# Daence: Salsa20 and ChaCha in Deterministic Authenticated Encryption with no noNCEnse

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**Abstract**

We present Daence, a deterministic authenticated cipher based on a pseudorandom function family and a universal hash family, similar to siv [35]. We recommend instances with Salsa20 [14] or ChaCha [15], and Poly1305 [13], for high performance, high security, and easy deployment.

## 1 Introduction

The nonce-based authenticated cipher crypto_secretbox_xsalsa20poly1305 in NaCl [16], and the variant ChaCha/Poly1305 defined by the IETF [33] for TLS [31], are widely available in fast software implementations resistant to timing side channels. The nonce-based authenticated cipher AES-GCM [23] is popular, though only with hardware support is it fast and resistant to timing side channels.

These nonce-based ciphers fail catastrophically in the face of nonce reuse. They are best suited to protocols that are designed to support sequential message numbers, such as the record number in TLS. Some applications are unable to keep the state needed to maintain a sequential message number, and although they could use an extended nonce like XSalsa20 [17] chosen randomly, some environments may not have a reliable entropy source. The *nonce-misuse-resistant* authenticated cipher AES-GCM-SIV [24] was developed to address these use cases, but it carries with it the performance and side channel costs of AES-GCM—and amplifies the performance cost by deriving fresh keys for each distinct nonce, yet has very narrow security margins.

We propose a deterministic authenticated cipher Daence built out of the Salsa20 or ChaCha pseudorandom function family and the Poly1305 universal hash family. The design is based on the siv construction of Rogaway and Shrimpton [35], with a variable-input-prf made by composing a universal hash family with a fixed-input prf [6, §1.5][11, §9, Theorem 9.2]. Daence is easily implemented in terms of the primitives available in NaCl and libsodium.

## 2 Security contract

DAENCE is a deterministic authenticated cipher. This means it consists of two functions:

$t \parallel c = \text{DAENCE-ENCRYPT}(k, a, m)$ takes a key $k$ (96-byte in SALSA20-DAENCE, 64-byte in CHACHA-DAENCE), a string $a$ of at most $2^{38}$ bytes of associated data, and a message $m$ of at most $2^{38}$ bytes (256 GB).

DAENCE-ENCRYPT returns an authenticated ciphertext $t \parallel c$ which is 24 bytes longer than $m$.

$m = \text{DAENCE-DECRYPT}(k, a, t \parallel c)$ takes a key $k$, a string $a$ of at most $2^{38}$ bytes of associated data, and an alleged authenticated ciphertext $t \parallel c$ of at most $24 + 2^{38}$ bytes.

- If $t \parallel c = \text{DAENCE-ENCRYPT}(k, a, m)$, DAENCE-DECRYPT returns $m$.
- Otherwise, DAENCE-DECRYPT reports a forgery with high probability. In the sequel we denote this by the symbol '$\perp$'; in practice, a `crypto_dae_salsa20daence_open` function in the style of NaCl may return an error code or throw an exception.

**Responsibilities of the user.**

1. You must choose a secret key $k$ uniformly at random and independently of everything else in your application. (You may safely derive the 96-byte key $k$ from a 32-byte key $k'$ by a key derivation function—*e.g.*, $k = \text{HKDF-SHA256}_{k'}(salt, \text{'foo'}, 96)$.)
2. If DAENCE-DECRYPT reports a forgery, you must decline to act on the alleged message content except by immediately dropping it on the floor.
3. You must encrypt at most $2^{52}$ messages with each key.

   Applications limited to smaller *messages* can safely process a larger *number* of messages: if every message is at most $L < 2^{38}$ bytes long (including associated data), then you may process up to $2^{90}/L$ messages.

**Security guarantee.** Under any key $k$ independently:

1. If you choose a distinct associated data string for every message, then an adversary has no hope of distinguishing the ciphertexts of your messages from uniform random byte strings of the same length, or of distingushing the tags from uniform random 24-byte strings.
2. If you repeat an associated data string, then an adversary has no hope of distinguishing the ciphertexts of *distinct* messages from uniform random byte strings of the same length, but can tell when messages are repeated.
3. The adversary's probability of succeeding at forgery—even after flooding your system with up to $2^{100}$ forgery attempts—is less than $1/2^{32}$.

## 2.1 Safe usage limits

We recommend that each key be used to encrypt no more than $2^{52}$ messages if an application may attain the maximum length of $2^{38}$ bytes in the associated data and $2^{38}$ bytes in the message. Such applications can withstand well over $2^{100}$ forgery attempts before the adversary's advantage exceeds $1/2^{32}$.

For better security, we recommend that each application set application-specific limits on the sum $\ell_a + \ell_m$ of the associated data and message length. This limit should be chosen according to how much memory the application is willing to let a forger waste in a denial of service attack before detection. For example:

- an IP packet (on a path with the standard ethernet MTU) is at most 1500 bytes;
- a TLS record is at most $2^{14}$ bytes;
- a file system block is typically at most $2^{15}$ or $2^{16}$ bytes;
- a Tarsnap file chunk can be up to around $2^{18}$ bytes.

Applications limited to smaller *messages* can safely process a larger *number* of messages per key—*e.g.*, applications limited to $2^{30}$ bytes per message can safely process $2^{60}$ messages and withstand $2^{120}$ forgery attempts, and applications limited to 1500 bytes per message can safely process $2^{79}$ messages and withstand $2^{158}$ forgery attempts, before the adversary's advantage exceeds $1/2^{32}$. In general, a single DAENCE key is safe for up to $2^{90}/(\ell_a + \ell_m)$ messages, or $2^{80}$ messages, whichever is smaller.

## 2.2 Comparison to alternative ciphers

In Table 1, we compare the adversary's advantage against DAENCE to several obvious alternatives, for various maximum message sizes and numbers of messages:

**AES-SIV** ('SIV') a deterministic authenticated cipher in the SIV construction, built out of AES-CTR and AES-CMAC. (A variant, AES-PMAC-SIV [2], uses AES-PMAC [19] instead of AES-CMAC for better parallelism and essentially the same security.)

Security [35, §4, Theorem 2][35, §5, Theorem 3, with $p = 1$][12, §2, Theorem 2.2] is dominated by the birthday bound on the 128-bit block size of AES. DAENCE avoids this bottleneck by using a native PRF—SALSA20 or CHACHA—instead of approximating one by a PRP like AES.

**AES-GCM-SIV** ('GCM-SIV') a nonce-misuse-resistant authenticated cipher built out of AES-CTR and the polynomial evaluation hash POLYVAL related to AES-GCM's GHASH.

We consider both AES-GCM-SIV's *deterministic* security with a fixed nonce [29, §4, Theorem 3, with 256-bit AES keys and $Q = 1$ distinct

nonces] as well as its *randomized* security [29, §3.3, Corollary 1, with 256-bit AES keys and random nonces].

Obviously AES-GCM-SIV's randomized security, with no misuse, is better; we consider both because the cipher is advertised as 'misuse-resistant'—if misused to the point that the same nonce is used for every message, whether because of entropy failure [22][25] or virtual machine rollbacks or coding errors, AES-GCM-SIV gives the deterministic security. The margin of this paper is too small to fit a neat visual representation of all the dimensions in which nonce reuse might occur—maximum reuses per nonce, average reuses per nonce, *etc*.

- For *deterministic security*, AES-GCM-SIV is dominated by the birthday bound on the 128-bit block size of AES—and the birthday bound on the 128-bit tag size *multiplied* by the maximum message length, because of POLYVAL collision probability.

  DAENCE avoids these bottlenecks by using a native PRF and by using a much larger universal hash family to derive a 192-bit tag.
- For *randomized security with no misuse*, AES-GCM-SIV avoids the birthday bound on the block and tag size by deriving a fresh AES key for each message—at high cost (whether or not it is misused) to performance and side channel security in implementations that cannot rely on hardware AES acceleration.

The deterministic security bound could be made tighter by judiciously incorporating the better PRF/PRP switching lemma of [12, §2, Theorem 2.2] into [29, Appendix A, Lemma 2], but it would remain slightly worse than AES-SIV because POLYVAL's collision probability contributes a factor of the maximum message length.

**AES-GCM** ('GCM') a nonce-based authenticated cipher built out of AES-CTR and the polynomial evaluation hash GHASH.

Security [27, Appendix C, Eq. (22)] is dominated by the birthday bound on the 128-bit block size of AES. No misuse-resistance—repeating a nonce is fatal.

**CHACHA/POLY1305** ('C/P') a nonce-based authenticated cipher built out of CHACHA and POLY1305.

Security [16, §9, Security notes] is *not* affected by any birthday bound, but the POLY1305 forgery advantage denominator, $2^{103}$, is smaller than for GHASH, $2^{128}$, which is why advantage against CHACHA/POLY1305 starts higher but rises slower than AES-GCM. No misuse-resistance—repeating a nonce is fatal.

Unlike CHACHA/POLY1305, DAENCE *is* subject to the birthday bound (on the SIV tag size) because it has no nonce—but it drives the denominator up to $2^{206}$ by running two independent POLY1305 instances in parallel, which still leaves room to truncate the tag to 192 bits.

Table 1: Comparison of adversary's advantage for various authenticated ciphers. We suppose for the sake of presentation on two-dimensional paper that the adversary can attempt about a million times as many forgeries ($2^{20}$) as there are legitimate messages encrypted by the user; users for whom this is not accurate can use the theorems below to compute safe usage limits.
Advantage bounds above $2^{-32}$ are ***highlighted***; this somewhat arbitrary cutoff is derived from NIST guidance on AES-GCM [23, §8, p. 18].

