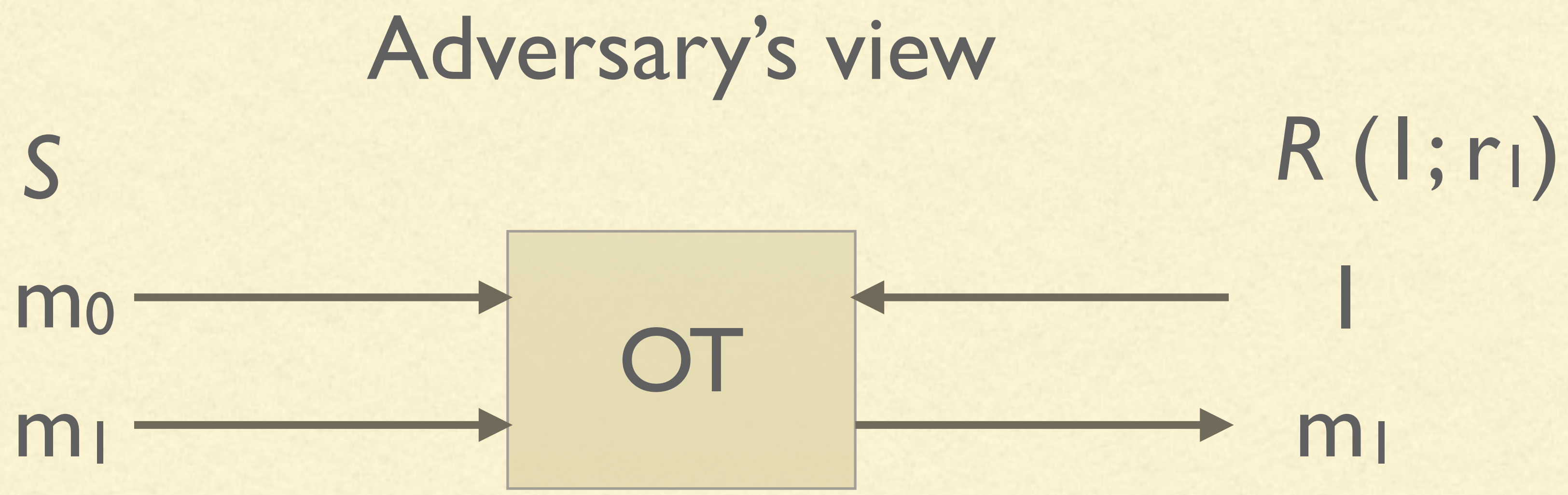

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- Instantiable under any of DDH, LWE, LPN, QR assumptions
- UC-secure with local CRS as trusted setup

HARDEST CASE: ***V*** , ***P***

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r

$GC, e, Z \leftarrow Gb(f_x, 1^k)$

RE-OT

X^0

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Independent of ***P***'s inputs

