Rugged Pseudorandom Permutations with Beyond-Birthday-Bound Security

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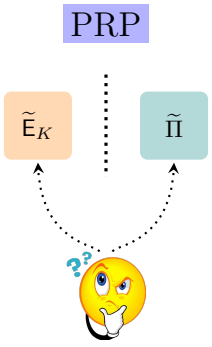
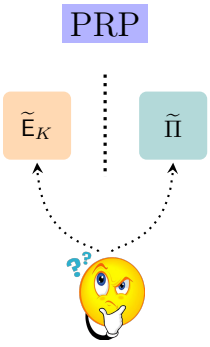
AsiaCCS 2026, Bangalore, India

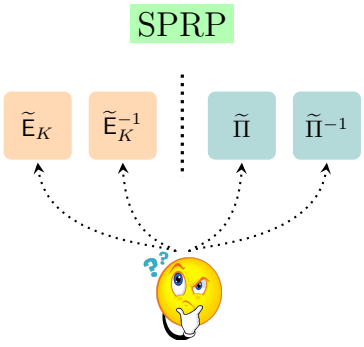
June 3, 2026

PRP vs RPRP vs SPRP



PRP vs RPRP vs SPRP





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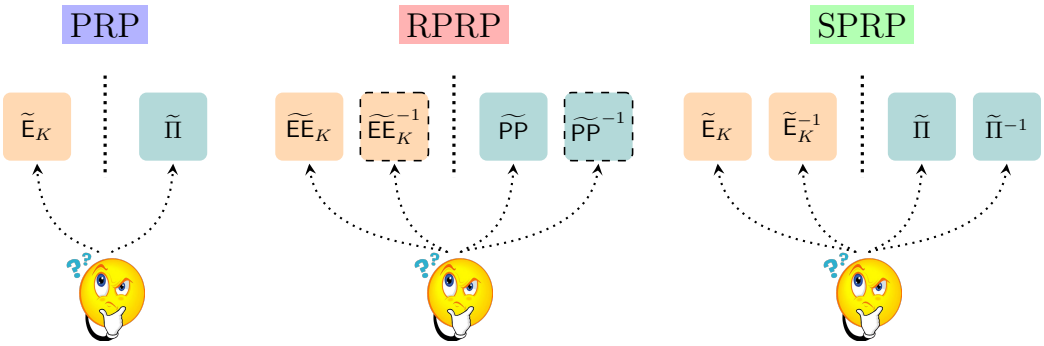

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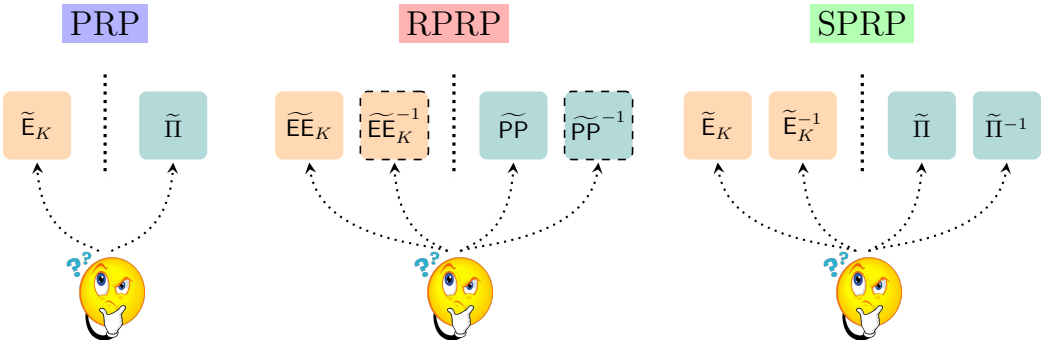
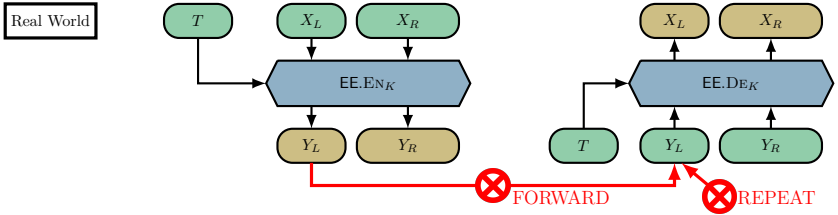
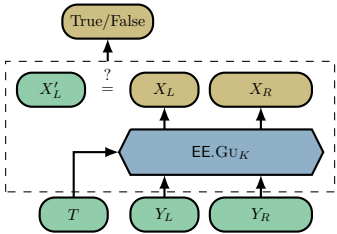


- Proposed by Degabriele et al. at CRYPTO'22.
- It is an intermediate security notion of PRP and SPRP.
- An RPRP is a strictly weaker notion than an SPRP, but at the same time it is more efficient.