| | | | deterministic | | | randomized | nonce-based | |
|---|---|---|---|---|---|---|---|---|
| max bytes per msg | | msgs | DAENCE | SIV | GCM-SIV | GCM-SIV | GCM | C/P |
| IP packet: | $2^{11}$ | $2^{20}$ | $2^{-149}$ | $2^{-86}$ | $2^{-35}$ | $2^{-83}$ | $2^{-81}$ | $2^{-56}$ |
| | $2^{11}$ | $2^{30}$ | $2^{-130}$ | $2^{-76}$ | ***$2^{-15}$*** | $2^{-63}$ | $2^{-70}$ | $2^{-46}$ |
| | $2^{11}$ | $2^{40}$ | $2^{-110}$ | $2^{-55}$ | ***1*** | $2^{-53}$ | $2^{-60}$ | $2^{-36}$ |
| | $2^{11}$ | $2^{50}$ | $2^{-90}$ | ***1*** | ***1*** | $2^{-43}$ | ***1*** | ***$2^{-26}$*** |
| | $2^{11}$ | $2^{79}$ | $2^{-33}$ | ***1*** | ***1*** | ***1*** | ***1*** | ***1*** |
| megabyte: | $2^{20}$ | $2^{10}$ | $2^{-142}$ | $2^{-96}$ | $2^{-37}$ | $2^{-83}$ | $2^{-82}$ | $2^{-57}$ |
| | $2^{20}$ | $2^{20}$ | $2^{-132}$ | $2^{-86}$ | ***$2^{-17}$*** | $2^{-73}$ | $2^{-72}$ | $2^{-47}$ |
| | $2^{20}$ | $2^{30}$ | $2^{-114}$ | $2^{-74}$ | ***1*** | $2^{-62}$ | $2^{-61}$ | $2^{-37}$ |
| | $2^{20}$ | $2^{40}$ | $2^{-94}$ | ***1*** | ***1*** | $2^{-52}$ | $2^{-51}$ | ***$2^{-27}$*** |
| | $2^{20}$ | $2^{50}$ | $2^{-74}$ | ***1*** | ***1*** | $2^{-42}$ | ***1*** | ***$2^{-17}$*** |
| | $2^{20}$ | $2^{70}$ | $2^{-34}$ | ***1*** | ***1*** | ***$2^{-12}$*** | ***1*** | ***1*** |
| gigabyte: | $2^{30}$ | $2^{10}$ | $2^{-122}$ | $2^{-96}$ | ***$2^{-17}$*** | $2^{-63}$ | $2^{-72}$ | $2^{-47}$ |
| | $2^{30}$ | $2^{20}$ | $2^{-112}$ | $2^{-84}$ | ***1*** | $2^{-53}$ | $2^{-61}$ | $2^{-37}$ |
| | $2^{30}$ | $2^{30}$ | $2^{-94}$ | ***1*** | ***1*** | $2^{-43}$ | $2^{-51}$ | ***$2^{-27}$*** |
| | $2^{30}$ | $2^{40}$ | $2^{-74}$ | ***1*** | ***1*** | $2^{-33}$ | $2^{-38}$ | ***$2^{-17}$*** |
| | $2^{30}$ | $2^{60}$ | $2^{-34}$ | ***1*** | ***1*** | ***$2^{-13}$*** | ***1*** | ***1*** |
| AES-GCM max: | $2^{36}$ | $2^{10}$ | $2^{-110}$ | $2^{-96}$ | ***$2^{-5}$*** | $2^{-51}$ | $2^{-65}$ | $2^{-41}$ |
| | $2^{36}$ | $2^{25}$ | $2^{-92}$ | ***1*** | ***1*** | $2^{-36}$ | $2^{-50}$ | ***$2^{-26}$*** |
| | $2^{36}$ | $2^{54}$ | $2^{-34}$ | ***1*** | ***1*** | ***$2^{-7}$*** | ***1*** | ***1*** |
| ChaCha max: | $2^{38}$ | $2^{10}$ | $2^{-106}$ | $2^{-96}$ | ***$2^{-1}$*** | $2^{-47}$ | $2^{-63}$ | $2^{-39}$ |
| | $2^{38}$ | $2^{25}$ | $2^{-88}$ | ***1*** | ***1*** | $2^{-32}$ | $2^{-48}$ | ***$2^{-24}$*** |
| | $2^{38}$ | $2^{52}$ | $2^{-34}$ | ***1*** | ***1*** | ***$2^{-5}$*** | ***1*** | ***1*** |

# 3 Definition

**Poly1305$^2$.** For 16-byte strings $k_1, \ldots, k_4$, and a byte string $m$, define

$$\textsc{Poly1305}^2_{k_1,k_2}(m) := \textsc{Poly1305}_{k_1}(m) \parallel \textsc{Poly1305}_{k_2}(m),$$

a 32-byte string. For byte strings $a$ and $m$, define

$$\textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a, m) := \textsc{Poly1305}^2_{k_3,k_4}(h_a \parallel h_m),$$

where $h_a = \textsc{Poly1305}^2_{k_1,k_2}(a)$ and $h_m = \textsc{Poly1305}^2_{k_1,k_2}(m)$.

**HXSalsa20.** For 32-byte key $k_0$ and 16-byte inputs $i$ and $j$, define

$$\text{HXSalsa20}_{k_0}(i \parallel j) := \text{HSalsa20}_{\text{HSalsa20}_{k_0}(i)}(j),$$

a 32-byte string. Note there is a public function $G$ such that $\text{HXSalsa20}_{k_0}(i \parallel j) = G(\text{XSalsa20}_{k_0}(i \parallel j), j)$, just as HSalsa20 can be defined in terms of Salsa20 [17] by $\text{HSalsa20}_{k_0}(i) = G(\text{Salsa20}_{k_0}(i), i)$.

**Salsa20-Daence.** To **encrypt**, given a 96-byte key $k$, associated data $a$ of at most $2^{38}$ bytes, and a message $m$ of at most $2^{38}$ bytes, compute:

1. $k_0 \parallel k_1 \parallel k_2 \parallel k_3 \parallel k_4 := k$ (32-byte $k_0$; 16-byte $k_1, \ldots, k_4$)
2. $t := \text{trunc}_{192}\big(\text{HXSalsa20}_{k_0}(\textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a, m))\big)$ (24-byte $t$)
3. $c := m \oplus \big(\text{XSalsa20}_{k_0}(t \parallel 0) \parallel \text{XSalsa20}_{k_0}(t \parallel 1) \parallel \cdots\big)$

The authenticated ciphertext is $t \parallel c$.

To **decrypt**, given a 96-byte key $k$, associated data $a$ of at most $2^{38}$ bytes, and an alleged authenticated ciphertext $t \parallel c$ of 24 to $24 + 2^{38}$ bytes, compute:

1. $k_0 \parallel k_1 \parallel k_2 \parallel k_3 \parallel k_4 := k$ (32-byte $k_0$; 16-byte $k_1, \ldots, k_4$)
2. $m := c \oplus \big(\text{XSalsa20}_{k_0}(t \parallel 0) \parallel \text{XSalsa20}_{k_0}(t \parallel 1) \parallel \cdots\big)$
3. $t' := \text{trunc}_{192}\big(\text{HXSalsa20}_{k_0}(\textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a, m))\big)$ (24-byte $t'$)

If $t' \stackrel{?}{=} t$, return $m$; otherwise erase $m$ and report a forgery.

**ChaCha-Daence.** ChaCha-Daence has a 64-byte key, replaces Salsa20 by ChaCha (extended XChaCha [3]), and tweaks the encoding to match ChaCha/Poly1305 [33] by zero-padding the associated data and message to multiples 16 bytes as $\underline{a}$ and $\underline{m}$ and appending 8-byte little-endian lengths:

1. $k_0 \parallel k_1 \parallel k_2 := k$ (32-byte $k_0$, 16-byte $k_1$, 16-byte $k_2$)
2. $t := \text{trunc}_{192}\big(\text{HXChaCha}_{k_0}(\textsc{Poly1305}^2_{k_1,k_2}(\underline{a} \parallel \underline{m} \parallel |a|_8 \parallel |m|_8))\big)$
3. $c := m \oplus \big(\text{XChaCha}_{k_0}(t, 0) \parallel \text{XChaCha}_{k_0}(t, 1) \parallel \cdots\big)$

The XChaCha input $(t, n)$ is encoded as $t_0 \parallel n \parallel 0^4 \parallel t_1$, where $t_0$ is the first 16 bytes of $t$, $n$ is a 4-byte little-endian block counter, $0^4$ is four zero bytes, and $t_1$ is the last 8 bytes of $t$. Decryption is derived similarly.

# 4 Security notions

Let $A$ be a random decision algorithm with access to an oracle $\mathcal{O}$. Write $\Pr[A(\mathcal{O})]$ for the probability $A$ accepts after making various queries to $\mathcal{O}$:

**Encryption queries for a *single* user** Given associated data $a$ and message $m$, return an authenticated ciphertext $t \parallel c$.

**Decryption queries for a *single* user** Given associated data $a$ and alleged authenticated ciphertext $t \parallel c$, return a message $m$, or $\perp$ if the alleged authenticated ciphertext is deemed a forgery.

**Encryption queries for *multiple* users** Given a user number $u$, associated data $a$, and message $m$, return an authenticated ciphertext $t \parallel c$.

**Decryption queries for *multiple* users** Given a user number $u$, associated data $a$, and alleged authenticated ciphertext $t \parallel c$, return a message $m$, or $\perp$ if the alleged ciphertext is deemed a forgery.

**Function queries for *multiple* users** Given a user number $u$ and an input $x$, return an output $y$.

The adversary $A$ is assumed not to repeat queries, nor to submit the answers from encryption queries as decryption queries. We review standard notions of security (*e.g.*, [35, Definition 1][5, §3]), loosely summarized as how well $A$ can tell users of a real cryptosystem—Daence, XSalsa20, *etc.*—from pranksters who just roll dice to answer every query.

**Definition 1.** *The **pathological deterministic authenticated cipher** $U_1$ returns an independent uniform random authenticated ciphertext of the appropriate length for each encryption query, and returns $\perp$ for every decryption query. The notion extends naturally to the multi-user setting; call it $U$.*

**Definition 2.** *For a deterministic authenticated cipher $E_k$ with random key $k$, the **multi-user deterministic authenticated encryption advantage** of $A$ against $E$ is the statistical distance from $E_k$ to $U$ measured by $A$, where by abuse of language $k$ is understood to mean a collection of keys chosen independently by many users and $E_k$ is understood to mean a collection of instances of $E$ for many users keyed by their respective keys:*

$$\mathrm{Adv}_E^{\text{mu-DAE}}(A) := |\Pr[A(E_k)] - \Pr[A(U)]|.$$

*Here $A$ may submit encryption and decryption queries for* multiple *users.*

The single-user $\mathrm{Adv}_E^{\mathrm{DAE}}(A)$ is defined similarly.

**Definition 3.** *For a function family $\phi_k$ with random key $k$, the **multi-user pseudorandom function advantage** of $A$ against $\phi$ is the statistical distance from $\phi_k$ to $f$ measured by $A$, where $f$ is a a uniform random function of the same domain and codomain (where '$\phi_k$' and '$f$' again mean many independent instances):*

$$\mathrm{Adv}_\phi^{\text{mu-PRF}}(A) := |\Pr[A(\phi_k)] - \Pr[A(f)]|.$$

*Here $A$ may submit function queries for* multiple *users.*

# 5 Analysis

**Theorem 1** (SALSA20-DAENCE)**.** *Let $A$ be a random decision algorithm with encryption and decryption oracles for a set of deterministic authenticated cipher users. Suppose $A$ submits $E(u)$ encryption queries and $D(u)$ decryption queries to the $u^{th}$ user of up to $\ell_a(u)$ bytes of associated data and $\ell_m(u)$-byte messages. Then there is an algorithm $A'$ making at most $\sum_u \big(1+\lceil \ell_m(u)/64 \rceil\big)\big(E(u)+D(u)\big)$ oracle queries and having the cost of $A$ plus the cost of evaluating* POLY1305$^2$ *and $\oplus$ on $\sum_u E(u)+D(u)$ different $(\ell_a(u),\ell_m(u))$-byte inputs, such that*

$$\begin{aligned}\mathrm{Adv}^{\text{mu-DAE}}_{\text{DAENCE}}(A) \le \mathrm{Adv}^{\text{mu-PRF}}_{\text{XSALSA20}}(A') \\ + \sum_u \frac{2D(u) + E(u)^2 + \binom{E(u)}{2}}{2^{192}} \\ + \varepsilon(\ell_a(u),\ell_m(u)) \cdot \big(D(u) + \tbinom{E(u)}{2}\big),\end{aligned}$$

