Revisiting the Security of COMET Authenticated Encryption Scheme

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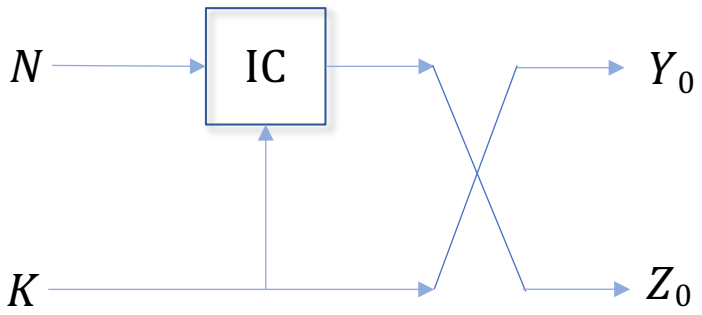
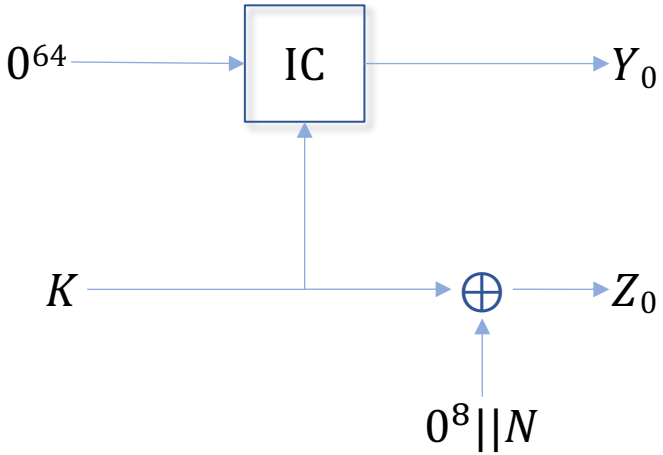
COMET: a quick overview

Initialization:



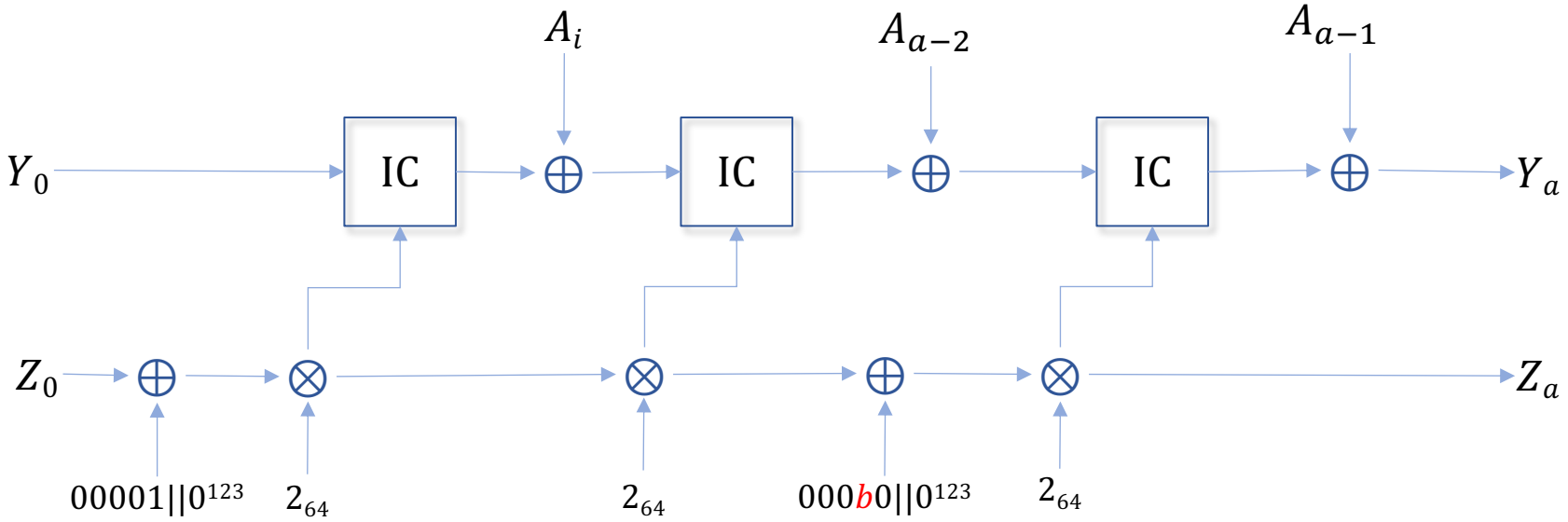
COMET-128



COMET-64

COMET: a quick overview

Associated Data Processing:

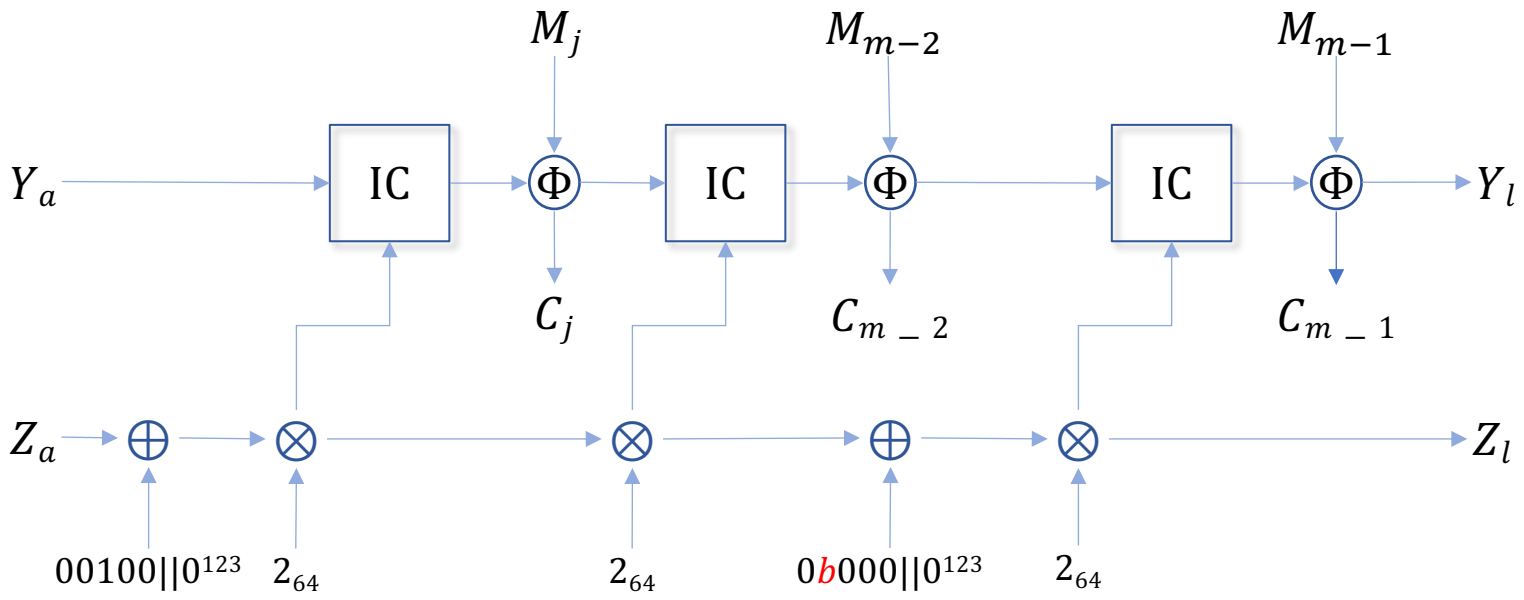


$0 \leq i \leq a-3$

2_{64} is primitive element of $\mathrm{GF}(2^{64})$

COMET: a quick overview

Plaintext Processing:

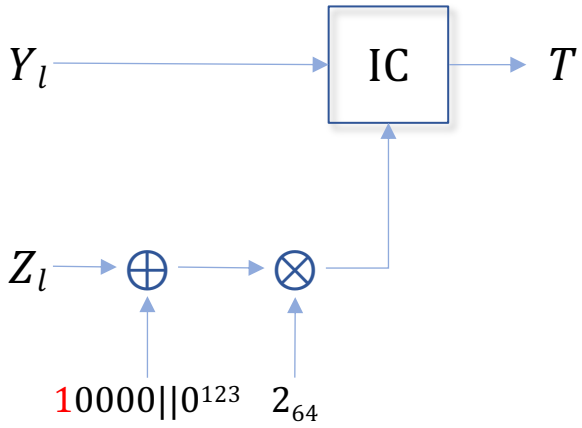


$$0 \leq j \leq m-3$$

$$l = a + m$$

COMET: a quick overview

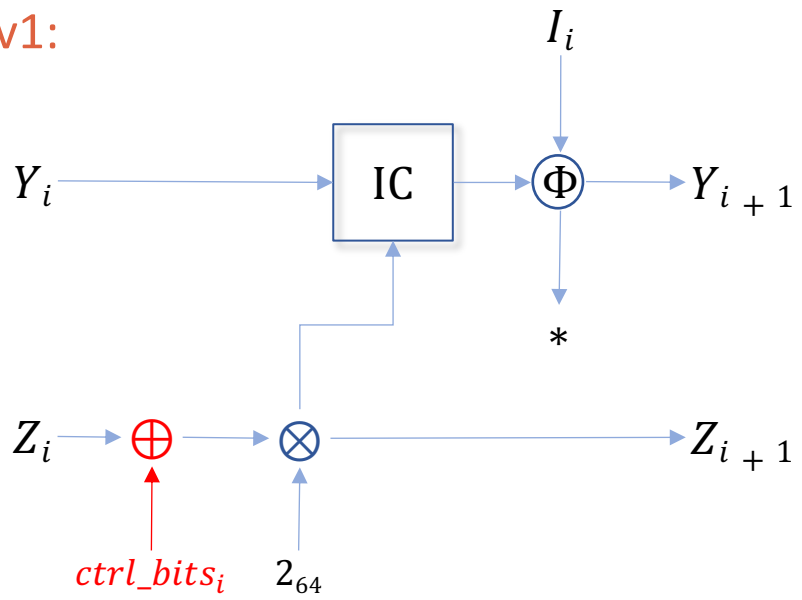
Tag Generation:



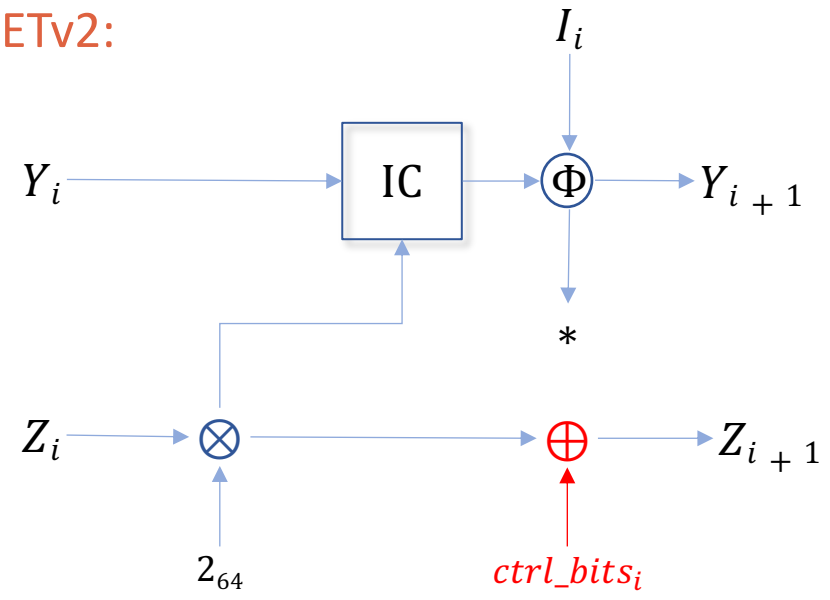
COMETv2: two updates

Change in control bits absorption:

COMETv1:



COMETv2:



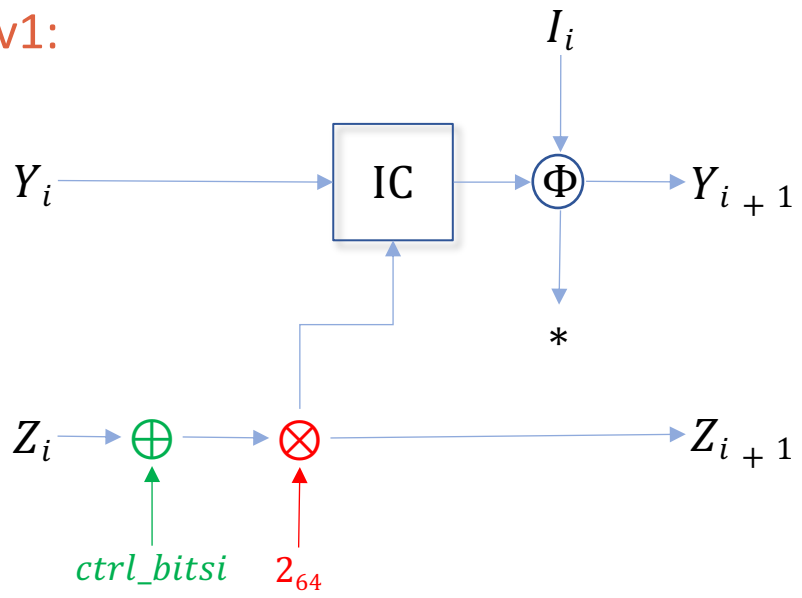
- $ctrl\_bits_i$ depends on the next input block I_i
- Requires n-bit additional memory in hardware.

- Shift the control bits absorption.
- Saves the n-bit additional memory.

COMETv2: two updates

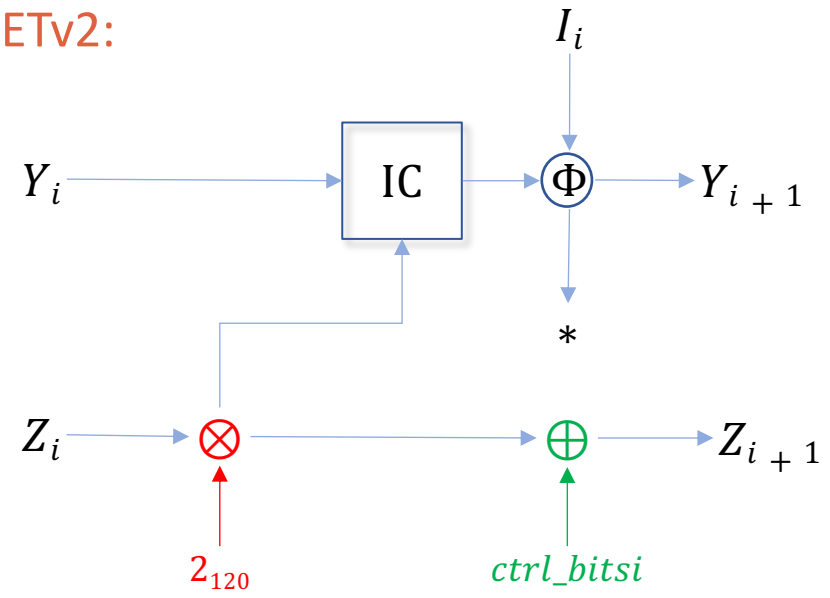
Change in primitive multiplication:

COMETv1:



- Only 64-LSBs of key is updated.
- Leads to key collisions if the 64-LSBs are fixed to 0^{64} .

COMETv2:



$$f(x) = x^{120} + x^9 + x^6 + x^2 + 1$$

- 120-LSBs of key is updated.
- Avoids earlier key-recovery attack strategies.

gCOMET: a generalization of COMET

- Control bit generator (Δ)

$$\Delta(A, M) := (ctrl_0, \ldots, ctrl_{a+m+2}), \qquad \text{where } |ctrl_i| = c.$$

- Feedback matrix (ϕ)

(similar to Beetle feedback)

$$\begin{pmatrix} Y \\ C \end{pmatrix} := \begin{pmatrix} \phi & I_n \\ I_n & I_n \end{pmatrix} . \begin{pmatrix} X \\ M \end{pmatrix}$$

