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Authors: B. Laurie, *Google*; E. Messeri, *Google*; R. Stradling, *Sectigo*

RFC 9162
Certificate Transparency Version 2.0

Abstract

This document describes version 2.0 of the Certificate Transparency (CT) protocol for publicly logging the existence of Transport Layer Security (TLS) server certificates as they are issued or observed, in a manner that allows anyone to audit certification authority (CA) activity and notice the issuance of suspect certificates as well as to audit the certificate logs themselves. The intent is that eventually clients would refuse to honor certificates that do not appear in a log, effectively forcing CAs to add all issued certificates to the logs.

This document obsoletes RFC 6962. It also specifies a new TLS extension that is used to send various CT log artifacts.

Logs are network services that implement the protocol operations for submissions and queries that are defined in this document.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for examination, experimental implementation, and evaluation.

This document defines an Experimental Protocol for the Internet community. This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Not all documents approved by the IESG are candidates for any level of Internet Standard; see Section 2 of RFC 7841.

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1. Introduction

Certificate Transparency aims to mitigate the problem of misissued certificates by providing append-only logs of issued certificates. The logs do not themselves prevent misissuance, but they ensure that interested parties (particularly those named in certificates) can detect such misissuance. Note that this is a general mechanism that could be used for transparently logging any form of binary data, subject to some kind of inclusion criteria. In this document, we only describe its use for public TLS server certificates (i.e., where the inclusion criteria is a valid certificate issued by a public certification authority (CA)). A typical definition of "public" can be found in [CABBR].

Each log contains certificate chains, which can be submitted by anyone. It is expected that public CAs will contribute all their newly issued certificates to one or more logs; however, certificate holders can also contribute their own certificate chains, as can third parties. In order to avoid logs being rendered useless by the submission of large numbers of spurious certificates, it is required that each chain ends with a trust anchor that is accepted by the log. A log may also limit the length of the chain it is willing to accept; such chains must also end with an acceptable trust anchor. When a chain is accepted by a log, a signed timestamp is returned, which can later be used to provide evidence to TLS clients that the chain has been submitted. TLS clients can thus require that all certificates they accept as valid are accompanied by signed timestamps.

Those who are concerned about misissuance can monitor the logs, asking them regularly for all new entries, and can thus check whether domains for which they are responsible have had certificates issued that they did not expect. What they do with this information, particularly when they find that a misissuance has happened, is beyond the scope of this document. However, broadly speaking, they can invoke existing business mechanisms for dealing with misissued certificates, such as working with the CA to get the certificate revoked or with maintainers of trust anchor lists to get the CA removed. Of course, anyone who wants can monitor the logs and, if they believe a certificate is incorrectly issued, take action as they see fit.

Similarly, those who have seen signed timestamps from a particular log can later demand a proof of inclusion from that log. If the log is unable to provide this (or, indeed, if the corresponding certificate is absent from monitors' copies of that log), that is evidence of the incorrect operation of the log. The checking operation is asynchronous to allow clients to proceed without delay, despite possible issues, such as network connectivity and the vagaries of firewalls.

The append-only property of each log is achieved using Merkle Trees, which can be used to efficiently prove that any particular instance of the log is a superset of any particular previous instance and to efficiently detect various misbehaviors of the log (e.g., issuing a signed timestamp for a certificate that is not subsequently logged).

The log auditing mechanisms described in this document can be circumvented by a misbehaving log that shows different, inconsistent views of itself to different clients. Therefore, it is necessary to treat each log as a trusted third party. While mechanisms are being developed to address these shortcomings and thereby avoid the need to blindly trust logs, such mechanisms are outside the scope of this document.

1.1. Requirements Language

The key words "**MUST**", "**MUST NOT**", "**REQUIRED**", "**SHALL**", "**SHALL NOT**", "**SHOULD**", "**SHOULD NOT**", "**RECOMMENDED**", "**NOT RECOMMENDED**", "**MAY**", and "**OPTIONAL**" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

1.2. Data Structures

Data structures are defined and encoded according to the conventions laid out in Section 3 of [RFC8446].

This document uses object identifiers (OIDs) to identify Log IDs (see Section 4.4), the precertificate Cryptographic Message Syntax (CMS) `eContentType` (see Section 3.2), X.509v3 extensions in certificates (see Section 7.1.2), and Online Certificate Status Protocol (OCSP) responses (see Section 7.1.1). The OIDs are defined in an arc that was selected due to its short encoding.

1.3. Major Differences from CT 1.0

This document revises and obsoletes the CT 1.0 protocol [RFC6962], drawing on insights gained from CT 1.0 deployments and on feedback from the community. The major changes are:

- Hash and signature algorithm agility: Permitted algorithms are now specified in IANA registries.
- Precertificate format: Precertificates are now CMS objects rather than X.509 certificates, which avoids violating the certificate serial number uniqueness requirement in Section 4.1.2.2 of [RFC5280].
- Removal of precertificate signing certificates and the precertificate poison extension: The change of precertificate format means that these are no longer needed.

- Logs IDs: Each log is now identified by an OID rather than by the hash of its public key. OID allocations are available from an IANA registry.
- `TransItem` structure: This new data structure is used to encapsulate most types of CT data. A `TransItemList`, consisting of one or more `TransItem` structures, can be used anywhere that `SignedCertificateTimestampList` was used in [RFC6962].
- Merkle Tree leaves: The `MerkleTreeLeaf` structure has been replaced by the `TransItem` structure, which eases extensibility and simplifies the leaf structure by removing one layer of abstraction.
- Unified leaf format: The structure for both certificate and precertificate entries now includes only the TBSCertificate (whereas certificate entries in [RFC6962] included the entire certificate).
- Log artifact extensions: These are now typed and managed by an IANA registry, and they can now appear not only in Signed Certificate Timestamps (SCTs) but also in Signed Tree Heads (STHs).
- API outputs: Complete `TransItem` structures are returned rather than the constituent parts of each structure.
- `get-all-by-hash`: This is a new client API for obtaining an inclusion proof and the corresponding consistency proof at the same time.
- `submit-entry`: This is a new client API, replacing `add-chain` and `add-pre-chain`.
- Presenting SCTs with proofs: TLS servers may present SCTs together with the corresponding inclusion proofs, using any of the mechanisms that [RFC6962] defined for presenting SCTs only. (Presenting SCTs only is still supported).
- CT TLS extension: The `signed_certificate_timestamp` TLS extension has been replaced by the `transparency_info` TLS extension.
- Verification algorithms: Detailed algorithms for verifying inclusion proofs, for verifying consistency between two STHs, and for verifying a root hash given a complete list of the relevant leaf input entries have been added.
- Extensive clarifications and editorial work.

2. Cryptographic Components

2.1. Merkle Trees

A full description of the Merkle Tree is beyond the scope of this document. Briefly, it is a binary tree where each non-leaf node is a hash of its children. For CT, the number of children is at most two. Additional information can be found in the Introduction and Reference sections of [RFC8391].

2.1.1. Definition of the Merkle Tree

The log uses a binary Merkle Tree for efficient auditing. The hash algorithm used is one of the log's parameters (see Section 4.1). This document establishes a registry of acceptable hash algorithms (see Section 10.2.1). Throughout this document, the hash algorithm in use is referred to as HASH and the size of its output in bytes is referred to as HASH_SIZE. The input to the

Merkle Tree Hash is a list of data entries; these entries will be hashed to form the leaves of the Merkle Tree. The output is a single HASH_SIZE Merkle Tree Hash. Given an ordered list of n inputs, D_n = {d[0], d[1], ..., d[n-1]}, the Merkle Tree Hash (MTH) is thus defined as follows:

The hash of an empty list is the hash of an empty string:

```
MTH({}) = HASH().
```

The hash of a list with one entry (also known as a leaf hash) is:

```
MTH({d[0]}) = HASH(0x00 || d[0]).
```

For n > 1, let k be the largest power of two smaller than n (i.e., k < n <= 2k). The Merkle Tree Hash of an n-element list D_n is then defined recursively as:

```
MTH(D_n) = HASH(0x01 || MTH(D[0:k]) || MTH(D[k:n])),
```

where:

- || denotes concatenation
- : denotes concatenation of lists
- D[k1:k2] = D'_(k2-k1) denotes the list {d'[0] = d[k1], d'[1] = d[k1+1], ..., d'[k2-k1-1] = d[k2-1]} of length (k2 - k1).

Note that the hash calculations for leaves and nodes differ; this domain separation is required to give second preimage resistance.

Note that we do not require the length of the input list to be a power of two. The resulting Merkle Tree may thus not be balanced; however, its shape is uniquely determined by the number of leaves. (Note: This Merkle Tree is essentially the same as the history tree proposed by [CrosbyWallach], except our definition handles non-full trees differently.)

2.1.2. Verifying a Tree Head Given Entries

When a client has a complete list of `entries` from `0` up to `tree_size - 1` and wishes to verify this list against a tree head `root_hash` returned by the log for the same `tree_size`, the following algorithm may be used:

1. Set `stack` to an empty stack.
2. For each `i` from `0` up to `tree_size - 1`:
   a. Push `HASH(0x00 || entries[i])` to `stack`.
   b. Set `merge_count` to the lowest value (`0` included) such that `LSB(i >> merge_count)` is not set, where `LSB` means the least significant bit. In other words, set `merge_count` to the number of consecutive `1`s found starting at the least significant bit of `i`.

c. Repeat `merge_count` times:

i. Pop `right` from `stack`.

ii. Pop `left` from `stack`.

iii. Push `HASH(0x01 || left || right)` to `stack`.

3. If there is more than one element in the `stack`, repeat the same merge procedure (the sub-items of Step 2(c) above) until only a single element remains.
4. The remaining element in `stack` is the Merkle Tree Hash for the given `tree_size` and should be compared by equality against the supplied `root_hash`.

2.1.3. Merkle Inclusion Proofs

A Merkle inclusion proof for a leaf in a Merkle Tree is the shortest list of additional nodes in the Merkle Tree required to compute the Merkle Tree Hash for that tree. Each node in the tree is either a leaf node or is computed from the two nodes immediately below it (i.e., towards the leaves). At each step up the tree (towards the root), a node from the inclusion proof is combined with the node computed so far. In other words, the inclusion proof consists of the list of missing nodes required to compute the nodes leading from a leaf to the root of the tree. If the root computed from the inclusion proof matches the true root, then the inclusion proof proves that the leaf exists in the tree.

2.1.3.1. Generating an Inclusion Proof

Given an ordered list of n inputs to the tree, D_n = {d[0], d[1], ..., d[n-1]}, the Merkle inclusion proof PATH(m, D_n) for the (m+1)th input d[m], 0 <= m < n, is defined as follows:

The proof for the single leaf in a tree with a one-element input list D[1] = {d[0]} is empty:

```
PATH(0, {d[0]}) = {}
```

For n > 1, let k be the largest power of two smaller than n. The proof for the (m+1)th element d[m] in a list of n > m elements is then defined recursively as:

```
PATH(m, D_n) = PATH(m, D[0:k]) : MTH(D[k:n]) for m < k; and

PATH(m, D_n) = PATH(m - k, D[k:n]) : MTH(D[0:k]) for m >= k,
```

The : operator and D[k1:k2] are defined the same as in Section 2.1.1.