*where*

$$\varepsilon(\ell_a,\ell_m) := \frac{\max\{\lceil \ell_a/16 \rceil^2, \lceil \ell_m/16 \rceil^2\} + 16}{2^{206}}.$$

**Theorem 2** (CHACHA-DAENCE)**.** *Let $A$ be a random decision algorithm with encryption and decryption oracles for a set of deterministic authenticated cipher users. Suppose $A$ submits $E(u)$ encryption queries and $D(u)$ decryption queries to the $u^{th}$ user of up to $\ell_a(u)$ bytes of associated data and $\ell_m(u)$-byte messages. Then there is an algorithm $A'$ making at most $\sum_u \big(1+\lceil \ell_m(u)/64 \rceil\big)\big(E(u)+D(u)\big)$ oracle queries and having the cost of $A$ plus the cost of evaluating* POLY1305$^2$ *and $\oplus$ on $\sum_u E(u)+D(u)$ different $(\ell_a(u),\ell_m(u))$-byte inputs, such that*

$$\begin{aligned}\mathrm{Adv}^{\text{mu-DAE}}_{\text{DAENCE}}(A) \le \mathrm{Adv}^{\text{mu-PRF}}_{\text{XCHACHA}}(A') \\ + \sum_u \frac{2D(u) + E(u)^2 + \binom{E(u)}{2}}{2^{192}} \\ + \frac{\lceil (\ell_a(u) + \ell_m(u) + 16)/16 \rceil^2}{2^{206}} \cdot \big(D(u) + \tbinom{E(u)}{2}\big).\end{aligned}$$

**Outline of proof.**

1. Set a bound on the collision probability of POLY1305$^2$.
2. Set a bound on DAE advantage against an idealized version of DAENCE.
3. Extend the bound to the multi-user setting.
4. Instantiate the idealization with the actual PRF, XSALSA20 or XCHACHA.

## 5.1 Collisions under double-hashing with associated data

**Lemma 1** (Double-hashing)**.** *Let $k_1, k_2$ be independent* Poly1305 *keys. For any distinct strings $m \neq m'$ of at most $\ell$ bytes,*

$$\Pr[\textsc{Poly1305}^2_{k_1,k_2}(m) = \textsc{Poly1305}^2_{k_1,k_2}(m')] \leq \varepsilon(\ell) := \frac{\lceil \ell/16 \rceil^2}{2^{206}}.$$

*Proof.* By [13, Theorem 3.3],

$$\Pr[\textsc{Poly1305}_{k_1}(m) = \textsc{Poly1305}_{k_1}(m')] \leq \frac{8\lceil \ell/16 \rceil}{2^{106}},$$

and likewise for $k_2$. Since $k_1$ and $k_2$ are independent,

$$\begin{aligned}
&\Pr[\textsc{Poly1305}^2_{k_1,k_2}(m) = \textsc{Poly1305}^2_{k_1,k_2}(m')] \\
&\quad = \Pr[\textsc{Poly1305}_{k_1}(m) = \textsc{Poly1305}_{k_1}(m'), \\
&\qquad\qquad \textsc{Poly1305}_{k_2}(m) = \textsc{Poly1305}_{k_2}(m')] \\
&\quad = \Pr[\textsc{Poly1305}_{k_1}(m) = \textsc{Poly1305}_{k_1}(m')] \\
&\qquad \cdot \Pr[\textsc{Poly1305}_{k_2}(m) = \textsc{Poly1305}_{k_2}(m')] \\
&\quad \leq \left(\frac{8\lceil \ell/16 \rceil}{2^{106}}\right)^2 = \frac{64\lceil \ell/16 \rceil^2}{2^{212}} = \frac{\lceil \ell/16 \rceil^2}{2^{206}}.
\end{aligned}$$

□

**Lemma 2** (Hashing tuples)**.** *Let $k_1, \ldots, k_4$ be independent* Poly1305 *keys. For strings $a, a'$ up to $\ell_a$ bytes and $m, m'$ up to $\ell_m$ bytes, if $(a, m) \neq (a', m')$ then*

$$\begin{aligned}
&\Pr[\textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a, m) = \textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a', m')] \\
&\qquad\qquad \leq \varepsilon(\ell_a, \ell_m) := \frac{\max\{\lceil \ell_a/16 \rceil^2, \lceil \ell_m/16 \rceil^2\} + 16}{2^{206}}.
\end{aligned}$$

*Proof.* Write $H := \textsc{Poly1305}^2_{k_1,k_2}$ and $H^* := \textsc{Poly1305}^2_{k_3,k_4}$. Let $h_x := H(x)$. We must have either $a \neq a'$ or $m \neq m'$, or both. If $a \neq a'$, then by Lemma 1, $\Pr[(h_a, h_m) = (h_{a'}, h_{m'})] \leq \Pr[h_a = h_{a'}] \leq \varepsilon(\ell_a)$. Similarly, if $m \neq m'$, the probability is bounded by $\varepsilon(\ell_m)$, so in either case,

$$\Pr[(h_a, h_m) = (h_{a'}, h_{m'})] \leq \max\{\varepsilon(\ell_a), \varepsilon(\ell_m)\}.$$

Finally, since $H^*$ is independent of $H$ and thus of the $h_x$:

$$\begin{aligned}
&\Pr[H^*(h_a \parallel h_m) = H^*(h_{a'} \parallel h_{m'})] \\
&\quad \leq \Pr[(h_a, h_m) = (h_{a'}, h_{m'})] \\
&\qquad + \Pr[H^*(h_a \parallel h_m) = H^*(h_{a'} \parallel h_{m'}) \mid (h_a, h_m) \neq (h_{a'}, h_{m'})] \\
&\quad \leq \max\{\varepsilon(\ell_a), \varepsilon(\ell_m)\} + \varepsilon(64) = \frac{\max\{\lceil \ell_a/16 \rceil^2, \lceil \ell_m/16 \rceil^2\} + 4^2}{2^{206}}.
\end{aligned}$$

□

## 5.2 Idealizing the cipher

Let $f\colon \{0,1\}^{256} \to \{0,1\}^{512}$ be a uniform random function, an idealization of XSalsa20 under a uniform random key. Denote by $\hat{f}\colon \{0,1\}^{256} \to \{0,1\}^{256}$ the function $\hat{f}(n_0 \,\|\, n_1) := G(f(n_0 \,\|\, n_1), n_1)$, for 16-byte $n_0$ and $n_1$, *i.e.*, the corresponding idealization of HXSalsa20 under the *same* key. For 192-bit $t$, denote by $f_*(t)$ the concatenation $f(t \,\|\, 0) \,\|\, f(t \,\|\, 1) \,\|\, f(t \,\|\, 2) \,\|\, \cdots$, with the 64-bit input counter $0, 1, 2, \ldots$ (limited below $2^{32}$) encoded in little-endian—this idealizes the XSalsa20 stream cipher, again under the *same* key. Note that $f$, $\hat{f}$, and $f_*$ are all uniformly distributed (but not independent of one another!).

Define **Deuce** to be as Daence, but with $f$ substituted for $\text{XSalsa20}_{k_0}$:

1. $h := \text{Poly1305}^2_{k_1,k_2,k_3,k_4}(a, m)$ (32-byte $h$)
2. $t := \text{trunc}_{192}(\hat{f}(h))$ (24-byte $t$)
3. $c := m \oplus f_*(t)$
4. return $t \,\|\, c$

(Decryption is defined the obvious way.)

**Lemma 3** (Single-user idealized security)**.** *Let $A$ be a random decision algorithm with encryption and decryption oracles for a deterministic authenticated cipher. Suppose $A$ makes $E$ encryption queries and $D$ decryption queries of up to $\ell_a$ bytes of associated data and $\ell_m$-byte messages. Then*

$$\text{Adv}^{\text{DAE}}_{\text{Deuce}}(A) \le \frac{2D + E^2 + \binom{E}{2}}{2^{192}} + \varepsilon(\ell_a, \ell_m) \cdot \left(D + \binom{E}{2}\right).$$

*Proof.* Recall $\text{Adv}^{\text{DAE}}_{\text{Deuce}}(A) := |\Pr[A(\text{Deuce})] - \Pr[A(U_1)]$ where $U_1$ is the pathological 'DAE' whose encryption oracle always answers with independent uniform random bit strings and whose decryption oracle always answers with $\perp$. We will show that queries to a Deuce oracle likewise all return independent uniform random bit strings for encryption and $\perp$ for decryption, except in events of low probability.

Setting aside forgery attempts (decryption queries) for the moment, consider the following set of encryption queries to a Deuce oracle and its responses:

$$(a_1, m_1) \mapsto t_1 \,\|\, c_1, \quad (a_2, m_2) \mapsto t_2 \,\|\, c_2, \quad \cdots, \quad (a_E, m_E) \mapsto t_E \,\|\, c_E,$$

where

$$\begin{aligned} h_i &= \text{Poly1305}^2_{k_1,k_2,k_3,k_4}(a_i, m_i), \\ t_i &= \text{trunc}_{192}(\hat{f}(h_i)) = \text{trunc}_{192}(G(f(h_i), h_i)), \\ c_i &= m_i \oplus f_*(t_i) = m_i \oplus \big(f(t_i \,\|\, 0) \,\|\, f(t_i \,\|\, 1) \,\|\, \cdots\big). \end{aligned}$$

Note that for each $i$, both $t_i$ and $c_i$ are uniform random on their own. Further, as long as all the *inputs* to $f$, via $\hat{f}$ and $f_*$, are *distinct*, all the *outputs*—and thus all the $t_i \,\|\, c_i$—are *independent*. Conditional on this event, the distribution

on the encryption oracle query responses for DEUCE is exactly the same as the distribution on encryption oracle query responses for $U_1$—independent uniform random bit strings. Conditional also on the event that there are no successful forgeries, DEUCE and $U_1$ have exactly the same distribution for *all* queries.

Among the oracle queries, either a successful forgery must happen first, or a collision in the inputs to $f$ must happen first. It will be convenient to study the probability of a collision between a hash value $h_i$ and a tag/counter input $t_j \| n$, separately from the probability of tag collision $t_i = t_j$ for some $i \neq j$. So we will break the 'bad' events into:

1. $C_{th} := \exists i, j, n.\ h_i = t_j \| n$ — a collision between a hash $h_i$ and a tag/counter $t_j \| n$, *before* a successful forgery and *before* a collision among the tags.
2. $C_t := \exists i \neq j.\ t_i = t_j$ — a collision between two tag values $t_i = t_j$ for $i \neq j$, *before* a hash and tag/counter collision and *before* a successful forgery.
3. $F$ — a successful forgery *before* a collision in the inputs to $f$.

