Toward a New Block Cipher Mode Standard: Reasoning about Requirements

Featuring the NECST Framework

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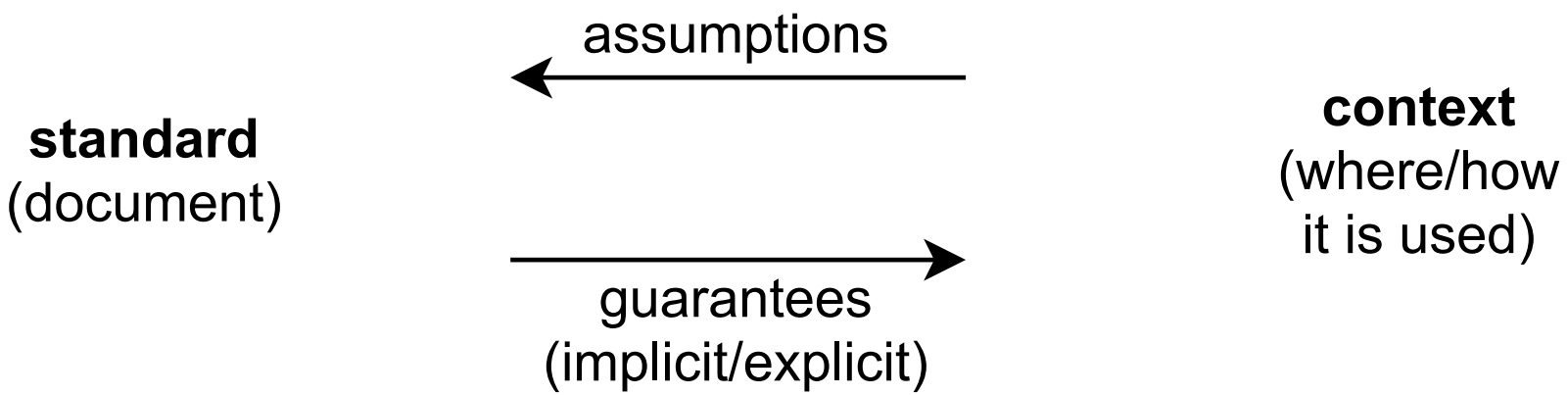
- Information Security Conference (ISC 2024)
  - October 23-25, Arlington, VA

Standards Review

- NIST commitment:
  - Periodical review of standards
- First review: AES (FIPS 197)
  - NISTIR 8319: Review of the AES (July 2021)
- Next: Modes of operation (SP 800-38 Series)
  - Draft NISTIR 8459: Modes Report (March 2023)

Methodology

- Where is the standard used?
- What security properties are required there?
- Does failure of security properties lead to **attacks**?



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- Again, focus on **attacks**...
  - Exhaustive search is infeasible, but...
    ...side-channel attacks recover key in minutes?
  - Block cipher secure against related-key attacks, or...
    ...disallow generating keys with known relations?
  - Vulnerabilities (CVE numbers)?

NIST SP 800-38 Series

- NIST SP 800-38A + Add: ECB, CBC, CFB, OFB, CTR
- NIST SP 800-38B: CMAC
- NIST SP 800-38C: CCM
- NIST SP 800-38D: GCM
- NIST SP 800-38E: XTS-AES
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  - CCA up-to-block (without MAC)
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  - CCA (without MAC)
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  - CCA (without MAC)

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  - CPA security (except ECB), IV (except ECB)
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- NIST SP 800-38D: GCM
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- NIST SP 800-38E: XTS-AES
  - CCA up-to-block (without MAC), tweak
- NIST SP 800-38F: KW, KWP, TKW
  - CCA (without MAC), no tweak
- NIST SP 800-38G: FF1, FF3
  - CCA (without MAC), tweak

Where Are 38A Modes Used?

- Length-preserving encryption
  - XTS (38E): only for storage devices
    (but 38A modes "continue to be approved for such devices")
  - Applications exist where ciphertext cannot be expanded...
- Building block for AEAD
  - Authentication-only mode: CMAC (38B), HMAC (FIPS 198-1)
  - Generic AEAD: e.g., CBC + HMAC
  - CCM (38C) and GCM (38D): AEAD based on CTR!

Always Use AEAD Modes?

- GCM (38C) and CCM (38D)
  - Based on **CTR**
- Nonce reuse:
  - Deduce plaintext from ciphertext difference!
- Short tag / no tag:
  - Control plaintext through ciphertext difference!