2.1.3.2. Verifying an Inclusion Proof

When a client has received an inclusion proof (e.g., in a `TransItem` of type `inclusion_proof_v2`) and wishes to verify inclusion of an input `hash` for a given `tree_size` and `root_hash`, the following algorithm may be used to prove the `hash` was included in the `root_hash`:

1. Compare `leaf_index` from the `inclusion_proof_v2` structure against `tree_size`. If `leaf_index` is greater than or equal to `tree_size`, then fail the proof verification.

2. Set `fn` to `leaf_index` and `sn` to `tree_size - 1`.
3. Set `r` to `hash`.
4. For each value `p` in the `inclusion_path` array:
   a. If `sn` is 0, then stop the iteration and fail the proof verification.
   b. If `LSB(fn)` is set, or if `fn` is equal to `sn`, then:
      i. Set `r` to `HASH(0x01 || p || r)`.
      ii. If `LSB(fn)` is not set, then right-shift both `fn` and `sn` equally until either `LSB(fn)` is set or `fn` is `0`.

      Otherwise:
      i. Set `r` to `HASH(0x01 || r || p)`.
   c. Finally, right-shift both `fn` and `sn` one time.
5. Compare `sn` to 0. Compare `r` against the `root_hash`. If `sn` is equal to 0 and `r` and the `root_hash` are equal, then the log has proven the inclusion of `hash`. Otherwise, fail the proof verification.

2.1.4. Merkle Consistency Proofs

Merkle consistency proofs prove the append-only property of the tree. A Merkle consistency proof for a Merkle Tree Hash MTH(D_n) and a previously advertised hash MTH(D[0:m]) of the first m leaves, m <= n, is the list of nodes in the Merkle Tree required to verify that the first m inputs D[0:m] are equal in both trees. Thus, a consistency proof must contain a set of intermediate nodes (i.e., commitments to inputs) sufficient to verify MTH(D_n), such that (a subset of) the same nodes can be used to verify MTH(D[0:m]). We define an algorithm that outputs the (unique) minimal consistency proof.

2.1.4.1. Generating a Consistency Proof

Given an ordered list of n inputs to the tree, D_n = {d[0], d[1], ..., d[n-1]}, the Merkle consistency proof PROOF(m, D_n) for a previous Merkle Tree Hash MTH(D[0:m]), 0 < m < n, is defined as:

```
PROOF(m, D_n) = SUBPROOF(m, D_n, true)
```

In SUBPROOF, the boolean value represents whether the subtree created from D[0:m] is a complete subtree of the Merkle Tree created from D_n and, consequently, whether the subtree Merkle Tree Hash MTH(D[0:m]) is known. The initial call to SUBPROOF sets this to be true, and SUBPROOF is then defined as follows:

The subproof for m = n is empty if m is the value for which PROOF was originally requested (meaning that the subtree created from D[0:m] is a complete subtree of the Merkle Tree created from the original D_n for which PROOF was requested and the subtree Merkle Tree Hash MTH(D[0:m]) is known):

```
SUBPROOF(m, D_m, true) = {}
```

Otherwise, the subproof for m = n is the Merkle Tree Hash committing inputs D[0:m]:

```
SUBPROOF(m, D_m, false) = {MTH(D_m)}
```

For m < n, let k be the largest power of two smaller than n. The subproof is then defined recursively, using the appropriate step below:

If m <= k, the right subtree entries D[k:n] only exist in the current tree. We prove that the left subtree entries D[0:k] are consistent and add a commitment to D[k:n]:

```
SUBPROOF(m, D_n, b) = SUBPROOF(m, D[0:k], b) : MTH(D[k:n])
```

If m > k, the left subtree entries D[0:k] are identical in both trees. We prove that the right subtree entries D[k:n] are consistent and add a commitment to D[0:k]:

```
SUBPROOF(m, D_n, b) = SUBPROOF(m - k, D[k:n], false) : MTH(D[0:k])
```

The number of nodes in the resulting proof is bounded above by ceil(log2(n)) + 1.

The : operator and D[k1:k2] are defined the same as in Section 2.1.1.

2.1.4.2. Verifying Consistency between Two Tree Heads

When a client has a tree head `first_hash` for tree size `first`, has a tree head `second_hash` for tree size `second` where `0 < first < second`, and has received a consistency proof between the two (e.g., in a `TransItem` of type `consistency_proof_v2`), the following algorithm may be used to verify the consistency proof:

1. If `consistency_path` is an empty array, stop and fail the proof verification.
2. If `first` is an exact power of 2, then prepend `first_hash` to the `consistency_path` array.
3. Set `fn` to `first - 1` and `sn` to `second - 1`.
4. If `LSB(fn)` is set, then right-shift both `fn` and `sn` equally until `LSB(fn)` is not set.
5. Set both `fr` and `sr` to the first value in the `consistency_path` array.
6. For each subsequent value `c` in the `consistency_path` array:
   a. If `sn` is 0, then stop the iteration and fail the proof verification.
   b. If `LSB(fn)` is set, or if `fn` is equal to `sn`, then:
      i. Set `fr` to `HASH(0x01 || c || fr)`.
      ii. Set `sr` to `HASH(0x01 || c || sr)`.
      iii. If `LSB(fn)` is not set, then right-shift both `fn` and `sn` equally until either `LSB(fn)` is set or `fn` is `0`.

Otherwise:

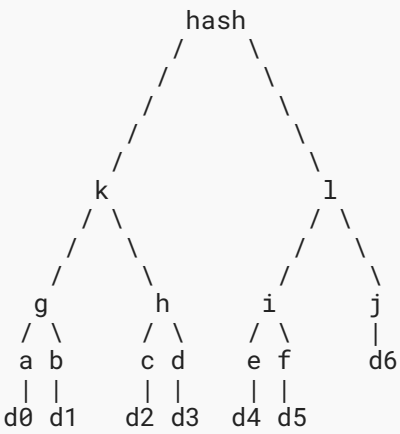
i. Set `sr` to `HASH(0x01 || sr || c)`.

c. Finally, right-shift both `fn` and `sn` one time.

7. After completing iterating through the `consistency_path` array as described above, verify that the `fr` calculated is equal to the `first_hash` supplied, that the `sr` calculated is equal to the `second_hash` supplied, and that `sn` is 0.

2.1.5. Example

The following is a binary Merkle Tree with 7 leaves:



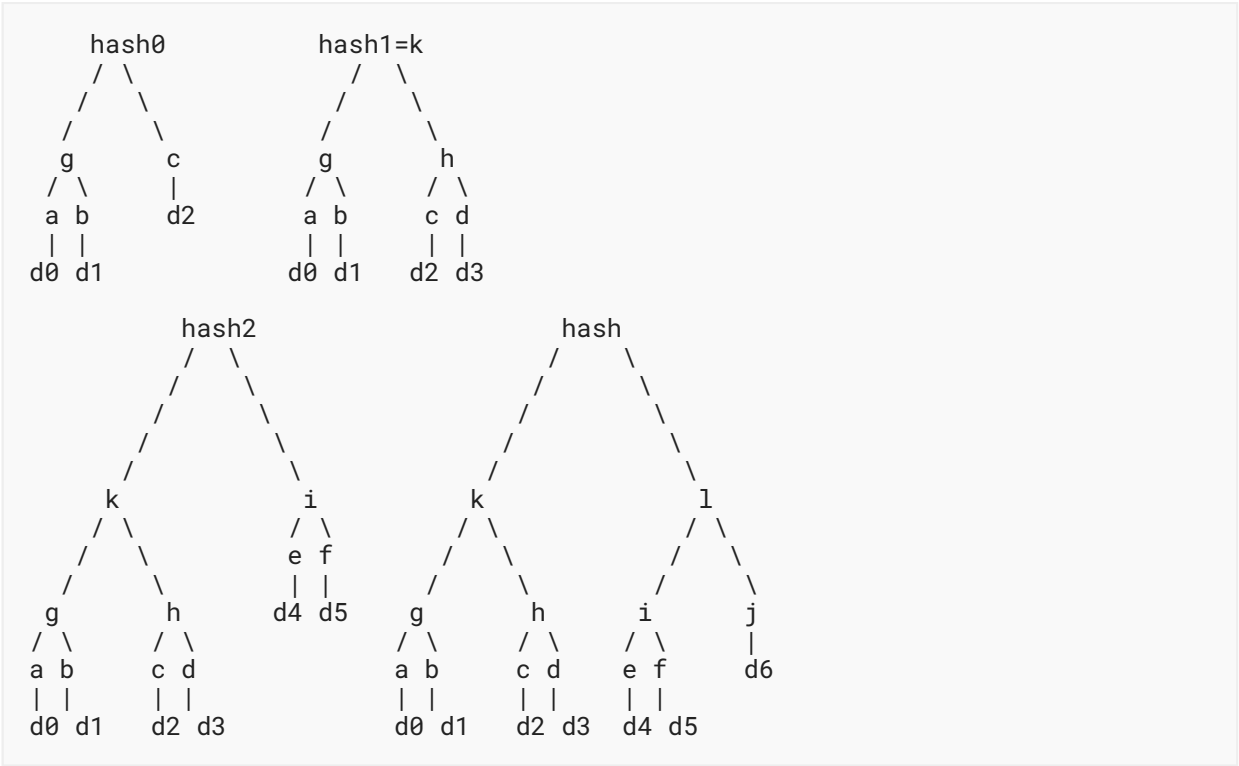
The inclusion proof for `d0` is [`b`, `h`, `l`].

The inclusion proof for `d3` is [`c`, `g`, `l`].

The inclusion proof for `d4` is [`f`, `j`, `k`].

The inclusion proof for `d6` is [`i`, `k`].

The same tree, built incrementally in four steps:



The consistency proof between `hash0` and `hash` is PROOF(3, D[7]) = [`c`, `d`, `g`, `l`]. Non-leaf nodes `c`, `g` are used to verify `hash0`, and non-leaf nodes `d`, `l` are additionally used to show `hash` is consistent with `hash0`.

The consistency proof between `hash1` and `hash` is PROOF(4, D[7]) = [`l`]. `hash` can be verified using `hash1=k` and `l`.

The consistency proof between `hash2` and `hash` is PROOF(6, D[7]) = [`i`, `j`, `k`]. Non-leaf nodes `k`, `i` are used to verify `hash2`, and non-leaf node `j` is additionally used to show `hash` is consistent with `hash2`.

2.2. Signatures

When signing data structures, a log **MUST** use one of the signature algorithms from the IANA "Signature Algorithms" registry, described in Section 10.2.2.

3. Submitters

Submitters submit certificates or preannouncements of certificates prior to issuance (precertificates) to logs for public auditing, as described below. In order to enable attribution of each logged certificate or precertificate to its issuer, each submission **MUST** be accompanied by all additional certificates required to verify the chain up to an accepted trust anchor (Section 5.7). The trust anchor (a root or intermediate CA certificate) **MAY** be omitted from the submission.