If none of these happen—no collision in $f$ inputs, no forgery—DEUCE and $U_1$ have the same distribution, so

$$\begin{aligned}\Pr[A(\text{DEUCE})] &\leq \Pr[A(\text{DEUCE}) \mid \neg C_{th}, \neg C_t, \neg F] + \Pr[C_{th}] + \Pr[C_t] + \Pr[F] \\ &= \Pr[A(U_1)] + \Pr[C_{th}] + \Pr[C_t] + \Pr[F],\end{aligned}$$

and since $A$ was arbitrary and could be replaced by $\neg A$, we have

$$|\Pr[A(\text{DEUCE})] - \Pr[A(U_1)]| \leq \Pr[C_{th}] + \Pr[C_t] + \Pr[F].$$

We will next show that the events $C_{th}$, $C_t$, and $F$ occur only with low probability.

For upper bounds on $\Pr[C_{th}]$ and $\Pr[C_t]$, we can assume $A$ makes no forgery attempts—if it attempted forgeries (decryption queries) interspersed with encryption queries, we could construct an adversary $A'$ that is identical except without the forgery attempts. The probabilities $\Pr[C_{th}]$ and $\Pr[C_t]$ of collisions *before* a successful forgery are at least as high for $A'$, which never even attempts a forgery and so can never be interrupted in its quest for collisions by a successful forgery, as for $A$, which may succeed at forgery before it has had the opportunity to submit all the encryption queries that $A'$ would have submitted. (This follows the argument of [21, Theorem 1].)

**Probability of hash and tag/counter collision.** To set an *upper* bound on the probability of $h_i = t_j \| n$ for some $i, j, n$, it suffices to consider the event that the first 192 bits $\text{trunc}_{192}(h_i)$ of hash $h_i$ coincides with tag $t_j$ (before a successful forgery), ignoring the counter $n$:

$$\begin{aligned}\Pr[C_{th}] = \Pr[\exists i, j, n.\ h_i = t_j \| n] &\leq \Pr[\exists i, j.\ \text{trunc}_{192}(h_i) = t_j] \\ &\leq \sum_{i,j} \Pr[\text{trunc}_{192}(h_i) = t_j] = \sum_{i,j} \frac{1}{2^{192}} = \frac{E^2}{2^{192}},\end{aligned}$$

where $\Pr[\mathrm{trunc}_{192}(h_i) = t_j] = 1/2^{192}$ because $t_j = f(h_j)$ is a uniform random 192-bit string independent of $\mathrm{trunc}_{192}(h_i)$. (This holds even if $i = j$, because $f$ is a uniform random function—its output on any input is independent of the input.)

**Probability of tag collision.** The collision $t_i = t_j$ for $i \neq j$ in the event $C_t$ may arise either from the hashes $h_i = \textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a_i, m_i)$, or from the tags $t_i = f(h_i)$ in encryption queries. Let $C_h$ be the event of a collision $h_i = h_j$ for $i \neq j$ (before a successful forgery, and before a hash and tag/counter collision). Since $\textsc{Poly1305}^2$ has collision probability bounded by $\varepsilon(\ell_a, \ell_m)$, we have

$$\begin{aligned}\Pr[C_h] &= \Pr[\exists i < j \colon h_i = h_j] \leq \sum_{i<j} \Pr[h_i = h_j] \\ &= \sum_{i<j} \Pr[\textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a_i, m_i) = \textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a_j, m_j)] \\ &\leq \sum_{i<j} \varepsilon(\ell_a, \ell_m) = \binom{E}{2}\varepsilon(\ell_a, \ell_m).\end{aligned}$$

If the $h_i$ are all distinct, then the $t_i$ are uniform random bit strings independent of everything else involved—which means an adversary learns no new information from each query to adaptively act on in subsequent queries—so there is a collision among the $t_i$ only with probability

$$\begin{aligned}\Pr[C_t \mid \neg C_h] = \Pr[\exists i < j \colon t_i = t_j \mid \neg C_h] &\leq \sum_{i<j} \Pr[t_i = t_j \mid \neg C_h] \\ &= \sum_{i<j} \Pr[f(h_i) = f(h_j) \mid h_i \neq h_j] \leq \sum_{i<j} \frac{1}{2^{192}} = \binom{E}{2}\frac{1}{2^{192}}.\end{aligned}$$

Thus,

$$\Pr[C_t] \leq \Pr[C_h] + \Pr[C_t \mid \neg C_h] \leq \binom{E}{2}\left(\varepsilon(\ell_a, \ell_m) + \frac{1}{2^{192}}\right).$$

**Forgery probability.** To bound $\Pr[F]$, assume $A$ halts after the first forgery attempt—an adversary that makes $D > 1$ forgery attempts can be broken into one that halts after the first forgery attempt, and another one that simulates forgery failure for the first attempt before making $D - 1$ more attempts. If the first succeeded with probability at most $\Pr[F_0]$, then by induction the second succeeds with probability at most $(D-1) \cdot \Pr[F_0]$, so that the original succeeds with probability at most $\Pr[F_0] + (D-1) \cdot \Pr[F_0] = D \cdot \Pr[F_0]$.

Let $(a', t' \parallel c')$ be the single forgery attempt of $A$, with $t' \parallel c' \neq t_i \parallel c_i$ for all $i$. Let $m' = c' \oplus f_*(t')$ and $h' = \textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a', m')$. The forgery succeeds if $t' = f(h')$. Note that $(a', m') \neq (a_i, m_i)$, for if $(a', m') = (a_i, m_i)$,

then we would have $t' \,\|\, c' = t_i \,\|\, c_i$, since—for fixed $f, k_1, \ldots, k_4$ values—$t' \,\|\, c'$ is a deterministic function of $(a', m')$.

Let $F_0^{\neq}$ be the event that the forgery is successful *and* $t' \neq t_i$ for all $i$, and let $F_0^{=}$ be the event that the forgery is successful *and* $t' = t_i$ for some $i$, so that $\Pr[F_0] = \Pr[F_0^{\neq}] + \Pr[F_0^{=}]$.

- If $t' \neq t_i$ for all $i$, we must have $h' \neq h_i$ for all $i$, since $t' = f(h')$ and $t_i = f(h_i)$. Hence $f(h')$ is a uniform random 192-bit string independent of all the $t_i$ and $c_i$, so $t' = f(h')$ only with probability $1/2^{192}$ for this forgery attempt; that is,
$$\Pr[F_0^{\neq}] = 1/2^{192}.$$
- If $t' = t_i$ for some $i$, then necessarily $m' \neq m_i$ for all $i$, and the forgery succeeds only when $h' = h_i$, which occurs with probability at most $\varepsilon(\ell_a, \ell_m)$; or, if $h' \neq h_i$, when $f(h') = f(h_i)$, which occurs with probability $1/2^{192}$. Thus,
$$\Pr[F_0^{=}] \leq \varepsilon(\ell_a, \ell_m) + 1/2^{192}.$$

Combining these, we see the probability of a forgery (before any collisions) is bounded by

$$\Pr[F] \leq D \cdot \Pr[F_0] \leq D \cdot \Pr[F_0^{\neq}] + D \cdot \Pr[F_0^{=}] \leq \frac{2D}{2^{192}} + D \cdot \varepsilon(\ell_a, \ell_m).$$

**Summing it up.**

$$\begin{aligned}
&|\Pr[A(\textsc{Deuce})] - \Pr[A(U_1)]| \\
&\quad \leq \Pr[C_{th}] + \Pr[C_t] + \Pr[F] \\
&\quad \leq \frac{E^2}{2^{192}} + \binom{E}{2}\left(\varepsilon(\ell_a, \ell_m) + \frac{1}{2^{192}}\right) + \frac{2D}{2^{192}} + D \cdot \varepsilon(\ell_a, \ell_m) \\
&\quad \leq \frac{2D + E^2 + \binom{E}{2}}{2^{192}} + \varepsilon(\ell_a, \ell_m) \cdot \left(D + \binom{E}{2}\right).
\end{aligned}$$

□

## 5.3 Multi-user security

**Lemma 4** (Multi-user idealized security)**.** *Let $A$ be a random decision algorithm with encryption and decryption oracles for a* set *of deterministic authenticated cipher users. Suppose $A$ makes $E(u)$ encryption queries and $D(u)$ decryption queries to the $u^{th}$ user of up to $\ell_a(u)$ bytes of associated data and $\ell_m(u)$-byte messages. Then*

$$\begin{aligned}
\mathrm{Adv}^{\text{mu-DAE}}_{\textsc{Deuce}}(A) \leq \sum_u \frac{2D(u) + E(u)^2 + \binom{E(u)}{2}}{2^{192}} \\
+ \varepsilon(\ell_a(u), \ell_m(u)) \cdot \left(D(u) + \binom{E(u)}{2}\right).
\end{aligned}$$

*Proof.* In the foregoing analysis of the idealized cipher DEUCE in the single-user setting (Lemma 3), the probabilities of the critical events—$C_{th}$, $C_t$, and $F$—can be straightforwardly seen to sum over the users. For example, let $C_t^u$ be the event of a tag collision for the $u^{th}$ user, and let $C_t^*$ be the event of a tag collision in *any one* of the users; then

$$\Pr[C_t^*] = \Pr[\exists u.\ C_t^u] \leq \textstyle\sum_u \Pr[C_t^u].$$

Consequently, the multi-user DAE advantage against DEUCE—that is, the statistical distance under $A$ from DEUCE to a pathological 'DAE' collection $U$—is at most the sum of the single-user DAE advantages. □

**Discussion.** The generic single-user-to-multi-user advantage bound lemma [6, Lemma 3.3][8, Lemma 1] shows that if an adversary making a total of $q$ queries to *one* user has advantage at most $\epsilon$, then an adversary making a total of $q$ queries distributed across $N$ users has advantage at most $N \cdot \epsilon$. Here, with $q = \sum_u E(u) + D(u)$, we have shown a multi-user advantage bound much smaller than the generic lemma yields as a corollary. Loosely, where the generic would be $N \cdot \left(\sum_u \cdots\right)^2/2^\lambda$, we show $\sum_u (\cdots)^2/2^\lambda$ instead. How does this work?

In DEUCE, a query to a never-before-queried user gives a response independent of all prior query responses, and so queries to new users contribute only *linearly* to the adversary's advantage. But a query to a previously-queried user may lead to a collision involving that user's secret $f$ or $\text{POLY1305}^2_{k_1,\ldots,k_4}$, and so by the birthday bound repeated queries to the same user contribute *quadratically* to the adversary's advantage. Thus, the best strategy at breaking the idealized cipher—recall this is before we have instantiated it with XSALSA20 so there is no batch key search advantage yet—is to focus on the user with the highest maximum message length or bandwidth, ignoring all other users.

## 5.4 Instantiating the idealized cipher

**Lemma 5** (Multi-user instantiation)**.** *Let $A$ be a random decision algorithm with encryption and decryption oracles for a* set *of deterministic authenticated cipher users. Suppose $A$ makes $E(u)$ encryption queries and $D(u)$ decryption queries to the $u^{th}$ user of up to $\ell_a(u)$ bytes of associated data and $\ell_m(u)$-byte messages. Then there is an algorithm $A'$ making at most $\sum_u \big(1 + \lceil \ell_m(u)/64 \rceil\big)\big(E(u) + D(u)\big)$ oracle queries and having the cost of $A$ plus the cost of evaluating* $\text{POLY1305}^2$ *and $\oplus$ on $\sum_u E(u) + D(u)$ different $(\ell_a(u), \ell_m(u))$-byte inputs, such that*

$$|\Pr[A(\text{DAENCE})] - \Pr[A(\text{DEUCE})]| = \text{Adv}^{\text{mu-PRF}}_{\text{XSALSA20}}(A').$$

*Proof.* DEUCE is simply DAENCE with a uniform random function $f$ substituted for $\text{XSALSA20}_{k_0}$, so if $A$ can distinguish a collection of DAENCE users from a collection of DEUCE users then it can be used in an algorithm $A'$ to distinguish a collection of $\text{XSALSA20}_{k_0}$ users from a collection of $f$ users (recall $f\colon \{0,1\}^{256} \to \{0,1\}^{512}$ is a uniform random function).