Alternatives?

- Nonce reuse: KW/KWP/TKW (38F) or FF1/FF3 (38G)
  - "Misuse resistant" AEAD
  - Most suitable for key wrapping (38F) or formatted data (38G)
  - Very slow for general use...
- No tag: XTS (38E)
  - ECB-like mode: independently encrypts every block...
  - Only for storage devices
  - CBC (38A): sometimes preferable?

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  - ~~Other?~~
- Why?
  - IV reuse, short or no tags, no key commitment, release of unverified plaintext,...
  - Many applications: disk encryption, packet encryption, message franking,...

Where We Are Now

- Third Block Cipher Modes Workshop (BCM3)
  - "NIST is particularly interested in discussing the possibility of standardizing a tweakable wide block encryption technique that could support a large range of input lengths"
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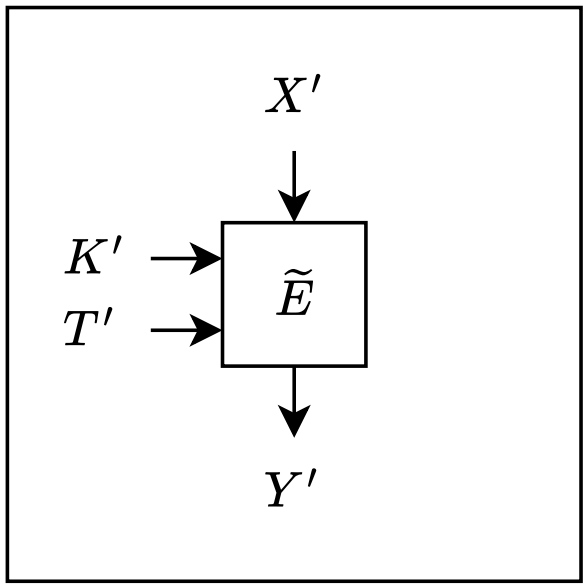
- This Workshop
  - Mode with provable security based on underlying block cipher
- Next
  - Requirements for mode of operation?
  - Block cipher: AES or Rijndael? Related keys? Tweak input?

Hierarchy

AEAD, Key Wrapping, Disk Encryption, etc. (derived functions) ← only encoding here

Accordion Cipher (mode of operation) ← all crypto here

(Tweakable) Block Cipher ← AES/Rijndael here



NECST Framework

- New features / future-proofing
- Efficiency / performance
- Compatibility (can it replace existing standards?)
- Security
- Technical reason (something doesn't work / can't be done)

Rogaway at BCM3

- Rogaway's Observation on SP 800-38 Series (BCM3)
  - SP 800-38 Series: 17 AES-based modes
  - Starting from scratch: maybe we would just have one?
  - "A mode that is like a wide block cipher"

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  - "A mode that is like a wide block cipher"
- Requirements
  - (C) Can replace SP 800-38 Series modes
  - (T) Except 38G (FF1, FF3) (e.g., radix causes headaches)

Accordion Cipher

- Accordion Cipher: $Y = E_{K,T}(X)$
  - Key $K \in \{0,1\}^k$
  - Tweak $T \in \{0,1\}^*$
  - Input X, Output $Y \in \{0,1\}^{m+\ell g}$, $\ell \in \{0,1,2,\ldots\}$
  - Minimum input size m
  - Granularity g
  - Invertible

- CTR, OFB

  ($\ell \geq 0$)