If a log accepts a submission, it will return a Signed Certificate Timestamp (SCT) (see Section 4.8). The submitter **SHOULD** validate the returned SCT, as described in Section 8.1, if they understand its format and they intend to use it directly in a TLS handshake or to construct a certificate. If the submitter does not need the SCT (for example, the certificate is being submitted simply to make it available in the log), it **MAY** validate the SCT.

3.1. Certificates

Any entity can submit a certificate (Section 5.1) to a log. Since it is anticipated that TLS clients will reject certificates that are not logged, it is expected that certificate issuers and subjects will be strongly motivated to submit them.

3.2. Precertificates

CAs may preannounce a certificate prior to issuance by submitting a precertificate (Section 5.1) that the log can use to create an entry that will be valid against the issued certificate. The CA **MAY** incorporate the returned SCT in the issued certificate. One example of where the returned SCT is not incorporated in the issued certificate is when a CA sends the precertificate to multiple logs but only incorporates the SCTs that are returned first.

A precertificate is a CMS [RFC5652] `signed-data` object that conforms to the following profile:

- It **MUST** be DER encoded, as described in [X690].
- `SignedData.version` **MUST** be v3(3).
- `SignedData.digestAlgorithms` **MUST** be the same as the `SignerInfo.digestAlgorithm` OID value (see below).
- `SignedData.encapContentInfo`:
  - `eContentType` **MUST** be the OID 1.3.101.78.
  - `eContent` **MUST** contain a TBSCertificate [RFC5280] that will be identical to the TBSCertificate in the issued certificate, except that the Transparency Information (Section 7.1) extension **MUST** be omitted.
- `SignedData.certificates` **MUST** be omitted.
- `SignedData.crls` **MUST** be omitted.
- `SignedData.signerInfos` **MUST** contain one `SignerInfo`:
  - `version` **MUST** be v3(3).
  - `sid` **MUST** use the `subjectKeyIdentifier` option.
  - `digestAlgorithm` **MUST** be one of the hash algorithm OIDs listed in the IANA "Hash Algorithms" registry, described in Section 10.2.1.
  - `signedAttrs` **MUST** be present and **MUST** contain two attributes:
    - a content-type attribute whose value is the same as `SignedData.encapContentInfo.eContentType` and
    - a message-digest attribute whose value is the message digest of `SignedData.encapContentInfo.eContent`.

- `signatureAlgorithm` **MUST** be the same OID as `TBSCertificate.signature`.
- `signature` **MUST** be from the same (root or intermediate) CA that intends to issue the corresponding certificate (see Section 3.2.1).
- `unsignedAttrs` **MUST** be omitted.

`SignerInfo.signedAttrs` is included in the message digest calculation process (see Section 5.4 of [RFC5652]), which ensures that the `SignerInfo.signature` value will not be a valid X.509v3 signature that could be used in conjunction with the TBSCertificate (from `SignedData.encapContentInfo.eContent`) to construct a valid certificate.

3.2.1. Binding Intent to Issue

Under normal circumstances, there will be a short delay between precertificate submission and issuance of the corresponding certificate. Longer delays are to be expected occasionally (e.g., due to log server downtime); in some cases, the CA might not actually issue the corresponding certificate. Nevertheless, a precertificate's `signature` indicates the CA's binding intent to issue the corresponding certificate, which means that:

- Misissuance of a precertificate is considered equivalent to misissuance of the corresponding certificate. The CA should expect to be held accountable, even if the corresponding certificate has not actually been issued.
- Upon observing a precertificate, a client can reasonably presume that the corresponding certificate has been issued. A client may wish to obtain status information (e.g., by using the Online Certificate Status Protocol [RFC6960] or by checking a Certificate Revocation List [RFC5280]) about a certificate that is presumed to exist, especially if there is evidence or suspicion that the corresponding precertificate was misissued.
- TLS clients may have policies that require CAs to be able to revoke and to provide certificate status services for each certificate that is presumed to exist based on the existence of a corresponding precertificate.

4. Log Format and Operation

A log is a single, append-only Merkle Tree of submitted certificate and precertificate entries.

When it receives and accepts a valid submission, the log **MUST** return an SCT that corresponds to the submitted certificate or precertificate. If the log has previously seen this valid submission, it **SHOULD** return the same SCT as it returned before, as discussed in Section 11.3. If different SCTs are produced for the same submission, multiple log entries will have to be created, one for each SCT (as the timestamp is a part of the leaf structure). Note that if a certificate was previously logged as a precertificate, then the precertificate's SCT of type `precert_sct_v2` would not be appropriate; instead, a fresh SCT of type `x509_sct_v2` should be generated.

An SCT is the log's promise to append to its Merkle Tree an entry for the accepted submission. Upon producing an SCT, the log **MUST** fulfill this promise by performing the following actions within a fixed amount of time known as the Maximum Merge Delay (MMD), which is one of the log's parameters (see Section 4.1):

- Allocate a tree index to the entry representing the accepted submission.
- Calculate the root of the tree.
- Sign the root of the tree (see Section 4.10).

The log may append multiple entries before signing the root of the tree.

Log operators **SHOULD NOT** impose any conditions on retrieving or sharing data from the log.

4.1. Log Parameters

A log is defined by a collection of immutable parameters, which are used by clients to communicate with the log and to verify log artifacts. Except for the Final STH, each of these parameters **MUST** be established before the log operator begins to operate the log.

Base URL: The prefix used to construct URLs [RFC3986] for client messages (see Section 5). The base URL **MUST** be an "https" URL, **MAY** contain a port, and **MAY** contain a path with any number of path segments but **MUST NOT** contain a query string, fragment, or trailing "/". Example: https://ct.example.org/blue.

Hash Algorithm: The hash algorithm used for the Merkle Tree (see Section 10.2.1).

Signature Algorithm: The signature algorithm used (see Section 2.2).

Public Key: The public key used to verify signatures generated by the log. A log **MUST NOT** use the same keypair as any other log.

Log ID: The OID that uniquely identifies the log.

Maximum Merge Delay: The MMD the log has committed to. This document deliberately does not specify any limits on the value to allow for experimentation.

Version: The version of the protocol supported by the log (currently 1 or 2).

Maximum Chain Length: The longest certificate chain submission the log is willing to accept, if the log imposes any limit.

STH Frequency Count: The maximum number of STHs the log may produce in any period equal to the `Maximum Merge Delay` (see Section 4.10).

Final STH: If a log has been closed down (i.e., no longer accepts new entries), existing entries may still be valid. In this case, the client should know the final valid STH in the log to ensure no new entries can be added without detection. This value **MUST** be provided in the form of a `TransItem` of type `signed_tree_head_v2`. If a log is still accepting entries, this value should not be provided.

[JSON.Metadata] is an example of a metadata format that includes the above elements.

4.2. Evaluating Submissions

A log determines whether to accept or reject a submission by evaluating it against the minimum acceptance criteria (see Section 4.2.1) and against the log's discretionary acceptance criteria (see Section 4.2.2).

If the acceptance criteria are met, the log **SHOULD** accept the submission. (A log may decide, for example, to temporarily reject acceptable submissions to protect itself against denial-of-service attacks.)

The log **SHALL** allow retrieval of its list of accepted trust anchors (see Section 5.7), each of which is a root or intermediate CA certificate. This list might usefully be the union of root certificates trusted by major browser vendors.

4.2.1. Minimum Acceptance Criteria

To ensure that logged certificates and precertificates are attributable to an accepted trust anchor, to set clear expectations for what monitors would find in the log, and to avoid being overloaded by invalid submissions, the log **MUST** reject a submission if any of the following conditions are not met:

- The `submission`, `type`, and `chain` inputs **MUST** be set as described in Section 5.1. The log **MUST NOT** accommodate misordered CA certificates or use any other source of intermediate CA certificates to attempt certification path construction.
- Each of the zero or more intermediate CA certificates in the chain **MUST** have one or both of the following features:
  - The Basic Constraints extension with the cA boolean asserted.
  - The Key Usage extension with the keyCertSign bit asserted.
- Each certificate in the chain **MUST** fall within the limits imposed by the zero or more Basic Constraints pathLenConstraint values found higher up the chain.
- Precertificate submissions **MUST** conform to all of the requirements in Section 3.2.

4.2.2. Discretionary Acceptance Criteria

If the minimum acceptance criteria are met but the submission is not fully valid according to [RFC5280] verification rules (e.g., the certificate or precertificate has expired, is not yet valid, has been revoked, exhibits ASN.1 DER encoding errors but the log can still parse it, etc.), then the acceptability of the submission is left to the log's discretion. It is useful for logs to accept such submissions in order to accommodate quirks of CA certificate-issuing software and to facilitate monitoring of CA compliance with applicable policies and technical standards. However, it is impractical for this document to enumerate, and for logs to consider, all of the ways that a submission might fail to comply with [RFC5280].

Logs **SHOULD** limit the length of chain they will accept. The maximum chain length is one of the log's parameters (see Section 4.1).

4.3. Log Entries

If a submission is accepted and an SCT is issued, the accepting log **MUST** store the entire chain used for verification. This chain **MUST** include the certificate or precertificate itself, the zero or more intermediate CA certificates provided by the submitter, and the trust anchor used to verify the chain (even if it was omitted from the submission). The log **MUST** provide this chain for auditing upon request (see Section 5.6) so that the CA cannot avoid blame by logging a partial or empty chain. Each log entry is a `TransItem` structure of type `x509_entry_v2` or `precert_entry_v2`. However, a log may store its entries in any format. If a log does not store this `TransItem` in full, it must store the `timestamp` and `sct_extensions` of the corresponding `TimestampedCertificateEntryDataV2` structure. The `TransItem` can be reconstructed from these fields and the entire chain that the log used to verify the submission.

4.4. Log ID

Each log is identified by an OID, which is one of the log's parameters (see Section 4.1) and which **MUST NOT** be used to identify any other log. A log's operator **MUST** either allocate the OID themselves or request an OID from the Log ID registry (see Section 10.2.5). One way to get an OID arc, from which OIDs can be allocated, is to request a Private Enterprise Number from IANA by completing the registration form. The only advantage of the registry is that the DER encoding can be small. (Recall that OID allocations do not require a central registration, although logs will most likely want to make themselves known to potential clients through out-of-band means.) Various data structures include the DER encoding of this OID, excluding the ASN.1 tag and length bytes, in an opaque vector:

```
opaque LogID<2..127>;
```

Note that the ASN.1 length and the opaque vector length are identical in size (1 byte) and value, so the full DER encoding (including the tag and length) of the OID can be reproduced simply by prepending an OBJECT IDENTIFIER tag (0x06) to the opaque vector length and contents.

The OID used to identify a log is limited such that the DER encoding of its value, excluding the tag and length, **MUST** be no longer than 127 octets.