If $\mathcal{O}(u, x)$ is an oracle for a collection of function instances indexed by $u$, define $A'(\mathcal{O})$ to run $A$ with oracles for the following DAE under independent uniform random keys $k_1, \ldots, k_4$ for the $u^{th}$ user, decryption being defined the obvious way:

1. $h := \textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a, m)$ (32-byte $h$)
2. $t := \text{trunc}_{192}(\hat{\mathcal{O}}(u, h))$ (24-byte $t$)
3. $c := m \oplus \mathcal{O}_*(u, t)$
4. return $t \parallel c$

This invokes the oracle once for each message (via $\hat{\mathcal{O}}$) and once for each 64-byte block in each message (via $\mathcal{O}_*$). Then $A'(\textsc{XSalsa20}_{k_0}) = A(\textsc{Daence})$ and $A'(f) = A(\textsc{Deuce})$ (with '$k_0$' and '$f$' understood to mean a collection of independent keys/functions), so

$$\begin{aligned}|\Pr[A(\textsc{Daence})] - \Pr[A(\textsc{Deuce})]| &= |\Pr[A'(\textsc{XSalsa20}_{k_0})] - \Pr[A'(f)]| \\ &= \text{Adv}^{\text{mu-PRF}}_{\textsc{XSalsa20}}(A'). \qquad \square\end{aligned}$$

## 5.5 Tying the room together

*Proof of Theorem 1.* By stringing all the inequalities together, we complete the proof:

$$\begin{aligned}\text{Adv}^{\text{mu-DAE}}_{\textsc{Daence}}(A) &= |\Pr[A(\textsc{Daence})] - \Pr[A(U)]| \\ &\le |\Pr[A(\textsc{Daence})] - \Pr[A(\textsc{Deuce})]| \\ &\quad + |\Pr[A(\textsc{Deuce})] - \Pr[A(U)]| \\ &\le \text{Adv}^{\text{mu-PRF}}_{\textsc{XSalsa20}}(A') \\ &\quad + \sum_u \frac{2D(u) + E(u)^2 + \binom{E(u)}{2}}{2^{192}} \\ &\quad + \varepsilon(\ell_a(u), \ell_m(u)) \cdot \left(D(u) + \tbinom{E(u)}{2}\right). \qquad \square\end{aligned}$$

*Proof of Theorem 2.* The ChaCha version of Daence uses

$$\textsc{Poly1305}^2_{k_1,k_2}(a \parallel m \parallel |a|_8 \parallel |m|_8)$$

instead of

$$\textsc{Poly1305}^2_{k_1,k_2,k_3,k_4}(a, m).$$

By Lemma 1, the collision probability is bounded by $\varepsilon(\ell_a + \ell_m + 16)$ rather than by $\varepsilon(\ell_a, \ell_m)$; the rest of the analysis carries over identically, with XChaCha in the place of XSalsa20. $\square$

## 6 Shaving IAQs—Infrequently Asked Questions

**Why not just use the CAESAR competition winner?** In our estimation, the CAESAR competition[1] was too broad and dragged on for too long, and in the end—although it produced a wealth of valuable research—it failed to gain the traction it needed for real-world deployment. While NaCl, IETF ChaCha/Poly1305, and AES-GCM are ubiquitous today, with a variety of high-quality implementations available in many programming languages, the benefits of the CAESAR winners do not seem to justify the engineering effort to make the novel cryptographic primitives as ubiquitous. In contrast, DAENCE requires negligible effort on top of NaCl or libsodium.

**Why not just use AES-GCM-SIV?** AES-GCM-SIV is optimized for applications that can *guarantee* hardware support for the primitives—otherwise it may be subject to severe performance degradation and/or timing side channel attacks. This may be reasonable when the engineer can control everything about the hardware and software stack, and audit the software stack all the way down to the hardware to ensure safety, but it's less appealing for a general-purpose tool.

The AES-GCM-SIV security guarantee requires unusually detailed safe usage limits [24, §9], and users are advised to choose nonces at random—which is exactly the opposite of the advice for nonce-based ciphers like AES-GCM and NaCl crypto_secretbox_xsalsa20poly1305. This limits AES-GCM-SIV's value as a drop-in replacement for nonce-based ciphers with a safety net for Tarsnap-style accidental nonce reuse bugs [34] and virtual machine rollbacks, and makes applications *more* vulnerable to broken entropy sources than DAENCE would.

**Why not a prior ChaCha/Poly1305-based design?** There have been past designs for nonce-misuse-resistant ciphers built with ChaCha and Poly1305, such as HS1-SIV in CAESAR [30] and XChaCha20-HMAC-SHA256-SIV proposed as a now-withdrawn internet-draft [32].

HS1-SIV relies on nonstandard security assumptions about ChaCha, requires a large key of 176 bytes at the low end or 368 bytes for security comparable to DAENCE, and by using polynomial evaluation modulo $2^{61}-1$ can't take advantage of existing high-speed constant-time Poly1305 logic—it is not just a few lines of code to call out to ChaCha and Poly1305.

XChaCha20-HMAC-SHA256-SIV is a more conservative design, but it uses the expensive and overpowered HMAC-SHA256 rather than taking advantage of cheap Poly1305 code that is likely to be hanging out in the neighbourhood of ChaCha code.

Further, despite being flavours of SIV, both HS1-SIV and XChaCha20-HMAC-SHA256-SIV still require nonces, which we feel is an unnecessary complication, addressed below.

[1] CAESAR: Competition for Authenticated Encryption: Security, Applicability, and Robustness. https://competitions.cr.yp.to/caesar.html

**Why not a nonce-misuse-resistant authenticated cipher?** If you have a nonce—say a message sequence number—then you can use it in the associated data to conceal repeated messages like a nonce-based cipher does. So out of Daence you can build your own nonce-misuse-resistant authenticated cipher: just prefix a fixed-size nonce to the associated data! You can also safely incorporate a *secret* nonce [10] into the encrypted payload.

But there is a conceptual cost to *requiring* a nonce parameter *and* associated data—what are you supposed to put in the nonce and what are you supposed to put in the associated data? The terms 'nonce' and 'nonce-misuse-resistant authenticated cipher' are confusing to non-experts (not to mention the British).

The security bounds could be better if we derived a fresh key for each distinct nonce like AES-GCM-SIV does. But AES-GCM-SIV has weaker security bounds to begin with. At the level of security that Daence provides, there is little reason to pay the interface complexity cost.

**Why bother with Salsa20? Why not just ChaCha?** NaCl and many of its derivatives support only Salsa20, not ChaCha, and for Poly1305 only have a one-shot crypto_onetimeauth_poly1305 function that processes a whole message at once. It is easy to implement Salsa20-Daence in terms of this interface, but not ChaCha-Daence.

On the other hand, ChaCha/Poly1305 is seeing wider use after IETF standardization in TLS—and systems with ChaCha/Poly1305 will generally have the parts needed to implement ChaCha-Daence just as easily.

There is a small security advantage to the hashing in Salsa20-Daence; there may be a small performance advantage to the hashing in ChaCha-Daence; but the primary advantage to defining both alternatives is to reduce the engineering costs to adopting either one in environments that already use NaCl or already implement ChaCha/Poly1305.

**Why not ChaCha12?** The reduced-round variant ChaCha12 is faster than ChaCha20 (*i.e.*, ChaCha with the default number of rounds, 20), and still has a comfortable security margin from the best attacks on reduced-round ChaCha in the literature to date. This is why, for instance, Google selected ChaCha12 in Adiantum disk encryption [20].

However, ChaCha20 is much more widely available in libraries today—*e.g.*, libsodium, OpenSSL, BearSSL, Nettle, the Rust `crypto::chacha20` module, the Go `golang.org/x/crypto/chacha20` package, and the Python pyca cryptography.io library, none of which provide ChaCha12.

Similarly, Salsa20/12 was selected over Salsa20/20 in the eSTREAM portfolio for the same performance improvement with a comfortable security margin, but also seems to be much less widely deployed than Salsa20/20.

So although in principle ChaCha12 or Salsa20/12 would improve performance over ChaCha20 or Salsa20/20 at negligible security cost, they appear to raise the engineering costs of deployment in practice.

**Why not use AUTH256?** The AUTH256 [18] message authentication code is based on a universal hash family with collision probability bounded by $1/2^{255}$ using a key as long as the message. This bound obviously seems better than the $\approx \ell^2/2^{206}$ bound for POLY1305[2], so why not reach for it?

With DAENCE, even if an application allowed messages up to the maximum length, $2^{39}$ ($2^{38}$ bytes of associated data and $2^{38}$ bytes of message), exposed quadrillions of legitimate messages ($2^{52}$) to the adversary, and the adversary attempted an unimaginable $2^{100}$ forgeries, the probability of *one* forgery would stay below $1/2^{32}$. So there is little *security* motivation to replace POLY1305 by a larger hash.

What about performance? AUTH256, even at its best on very long messages, is not faster than POLY1305 in software. Maybe AUTH256 would improve on POLY1305[2]—it's not clear, *a priori*, and since AUTH256 requires a message-length key the cost would have to figure in key generation.

But most importantly, neither AUTH256 nor any other ≈256-bit universal hash family, whether in a binary field or large prime field, is widely implemented and deployed the way POLY1305 is. So—even if there may be a slim performance improvement—switching from POLY1305 would substantially raise the engineering costs of adopting DAENCE.

**How fast is it?** The main cost over crypto_secretbox_xsalsa20poly1305 is evaluating POLY1305 twice rather than once, and completing it before starting XSALSA20, so SALSA20-DAENCE should cost about 1–2x what crypto_secretbox_xsalsa20poly1305 costs. If the analysis survives some scrutiny, we will submit DAENCE to SUPERCOP[2] for reliable, fair measurements across a variety of machines.

But if you must see rough numbers first, on our Intel Kaby Lake i7, SUPERCOP measures ≈2.5 cpb for crypto_secretbox_xsalsa20poly1305, ≈1.9 cpb for hardware-accelerated AES-GCM, and ≈3.6 cpb for SALSA20-DAENCE. There is room for improvement: this naïve code makes no attempt to compute the two POLY1305's in parallel, which may be faster than computing them serially—both for messages exceeding the CPU cache, and for short messages for which setting up many powers of the evaluation point is not worthwhile.

**Why a 96-byte key (or 64-byte for CHACHA-DAENCE)?** For CHACHA-DAENCE, in addition to CHACHA we use two independent POLY1305 instances—each requiring 16-byte keys, for a total of $32 + 2 \cdot 16 = 64$ bytes of key material—in order to provide high security without nonces.