- CFB

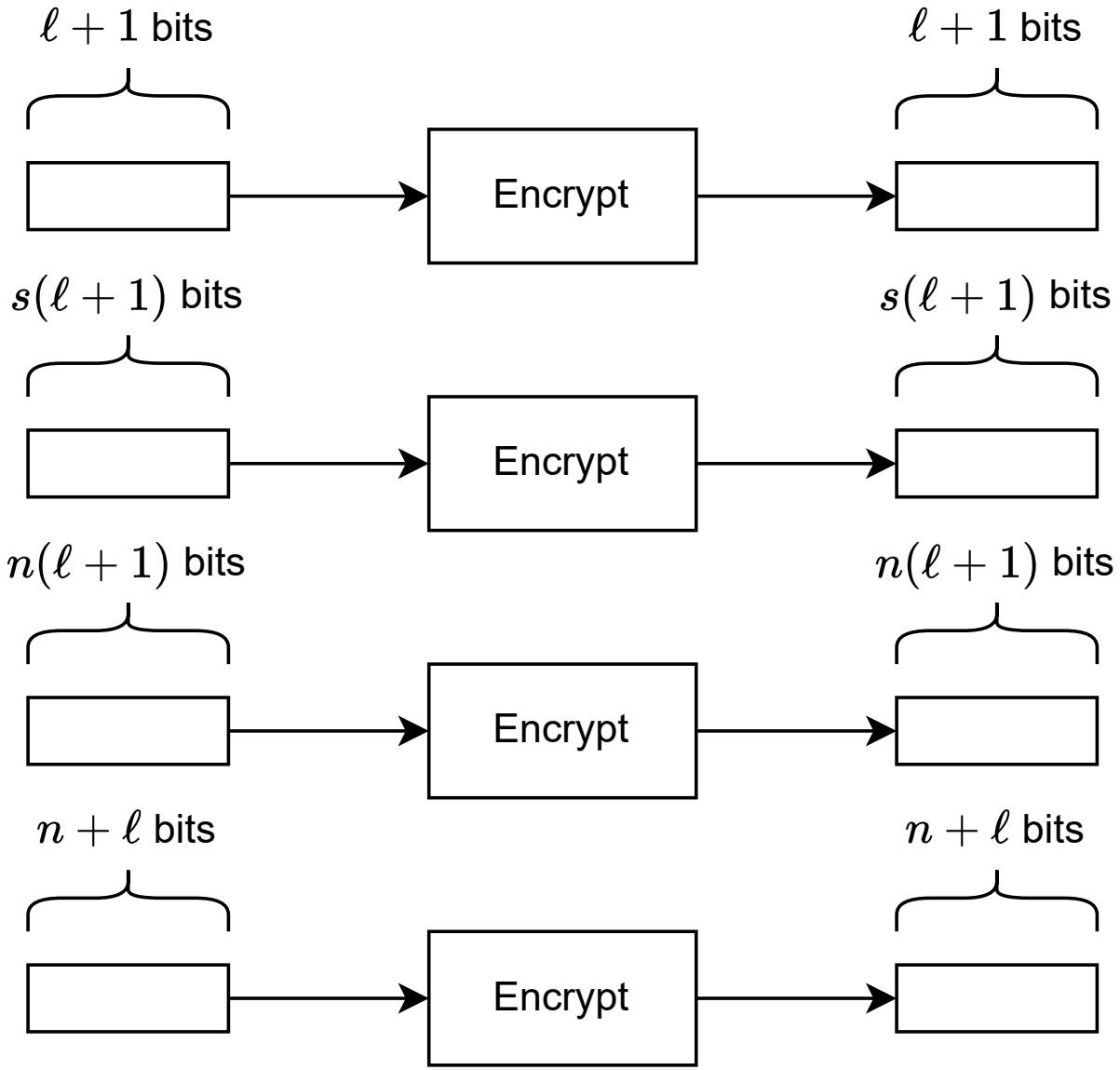
  (s = size of segment)

- ECB, CBC

  (n = block size)

- CBC-CS

  (CS1, CS2, CS3)



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or

  - (T) $m = 2n$ bits may simplify designs (e.g., AEZ v5 [HKR17])

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or

  - (S) large g helps to hide plaintext length [GJLN22]
    (but more secure: length-hiding padding)
  - (C,N) $g = 8$ bits sometimes needed: e.g., 509-byte for Tor

Maximum Input Size For 38-Series Compatibility

- Maximum Input Size?
  - (C) No limit specified in 38A for CBC, OFB, CFB
    (CTR limit can be small in practice, e.g.: 64 KiB [RW03])
  - (S) Stay well below $2^{n/2}$ blocks [BL16]
  - (N) BCM3: consider $n = 256$ (512?) to avoid limits in practice
    (Note: NIST LWC call required at least $2^{50} - 1$ bytes)

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- (E) Note: Increasing n is much more efficient than mode with beyond-birthday-bound security

Key Size for 38-Series Compatibility

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  - (C,S) 128, 192, 256 bits
  - (E) Fastest: 128 bits
  - (N) 512 bits? (seems not necessary: [Mou21])

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- Bit Strength
  - NIST LWC call: 128 bit length, 112 bit strength
  - (E) 256 bit length, 128 bit strength?

Tweak Size for 38-Series Compatibility

- Tweak Size
  - (C) empty for Key Wrapping (38F),
    $1 \ldots 2^{64} - 1$ bits for GCM IV,
    $0 \ldots$ *maxTlen* bytes for FF1 (no restrictions on *maxTlen*)
  - (S) Stay well below $2^{n/2}$ blocks
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(N) Extra Requirements?