4.5. TransItem Structure

Various data structures are encapsulated in the `TransItem` structure to ensure that the type and version of each one is identified in a common fashion:

```
    enum {
        x509_entry_v2(0x0100), precert_entry_v2(0x0101),
        x509_sct_v2(0x0102), precert_sct_v2(0x0103),
        signed_tree_head_v2(0x0104), consistency_proof_v2(0x0105),
        inclusion_proof_v2(0x0106),

        /* Reserved Code Points */
        reserved_rfc6962(0x0000..0x00FF),
        reserved_experimentaluse(0xE000..0xEFFF),
        reserved_privateuse(0xF000..0xFFFF),
        (0xFFFF)
    } VersionedTransType;

    struct {
        VersionedTransType versioned_type;
        select (versioned_type) {
            case x509_entry_v2: TimestampedCertificateEntryDataV2;
            case precert_entry_v2: TimestampedCertificateEntryDataV2;
            case x509_sct_v2: SignedCertificateTimestampDataV2;
            case precert_sct_v2: SignedCertificateTimestampDataV2;
            case signed_tree_head_v2: SignedTreeHeadDataV2;
            case consistency_proof_v2: ConsistencyProofDataV2;
            case inclusion_proof_v2: InclusionProofDataV2;
        } data;
    } TransItem;
```

`versioned_type` is a value from the IANA registry in Section 10.2.3 that identifies the type of the encapsulated data structure and the earliest version of this protocol to which it conforms. This document is v2.

`data` is the encapsulated data structure. The various structures named with the `DataV2` suffix are defined in later sections of this document.

Note that `VersionedTransType` combines the v1 type enumerations `Version`, `LogEntryType`, `SignatureType`, and `MerkleLeafType` [RFC6962]. Note also that v1 did not define `TransItem`, but this document provides guidelines (see Appendix A) on how v2 implementations can coexist with v1 implementations.

Future versions of this protocol may reuse `VersionedTransType` values defined in this document as long as the corresponding data structures are not modified and may add new `VersionedTransType` values for new or modified data structures.

4.6. Log Artifact Extensions

```
enum {
    reserved(65535)
} ExtensionType;

struct {
    ExtensionType extension_type;
    opaque extension_data<0..2^16-1>;
} Extension;
```

The `Extension` structure provides a generic extensibility for log artifacts, including SCTs (Section 4.8) and STHs (Section 4.10). The interpretation of the `extension_data` field is determined solely by the value of the `extension_type` field.

This document does not define any extensions, but it does establish a registry for future `ExtensionType` values (see Section 10.2.4). Each document that registers a new `ExtensionType` must specify the context in which it may be used (e.g., SCT, STH, or both) and describe how to interpret the corresponding `extension_data`.

4.7. Merkle Tree Leaves

The leaves of a log's Merkle Tree correspond to the log's entries (see Section 4.3). Each leaf is the leaf hash (Section 2.1) of a `TransItem` structure of type `x509_entry_v2` or `precert_entry_v2`, which encapsulates a `TimestampedCertificateEntryDataV2` structure. Note that leaf hashes are calculated as `HASH(0x00 || TransItem)`, where the hash algorithm is one of the log's parameters.

```
opaque TBSCertificate<1..2^24-1>;

struct {
    uint64 timestamp;
    opaque issuer_key_hash<32..2^8-1>;
    TBSCertificate tbs_certificate;
    Extension sct_extensions<0..2^16-1>;
} TimestampedCertificateEntryDataV2;
```

`timestamp` is the date and time at which the certificate or precertificate was accepted by the log, in the form of a 64-bit unsigned number of milliseconds elapsed since the Unix Epoch (1 January 1970 00:00:00 UTC -- see [UNIXTIME]), ignoring leap seconds, in network byte order. Note that the leaves of a log's Merkle Tree are not required to be in strict chronological order.

`issuer_key_hash` is the HASH of the public key of the CA that issued the certificate or precertificate, calculated over the DER encoding of the key represented as SubjectPublicKeyInfo [RFC5280]. This is needed to bind the CA to the certificate or precertificate, making it impossible

for the corresponding SCT to be valid for any other certificate or precertificate whose TBSCertificate matches `tbs_certificate`. The length of the `issuer_key_hash` **MUST** match HASH_SIZE.

`tbs_certificate` is the DER-encoded TBSCertificate from the submission. (Note that a precertificate's TBSCertificate can be reconstructed from the corresponding certificate, as described in Section 8.1.2).

`sct_extensions` is byte-for-byte identical to the SCT extensions of the corresponding SCT.

The type of the `TransItem` corresponds to the value of the `type` parameter supplied in the Section 5.1 call.

4.8. Signed Certificate Timestamp (SCT)

An SCT is a `TransItem` structure of type `x509_sct_v2` or `precert_sct_v2`, which encapsulates a `SignedCertificateTimestampDataV2` structure:

```
struct {
    LogID log_id;
    uint64 timestamp;
    Extension sct_extensions<0..2^16-1>;
    opaque signature<1..2^16-1>;
} SignedCertificateTimestampDataV2;
```

`log_id` is this log's unique ID, encoded in an opaque vector, as described in Section 4.4.

`timestamp` is equal to the timestamp from the corresponding `TimestampedCertificateEntryDataV2` structure.

`sct_extensions` is a vector of 0 or more SCT extensions. This vector **MUST NOT** include more than one extension with the same `extension_type`. The extensions in the vector **MUST** be ordered by the value of the `extension_type` field, smallest value first. All SCT extensions are similar to noncritical X.509v3 extensions (i.e., the `mustUnderstand` field is not set), and a recipient **SHOULD** ignore any extension it does not understand. Furthermore, an implementation **MAY** choose to ignore any extension(s) that it does understand.

`signature` is computed over a `TransItem` structure of type `x509_entry_v2` or `precert_entry_v2` (see Section 4.7) using the signature algorithm declared in the log's parameters (see Section 4.1).

4.9. Merkle Tree Head

The log stores information about its Merkle Tree in a `TreeHeadDataV2`:

```
opaque NodeHash<32..2^8-1>;

struct {
    uint64 timestamp;
    uint64 tree_size;
    NodeHash root_hash;
    Extension sth_extensions<0..2^16-1>;
} TreeHeadDataV2;
```

The length of NodeHash **MUST** match HASH_SIZE of the log.

`timestamp` is the current date and time, using the format defined in Section 4.7.

`tree_size` is the number of entries currently in the log's Merkle Tree.

`root_hash` is the root of the Merkle Tree.

`sth_extensions` is a vector of 0 or more STH extensions. This vector **MUST NOT** include more than one extension with the same `extension_type`. The extensions in the vector **MUST** be ordered by the value of the `extension_type` field, smallest value first. If an implementation sees an extension that it does not understand, it **SHOULD** ignore that extension. Furthermore, an implementation **MAY** choose to ignore any extension(s) that it does understand.

4.10. Signed Tree Head (STH)

Periodically, each log **SHOULD** sign its current tree head information (see Section 4.9) to produce an STH. When a client requests a log's latest STH (see Section 5.2), the log **MUST** return an STH that is no older than the log's MMD. However, since STHs could be used to mark individual clients (by producing a new STH for each query), a log **MUST NOT** produce STHs more frequently than its parameters declare (see Section 4.1). In general, there is no need to produce a new STH unless there are new entries in the log; however, in the event that a log does not accept any submissions during an MMD period, the log **MUST** sign the same Merkle Tree Hash with a fresh timestamp.

An STH is a `TransItem` structure of type `signed_tree_head_v2`, which encapsulates a `SignedTreeHeadDataV2` structure:

```
struct {
    LogID log_id;
    TreeHeadDataV2 tree_head;
    opaque signature<1..2^16-1>;
} SignedTreeHeadDataV2;
```

`log_id` is this log's unique ID encoded in an opaque vector, as described in Section 4.4.

The `timestamp` in `tree_head` **MUST** be at least as recent as the most recent SCT timestamp in the tree. Each subsequent timestamp **MUST** be more recent than the timestamp of the previous update.

`tree_head` contains the latest tree head information (see Section 4.9).

`signature` is computed over the `tree_head` field using the signature algorithm declared in the log's parameters (see Section 4.1).

4.11. Merkle Consistency Proofs

To prepare a Merkle consistency proof for distribution to clients, the log produces a `TransItem` structure of type `consistency_proof_v2`, which encapsulates a `ConsistencyProofDataV2` structure:

```
struct {
    LogID log_id;
    uint64 tree_size_1;
    uint64 tree_size_2;
    NodeHash consistency_path<0..2^16-1>;
} ConsistencyProofDataV2;
```

`log_id` is this log's unique ID encoded in an opaque vector, as described in Section 4.4.

`tree_size_1` is the size of the older tree.

`tree_size_2` is the size of the newer tree.

`consistency_path` is a vector of Merkle Tree nodes proving the consistency of two STHs, as described in Section 2.1.4.

4.12. Merkle Inclusion Proofs

To prepare a Merkle inclusion proof for distribution to clients, the log produces a `TransItem` structure of type `inclusion_proof_v2`, which encapsulates an `InclusionProofDataV2` structure:

```
struct {
    LogID log_id;
    uint64 tree_size;
    uint64 leaf_index;
    NodeHash inclusion_path<0..2^16-1>;
} InclusionProofDataV2;
```

`log_id` is this log's unique ID encoded in an opaque vector, as described in Section 4.4.

`tree_size` is the size of the tree on which this inclusion proof is based.

`leaf_index` is the 0-based index of the log entry corresponding to this inclusion proof.

`inclusion_path` is a vector of Merkle Tree nodes proving the inclusion of the chosen certificate or precertificate, as described in Section 2.1.3.

4.13. Shutting Down a Log

Log operators may decide to shut down a log for various reasons, such as deprecation of the signature algorithm. If there are entries in the log for certificates that have not yet expired, simply making TLS clients stop recognizing that log will have the effect of invalidating SCTs from that log. In order to avoid that, the following actions **SHOULD** be taken:

- Make it known to clients and monitors that the log will be frozen. This is not part of the API, so it will have to be done via a relevant out-of-band mechanism.
- Stop accepting new submissions (the error code "shutdown" should be returned for such requests).
- Once MMD from the last accepted submission has passed and all pending submissions are incorporated, issue a final STH and publish it as one of the log's parameters. Having an STH with a timestamp that is after the MMD has passed from the last SCT issuance allows clients to audit this log regularly without special handling for the final STH. At this point, the log's private key is no longer needed and can be destroyed.
- Keep the log running until the certificates in all of its entries have expired or exist in other logs (this can be determined by scanning other logs or connecting to domains mentioned in the certificates and inspecting the SCTs served).

5. Log Client Messages

Messages are sent as HTTPS GET or POST requests. Parameters for POSTs and all responses are encoded as JavaScript Object Notation (JSON) objects [RFC8259]. Parameters for GETs are encoded as order-independent key/value URL parameters, using the "application/x-www-form-urlencoded" format described in the "HTML 4.01 Specification" [HTML401]. Binary data is base64 encoded according to Section 4 of [RFC4648], as specified in the individual messages.

Clients are configured with a log's base URL, which is one of the log's parameters. Clients construct URLs for requests by appending suffixes to this base URL. This structure places some degree of restriction on how log operators can deploy these services, as noted in [RFC8820]. However, operational experience with version 1 of this protocol has not indicated that these restrictions are a problem in practice.

Note that JSON objects and URL parameters may contain fields not specified here to allow for experimentation. Any fields that are not understood **SHOULD** be ignored.