For SALSA20-DAENCE, in addition to SALSA20 we use *four* independent POLY1305 instances—each requiring 16-byte keys, for a total of $32+4 \cdot 16 = 96$ bytes of key material—primarily to support incorporating associated data without relying an incremental-update API for POLY1305. This way,

[2] https://bench.cr.yp.to/

Salsa20-Daence can take advantage of the existing deployed NaCl library which can only compute Poly1305 on an entire message.

We could start from a 32-byte master key and then derive subkeys from it. However, doing this with the obvious tool at hand—either Salsa20 or ChaCha—would add hundreds of cycles to the cost of processing each message. Since many applications already use trees of key derivation for various purposes, we feel that the cost of deriving another few dozen bytes of key material—which can be cached and reused by the application—is not worth the cost of hundreds of additional cycles per message.

**Can Daence do streaming or random access?** If you want to handle large files, break them into bite-size pieces to be encrypted as separate messages. You should ensure the pieces are no larger than the amount of memory you are willing to let an adversary waste with a forgery in a denial of service attack. In the associated data or message (depending on whether you need to keep it secret), include:

- a unique file name, so the pieces can't be swapped around between multiple different files;
- a piece number or byte position within the file, so the pieces of a single file can't be reordered; and
- a flag indicating whether the piece is the last one in the file or not, so files can't be truncated without your noticing.

Alternatively, instead of an end-of-file flag in each piece, you might include a manifest at the beginning of the stream specifying the file's size, if it is available then.

This provides 'nOAE' security [26] like the 'STREAM' construction. Additionally incorporating the tag of the previous message (or, really, any tag-sized substring of the previous ciphertext) into the associated data of the next one provides 'OAE2' security, like the 'CHAIN' construction, which provides a weak defence against reusing a file name for two different files, at the cost of losing random access.

**Does Daence have int-rup security?** Yes.

Loosely, int-rup [1] means that even if the legitimate user reveals unverified plaintext in decryption queries, the adversary can't forge a message that passes verification.

In the analysis above, the hashes $h_i$ are distributed with maximum probability around $1/2^{200}$ and independent of the tags and ciphertexts, except in the low-probability event of one of the collisions discussed in the analysis, so the probability that a decryption query reveals a key stream $f(t \parallel 0) \parallel f(t \parallel 1) \parallel f(t \parallel 2) \parallel \cdots$ any of whose blocks are related to a valid message's tag is low, even when the adversary chooses $t$. (Filling out the quantitative details is left as an exercise for the reader.)

Nevertheless, we recommend zeroing any forgery immediately so this doesn't come up. DAENCE is *not* 'plaintext-aware'—releasing unverified plaintext to a decryption query may enable the adversary to decrypt other messages.

The primary motivation for INT-RUP (and plaintext-awareness) is as a safety net for the temptation of 'streaming' decryption *before* verification. But if you just break large files into bite-size authenticated pieces as described above, you get the nOAE or OAE2 security you would have wanted for streaming without any temptation to skip verification.

**Isn't DAENCE kind of boring?** Yes. That's the point. DAENCE does not provide asymmetric impermeability under semi-consensual-plaintext attack in the Delphic oracle model, or achieve any asymptotic lower bound that solves an open research question, or have eighteen different parameters and knobs and bells and whistles. DAENCE is boring crypto built out of parts you probably have lying around that you can confidently use now to avoid nonce reuse catastrophe.

**How is the 'ae' in DAENCE pronounced?** Like the 'a' in 'data'.

We do not anticipate that DAENCE will replace CHACHA/POLY1305 in major protocols such as TLS designed by world-class cryptographers, which can easily take advantage of a message number guaranteed not to repeat. We do hope that DAENCE will find its way into the repertoire of general-purpose application engineers who need to store messages safe from eavesdropping and forgery in diverse software environments—*without* auditing the software stack all the way down to machine instructions to ensure their use of AES-GCM-SIV is safe from timing side channels, *without* adopting unusual cryptographic primitives or an entirely new cryptography library, and *without* teetering on the brink of catastrophe from nonce reuse in crypto_secretbox_xsalsa20poly1305 or AES-GCM.

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# A Tweetable implementation

```
#include "tweetdaence.h"    /* declares prototypes */
#include "tweetnacl.h"
#define FOR(i,n) for (i = 0;i < n;++i)
typedef unsigned char u8;
typedef unsigned long long u64;
static const u8 sigma[] = "expand 32-byte k";

static void prf(u8 *t,const u8 *m,u64 mlen,
    const u8 *a,u64 alen,const u8 *k)
{
  u8 k1[32],k2[32],ham[64],h[32],i;
  FOR(i,16) { k1[i] = k[32 + i]; k1[16 + i] = 0; }
  FOR(i,16) { k2[i] = k[48 + i]; k2[16 + i] = 0; }
  crypto_onetimeauth_poly1305(ham,a,alen,k1);
  crypto_onetimeauth_poly1305(ham + 16,a,alen,k2);
  crypto_onetimeauth_poly1305(ham + 32,m,mlen,k1);
  crypto_onetimeauth_poly1305(ham + 48,m,mlen,k2);
  FOR(i,16) { k1[i] = k[64 + i]; k1[16 + i] = 0; }
  FOR(i,16) { k2[i] = k[80 + i]; k2[16 + i] = 0; }
  crypto_onetimeauth_poly1305(h,ham,64,k1);
  crypto_onetimeauth_poly1305(h + 16,ham,64,k2);
  crypto_core_hsalsa20(t,h,k,sigma);
  crypto_core_hsalsa20(t,h + 16,t,sigma);
}
void crypto_dae_salsa20daence(u8 *c,const u8 *m,
    u64 mlen,const u8 *a,u64 alen,const u8 *k)
{
  u8 t[32],i;
  prf(t,m,mlen,a,alen,k);
  FOR(i,24) c[i] = t[i];
  crypto_stream_xsalsa20_xor(c + 24,m,mlen,c,k);
}
int crypto_dae_salsa20daence_open(u8 *m,const u8 *c,
    u64 mlen,const u8 *a,u64 alen,const u8 *k)
{
  u8 t[32],t_[32];
  u64 i;
  crypto_stream_xsalsa20_xor(m,c + 24,mlen,c,k);
  prf(t,m,mlen,a,alen,k);
  FOR(i,24) t_[i] = c[i];
  FOR(i,8) t[24 + i] = t_[24 + i] = 0;
  if (crypto_verify_32(t,t_)) {
    FOR(i,mlen) m[i] = 0;
    return -1;
  }
  return 0;
}
```