Rugged Pseudorandom Permutations (RPRP)



- Deciphering can be accessed via two separate oracles:
  - Decryption Oracle - restricted queries, full output,
  - Guess Oracle - unrestricted queries, 1-bit output.
- Trivial Guess queries should be avoid.



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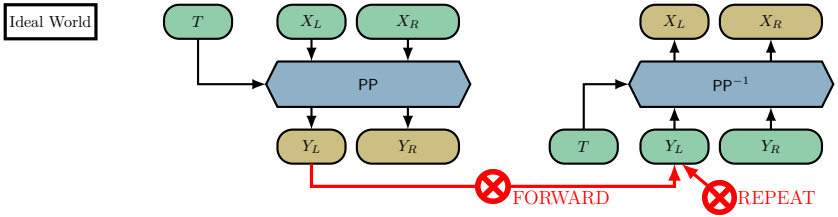
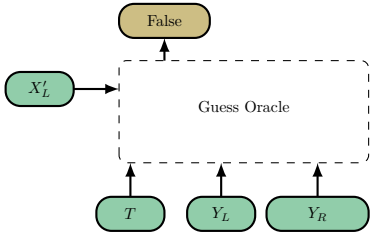


- Replace EE with an ideal cipher PP.
- Guess oracle always returns False.
- Trivial Guess queries should be avoid.



Existing RPRP Constructions

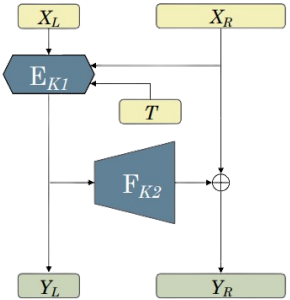


Figure: UIV Construction

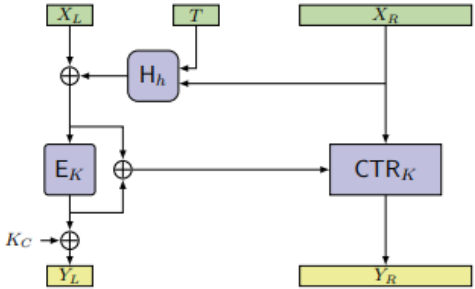


Figure: HEC Construction

- Both the UIV construction and the HEC construction achieve birthday bound security.

Our Contribution: THEC Construction

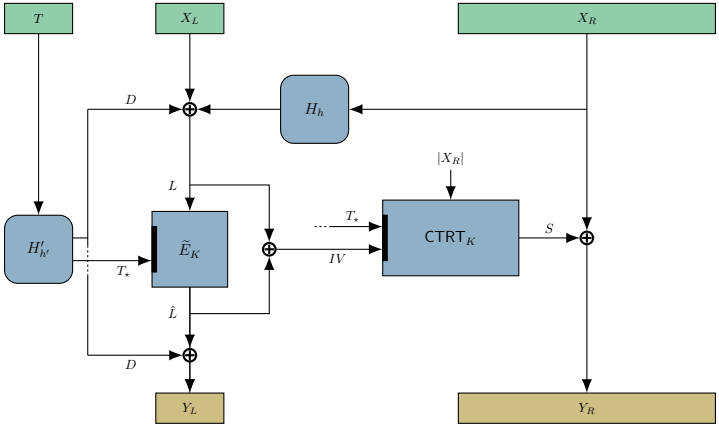


Figure: THEC construction

- THEC offers BBB RPRP security with a graceful security degradation on tweak repetitions.

Our Contribution: DE-THEC Construction

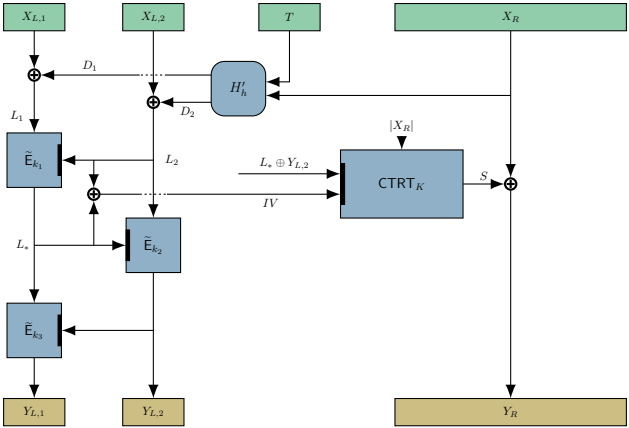


Figure: DE-THEC construction

- DE-THEC achieves optimal RPRP security without any restriction on tweak repetitions.