In practice, log servers may include multiple front-end machines. Since it is impractical to keep these machines in perfect sync, errors that are caused by skew between the machines may occur. Where such errors are possible, the front end will return additional information (as specified below), making it possible for clients to make progress, if progress is possible. Front ends **MUST** only serve data that is free of gaps (that is, for example, no front end will respond with an STH unless it is also able to prove consistency from all log entries logged within that STH).

For example, when a consistency proof between two STHs is requested, the front end reached may not yet be aware of one or both STHs. In the case where it is unaware of both, it will return the latest STH it is aware of. Where it is aware of the first but not the second, it will return the latest STH it is aware of and a consistency proof from the first STH to the returned STH. The case where it knows the second but not the first should not arise (see the "no gaps" requirement above).

If the log is unable to process a client's request, it **MUST** return an HTTP response code of 4xx/5xx (see [RFC7231]), and, in place of the responses outlined in the subsections below, the body **SHOULD** be a JSON problem details object (see Section 3 of [RFC7807]) containing:

type: A URN reference identifying the problem. To facilitate automated response to errors, this document defines a set of standard tokens for use in the `type` field within the URN namespace of: "urn:ietf:params:trans:error:".

detail: A human-readable string describing the error that prevented the log from processing the request, ideally with sufficient detail to enable the error to be rectified.

For example, in response to a request of `<Base URL>/ct/v2/get-entries?start=100&end=99`, the log would return a `400 Bad Request` response code with a body similar to the following:

```
{
    "type": "urn:ietf:params:trans:error:endBeforeStart",
    "detail": "'start' cannot be greater than 'end'"
}
```

Most error types are specific to the type of request and are defined in the respective subsections below. The one exception is the "malformed" error type, which indicates that the log server could not parse the client's request because it did not comply with this document:

type	detail
malformed	The request could not be parsed.

Table 1

Clients **SHOULD** treat `500 Internal Server Error` and `503 Service Unavailable` responses as transient failures and **MAY** retry the same request without modification at a later date. Note that in the case of a 503 response, the log **MAY** include a `Retry-After` header field per [RFC7231] in order to request a minimum time for the client to wait before retrying the request. In the absence of this header field, this document does not specify a minimum.

Clients **SHOULD** treat any 4xx error as a problem with the request and not attempt to resubmit without some modification to the request. The full status code **MAY** provide additional details.

This document deliberately does not provide more specific guidance on the use of HTTP status codes.

5.1. Submit Entry to Log

POST <Base URL>/ct/v2/submit-entry

Inputs:

submission: The base64-encoded certificate or precertificate.

type: The `VersionedTransType` integer value that indicates the type of the `submission`: 1 for `x509_entry_v2` or 2 for `precert_entry_v2`.

chain: An array of zero or more JSON strings, each of which is a base64-encoded CA certificate. The first element is the certifier of the `submission`, the second certifies the first, etc. The last element of `chain` (or, if `chain` is an empty array, the `submission`) is certified by an accepted trust anchor.

Outputs:

sct: A base64-encoded `TransItem` of type `x509_sct_v2` or `precert_sct_v2`, signed by this log, that corresponds to the `submission`.

If the submitted entry is immediately appended to (or already exists in) this log's tree, then the log **SHOULD** also output:

sth: A base64-encoded `TransItem` of type `signed_tree_head_v2` signed by this log.

inclusion: A base64-encoded `TransItem` of type `inclusion_proof_v2` whose `inclusion_path` array of Merkle Tree nodes proves the inclusion of the `submission` in the returned `sth`.

Error codes:

type	detail
badSubmission	`submission` is neither a valid certificate nor a valid precertificate.
badType	`type` is neither 1 nor 2.
badChain	The first element of `chain` is not the certifier of the `submission`, or the second element does not certify the first, etc.
badCertificate	One or more certificates in `chain` are not valid (e.g., not properly encoded).
unknownAnchor	The last element of `chain` (or, if `chain` is an empty array, the `submission`) is not, nor is it certified by, an accepted trust anchor.
shutdown	The log is no longer accepting submissions.

Table 2

If the version of `sct` is not v2, then a v2 client may be unable to verify the signature. It **MUST NOT** construe this as an error. This is to avoid forcing an upgrade of compliant v2 clients that do not use the returned SCTs.

If a log detects bad encoding in a chain that otherwise verifies correctly, then the log **MUST** either log the certificate or return the "badCertificate" error. If the certificate is logged, an SCT **MUST** be issued. Logging the certificate is useful, because monitors (Section 8.2) can then detect these encoding errors, which may be accepted by some TLS clients.

If `submission` is an accepted trust anchor whose certifier is neither an accepted trust anchor nor the first element of `chain`, then the log **MUST** return the "unknownAnchor" error. A log is not able to generate an SCT for a submission if it does not have access to the issuer's public key.

If the returned `sct` is intended to be provided to TLS clients, then `sth` and `inclusion` (if returned) **SHOULD** also be provided to TLS clients. For example, if `type` was 2 (indicating `precert_sct_v2`), then all three `TransItem`s could be embedded in the certificate.

5.2. Retrieve Latest STH

GET <Base URL>/ct/v2/get-sth

No inputs.

Outputs:

sth: A base64-encoded `TransItem` of type `signed_tree_head_v2` signed by this log that is no older than the log's MMD.

5.3. Retrieve Merkle Consistency Proof between Two STHs

GET <Base URL>/ct/v2/get-sth-consistency

Inputs:

first: The `tree_size` of the older tree, in decimal.

second: The `tree_size` of the newer tree, in decimal (optional).

Both tree sizes must be from existing v2 STHs. However, because of skew, the receiving front end may not know one or both of the existing STHs. If both are known, then only the `consistency` output is returned. If the first is known but the second is not (or has been omitted), then the latest known STH is returned, along with a consistency proof between the first STH and the latest. If neither are known, then the latest known STH is returned without a consistency proof.

Outputs:

consistency:

A base64-encoded `TransItem` of type `consistency_proof_v2` whose `tree_size_1` **MUST** match the `first` input. If the `sth` output is omitted, then `tree_size_2` **MUST** match the `second` input. If `first` and `second` are equal and correspond to a known STH, the returned consistency proof **MUST** be empty (a `consistency_path` array with zero elements).

sth: A base64-encoded `TransItem` of type `signed_tree_head_v2`, signed by this log.

Note that no signature is required for the `consistency` output, as it is used to verify the consistency between two signed STHs.

Error codes:

type	detail
firstUnknown	`first` is before the latest known STH but is not from an existing STH.
secondUnknown	`second` is before the latest known STH but is not from an existing STH.
secondBeforeFirst	`second` is smaller than `first`.

Table 3

See Section 2.1.4.2 for an outline of how to use the `consistency` output.

5.4. Retrieve Merkle Inclusion Proof from Log by Leaf Hash

GET <Base URL>/ct/v2/get-proof-by-hash

Inputs:

hash: A base64-encoded v2 leaf hash.

tree_size: The `tree_size` of the tree on which to base the proof, in decimal.

The `hash` must be calculated as defined in Section 4.7. A v2 STH must exist for the `tree_size`. Because of skew, the front end may not know the requested tree head. In that case, it will return the latest STH it knows, along with an inclusion proof to that STH. If the front end knows the requested tree head, then only `inclusion` is returned.

Outputs:

inclusion: A base64-encoded `TransItem` of type `inclusion_proof_v2` whose `inclusion_path` array of Merkle Tree nodes proves the inclusion of the certificate (as specified by the `hash` parameter) in the selected STH.

sth: A base64-encoded `TransItem` of type `signed_tree_head_v2`, signed by this log.

Note that no signature is required for the `inclusion` output, as it is used to verify inclusion in the selected STH, which is signed.

Error codes:

type	detail
hashUnknown	`hash` is not the hash of a known leaf (may be caused by skew or by a known certificate not yet merged).
treeSizeUnknown	`hash` is before the latest known STH but is not from an existing STH.

Table 4

See Section 2.1.3.2 for an outline of how to use the `inclusion` output.

5.5. Retrieve Merkle Inclusion Proof, STH, and Consistency Proof by Leaf Hash

GET <Base URL>/ct/v2/get-all-by-hash

Inputs:

hash: A base64-encoded v2 leaf hash.

tree_size: The `tree_size` of the tree on which to base the proofs, in decimal.

The `hash` must be calculated as defined in Section 4.7. A v2 STH must exist for the `tree_size`.

Because of skew, the front end may not know the requested tree head or the requested hash, which leads to a number of cases:

Case	Response
latest STH < requested tree head	Return latest STH.
latest STH > requested tree head	Return latest STH and a consistency proof between it and the requested tree head (see Section 5.3).
index of requested hash < latest STH	Return `inclusion`.

Table 5

Note that more than one case can be true; in which case, the returned data is their union. It is also possible for none to be true; in which case, the front end **MUST** return an empty response.

Outputs:

inclusion: A base64-encoded `TransItem` of type `inclusion_proof_v2` whose `inclusion_path` array of Merkle Tree nodes proves the inclusion of the certificate (as specified by the `hash` parameter) in the selected STH.

sth: A base64-encoded `TransItem` of type `signed_tree_head_v2`, signed by this log.

consistency: A base64-encoded `TransItem` of type `consistency_proof_v2` that proves the consistency of the requested tree head and the returned STH.

Note that no signature is required for the `inclusion` or `consistency` outputs, as they are used to verify inclusion in and consistency of signed STHs.

Errors are the same as in Section 5.4.

See Section 2.1.3.2 for an outline of how to use the `inclusion` output, and see Section 2.1.4.2 for an outline of how to use the `consistency` output.

5.6. Retrieve Entries and STH from Log

GET <Base URL>/ct/v2/get-entries

Inputs:

start: 0-based index of first entry to retrieve, in decimal.

end: 0-based index of last entry to retrieve, in decimal.

Outputs:

entries: An array of objects, each consisting of:

log_entry: The base64-encoded `TransItem` structure of type `x509_entry_v2` or `precert_entry_v2` (see Section 4.3).

submitted_entry: JSON object equivalent to inputs that were submitted to `submit-entry`, with the addition of the trust anchor to the `chain` field if the submission did not include it.

sct: The base64-encoded `TransItem` of type `x509_sct_v2` or `precert_sct_v2`, corresponding to this log entry.

sth: A base64-encoded `TransItem` of type `signed_tree_head_v2`, signed by this log.

Note that this message is not signed -- the `entries` data can be verified by constructing the Merkle Tree Hash corresponding to a retrieved STH. All leaves **MUST** be v2. However, a compliant v2 client **MUST NOT** construe an unrecognized `TransItem` type as an error. This means it may be unable to parse some entries, but note that each client can inspect the entries it does recognize as well as verify the integrity of the data by treating unrecognized leaves as opaque input to the tree.

The `start` and `end` parameters **SHOULD** be within the range 0 <= x < `tree_size`, as returned by `get-sth` in Section 5.2.

The `start` parameter **MUST** be less than or equal to the `end` parameter.

Each `submitted_entry` output parameter **MUST** include the trust anchor that the log used to verify the `submission`, even if that trust anchor was not provided to `submit-entry` (see Section 5.1). If the `submission` does not certify itself, then the first element of `chain` **MUST** be present and **MUST** certify the `submission`.