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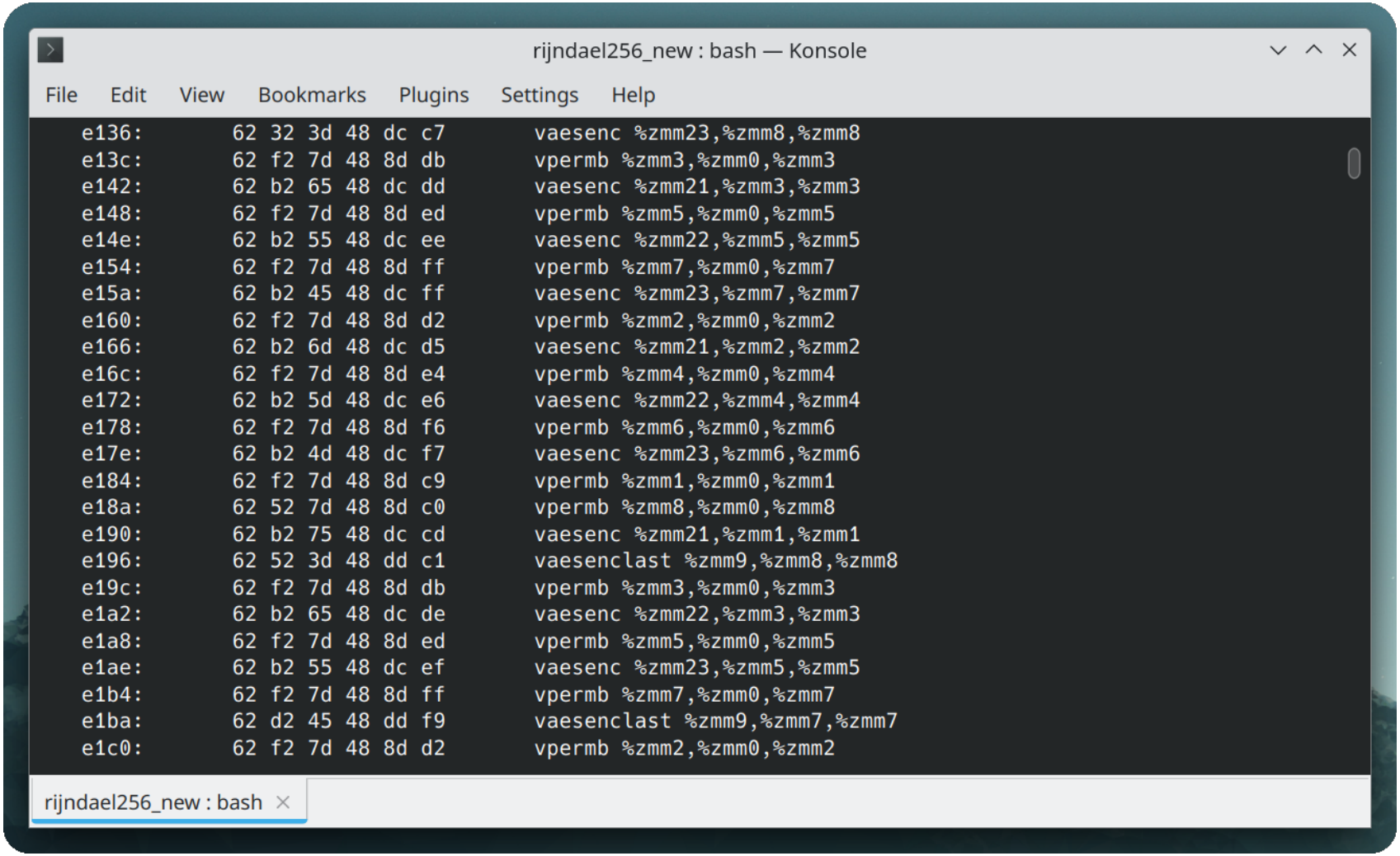
- Inverse-Free?
  - CMAC, GCM, CCM, FF1, etc. do not use inverse block cipher

(E) Block Cipher Requirements



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- Rijndael ($n = 256$, also $n = 512$) on same platform?
  - Same as AES would be: 0.22 cycles/byte
  - Rijndael benchmarks: 0.25 cycles/byte
  - Benchmark speed independent of key schedule!
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- (E) Note: New mode needs to be parallel (so that bottleneck is throughput, not latency)

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