Security Results of THEC & DE-THEC

Results:

Let H is ϵ-AXU, ρ-almost regular and δ-AU. Let $\widetilde{\mathsf{E}}$ be a tweakable block cipher. Then

$$\mathbf{Adv}^{\mathsf{RPRP}}_{\mathsf{THEC}}(\mathcal{A}, v) \leq \mathbf{Adv}^{\mathsf{STPRP}}_{\widetilde{\mathsf{E}}}(\mathcal{B}) + q(\mu-1)\epsilon + q^2\delta\epsilon + \frac{q(\mu-1)}{2^{n-1}} + \frac{q^2\delta}{2^{n-1}} + \mu\sigma\rho + q\sigma\rho^2 + \frac{q\sigma\rho}{2^{n-1}} + 2\sigma\rho + \frac{q(\mu-1)l_m}{2^{n-1}} + \frac{\min\{q^2 l_m, \sigma^2\}\delta}{2^{n-1}} + \frac{\min\{q^2 l_m, \sigma^2\}}{2^{2n-2}} + q_{gu}v\left(\epsilon + \frac{2}{2^{n-1}}\right) + (\mu-1)\frac{q}{2^n}.$$

$$\mathbf{Adv}^{\mathsf{RPRP}}_{\mathsf{DE\text{-}THEC}}(\mathcal{A}, v) \leq 4\mathbf{Adv}^{\mathsf{STPRP}}_{\widetilde{\mathsf{E}}}(\mathcal{B}) + q^2\epsilon + \frac{2qq_{en}}{2^{2n-2}} + \frac{qq_{de}}{2^{2n-2}} + \frac{2\min\{q^2 l_m, \sigma^2\}}{2^{2n-2}} + q_{gu}v\left(2\epsilon + \frac{1}{2^{2n-2}}\right) + \frac{q^2}{2^{2n}}.$$

where $q \leq 2^{n-1}$, $\mu \leq q$ and $q_{gu}v \leq 2^{n-1}$, μ denotes the maximum number of tweak repetitions.

Applications: Constructing AEAD using RPRP

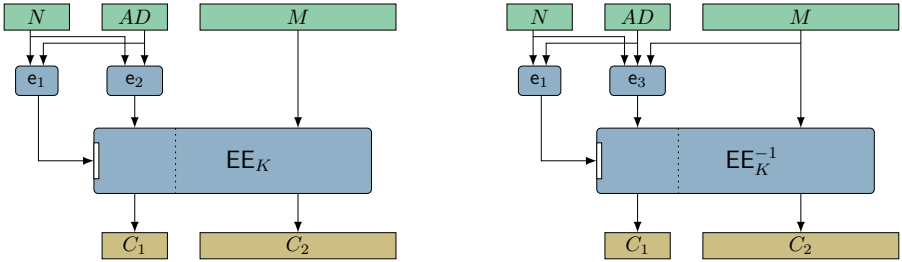


Figure: EtE (**left**) and EtD (**right**) instantiated with a RPRP-secure cipher EE

- EtE[THEC] : a nonce-based or nonce-hiding BBB MRAE secure AEAD (with a graceful security degradation on the nonce repetitions).
- EtE[DE-THEC] : a nonce-based or nonce-hiding BBB MRAE secure AEAD scheme (without graceful degradation).
- EtD[DE-THEC] : a RUP-secure AEAD scheme with full n-bit security with no restrictions.

Performance Comparison

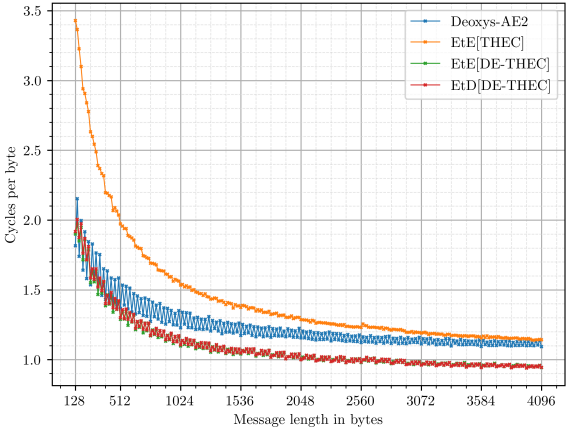


Figure: Benchmarks of encryption algorithm speeds of our derived AEAD schemes and Deoxys-AE2 scheme, for different message length (in bytes) and A of 128 bytes. The plot contains data points for every input length in $\{128, 144, \ldots, 4096\}$.

Applications: Beyond AEAD

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- Both of our RPRP constructions can be integrated into CGO to obtain an onion encryption scheme achieving BBB security.

Future Directions

- Our work primarily focuses on achieving high security levels together with strong software efficiency; however, the hardware footprint and implementation costs of these constructions remain to be thoroughly investigated.
- Another important direction for future research is to study whether the security guarantees of THEC and DE-THEC can be preserved in the multi-user setting.

Thank You!