Log servers **MUST** honor requests where 0 <= `start` < `tree_size` and `end` >= `tree_size` by returning a partial response covering only the valid entries in the specified range. `end` >= `tree_size` could be caused by skew. Note that the following restriction may also apply:

Logs **MAY** restrict the number of entries that can be retrieved per `get-entries` request. If a client requests more than the permitted number of entries, the log **SHALL** return the maximum number of entries permissible. These entries **SHALL** be sequential beginning with the entry specified by `start`. Note that a limit on the number of entries is not immutable, and therefore the restriction may be changed or lifted at any time and is not listed with the other Log Parameters in Section 4.1.

Because of skew, it is possible the log server will not have any entries between `start` and `end`. In this case, it **MUST** return an empty `entries` array.

In any case, the log server **MUST** return the latest STH it knows about.

See Section 2.1.2 for an outline of how to use a complete list of `log_entry` entries to verify the `root_hash`.

Error codes:

type	detail
startUnknown	`start` is greater than the number of entries in the Merkle Tree.
endBeforeStart	`start` cannot be greater than `end`.

Table 6

5.7. Retrieve Accepted Trust Anchors

GET <Base URL>/ct/v2/get-anchors

No inputs.

Outputs:

certificates: An array of JSON strings, each of which is a base64-encoded CA certificate that is acceptable to the log.

max_chain_length: If the server has chosen to limit the length of chains it accepts, this is the maximum number of certificates in the chain, in decimal. If there is no limit, this is omitted.

This data is not signed, and the protocol depends on the security guarantees of TLS to ensure correctness.

6. TLS Servers

CT-using TLS servers **MUST** use at least one of the mechanisms described below to present one or more SCTs from one or more logs to each TLS client during full TLS handshakes, when requested by the client, where each SCT corresponds to the server certificate. (Of course, a server can only send a TLS extension if the client has specified it first.) Servers **SHOULD** also present corresponding inclusion proofs and STHs.

A server can provide SCTs using a TLS 1.3 extension (Section 4.2 of [RFC8446]) with type `transparency_info` (see Section 6.5). This mechanism allows TLS servers to participate in CT without the cooperation of CAs, unlike the other two mechanisms. It also allows SCTs and inclusion proofs to be updated on the fly.

The server may also use an Online Certificate Status Protocol (OCSP) [RFC6960] response extension (see Section 7.1.1), providing the OCSP response as part of the TLS handshake. Providing a response during a TLS handshake is popularly known as "OCSP stapling". For TLS 1.3, the information is encoded as an extension in the `status_request` extension data; see Section 4.4.2.1 of [RFC8446]. For TLS 1.2 [RFC5246], the information is encoded in the `CertificateStatus` message; see Section 8 of [RFC6066]. Using stapling also allows SCTs and inclusion proofs to be updated on the fly.

CT information can also be encoded as an extension in the X.509v3 certificate (see Section 7.1.2). This mechanism allows the use of unmodified TLS servers, but the SCTs and inclusion proofs cannot be updated on the fly. Since the logs from which the SCTs and inclusion proofs originated won't necessarily be accepted by TLS clients for the full lifetime of the certificate, there is a risk that TLS clients may subsequently consider the certificate to be noncompliant. In such an event, one of the other two mechanisms will need to be used to deliver CT information, or, if this is not possible, the certificate will need to be reissued.

6.1. TLS Client Authentication

This specification includes no description of how a TLS server can use CT for TLS client certificates. While this may be useful, it is not documented here for the following reasons:

- The greater security exposure is for clients to end up interacting with an illegitimate server.
- In general, TLS client certificates are not expected to be submitted to CT logs, particularly those intended for general public use.

A future version could include such information.

6.2. Multiple SCTs

CT-using TLS servers **SHOULD** send SCTs from multiple logs because:

- The set of logs trusted by TLS clients is neither unified nor static; each client vendor may maintain an independent list of trusted logs, and, over time, new logs may become trusted and current logs may become distrusted. Note that client discovery, trust, and distrust of logs are expected to be handled out of band and are out of scope of this document.
- If a CA and a log collude, it is possible to temporarily hide misissuance from clients. When a TLS client requires SCTs from multiple logs to be provided, it is more difficult to mount this attack.
- If a log misbehaves or suffers a key compromise, a consequence may be that clients cease to trust it. Since the time an SCT may be in use can be considerable (several years is common in current practice when embedded in a certificate), including SCTs from multiple logs reduces the probability of the certificate being rejected by TLS clients.
- TLS clients may have policies related to the above risks requiring TLS servers to present multiple SCTs. For example, at the time of writing, Chromium [Chromium.Log.Policy] requires multiple SCTs to be presented with Extended Validation (EV) certificates in order for the EV indicator to be shown.

To select the logs from which to obtain SCTs, a TLS server can, for example, examine the set of logs popular TLS clients accept and recognize.

6.3. TransItemList Structure

Multiple SCTs, inclusion proofs, and indeed `TransItem` structures of any type are combined into a list as follows:

```
opaque SerializedTransItem<1..2^16-1>;

struct {
    SerializedTransItem trans_item_list<1..2^16-1>;
} TransItemList;
```

Here, `SerializedTransItem` is an opaque byte string that contains the serialized `TransItem` structure. This encoding ensures that TLS clients can decode each `TransItem` individually (so, for example, if there is a version upgrade, out-of-date clients can still parse old `TransItem` structures while skipping over new `TransItem` structures whose versions they don't understand).

6.4. Presenting SCTs, Inclusions Proofs, and STHs

In each `TransItemList` that is sent during a TLS handshake, the TLS server **MUST** include a `TransItem` structure of type `x509_sct_v2` or `precert_sct_v2`.

Presenting inclusion proofs and STHs in the TLS handshake helps to protect the client's privacy (see Section 8.1.4) and reduces load on log servers. Therefore, if the TLS server can obtain them, it **SHOULD** also include `TransItems` of type `inclusion_proof_v2` and `signed_tree_head_v2` in the `TransItemList`.

6.5. transparency_info TLS Extension

Provided that a TLS client includes the `transparency_info` extension type in the ClientHello and the TLS server supports the `transparency_info` extension:

- The TLS server **MUST** verify that the received `extension_data` is empty.
- The TLS server **MUST** construct a `TransItemList` of relevant `TransItems` (see Section 6.4), which **SHOULD** omit any `TransItems` that are already embedded in the server certificate or the stapled OCSP response (see Section 7.1). If the constructed `TransItemList` is not empty, then the TLS server **MUST** include the `transparency_info` extension with the `extension_data` set to this `TransItemList`. If the list is empty, then the server **SHOULD** omit the `extension_data` element but **MAY** send it with an empty array.

TLS servers **MUST** only include this extension in the following messages:

- the ServerHello message (for TLS 1.2 or earlier)
- the Certificate or CertificateRequest message (for TLS 1.3)

TLS servers **MUST NOT** process or include this extension when a TLS session is resumed, since session resumption uses the original session information.

7. Certification Authorities

7.1. Transparency Information X.509v3 Extension

The Transparency Information X.509v3 extension, which has OID 1.3.101.75 and **SHOULD** be noncritical, contains one or more `TransItem` structures in a `TransItemList`. This extension **MAY** be included in OCSP responses (see Section 7.1.1) and certificates (see Section 7.1.2). Since [RFC5280] requires the `extnValue` field (an OCTET STRING) of each X.509v3 extension to include the DER encoding of an ASN.1 value, a `TransItemList` **MUST NOT** be included directly. Instead, it **MUST** be wrapped inside an additional OCTET STRING, which is then put into the `extnValue` field:

```
    TransparencyInformationSyntax ::= OCTET STRING
```

`TransparencyInformationSyntax` contains a `TransItemList`.

7.1.1. OCSP Response Extension

A certification authority **MAY** include a Transparency Information X.509v3 extension in the `singleExtensions` of a `SingleResponse` in an OCSP response. All included SCTs and inclusion proofs **MUST** be for the certificate identified by the `certID` of that `SingleResponse` or for a precertificate that corresponds to that certificate.

7.1.2. Certificate Extension

A certification authority **MAY** include a Transparency Information X.509v3 extension in a certificate. All included SCTs and inclusion proofs **MUST** be for a precertificate that corresponds to this certificate.

7.2. TLS Feature X.509v3 Extension

A certification authority **SHOULD NOT** issue any certificate that identifies the `transparency_info` TLS extension in a TLS feature extension [RFC7633], because TLS servers are not required to support the `transparency_info` TLS extension in order to participate in CT (see Section 6).

8. Clients

There are various different functions clients of logs might perform. We describe here some typical clients and how they should function. Any inconsistency may be used as evidence that a log has not behaved correctly, and the signatures on the data structures prevent the log from denying that misbehavior.

All clients need various parameters in order to communicate with logs and verify their responses. These parameters are described in Section 4.1, but note that this document does not describe how the parameters are obtained, which is implementation dependent (for example, see [Chromium.Policy]).

8.1. TLS Client

8.1.1. Receiving SCTs and Inclusion Proofs

TLS clients receive SCTs and inclusion proofs alongside or in certificates. CT-using TLS clients **MUST** implement all of the three mechanisms by which TLS servers may present SCTs (see Section 6).

TLS clients that support the `transparency_info` TLS extension (see Section 6.5) **SHOULD** include it in ClientHello messages, with empty `extension_data`. If a TLS server includes the `transparency_info` TLS extension when resuming a TLS session, the TLS client **MUST** abort the handshake.

8.1.2. Reconstructing the TBSCertificate

Validation of an SCT for a certificate (where the `type` of the `TransItem` is `x509_sct_v2`) uses the unmodified TBSCertificate component of the certificate.

Before an SCT for a precertificate (where the `type` of the `TransItem` is `precert_sct_v2`) can be validated, the TBSCertificate component of the precertificate needs to be reconstructed from the TBSCertificate component of the certificate as follows:

- Remove the Transparency Information extension (see Section 7.1).
- Remove embedded v1 SCTs, identified by OID 1.3.6.1.4.1.11129.2.4.2 (see Section 3.3 of [RFC6962]). This allows embedded v1 and v2 SCTs to co-exist in a certificate (see Appendix A).

8.1.3. Validating SCTs

In order to make use of a received SCT, the TLS client **MUST** first validate it as follows:

- Compute the signature input by constructing a `TransItem` of type `x509_entry_v2` or `precert_entry_v2`, depending on the SCT's `TransItem` type. The `TimestampedCertificateEntryDataV2` structure is constructed in the following manner:
  - `timestamp` is copied from the SCT.
  - `tbs_certificate` is the reconstructed TBSCertificate portion of the server certificate, as described in Section 8.1.2.
  - `issuer_key_hash` is computed as described in Section 4.7.
  - `sct_extensions` is copied from the SCT.
- Verify the SCT's `signature` against the computed signature input using the public key of the corresponding log, which is identified by the `log_id`. The required signature algorithm is one of the log's parameters.

If the TLS client does not have the corresponding log's parameters, it cannot attempt to validate the SCT. When evaluating compliance (see Section 8.1.6), the TLS client will consider only those SCTs that it was able to validate.

Note that SCT validation is not a substitute for the normal validation of the server certificate and its chain.