# B Reference implementation

```
#include <string.h>

#include <sodium/crypto_core_hsalsa20.h>
#include <sodium/crypto_onetimeauth_poly1305.h>
#include <sodium/crypto_stream_xsalsa20.h>
#include <sodium/crypto_verify_32.h>
#include <sodium/utils.h>

static const unsigned char sigma[16] = "expand 32-byte k";

static void
compressauth(unsigned char t[static 24],
#ifdef DAENCE_GENERATE_KAT
    unsigned char v_ham[static restrict 64],
    unsigned char v_h[static restrict 32],
    unsigned char v_u[static restrict 32],
#endif
    const unsigned char *m, unsigned long long mlen,
    const unsigned char *a, unsigned long long alen,
    const unsigned char k[static 96])
{
    const unsigned char *k0 = k;    /* k0 := k[0..32] */
    unsigned char k1[32], k2[32], k3[32], k4[32], ham[64];
    unsigned char *ha1 = ham +  0, *ha2 = ham + 16;
    unsigned char *hm1 = ham + 32, *hm2 = ham + 48;
    unsigned char h[32], *h3 = h, *h4 = h + 16;
    unsigned char u[32];

    /* Poly1305: Set evaluation point; zero addend.  */
    memcpy(k1, k + 32, 16); memset(k1 + 16, 0, 16);
    memcpy(k2, k + 48, 16); memset(k2 + 16, 0, 16);
    memcpy(k3, k + 64, 16); memset(k3 + 16, 0, 16);
    memcpy(k4, k + 80, 16); memset(k4 + 16, 0, 16);

    /*
     * Message compression:
     *  ha := Poly1305^2_{k1,k2}(a)
     *  hm := Poly1305^2_{k1,k2}(m)
     *  h := Poly1305^2_{k3,k4}(ha || hm)
     */
    crypto_onetimeauth_poly1305(ha1, a, alen, k1);
    crypto_onetimeauth_poly1305(ha2, a, alen, k2);
    crypto_onetimeauth_poly1305(hm1, m, mlen, k1);
    crypto_onetimeauth_poly1305(hm2, m, mlen, k2);
    crypto_onetimeauth_poly1305(h3, ham, 64, k3);
    crypto_onetimeauth_poly1305(h4, ham, 64, k4);
```

```
    /* Tag generation: t, _ := HXSalsa20_k0(h3 || h4) */
    crypto_core_hsalsa20(u, h3, k0, sigma);
#ifdef DAENCE_GENERATE_KAT
    memcpy(v_ham, ham, sizeof ham);
    memcpy(v_h, h, sizeof h);
    memcpy(v_u, u, 32);
#endif
    crypto_core_hsalsa20(u, h4, u, sigma);
    memcpy(t, u, 24);

    /* paranoia */
    sodium_memzero(k1, sizeof k1);
    sodium_memzero(k2, sizeof k2);
    sodium_memzero(k3, sizeof k3);
    sodium_memzero(k4, sizeof k4);
    sodium_memzero(ham, sizeof ham);
    sodium_memzero(h, sizeof h);
    sodium_memzero(u, sizeof u);
}

void
crypto_dae_salsa20daence_test(unsigned char *c,
#ifdef DAENCE_GENERATE_KAT
    unsigned char v_ham[static restrict 64],
    unsigned char v_h[static restrict 32],
    unsigned char v_u[static restrict 32],
#endif
    const unsigned char *m, unsigned long long mlen,
    const unsigned char *a, unsigned long long alen,
    const unsigned char k[static 96])
{
    const unsigned char *k0 = k;    /* k0 := k[0..32] */

    /* c[0..24] := HXSalsa20_k0(Poly1305^2(a,m)) */
    compressauth(c,
#ifdef DAENCE_GENERATE_KAT
        v_ham, v_h, v_u,
#endif
        m, mlen, a, alen, k);

    /*
     * Stream cipher:
     *  c[24..24+mlen] := m[0..mlen]
     *      ^ XSalsa20_k0(t @ c[0..24])
     */
    crypto_stream_xsalsa20_xor(c + 24, m, mlen, c, k0);
}
```

```
int
crypto_dae_salsa20daence_open(unsigned char *m,
    const unsigned char *c, unsigned long long mlen,
    const unsigned char *a, unsigned long long alen,
    const unsigned char k[static 96])
{
    const unsigned char *k0 = k;    /* k0 := k[0..32] */
#ifdef DAENCE_GENERATE_KAT
    unsigned char v_ham[64], v_h[32], v_u[32];
#endif
    unsigned char t[32], t_[32];
    int ret;

    /*
     * Stream cipher:
     *  m[0..mlen] := c[24..24+mlen]
     *      ^ XSalsa20_k0(t' @ c[0..24])
     */
    crypto_stream_xsalsa20_xor(m, c + 24, mlen, c, k0);

    /* t := HXSalsa20_k0(Poly1305^2(a,m)) */
    compressauth(t,
#ifdef DAENCE_GENERATE_KAT
        v_ham, v_h, v_u,
#endif
        m, mlen, a, alen, k);

    /* Verify tag: c[0..24] ?= t (no crypto_verify_24) */
    memcpy(t_, c, 24);
    memset(t + 24, 0, 8);
    memset(t_ + 24, 0, 8);
    ret = crypto_verify_32(t_, t);
    if (ret)
        sodium_memzero(m, mlen); /* paranoia */

    /* paranoia */
    sodium_memzero(t, sizeof t);
    sodium_memzero(t_, sizeof t_);
#ifdef DAENCE_GENERATE_KAT
    sodium_memzero(v_ham, sizeof v_ham);
    sodium_memzero(v_h, sizeof v_h);
    sodium_memzero(v_u, sizeof v_u);
#endif

    return ret;
}
```

```
#ifdef DAENCE_GENERATE_KAT

static const unsigned char k[96] = {
    0x00,0x01,0x02,0x03,0x04,0x05,0x06,0x07,
    0x08,0x09,0x0a,0x0b,0x0c,0x0d,0x0e,0x0f,
    0x10,0x11,0x12,0x13,0x14,0x15,0x16,0x17,
    0x18,0x19,0x1a,0x1b,0x1c,0x1d,0x1e,0x1f,
    0x20,0x21,0x22,0x23,0x24,0x25,0x26,0x27,
    0x28,0x29,0x2a,0x2b,0x2c,0x2d,0x2e,0x2f,
    0x30,0x31,0x32,0x33,0x34,0x35,0x36,0x37,
    0x38,0x39,0x3a,0x3b,0x3c,0x3d,0x3e,0x3f,
    0x40,0x41,0x42,0x43,0x44,0x45,0x46,0x47,
    0x48,0x49,0x4a,0x4b,0x4c,0x4d,0x4e,0x4f,
    0x50,0x51,0x52,0x53,0x54,0x55,0x56,0x57,
    0x58,0x59,0x5a,0x5b,0x5c,0x5d,0x5e,0x5f,
};

static const unsigned char a[16] = {
    0x60,0x61,0x62,0x63,0x64,0x65,0x66,0x67,
    0x68,0x69,0x6a,0x6b,0x6c,0x6d,0x6e,0x6f,
};

static const unsigned char m[33] = {
    0x70,0x71,0x72,0x73,0x74,0x75,0x76,0x77,
    0x78,0x79,0x7a,0x7b,0x7c,0x7d,0x7e,0x7f,
    0x80,0x81,0x82,0x83,0x84,0x85,0x86,0x87,
    0x88,0x89,0x8a,0x8b,0x8c,0x8d,0x8e,0x8f, 0x90,
};

static void
show(const char *name, const unsigned char *buf, size_t len)
{
    size_t i;

    printf("%s=", name);
    for (i = 0; i < len; i++) {
        printf("%02hhx", buf[i]);
        if (i + 1 < len && ((i + 1) % 24) == 0)
            printf("\n%*s", (int)strlen(name) + 1, "");
    }
    printf("\n");
}
```

```
int
main(void)
{
    unsigned char ham[64], h[32], u[32];
    unsigned char c[24 + sizeof m], m_[sizeof m];
    unsigned i;
    int ret = 0;

    for (i = 0; i <= sizeof m; i++) {
        /* paranoia */
        memset(ham, 0, sizeof ham);
        memset(h, 0, sizeof h);
        memset(u, 0, sizeof u);
        memset(c, 0, sizeof c);
        memset(m_, 0, sizeof m_);

        /* test */
        crypto_dae_salsa20daence_test(c,
            ham,h,u, m, i, a, sizeof a, k);
        if (crypto_dae_salsa20daence_open(m_, c,
            i, a, sizeof a, k) != 0)
            ret = 1;
        if (memcmp(m, m_, i) != 0)
            ret = 2;

        /* show */
        printf("mlen=%u\n", i);
        printf("alen=%zu\n", sizeof a);
        show("m", m, i);
        show("m_", m_, i);
        show("k", k, sizeof k);
        show("a", a, sizeof a);
        show("h_a", ham, 32);
        show("h_m", ham + 32, 32);
        show("h", h, sizeof h);
        show("u", u, sizeof u);
        show("c", c, 24 + i);
        printf("\n");
    }

    fflush(stdout);
    if (ferror(stdout))
        ret = 3;

    return ret;
}

#endif  /* DAENCE_GENERATE_KAT */
```