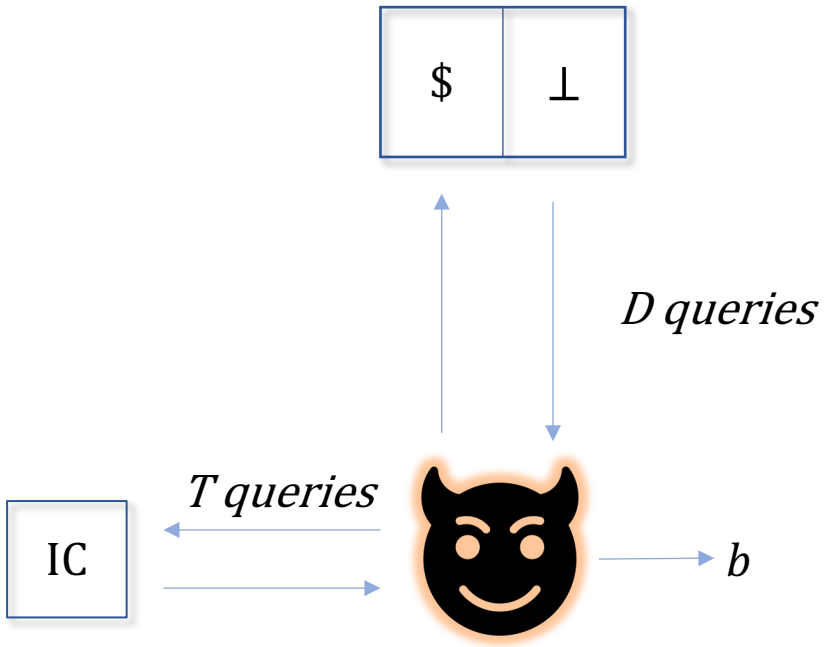
- Key-update matrix (α)

$$K_{i+1} := \begin{pmatrix} I_c & 0_{c \times (\kappa - c)} \\ 0_{(\kappa - c) \times c} & \alpha \end{pmatrix} . K_i$$

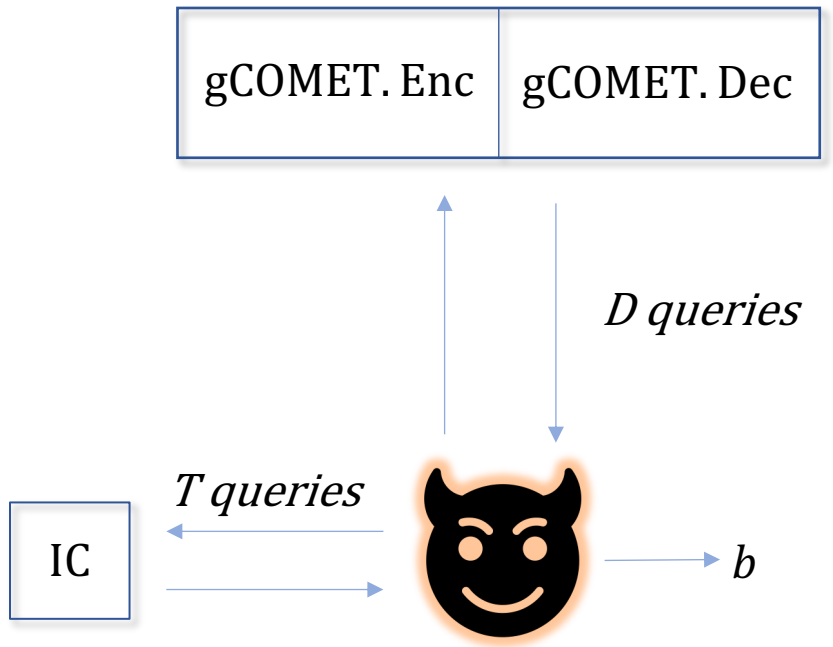
AEAD Security of gCOMET

AEAD Security Notion:

Ideal world (0):



Real world (1):



$$\mathbf{Adv}^{\text{aead}}(😈) := \left|\Pr(b = 1 \text{ in the ideal world}) - \Pr(b = 1 \text{ in the real world})\right|$$