8.1.4. Fetching Inclusion Proofs

When a TLS client has validated a received SCT but does not yet possess a corresponding inclusion proof, the TLS client **MAY** request the inclusion proof directly from a log using `get-proof-by-hash` (Section 5.4) or `get-all-by-hash` (Section 5.5).

Note that fetching inclusion proofs directly from a log will disclose to the log which TLS server the client has been communicating with. This may be regarded as a significant privacy concern, and so it is preferable for the TLS server to send the inclusion proofs (see Section 6.4).

8.1.5. Validating Inclusion Proofs

When a TLS client has received, or fetched, an inclusion proof (and an STH), it **SHOULD** proceed to verify the inclusion proof to the provided STH. The TLS client **SHOULD** also verify consistency between the provided STH and an STH it knows about.

If the TLS client holds an STH that predates the SCT, it **MAY**, in the process of auditing, request a new STH from the log (Section 5.2) and then verify it by requesting a consistency proof (Section 5.3). Note that if the TLS client uses `get-all-by-hash`, then it will already have the new STH.

8.1.6. Evaluating Compliance

It is up to a client's local policy to specify the quantity and form of evidence (SCTs, inclusion proofs, or a combination) needed to achieve compliance and how to handle noncompliance.

A TLS client can only evaluate compliance if it has given the TLS server the opportunity to send SCTs and inclusion proofs by any of the three mechanisms that are mandatory to implement for CT-using TLS clients (see Section 8.1.1). Therefore, a TLS client **MUST NOT** evaluate compliance if it did not include both the `transparency_info` and `status_request` TLS extensions in the ClientHello.

8.2. Monitor

Monitors watch logs to check for correct behavior, for certificates of interest, or for both. For example, a monitor may be configured to report on all certificates that apply to a specific domain name when fetching new entries for consistency validation.

A monitor **MUST** at least inspect every new entry in every log it watches, and it **MAY** also choose to keep copies of entire logs.

To inspect all of the existing entries, the monitor **SHOULD** follow these steps once for each log:

1. Fetch the current STH (Section 5.2).
2. Verify the STH signature.
3. Fetch all the entries in the tree corresponding to the STH (Section 5.6).
4. If applicable, check each entry to see if it's a certificate of interest.
5. Confirm that the tree made from the fetched entries produces the same hash as that in the STH.

To inspect new entries, the monitor **SHOULD** follow these steps repeatedly for each log:

1. Fetch the current STH (Section 5.2). Repeat until the STH changes. To allow for experimentation, this document does not specify the polling frequency.
2. Verify the STH signature.
3. Fetch all the new entries in the tree corresponding to the STH (Section 5.6). If they remain unavailable for an extended period, then this should be viewed as misbehavior on the part of the log.
4. If applicable, check each entry to see if it's a certificate of interest.
5. Either:
   a. Verify that the updated list of all entries generates a tree with the same hash as the new STH.

Or, if it is not keeping all log entries:

a. Fetch a consistency proof for the new STH with the previous STH (Section 5.3).

b. Verify the consistency proof.

c. Verify that the new entries generate the corresponding elements in the consistency proof.

6. Repeat from Step 1.

8.3. Auditing

Auditing ensures that the current published state of a log is reachable from previously published states that are known to be good and that the promises made by the log, in the form of SCTs, have been kept. Audits are performed by monitors or TLS clients.

In particular, there are four properties of log behavior that should be checked:

- the Maximum Merge Delay (MMD)
- the STH Frequency Count
- the append-only property
- the consistency of the log view presented to all query sources

A benign, conformant log publishes a series of STHs over time, each derived from the previous STH and the submitted entries incorporated into the log since publication of the previous STH. This can be proven through auditing of STHs. SCTs returned to TLS clients can be audited by verifying against the accompanying certificate and using Merkle inclusion proofs against the log's Merkle Tree.

The action taken by the auditor, if an audit fails, is not specified, but note that in general, if an audit fails, the auditor is in possession of signed proof of the log's misbehavior.

A monitor (Section 8.2) can audit by verifying the consistency of STHs it receives, ensuring that each entry can be fetched and that the STH is indeed the result of making a tree from all fetched entries.

A TLS client (Section 8.1) can audit by verifying an SCT against any STH dated after the SCT timestamp + the Maximum Merge Delay by requesting a Merkle inclusion proof (Section 5.4). It can also verify that the SCT corresponds to the server certificate it arrived with (i.e., the log entry is that certificate or is a precertificate corresponding to that certificate).

Checking of the consistency of the log view presented to all entities is more difficult to perform because it requires a way to share log responses among a set of CT-using entities and is discussed in Section 11.3.

9. Algorithm Agility

It is not possible for a log to change either of its algorithms part way through its lifetime:

Signature algorithm: SCT signatures must remain valid so signature algorithms can only be added, not removed.

Hash algorithm: A log would have to support the old and new hash algorithms to allow backwards compatibility with clients that are not aware of a hash algorithm change.

Allowing multiple signature or hash algorithms for a log would require that all data structures support it and would significantly complicate client implementation, which is why it is not supported by this document.

If it should become necessary to deprecate an algorithm used by a live log, then the log **MUST** be frozen, as specified in Section 4.13, and a new log **SHOULD** be started. Certificates in the frozen log that have not yet expired and require new SCTs **SHOULD** be submitted to the new log and the SCTs from that log used instead.

10. IANA Considerations

The assignment policy criteria mentioned in this section refer to the policies outlined in [RFC8126].

10.1. Additions to Existing Registries

This subsection defines additions to existing registries.

10.1.1. New Entry to the TLS ExtensionType Registry

IANA has added the following entry to the "TLS ExtensionType Values" registry defined in [RFC8446], with an assigned Value:

Value	Extension Name	TLS 1.3	DTLS-Only	Recommended	Reference
52	transparency_info	CH, CR, CT	N	Y	RFC 9162

Table 7

10.1.2. URN Sub-namespace for TRANS (urn:ietf:params:trans)

IANA has added a new entry in the "IETF URN Sub-namespace for Registered Protocol Parameter Identifiers" registry, following the template in [RFC3553]:

Registry name: trans
Specification: RFC 9162
Repository: <https://www.iana.org/assignments/trans>
Index value: No transformation needed.

10.2. New CT-Related Registries

IANA has added a new protocol registry, "Public Notary Transparency", to the list that appears at <https://www.iana.org/assignments/>

The rest of this section defines the subregistries that have been created within the new "Public Notary Transparency" registry.

10.2.1. Hash Algorithms

IANA has established a registry of hash algorithm values, named "Hash Algorithms", with the following registration procedures:

Range	Registration Procedures
0x00-0xDF	Specification Required
0xE0-0xEF	Experimental Use
0xF0-0xFF	Private Use

Table 8

The "Hash Algorithms" registry initially consists of:

Value	Hash Algorithm	OID	Reference
0x00	SHA-256	2.16.840.1.101.3.4.2.1	[RFC6234]
0x01 - 0xDF	Unassigned		RFC 9162
0xE0 - 0xEF	Reserved for Experimental Use		RFC 9162
0xF0 - 0xFF	Reserved for Private Use		RFC 9162

Table 9

The designated expert(s) should ensure that the proposed algorithm has a public specification and is suitable for use as a cryptographic hash algorithm with no known preimage or collision attacks. These attacks can damage the integrity of the log.

10.2.2. Signature Algorithms

IANA has established a registry of signature algorithm values, named "Signature Algorithms".

The following notes have been added to the registry:

> **Note:**
> This is a subset of the "TLS SignatureScheme" registry, limited to those algorithms that are appropriate for CT. A major advantage of this is leveraging the expertise of the TLS Working Group and its designated expert(s).

Note:
The value `0x0403` appears twice. While this may be confusing, it is okay because the verification process is the same for both algorithms, and the choice of which to use when generating a signature is purely internal to the log server.

The "Signature Algorithms" registry has the following registration procedures:

Range	Registration Procedures
0x0000-0x0807	Specification Required
0x0808-0xFDFF	Expert Review
0xFE00-0xFEFF	Experimental Use
0xFF00-0xFFFF	Private Use

Table 10

The "Signature Algorithms" registry initially consists of:

SignatureScheme Value	Signature Algorithm	Reference
0x0000 - 0x0402	Unassigned	
ecdsa_secp256r1_sha256 (0x0403)	ECDSA (NIST P-256) with SHA-256	[FIPS186-4]
ecdsa_secp256r1_sha256 (0x0403)	Deterministic ECDSA (NIST P-256) with HMAC-SHA256	[RFC6979]
0x0404 - 0x0806	Unassigned	
ed25519 (0x0807)	Ed25519 (PureEdDSA with the edwards25519 curve)	[RFC8032]
0x0808 - 0xFDFF	Unassigned	
0xFE00 - 0xFEFF	Reserved for Experimental Use	RFC 9162
0xFF00 - 0xFFFF	Reserved for Private Use	RFC 9162

Table 11

The designated expert(s) should ensure that the proposed algorithm has a public specification, has a value assigned to it in the "TLS SignatureScheme" registry (which was established by [RFC8446]), and is suitable for use as a cryptographic signature algorithm.

10.2.3. VersionedTransTypes

IANA has established a registry of `VersionedTransType` values, named "VersionedTransTypes".

The following note has been added:

> **Note:**
> The range 0x0000..0x00FF is reserved so that v1 SCTs are distinguishable from v2 SCTs and other `TransItem` structures.

The registration procedures for the "VersionedTransTypes" registry are the following:

Range	Registration Procedures
0x0100-0xDFFF	Specification Required
0xE000-0xEFFF	Experimental Use
0xF000-0xFFFF	Private Use

Table 12

The "VersionedTransTypes" registry initially consists of:

Value	Type and Version	Reference
0x0000 - 0x00FF	Reserved	[RFC6962]
0x0100	x509_entry_v2	RFC 9162
0x0101	precert_entry_v2	RFC 9162
0x0102	x509_sct_v2	RFC 9162
0x0103	precert_sct_v2	RFC 9162
0x0104	signed_tree_head_v2	RFC 9162
0x0105	consistency_proof_v2	RFC 9162
0x0106	inclusion_proof_v2	RFC 9162
0x0107 - 0xDFFF	Unassigned	
0xE000 - 0xEFFF	Reserved for Experimental Use	RFC 9162

Value	Type and Version	Reference
0xF000 - 0xFFFF	Reserved for Private Use	RFC 9162

Table 13

The designated expert(s) should review the public specification to ensure that it is detailed enough to ensure implementation interoperability.

10.2.4. Log Artifact Extensions

IANA has established a registry of `ExtensionType` values, named "Log Artifact Extensions".

The registration procedures for the "Log Artifact Extensions" registry are the following:

Range	Registration Procedures
0x0000-0xDFFF	Specification Required
0xE000-0xEFFF	Experimental Use
0xF000-0xFFFF	Private Use

Table 14

The "Log Artifact Extensions" registry initially consists of:

ExtensionType	Status	Use	Reference
0x0000 - 0xDFFF	Unassigned	n/a	
0xE000 - 0xEFFF	Reserved for Experimental Use	n/a	RFC 9162
0xF000 - 0xFFFF	Reserved for Private Use	n/a	RFC 9162

Table 15

The "Use" column should contain one or both of the following values:

- "SCT", for extensions specified for use in Signed Certificate Timestamps.
- "STH", for extensions specified for use in Signed Tree Heads.