# C Test vectors

```
mlen=0
alen=16
m=
m_=
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=0000000000000000000000000000000000000000000000000
    0000000000000000
h=da2fa7a11e4476ed9dc3384f196c7afd52bc3543af53eca1
  d498781dc8e91246
u=cb9fdd8b7d715b47fa571f1c27aebda1ed556f4b55a68033
  f3350fdac10b43f4
c=762709b9b287e7bd12351f2b0371509cc923f6c2ae612e61

mlen=1
alen=16
m=70
m_=70
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=199e0f81c463d5468a299b0c50ef60d219b52698c47aec5d
    8a40b223500678e9
h=b860cc41353a31d18f44bea79c237bd3921531ed61ea2b28
  0c5fdc236b02cca7
u=ca0397f120d48a492d901f2254ce82ca0892d0c7a61179a4
  f7db29838d39e92d
c=844c482d0cfb1b658bbdd74ba1404eeeb5206bde14c70ccf
  ec

mlen=2
alen=16
m=7071
m_=7071
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
```

```
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=62b9ad904528391cd1b3c4a75c3f50337bd0dbbe5c3f674a
    e8caf2d573567e61
h=f8ea8c4aa43831a1ad45a54b68a1aeab81a0a20bf4042b53
  10174c2262119869
u=f6e114983789324bcfad887a532a53ccc31816434c942a7a
  3adcea440cf0879c
c=6dce0f262deddde10ba72249e4bddb454119cb8580c6ef76
  3d1e

mlen=3
alen=16
m=707172
m_=707172
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=5113e94f77ac21a5cc0177fa2157cc4f614727a5b5da5ffa
    0a30b54f60850aa5
h=b690dd3a1edf2489de743ed1e3c6bd93047b87ac06ef22d9
  0ef93731c6ab048d
u=ac4b3e835031edaa2bbe03156726bda452350f9195fcd458
  0acfbd13674c6268
c=b3e66c3fc5ac774608a2f3d255b6738f0ee28d8b3eda60ac
  2fed3f

mlen=4
alen=16
m=70717273
m_=70717273
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=f0ff55ab5700a9b17a23ccd49d46eff70139b120cd65fe26
    f088214a13ac446d
h=bcf61c535749d2709ac96245db02e538df398cc0cc666403
  418d7eb728b64b98
u=f156f947c26c6498443d838be3c571bab1d9b02c95c80f03
  d806605f3261e5bb
c=de839ad762740fe5f3284d596109089e45fdc578795299cb
```

```
  824c3cca

mlen=5
alen=16
m=7071727374
m_=7071727374
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=79543c2bd3011f3cabf61331a0eb082686a6b0bd78aebbc8
    50a3b0bd4598a5b2
h=58bb88ebb8615e4689155387a657dbff76d173d0cb60c3de
  b51fe5604a84e468
u=d0959a8374902d61a27814e8b63aebab36f4cb303caebf5e
  af4a7f9ec788586b
c=91850eb531e6162198ead702942debbc59c1616e30ebe629
  f2348d130b

mlen=6
alen=16
m=707172737475
m_=707172737475
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=bf54490b669d41d4384b0c9f0316d769eab6eaca288a35b8
    f5370083c002cb4d
h=9873c5599810462e9e2939580058437ec020d073ee6903e0
  f5a6f268bc75f10e
u=2fc7f16f864fdd0208031a802bb9a2523df3457be9819df4
  cceb71bda5592a33
c=14b840b3392558f62dfd41747acb52cbc5e812a5d8715eaa
  9b86a776e3af

mlen=7
alen=16
m=70717273747576
m_=70717273747576
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
```

```
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=4baac0d03f43fd17f3db84bc97802961b82986d1434d4163
    17e0c807bc846dac
h=45b41d51774e9eadca4ff16242742946213bd2d0632e9073
  8bd46aa3f7e79b47
u=3d82843a4d745c237a5414734f348bbccacf8265494e9307
  77b8128dfa5ea3bc
c=81c5243427c8cc5d0ef985b9ab15384f32efc6ea454c7d88
  7b182646883f1e

mlen=8
alen=16
m=7071727374757677
m_=7071727374757677
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=732824bfbd16b6f357b81859da3a9bdb36fd06f81676179f
    f333740476b6f686
h=8fdf405b620bbaa19a70fd64961e50a24f3ccc2a7ba51c58
  2cafd33c5fe7fbc8
u=d0cacdbffca0825141e8567e017fcccd2a6c0fbce190ccf0
  88dd5aa306d57835
c=8200c3085ba9c392bc384a276f67f8ff988c1dcdb5ab660e
  02c5d2b9ef498849

mlen=9
alen=16
m=707172737475767778
m_=707172737475767778
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=7b049730234d83bf533e17f09aa27b548a42e386c8154e88
    5f41fab2a6a55e17
h=b366d74801bb445de175ab9d1c695e5d381c6ef5b8fdbd52
  1901625f176aa6a4
u=f2e26553420d4c882507e0e7d7b278592b5582303e597a35
  e9679bd235e48275
c=7c2772be0bf9e5aa90fbf9041af3948caead0daa0287943c
```

```
  f6688b6180def2ed91

mlen=10
alen=16
m=70717273747576777879
m_=70717273747576777879
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=9b812698a2297286325abe103587085bc81ff06b6552bacc
    5bdd386b580a83b5
h=2b235e4fec7aa0d7df12a7ae0d497677e98f773c1a403cf7
  89bc9c12e333384f
u=11ec8d3f3c97bfe56496b22b0305757dceab0e05adebb1de
  72b251d78edfe232
c=1f0151626829065e7b8e79c8da1a56a5be6f02240e96671b
  f668b3d121e631384206

mlen=11
alen=16
m=707172737475767778797a
m_=707172737475767778797a
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=97aa15dbfeb6c52df34bfad87724110d5166534053fd8105
    aeec04db42bf1b0f
h=daf8b916e1772628577fbfd2ff15375ae356c0f874094b6f
  eade4936a03074fe
u=19b4e3bf1762d7da9dd2017284d5e89a61bd42b860215882
  63a572926551ba9c
c=d7e39253df23a93cf06af34ca9b58f3ff92fd591faf4ef1d
  23fddea6bf3e5ead731c52

mlen=12
alen=16
m=7071727374757677787 97a7b
m_=7071727374757677787 97a7b
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
```

```
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=2092473cf50761f85206ff346189b13985f3a229eff33a58
    b34c27d7e3dbd3db
h=1f75b7be8c1a9a19e21c99318e032ece6ea76339c146b5c5
  72c90512938829c9
u=4dfcb2f5a9f19c4631e398e7c6c3cb63deceb1da65ce631d
  6065a7b641d3da82
c=ddcc71b2d2b801a973f182bf57706e6b441bff52ba19415e
  4ee562aaf5ea9ccc75b40388

mlen=13
alen=16
m=70717273747576777879 7b7c
m_=70717273747576777879 7b7c
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=84cd1e77c8b1a6a1941eb34cdd9338dd85e833825e573a1f
    911e950c10ae2297
h=c5063b361676c732800afc74e417e2f586de76c028d22e12
  9984a697063b4856
u=2fdd46ce74bffd164dbfec9f237433abda5d8b964cf446c4
  81b77d5656f243f4
c=75554db41fb176c7c73623d43057d3dc48a350aa2cb89261
  c5a567c3f88f343f708df4fda9

mlen=14
alen=16
m=70717273747576777879 7b7c7d
m_=70717273747576777879 7b7c7d
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=569f083e0cf703dc4bd783fa07306486756aeb16c04c6527
    66873388580a2618
h=c9f1d84061c8673aeda2bdcbad3cf7b40b4b0ce911ad78e7
  46aed4dadf74d91c
u=231947fc4f1ddbcab4fd0919c32803916003a680c7204b2a
  b95d8194e428e1cc
c=f3b9e3e78fc196d85489e653f058e99543219469b6e382a5
```

```
  1aaa95bf3d4a7b7eb8ee9d57a561

mlen=15
alen=16
m=707172737475767778797a7b7c7d7e
m_=707172737475767778797a7b7c7d7e
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=957347d6c243bbec7a9cb383af6d20d3965cee9058b7e019
    776a27f3e165b24c
h=6005e5089f73d7ecbae8a06ab59fd2b01d3c91a6fd802d24
  a7980c2080de9cb9
u=6d8fb42fe180aaa6edf25ce8fa63d68be70b4fecea549ff1
  ed67369800d883a8
c=30dad0b473cd10d3080513d104098fcee23961ffa01c574b
  a76b428a928658905d10d4e8825f4c

mlen=16
alen=16
m=707172737475767778797a7b7c7d7e7f
m_=707172737475767778797a7b7c7d7e7f
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=5c9c1f8209ea10163fc0862af10e71af537be4149553541b
    3184187219fd2009
h=52b326c9caa73391488ff7f75c9cdfe99927c3f19c8f4799
  bef333b22ea79621
u=2218ddf34a39e717202134869b79668906966b85a8809b36
  200a07a1ddbbfdf2
c=75236be4a3d3df0614d2bd8f2ceb6b12c4e986e918e513fa
  41a90081283be2ba2273c376dd08c3b2

mlen=17
alen=16
m=707172737475767778797a7b7c7d7e7f80
m_=707172737475767778797a7b7c7d7e7f80
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
```

```
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=0b70e14933fb764a55520ac2afec3572d1cbf1ef0f8a819f
    1649c51557164e6b
h=e910f931eb3c59e7d741b55c11d8eb0bead5711f6c4a40a0
  a36ac9b677a1bf67
u=0b6e71f1f1e5e015cb836a7ec20c17b78380844100216693
  37af799296e13ca2
c=35ed97cde04e867d6646d7206c9a1afc86751a075cc6bdae
  baf7d0d042ca68c6de99aae3bfa0cd67e9

mlen=18
alen=16
m=707172737475767778797a7b7c7d7e7f8081
m_=707172737475767778797a7b7c7d7e7f8081
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
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h_m=858c917be6ff2c820e5dc6ff6efdf7b564e8b939db8e4fef
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h=3a19c87bdb3e044189e053805d9b3410c4ce03ec3a40a59f
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u=41001223ba749e7bd560537f6e1c5d30bc34ccd417097e44
  2e582c003ae82a68
c=ce5361c1f3b8799acf51abc5ae105dea99db455fc4d0c338
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m_=7071727374757677787 97a7b7c7d7e7f808182
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=1116ce4c3ab6555d6c1df9e4d6c734a527900633575d88f2
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h=bda5c578c4b5a386b6ef33b1a121cfe2b5817b7f2bb246cd
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u=4ce0c457c93746ed1ec98b95472c91444ca4220565391b9c
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c=bd16fdd2ebd7e29e9dfbd07bf73ae8fdaff99fb3809a2031
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mlen=20
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m_=707172737475767778797a7b7c7d7e7f80818283
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  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=349e6aa92c2c0faa6ca1c03fe5590a0e905ec1af810b5a5f
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h=0e2a40a2f9aa792125d56602045193883dc5cc1f0e57d6bd
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u=b0931de0261ab7aa0eea763f8e8d04859cfad53f049b419e
  0ec802258f30e68d
c=b6eecfc2d50fa56f845e0d757a9c59d8298a59ee2a54148b
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mlen=21
alen=16
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m_=7071727374757677787978a7b7c7d7e7f8081828384
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=2d7aec58a93fa766ddc66a0e6891c6eec5949d7d2e673a34
    4756aedab7536760
h=34857e128f04c06a7b6ace6ffce9f2996876088828b72814
  a92bc8ced645763d
u=e71ee727c6eabb06a028d98521e6a4f3611db8e024c654c8
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c=03b637d04e5b0d77c6c140b99716627ce4f04c8d2c49b036
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mlen=22
alen=16
m=707172737475767778797a7b7c7d7e7f808182838485
m_=707172737475767778797a7b7c7d7e7f808182838485
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
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h_m=54eb80d46bdcdb209d5bb5de3d3c27d50a56a0670f44c746
    1f2b5103a63e209f
h=bba9d7bda795f7b9705990a2f44ab0a496c0bcfc2feea777
  e066ddf50f59d014
u=822c587bfaa63e39617c15b798ea68a5622c7db4fd640a5e
  c4028527a0e6808a
c=8993e03339201e7c6fcb17c4e19b4fa8412c617a5bd91bbd
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mlen=23
alen=16
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m_=70717273747576777879 7a7b7c7d7e7f80818283848586
k=000102030405060708090a0b0c0d0e0f1011121314151617
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
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h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=2d206921e1b19876791e6e4e3419fa5e60a9ec360738d404
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h=fddb200234601cd95c556ef3d3979d41bf5d6accadc28a33
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u=566529a2b8e279121a0b3d28b95c8fafa58a13f3f31a9eca
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c=2cfd1fe271bc8dc6aa8ff86f8cd4d29250fa5720fcd9f9c0
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mlen=24
alen=16
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=89e9ab80e6208153f01c342bc935de5957094e0ea33ddb41
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h=c9ae25475fb25057f722b9a1394fcc9969dc7116a6299049
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u=2194349372c64bb783442227c8dbf29cab22793b31c8c90a
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
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k=000102030405060708090a0b0c0d0e0f1011121314151617
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  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=b6fc69d1bcdee94eedb454f4c9ef204510c7b67d05a6ee5b
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h=654ccb34c608e4b36d61a7fcf7cc220073ad2191a02a3331
  1c97969a4b1619e7
u=da8296265b3a1cce01522540ff3e7796707ac265ae4940e3
  e2f0a765140b8bde
c=e55749c4765d25bb1229b7b884a7be1873bfdc92bf28bef0
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mlen=26
alen=16
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
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k=000102030405060708090a0b0c0d0e0f1011121314151617
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=679a30841b2c60b1fbd10d37961400aedf043cef8293237d
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h=d408232105058a6ce09277fb806738c95dd29a3c096e2103
  d459824384134c44
u=5114f35c9352f760c846ae23759e88262607c58d1f1db681
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c=c1ed1e6aa0245740cc4ecb1533d948495d2ae9d0e0a8bc8a
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mlen=27
alen=16
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m=707172737475767778797a7b7c7d7e7f8081828384858687
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
   88898a
k=000102030405060708090a0b0c0d0e0f1011121314151617
  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=565240fec29824e057f34a11fbe348b2a5dbff3bfd1e9c7e
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h=fea6bfb210a797ba08a2fc0be8d23b71293756b6dada8139
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mlen=28
alen=16
m=707172737475767778797a7b7c7d7e7f8081828384858687
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
   88898a8b
k=000102030405060708090a0b0c0d0e0f1011121314151617
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=cd340180f0349f1b3f497f6ef66a1b1ffda4df8511a23582
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h=e8a07cf78ccf0a0667dd13c676d7acfb23a5bfa1f5aa2a76
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c=1d58a6548207fb20d8307a69335985f0c8e381979f277d00
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mlen=29
alen=16
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
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k=000102030405060708090a0b0c0d0e0f1011121314151617
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  303132333435363738393a3b3c3d3e3f4041424344454647
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h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=0157d349e41530a4f1e8ceb57387c4f40dc2ac6ee17dc129
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h=7a869e2cd476f1b5fe91194f376271528e66c2ccbff3b1b4
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u=8ec07f6f0e219056f9d683ebb3d6e535f6719b42730274a1
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c=bafc2b4212a6066bc1b2b0d0839a54743219336df76d147d
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mlen=30
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   88898a8b8c8d
k=000102030405060708090a0b0c0d0e0f1011121314151617
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  303132333435363738393a3b3c3d3e3f4041424344454647
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a=606162636465666768696a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
    6fa724ab421b385d
h_m=0ff9a30bb77bc429881227ffcd2402c03e548c3fd3d364be
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h=8de51dadb41a72e46dd560797c01316b01bf5692e0084d95
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mlen=31
alen=16
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
   88898a8b8c8d8e
k=000102030405060708090a0b0c0d0e0f1011121314151617
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  303132333435363738393a3b3c3d3e3f4041424344454647
  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
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h_m=fb0bb38a68579c7102b7c70f1192bf1e47869fe1a7ce4029
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mlen=32
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   88898a8b8c8d8e8f
k=000102030405060708090a0b0c0d0e0f1011121314151617
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
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h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=56dfc90696f880bbfd257a27dace3ffce290d5750ca7448b
    fed57b77361bfc42
h=9bd930763a03e95602c96482d30a0da7da2c8e8237547a79
  4c753f0969ab0c7c
u=99e99122d1bd10e40dcc736ae2d57b3bcd150170712d5599
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c=4f79fba5c6821587611154c7a386ca5df87865d5774c73ed
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mlen=33
alen=16
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m_=707172737475767778797a7b7c7d7e7f8081828384858687
   88898a8b8c8d8e8f90
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  18191a1b1c1d1e1f202122232425262728292a2b2c2d2e2f
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  48494a4b4c4d4e4f505152535455565758595a5b5c5d5e5f
a=6061626364656667686 96a6b6c6d6e6f
h_a=59192594ab20e001cbf05f30a779940f7c699bd828bc9579
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h_m=0285637b57b6dde5cb69ccc05b7a96968715651951b52560
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h=9c344e839ead36cd4c258b44448a869cffae9223b6a17314
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u=c31b08fdfaecf5c7384a43322da3ceb3fc82bcd41caceada
  029845b7bd122d8c
c=a5096e6cd6564131dcfbd186cb1e13728e2b6719b0bf7194
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  b90cc90829a9d960f9
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