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RE-OT

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X^1

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GC ← GC

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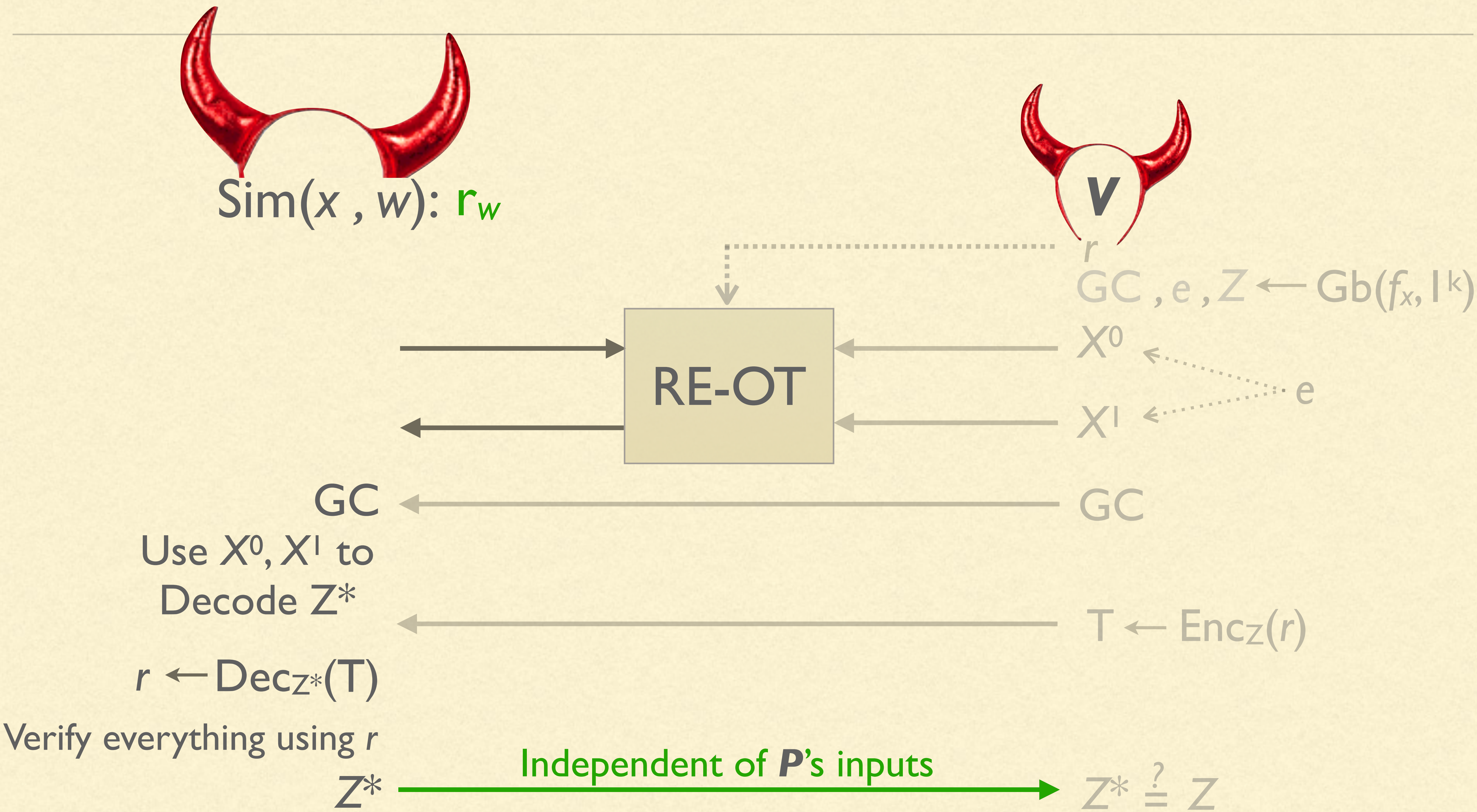
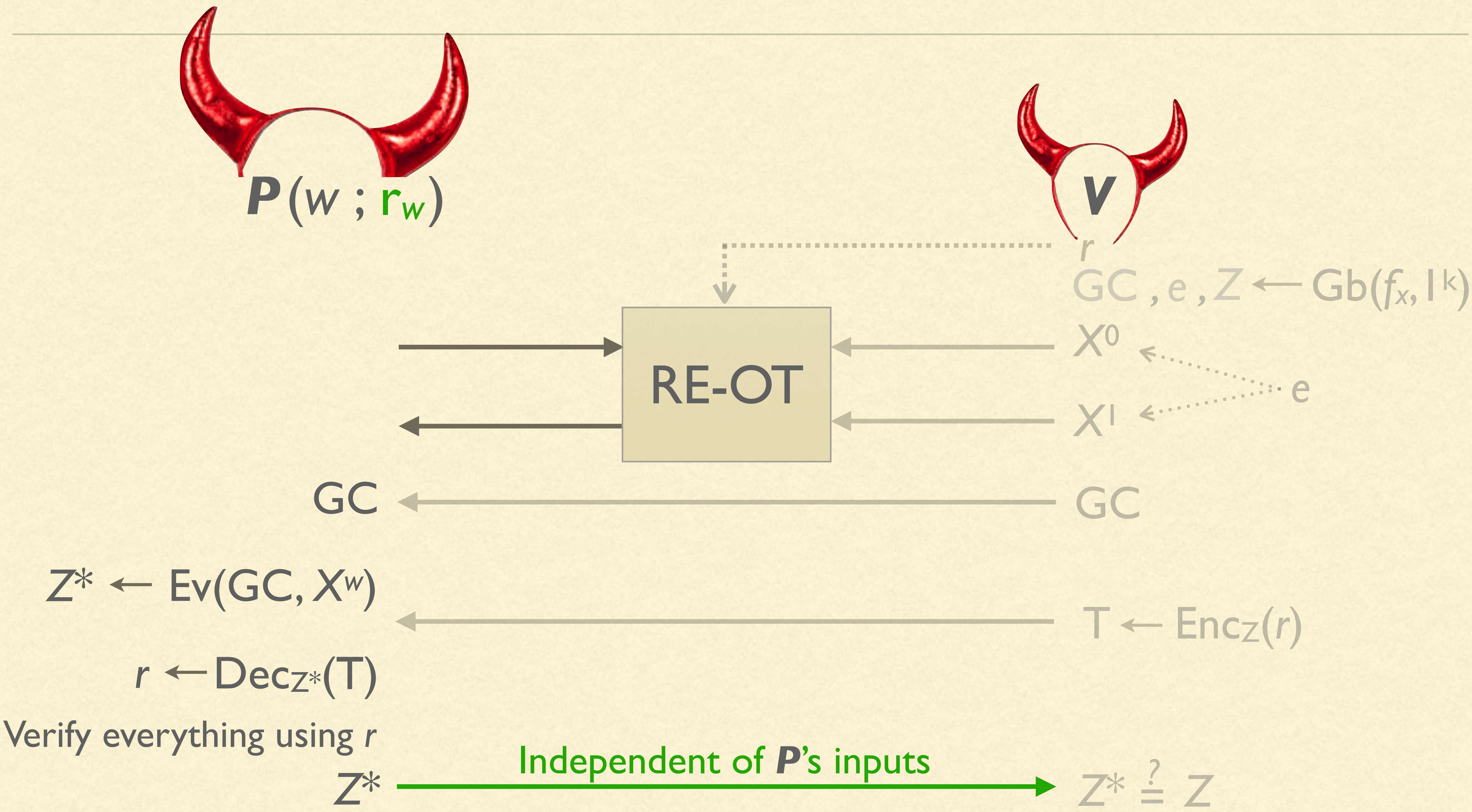