The designated expert(s) should review the public specification to ensure that it is detailed enough to ensure implementation interoperability. They should also verify that the extension is appropriate to the contexts in which it is specified to be used (SCT, STH, or both).

10.2.5. Log IDs

IANA has established a registry of Log IDs, named "Log IDs".

The registry's registration procedure is First Come First Served.

The "Log IDs" registry initially consists of:

Log ID	Log Base URL	Log Operator	Reference
1.3.101.8192 - 1.3.101.16383	Unassigned	Unassigned	
1.3.101.80.0 - 1.3.101.80.*	Unassigned	Unassigned	

Table 16

The following notes have been added to the registry:

> **Note:**
> All OIDs in the range from 1.3.101.8192 to 1.3.101.16383 have been set aside for Log IDs. This is a limited resource of 8,192 OIDs, each of which has an encoded length of 4 octets.

> **Note:**
> The 1.3.101.80 arc has also been set aside for Log IDs. This is an unlimited resource, but only the 128 OIDs from 1.3.101.80.0 to 1.3.101.80.127 have an encoded length of only 4 octets.

Each application for the allocation of a Log ID **MUST** be accompanied by:

- the Log's Base URL (see Section 4.1) and
- the Log Operator's contact details.

IANA is asked to reject any request to update a Log ID or Log Base URL in this registry because these fields are immutable (see Section 4.1).

IANA is asked to accept requests from log operators to update their contact details in this registry.

Since log operators can choose to not use this registry (see Section 4.4), it is not expected to be a global directory of all logs.

10.2.6. Error Types

IANA has created a new registry for errors, the "Error Types" registry.

The registration procedure for this registry is Specification Required.

This registry has the following three fields:

Field Name	Type	Reference
Identifier	string	RFC 9162
Meaning	string	RFC 9162
Reference	string	RFC 9162

Table 17

The initial values of the "Error Types" registry, which are taken from the text in Section 5, are as follows:

Identifier	Meaning	Reference
malformed	The request could not be parsed.	RFC 9162
badSubmission	`submission` is neither a valid certificate nor a valid precertificate.	RFC 9162
badType	`type` is neither 1 nor 2.	RFC 9162
badChain	The first element of `chain` is not the certifier of the `submission`, or the second element does not certify the first, etc.	RFC 9162
badCertificate	One or more certificates in `chain` are not valid (e.g., not properly encoded).	RFC 9162
unknownAnchor	The last element of `chain` (or, if `chain` is an empty array, the `submission`) is not, nor is it certified by, an accepted trust anchor.	RFC 9162
shutdown	The log is no longer accepting submissions.	RFC 9162
firstUnknown	`first` is before the latest known STH but is not from an existing STH.	RFC 9162
secondUnknown	`second` is before the latest known STH but is not from an existing STH.	RFC 9162
secondBeforeFirst	`second` is smaller than `first`.	RFC 9162
hashUnknown	`hash` is not the hash of a known leaf (may be caused by skew or by a known certificate not yet merged).	RFC 9162
treeSizeUnknown	`hash` is before the latest known STH but is not from an existing STH.	RFC 9162

Identifier	Meaning	Reference
startUnknown	`start` is greater than the number of entries in the Merkle Tree.	RFC 9162
endBeforeStart	`start` cannot be greater than `end`.	RFC 9162

Table 18

10.3. OID Assignment

IANA has assigned an object identifier from the "SMI Security for PKIX Module Identifier" registry to identify the ASN.1 module in Appendix B of this document.

Decimal	Description	References
102	id-mod-public-notary-v2	RFC 9162

Table 19

11. Security Considerations

With CAs, logs, and servers performing the actions described here, TLS clients can use logs and signed timestamps to reduce the likelihood that they will accept misissued certificates. If a server presents a valid signed timestamp for a certificate, then the client knows that a log has committed to publishing the certificate. From this, the client knows that monitors acting for the subject of the certificate have had some time to notice the misissuance and take some action, such as asking a CA to revoke a misissued certificate. A signed timestamp does not guarantee this, though, since appropriate monitors might not have checked the logs or the CA might have refused to revoke the certificate.

In addition, if TLS clients will not accept unlogged certificates, then site owners will have a greater incentive to submit certificates to logs, possibly with the assistance of their CA, increasing the overall transparency of the system.

11.1. Misissued Certificates

Misissued certificates that have not been publicly logged, and thus do not have a valid SCT, are not considered compliant. Misissued certificates that do have an SCT from a log will appear in that public log within the Maximum Merge Delay, assuming the log is operating correctly. Since a log is allowed to serve an STH of any age up to the MMD, the maximum period of time during which a misissued certificate can be used without being available for audit is twice the MMD.

11.2. Detection of Misissue

The logs do not themselves detect misissued certificates; they rely instead on interested parties, such as domain owners, to monitor them and take corrective action when a misissue is detected.

11.3. Misbehaving Logs

A log can misbehave in several ways. Examples include the following: failing to incorporate a certificate with an SCT in the Merkle Tree within the MMD; presenting different, conflicting views of the Merkle Tree at different times and/or to different parties; issuing STHs too frequently; mutating the signature of a logged certificate; and failing to present a chain containing the certifier of a logged certificate.

Violation of the MMD contract is detected by log clients requesting a Merkle inclusion proof (Section 5.4) for each observed SCT. These checks can be asynchronous and need only be done once per certificate. However, note that there may be privacy concerns (see Section 8.1.4).

Violation of the append-only property or the STH issuance rate limit can be detected by multiple clients comparing their instances of the STHs. This technique, known as "gossip", is an active area of research and not defined here. Proof of misbehavior in such cases would be either a series of STHs that were issued too closely together, proving violation of the STH issuance rate limit, or an STH with a root hash that does not match the one calculated from a copy of the log, proving violation of the append-only property.

Clients that report back SCTs can be tracked or traced if a log produces multiple STHs or SCTs with the same timestamp and data but different signatures. Logs **SHOULD** mitigate this risk by either:

- using deterministic signature schemes or
- producing no more than one SCT for each distinct submission and no more than one STH for each distinct `tree_size`. Each of these SCTs and STHs can be stored by the log and served to other clients that submit the same certificate or request the same STH.

11.4. Multiple SCTs

By requiring TLS servers to offer multiple SCTs, each from a different log, TLS clients reduce the effectiveness of an attack where a CA and a log collude (see Section 6.2).

11.5. Leakage of DNS Information

Malicious monitors can use logs to learn about the existence of domain names that might not otherwise be easy to discover. Some subdomain labels may reveal information about the service and software for which the subdomain is used, which in turn might facilitate targeted attacks.

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12.1. Normative References

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Appendix A. Supporting v1 and v2 Simultaneously (Informative)

Certificate Transparency logs have to be either v1 (conforming to [RFC6962]) or v2 (conforming to this document), as the data structures are incompatible, and so a v2 log could not issue a valid v1 SCT.

CT clients, however, can support v1 and v2 SCTs for the same certificate simultaneously, as v1 SCTs are delivered in different TLS, X.509, and OCSP extensions than v2 SCTs.

v1 and v2 SCTs for X.509 certificates can be validated independently. For precertificates, v2 SCTs should be embedded in the TBSCertificate before submission of the TBSCertificate (inside a v1 precertificate, as described in Section 3.1 of [RFC6962]) to a v1 log so that TLS clients conforming to [RFC6962] but not this document are oblivious to the embedded v2 SCTs. An issuer can follow these steps to produce an X.509 certificate with embedded v1 and v2 SCTs:

- Create a CMS precertificate, as described in Section 3.2, and submit it to v2 logs.

- Embed the obtained v2 SCTs in the TBSCertificate, as described in Section 7.1.2.
- Use that TBSCertificate to create a v1 precertificate, as described in Section 3.1 of [RFC6962], and submit it to v1 logs.
- Embed the v1 SCTs in the TBSCertificate, as described in Section 3.3 of [RFC6962].
- Sign that TBSCertificate (which now contains v1 and v2 SCTs) to issue the final X.509 certificate.

Appendix B. An ASN.1 Module (Informative)

The following ASN.1 [X.680] module may be useful to implementors. This module references [RFC5912] and [RFC6268].

```
CertificateTransparencyV2Module-2021
 -- { id-mod-public-notary-v2 from above, in
        iso(1) identified-organization(3) ...
    form }
DEFINITIONS IMPLICIT TAGS ::= BEGIN

-- EXPORTS ALL --

IMPORTS
  EXTENSION
  FROM PKIX-CommonTypes-2009 -- RFC 5912
    { iso(1) identified-organization(3) dod(6) internet(1)
      security(5) mechanisms(5) pkix(7) id-mod(0)
      id-mod-pkixCommon-02(57) }

  CONTENT-TYPE
  FROM CryptographicMessageSyntax-2010  -- RFC 6268
    { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
      pkcs-9(9) smime(16) modules(0) id-mod-cms-2009(58) }

  TBSCertificate
  FROM PKIX1Explicit-2009 -- RFC 5912
    { iso(1) identified-organization(3) dod(6) internet(1)
      security(5) mechanisms(5) pkix(7) id-mod(0)
      id-mod-pkix1-explicit-02(51) }
;

--
-- Section 3.2.  Precertificates
--

ct-tbsCertificate CONTENT-TYPE ::= {
  TYPE TBSCertificate
  IDENTIFIED BY id-ct-tbsCertificate }

id-ct-tbsCertificate OBJECT IDENTIFIER ::= { 1 3 101 78 }

--
-- Section 7.1.  Transparency Information X.509v3 Extension
--
```

```
ext-transparencyInfo EXTENSION ::= {
   SYNTAX TransparencyInformationSyntax
   IDENTIFIED BY id-ce-transparencyInfo
   CRITICALITY { FALSE } }

id-ce-transparencyInfo OBJECT IDENTIFIER ::= { 1 3 101 75 }

TransparencyInformationSyntax ::= OCTET STRING

--
-- Section 7.1.1.  OCSP Response Extension
--

ext-ocsp-transparencyInfo EXTENSION ::= {
   SYNTAX TransparencyInformationSyntax
   IDENTIFIED BY id-pkix-ocsp-transparencyInfo
   CRITICALITY { FALSE } }

id-pkix-ocsp-transparencyInfo OBJECT IDENTIFIER ::=
   id-ce-transparencyInfo

--
-- Section 8.1.2.  Reconstructing the TBSCertificate
--

ext-embeddedSCT-CTv1 EXTENSION ::= {
   SYNTAX SignedCertificateTimestampList
   IDENTIFIED BY id-ce-embeddedSCT-CTv1
   CRITICALITY { FALSE } }

id-ce-embeddedSCT-CTv1 OBJECT IDENTIFIER ::= {
   1 3 6 1 4 1 11129 2 4 2 }

SignedCertificateTimestampList ::= OCTET STRING

END
```

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Authors' Addresses

Ben Laurie
Google UK Ltd.
Email: benl@google.com

Eran Messeri
Google UK Ltd.
Email: eranm@google.com

Rob Stradling
Sectigo Ltd.
Email: rob@sectigo.com