AEAD Security of gCOMET

$$\mathbf{Adv}^{\mathsf{aead}}_{\mathsf{gCOMET}}(\mathcal{A}) \leq \left(\frac{2T}{2^{\kappa}} + \frac{6D}{2^{\mathsf{rank}(\alpha)}} + \frac{4D}{2^{\mathsf{rank}(\alpha)+n}}\right)\mu(D,n) + \frac{4D}{2^{\kappa}}\mu(T,n)$$

$$+ \min\left\{\frac{2D^2}{2^{\kappa}}\mu'(T,n,\mathsf{rank}(\phi)), \frac{2D^2}{2^{\mathsf{rank}(\alpha)}} + \frac{2D}{2^{\kappa}}\mu'(T,n,\mathsf{rank}(\phi))\right\}$$

$$+ \frac{18.77nDT}{2^{\kappa+\frac{\mathsf{rank}(\phi)}{2}}} + \frac{D+T}{2^{\kappa}} + \frac{D}{2^{\mathsf{rank}(\alpha)}} + \frac{4D^2}{2^{\mathsf{rank}(\alpha)+n}} + \frac{4DT}{2^{\kappa+n}} + \frac{2D}{2^{n}}.$$

AEAD Security of gCOMET

Some details:

$$(X_1, \ldots, X_q) \xleftarrow{\$} \{0,1\}^n$$

$$\mu(q,n) := \mathbb{E}\left(\max_a |\{i : X_i = a\}|\right) \qquad \mu'(q,n,\mathsf{rank}(\phi)) := \mathbb{E}\left(\max_a |\{i : \phi(X_i) = a\}|\right)$$

$$\mu(q,n) \leq \begin{cases} 3 & q \leq 2^{n/2} \\ \frac{4n}{\log_2 n} & 2^{n/2} < q \leq 2^n \\ 5n\left\lceil \frac{q}{n2^n} \right\rceil & q > 2^n. \end{cases} \qquad \mu'(q,n,\mathsf{rank}(\phi)) \leq \begin{cases} \frac{4n}{\log_2 n} & q \leq 2^{\mathsf{rank}(\phi)} \\ 5n\left\lceil \frac{q}{n2^{\mathsf{rank}(\phi)}} \right\rceil & q > 2^{\mathsf{rank}(\phi)}. \end{cases}$$

AEAD Security of COMETv1

COMETv1-128:

$$\mathbf{Adv}^{\text{aead}}_{\text{COMET-128}}(\mathcal{A}) \leq \frac{D}{2^{63.75}} + \frac{T}{2^{125.19}} + \frac{DT}{2^{184.24}}$$

Secure while $D \leq 2^{64}$ bytes and $T \leq 2^{120}$.

AEAD Security of COMETv1

COMETv1-64:

$$\mathbf{Adv}^{\text{aead}}_{\text{COMET-64}}(\mathcal{A}) \leq \frac{D}{2^{58.98}} + \frac{T}{2^{121.58}} + \frac{DT}{2^{152.24}} + \frac{D^2T}{2^{193.67}}$$

Secure while $D \leq 2^{40}$ bytes and $T \leq 2^{112}$.

AEAD Security of COMETv2

COMETv2-128:

$$\mathbf{Adv}^{\text{aead}}_{\text{COMETv2-128}}(\mathcal{A}) \leq \frac{D}{2^{119.5}} + \frac{T}{2^{125.19}} + \frac{DT}{2^{184.24}}$$

Secure while $D \leq 2^{64}$ bytes and $T \leq 2^{120}$.

AEAD Security of COMETv2

COMETv2-64:

$$\mathbf{Adv}^{\text{aead}}_{\text{COMETv2-64}}(\mathcal{A}) \leq \frac{D}{2^{66}} + \frac{T}{2^{121.58}} + \frac{DT}{2^{152.24}}$$

Secure while $D \leq 2^{40}$ bytes and $T \leq 2^{112}$.

Some Future Directions

1. Better bounds for COMETv2-64

$$O\left(\frac{nDT}{2^{\kappa+\frac{n}{2}}}\right) \quad \xrightarrow{?} \quad O\left(\frac{DT}{2^{\kappa+\frac{n}{2}}}\right)$$

2. Is perfectly random permutation necessary for Sponge-like AEAD?

COMET is a Sponge-like AEAD with a non-idealized permutation!

3. Key-recovery security can be proved $O(2^{120})$.
   - We have identified bad events corresponding to key-recovery.
   - Need to show it more formally.

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Thank you! Questions?