HARDEST CASE: *V* , *P*



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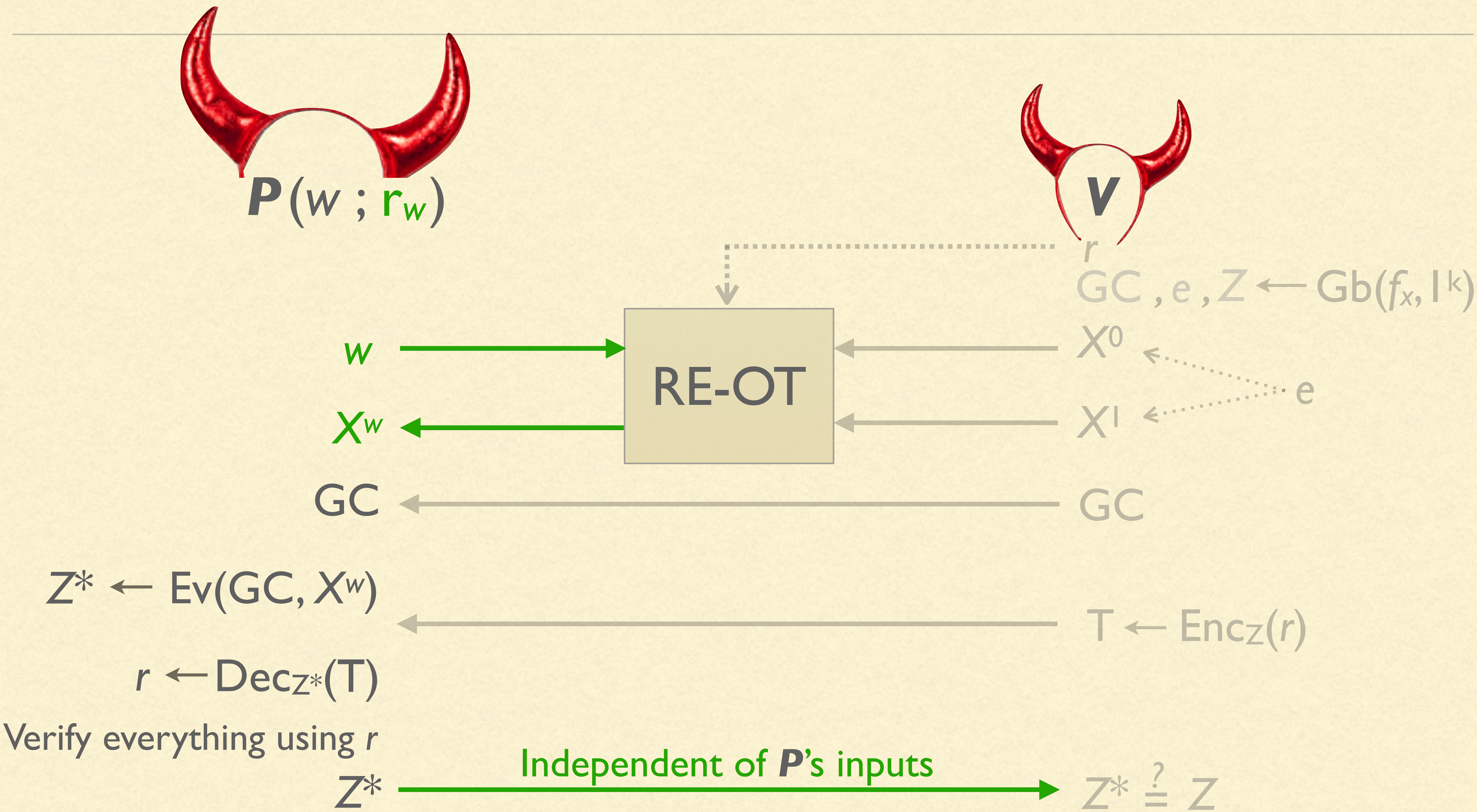

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- Also in paper: 2-round ZK proofs from GCs (cut and choose), authenticity-free garbling

THANK YOU